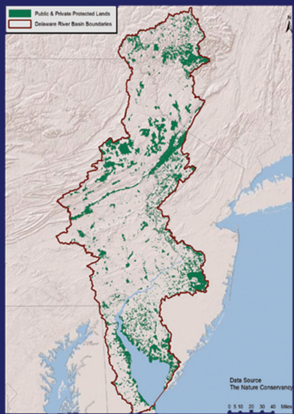
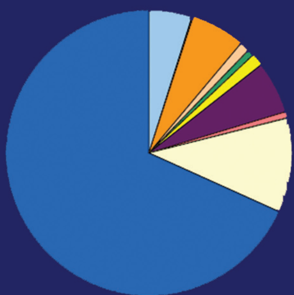
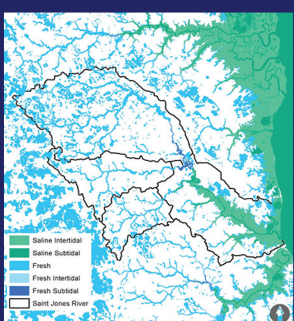
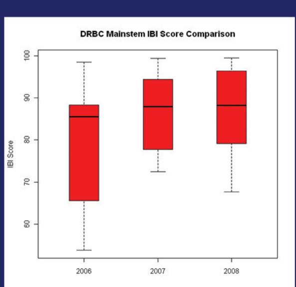








Technical Report for the Delaware Estuary & Basin

Partnership for the Delaware Estuary

2012

Abstract

The Partnership for the Delaware Estuary (PDE) periodically reports on the status and trends of environmental indicators for the health of the Delaware Estuary and River Basin, about every three to five years. The Technical Report for the Delaware Estuary and Basin analyzes best possible current data for the status and trends of a broad suite of more than 50 water, habitat, and living resource indicators. There are eight categories of indicators: watershed land use, water quantity, water quality, habitats, living resources, climate change, and restoration progress. For each indicator, scientists and managers also discuss predicted future changes in its health as well as future actions and needs to strengthen indicator reporting and to improve environmental conditions. Taken together, the findings in this report suggest that overall environmental conditions in the Delaware Estuary and river basin are fair, with a mix of both improving and declining status indicators. A companion report, the State of the Delaware Estuary 2012, uses example indicators to provide a synopsis of these results for the public.

How to Cite this Report

Partnership for the Delaware Estuary. 2012. Technical Report for the Delaware Estuary and Basin. PDE Report No. 12-01. 255 pages. www.delawareestuary.org/science_programs_state_of_the_estuary.asp. A complete section author list is available at the end of the report.

Acknowledgements

Funding for development of the Technical Report for the Delaware Estuary and River Basin was provided by the Environmental Protection Agency to the Partnership for the Delaware Estuary (PDE), under National Estuary Program Grant Section 320 Grant Funding. In addition, the Delaware River Basin Commission provided substantial in-kind contributions of staff time and resources. The report was also prepared with substantial efforts of many individual volunteers, representing diverse agencies, academic institutions, companies, and non-profit entities, and who are listed as authors or contributors. We are also grateful to the PDE Science and Technical Advisory Committee and its Estuary Implementation Committee for helping marshal necessary staff and resources and providing peer review.

Partnership for the Delaware Estuary

The Partnership for the Delaware Estuary is a nonprofit organization established in 1996 to take a leadership role in protecting and enhancing the Delaware Estuary, where fresh water from the Delaware River mixes with salt water from the Atlantic Ocean. It is one of 28 congressionally designated National Estuary Programs throughout the coastal United States working to improve the environmental health of the nation's estuaries. Its staff works with partners in three states to increase awareness, understanding, and scientific knowledge about the Delaware Estuary, the region's most important cultural, economic, and recreational resource.

Mission

The mission of the Partnership for the Delaware Estuary is to lead collaborative and creative efforts to protect and enhance the Delaware Estuary and its tributaries for current and future generations.

Cover Graphics

- Satellite graphic provided by by NASA
- Map of protected lands from Chapter 1
- Pie chart of water usage from Chapter 2
- Insect Picture taken by David Funk, found in Chapter 6-12
- Map of wetlands from Chapter 5B
- Wetland picture taken by Danielle Kreeger, found in Chapter 5B

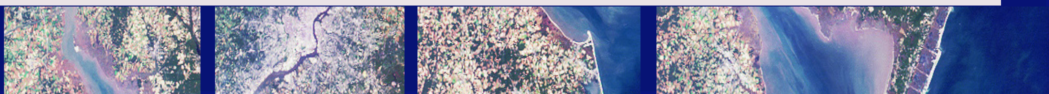
Executive Summary

The Delaware Estuary and River Basin is a large and complex watershed, encompassing more than 35,000 square kilometers (>13,500 square miles) and extending from headwater streams and mountains in New York State to the coastal plain and ocean near Cape May NJ and Cape Henlopen, DE. The watershed spans four ecoregions, is home to about 9 million people, and supplies drinking water to another seven million in New York City and northern New Jersey living outside the basin. Hundreds of plant and animal species live in balance with people in diverse habitats, including many ecological treasures. The region also has a storied history, starting with rich Native American peoples and extending through the birth of the United States and the Industrial Revolution, up to the present day where it continues to function as a nationally important economic center and strategic port.

With this complex spatial and temporal landscape, it is challenging to assess the overall environmental condition of this system. Environmental indicators are aspects of the environment which can be quantified and are representative of prevailing local conditions. The approach used in this report was to gather, analyze and interpret the best and most recent data for a broad suite of more than 50 indicators that represent different facets of the natural ecosystem, such as water quality, living resources, habitats, and land cover. When considered together, this indicator-based report provides a comprehensive picture of the status and trends in environmental health of the Delaware Estuary and River Basin, showing that some conditions are good, and others are not so good; some indicators appear to be improving, while others appear to be worsening. When taken all together, the contents of this report suggest that ***overall environmental conditions are fair,*** with some improvements since our last State of the Estuary Report in 2008, and some conditions apparently declining.

The eight chapters of this *Technical Report on the State of the Delaware Estuary and River Basin* are organized topically into the following sections: watershed and landscapes, water quantity, water quality, sediments, aquatic habitats, living resources, climate change, and restoration progress. Each section includes a number of different indicators and was written by a different set of authors with science and management expertise relevant to the topic.

Chapter	Ten Positives		Ten Negatives	
	Indicator	Condition	Indicator	Condition
Watersheds	Ecosystem Services	Worth >$12 billion annually	Forest Cover	Declined almost 50 square miles (127 km^2) 1996-2006
Water Quantity	Consumptive Use (Public)	Declined per capita 1990-2008	Consumptive Use (Industry)	Increased about 20% between 1994-2008
Water Quality	Dissolved Oxygen	Increased dramatically 1960s to present	Nutrients	Nitrogen remains high relative to other estuaries
	pH	Increasing slightly despite global acidification risk	Contaminants	Exceeds risk-thresholds for consumption of many fish
Sediments	Total Organic Carbon	Decreased, suggesting lower organic pollution	Sediment Budget	Sediment removal exceeds inputs, possibly impairing estuary habitats
Aquatic Habitats	Fish Passage (Rivers)	>160 km now accessible on Lehigh and Schuylkill Rivers, since 1990	Tidal Wetlands	Acreage decreased >2% 1996-2006, mainly from salt marsh loss
Living Resources	Horseshoe Crabs	Male spawning activity increased 1999-2010	Atlantic Sturgeon	Despite young-of-year fish seen in 2009, the species is now federally endangered
	Striped Bass	Once nearly extirpated, the current population is a major spawning stock	Freshwater Mussels	Abundance and range continues to decline
Climate	Ice Jams	Decreased over period of record	Precipitation	Increased, especially in past 30 years, increasing flooding
Restoration Progress	Habitat Type	Progress among types matches current priorities	Funding	Investment is very low compared to other large estuaries



For example, the climate change chapter considers long-term changes in air temperature, precipitation, extremes in air temperature and precipitation, snow cover, wind speed, stream flow, ice jams, and sea level. For each indicator, the authors discuss predicted future conditions as well as actions and needs that could strengthen future indicator reporting or lead to improved environmental conditions. Examples of key findings in this report are summarized in the previous table which shows both improving and declining environmental conditions. The list is not prioritized, and many more similar examples can be found in various report sections.

The information in this report should be interpreted carefully because changes in some indicators do not necessarily reflect declining or improving conditions per se, but instead reflect natural variability. For example, it is possible that some species or conditions are actually improving at the expense of others, due to complex ecological inter-relationships. In some cases, this report effort was hampered because some components of the ecosystem that could serve as strong indicators were not able to be included due to insufficient data. The development of this report therefore allows us to assess not only the state of the environment, but also the state of our knowledge and understanding. Furthermore, the restoration chapter is a new attempt to begin using available data to assess our management progress in preserving, enhancing and restoring environmental conditions, in addition to assessing intrinsic environmental conditions (which is the focus of most of the rest of this report.) A synopsis of results pertaining to the Delaware Estuary (the lower 52% of the basin) is being produced in a companion *2012 State of the Delaware Estuary Report*.

Where possible, the future status and trends of indicators are also discussed. The human population in the watershed is expected to increase by 80% by 2100. This is likely to increasingly tax our natural resources and require management diligence, especially with regard to water withdrawals, forest cutting, wetland loss, and development. These challenges will be exacerbated by a shifting climate, especially increasing temperature, precipitation, sea level, and salinity. The cumulative impacts to natural resources from both anthropogenic alterations and shifting climate conditions are difficult to predict. Hence, continued careful monitoring of the indicators reported here will be critical so that environmental managers can make adaptive decisions to sustain crucial life-sustaining ecosystem services, which we know are worth billions of dollars per year. Specifically, to address future environmental challenges while preserving prosperity in the region, agencies, scientists, and others must work together to:

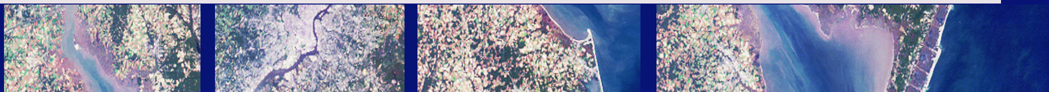
- Sustain and strengthen the effectiveness of monitoring, protection and restoration efforts by focusing on a set of shared, strategic priorities
- Set science-based goals that plan for change as part of the natural landscape
- Adopt realistic environmental targets that focus on the preservation and augmentation of key life-sustaining features
- Apply an ecosystem-based approach to management that considers cumulative impacts

Facilitating this collaborative effort is part of what the Partnership for the Delaware Estuary seeks to do as the National Estuary Program for the Delaware River and Bay.

Taken together, the report indicates that the overall environmental integrity of the Delaware Estuary and River Basin is fair, having improved significantly in recent decades but still facing some old problems as well as some emerging challenges. Continued loss and degradation of important habitats and emerging threats associated with climate change threaten to undermine the recent recovery. Achieving measurable improvements in these indicators requires action by a wide variety of public and private partners over an extended period of time.

The information, perspectives and future goals stated in the Technical Report for the Delaware Estuary and Basin reflect the best current scientific consensus of the authors that drafted individual sections and do not necessarily represent the official views or goals of the Partnership for the Delaware Estuary or any other participating entity or specific author. This report is a collective, peer reviewed effort which attempted to coordinate a consistent style and content among sections; however, the written presentations and depth of analysis will reflect (or vary in accordance with) the availability of data, methods of presentation, and analytical rigor that are appropriate for different fields and different writing styles of various authors.

Table of Contents



List of Figures

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

Chapter 8

List of Tables

Introduction

The 2011 Technical Report for the Delaware Estuary and Basin (TREB) reviews the status and trends in extent or health of numerous environmental indicators as a way to take a scientific look at the current health of the Delaware Estuary and River Basin.

Environmental indicators are specific, measureable markers that are used to assess the condition of the environment and indicate whether conditions are improving or worsening over time (EPA 2007). Additionally, indicators help raise awareness about important environmental issues, serve as tools for evaluating the effectiveness of management actions, and can function as early warning signals for detecting adverse changes in environmental quality (EPA 2007).

This report was prepared by the Partnership for the Delaware Estuary's Science and Technical Advisory Committee (STAC) in collaboration with many additional contributing scientists and managers, which together formed an ad hoc TREB workgroup. The suite of environmental indicators covered in this report was selected jointly by the PDE STAC and the Delaware River Basin Commission (DRBC). Indicators were chosen based on data availability and an indicator's ability to tell something important about the status of the natural resources, water quality, and climate conditions of the Delaware Estuary and its watershed.

Efforts to produce this report began in late 2009 when the STAC met jointly with the DRBC Monitoring Advisory Committee in a series of workshops to reexamine environmental indicators used in our 2008 State of the Estuary

Report (PDE 2008) and to prepare a "next generation" set of indicators. In many cases, that wish list remains unfulfilled due to insufficient resources to obtain critical new data to fill gaps or due to comparability issues (e.g. among states) with available data. This report provides the best possible current synthesis of status and trends for the important environmental indicators that could be examined.

The purpose of this report is to compile a scientific synthesis of the most recent status and trends data into a technical report, which can serve as the basis for a new State of the Estuary Report for the public in 2012. Although data and analyses were not able to be obtained for some important resource conditions, the findings in this report do tell a story from a regional perspective and will continue to serve as a baseline for measuring the progress made toward implementing the PDE Comprehensive Conservation and Management Plan (CCMP) in the future.

In addition, this report provides guidance on future "Actions and Needs," which are discussed for each indicator. In many cases, these actions and needs call for improved coordination and/or monitoring. Where data are currently incomplete or unavailable, PDE will continue to work with partners to improve monitoring and data management. PDE also intends to use these results to strengthen linkages between environmental monitoring, management and progress measures for CCMP implementation.

Organization of the Technical Report for the Delaware Estuary and Basin

Indicators are grouped into eight topical chapters, beginning with watershed traits and land use in Chapter 1. The Watershed chapter also provides an orientation to eleven watershed regions that were used to delineate geospatial boundaries for analysis of many of the TREB indicators in other chapters. These watershed regions extend from headwater streams in New York to the mouth of Delaware Bay between Cape May, NJ and Cape Henlopen, DE.

Water resource indicators are next discussed in Chapters 2 and 3, followed by sediment indicators in Chapter 4. Habitat-related indicators are examined in Chapter 5, distinguishing among subtidal, intertidal and non-tidal habitats. Living resources are similarly grouped as non-tidal and tidal in Chapter 6, summarizing status and trends of key animals that living primarily above or below the head of tide, respectively.

Chapter 7 focused on climate indicators, building on our last State of the Estuary report in 2008 where we introduced this category. Indicators reported in Chapters 1-7 focus on status and trends in environmental conditions; whereas, in Chapter 8 we focus on measures of progress for improving conditions through protection and restoration efforts.

How to Use the Technical Report for the Delaware Estuary and Basin

For information on the status and trends of any specific indicator (e.g., American eels), simply refer to the appropriate section. However, to obtain an overall status summary for the Delaware Estuary and River Basin, we recommend reviewing the entire report for several reasons.

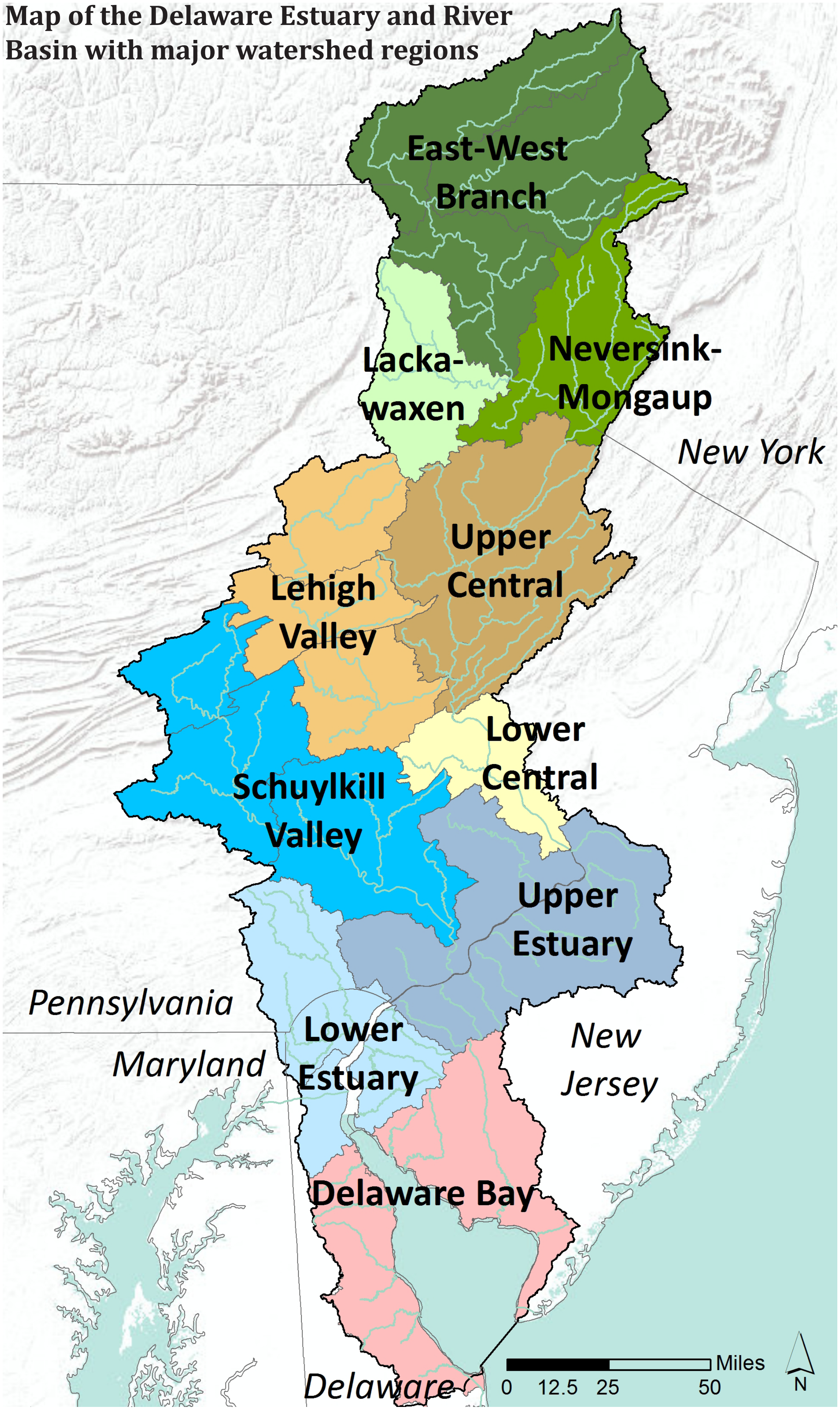
Many indicators interact through complex physical, chemical and biological relationships, and a complete review facilitates a more full understanding of the status of functional interrelationships (how the system is working) in addition to any single parameter (what is present). For example, the population abundance of some fish species may depend on others through predation or competition relationships (striped bass versus weakfish, both are never abundant at the same time). Sediment dynamics might either impair or help sustain important types of habitats, such as oyster reefs or tidal wetlands, respectively. At the same time, the naturally "muddy" traits of this estuary is thought to help to stem eutrophication problems by light shading of phytoplankton blooms, despite having high nutrient loadings. By cross-comparing results among chapters, one can obtain a better understanding of such complex interactions.

Similarly, no single indicator or chapter is diagnostic for overall environmental conditions. With respect to water quality, for example, there has been dramatic improvement in dissolved oxygen conditions in the system since the 1972 Clean Water Act, which led to widespread upgrades in wastewater treatment and other remedies. On the other hand, the system remains saddled with a contaminant legacy resulting from being the seat of the Industrial Revolution and some types of pollutants such as nitrogen continue to increase.

Because of such mixed trends, which are common for most indicator classes, it is difficult to assign any single grade (good, fair, poor) to the overall environment within watershed. Taken together, however, analysis of all chapters will provide the best possible basis for making one's own determination of current status and trends in environmental conditions across the Delaware Estuary and River Basin.

Citation: 2007. U.S. EPA. Indicator Development for Estuaries. EPA842-B-07-004. Available at:

http://www.epa.gov/owow/estuaries


Map of the Delaware Estuary and River Basin with major watershed regions
East-West Branch
Lacka-waxen
Neversink-Mongaup
New York
Upper Central
Lehigh Valley
Lower Central
Schuylkill Valley
Upper Estuary
Pennsylvania
Maryland
Lower Estuary
New Jersey
Delaware Bay
Delaware
0 12.5 25 50 Miles
N

1

Watersheds & Landscapes

1 - Population
2 - Land Use/ Land Cover
3 - Land Use/ Land Cover Change
4 - Impervious Cover
5 - State & Federal Protected Lands
6 - Public Access Points
7 - Natural Capital Value

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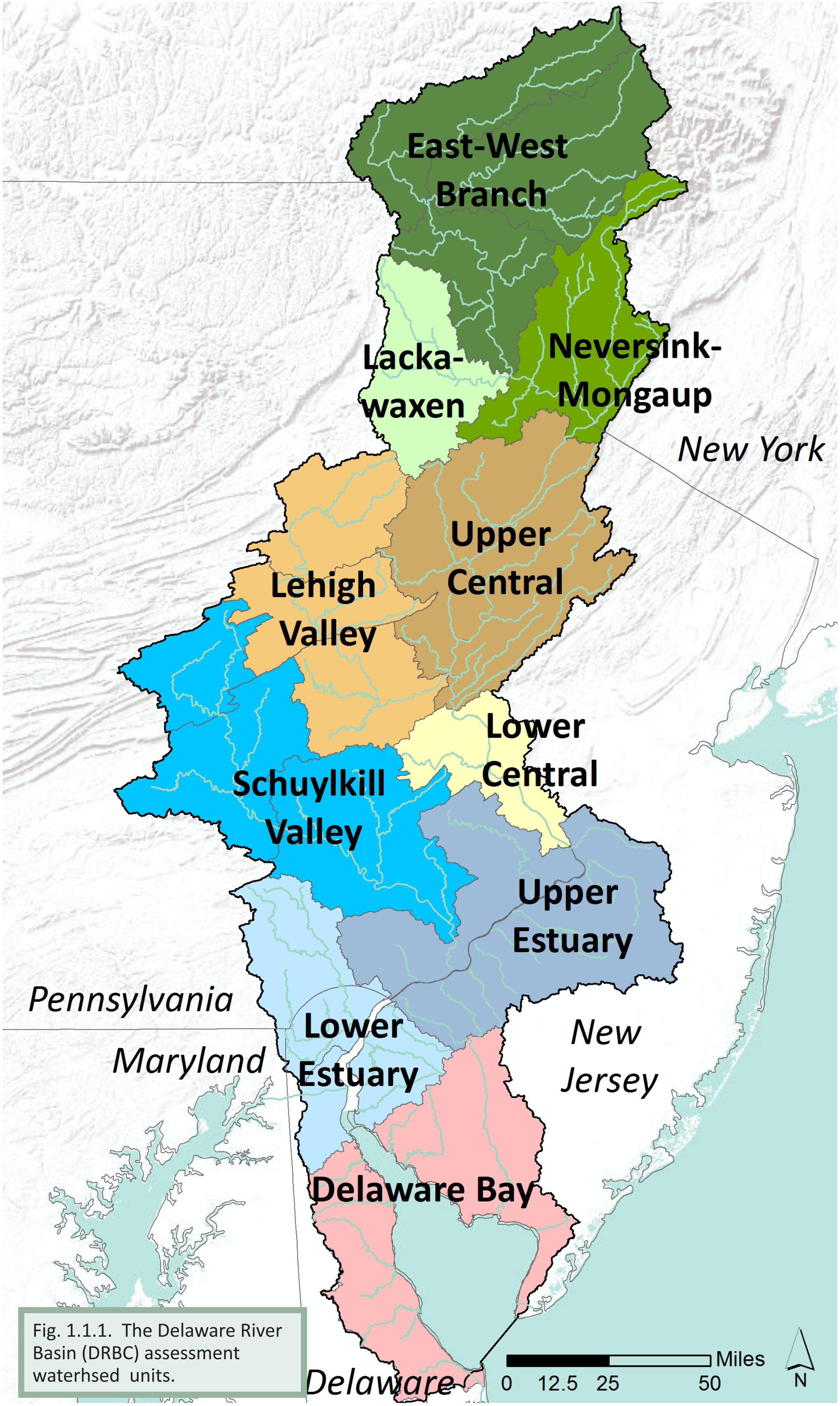


Fig. 1.1.1. The Delaware River Basin (DRBC) assessment waterhsed units.

Chapter 1 – Watersheds & Landscapes

1 – Population

1.1 Description of Indicator

This indicator quantifies the human population within the Delaware River Basin based on data from the U.S. Census. Water quality (pollution) and quantity (water supply and flooding) impacts in the watershed are directly proportional to the size of the population.

1.2 Present Status

The Delaware River Basin occupies 12,769 sq mi (33071 km^2) (not including the river and bay) in Delaware (8% of basin), New Jersey (23%), New York (20%), and Pennsylvania (49%). Population data from the 2010 U.S.Census (Table 1.1.1) indicates 8,256,005 residents live in the basin including 703,963 people in Delaware (9%), 6,339 in Maryland, 1,945,966 in New Jersey (24%), 121,160 in New York (1%), 5,478,577 in Pennsylvania (66%), and 6,339 in Maryland (<1%). In 2009, nearly 3,500,000 people worked in the Delaware Basin with 316,014 jobs in Delaware (9%), 1,172 jobs in Maryland, 823,294 jobs in New Jersey (24%), 69,858 jobs in New York (2%), and 2,271,317 jobs in Pennsylvania (65%).

Table 1.1.1. Land area, population, and employment in the Delaware River Basin

State	Area in mi^2 (km^2)	Population[1] 2010	Employment[2] 2009
Delaware	965 (2498)	703,963	316,014
Maryland	8 (21)	6,339	1,172
New Jersey	2,961 (7666)	1,945,966	823,294
New York	2,555 (6615)	121,160	69,858
Pennsylvania	6,280 (16,259)	5,478,577	2,271,317
Total	**12,769 (33,059)**	**8,256,005**	**3,481,655**

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

The population of the Delaware Basin now exceeds 8 million people which if considered a single jurisdiction, would be the 11th most populous state in the U.S. after North Carolina and New Jersey but ahead of Virginia and Massachusetts. Table 1.1.2 summarizes the area, population, and employment by state and county in the Delaware Basin. In Delaware, the basin covers 50% of the State's area yet includes 74% of the First State's population. The New Jersey portion of the basin covers 40% of the State's land area and includes 22% of the Garden State's population. The New York portion covers 5% of the State's land area and includes 0.7% of the Empire State's population. The Pennsylvania part of the basin covers just 14% of the State's area yet includes 43% of the Keystone State's population.

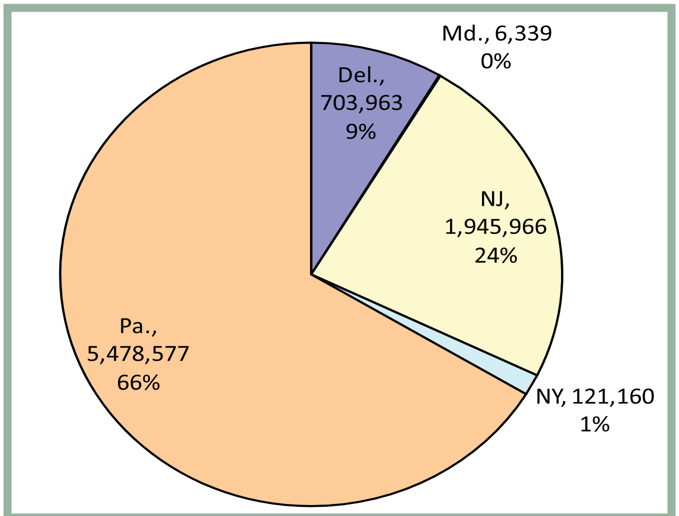


Fig. 1.1.2. Population in the Delaware River Basin by state.

1.3 Past Trends

Between 2000 and 2010, the population in the Delaware Basin increased by 6.3% or 492,942 people (Table 1.1.3). This population increase is equivalent to adding the cities of Dover and Wilmington, DE; Camden and Trenton, NJ: Allentown, Bethlehem, Easton, and Stroudsburg, PA; and Port Jervis, NY to the basin, in just 10 years! Over the last decade, population increased by over 30% in Kent and Sussex counties, Del. and by over 20% in Pike County and Monroe County, PA Philadelphia gained population for the first time in half a century. Several counties in the basin slightly lost population since 2000: Cape May, NJ; Ulster and Broome counties, NY; and Schuylkill County, PA. Eight counties gained over 30,000 people: New Castle and Kent counties, DE, and Berks, Chester, Montgomery, Monroe, Northampton, and Lehigh counties, PA.

Table 1.1.2. Land area, population, and employment by county in the Delaware River Basin

State/county	Area 2005[1] in mi² (km²)	Population[2] 2010	Employment[3] 2009
Kent	389 (1007)	141,346	50,412
New Castle	381 (986)	519,130	252,534
Sussex	195 (505)	43,487	13,068
Delaware	**965 (2498)**	**703,963**	**316,014**
Cecil	**8 (21)**	6,339	**1,172**
Maryland	**8 (21)**	**6,339**	**1,172**
Atlantic		5,470	
Burlington	495 (1282)	439,697	187,758
Camden	123 (318)	442,152	169,909
Cape May	104 (269)	30,845	14,545
Cumberland	490 (1269)	156,901	61,868
Gloucester	279 (722)	258,306	89,183
Hunterdon	215 (557)	35,139	23,650
Mercer	180 (466)	269,344	178,320
Monmouth	20 (52)	12,360	9,864
Morris		30,575	
Ocean	30 (78)	11,724	7,495
Salem	347 (898)	65,976	21,900
Sussex	320 (828)	78,917	23,302
Warren	358 (927)	108,559	35,500
New Jersey	**2,961 (7666)**	**1,945,966**	**823,294**
Broome	85 (220)	2,292	11,292
Chenango		103	
Delaware	1,295 (3353)	32,865	14,240
Greene	25 (65)	236	572
Orange	65 (168)	18,250	10,456
Schoharie		135	
Sullivan	940 (2434)	66,332	25,511
Ulster	145 (375)	946	7,787
New York	**2,555 (6615)**	**121,160**	**69,858**
Berks	777 (2012)	397,634	150,665
Bucks	607 (1572)	622,157	244,453
Carbon	381 (986)	65,979	16,730
Chester	616 (1595)	453,757	212,996
Delaware	184 (476)	553,166	201,208
Lackawanna	25 (65)	6,426	4,830
Lancaster		1,086	
Lebanon	20 (52)	17,021	2,750
Lehigh	347 (898)	343,054	166,932
Luzerne	50 (129)	23,161	8,074
Monroe	609 (1577)	169,172	56,025
Montgomery	483 (1250)	802,342	453,771
Northampton	374 (968)	304,002	96,536
Philadelphia	135 (350)	1,525,400	619,396
Pike	547 (1416)	57,177	9,874
Schuylkill	420 (1087)	85,893	27,077
Wayne	705 (1825)	51,151	14,114
Pennsylvania	**6,280 (1825)**	**5,478,577**	**2,271,317**
Delaware Basin	**12,761 (16,259)**	**8,256,005**	**3,481,655**

1. NOAA CSC 2005. 2. U. S. Census Bureau 2010. 3. U. S. Bureau of Labor Statistics 2009.

Table 1.1.3. Population change in the Delaware River Basin, 2000-2010 (U. S. Census)

State/County	2000	2010	Change	%
Kent	107,850	141,346	33,496	31.1%
New Castle	486,336	519,130	32,794	6.7%
Sussex	29,622	43,487	13,865	46.8%
Delaware	**623,808**	**703,963**	**80,155**	**12.8%**
Cecil	5,496	6,339	843	15.3%
Maryland	**5,496**	**6,339**	**843**	**15.3%**
Atlantic	4,766	5,470	704	14.8%
Burlington	413,729	439,697	25,968	6.3%
Camden	440,664	442,152	1,488	0.3%
Cape May	31,758	30,845	-913	-2.9%
Cumberland	146,771	156,901	10,130	6.9%
Gloucester	231,921	258,306	26,385	11.4%
Hunterdon	32,555	35,139	2,584	7.9%
Mercer	259,121	269,344	10,223	3.9%
Monmouth	9,850	12,360	2,510	25.5%
Morris	27,023	30,575	3,552	13.1%
Ocean	10,228	11,724	1,497	14.6%
Salem	64,553	65,976	1,423	2.2%
Sussex	76,429	78,917	2,488	3.3%
Warren	101,846	108,559	6,713	6.6%
New Jersey	**1,851,214**	**1,945,966**	**94,752**	**5.1%**
Broome	2,364	2,292	-72	-3.0%
Chenango	120	103	-17	-13.9%
Delaware	32,448	32,865	418	1.3%
Greene	224	236	12	5.2%
Orange	17,693	18,250	557	3.1%
Schoharie	124	135	11	8.8%
Sullivan	63,440	66,332	2,893	4.6%
Ulster	1,040	946	-94	-9.0%
New York	**117,453**	**121,160**	**3,708**	**3.2%**
Berks	361,361	397,634	36,273	10.0%
Bucks	593,922	622,157	28,235	4.8%
Carbon	59,011	65,979	6,967	11.8%
Chester	396,849	453,757	56,908	14.3%
Delaware	544,561	553,166	8,605	1.6%
Lackawanna	5,597	6,426	829	14.8%
Lancaster	737	1,086	349	47.4%
Lebanon	14,981	17,021	2,040	13.6%
Lehigh	305,656	343,054	37,398	12.2%
Luzerne	21,373	23,161	1,789	8.4%
Monroe	137,583	169,172	31,589	23.0%
Montgomery	751,287	802,342	51,055	6.8%
Northampton	273,549	304,002	30,453	11.1%
Philadelphia	1,518,220	1,525,400	7,180	0.5%
Pike	46,493	57,177	10,684	23.0%
Schuylkill	87,298	85,893	-1,405	-1.6%
Wayne	46,613	51,151	4,538	9.7%
Pennsylvania	**5,165,092**	**5,478,577**	**313,485**	**6.1%**
Delaware Basin	**7,763,062**	**8,256,005**	**492,942**	**6.3%**

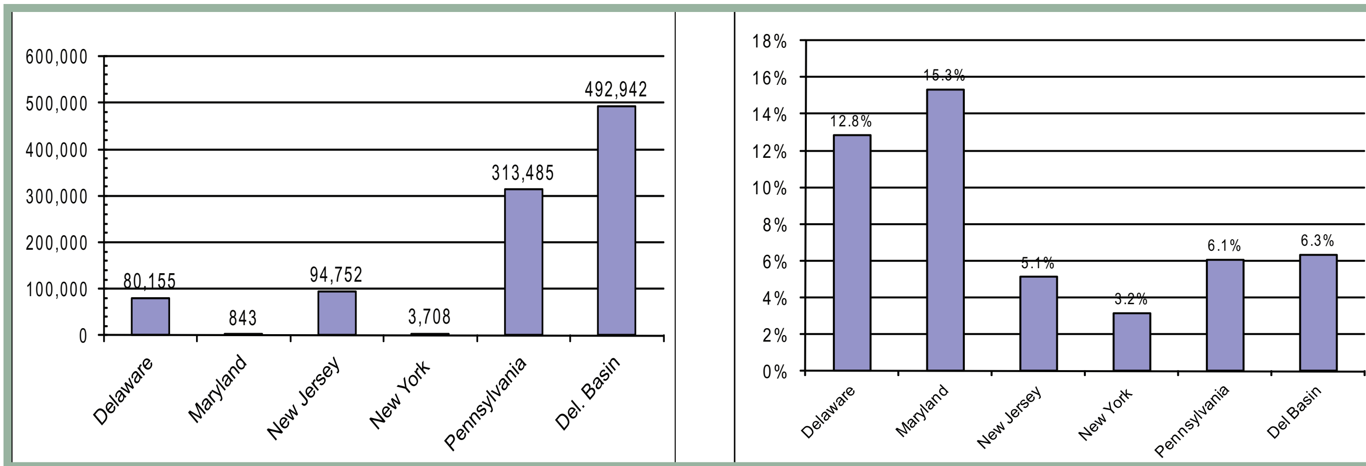


Fig. 1.1.3. Population change in the Delaware River Basin, 2000-2010 (U.S. Census)

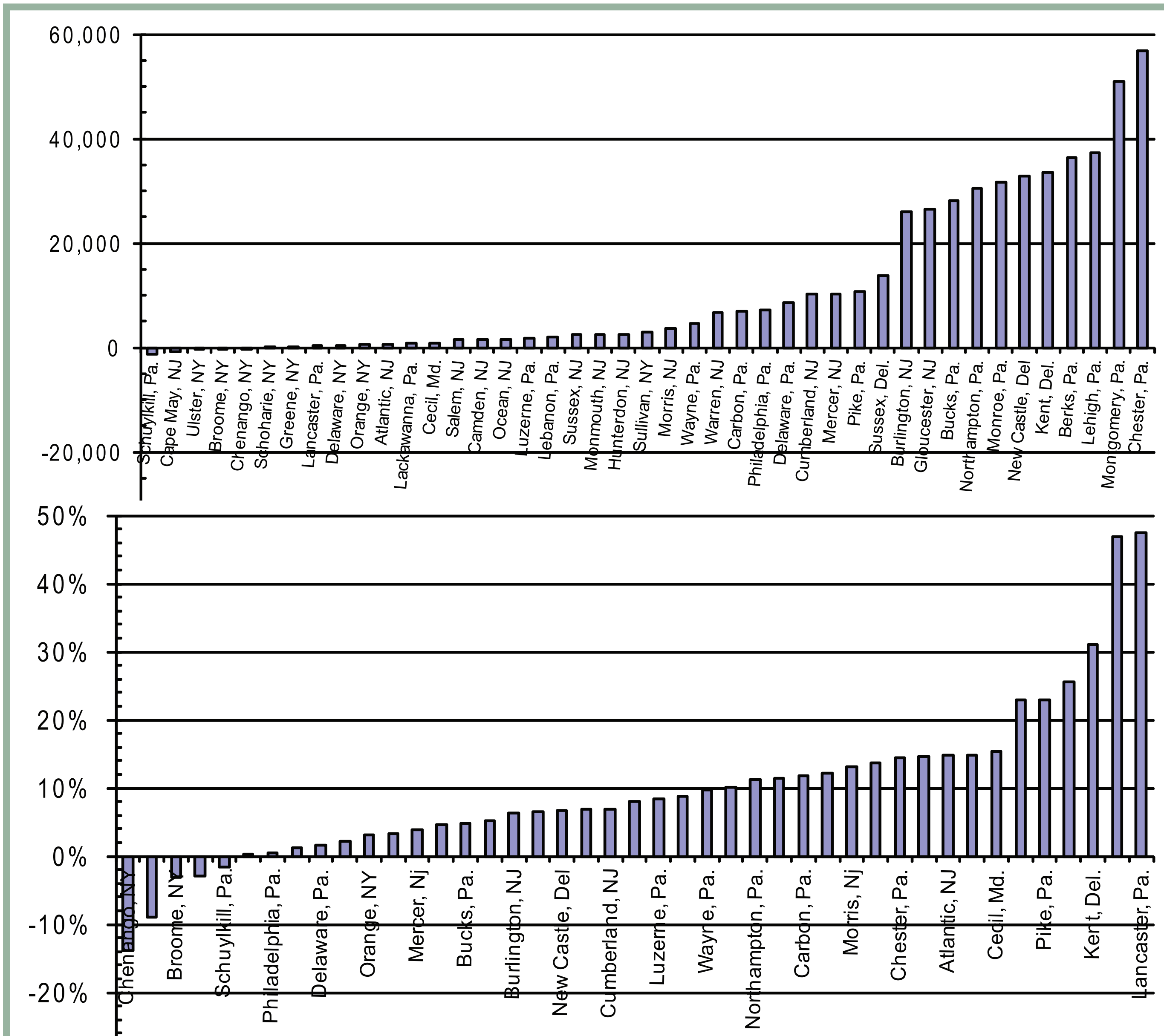


Fig. 1.1.4. Population change in Delaware Basin counties, 2000-2010 (U.S. Census)

Table 1.1.4. Watersheds in the Delaware River Basin

Watershed	Area in mi² (km²)	Population 2000	Population 2010	Change	%
LE1 Brandywine/Christina	187 (484)	424694	430615	5921	1.4%
LE2 C&D Canal	152 (394)	57613	83428	25815	44.8%
DB1 Delaware Bay	626 (1612)	141472	189891	48419	34.2%
Delaware	**965 (2498)**	**623,779**	**703,934**	**80155**	**12.8%**
LE 1 Maryland	**9 (23)**	5496	6339	843	15.3%
Maryland	**9 (23)**	**5496**	**6339**	**843**	
UC2 NJ Highlands	745 (1929)	218808	232511	13,703	6.3%
LC1 Del. R. above Trenton	159 (412)	58146	57828	-318	-0.5%
UE2 New Jersey Coastal Plain	1,021 (2643)	1292170	1353930	61,760	4.8%
LE3 Salem River	254 (658)	54518	59457	4,938	9.1%
DB2 Delaware Bay	782 (2025)	234537	249785	15,248	6.5%
New Jersey	**2,961 (7666)**	**1,858,179**	**1,953,511**	**95,331**	**5.1%**
EW1 East Branch Del. R.	666 (1724)	22155	22791	637	2.9%
EW2 West Branch Del. R.	841 (2177)	19222	18789	-433	-2.3%
EW3 Del. R. above Pt. Jervis	314 (813)	11188	11298	110	1.0%
NM1 Neversink R.	734 (1900)	64982	68352	3,370	5.2%
New York	**2,555 (6615)**	**117,546**	**121,230**	**3,684**	**3.1%**
EW3 Del. R. above Pt. Jervis	210 (544)	8633	9030	398	4.6%
NM1 Neversink R.	82 (212)	12136	13053	917	7.6%
LW1 Lackawaxen R.	598 (1548)	49736	56502	6,765	13.6%
UC1 Pocono Mt.	779 (2017)	208525	251121	42,596	20.4%
LV1 Lehigh River above Lehighton	451 (1168)	37667	48120	10,454	27.8%
LV2 Lehigh River abv Jim Thorpe	430 (1113)	88387	99152	10,765	12.2%
LV3 Lehigh River above Bethlehem	480 (1243)	478573	529935	51,362	10.7%
LC1 Del. R. above Trenton	295 (764)	101683	107933	6,250	6.1%
SV1 Schuylkill above Reading	338 (875)	88741	87033	-1,708	-1.9%
SV2 Schuylkill above Valley Forge	649 (1680)	321337	354874	33,537	10.4%
SV3 Schuylkill above Philadelphia	874 (2263)	952451	1010730	58,279	6.1%
UE1 Penna Fall Line	693 (1794)	2573270	2625750	52,480	2.0%
LE1 Brandywine/Christina	401 (1038)	235237	276033	40,796	17.3%
Pennsylvania	**6,280 (16,259)**	**5,156,376**	**5,469,266**	**312,890**	**6.1%**
Delaware Basin	**12,761 (33,038)**	**7,755,881**	**8,247,941**	**492,060**	**6.3%**

The Delaware Basin includes 21 watersheds that flow to the river and bay (Table 1.1.4).

1.4 Future Predictions

Based on past growth (1990-2020), the population of the Delaware River Basin is projected to grow from 8.2 million in 2010 to 8.7 million people by 2020 and 9 million by 2030. Every million adds approximately 100 mgd to public water supply demand and wastewater treatment needs in the basin with accompanying water resources infrastructure.

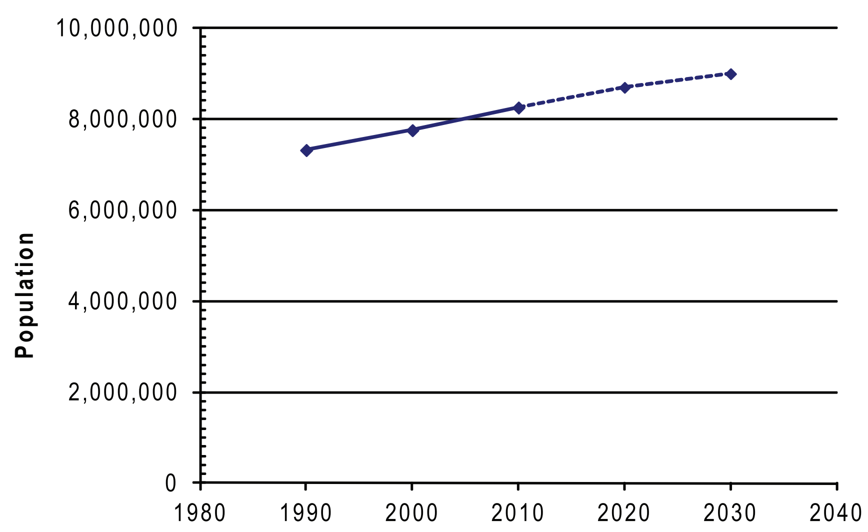


Fig. 1.1.5. Population in the Delaware River Basin

1.5 Actions and Needs

To accomodate the projected population growth, 5-year watershed master plans should be prepared for each of the 10 watersheds in the basin. The master plans should incorporate population projections and impact on drinking water demands, wastewater treatment, water quality, stormwater, and flood control.

1.6 Summary

Population data from the 2010 U.S.Census (Table 1.1.1) indicates 8,256,005 residents live in the basin including 703,963 people in Delaware (9%), 6,339 in Maryland, 1,945,966 in New Jersey (24%), 121,160 in New York (2%), and 5,478,577 in Pennsylvania (66%). Between 2000 and 2010, the population in the Delaware Basin increased by 6.3% or 492,942 people. The population of the Delaware River Basin is projected to grow from 8.2 million in 2010 to 8.7 million by 2020 and 9 million by 2030.

2 – Land Use/Land Cover

Data Sources and Processing

There are several potential sources of land use/land cover data. One is satellite imagery, another is aerial photography. The classification of land cover from satellite imagery is based on multi-spectral analysis of physical properties of reflectance at 30m by 30m resolution (The terms "land use" and "land cover" will be used interchangeably in this report. However, reflectance-based satellite imagery is more accurately a land *cover* data set, and may underestimate, for example, low density land use or cover [e.g., wetlands] under tree canopy). Aerial photography, while usually of higher resolution, is also highly idiosyncratic and not comparable across state lines—each of the four basin states has different policies and timeframes for their photogrammetry and divergent methodologies for assessment. For these reasons, this analysis is based on satellite imagery which offers a higher degree of consistency and replicability across a large study area. It is also available at regular time intervals from one provider employing dependable analytical methods.

The US Geological Survey (USGS) produces the National Land Cover Dataset (NLCD) which was used for parts of the land use assessment issued in the State of the Estuary 2008 and State of the Basin 2008. The NLCD is produced approximately every 10 years. A change in assessment methodology created comparison issues for the 1992 and 2001 data sets and another data set from The National Oceanic and Atmospheric Administration (NOAA) was considered.

The data set from NOAA is produced by the Center for Coastal Services (CSC). However, until 2010 their analysis area excluded a sizeable portion of the basin (approximately 750 mile^2, 1942 km^2) straddling the Central and Upper regions, an artifact of capturing the Atlantic and Great Lakes coastal regions. We are grateful to NOAA's CSC for generously agreeing to revisit the three most recent assessment years to incorporate that missing area, and to continue to include the entire Delaware River Basin in their analyses into the future, funding permitting. The CSC dataset has been available in five- year increments. A comparison of the NLCD and the NOAA-CSC data sets is shown in Figure 1.2.1. The NOAA-CSC data set appears to present a more consistent and reasonable trend in land cover change over the decade 1996-2006 than the NLCD presents for 1992-2001.

The NOAA-CSC data set was chosen for this assessment based on the frequency of publication and the consistency of the assessment methodology, availability, and reliability. NOAA-CSC expanded their area of coverage to include a previously missing area in the center of the basin in order to provide three assessment years of land use data: 1996-2001-2006. NOAA employs 21 classifications of land cover/land use, which have been consolidated into 6 categories for this analysis:

- Developed: low, medium, and high intensity development and developed open space
- Agriculture: cultivated lands, pasture, grasslands and transitional land
- Forest: deciduous, evergreen and mixed forest
- Wetlands: palustrine and estuarine emergent, scrub/shrub and forested wetland types
- Open Water: open water and palustrine aquatic beds
- Barren land: unconsolidated shore and barren land

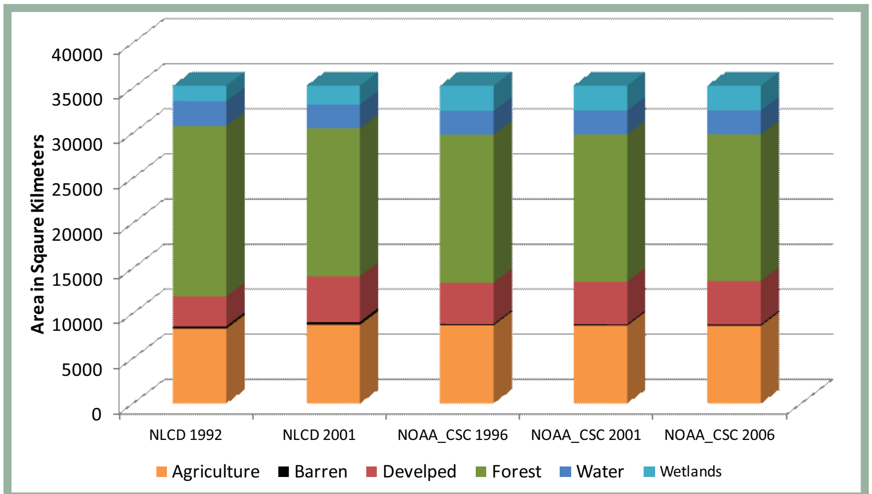


Fig. 1.2.1. LULC Data Set Comparison. The NOAA-CSC data set was chosen for this assessment based on frequency and consistency.

The NOAA-CSC data was developed to meet an 85% overall target accuracy specification, but can vary by geography and date. The NOAA-CSC data was parsed by the Delaware River Basin Commission (DRBC) and the University of Delaware into 21 sub-watershed groups and subsequently aggregated into 11 watersheds, 4 regions, and the basin for analysis. Additionally, the Upper and Central Regions combined drain into the non-tidal river, while the Lower and Bayshore regions drain to the tidal river and the bay, or Delaware Estuary. This distinction is included as an additional geographic unit of analysis. See Fig. 1.2.1 for basin assessment unit heirarchy.

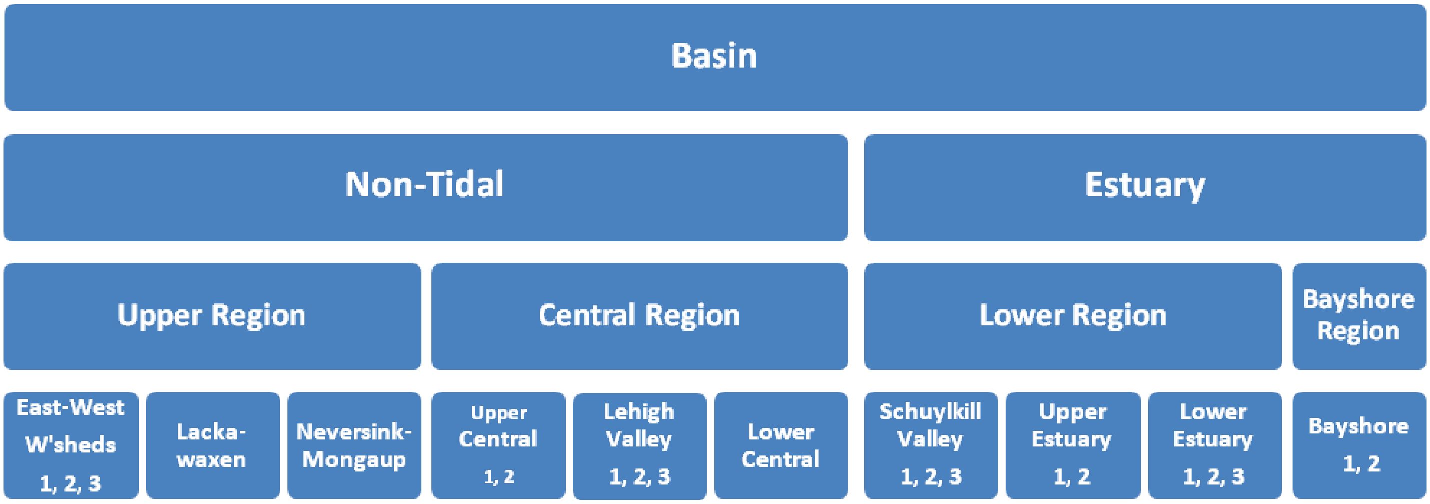


Fig. 1.2.2. Basin Assessment Units & Reporting Hierarchy. The basin can be subdivided into regions and watershed groups for more definitive reporting. See map for watershed units Fig. 1.1.1.

See watershed map Fig. 1.1.1, Table 1.2.1 , and Fig. 1.2.3 for geographic location and relative sizes.

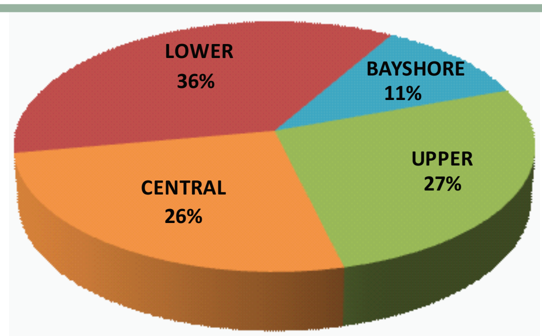


Fig. 1.2.3. Basin Regions. The four regions of the basin cover varying amounts of land area.
Note: Delaware Bay is not included in the analysis.

2.1 Description of Indicator

Land use/Land cover is a way to characterize the landscape; it includes both natural land cover (such as forests and wetlands) as well as the use of land for human habitation, commerce, and industry. The presence of land cover and land use types, as well as changes over time, often correlate to the condition of water resources and habitat.

Forest cover is a natural land cover strongly associated with pre-development conditions of water quality and hydrology. Forests cycle nutrients and carbon dioxide, capture rainfall and inhibit erosion, playing an important role in the supply and quality of water for streams and wetlands; they also provide forage and habitat for wildlife. Large areas of forested land are associated with water supply and water quality (Barnes et al. 2009) and forested watersheds are often routinely used to define natural reference conditions for streams. Mature forest is considered to be the main benchmark for defining pre-development hydrology within a subwatershed (Center for Watershed Protection 2003).

Value of Forest Cover as an Indicator

It should come as little surprise that the progressive loss of Forest Cover has been linked to declining stream quality indicators, given that forested watersheds are often routinely used to define natural reference conditions for streams . . . Mature forest is considered to be the main benchmark for defining pre- development hydrology within a subwatershed, as well. ***Consequently, forest cover is perhaps the most powerful indicator to predict the quality of streams within the "sensitive"category (i.e., with zero to 10% impervious cover).***

Impacts of Impervious Cover
Monogrqaph No. 1
Center for Watershed Protection 2003

Similarly, wetlands are positively associated with water resource quality and abundance, although that positive relationship can be dependent on size, connectivity, and functional integrity. Less is documented on the relationship of grasslands on water resources, and the effects of agricultural land uses can vary greatly—from benign to detrimental—depending on crop, intensity of use, degree of soil compaction, and the application of nutrient amendments and pesticides.

Agricultural lands include cultivated cropland, pasture, grasslands, and lands in transition (scrub/shrub). Abandoned agricultural lands may, through natural succession, return to more naturalized conditions, or they may be developed for more intense human use and habitation. The suitability as habitat and impacts on water resources are commensurate with the intensity of use.

Development or degree of urbanization, and its corollaries of population density, road network density, and impervious cover, are associated with the loss of native land cover and change (usually deleterious) to water quality and hydrology. Land uses, such as residential development or agriculture, may correlate to demand for water and an increase in potential water quality impacts through wastewater discharge and surface runoff.

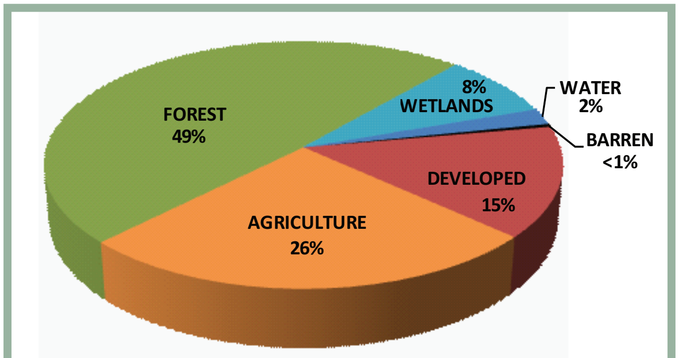


Fig. 1.2.4. Basin Land Cover 2006. The predominant land cover in the basin is forest. About 15% of the basin is classified as developed.

Knowledge of the proportion and distribution of land use and land cover types is one way to assess the conditions of watersheds and identify potential long-term concerns. This indicator is most effectively used in combination with population. Land cover and land use are also used as a basis for estimating impervious cover (IC), another indicator of potential degradation in water quality and hydrologic condition that is assessed in Section 5: Impervious Cover. Much research exists correlating the degree of land cover and intensity of use with water quality, stream flow, and habitat for aquatic and terrestrial communities. The US Geological Survey routinely assesses water quality and aquatic community impairment along an urban gradient (Ayers, et al. 2000).

At this aggregated scale, the proportion of land use can be a very general indicator of potential water resource quality and use issues that may need to be addressed. However, given the unit of analysis ($30m^2$), standard error, and aggregation of land use types, the results are general and suggestive across a broad landscape area. Definitive watershed analyses require aerial photography and field checks to ground-truth actual conditions.

2.2 Present Status

Basin Landscape

The basin has approximately 12,866 $miles^2$ (33,323 km^2) of land area within the states of Delaware New Jersey, New York, and Pennsylvania. (This does not include approximately 8 $miles^2$ (20.7 km^2)of land in the state of Maryland). More than half (53%) of the land area drains to the non-tidal Delaware River above the fall line near Trenton. The Delaware Bay adds 747 mi^2 (1,936 km^2) of area to the basin increasing the total to 13,614 $miles^2$ (35,268 km^2). With the bay included, more than half (50.2%) of the basin is part of the Delaware Estuary in the National Estuary Program. The following analysis reflects only that area (land and water) considered as part of the land cover assessment; the area of the bay has not been included in this landscape analysis. See Table 1.2.1.

Table. 1.2.1. Watershed Regions of the Basin – Land Area

Region	Upper			Central			Lower			Bayshore	
Water-shed	East-West	Lackwax.	N-M	Lehigh Valley	Upper Central	Lower Central	Schuyl. Val.	Upper Estuary	Lwr. Estuary	DE	NJ
Area in mi^2 (km^2)	2030 (5256)	598 (1548)	816 (2113)	1362 (3526)	1524 (3946)	454 (1175)	1892 (4898)	1745 (4518)	1021 (2643)	634 (1641)	790 (2045)
% of Region	59 %	17 %	24 %	41 %	46 %	14 %	41 %	37 %	22 %	45 %	55 %
% of Basin	27 %			26 %			36 %			11 %	
% of Estuary	NA						77 %			23 %	

Fig. 1.2.4 and Table 1.2.2a illustrates the amount and percentages of landscape types in the basin. The predominant land cover is forest which overlays 6,288 mi^2 (16,280 km^2) or 48.9 % of the basin land area; nearly three quarters of forested landscapes are found in the Upper and Central regions. Agricultural use and grasslands cover about 3,325 mi^2 (8,608 km^2) or 25.8% of the landscape. Wetlands and water combined account for an additional 10 % (1,334 mi^2, 3,454 km^2), although freshwater wetlands, especially in forested areas, may be under-reported in satellite imagery analysis. Developed landscapes—a combination of low, moderate, and high density residential,

Table. 1.2.2. Land use and land cover for the enitre basin, rounded to the nearest mi^2 (km^2)

	DEVELOPED	AGRICULTURE	FOREST	WETLANDS	WATER	BARREN	TOTAL AREA
UPPER	48 (124)	437 (1131)	2,778 (7192)	95 (247)	76 (197)	9 (23)	3,443 (8913)
CENTRAL	327 (847)	815 (2110)	1,925 (4983)	197 (510)	62 (161)	15 (40)	3,341 (8651)
LOWER	1,352 (3500)	1,514 (3919)	1,351 (3498)	334 (865)	82 (213)	22 (58)	4,656 (12053)
BAYSHORE	134 (347)	559 (1447)	234 (607)	434 (1124)	53 (137)	9 (23)	1,424 (3686)
BASIN	1,861 (4818)	3,325 (8608)	6,288 (16279)	1,061 (2746)	273 (708)	56 (144)	12,863 (33303)
% Cover	14.5%	25.8%	48.9%	8.2%	2.1%	0.4%	100%

commercial, and industrial development – cover 1,861 mi^2 (4818 km^2) or 14.5% of the basin.

Types of land cover are not equally distributed across the basin, as Fig. 1.2.5 illustrates. See also Table 1.2.2. The Upper and Central regions are dominated by forest cover and account for about 75% of the basin's forested area. The Lower region is the most heavily developed and populated area of the Basin, as reflected in the predominance of human use—development (29%) and agriculture (33%); indeed, nearly three-quarters of all development within the basin is found in the watersheds of the Lower region, a factor that can be related to the water quality of the region's tributaries and the mainstem Delaware River here. Wetlands are found throughout the basin, but their presence is most notable as the tidal wetlands in the Upper Estuary and Bayshore watersheds. See Chapter 5B for more detail on tidal wetlands. Along with population density and development patterns, the varying combinations of land cover and land use in each region and each watershed affect the way and the amount of water use and the ways water quality can be affected by point and non-point sources of pollution.

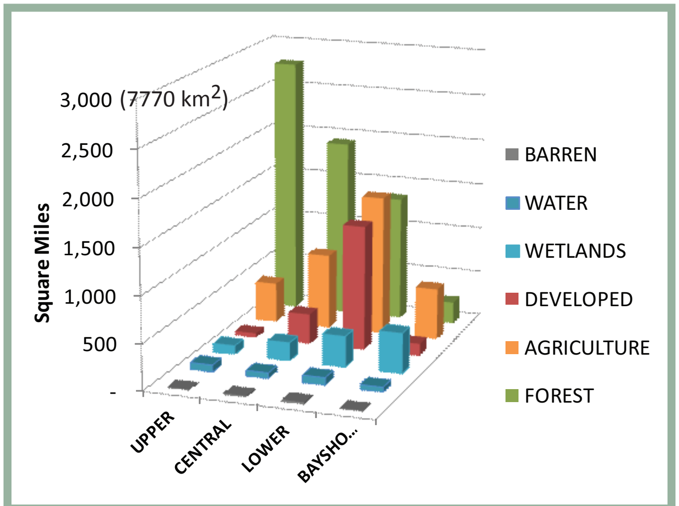


Fig. 1.2.5. Land Cover 2006 by Basin Region. Forest cover predominates in the Upper and Central Regions. The Lower Region is a mix of agriculture, forest and developed lands. the The Bayshore Region is characterized by coastal wetlands and agricultural land use.

Similarly, watershed groups within regions exhibit notable variation in land cover and use. Fig. 1.2.6 illustrates the variation in the landscape characterisitics of watershed from north (East-West) to south (Bayshore). While forest dominates the landscape of the watersheds from the headwaters down through the Lehigh Valley, its presence is considerably muted in the watersheds of the Lower Central and south to the Bayshore watersheds. Agriculture is a dominant use in the Schuylkill valley, the Lower Estuary and the Bayshore watersheds. The population centers of in the Lehigh, Schuylkill, Upper and Lower Estuary watersheds are also very visible. In the Upper Estuary, development dwarfs all other land cover.

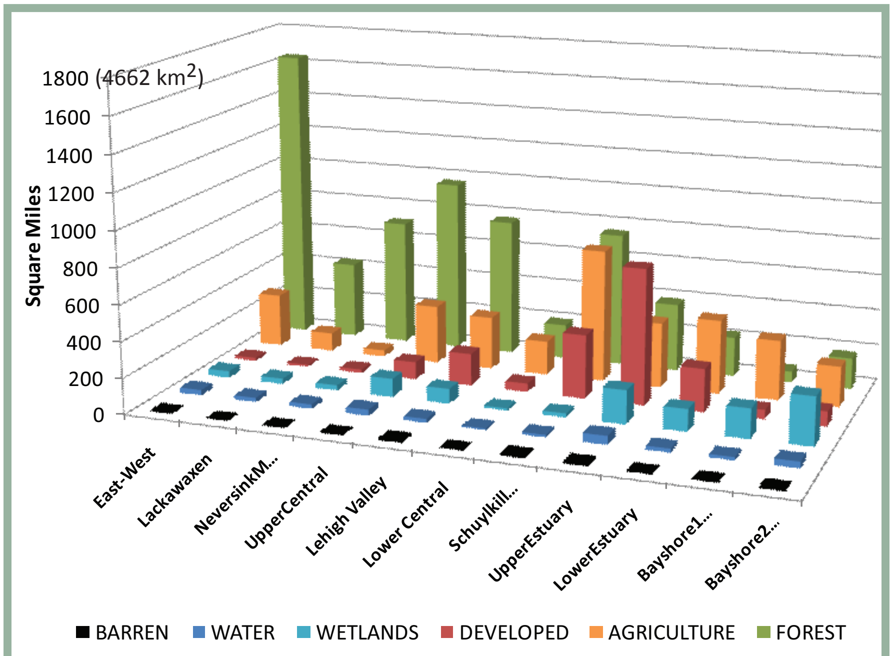


Fig. 1.2.6. Land Cover 2006 by Watershed Group. The variation of land cover across the basin is most evident when viewed from a watershed perspective.

The Delaware Estuary

The land area of the Delaware Estuary is nearly 6,100 mi^2 (15,793 km^2), comprised of the five watershed groups of the Lower and Bayshore regions which drain the Schuylkill Valley, the Upper Estuary, the Lower Estuary and the eastern (NJ) and western (DE) Bayshore. Although the Estuary contains slightly less than half (47%) of the basin's land area, it accounts for 79.9% of all developed land, 62.3% of cultivated and scrub land, and 72.4% of the basin's wetlands. See Fig. 1.2.7, and Table 1.2.3 for details. Next to agriculture, wetlands are the notable and most important feature of the Estuary, especially of the Bayshore watersheds where they ring the Bay, functioning as nursery, nutrient sink, sediment source, temperature-moderating, and flood-regulating system. See Chapter 5B for additional information on wetlands.

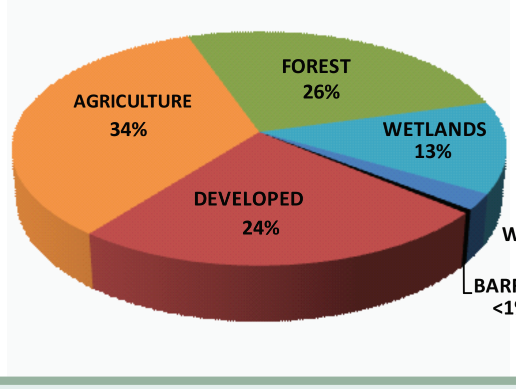


Fig. 1.2.7. Estuary Land Cover 2006.

Table 1.2.3a Estuary Land Cover & Use in mi^2

	DEVELOPED	AGRICULTURE	FOREST	WETLANDS	WATER	BARREN	ESTUARY
SV	356.45	739.10	749.46	22.20	13.23	10.55	1,890.99
UE	755.34	362.86	379.49	187.96	48.15	9.34	1,743.14
LE	240.22	411.83	222.20	123.78	20.90	2.49	1,021.42
DB1-West	51.98	333.87	61.62	166.02	17.45	3.46	634.40
DB2-East	82.04	225.22	172.78	268.29	35.53	5.43	789.29
ESTUARY	1,486.03	2,072.88	1,585.55	768.25	135.25	31.28	6,079.24

Table 1.2.3b Estuary Land Cover & Use in km^2

	DEVELOPED	AGRICULTURE	FOREST	WETLANDS	WATER	BARREN	ESTUARY
SV	923.18	1,914.19	1,941.04	57.49	34.26	27.33	4,897.48
UE	1,956.26	939.78	982.84	486.80	124.69	24.20	4,514.57
LE	622.14	1,066.61	575.48	320.57	54.13	6.45	2,645.38
DB1	134.62	864.69	159.59	429.97	45.18	8.97	1,643.03
DB2	212.48	583.29	447.48	694.84	92.01	14.07	2,044.17
ESTUARY	3,848.68	5,368.55	4,106.42	1,989.68	350.28	81.02	15,744.63
% of ESTUARY	24.4%	34.1%	26.1%	12.6%	2.2%	0.5%	100.0%
% of Basin LC/LU	79.9%	62.3%	25.2%	72.4%	49.5%	56.2%	

2.3 Past Trends

While satellite imagery has enabled the consistent measurement of land use change over time, it is a relatively new tool. The first land use imagery base was generated in 1972 based on multispectral imagery from Landsat1. Technological innovations, improvements in methodology, and cost confound a quantitative assessment of landscape change over a broad time frame, and is therefore not within the scope of this report. However, historic evaluation of landscape change can help identify the proximate causes of current conditions that are linked to antecedent land use and management. A description of land use and land cover change between 1996 and 2006 is found in Section 3.

2.4 Future Predictions

It is expected that as population increases, developed (urban) land will continue to increase and forests, grasslands and fields will be converted for human habitation, commercial and industrial uses. The rate of change will be dependent on demand and how intensely land is used—that is, how many acres are developed for each net increase in population, economic growth or shift in resource needs. While filling and conversion of wetlands for agricultural and urban development has generally decreased over time, the loss of coastal wetlands is expected to continue exacerbated by sea level rise and the inability of wetlands to migrate. See Chapter 5. While agricultural use has shown a generally decreasing trend, the demand for locally-sourced produce and meat may enhance the economic viability of small farm agriculture. Longer growing seasons—a condition expected to accompany climate change—could stabilize or even increase the amount of land in agricultural use. As the effects of climatic changes are realized, the ecological service value of wetlands and forests – especially their ability to sequester carbon, might alter the economic valuation of these landscapes and, in turn, how they are used. Ideally, we will accommodate population increases with improved efficiency, which would result in the amount of developed land holding steady—or decreasing—over time. In addition, water supply and quality issues, coupled with a desire to reduce energy consumption, could result in the "greening" of urban areas to offset the adverse impacts of dense human settlement patterns on air and water temperature, air quality and surface water flow and quality. Significant challenges exist—political, economic and cultural—before positive land use outcomes can be realized. See Section 3.4.

2.5 Actions and Needs

The satellite imagery data set is the only one that offers consistent evaluation of land cover across the basin. As long as NOAA-CSC is able to include full basin coverage in their analyses, this will continue to be the data set of preference for land cover analysis at the basin scale. However, the 30m resolution, while adequate for the basin in aggregate, is not ideal for capturing land cover change at a smaller sub-basin scale. The use of vector-based land cover data from aerial photography may be preferable for watershed-scale analyses, but is not possible under current conditions; each basin state has differing schedules for their photogrammetry and differing methods of analysis. Until synchronized and normalized across the basin, the state-based information, while more detailed, is not useful for any comparative analyses.

2.6 Summary

The basin land cover and land use includes forest (49%), agriculture (26%), developed (15%), wetlands (8%), water (2%), and barren (1%). This varies significantly by region. The dominant feature of the Upper region is forest (80%) and that region has the least amount and percentage of developed land. The landscape of the Lower regions is more or less equally divided into agriculture, forest and developed land. This is the most highly developed region of the basin, accounting for nearly 73% of all development. The Estuary area, that is the Lower and Bayshore regions combined, accounts for nearly 80% of all developed land in the basin, as well as about 72% of the basin's wetlands visible via satellite imagery. The Bayshore and Central regions exhibit similar levels of development (about 9% and 10% respectively), although they are each unique. The Central region is still slightly dominated by forest (58%) and nearly a quarter of the landscape is in agriculture. The Bayshore region landscape is best characterized by a mix of agricultural use and coastal wetlands; approximately 16% of the Bayshore landscape is forested.

3 – Land Use /Land Cover Change

This analysis considers the *net* change in land cover based on the dates of the NOAA-CSC data for 1996, 2001, and 2006. It includes changes across the basin, among regions and across watersheds by the six land cover types defined earlier in Chapter 1.2: developed, agriculture, forest, wetlands, water and barren land.

3.1 Description of Indicator

Land cover changes over time. It may change by natural succession—as when woody plants volunteer and eventually replace grasslands and abandoned fields—or by other natural processes—erosion or inundation of shoreline and wetlands, for example. Disasters notwithstanding, landscape changes due to natural causes generally occur at a very slow pace, especially in comparison to the relatively rapid changes wrought by human activity. In general, however, land cover changes relatively slowly in the aggregate, landscape scale. Scale plays a role in our perception of change, as well as our ability to capture it. For example, while one may notice the lot or parcel being cleared in a community for new housing or stores, that change of a few acres may not be sufficiently significant to register in an analysis of net change.

Tracking land cover change at a watershed level is valuable for planning and protection efforts, and for correlating with water use and water quality. It is not simply the change of land classification that is of interest, but the potential change or loss of the function of the natural landscape that makes this indicator worth tracking. However, statements of aggregated "net" change can yield only a very general assessment of conditions at large scales and may mask significant land cover change at the watershed or local level.

Relative changes, trends, and rates of change may be useful for indicating potential impairments to water quality or hydrology and where additional assessment work would be beneficial. Change in land cover and use, in tandem with changes in population, can indicate a need for re-visiting plans for water supply and wastewater to ensure the maintenance of adequate stream flow and quality.

3.2 & 3.3 Past Trends & Present Status

Land Cover Change in the Basin and Regions

Historically, land use change has occurred in a stepped process, generally increasing in intensity over time, as land has first been cleared (forest) or filled (wetlands), then put to a succession of uses that serve community needs and the demands of commerce and industry. It is far less likely that developed land will revert back to a natural, undeveloped landscape. As former Secretary of Agriculture Rupert Cutler noted, "Asphalt is the land's last crop" (R. Cutler, 1984).

Table. 1.3.1. Net Land Cover Change 1996-2006 by Regions

	DEVELOPED	AGRICULTURE	FOREST	WETLANDS	WATER	BARREN
Percent Change	**4.7%**	**-0.7%**	**-0.8%**	**-1.8%**	**-0.7%**	**7.1%**
Net Change in mi²						
UPPER	1.69	8.74	-10.14	0.03	-1.27	0.95
CENTRAL	20.75	-5.36	-11.06	-4.26	-2.16	1.70
LOWER	61.11	-25.18	-25.07	-8.94	-2.52	0.62
BAYSHORE	4.04	-0.02	-2.90	-5.77	3.97	0.68
BASIN	**87.59**	**-21.83**	**-49.17**	**-18.94**	**-1.98**	**3.95**
Total Land Cover	1,860.83	3,324.71	6,287.91	1,060.75	273.42	55.64
Net Change in km²						
UPPER	4.38	22.62	-26.27	0.09	-3.28	2.46
CENTRAL	53.73	-13.88	-28.64	-11.03	-5.60	4.41
LOWER	158.26	-65.23	-64.94	-23.17	-6.53	1.60
BAYSHORE	10.47	-0.06	-7.50	-14.94	10.27	1.76
BASIN	**226.84**	**-56.54**	**-127.35**	**-49.05**	**-5.14**	**10.22**
Total Land Cover	4,819.36	8,610.68	16,285.06	2,747.23	708.14	144.11
Net Change in Acres						
UPPER	1,082	5,591	-6,492	22	-810	608
CENTRAL	13,277	-3,429	-7,078	-2,727	-1,384	1,089
LOWER	39,108	-16,118	-16,047	-5,724	-1,614	395
BAYSHORE	2,588	-15	-1,854	-3,691	2,538	435
BASIN	**56,055**	**-13,971**	**-31,471**	**-12,120**	**-1,270**	**2,527**
Net Change in Hectares						
UPPER	438	2,262	-2,627	9	-328	246
CENTRAL	5,373	-1,388	-2,864	-1,103	-560	441
LOWER	15,826	-6,523	-6,494	-2,317	-653	160
BAYSHORE	1,047	-6	-750	-1,494	1,027	176
BASIN	**22,684**	**-5,654**	**-12,735**	**-4,905**	**-514**	**1,022**

We know from historic description that the Delaware basin was predominantly forested at the time of European colonization and that there were also significant areas of marshes and wetlands, especially throughout the estuary and including the vicinity of Philadelphia. We also know that forests throughout the basin have been successively and extensively cleared for use in shipbuilding, glass manufacturing (fuel), and for construction. Currently, forested area exceeds what was present in the early 20th century. The Interstate Commission on the Delaware River Basin (INCODEL) reported that only 4,117 square miles (10,659 km2) were forested in 1930 (INCODEL 1940). Human encroachment on the basin's wetlands, especially in the estuary, has been substantial; remaining wetlands are but a fraction of original estimates. See Chapter 5B.

During the decade between 1996 and 2006:

- Approximately 88 mi² (228 km²) were developed across the basin, an increase of 4.7%. The *State of the Basin Report 2008* (DRBC 2008, p. 71) overestimated the net change in developed area between and the net loss of forested land between 1996 and 2001.

- Twenty two mi² (57 km²) of cultivated or scrub land were converted to another use or succumbed to natural succession and reverted to forest, a net loss of 0.7 %.

- Nearly 20 mi² (52 km²) of wetlands were developed or otherwise lost, perhaps through inundation, a net loss of 1.8%.

- The basin also experienced a net loss of nearly 49 mi² (127 km²) of forest (-0.8%).

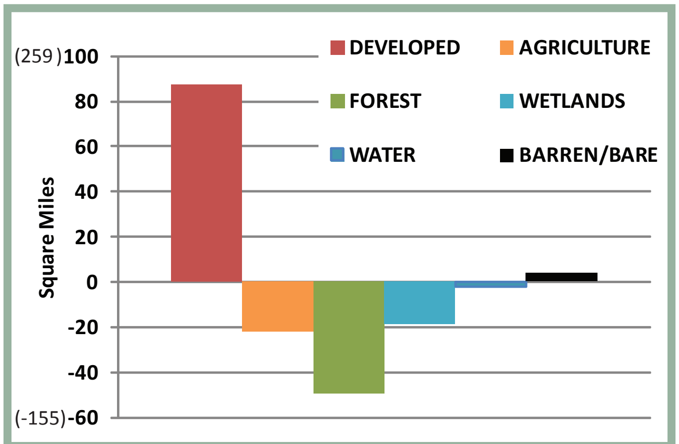


Fig. 1.3.1. Basin Land Cover Change 1996-2006. During the decade between 1996 and 2006, approximately 88 square miles (128 km2) of development was added across the basin. Overall, almost 50 square miles (127 km2) of forest was lost during the same time period. Changes in wetlands and barren land, although reported for completeness, are *de minimus* and within the margin of error of the analysis.

Change in Large Watersheds

The net changes that are calculated in aggregate are the result of changes in land cover within watersheds. As previously noted, the satellite imagery is most robust for large landscape analysis. If not particularly accurate for absolute change, such analyses can illustrate relative change among the watersheds. Figure 1.3.3 illustrates the relative net change in land cover type across the basin by the 10 watershed groups arranged north to south. Although not normalized for total area, the predominant type of land cover change is clear. Development is occurring in the Upper Central, Lower Central, and Lehigh watersheds, and is continuing in the Schuylkill, the Upper Estuary, and the Lower Estuary watersheds. At the northern end of the basin, the East-West, Lackawaxen, and Neversink-Mongaup watersheds are experiencing less development, but a net loss of the forested landscape, the hallmark landscape of the basin's headwater region. In the Bayshore watersheds, development increased and the net loss of wetlands continued, while the amount of agricultural landscape remained stable.

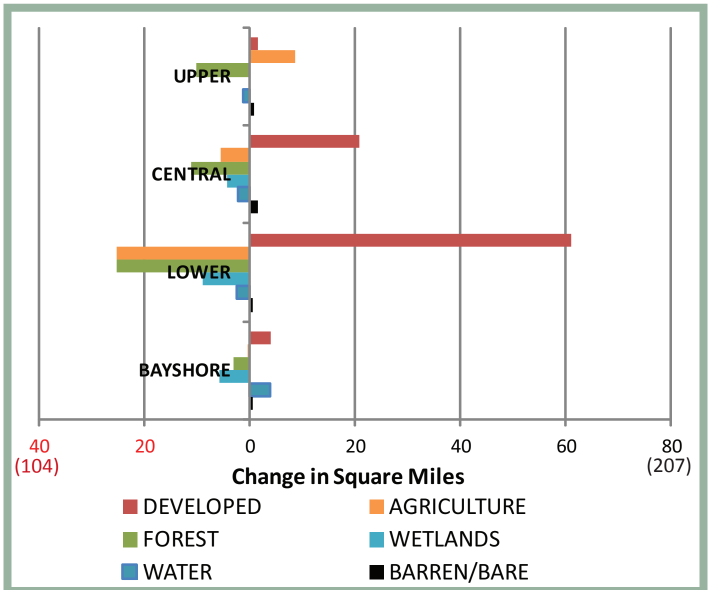


Fig. 1.3.2. Net Land Cover Change by Region 1996-2006. The Lower Region experienced three times the development of the Central Region

Change in Developed Area

Developed land increased in every watershed of the basin in the decade between 1996 and 2006. The greatest increase in development occurred in the Lower Region where more than 60 square miles (158 km²) of land were developed, and a combined total of more than 50 square miles (130 km²) of agricultural land and forest were lost. The Central Region had the second greatest gain of developed land (more than 20 square miles, about 54 km²) and a proportionately larger loss of forest than agricultural land.

Change in Agricultural Area.

A net decrease in the basin's agricultural land (22 mi², 57 km²) occurred with major losses in the Lower Region (25 mi², 65 km²). However, the Upper Region shows a net increase in agricultural landscapes (nearly 9 mi² or 29 km²). There was also loss of agriculture in the Central Region (5 mi², 14 km²) where a modest increase in crop and pasture land was overshadowed by a loss of scrub/shrub lands. Change in agricultural land in the Bayshore Region was unremarkable.

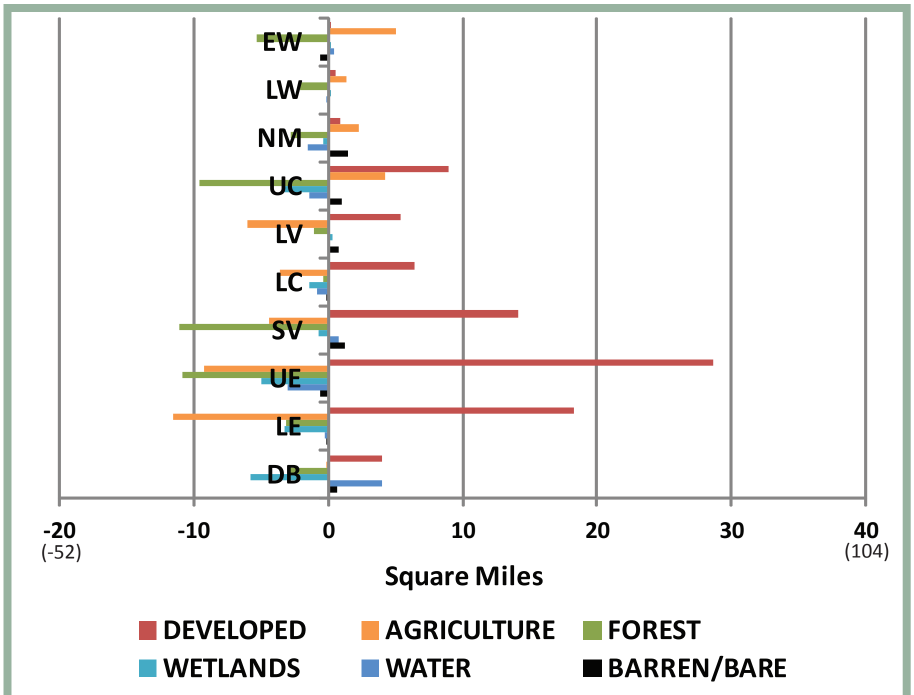


Fig. 1.3.3. Change in Land Cover 1996-2006 by Watershed. Land cover change analysis based on satellite imagery is better for indicating relative not absolute change, especially at the watershed scale. Because of scale and accuracy issues involved with satellite imagery, small changes should be considered suggestive and not definitive. Additional information would be required to support the changes suggested by this analysis.

Change in Forest Area

Between 1996 and 2006, there was a net loss of nearly 50 square miles (127 km^2) across the basin. Just slightly less than one percent (0.8%) of the forest existing in 1996 was lost in 10 years. A net loss was found in each of the 21 assessment units, and in every region. The greatest loss (25 mi^2, 65 km^2) occurred in the largest (Lower) Region. In the Central Region, modest gains in deciduous and evergreen forest were offset by greater losses in mixed forest. Even the Upper Region, which experienced very little development, had a net loss of more than 10 square miles (26 km^2) of forest.

Table. 1.3.2 Rate of Net Forest Loss 1996-2006

Net loss per decade	-31,471 ac (12733 ha)
Net loss per year	-3,147 ac/yr (1273 ha/yr)
Net Loss per Month	-262.25 ac/mo (106 ha/mo)
Net Loss per Week	-60.52 ac/wk (-24 ha/wk)
Net Loss per 5-Day Work Week	-12.10 ac/day (5 ha/day)
Football field	~1.3 ac (0.53 ha)
Forest Loss Equivalent	-9.2 football fields/day
8-hour work day	-1.2 football fields/hour

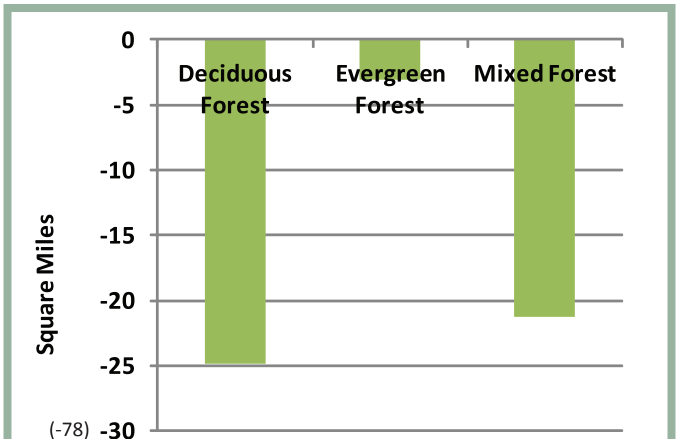


Fig.1.3.4. A decade of Forest Change. Bar graph of change in 3 forest types

Rate of Forest Change

Understanding the scale of landscape change over a long period of time can be confounding, so expressing that change in as a "comparable" can be helpful. A football field is a useful comparison, since a football field is just slightly larger than an acre. (An acre is 43,560 square feet. A football field is 360 ft by 160 feet, or 57,600 square feet, or 1.32 acres.) The estimated net loss of forest across the basin can be expressed as an average net loss over the decade, a year or even shorter time frame. For example, assuming 52 weeks per year, and an average of five 8-hour workdays per week, the average rate of net forest loss was approximately 9 football field per day, or about 1 per hour. See Table 1.3.3.

The net loss of forest in the time frames 1996-2001 and 2001-2006 were very similar (-16,082 ac/-6507 ha and -15,389 ac/-6226 ha, respectively), indicating a fairly constant rate of loss over the decade. Additional years of data will aid in the establishment of a trend.

Change in Forest Types

There is a difference in the change of types of forests. The NOAA-CSC data set classifies forest cover as one of three types: deciduous forest, evergreen forest, or mixed forest. Deciduous forests areas are dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover where more than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

Evergreen forests areas are dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover where more than 75 percent of the tree species maintain their leaves all year and the canopy is never without green foliage.

Mixed forest areas are dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.

The greatest amount of net loss was seen in deciduous and mixed forest types. See Fig 1.3.4. The change was differentiated across the basin regions. Deciduous forest decreased in every region but the Central Region, where slight net gains were calculated for deciduous and evergreen forests. See Fig 1.3.6

3.4 Future Predictions

Landscape change is only part of the suite of indicators that are needed to a) depict how efficiently and effectively we are using land, and b) predict issues of concern that may warrant further investigation. For example, the density of development and per capita land conversion, landscape change relative to population, are indicators of how efficiently we are using land. Lower density "suburban" development, also known as sprawl, is typical of the development pattern across the basin and is associated with greater travel times for work commutes and access to community services, as well as greater per capita loss of natural landscapes.

> *Pennsylvania's growth opportunity is green and walkable. Changing demographics suggest there is an emerging market for development that is green (energy and environmentally conscious) and walkable (compact, affordable, mixed-use, and favoring pedestrians). This is a win-win scenario. Pennsylvania CAN attract growth AND sprawl less.*
>
> State Land Use & Growth Management Report
> Executive Summary
> Governor's Center for Local Government Services (PA)
> 2010

> *"Since there is a cause-and-effect link between land development and [vehicle miles traveled] VMT, land use is directly and synergistically linked to the transportation sector...[I]t will be difficult for New Jersey to meet its statewide GHG [green house gasses] limits without a fundamental shift in the state's historic development patterns."*
>
> Global Warming Response Act Recommendations
> NJ Department of Environmental Protection 2009

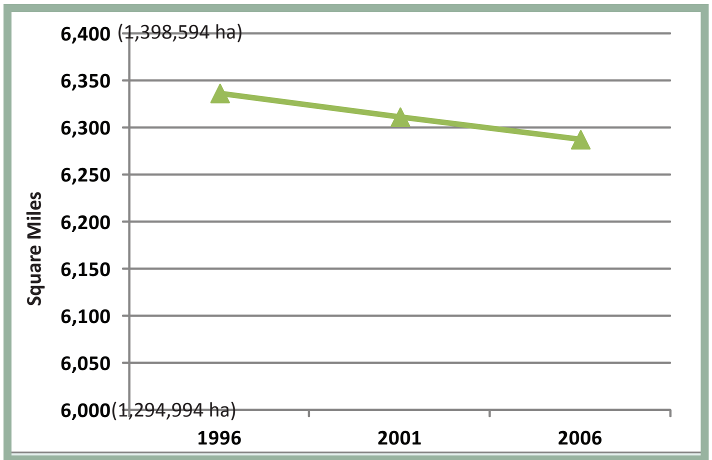


Fig. 1.3.5. Basin Forest Change 1996-2006. The net loss of forest between periods were similar 1996-2001= - 25.13 mi^2 ; 2001-2006 = - 24.04 mi^2 (-16,082 acres and -15,389 ac respectively; -41,636 and -39,842 ha respectively)

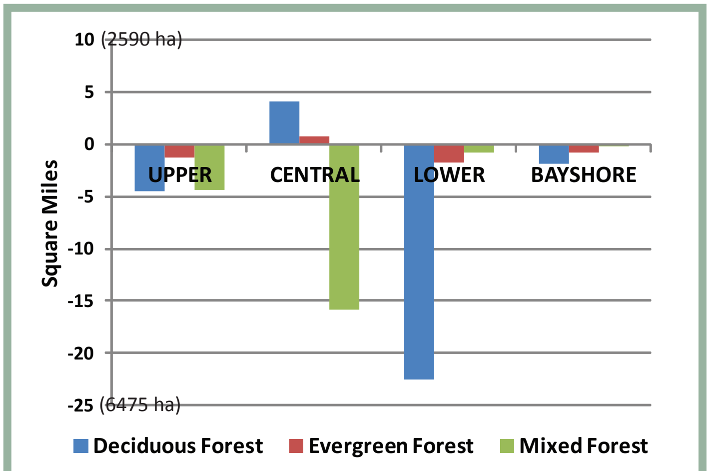


Fig. 1.3.6. Forest change by region 1996 - 2000

When compared to an array of known or perceived threats, landscape change has been identified as producing the "largest negative ecological and socio-economic impacts" including: habitat loss and fragmentation; permanent ecosystem destruction; increases in stormwater flows and flooding; skewed employments patterns and property values detrimental to older communities; traffic congestion; and public health impacts (NJDEP 2003).

In at least two basin states, recent reports recommend a focus on green, walkable (more compact—greater density) communities to reduce loss of natural lands and decrease traffic and vehicular trips while correspondingly improving air quality and public health. To date, no significant policy actions have been taken to advance this goal and amend the historic trends in land development.

Development patterns are affected by regulatory and economic forces. While the regulation of land use—how densely and for what uses land can be developed—remains delegated to local governments and largely uncoordinated across watersheds and states and effectively independent of broad transportation and environmental policies and state-wide programs, other economic factors may provide an impetus to change. Among them are higher energy costs—for gasoline in particular—and changing demographics—increased cohort of healthy retirees—which may create a resurgence of demand for urban living, the subsequent revitalization of older communities, and a reduced pressure to convert forest and field to buildings and asphalt. Anecdotal reports on housing and population trends from some cities, including Philadelphia, support this as a potential future trend in land use change.

In addition to the influence of population growth, economic development and climate on land use (see Section 2.4) emerging energy and industry trends may prove to have significant impact on the character of the landscape and possibly on the water resources of the basin. Marcellus shale, a geologic formation more than a mile below the surface, holds a significant reserve of natural gas which recently has become economically viable to extract. Marcellus shale underlays nearly 5,000 square miles, or approximately 36% of the basin, almost exclusively in the Central and Upper Region watersheds. However, less than a third of that area is above the "northern structural front" (the boundary of the Ridge and Valley physiographic province) and thought to be viable. Evolving technologies are making extraction more efficient: horizontal drilling and hydraulic fracturing can be used to extract more gas from a larger supply area from a single well, and several wells on a single pad can significantly reduce the amount of landscape disturbance.

Landscape changes can be expected as multi-well pads, staging areas, water supply facilities, wastewater holding and transfer areas, access roads, pipelines and compressor stations are developed to access, extract and distribute the natural gas. The introduction of this new industry to the upper basin is expected to increase demand for both temporary and permanent housing, and may accelerate the conversion of seasonal housing for year-round use.

Both the Delaware River Basin Commission and New York State have prepared new regulations to address natural gas extraction via high volume hydraulic fracturing. While the regulations may differ and neither has been adopted, it is possible that the portion of the basin associated with New York City watersheds will be off limits from that activity. The extent and rate of natural gas development will be dependent on many variables, including market price, lease conditions, pipeline access and capacity, and the resource potential of other shale formations, such as the Utica.

3.5 Actions and Needs

- Coordinated geospatial data and technologies to better inform and assist local governments in land use decision making.
- Improved mapping, assessment and tracking of forested wetlands.
- Identification and mapping of forested areas critical to water resources and habitats – and incorporation into land use planning and regulation.
- Prioritization of areas for protection (see current work by The Nature Conservancy for the National Fish and Wildfe Foundation).
- Identification of areas where forest loss is occurring in each Region, and its cause.
- Public action to protect priority forested areas, especially headwaters, in the basin.
- Local ordinances to manage forested areas and protect and improve tree canopy.

3.6 Summary

Developed land increased in every watershed of the basin in the decade between 1996 and 2006; nearly 88 mi2 (227 km2) of land was converted in total. The greatest aggregate loss was in forest (nearly 50 mi2, 127 km2). The watersheds of the Upper and Lower Estuary, Schuylkill Valley, and Lower region watersheds experienced the greatest increases in developed land. Agricultural land also experienced a net loss in the basin, although the Upper region experienced an increased in cultivated and grasslands. While wetland loss has been calculated at nearly 19 mi2 (49 km2) this number is not particularly reliable due to the nature of satellite imagery, the failure to capture freshwater wetlands under tree canopy, and reflectance issues associated with coastal wetlands and water. The loss of forest area continues to be a concern, as land is cleared for agriculture or development. The arrival of natural gas extraction in the upper basin poses a potential threat to the basin's important forested headwaters.

4 – Impervious Cover

Data Sources and Processing

Impervious cover was calculated for each NOAA-CSC land cover classification based on conversion factors (percent impervious cover) provided by University of Delaware based on independent analysis from values modified from the published literature (Grieg, et al., Cloud). Assessment units were summed to watershed groups and to regions. The conversion factors are shown in Table 1.4.1. The factors that have been applied for this analysis are reasonable, but are general and may over or under estimate the amount of impervious surface in any given watershed. Imperviousness is based on land cover and is more accurately determined for developed landscapes, and more problematic when estimated for "undeveloped" land cover, such as farm field, grasslands, and forests. Several attributes other than land cover, soil health and compaction, type of vegetation, and underlying geology, for example—can affect the functional degree of imperviousness. The results of this evaluation are best used as relative differences of imperviousness across the watersheds of the basin, rather than as precise estimates of the aerial extent of impervious cover.

Table 1.4.1. Impervious Cover Factor by Land Cover Type

CSC code	CSC_class	I.C. factor
2	High Intensity Developed	0.85
3	Medium Intensity Developed	0.6
4	Low Intensity Developed	0.3
5	Open Spaces Developed	0.08
6	Cultivated Land	0.02
7	Pasture/Hay	0.02
8	Grassland	0.02
9	Deciduous Forest	0.02
10	Evergreen Forest	0.02
11	Mixed Forest	0.02
12	Scrub/Shrub	0.02
13	Palustrine Forested Wetland	0
14	Palustrine Scrub/Shrub Wetland	0
15	Palustrine Emergent Wetland	0
16	Estuarine Forested Wetland	0
17	Estuarine Scrub/Shrub Wetland	0
18	Estuarine Emergent Wetland	0
19	Unconsolidated Shore	0.1
20	Bare Land	0.1
21	Water	0
22	Palustrine Aquatic Bed	0

Source: University of Delaware

4.1 Description of Indicator

Impervious cover comprises features on the ground which prevent water from infiltrating into the ground, and cause that water to run off to adjacent areas. Imperviousness is a measure of the degree to which an area of the ground is covered by such features, which include rooftops, asphalt or concrete paving, and other hard, impermeable surfaces. Locations with a high degree, or percentage, of imperviousness disrupt the normal hydrologic cycle, in which a portion of water from precipitation percolates into the ground, eventually recharging the water table. Impervious cover hinders a landscape's ability to capture, filter, store, and infiltrate water, and results in an increase in the amount of pollutants which enter streams and other waterbodies. A measure of imperviousness is therefore an indication of the overall health of a watershed. A high percentage of impervious cover leads to more polluted waters, and streams which flood more during storms and flow less during dry times, relative to more natural areas, such as forests or meadows. An example of a high impervious factor is a paved roadway or a parking lot.

A survey of 225 publications compiled by the Center for Watershed Protection assessing the correlation of imperviousness to stream health and aquatic life condition links impervious cover to a variety of impacts, which become detrimental when the percentage becomes high enough (usually when imperviousness is between 3 and 10% of the total area). These impacts include, among others:

- Reduced macroinvertebrate and fish diversity
- Decline in biological function
- Increase in stream temperature
- Decline in channel stability and fish habitat
- Compromised wetlands water quality and water level fluctuation

Impervious cover can also exacerbate the "heat island" effect—the phenomenon in which urban regions experience warmer temperatures than their rural surroundings.

See http://www.epa.gov/heatisld/resources/pdf/BasicsCompendium.pdf for additional information on urban heat islands.

Important Caveat

"When evaluating the direct impact of urbanization on streams, researchers have emphasized hydrologic, physical and biological indicators to define urban stream quality. In recent years, impervious cover (IC) has emerged as a key paradigm to explain and sometimes predict how severely these stream quality indicators change in response to different levels of watershed development . . .

Quite simply, the influence of IC in the one to 10% range is relatively weak compared to other potential watershed factors, such as percent forest cover, riparian continuity, historical land use, soils, agriculture, acid mine drainage or a host of other stressors. Consequently, watershed managers should never rely on IC alone to classify and manage streams in watersheds with less than 10% IC. Rather, they should evaluate a range of supplemental watershed variables to measure or predict actual stream quality within these lightly developed watersheds."

(Center for Watershed Protection, 2003).

4.2 Present Status

Based on values for each land cover types (see Table 1.4.1), the total amount of impervious cover has been estimated for each watershed group, as shown in Table 1.4.2. The Upper Estuary shows the highest percentage of impervious cover (18%), nearly twice that of the second-highest value, which is not surprising since these watersheds are also the most highly developed. The impervious cover values for each watershed group are compared in Table 1.4.2. See the more detailed discussion on impervious cover related to water quality in Chapter 5C. Note that the values for rates of imperviousness treated here have been derived from different data sources than those in Chapter 5.

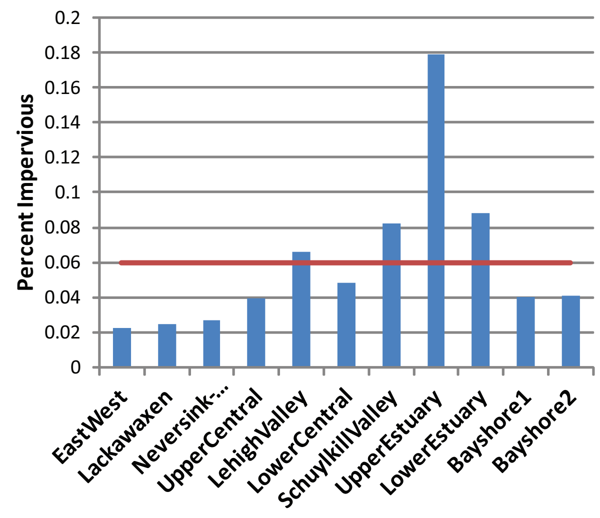


Fig. 1.4.1. Impervious Cover 2006 by Watershed

4.3 Past Trends

Impervious cover estimates were not calculated for past years. However, since developed land has steadily increased, impervious cover amounts could be expected to have increased proportionately.

Table 1.4.2. Impervious Cover by Watersheds and Regions, 2006.

	I.C. Km²	I.C. Mi²	% I.C.	Total Area Mi²	I.C. Hectares	I.C. Acres
Watershed Groups						
EastWest	116	45	2%	2,029	11,636	28,754
Lackawaxen	38	15	2%	597	3,801	9,394
Neversink-Mongaup	57	22	3%	816	5,727	14,151
Upper Central	157	61	4%	1,527	15,733	38,879
LehighValley	232	89	7%	1,360	23,165	57,244
Lower Central	57	22	5%	454	5,653	13,968
Schuylkill Valley	404	156	8%	1,891	40,418	99,880
Upper Estuary	809	312	18%	1,743	80,874	199,850
Lower Estuary	234	90	9%	1,021	23,354	57,710
Bayshore1(W)	66	26	4%	634	6,620	16,359
Bayshore2 (E)	83	32	4%	789	8,350	20,633
Regions						
UPPER	212	82	2.4%	3,443	21,164	52,299
CENTRAL	446	172	5.1%	3,341	44,551	110,092
LOWER	1446	558	12.0%	4,656	144,646	357,440
BAYSHORE	150	58	4.1%	1,424	14,970	36,992
ESTUARY	1596	616	10.1%	6,079	159,615	394,432
Basin						
	2253	870	6.8%	12,863	225,331	556,823

4.4 Future Predictions

Since impervious cover is a direct result of development, impervious cover will continue to increase as developed land increases. This trend could be slowed through the increased use of permeable materials to replace impervious paving for roads and parking lots. In addition, the effects of impervious cover can be mitigated. Stormwater runoff from impervious surfaces can be intercepted for passive treatment, detention and/or infiltration. Increasing green areas—such as parks, and street trees—in urban areas can reduce the heat island effect of impervious cover.

4.5 Actions and Needs

Calculations of impervious cover are most useful at scales smaller than those used for reporting here. The use of land use information with a finer resolution that satellite imagery would be a more robust source for useful impervious cover calculations at the community or catchment scale. Furthermore, since impervious cover is an indicator cause of several potential impacts, additional indicators should be developed to address the conditions most necessary to report.

- Impervious cover estimates at a finer resolution to be helpful at community-level planning & mitigation efforts.
- An indicator of urban "forest" and mitigation of the "heat island" effect, for example: ratio of tree canopy to impervious cover.

4.6 Summary

While impervious cover can be a useful indicator of both aquatic habitat condition and heat island issues in developed areas, reporting of the indicator should be at a scale suitable for informing planning, mitigation and remediation efforts.

5 – State and Federal Protected Land

5.1 Description of Indicator

Protected land is defined as federal, state, and local parks and conservation easements accessible to the public where urban and suburban development cannot occur. Watersheds with high amounts of protected land usually have healthier streams and habitat.

5.2 Present Status

According to data compiled by the Northeast Landscapes Initiatives Atlas and the Nature Conservancy, the Delaware Basin is covered by 2,160 mi^2 (5592 km^2) or 18% of the land area by federal, state, and local parks and conservation easements accessible to the public (Fig. 1.5.1).

Within the basin, protected land covers 15% of Delaware, 35% of Maryland, 36% of New Jersey, 30% of New York, and 15% of Pennsylvania (Table 1.5.1 and 1.5.2). The East/West Branch (NY), Christina Basin (DE/PA), and NJ Coastal Plain watersheds are covered by over 30% protected open space.

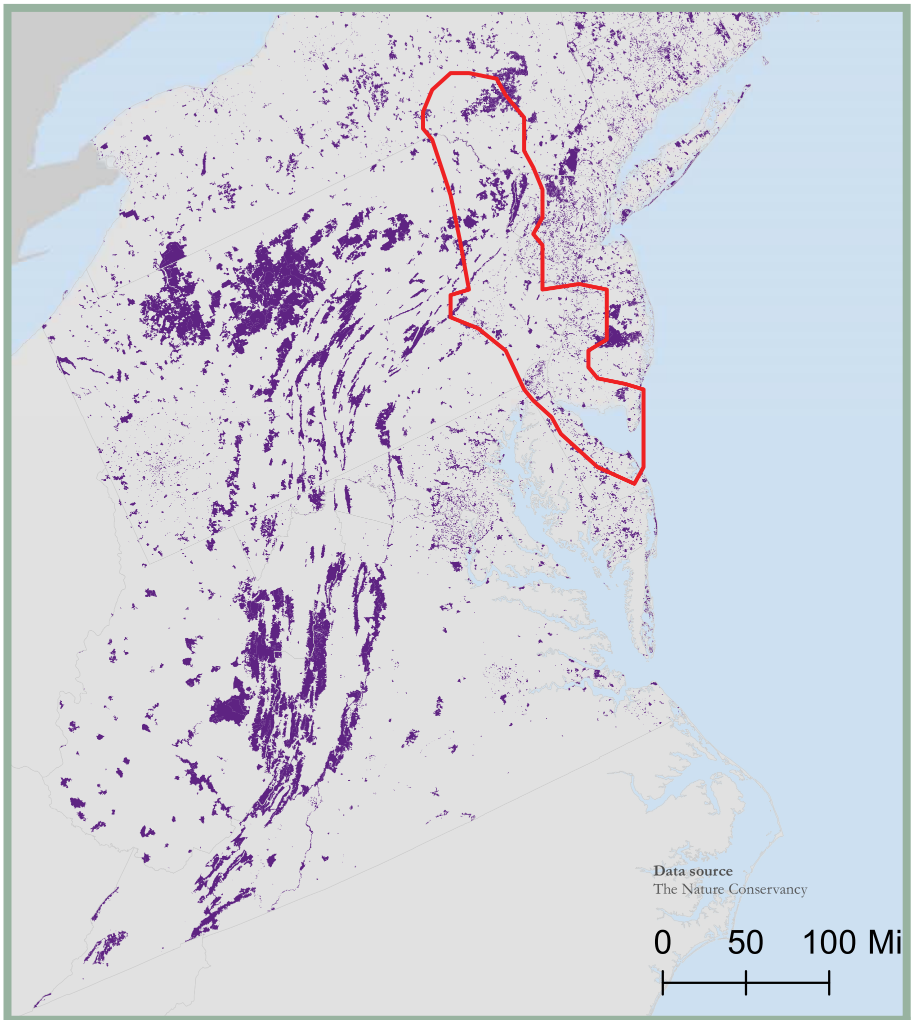


Figure 1.5.1 Location of local, state, and federal parks and conservation easements accessible to the public. Red outline shows the Delaware River Basin.

http://www.rpa.org/northeastlandscapes/images/openspace/834%20Open%20Space1.pdf

5.3 Past Trends

Protected open space data for is available only for 2010 and not for previous years. Therefore past trends are unavailable.

5.4 Future Predictions

Protected open space is projected to expand in the Delaware Basin as the federal, state, local, and nonprofit open space programs add to their inventories.

5.5 Actions and Needs

Each of the four basin states and the federal government should plan to achieve a goal of 20% protected land in the Delaware Basin by 2020 or a 2% increase from 2010. This increase would add 240 square miles (153,600 ac, 62160 ha) by 2020.

A strategic initiative should be established by the Delaware River Basin Commission and the Partnership for the Delaware Estuary to track open space inventory by GIS and recommend prioritized acquisition or conservation of land on a watershed basis.

5.6 Summary

According to data compiled by the Northeast Landscapes Initiatives Atlas and the Nature Conservancy, the Delaware Basin is covered by 2,160 mi^2 (5592 km^2) or 18% of the land area by federal, state, and local parks and conservation easements accessible to the public.

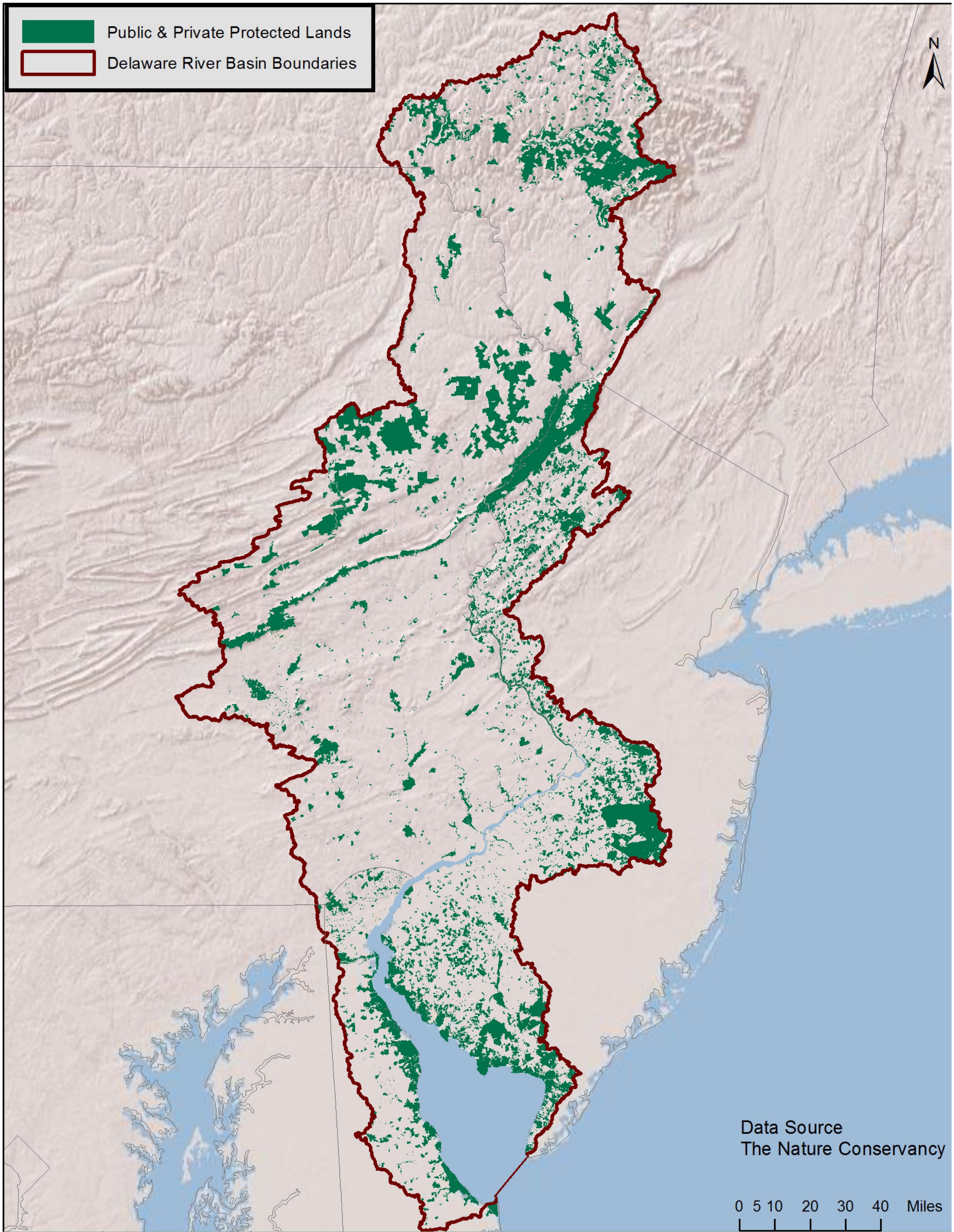


Fig. 1.5.2. Public and private lands in the Delaware River Basin

Table 1.5.1 Protected open space by county in the Delaware River Basin

State/county	Land Area[1] mi² (km²)
Kent	389 (1007)
New Castle	381 (986)
Sussex	195 (505)
Delaware	**965 (2498)**
Cecil	8 (21)
Maryland	**8 (21)**
Atlantic	
Burlington	495 (1282)
Camden	123 (318)
Cape May	104 (269)
Cumberland	490 (1269)
Gloucester	279 (722)
Hunterdon	215 (557)
Mercer	180 (466)
Monmouth	20 (52)
Morris	
Ocean	30 (78)
Salem	347 (898)
Sussex	320 (828)
Warren	358 (927)
New Jersey	**2,961 (7666)**
Broome	85 (220)
Chenango	
Delaware	1,295 (3353)
Greene	25 (65)
Orange	65 (168)
Schoharie	
Sullivan	940 (2434)
Ulster	145 (375)
New York	**2,555 (6615)**
Berks	777 (2012)
Bucks	607 (1572)
Carbon	381 (986)
Chester	616 (1595)
Delaware	184 (476)
Lackawanna	25 (65)
Lancaster	
Lebanon	20 (52)
Lehigh	347 (898)
Luzerne	50 (129)
Monroe	609 (1577)
Montgomery	483 (1250)
Northampton	374 (968)
Philadelphia	135 (350)
Pike	547 (1416)
Schuylkill	420 (1087)
Wayne	705 (1825)
Pennsylvania	**6,280 (16,259)**
Delaware Basin	**12,761 (33,038)**

1. NOAA CSC 2005. 2. The Nature Conservancy

Table 1.5.2. Protected open space by watershed in the Delaware River Basin

Watershed	Land Area[1] mi² (km²)
LE1 Brandywine/Christina	187 (484)
LE2 C&D Canal	152 (394)
DB1 Delaware Bay	626 (1621)
Delaware	**965 (2498)**
LE 1 Maryland	9 (23)
Maryland	**9 (23)**
UC2 NJ Highlands	745 (1929)
LC1 Del. R. above Trenton	159 (412)
UE2 New Jersey Coastal Plain	1,021 (2643)
LE3 Salem River	254 (658)
DB2 Delaware Bay	782 (2025)
New Jersey	**2,961 (7666)**
EW1 East Branch Del. R.	666 (1724)
EW2 West Branch Del. R.	841 (2177)
EW3 Del. R. above Pt. Jervis	314 (813)
NM1 Neversink R.	734 (1900)
New York	**2,555 (6615)**
EW3 Del. R. above Pt. Jervis	210 (544)
NM1 Neversink R.	82 (212)
LW1 Lackawaxen R.	598 (1548)
UC1 Pocono Mt.	779 (2017)
LV1 Lehigh River above Lehighton	451 (1168)
LV2 Lehigh River abv Jim Thorpe	430 (1113)
LV3 Lehigh River above Bethlehem	480 (1243)
LC1 Del. R. above Trenton	295 (764)
SV1 Schuylkill above Reading	338 (875)
SV2 Schuylkill above Valley Forge	649 (1680)
SV3 Schuylkill above Philadelphia	874 (2263)
UE1 Penna Fall Line	693 (1794)
LE1 Brandywine/Christina	401 (1038)
Pennsylvania	**6,280 (16259)**
Delaware Basin	**12,761 (33038)**

6 –Public Access Points

6.1 Description of Indicator

Public access points are publicly and privately owned land adjacent to the Delaware River and Bay that provide entrance for boaters, fishermen, and water-borne recreational activities.

6.2 Present Status

The States of Delaware, New Jersey, New York, and Pennsylvania; U.S. National Park Service; and private marinas own 150 public access points along 330 miles (531 km) of the Delaware River and Bay from Cape Henlopen, Delaware up to the Catskill Mountains of New York. This is a density of one access point for every 2 river miles (3.2 km).

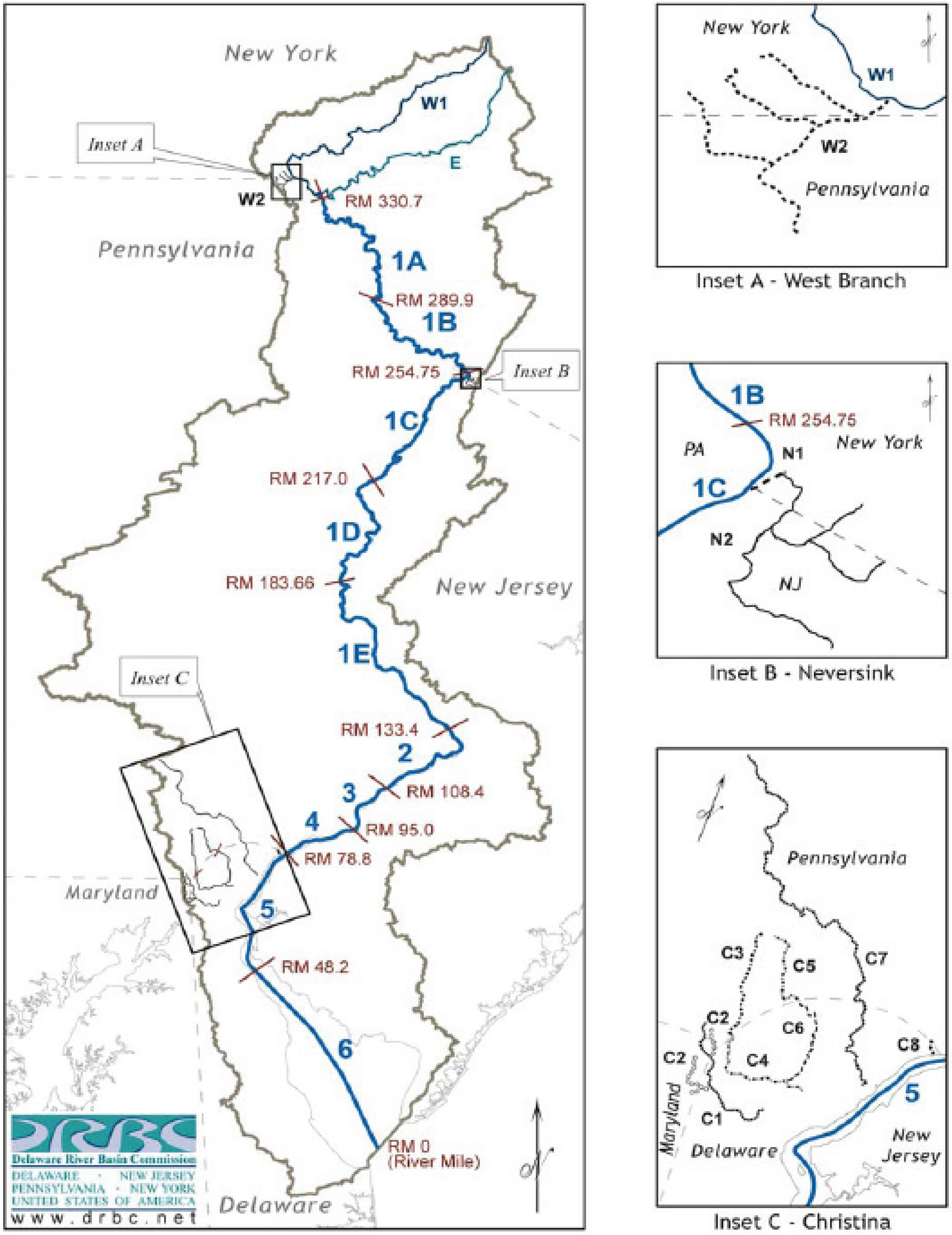


Fig. 1.6.1. Delaware River by river mile is used to locate public access sites (see Table 1.6.1).

Table 1.6.1. Delaware River and Bay Public Access Sites. (See map on previous page for locations)

River Mile	Location	State	County
1	Lewes Wildlife Mgmt. Area (DNREC DFW)	DE	Sussex
11	Cedar Creek Wildlife Mgmt. Area (DNREC DFW)	DE	Sussex
22	Bowers Beach Wildlife Mgmt. Area (DNREC DFW)	DE	Kent
29	Port Mahon Wildlife Mgmt. Area (DNREC DFW)	DE	Kent
41	Woodland Beach Wildlife Mgmt. Area (DNREC DFW)	DE	New Castle
44	Woodland Beach - Duck Creek Wildlife Mgmt. Area (DNREC DFW)	DE	New Castle
45	Collins Beach Wildlife Mgmt. Area (DNREC DFW)	DE	New Castle
49	NJDFW Mad Horse Creek WMA Stow Neck Rd. Canton	NJ	Cumberland
55	Augustine Beach Wildlife Mgmt. Area (DNREC DFW)	DE	New Castle
58	Fort DuPont Wildlife Mgmt. Area (DNREC DFW)	DE	New Castle
59	Penn Salem Marina Rte. 49 Salem	NJ	Salem
65	Pennsville Municipal Boat Ramp Riviera Dr.	NJ	Salem
81	Bridgeport Boat Yard (Raccoon Creek) 118 Ferry Lane	NJ	Gloucester
82	Chester Boat Ramp Commodore Barry Bridge	PA	Delaware
82	Chester City at Flower St	PA	Delaware
86	Anchorage Marina	NJ	Gloucester
86	Lagoon Marina	NJ	Gloucester
91	RiverWinds Point, West Deptford Township	NJ	Gloucester
93	West Deptford Mun. Boat Ramp Center St.	NJ	Gloucester
93	West Deptford Township	NJ	Gloucester
94	Fort Mifflin	PA	Philadelphia
95	William Hargrove Marina	PA	Philadelphia
95	West Creek Westville	NJ	Gloucester
99	Piers Marina	PA	Philadelphia
99	Penns Landing Corporation	PA	Philadelphia
99	Wiggins Park Camden	NJ	Camden
100	Pyne Point Marine Services 7th St. Camden	NJ	Camden
100	Philly Marine Center	PA	Philadelphia
104	NJDFW Pennsauken Boat Ramp Derousse Ave. Delair	NJ	Camden
105	Pennsauken	NJ	Camden
106	PFBC Frankford Arsenal Access 5600 Tacony St.	PA	Philadelphia
106	PFBC Frankford Arsenal	PA	Philadelphia
107	Palmyra Cove Nature Park	NJ	Burlington
108	PFBC Tacony Access Milner St.and Princeton Ave.	PA	Philadelphia
108	PFBC Tacony	PA	Philadelphia
110	Linden Ave at Pleasant Hill Park	PA	Philadelphia
110	Dredge Harbor Riverside	NJ	Burlington
110	Clarks Landing Marina	PA	Philadelphia
111	Lightening Jacks Marina 625 Harrison St. Riverside	NJ	Burlington
111	Philadelphia Boat Ramp Linden Ave.	PA	Philadelphia
111	Amico Island Riverside	NJ	Burlington
111	Lightning Jack's Marina	NJ	Burlington
111	Riverside Marina	NJ	Burlington
112	Hawks Island Marina 130 Rancocas Ave. Delanco	NJ	Burlington
112	Hawk Island Marina Delanco	NJ	Burlington
113	Station Avenue	PA	Philadelphia

Table 1.6.1. Continued...

115	Neshaminy State Park Marina	PA	Bucks
115	Three Seasons marina	NJ	
116	Neshaminy State Park State Rd. and Cedar Ave. Bensalem	PA	Bucks
116	Neshaminy State Park	PA	Bucks
118	Curtin Marina E.Pearl Str. Burlington City	NJ	Burlington
118	Burlington City Boat Ramp Tathem Ave and Pearl St.	NJ	Burlington
118	Burlington	NJ	Burlington
118	Curtin Marina Burlington	NJ	Burlington
119	Bristol	PA	Bucks
122	D&S Boats and Marina Florence	NJ	Burlington
123	Florence	NJ	Burlington
128	Bordentown	NJ	Burlington
129	Bordentown Beach Park St.	NJ	Burlington
131	Trenton	NJ	Mercer
131	Ross Marina Trenton	NJ	Mercer
132	Trenton Waterfront Park	NJ	Mercer
133	Trenton Waterfront Park 1595 Lamberton Rd. off Rte. 29	NJ	Mercer
133	Welcome Park, Morrisville	PA	Bucks
133	W Mercer County's Roebling Park	NJ	Mercer
135	Ferry Road, Morrisville	PA	Bucks
138	PFBC Yardley Access Rte. 32, north end Yardley Boro.	PA	Bucks
147	Firemans Eddy Rte. 29, 1.8 mi. south Lambertville/New Hope Br.	NJ	Mercer
149	D&R Canal State Park Lambertville Bridge St.	NJ	Hunterdon
154	Virginia Forest Recreation Area Rte. 32	PA	Bucks
155	D&R Canal Park Byram Rte. 29, 3.4 mi. north of Stockton	NJ	Hunterdon
156	D&R Canal State Park Bulls Island Rec. Area	NJ	Hunterdon
163	Tinicim Park Rte. 32, Erwinna	PA	Bucks
164	NJDFW Ringwood Access Rte. 29, 1 mi. below Frenchtown	NJ	Hunterdon
168	PFBC Upper Black Eddy Access Rte. 32, below Milford Bridge	PA	Bucks
174	NJDFW Holland Church River Rd., 1 mi. south of Riegelsville bridge	NJ	Hunterdon
174	PFBC Reigelsville Access Rte. 611 north of Rte. 212	PA	Bucks
177	Frys Run Park Rte. 611, 6 mi. south of Easton	PA	Northampton
178	Theodore Roosevelt Recreation Area Rte. 611, 1 mi. south Raubsville	PA	Northampton
181	Wi-Hit-Tuk County Park Holmes Drive, 3 mi. south of Easton	PA	Northampton
183	Scott Park Boat Ramp Easton Rte. 611,mouth of Lehigh River	PA	Northampton
184	Phiilipsburg Boat Ramp Riverside Way, by free bridge	NJ	Warren
186	Northampton County Park Frost Hollow Rte. 611, 2.3 mi. north	PA	Northampton
189	Martins Creek PP&LRte. 611, 5.2 mi above Easton bridge	PA	Northampton
189	PFBC Sandts Eddy Access Rte.611, 5.2 mile above Easton bridge	PA	Northampton
197	NJDFW Belvidere Access Downstream from Belvidere bridge	NJ	Warren
198	Northampton Co. Park Doe Hollow River Rd. u.s. f Belvidere bridge	PA	Northampton
212	DWGNRA Kittatinny Beach Del. Water Gap below I-80 bridge	NJ	Warren

Table 1.6.1. Continued...

216	Worthington State Forest Old Mine Rd., 4 mi. north of I-80	NJ	Warren
218	DWGNRA Smithfield Beach River Rd.,3 mi.north of Shawnee	PA	Warren
220	DWGNRA Poxono Old Mine Rd., 8 mi. north of Del. Water Gap	NJ	Warren
222	DWGNRA Depew Old Mine Rd., 9.3 mi. north of Del. Water Gap	NJ	Warren
227	DWGNRA BushkillRte. 209, 1 mile north of Bushkill	PA	Pike
232	DWGNRA Eshback Rte. 209 mile markers 6 and 7	PA	Pike
239	DWGNRA Dingmans Ferry Toute 739 at Dingmans Bridge	PA	Pike
246	DWGNRA Milford Beach Rte. 209, 0.2 miles north of Rte. 206 bridge	PA	Pike
254	Tri-States Monument Pt. Jervis I-84 bridge	NY	Orange
255	West End Beach, Port Jervis	NY	Orange
258	Deerpark north of junction Routes 97 and 42. Sparrowbush	NY	Sullivan
258	UDSRRA DWGNRA Sparrowbush	NY	Sullivan
259	Sparrowbush	NY	Sullivan
260	Monguap	NY	Sullivan
261	UDSRRA DWGNRA Mongaup Access	NY	Sullivan
267	Buckhorn Natural Area	PA	Sullivan
272	UDSRRA NPS Barryville Office	NY	Sullivan
273	National Park Service Barryville Office	NY	Sullivan
274	Highland. Route 97 1.5 miles west of Barryville.	NY	Sullivan
274	UDSRRA Highland	NY	Sullivan
277	UDSRRA Lackawaxen	PA	Wayne
278	Lackawaxen	PA	Wayne
278	Lackawaxen	PA	Wayne
282	Ten Mile River	NY	Sullivan
282	Highland	NY	Sullivan
282	Highland	NY	Sullivan
283	UDSRRA Ten Mile River	NY	Sullivan
290	Narrowsburg Race Course Road (Co Rte 24) to DeMauro Lane	NY	Sullivan
290	UDSRRA Narrowsburg, NY	NY	Sullivan
290	UDSRRA Narrowsburg, PA	PA	Wayne
290	Narrowburg,NY	NY	Sullivan
290	Narrowburg, PA	PA	Wayne
295	UDSRRA Skinners Falls	NY	Sullivan
296	Skinners Falls	NY	Sullivan
297	Milanville, PA	PA	Wayne
298	UDSRRA Damascus	PA	Wayne
299	Cochecton off Route 97 on Skinners Falls Road	NY	Sullivan
299	Damascus, PA	PA	Sullivan
304	Off Route 97 Callicoon,	NY	Sullivan
304	UDSRRA Callicoon, NY	NY	Sullivan
304	UDSRRA Callicoon, PA	PA	Wayne
304	Callicoon, NY	NY	Sullivan
304	Callicoon,PA	PA	Wayne
305	Kellams, Little Equinunk Creek	NY	Sullivan

Table 1.6.1. Continued...

310	Hankins	NY	Sullivan
311	UDSRRA River Estaamground	NY	Sullivan
312	Basket Creek at Basket Creek	NY	Sullivan
315	UDSRRA Long Eddy Access	NY	Sullivan
315	Long Eddy	NY	Sullivan
322	UDSRRA Lordville Access	NY	Delaware
323	Lordville	NY	Delaware
325	UDSRRA Buckingham Boat Access	NY	Delaware
325	Buckingham	PA	Wayne
330	Hancock Bard Parker Rd, south edge of Village off Rte. 97	NY	Delaware
330	UDSRRA Hancock Access	NY	Delaware
330	Hancock	NY	Delaware
W. Br.	Airport Rd. south edge of Deposit, ½ mi from Rte. 17	NY	Delaware
W. Br.	Hale Eddy Rte. 58 off Rte. 17, 6 ½ mi. west of Hancock	NY	Delaware
E. Br.	UDSRRA Balls Eddy Access	NY	Delaware

New Jersey Division of Fish and Wildlife (NJDFW)
Pennsylvania Fish and Boat Commission (PFBC)
Delaware Water Gap National Recreation Area (DWGNRA)
Upper Delaware River Scenic and Recreational Area (UDSRRA)
Delaware Department of Natural Resources and Environmental Control (DNREC) Division of Fish and Wildlife (DFW)

6.3 Past Trends

Past data is not available to establish trends.

6.4 Future Predictions

Federal, state, local, and nonprofit agencies will continue to acquire public access points along the Delaware River and Bay.

6.5 Actions and Needs

Public access points should be acquired to achieve a density of one site per mile compared to the present 2 sites per mile along the Delaware River and Bay. Gaps where public river access sites should be acquired include:

* Between RM 1 and 11 (Lewes to Cedar Creek)
* Between RM 11 and 22 (Bowers Beach)
* Between RM 29 and 41Woodland Beach)
* Between RM 65 and 81 (Chester)
* Between RM 138 and 147 ((Lambertville)
* Between RM 198 and 212 (Delaware Water Gap)
* Between RM 315 and 322 (Long Eddy)

6.6 Summary

The States of Delaware, New Jersey, New York, and Pennsylvania; U.S. National Park Service; and private marinas own 150 public access points along 330 miles (531 km) of the Delaware River and Bay from Cape Henlopen, Delaware up to the Catskill Mountains of New York. This is a density of one access point for every 2 river miles (3.2km).

7 – Natural Capital Value

7.1 Description of Indicator

This section tabulates the economic value of the Delaware Estuary watershed as (1) market and nonmarket economic activity, (2) value of ecosystem goods and services, and (3) jobs and wages related to the watershed (Kauffman 2011).

7.2 Present Status

The natural resources of the Delaware Estuary watershed provide tremendous economic value such as:

- **Through economic value directly related to the Delaware Estuary's water resources and habitats.** Using economic activity as a measure of value, we find that the Delaware Estuary contributes over **$10 billion** in annual economic activity from recreation, water quality and supply, hunting and fishing, forests, agriculture, and parks.

- **Through the value of the goods and services provided by the Delaware Estuary's ecosystems.** Using ecosystem goods and services as a measure of value, we find that the ecosystems of the Delaware Estuary provide **$12 billion** annually in goods and services in 2010 dollars ($2010), with a net present value (NPV) of **$392 billion** calculated over a 100-year period.

- **Through employment related to the Delaware Estuary's water resources and habitats.** Using employment as a measure of value, we find that the Delaware Estuary directly and indirectly supports over **500,000 jobs** with over **$10 billion** in wages annually. This does not include the thousands or even millions of jobs in companies and industries that rely on waters of the Delaware Estuary for their industrial and commercial processes.

Table 1.7.1. Ecosystem goods and services value of the Delaware Estuary

Economic Value	$ million
Market Value	**> 8 billion**
Water Quality	
Water Treatment by Forests ($62/mgd)	17
Wastewater Treatment ($4.00/1000 gal)	1,490
Increased Property Value (+8% over 20 years)	13
Water Supply	
Drinking Water Supply ($4.78/1000 gal)	1,333
Irrigation Water Supply ($300/ac-ft)	30
Thermoelectric Power Water Supply ($44/ac-ft)	298
Industrial Water Supply ($200/ac-ft)	140
Fish/Wildlife	
Commercial Fish Landings ($0.60/lb)	34
Fishing (11-18 trips/angler, $17-$53/trip)	334
Hunting (16 trips/hunter, $16-50/trip)	171
Wildlife/Bird-watching (8-13 trips/yr, $15-$27/trip)	306
Agriculture	
Crop, poultry, livestock value ($2,300/ac)	2,522
Maritime Transportation	
Navigation ($15/ac-ft)	221
Port Activity	2,400
Non-Market Value	**>2 billion**
Recreation (Boating, Fishing, Swimming)	
Swimming ($13.40/trip)	9
Boating ($30/trip)	47
Fishing ($62.79/trip)	52
Wildlife/bird watching ($77.73/trip)	104
Water Quality	
Willing to Pay for Clean Water ($38/nonuser-$121/user)	660
Forests	
Carbon Storage ($827/ac)	981
Carbon Sequestration ($29/ac)	34
Air Pollution Removal ($266/ac)	316
Building Energy Savings ($56/ac)	66
Avoided Carbon Emissions ($3/ac)	4
Public Parks	
Health Benefits ($9,734/ac)	1,057
Community Cohesion ($2,383/ac)	259
Stormwater Benefit ($921/ac)	100
Air Pollution Control ($88/ac)	9

Annual Economic Value

The Delaware Estuary watershed contributes over $10 billion in annual market and non-market value. Market value is determined by the sale/purchase of watershed goods such as drinking water, fish, or hunting supplies. Nonmarket value is provided by ecosystems such as pollution removal by forests, public willingness to pay for improved water quality, forest carbon storage benefits, and health benefits of parks. Note that totals are rounded down to avoid double counting (Table 1.7.1).

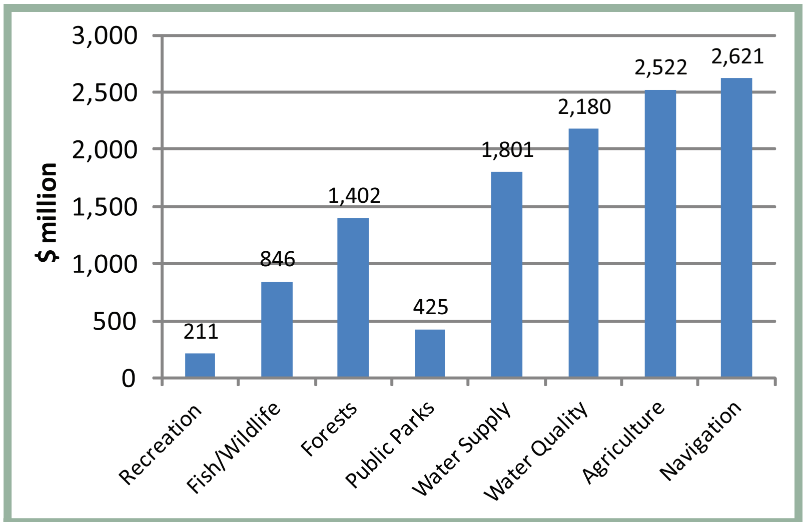


Fig. 1.7.1. Annual economic value of the Delaware Estuary watershed

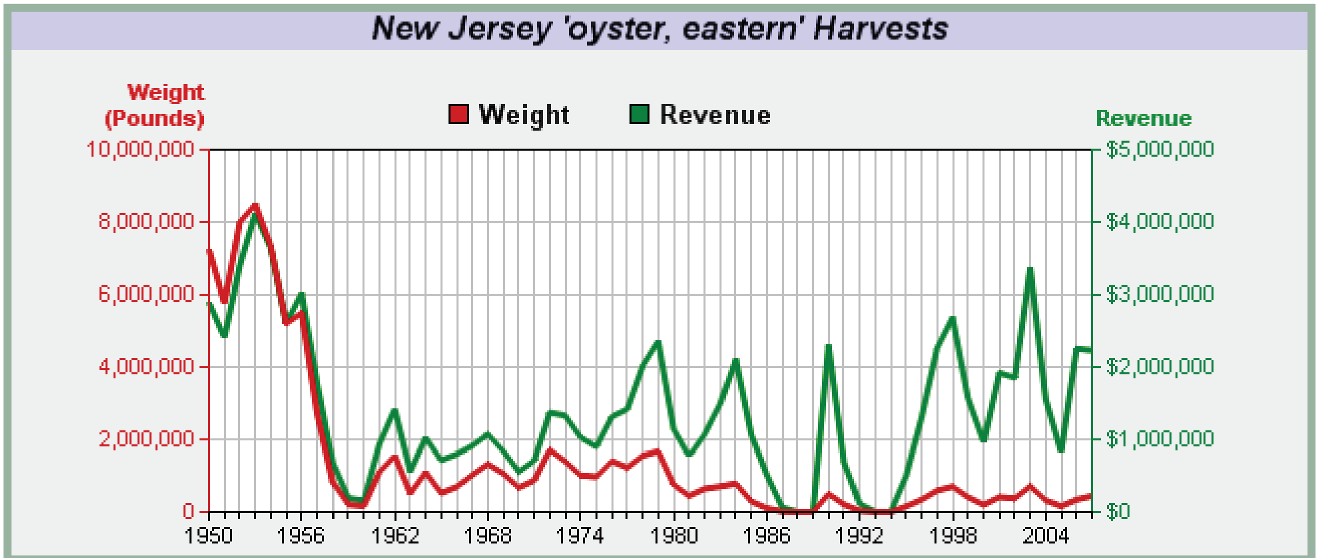


Fig. 1.7.2. New Jersey Eastern Oyster Harvests

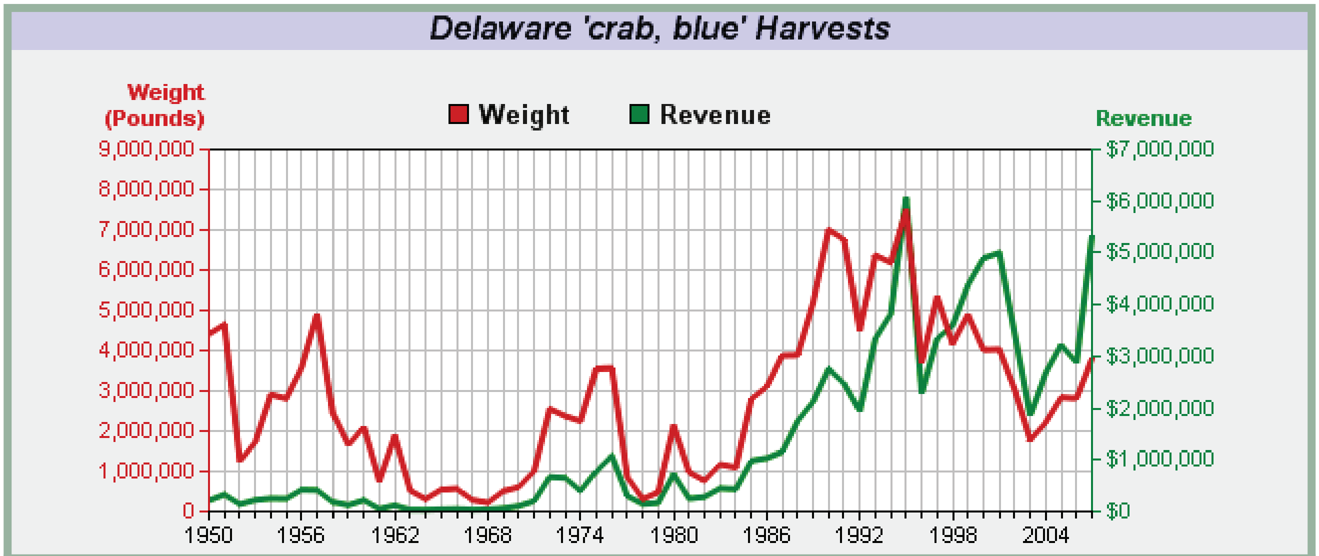


Fig. 1.7.3. Delaware Blue Crab Harvests

Ecosystem Services

The Delaware Estuary watershed is rich in natural resources and habitat as measured by the economic value of ecosystem goods and services. Ecosystem goods are benefits provided by sale of watershed products such as drinking water and fish. Ecosystem services are economic benefits provided to society by nature such as water filtration, flood reduction, and carbon storage. The value of natural goods and services from ecosystems in the Delaware Estuary watershed is $12 billion ($2010) with net present value (NPV) of $392 billion using a discount rate of 3% over in perpetuity (about 100 years) (Table 1.7.2). Ecosystem services by state include Delaware ($2.5 billion, NPV $81.9 billion), New Jersey ($5.3 billion, NPV 173.6 billion), and Pennsylvania ($4.1 billion, NPV $132.0 billion).

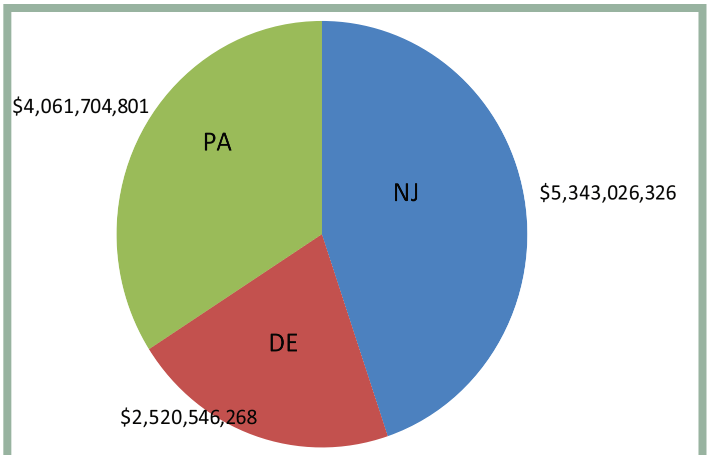


Fig. 1.7.4. Ecosystem services value in the Delaware Estuary watershed by state

The Delaware Estuary watershed is a jobs engine that supports over 500,000 direct and indirect jobs with $10 billion in annual wages in the coastal, farm, ecotourism, water/wastewater, recreation, and port industries. Note that total jobs and wages are rounded down to avoid double counting (Table 1.7.3).

Table 1.7.2. Ecosystem services value in the Delaware Estuary watershed

Ecosystem	Area ac	$/ac/yr 2010[1]	$/yr 2010	NPV million $
Freshwater wetlands	317,213 (128344)	13,621	4,320,647,087	140,421
Marine	16,588 (6712)	10,006	165,982,947	5,394
Farmland	1,112,580 (450,150)	3,215[2]	3,577,486,604	116,268
Forest land	1,186,784 (480,173)	1,978	2,347,605,465	76,297
Saltwater wetland	145,765 (58,977)	7,235	1,054,617,851	34,275
Barren land	18,630 (7538)	0	0	0
Urban	865,778 (350,294)	342	295,761,123	9,612
Beach/dune	900 (364)	48,644	43,758,633	1,422
Open water	131,388 (53,160)	1,946	255,655,983	8,308
Total	**3,795,626 (1,535,710)**		**12,061,000,000**	**391,999**

1. NJDEP 2004. 2. USDA 2009 Jobs and Wages

Table 1.7.3. Jobs and wages related to the Delaware Estuary watershed

Sector	Jobs	Wages ($ million)	Data Source
Direct Basin Related	192,785	4,280	U.S. Bureau of Labor Statistics (2009)
Indirect Basin Related	231,342	3,420	U.S. Census Bureau (2009)
Coastal	44,658	947	National Coastal Economics Program (20090
Farm	28,276	1,159	USDA Census of Agriculture (2007)
Fishing/Hunting/Birding	24,713	812	U.S. Fish and Wildlife Service (2008)
Water Supply Utilities	2,290	127	UDWRA and DRBC (2010)
Wastewater Utilities	1,021	51	UDWRA and DRBC (2010)
Watershed Organizations	150	8	UDWRA and DRBC (2010)
Port Jobs	12,121	772	Economy League of Greater Phila. (2008)
Delaware Estuary watershed	**> 500,000**	**>$10 billion**	

Jobs directly associated with the Delaware Estuary watershed (i.e. water/sewer construction, water utilities, fishing, recreation, tourism, and ports) employ 192,785 people with $4.3 billion in wages:

- Delaware (15,737 jobs, $340 million wages)
- New Jersey (52,007 jobs, $1.1 billion wages)
- Pennsylvania (125,041 jobs, $2.8 billion wages)

Jobs indirectly related to the waters of the Delaware Estuary watershed (based on multipliers of 2.2 for jobs and 1.8 for salaries) employ 231,342 people with $3.4 billion in wages in:

- Delaware (18,884 jobs, $270 million wages)
- New Jersey (62,408 jobs, $0.9 billion wages)
- Pennsylvania (150,049 jobs, $2.2 billion in wages)

The National Coastal Economy Program (2009) reports coastal employment in the Delaware Estuary watershed provides 44,658 jobs earning $947 million in wages in:

- Delaware (12,139 jobs, $214 million wages)
- New Jersey (4,423 jobs, $140 million wages)
- Pennsylvania (28,096 jobs, $593 wages).

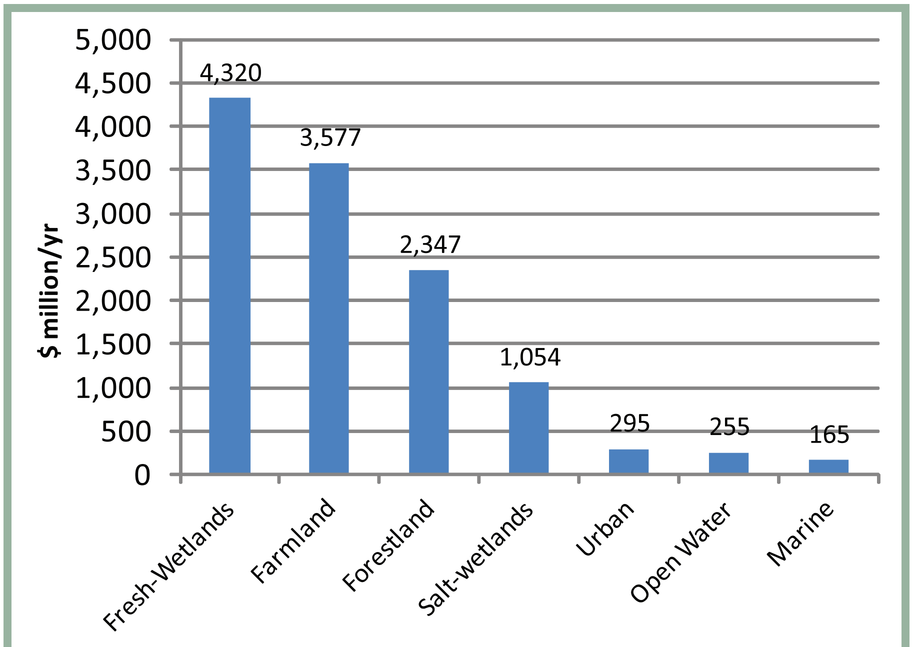


Fig. 1.7.6. Value of ecosystem services in the Delaware Estuary Watershed

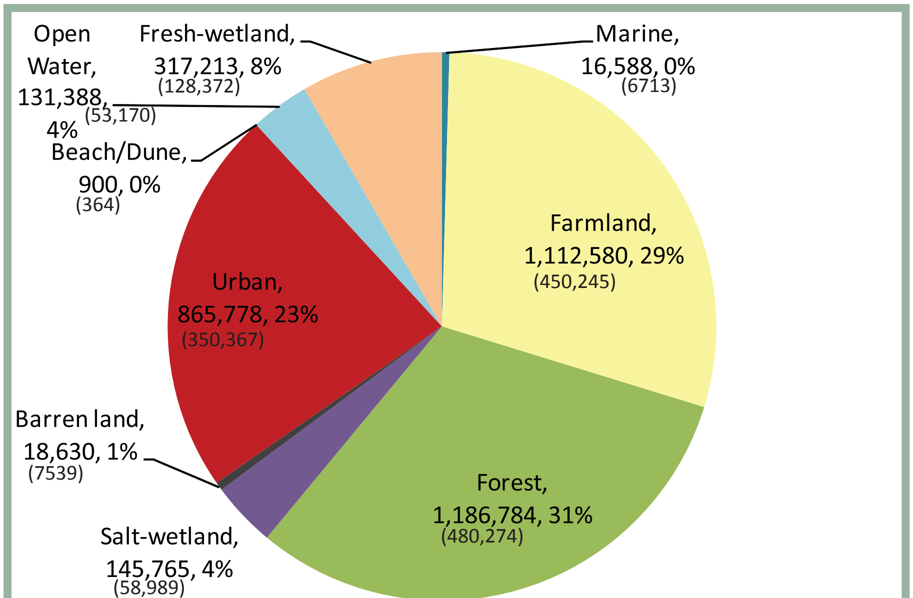
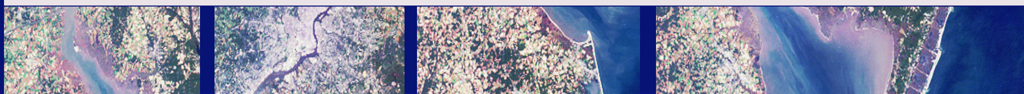


Fig. 1.7.7. Ecosystem acres (ha) in the Delaware Estuary Watershed, 2005

Table 1.7.4. Jobs and wages in the Delaware Estuary watershed by state.

Sector	DE Jobs	NJ Jobs	PA Jobs	DE Wages ($M)	NJ Wages ($M)	PA Wages ($M)
Direct Basin Related	15,737	52,007	125,041	340	1,100	2,800
Indirect Basin Related	18,884	62,408	150,049	270	900	2,200
Coastal	12,139	4,423	28,096	214	140	593
Farm	3,289	8,287	16,700	135	340	685
Fishing/Hunting/Birding	4,092	11,365	9,256	134	373	304
Water Supply Utilities	126	509	1,654	7	28	92
Wastewater Utilities	106	215	700	5	11	35
Delaware Estuary watershed	**54,373**	**139,214**	**331,496**	**1,105**	**2,892**	**6,709**



7.3 Past Trends

Based on recent forest loss estimates from section 3.3 of this chapter, if the basin lost 31,471 acres of forest from 1996-2006, then the loss in ecosystem services value is $62 million over 100 years at $1,978 per acre.

7.4 Future Predictions

The economic value of the Delaware Estuary and Basin may increase with improved water quality and habitat.

7.5 Actions and Needs

Continued investment is needed to support the multi-billion dollar economic value of the Delaware Estuary and Basin.

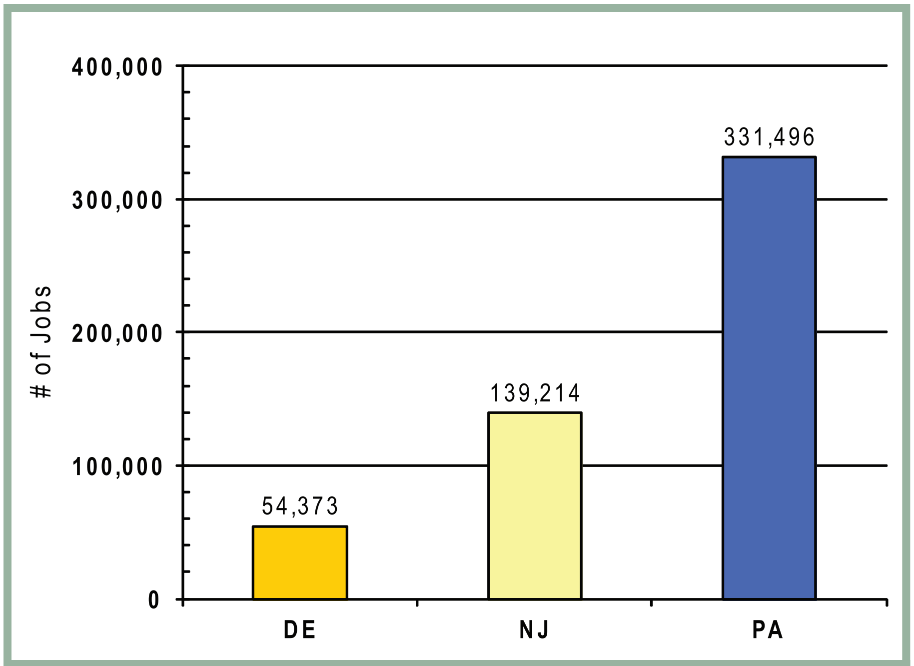


Fig. 1.7.8. Wages from jobs related to the Delaware Estuary watershed

7.6 Summary

The natural resources of the Delaware Estuary watershed provide tremendous economic value such as (a) $10 billion in annual economic activity from recreation, water quality and supply, hunting and fishing, forests, agriculture, and parks; (b) ecosystems goods and services value of $12 billion annually ($2010); and (c) direct and indirect support of over 500,000 jobs with over $10 billion in wages annually.

Chapter 1 - References

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2

Water Quantity

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Chapter 2 – Water Quantity & Hydrology

Data Sources

Several of the indicators described in this chapter are based on water withdrawal datasets. These data are typically reported annually by water users to the state environmental agencies. To avoid duplication, data are provided to the Delaware River Basin Commission (DRBC) in order to complete Basin-wide assessments. Over the past two decades data collection has not always been comprehensive and timely, however in recent years the basin states have begun to implement web-based reporting processes which streamline data reporting and data management. As a result, the exchange of data has improved, although further improvements are still necessary to achieve complete and timely data exchange. The merging, data checking and compilation of water withdrawal data from the four basin states requires significant effort. For the purposes of this report the calendar year 2007 was chosen as the target year for water withdrawals. Not all state agencies were able to provide data for this time period and in those cases, the latest available information has been used. In some cases, to fill data gaps or to obtain more recent data, the DRBC's own data sources have been used where available - these data come from the DRBC's Surface Water Charging program which tracks the largest withdrawals from the Delaware River Basin. Precipitation impacts water availability over the long-term. For a discussion of this see Chapter 7-2.

Table 2.1. Summary of available water withdrawal data by state

State	Year	Number of Withdrawals	Volume of Withdrawals Mil. Gallons/Day (MGD) and Cubic Meters/Sec (CMS)	% of total by volume
DE	2003	352	754 (33)	10
NJ	2007	3,660	4,374 (192)	58
NY*	2007	36	13 (0.57)	<1
PA	2003	2,017	2,388 (105)	31

* The New York City Export is not part of the data presented in the above table, but is included in the analysis in this chapter.

1 – Water Withdrawals - Tracking Water Supply & Demand

1.1 Description of Indicator

Water withdrawals are tracked to identify key water using sectors and trends. Accurate and comprehensive water use information enables the proper assessment, planning, and management of water resources. As reporting improves, so does our accounting and understanding of the need for water among various water using sectors. As noted above, 2007 water withdrawal data were compiled to generate a Basin-wide and regional assessment, by water-use sector. With the exception of data for the Agriculture and Self-supplied Domestic (individual homeowner wells) sectors, all data are based on withdrawals reported to state agencies. Water withdrawals reported for agricultural use in the Basin were not comprehensive and varied by state. To enable a uniform assessment, water use for agriculture was estimated from The Census of Agriculture (USDA, 2007). Self-supplied domestic use was estimated based on the population from Census 2010 data that reside outside of public water system (PWS) service areas. An estimated use of 75 gallons/capita/day (0.28 cubic meters) was applied to calculate water use by this sector.

Total water withdrawals from the Delaware River Basin, based on calendar year 2007 data are shown in Fig. 2.1. Figures 2.2 and 2.3 show total water withdrawals from the Upper and Central Regions and the Lower and Bay (Estuary) Regions, respectively.

1.2 Present Status

Approximately 15 million people rely on water from the Delaware basin for their water needs. On average, over 8 billion gallons (30 million cubic meter) of Delaware basin water are used each day. This includes an average of approximately 575 million gallons per day (MGD) (25 CMS) for populations in New York City and 90 MGD (3.94 CMS) for northeastern New Jersey, which combined account for around 7% of total water withdrawals from the Basin. A system of reservoirs in the Upper basin store water for export to New York City and make compensating releases to maintain water temperatures and flows for downstream uses. New Jersey exports water from the basin via the Delaware and Raritan canal which draws from the mainstem Delaware River in Hunterdon County, NJ.

Within the basin, uses related to power generation (thermoelectric) account for the majority of water withdrawals (68%). The next largest use is for public water supplies, or PWS (11%). However, in managing water resources, the withdrawal volume may not be as important as where and when the water is returned to the system. Water not immediately returned is considered consumptive use (see section 1.2).

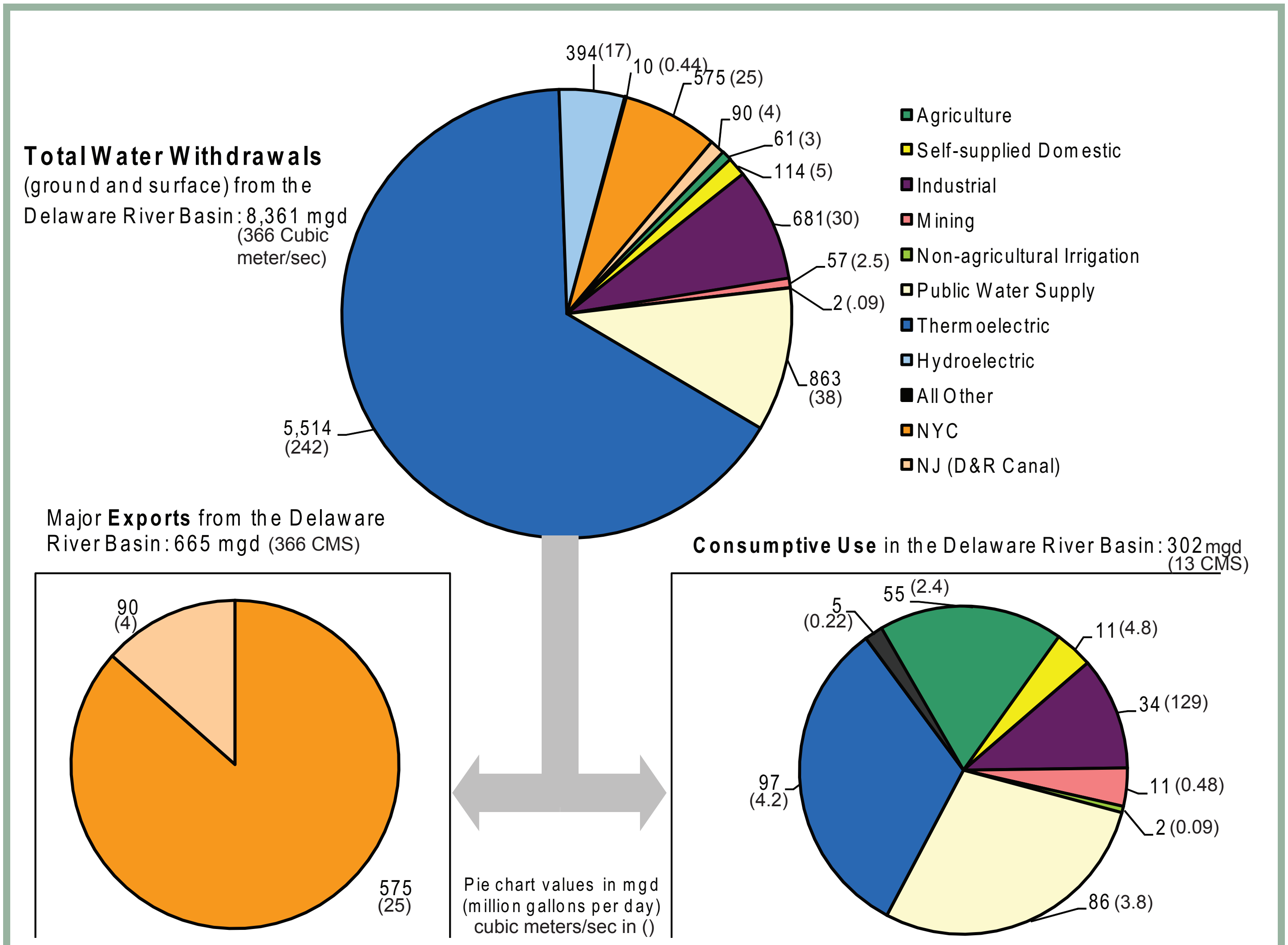


Fig. 2.1. Total Water Withdrawals for the Delaware River Basin, 2007

1.3 Past Trends

Over the past two decades the NYC diversion has decreased due in large parts to water conservation efforts. A long-term chart of water exported from the Basin to meet NYC needs is shown in Fig. 2.4. A five-year period moving average is included on the chart to smooth the impact of short-term fluctuations in water demand and the influence of weather patterns.

1.4 Future Predictions

Five-year water demand projections through the year 2030 were developed for each water-use sector under a collaborative project between the DRBC and the U.S. Army Corps of Engineers. These projections were published in 2008, under the title *Enhancing Multi-jurisdictional Use and Management of Water Resources for the Delaware River Basin, NY, NJ, PA, and DE.*

The projections were based on 2003 water withdrawal data. To improve accuracy of the projections a number of factors were considered including projected changes in population, employment, and historical trends in agriculture and power generation. Fig. 2.5 shows projected trends for all sectors.

In Fig. 2.5 water withdrawals for thermoelectric power generation show the greatest increase over the projection period. The trend is generated by extrapolating past usage patterns at existing facilities. The slope of the trend is also consistent with increased power generation predicted for the Mid-Atlantic Region by the U.S. Energy Information Administration. Water withdrawals for other sectors are projected to remain approximately flat. Additional information on demand projections is included in section 1.2.

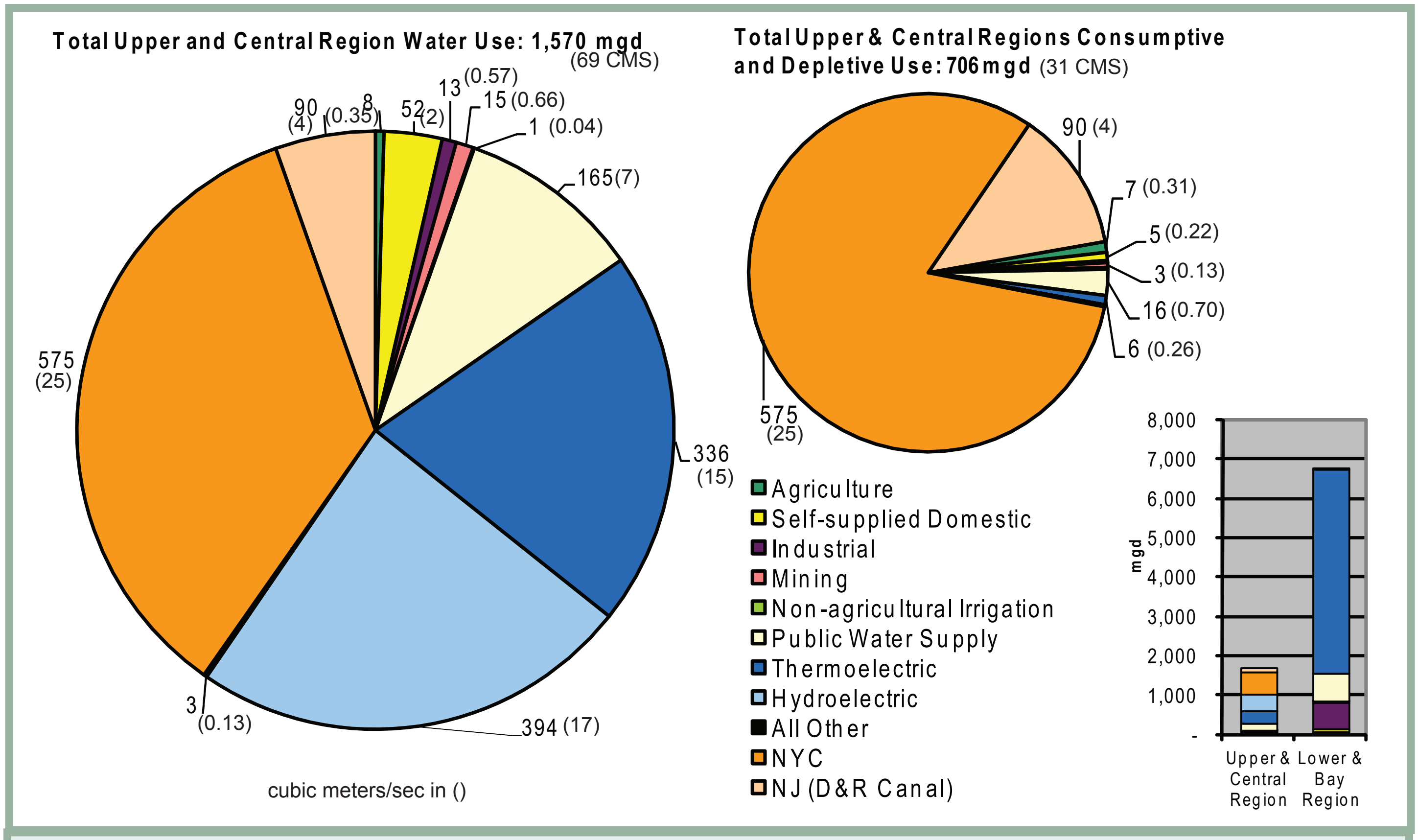


Fig. 2.2. Total Water Withdrawals For the Upper and Central Regions, 2007

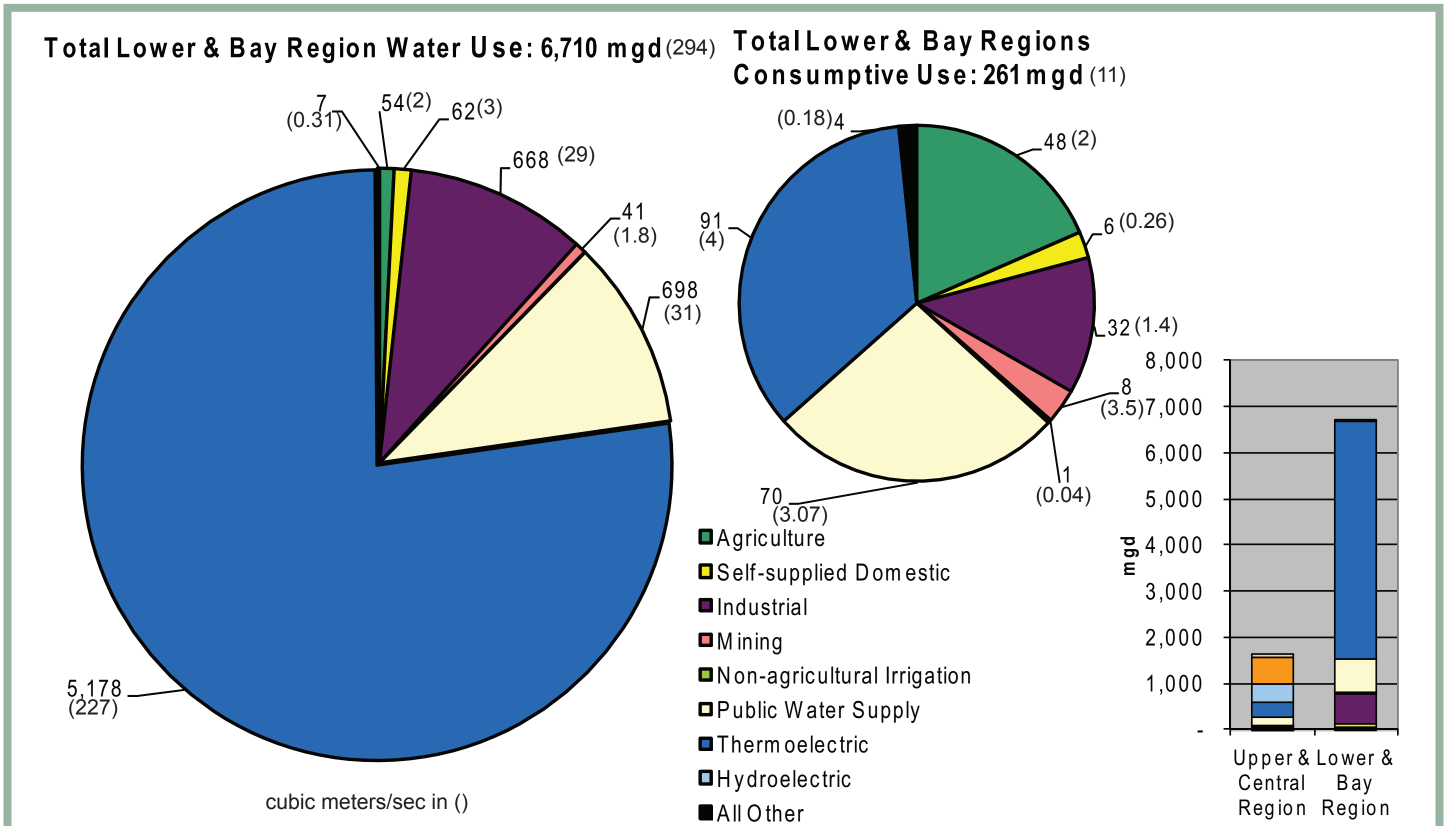
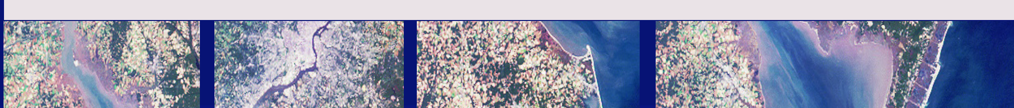


Fig. 2.3. Total Water Withdrawals For the Lower and Bay Regions, 2007



1.5 Actions and Needs

Reporting of water withdrawals has improved in recent years due to electronic, web-based reporting, although state agencies are adopting this approach at different speeds and there is still room for improvement.

Withdrawals for the agriculture sector are still estimated based on agriculture census data as the individual water withdrawals for the Basin are not complete or reliable. A better understanding of water use by this sector, which starts with accurate data reporting and collection, is needed in order to improve planning and management for this type of use.

Continued study 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.

Water use for natural gas development in the Delaware River Basin is likely to become an additional water demand on the system in future years. Initial projections estimate that during peak natural gas development (10 years in the future) water demand for this new sector may be 20mgd (0.88 CMS). Although the magnitude of estimated withdrawals in not large in a Basin-wide context, the water is likely to be sourced from the basin headwaters where this increase in demand will represent a significant increase compared to existing demand.

Advances in quantifying the in-stream needs of aquatic ecosystems are necessary for achieving a balance between in-stream and off-stream (withdrawal) water needs.

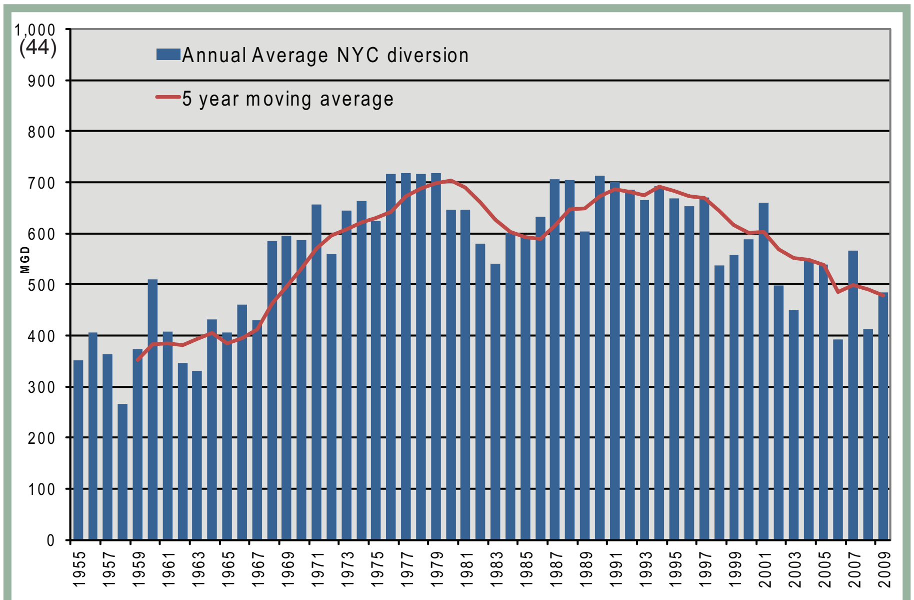


Fig. 2.4. Water Exported to New York City from Delaware River Basin 1955 - 2009 (Annual Data) (Cubic meters/sec in parentheses)

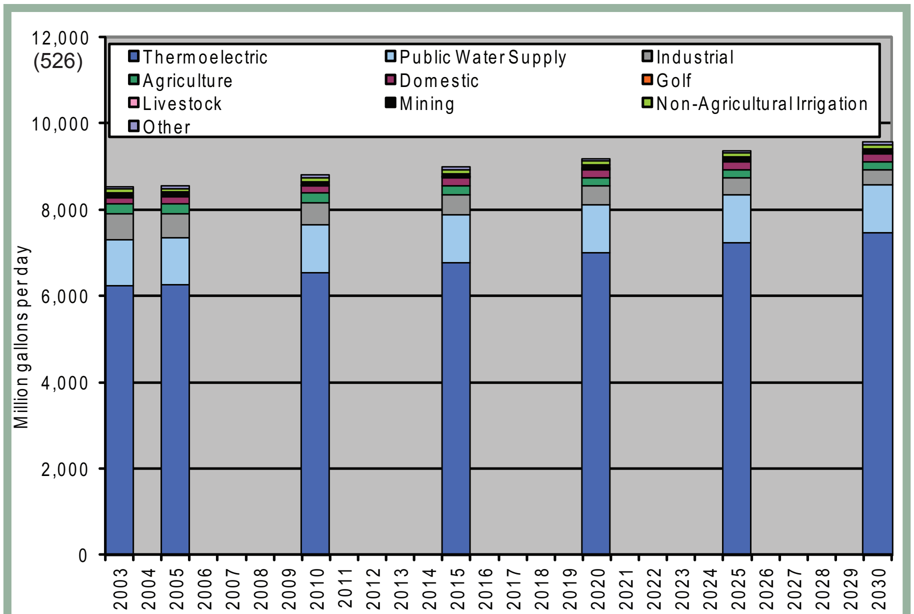


Fig. 2.5. Projected Trends in Water Withdrawals by Sector for the Delaware River Basin. (Cubic meters/sec in parentheses)

1.6 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.

2 – Consumptive Use

2.1 Description of Indicator

Section 1 described water withdrawals in the Delaware River Basin and Regions. However, in managing water resources a more important consideration than what is withdrawn is what is used or consumed which is known as *consumptive use.* Consumptive use is that portion of water withdrawn that is not immediately returned to the watershed. Different types of water use vary in their consumptive use. 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. PWS are typically considered to have a consumptive use of 10%, as only a small portion of water used in homes and cities is evaporated, the majority is returned via sewerage systems. Another factor that influences consumptive use from a watershed perspective is the location of the withdrawal and discharge points. A PWS system that withdraws from a watershed but discharges the wastewater it generates outside the watershed is 100% consumptive to the watershed from which it withdraws water. These types of issues need to be considered in a detailed water budget analysis. For the purposes of this report, sector-specific consumptive use factors were typically applied. However, for the power generation industry, which has a highly variable consumptive use based on the types of cooling processes used, site-specific consumptive use factors were applied to increase the accuracy of the estimate. Similarly, all industrial users over 1 mgd (0.04 CMS) were investigated and given site-specific consumptive use factors based on empirical data.

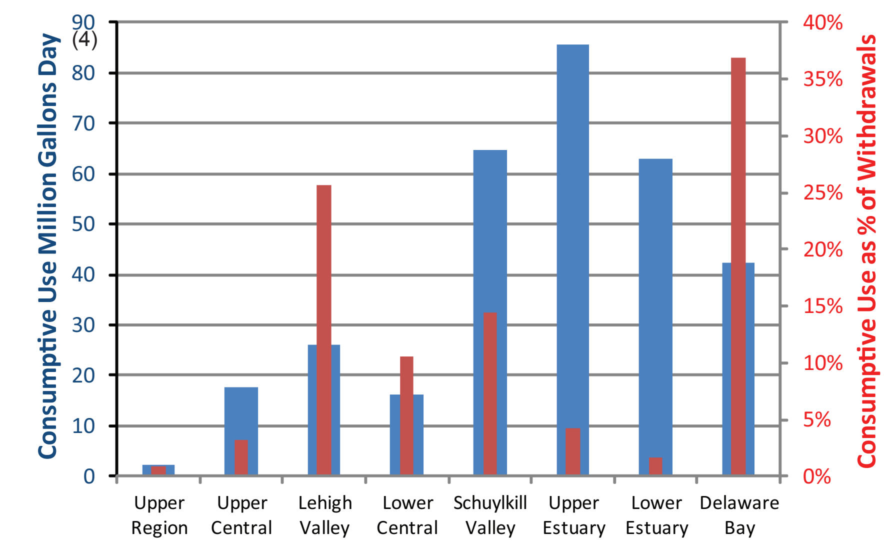


Fig. 2.6. Regional Consumptive Water Use (excluding NYC and NJ exports)

2.2 Present Status

Fig. 2.1 shows that the power generation and PWS sectors account for approximately 33% and 30%, respectively, of consumptive use in the Delaware River Basin and the Delaware Estuary. Agriculture and other irrigation-related uses (golf courses, nurseries) account for approximately another 20% of in-basin consumptive use. It should be noted that there are two major basin exports to New York City and northern New Jersey, which can also be considered as consumptive uses and these two combined exports are twice the volume of all in-basin consumptive uses. These exports were established as part of the 1954 Supreme Court Decree and are managed separately from other withdrawals and discharges in the Basin.

Fig. 2.6 shows in-basin consumptive water use and where this occurs by regional watershed. The figure shows the magnitude of consumptive use which is greater in the Lower and Bay regions. The figure also shows the percentage of the withdrawal that is consumptively used in each region. The percentage of consumptive use is highest in the Lehigh Valley and Delaware Bay subbasins; the high consumptive use factor in these sub-basins is primarily driven by estimated agricultural use which is a highly consumptive water use.

2.3 Past Trends

Consumptive use for the two largest sectors in the Delaware River Basin and Estuary has followed opposing trends in recent years. Consumptive use for PWS systems has decreased as withdrawals have decreased, most likely as a result of water conservation efforts. Fig. 2.7 shows total consumptive water use (estimated at 10% of PWS withdrawals) for the 38 largest PWS systems in the Delaware River Basin. Each data point represents a monthly consumptive use value and a linear trendline has been fitted to the data. Collectively, these systems account for approximately 80% of total demand for all PWS systems in the basin. The downward trend has been driven by changes in plumbing codes, enacted in the early 1990s, which made plumbing fixtures and fittings more efficient. In addition, education and awareness of water conservation practices have played a role in decreasing water use for this sector despite increases in population (shown by the red line in Fig. 2.7). However, it should be noted that water withdrawals, and therefore consumptive use, have increased in several systems where there are population growth hot-spots and where water conservation practices cannot offset the more rapid increase in population.

Gaps in the data of Fig. 2.7 indicate periods when one or more state agency did not collect records, or could not prepare a database of water withdrawals. These data gaps provide challenges in creating a comprehensive dataset for the Delaware River Basin; the introduction of web-based reporting processes for collecting water withdrawal and use information should lead to more comprehensive and timely datasets.

Water use and consumptive use for power generation has gone up in the past twenty years (see Fig. 2.8 which shows monthly consumptive use values for the power sector and a linear trendline). In the most part, water use at existing facilities has increased and some new facilities have come online and begun to use water.

Water withdrawals for thermoelectric power generation are primarily used for cooling purposes. The cooling process is typically achieved by either highly evaporative cooling towers or a once-through cooling process that uses a condenser to absorb heat. The two types of cooling use water in different ways. Evaporative cooling towers require a smaller volume of withdrawal but consume the majority of the water (>90% consumptive use). Once-through cooling requires a much greater availability of water but the rate of loss to evaporation is very small (typically <1%).

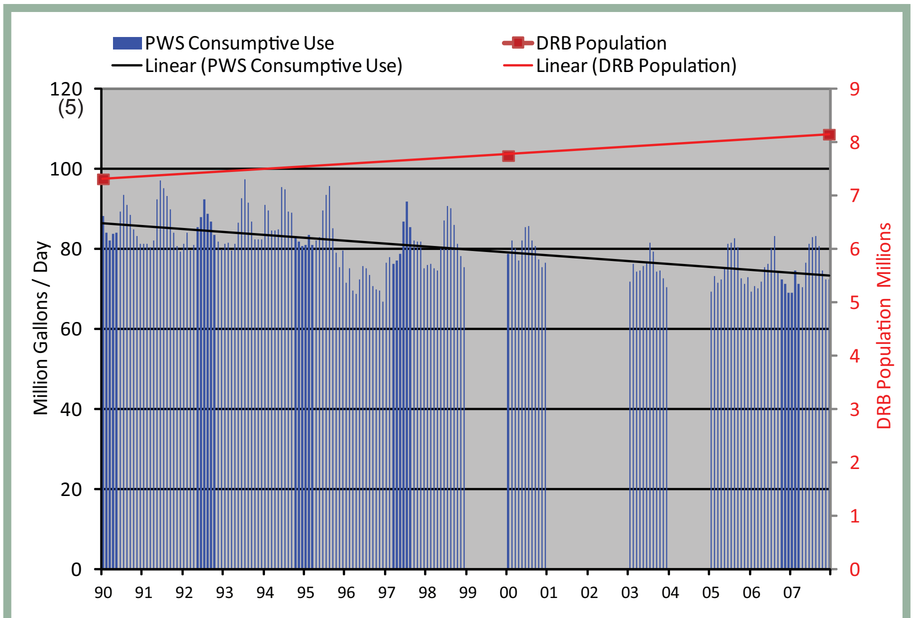


Fig. 2.7. Trends in Consumptive Water Use for Public Water Supply: Aggregate monthly water demand for 38 Large PWS Systems in the Delaware River Basin.

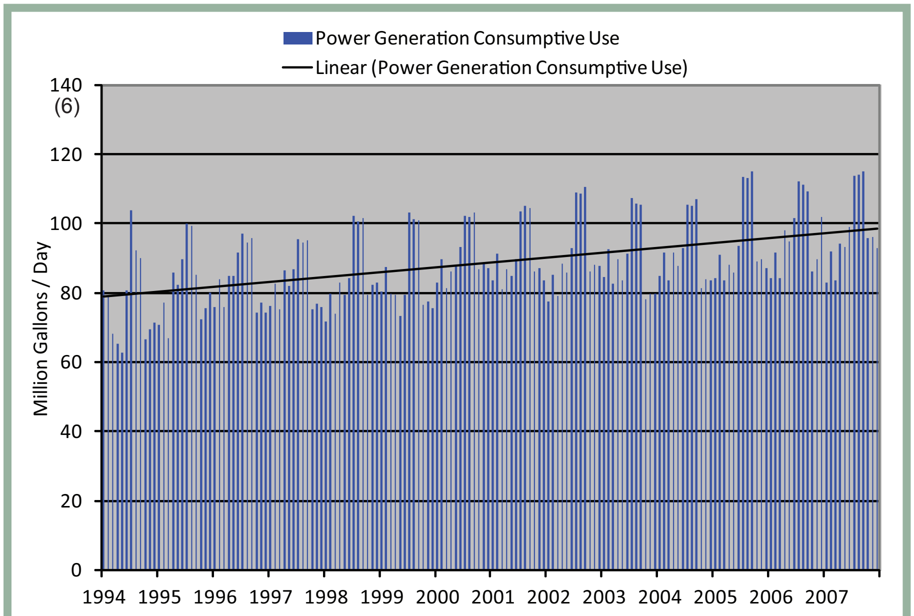


Fig. 2.8. Trends in Water Consumptive Water Use for Thermoelectric Power Generation: Aggregate monthly demand for 36 systems in the Delaware River Basin

The monthly data shown in Figures 2.7 and 2.8 highlight the extent to which water withdrawals and consumptive use vary seasonally. Thermoelectric power generation experiences peaks in the summer months that are related to the increased power demand for residential and commercial cooling. Simultaneously, public water suppliers experience peak demands in the summer months when lawn watering and other outside uses are greatest.

2.4 Future Predictions

Fig. 2.5 shows five-year water demand projections for the Delaware River Basin based on a collaborative study between the DRBC and the U.S. Army Corps of Engineers. Key findings of the study indicate that, at the Basin scale, future demand for the PWS sector is likely to remain flat due to continued efficiencies from implementation of water conservation appliances and practices. Water demand for the power generation sector was projected to increase between 2003 and 2030. In March 2010, U.S. EPA proposed regulations to enact the Clean

Water Act Section 316(b) rules (http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/). These regulations are designed to require the best technology available for minimizing adverse environmental impacts, particularly regarding impingement and entrainment (I&E) of fish and other organisms. The regulations are scheduled to be finalized in 2012 and could require power plants that currently use once-through cooling water systems to switch to recirculating water systems which require much less volumes of withdrawal (and hence reduce I&E impacts) but have a greater consumptive use. Due to the proposed rule change, it is likely that all new power generating facilities will require recirculating water systems that result in higher consumptive use. In addition to increasing the consumptive use in the basin, this switch potentially makes more upstream locations viable for the siting of power plants as recirculating cooling systems require a lesser volume of water withdrawal and could be accommodated further upstream, whereas once-through systems are typically constrained to the Estuary and Bay regions due to the large volumes of water required by these systems.

2.5 Actions and Needs

An accurate consumptive use characterization for a watershed requires a detailed analysis of each water use sector to determine accurate consumptive use factors representing site specific conditions. For example, at a small watershed scale, the simple assumption of 10% consumptive use for a PWS system that withdraws from the watershed but discharges wastewater outside the watershed would be inaccurate. This would need to be modeled as 100% consumptive, or as an export from the sending watershed and an import of wastewater (minus the 10% consumptive use) to the receiving watershed. More detailed tracking models that link withdrawals volumes more explicitly to discharge volumes are being applied in the Delaware River Basin, such as by New Jersey Geologic Survey's Water Transfer Data System www.state.nj.us/dep/njgs/geodata/dgs10-3.htm and through the State Water Plan process in Pennsylvania.

2.6 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 Delaware River Basin, the largest consumptive uses are from the thermoelectric, public water supply and agricultural water use sectors, accounting for almost 80% of in-basin consumptive use. There are also two significant exports from the Delaware River Basin as shown in Fig. 2.1 which can also be considered a form of consumptive use. These two exports combined account for more than twice the total quantity of in-basin consumptive use.

3 – Per Capita Water Use

3.1 Description of Indicator

In managing water resources it can be useful to have a metric for water use efficiency. One popular metric is *per capita water use*. This metric normalizes household water use for a given population. For the purposes of this report per capita water use has been calculated as follows:

$$(Self\,supplied\ domestic\ water\ use + Public\ Water\ Supply)\ /\ Population$$

The above calculation excludes, where possible, water use from other sectors, such as power generation, which would skew any calculations. However, inclusion of some sectors could not be avoided because many public water supply systems provide water to a significant non-residential customer base (i.e., industrial or commercial customers). This use could not be separated out and may result in a higher per capita water use estimate in some regions. PWS service areas cover approximately 21% of the Delaware River Basin by area, but serve water to approximately 82% of the Basin's population (see Fig. 2.9).

Per capita water use was calculated basin wide, and for individual regional watersheds (Fig. 2.10). For the per capita water use calculations by region not all transfers across watershed boundaries could be accounted for. Although the data were adjusted to account for the impact of the largest of these watershed transfers of water across sub-basin boundaries (Point Pleasant, PA diversion and NJ Delaware & Raritan Canal), some transfers could not be accounted for and may skew per capita water use comparisons between regions. For instance, some PWS water withdrawals are in one sub-basin, and the PWS service area is in a different sub-basin. Several of the largest service areas in the Delaware River Basin cross watershed boundaries, even at the sub-region watershed scale (see Fig. 2.9). As long as these limitations are acknowledged, per capita water use can be used as a measure of water use efficiency.

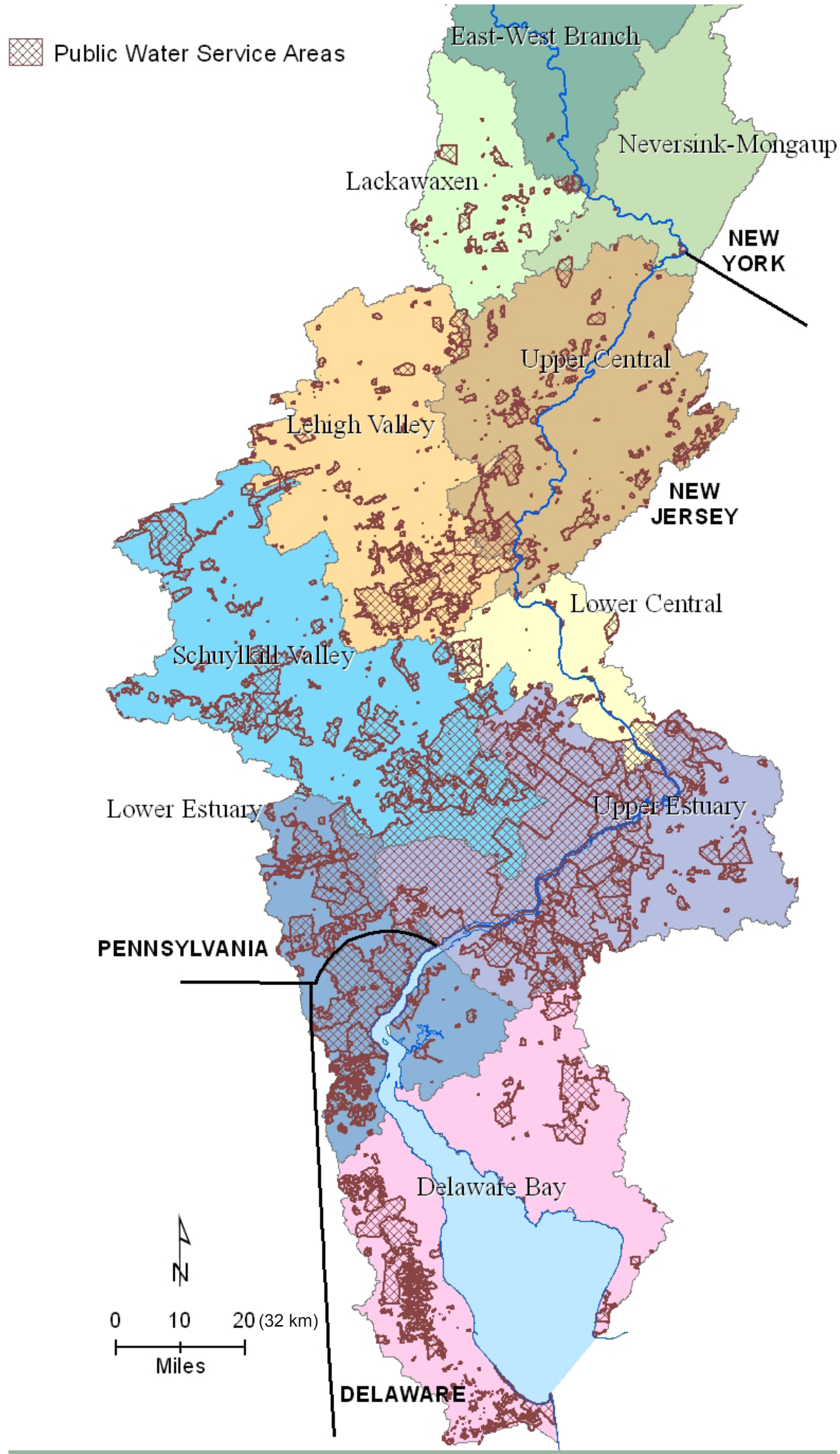


Fig. 2.9. Public Water Supply Service Area Coverage in the Delaware River Basin

3.2 Present Status

Moderate: Average per capita use in the Delaware River Basin is 116 gallons per capita per day (gpcd) (0.44CM/capita/day) and ranges from 78 gpcd to 171 gpcd (0.30 - 0.65 CM/capita/day) across the ten sub-basins. Fig. 2.10 shows Regional Per Capita Water Use for the ten subbasins. Average per capita water use is greater in the Lower and Bay Regions than in the Upper and Central Regions. The Schuylkill Valley sub-basin shows the highest per capita water use at 171 gpcd. Suburban areas with numerous residential developments and large lot-sizes would be expected to have a higher per capita use than heavily urbanized or rural areas.

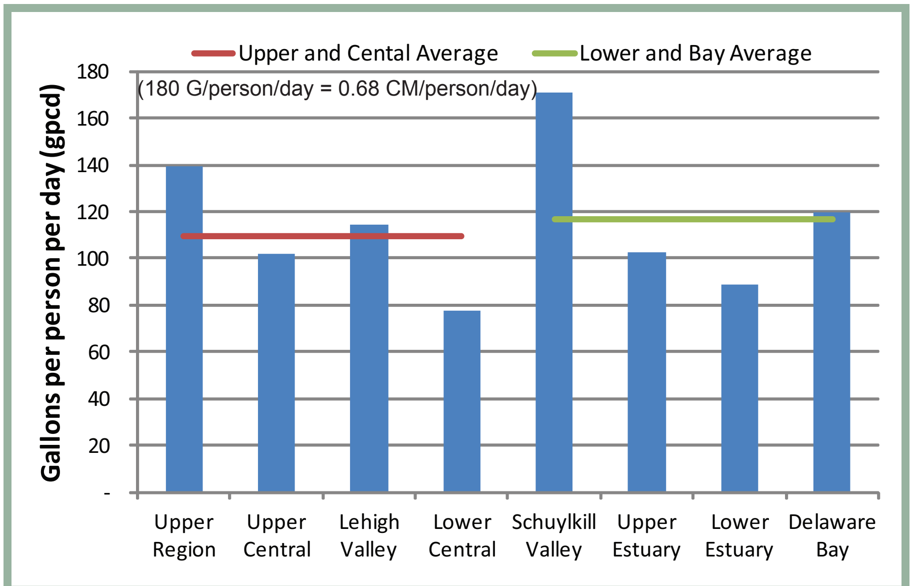


Fig. 2.10. Regional Per Capita Water Use

3.3 Past Trends

A detailed trend analysis is not available, however a previous study based on 2003 data estimated average Basin-wide per capita water use at 133 gpcd (0.5 cmcd) with a range between 90 and 190 gpcd (0.72 cmcd). Generally, per capita water use has decreased which is consistent with the trends shown in Fig. 2.7 which shows a decrease in public water supply withdrawals, despite increases in population.

3.4 Future Predictions

Per capita water use may continue to decline, as a result of increased water use efficiency, if the successes of water conservation strategies continue into the future. Changes in plumbing fixtures and fittings, which went into effect 20 years ago, led to greater water use efficiency. New construction has included the more efficient plumbing and older homes have replaced older plumbing fixtures and installed more efficient appliances. The majority of the benefit gained from these efficiencies may have already been realized; without additional effort and advances water use efficiency may level off and consequently water withdrawals may increase in response to growing population. One way to further increase water efficiency would be to improve the management and condition of water distribution infrastructure, which tends to be old and in need of significant investment in many areas. In some areas, as much as 50% of the water put into distribution systems never reaches the customer as it is lost to leaky infrastructure or poor accounting practices by the water purveyor; hence there is great potential to increase water efficiency by focusing attention in this area. Increasing water efficiency could lead to decreased water demand and decreased withdrawals, which would result in cost savings for water purveyors in the form of a reduced need for system expansion.

3.5 Actions and Needs

To improve the accuracy of per capita water use estimates, a detailed water use tracking model, such as that developed by the New Jersey Geological Survey, could be used to account for watershed transfers and link water withdrawals to the population served more accurately. Such a model is highly data intensive and requires a significant commitment of staff resources to populate and keep updated. However, the use of such a model, particularly in urbanized areas of the Delaware River Basin that have complex water distribution infrastructure and regional approaches to water supply management would provide a greater understanding of how water is moved and used around the watershed. Another measure to improve the accuracy and uniformity of the per capita consumption indicator would be to identify and report on PWS water use by customer type in order to separate residential uses from other types of use.

3.6 Summary

Per capita consumption can provide an indication of water use efficiency between different regions. The indicator needs to be interpreted carefully, as described above. Areas of above average per capita water consumption may be a result of anomalous data or may represent an area where increased incentives for water conservation could lead to a reduction in water demand and increased water use efficiency.

4 – Groundwater Availability

4.1 Description of Indicator

Stress on a water resource system can occur when withdrawals exceed natural recharge. 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 are showing signs of stress and are recognized as critical or protected areas: the Ground Water Protected Area in southeastern Pennsylvania and Critical Area No. 2 in south-central New Jersey which overlays the Potomac-Raritan-Magothy (PRM) aquifer (see Figure 2.11). New and/or expanded withdrawals in both of these critical areas are limited and managed subject to specific regulations which serve to allocate the resource on the basis of a sustainable long-term yield.

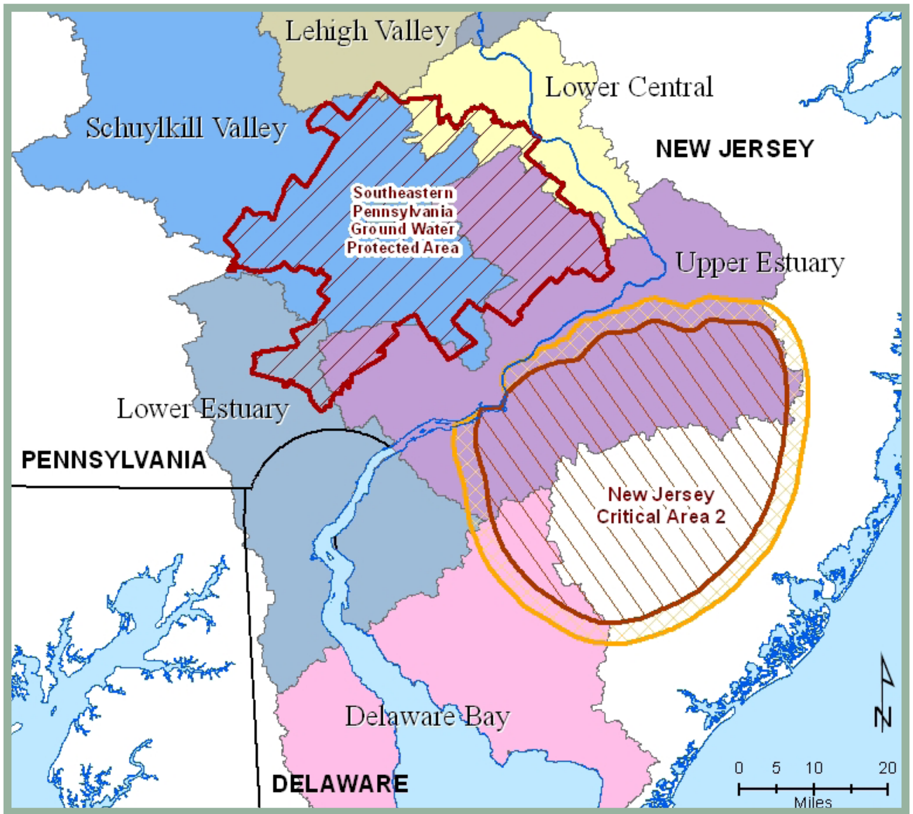


Fig. 2.11. Areas of Groundwater Stress in the Delaware River Basin. (20 mi = 32)

4.2 Present Status

Improving: Conjunctive use strategies and regional alternatives to the local supplies are easing the stress in these two areas.

In the South Eastern Pennsylvania Ground Water Protected Area (SEPA-GWPA) reductions in total annual ground water withdrawals have been observed over the past two decades. The DRBC created a management program for this area in 1980 and in 1999 numerical withdrawal limits were established for each of the area's 76 subbasins. This is the only area for which the Delaware River Basin Commission has cumulative water withdrawal limits. Between 1990 and 2007 total annual ground water withdrawals within the GWPA were reduced by approximately 3.9 billion gallons (10.9 mgd, 0.48 CMS). A significant cause of this reduction is the diversion of surface water from the Point Pleasant, PA intake on the Delaware River in the mid-1990s which alleviated the need for ground water withdrawals for two major public water supply systems in the area and also provided additional supply to Exelon's nuclear power station at Limerick, PA on the Schuylkill River. While this has had a significant impact on the development of the area, its impact in terms of reducing reliance on groundwater use is localized to a few sub-basins. There are other sub-basins that were identified as stressed, or potentially stressed, and their status has mostly remained static, as the management tool of sub-basin cumulative withdrawal limits has prevented further exacerbation of the problem.

4.3 Past Trends

Although individual sub-basin limits were not enacted until 1999, Fig. 2.12 shows several snapshots of the status of the 76 GWPA subbasins over a period of approximately 20 years, from 1990 to 2008. Only one sub-basin, the Upper Wissahickon watershed in Montgomery County, PA (circled in Fig. 2.12) was in excess of the withdrawal limit and that was in 1990 prior to the establishment of withdrawal limits. Groundwater pumping pressure was reduced on this sub-basin by the introduction of the Point Pleasant diversion which brought surface water from the Delaware River to the GWPA.

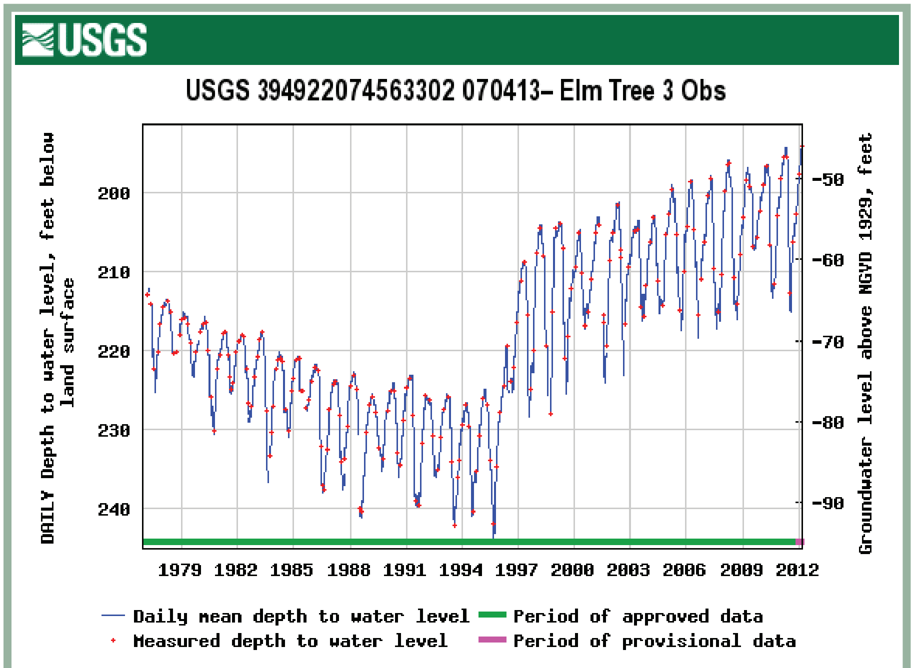


Fig. 2.12. USGS Elm Tree 3 Observation Well

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 (38 CM/mo) triggering regulatory review, as compared to 100,000 gallons/month (378 CM/mo) elsewhere in the Delaware River Basin.

The New Jersey Water Supply Critical Area #2 was established in 1996 by NJDEP and has resulted in reduced withdrawals from the Potomac-Raritan-Magothy (PRM) aquifer system. Many of the municipalities are now served by surface water diverted from the Delaware River near Delran, NJ. As a consequence of conjunctive use of ground and surface water, aquifer levels have risen and appear to be stabilizing in most parts of Critical Area #2. An example is shown in the hydrograph from USGS Elm Tree 3 Observation well (Fig. 2.12), which is located more than 700 ft (213 m) below land surface in the Middle PRM aquifer in Camden, NJ.

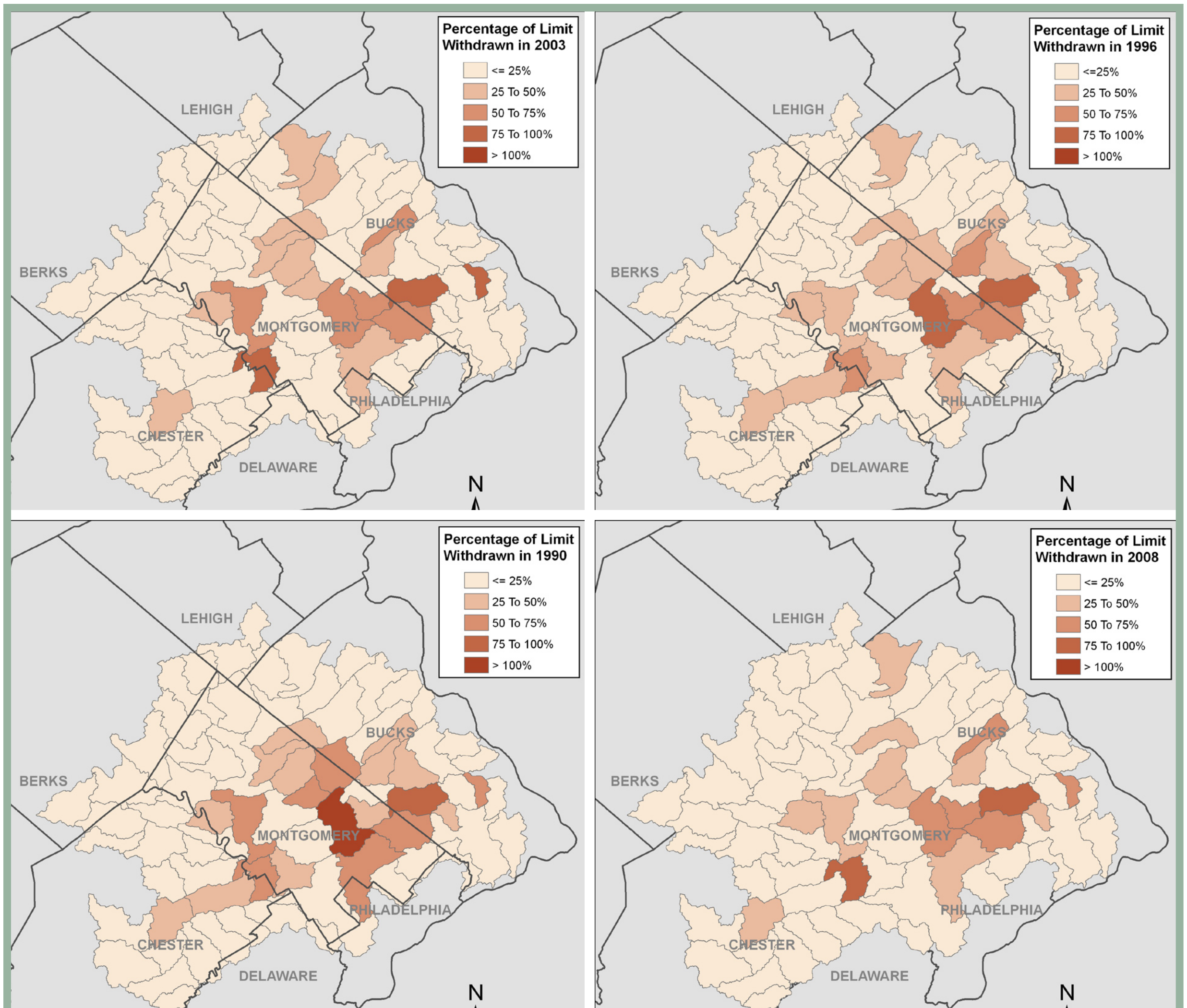


Fig. 2.13. Ground Water Withdrawals as a Percentage of GWPA Subbasin Withdrawal Limits, 1990-2008

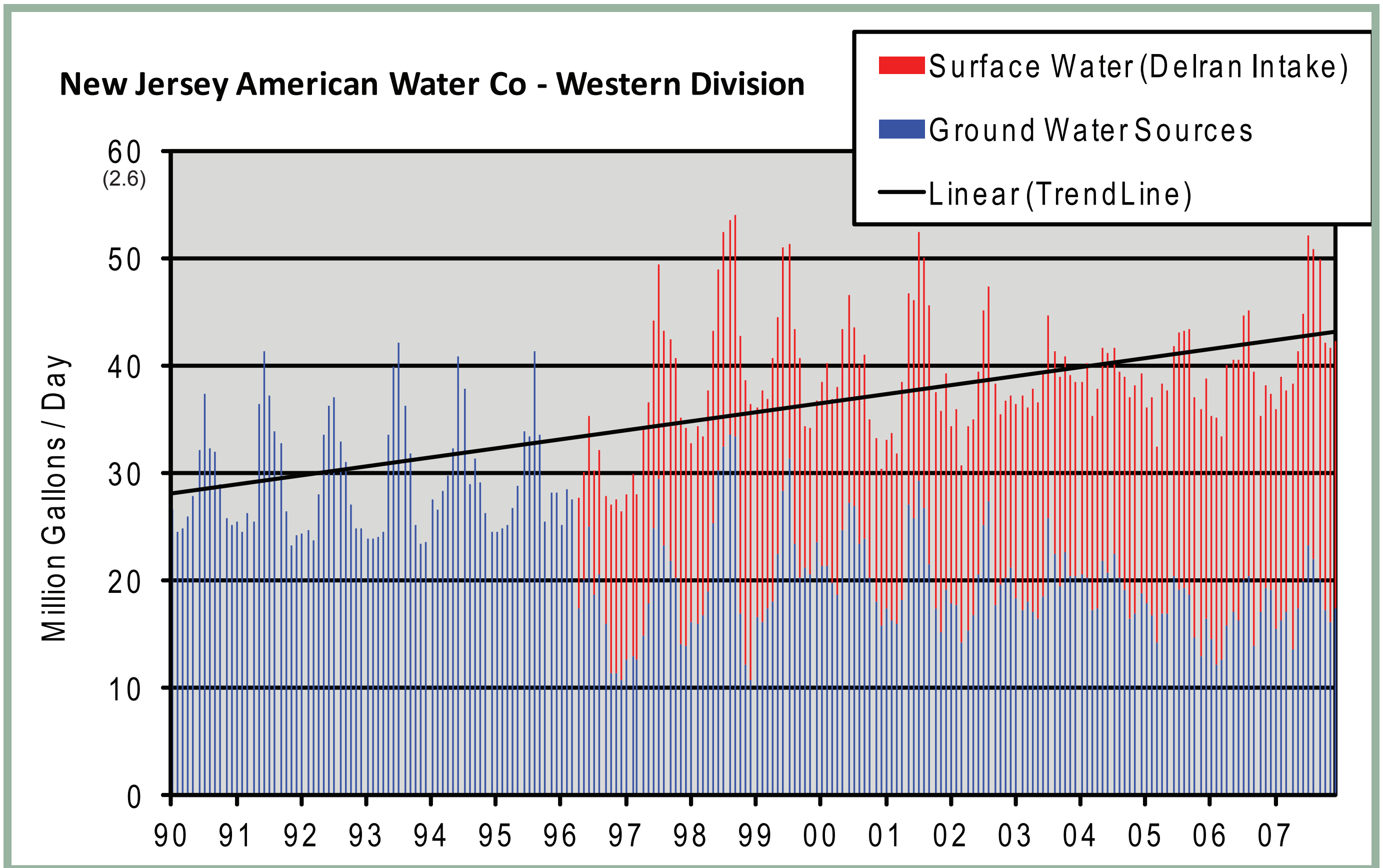


Fig. 2.14. Water Withdrawals by New Jersey American Water Company – Western Division

Fig. 2.14 shows water withdrawals by the New Jersey American Water Company (Western Division) over the past two decades and demonstrates how the Delran surface water intake has simultaneously provided water to meet an increasing demand and has reduced the need for pumping from groundwater sources.

4.4 Future Predictions

The PRM aquifer system extends under the Delaware River, through Delaware and into portions of Maryland. A 2008 report from the USACE on a ground water model developed for northern New Castle County in Delaware concluded that groundwater withdrawals in Delaware have resulted in diminishing stream baseflows and cones of depression. The impact of these withdrawals extends into Maryland and New Jersey. In recent years, Delaware has developed a program to enhance water supplies from surface sources for northern New Castle County and is better placed to withstand pressures of additional demand or a prolonged drought. Baseflow declines are still of concern in the Salem-Gloucester area and the Maurice River basin of southern New Jersey. New and/or expanded allocations are being denied or restricted to limit adverse impacts on the aquifers and to protect stream flows.

4.5 Actions and Needs

The progress made in recent years to improve water use reporting needs to be continued in order to provide the necessary data to monitor conditions in sensitive areas such as the southeastern Pennsylvania Ground Water Protected Area and the New Jersey Water Supply Critical Area #2. The metrics used to quantify groundwater availability in the GWPA could easily be applied to other areas of the basin for assessment purposes.

4.6 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 as a result of pumping groundwater.

5 –Salt Line Location & Movement

5.1 Description of Indicator

The salt line is an estimation of where the seven-day average chloride concentration equals 250 ppm along the tidal Delaware River. The location of the salt line plays an important role in the Delaware River Basin water quality and drought management programs because upstream migration of brackish water from the Delaware Bay, during low-flow and drought conditions, could increase sodium concentrations in public water supplies, presenting a health concern. Critical intakes on the Delaware River that could be adversely affected by salinity moving upstream are Philadelphia Water Department Baxter intake and the New Jersey American Water Company Delran intake. The intakes are both located at approximately river mile 110 (river kilometer 176). In addition, upstream migration of the salt line could adversely affect the PRM aquifer. High rates of pumping in the PRM draw tidal river water into the aquifer. If the salt line were to move too far upstream for an extended period of time, the presence of sodium could reduce the quality of water in the aquifer.

5.2 Present Status

Very good: Drinking water intakes in the tidal river are effectively protected and water quality in the PRM remains very good.

5.3 Past Trends

The salt line naturally advances and retreats with each tidal cycle and with seasonal variations in freshwater flow. For most of the year, the location of the salt line is between the Commodore Barry Bridge (RM 82/KM 131) and Artificial Island (RM 54/KM86). During droughts and periods of very low inflow to the Estuary, a management program releases water from upstream reservoirs to augment flows and to meet a daily flow target of 3,000 cfs (84.9 CMS) in the Delaware River at the Trenton, NJ gage. The program has worked well; since 1970 low-flow values that once occurred 10% of the time now occur only 1% of the time. The salt line has been successfully maintained below drinking water intakes, protecting drinking water supplies in the most urbanized area of the Basin (Fig. 2.15).

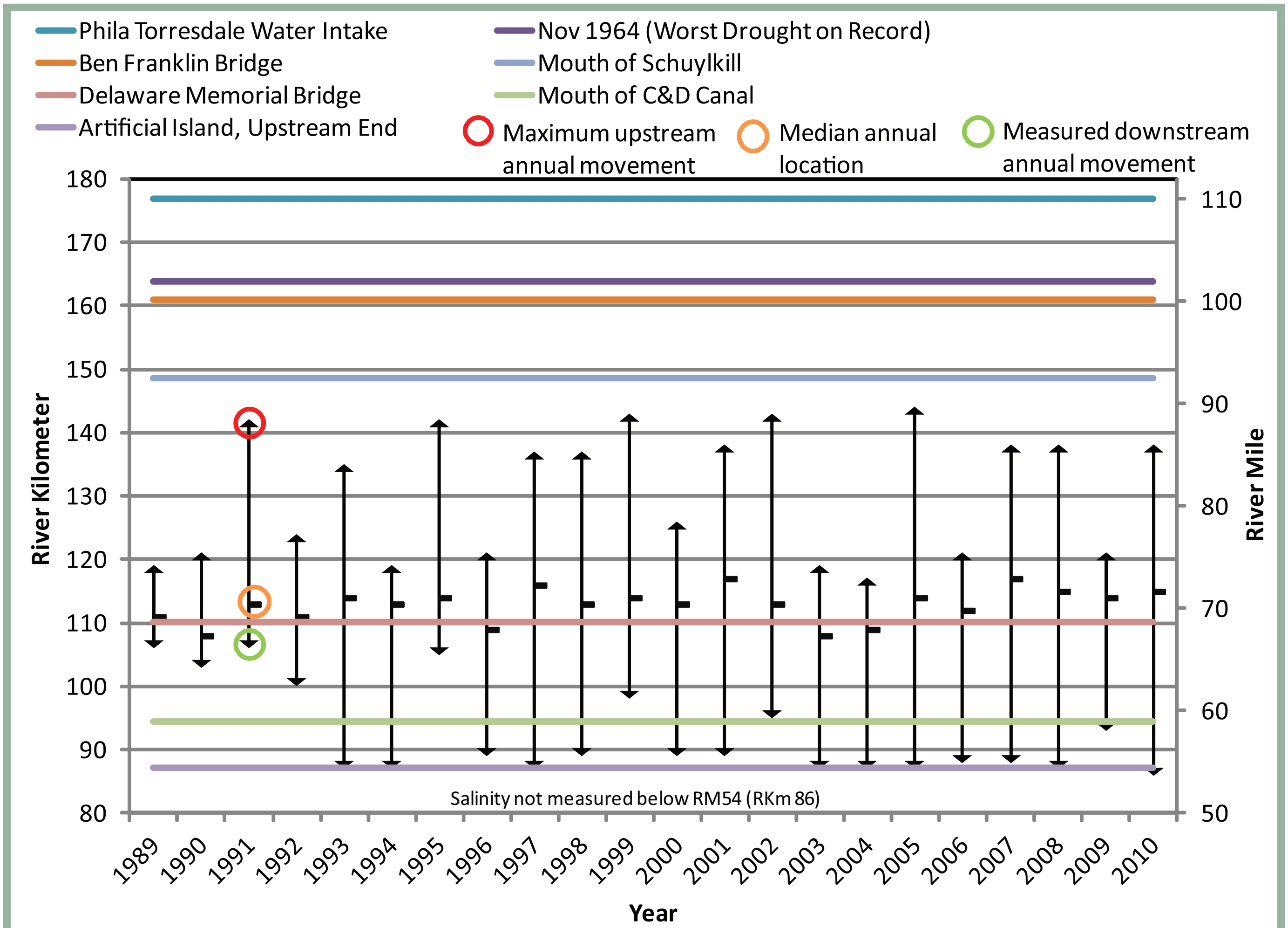


Fig. 2.15. Salt Line Movement 1989-2009.

Fig. 2.15 shows the maximum upstream location, lowest measured downstream location and median location of the salt line for each year during the period 1989 to 2010 compared to locations of interest along the Delaware River. (Note that the salt line location is not tracked and recorded below river mile 54 (river kilometer 86), and that the 250 ppm isochlor may move further downstream than this location, but this is not shown in Fig. 2.15.) Fig. 2.16 shows similar information in map form.

Fig. 2.16. Map of Historic Salt Line Locations.

5.4 Future Predictions

Sea level rise, channel deepening, and increasing variability in flow from climatic change may create additional challenges for management of the salt line in the future.

5.5 Actions and Needs

An investigation of additional sources of chlorides, such as from road salts and runoff, is warranted. An evaluation of the adequacy of the 3,000 cfs (84.9 CMS) target at Trenton, NJ in repelling the salt line is also warranted.

5.5 Summary

Flow management strategies have been successful in restricting the upstream movement of the salt line and have effectively protected drinking water intakes in the most densely populated area of the Basin.

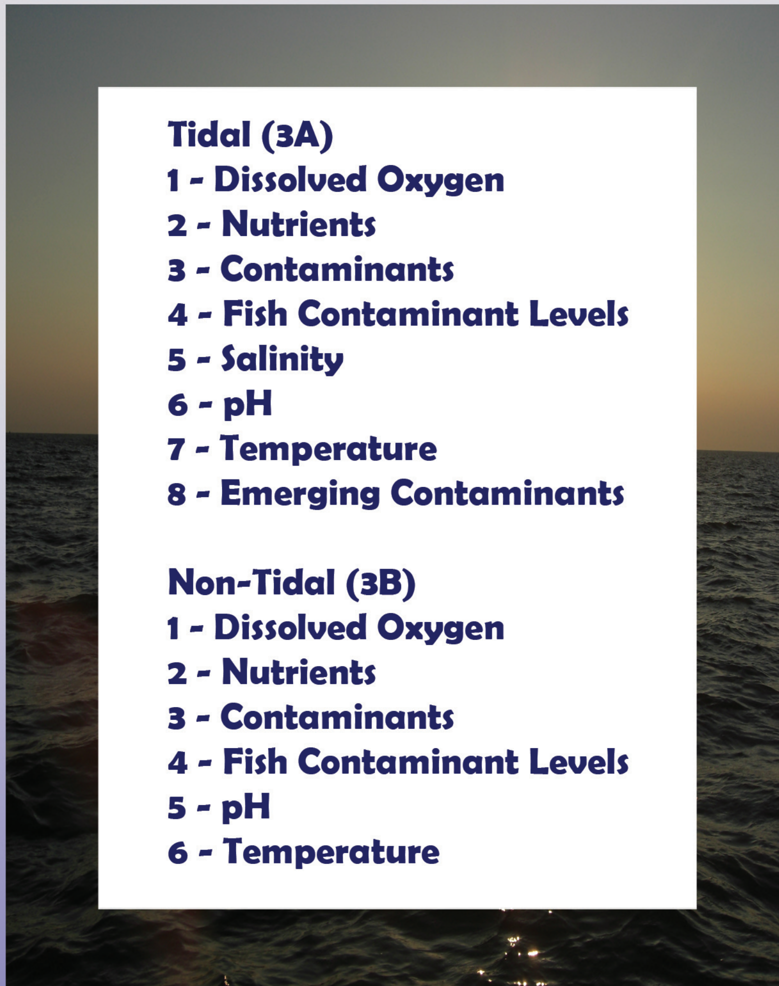
Chapter 2 - References and Works Cited

United States Department of Agriculture 2009. 2007 Census of Agriculture. United States Summary and State Data Volume 1 Geographic Area Series Part 51

USACE Philadelphia District, Delaware River Basin Commission 2008. Enhancing Multi-jurisdictional Use and Management of Water Resources for the Delaware River Basin, NY, NJ, PA and DE.

3

Water Quality



Tidal (3A)
1 - Dissolved Oxygen
2 - Nutrients
3 - Contaminants
4 - Fish Contaminant Levels
5 - Salinity
6 - pH
7 - Temperature
8 - Emerging Contaminants

Non-Tidal (3B)
1 - Dissolved Oxygen
2 - Nutrients
3 - Contaminants
4 - Fish Contaminant Levels
5 - pH
6 - Temperature

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Chapter 3 - Water Quality

Data Sources and Processing

For this assessment, the Delaware River Basin Commission (DRBC) retrieved and processed all available discrete water quality data contained in the US EPA STORET database, and the USGS NWIS database for the Delaware River Basin for the period 2000 through 2010. This is believed to constitute the majority of available water quality data in the basin.

Table 3.1 shows the total count of discrete observations available in each database. Over 424,000 discrete observations were considered as part of this assessment. Figure 3.1 shows the relative availability of discrete data by location from each database source for the basin.

In addition to the discrete observation data, DRBC also evaluated continuous real-time water quality data (Table 3.2). Continuous real-time data was retrieved from NWIS. Due to the nature of the continuous data, this information was assessed separately and is not included in the data totals listed in Table 3.1 or shown in Fig. 3.1.

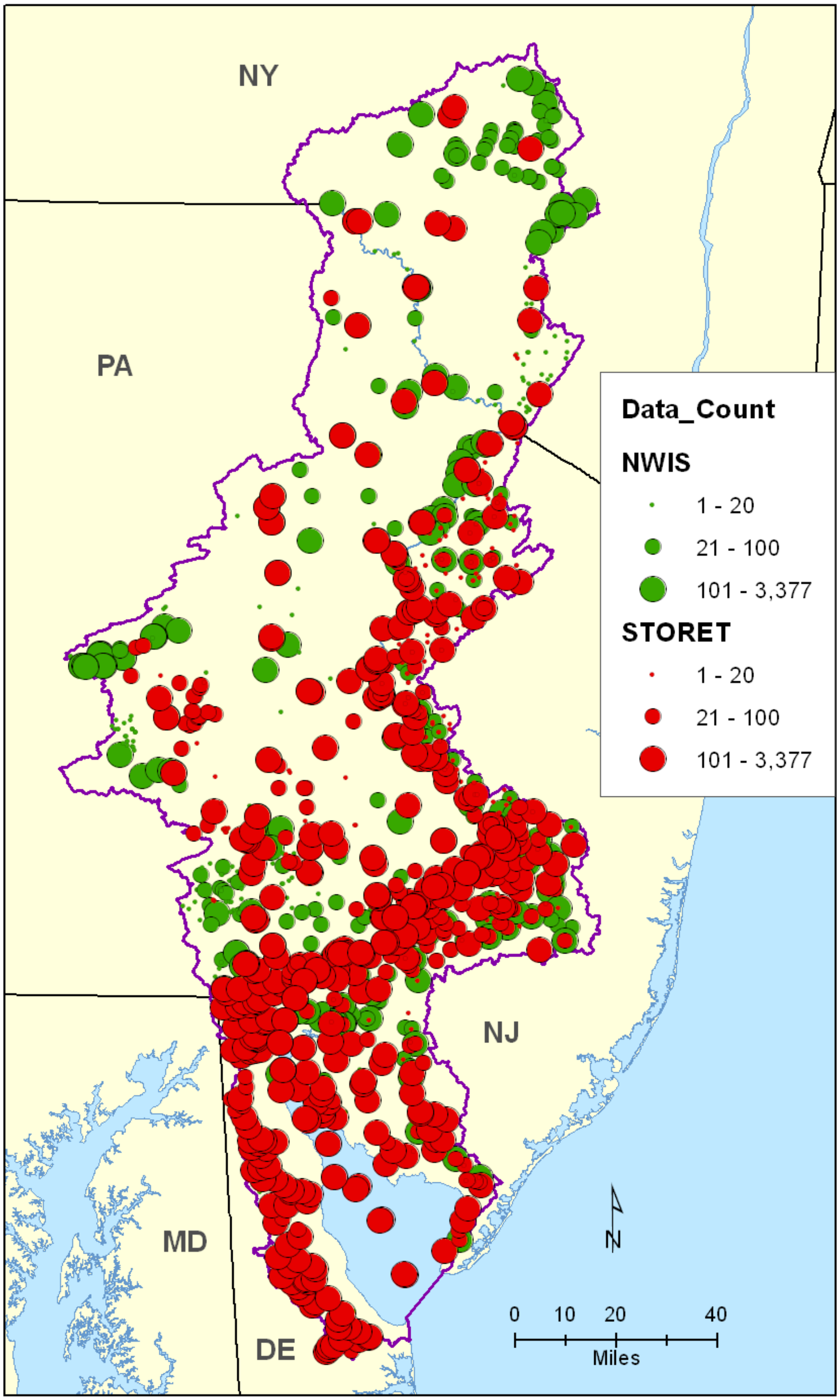

Fig. 3.1. NWIS and STORET Data Count by Location

Table 3.1. Number of Observations by Database

Database	No. of Discrete Observations
NWIS	176,015
STORET	248,344
Total	**424,359**

Table 3.2. Continuous Real-Time Water Quality Monitors in the Delaware Basin

Gage - USGS Code	Name	WQ Parameters
01480065	CHRISTINA RIVER AT NEWPORT	Temp., Sp. Cond., DO, pH, Turbidity
01481500	BRANDYWINE CREEK AT WILMINGTON	Temp., Sp. Cond., DO, pH, Turbidity
01463500	DELAWARE RIVER AT TRENTON	Temp., Sp. Cond., DO, pH, Turbidity
01417500	EAST BRANCH DELAWARE RIVER AT HARVARD	Temp.
01420500	BEAVER KILL AT COOKS FALL	Temp.
01421000	EAST BRANCH DELAWARE RIVER AT FISHS EDDY	Temp.
01425000	WEST BRANCH DELAWARE RIVER AT STILESVILLE	Temp.
01426500	WEST BRANCH DELAWARE RIVER AT HALE EDDY	Temp.
01427000	WEST BRANCH DELAWARE RIVER AT HANCOCK	Temp.
01427207	DELAWARE RIVER AT LORDVILLE, NY	Temp.
01427510	DELAWARE RIVER AT CALLICOON	Temp.
01428500	DELAWARE RIVER ABOVE LACKAWAXEN RIVER NEAR BARRYVILLE	Temp.
01436690	NEVERSINK RIVER AT BRIDGEVILLE	Temp.
01428750	WEST BRANCH LACKAWAXEN RIVER NEAR ALDENVILLE	Temp.
01429000	WB LACKAWAXEN RIVER AT PROMPTON	Temp.
01431500	LACKAWAXEN RIVER AT HAWLEY	Temp.
01432110	LACKAWAXEN RIVER AT ROWLAND	Temp.
01447500	LEHIGH RIVER AT STODDARTSVILLE	Temp.
01447720	TOBYHANNA CREEK NEAR BLAKESLEE	Temp.
01447800	LEHIGH R BLW FRNCS E. WLTR RES NR WHITE HAV	Temp.
01449360	POHOPOCO CREEK AT KRESGEVILLE	Temp.
01449800	POHOPOCO CR BL BELTZVILLE DAM NR PARRYVILLE	Temp.
01465798	POQUESSING CREEK AT GRANT AVE. AT PHILADELPHIA	Temp., Sp. Cond., DO, pH, Turbidity
01467042	PENNYPACK CR AT PINE ROAD, PHILA.	Temp., Sp. Cond., DO, pH, Turbidity
01467048	PENNYPACK CR AT LOWER RHAWN ST BDG, PHILA.	Temp., Sp. Cond., DO, pH, Turbidity
01467086	TACONY CREEK AT COUNTY LINE, PHILADELPHIA	Temp., Sp. Cond., DO, pH
01467087	FRANKFORD CREEK AT CASTOR AVE, PHILADELPHIA	Temp., Sp. Cond., DO, pH
01470779	TULPEHOCKEN CREEK NEAR BERNVILLE	Temp.
01470960	TULPEHOCKEN CR AT BLUE MARSH DAMSITE NEAR READING	Temp.
01473900	WISSAHICKON CREEK AT FORT WASHINGTON	Temp., Sp. Cond., DO, pH, Turbidity
01474000	WISSAHICKON CREEK AT MOUTH, PHILADELPHIA	Temp., Sp. Cond., DO, pH, Turbidity
01474500	SCHUYLKILL RIVER AT PHILADELPHIA	Temp., Sp. Cond., DO, pH, Turbidity
01475530	COBBS CR AT U.S. HGHWY NO. 1 AT PHILADELPHIA	Temp., Sp. Cond., DO, pH
01475548	COBBS CREEK AT MT. MORIAH CEM	Temp., Sp. Cond., DO, pH
01478120	EAST BRANCH WHITE CLAY CREEK AT AVONDALE	pH
01480400	BIRCH RUN NEAR WAGONTOWN	Temp.
01480500	WEST BRANCH BRANDYWINE CREEK AT COATESVILLE	Temp.
01480617	WEST BRANCH BRANDYWINE CREEK AT MODENA	Temp., Sp. Cond., DO, pH, Turbidity
01480870	EAST BR BRANDYWINE CREEK BELOW DOWNINGTOWN	Temp., Sp. Cond., DO, pH, Turbidity
01481000	BRANDYWINE CREEK AT CHADDS FORD	Temp., Sp. Cond., DO, pH, Turbidity
01454720	LEHIGH RIVER AT EASTON, PA	Temp., Sp. Cond., DO, pH
01460200	DELAWARE RIVER AT TOHICKON CREEK AT PT PLEASANT, PA	Temp., Sp. Cond., DO, pH, Turbidity
01467029	DELAWARE RIVER AT DELRAN, NJ	Temp., Sp. Cond., DO, pH, Turbidity
01467200	DELAWARE RIVER AT BEN FRANKLIN BRIDGE AT PHILADELPHIA	Temp., Sp. Cond., DO, pH, Turbidity
01472104	SCHUYLKILL RIVER AT VINCENT DAM AT LINFIELD, PA	Temp., DO
01474703	DELAWARE RIVER AT FORT MIFFLIN AT PHILADELPHIA, PA	Temp., Sp. Cond.
01477050	DELAWARE RIVER AT CHESTER, PA	Temp., Sp. Cond., DO, pH
01482800	DELAWARE RIVER AT REEDY ISLAND JETTY, DE	Temp., Sp. Cond., DO, pH, Turbidity

3A – Tidal

3A – 1 Dissolved Oxygen

Dissolved oxygen (DO) refers to the concentration of oxygen gas incorporated in water. Oxygen enters water from the atmosphere, which is enhanced by turbulence, and as a by-product of photosynthesis by algae and aquatic plants. Sufficient DO is essential to growth and reproduction of aerobic aquatic life. Oxygen levels in water bodies can be depressed by the discharge of oxygen-depleting materials (measured in aggregate as biochemical oxygen demand, [BOD], from wastewater treatment facilities), from the decomposition of organic matter including algae generated during nutrient-induced blooms, and from the oxidation of ammonia and other nitrogen-based compounds. The Delaware Estuary has historically been plagued by anoxic and hypoxic conditions (the lack of oxygen or the severe depression of oxygen, respectively) that resulted from the discharge of raw and poorly treated wastewater. Although the estuary has seen a remarkable recovery since the 1960s, with fish such as striped bass and sturgeon now able to spawn (at least some of the time) within the estuary, DO remains a critical issue for the estuary because of continued depression of oxygen levels far below saturation and because of possible indirect effects from elevated nutrient loadings.

3A – 1.1 Description of Indicator

For our review of oxygen values in the estuary, we looked at two different expressions of DO: concentration, as mg/L, and percent of saturation. DO concentration provides a direct comparison to water quality criteria and to aquatic life effects levels. Percent of saturation gives an indication of the oxygen content relative to saturation due to temperature and salinity.

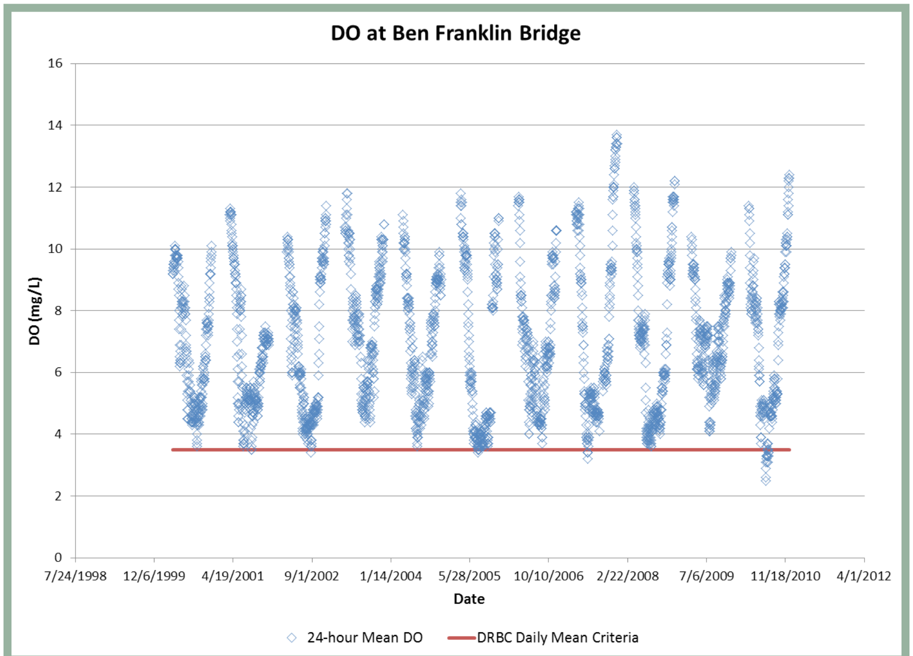

Fig. 3.2. Daily Mean DO Compared to Criteria at Ben Franklin Bridge

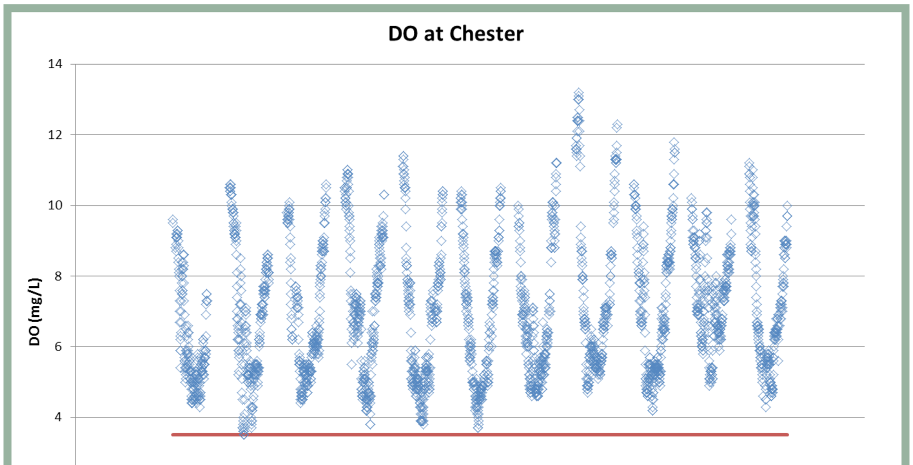

Fig. 3.3. Daily Mean DO Compared to Criteria at Chester

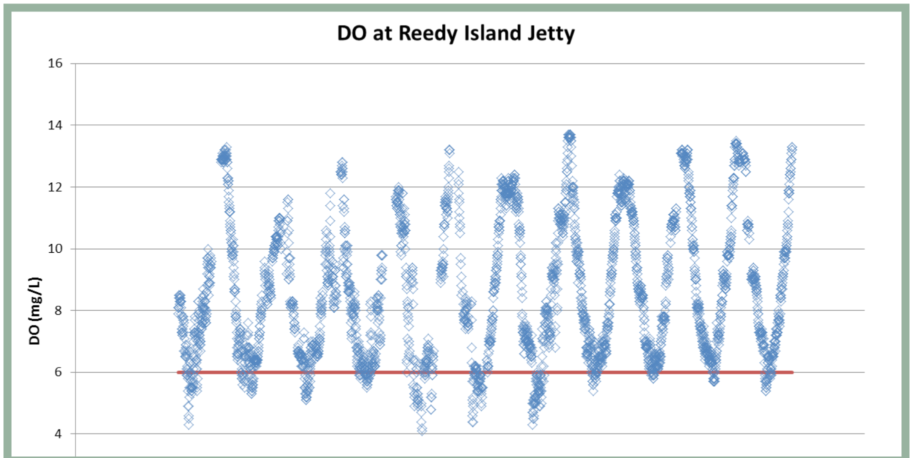

Fig. 3.4. Daily Mean DO Compared to Criteria at Reedy Island Jetty

For the Delaware Estuary, assessment of DO was best accomplished by review of data collected at the real time continuous monitors operated by the US Geological Survey (USGS) at the Ben Franklin Bridge (01467200), Chester (01477050), and Reedy Island Jetty (01482800). Limited additional data was also available from USGS monitors at Delran (01467029) and Ft. Mifflin (01474703). Because DO concentrations 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. In addition, continuous monitors provide a depth and continuity of data that could not be replicated with spot measurements.

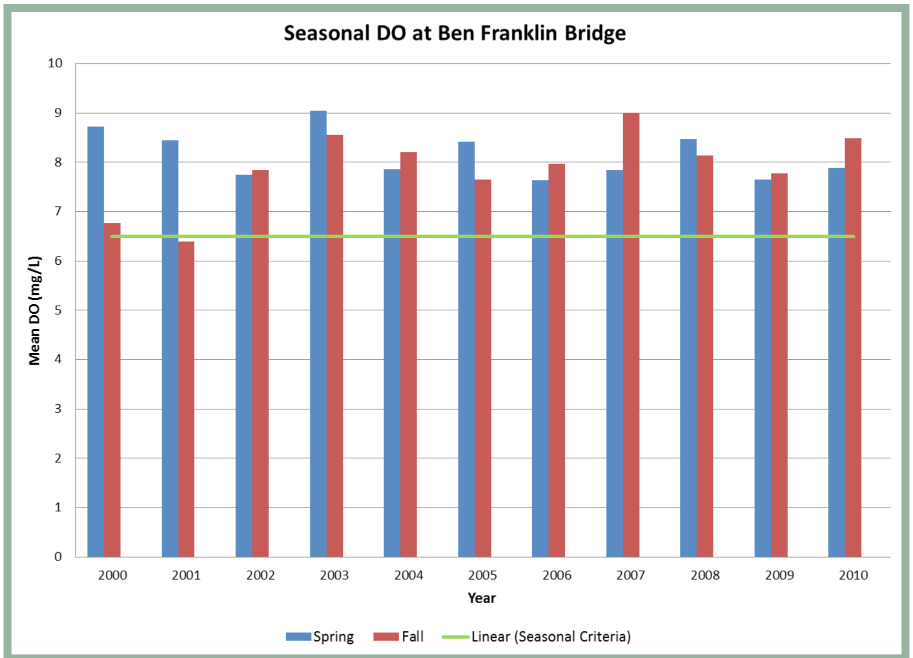

Fig. 3.5. Seasonal Mean DO Compared to Criteria at Ben Franklin Bridge

3A – 1.2 Present Status

As measured at the USGS monitors at the Ben Franklin Bridge, Chester, and the Reedy Island Jetty, DO concentrations were primarily above (meeting) criteria. At the Ben Franklin Bridge (Zone 3) and Chester (Zone 4), DRBC has published DO criteria of 3.5 mg/L on a 24-hour average basis. Reedy Island Jetty (lower Zone 5) has a criterion of 6 mg/L on a 24-hour average basis. Figures 3.2 through 3.4 show that the majority of 24-hour mean concentrations are above (meeting) criteria at all three stations. At the Ben Franklin Bridge, less than 1% of daily averages were below (not meeting) the 24-hour average criteria. At Chester, no daily averages were below (not meeting) the 24-hour average criteria. Although Reedy Island shows a higher proportion of days below (not meeting) criteria, the criterion at that location is 6 mg/L, and is thus more stringent than at either the Ben Franklin or Chester monitors. At Reedy Island, 9.4% of daily means were below (not meeting) the 24-hour average criteria. At Ben Franklin Bridge and Reedy Island Jetty, violations occurred primarily in June, July, and August.

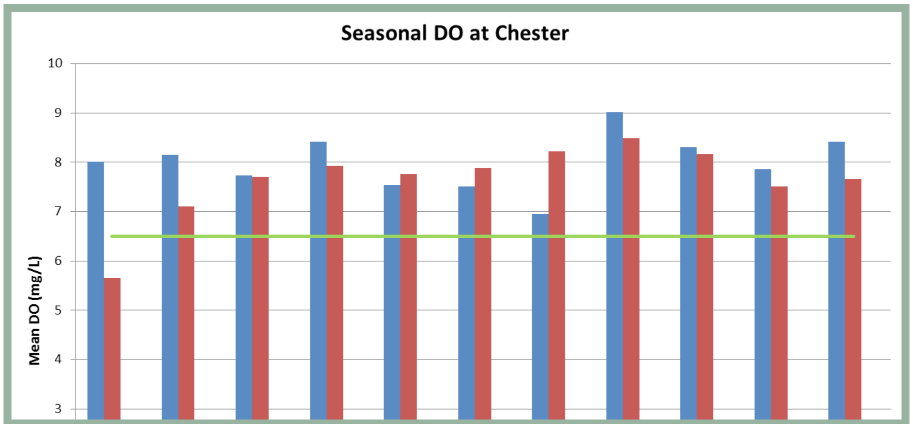

Fig. 3.6. Seasonal Mean DO Compared to Criteria at Chester

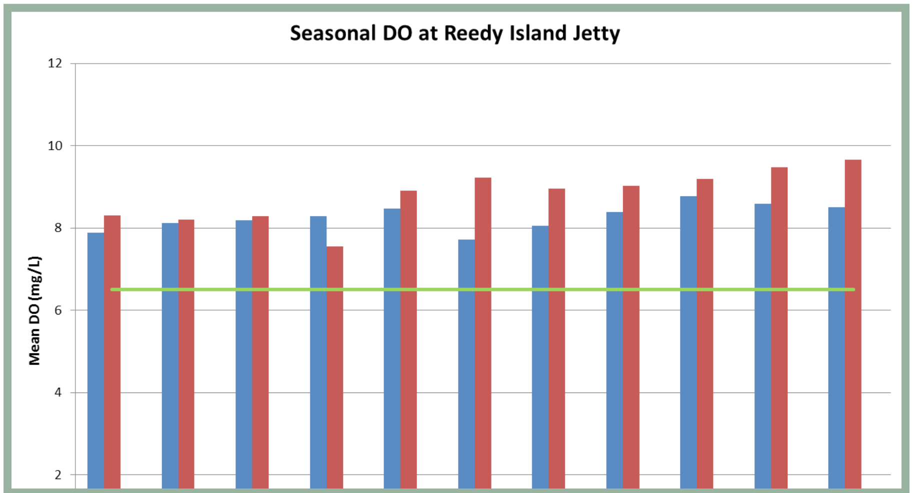

Fig. 3.7. Seasonal Mean DO Compared to Criteria Reedy Island Jetty

In addition to 24-hour mean criteria, DRBC has published criteria for seasonal mean DO values for the periods from April 1st through June 15th (spring) and September 16th through December 31st (fall), which correspond to important spawning and migration periods for estuarine fish. In Zones 3, 4, and 5, the mean Spring and Fall seasonal DO shall be no less than 6.5 mg/L. Figures 3.5, 3.6, and 3.7 show the comparison of the seasonal means to the criteria. At the Ben Franklin Bridge, only the Fall 2001 seasonal mean was below (not meeting) criteria. At Chester, the Fall 2000 seasonal mean was below criteria, and at Reedy Island Jetty, all seasonal means met criteria.

DO saturation factors in the oxygen carrying capacity of water due to temperature and salinity, and therefore may be more standardized for evaluating the entire basin over a range of atmospheric conditions. Results with low oxygen saturation indicate oxygen depleting materials in the water column or sediments, although 100% saturation is not regularly maintained even in relatively pristine estuarine settings during summer months.

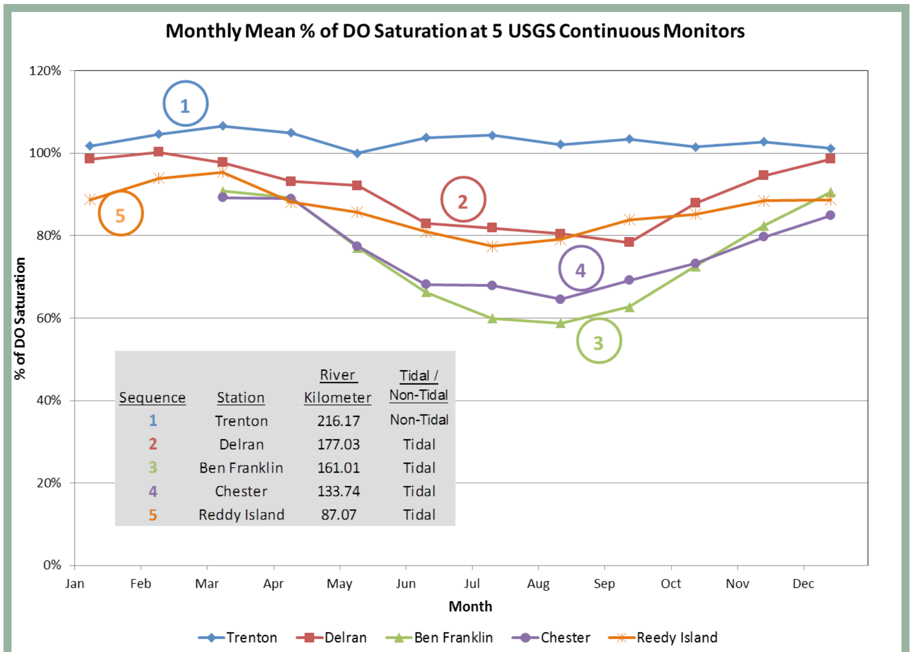

Fig. 3.8. Monthly Mean % of DO Saturation at 5 USGS Continuous Monitors

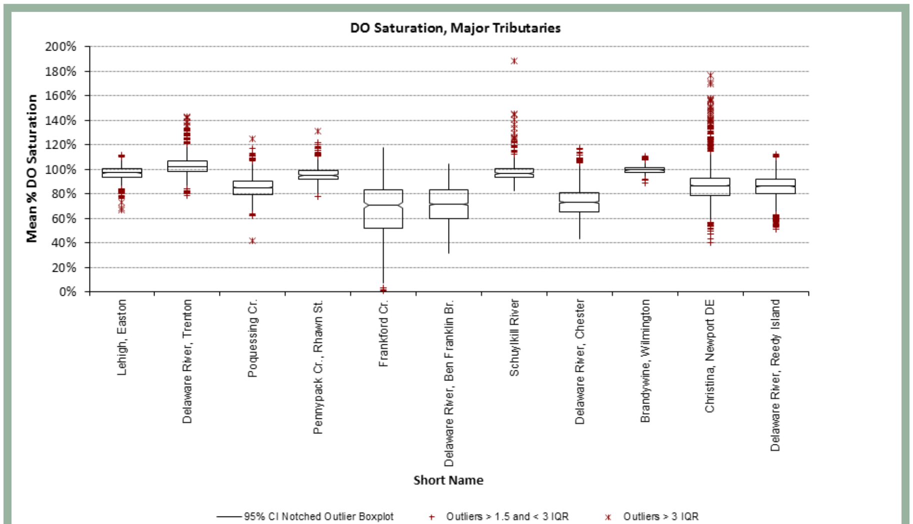

Fig. 3.9. Box and whisker plot of % of DO Saturation for Estuary and Major Tributaries

Figure 3.8 provides a sense of how current DO saturation changes both spatially and temporally in the estuary. DO saturation levels at Trenton are high, and remain high throughout the year. At Delran, in the upper freshwater portion of the estuary, a decline in DO saturation levels is evident, especially in summer and early autumn. The DO saturation sag is pronounced farther downstream in the vicinity of the Ben Franklin Bridge, with lowest levels occurring in July, August, and September. Levels begin to rebound near Chester. At Reedy Island, in the salinity transition zone, levels have returned to a range from 80% to 100% saturation, comparable to levels observed at Delran.

Box and whisker plots using available USGS continuous DO data comparing mainstem Delaware River DO saturation ranges to ranges of major tributaries and the non-tidal Delaware River at Trenton are shown in Fig. 3.9 includes both tidal and non-tidal locations. As indicated in the figure, the DO saturation range was high and narrow above the head of tide at Trenton. Poquessing and Pennypack creeks showed a moderately lower DO median, and Frankford Creek shows a substantially lower DO saturation median. At the Ben Franklin Bridge, the Delaware River is showing a lower median and more expanded DO saturation interquartile range than at Trenton. With the exception of Frankford Creek, the other tributaries are showing a higher median and narrower interquartile range of percent of DO saturation than the mainstem Delaware River.

3A – 1.3 Past Trends

This history of the DO recovery of the Delaware River is well known and has been extensively described in presentations, journal articles, and public outreach documents. Recently, DRBC reevaluated the historic data to refine our understanding of the historic changes in DO and to initiate discussion on what further improvements should be targeted.

Figure 3.10 shows the median DO values at the Ben Franklin Bridge monitor by month from 1966 through 2005 (note: these are the medians of the 24-hour daily averages). The data shows that as water quality improvements were made, primarily through the addition of secondary treatment at municipal waste water treatment plants, the temporal extent and the absolute magnitude of DO violations decreased, with daily average DO regularly attaining the 3.5 mg/L criteria beginning in the mid to late 1980's. Improvements continued through the 1990's and early 2000's, further reducing the magnitude and duration of the DO sag each summer.

Figure 3.11 shows a similar change at Chester, with the typical daily average approaching or exceeding the 3.5 mg/L criteria beginning in the early 1980's.

More temporally refined box and whisker plots of DO concentrations in July (representative of the lowest DO time period) from the 1960's through the late 2000's reveal the year-to-year variation, but generally show that most DO values were above criteria by the mid to late 1980's at Chester (Fig. 3.13) and consistently above criteria at the Ben Franklin Bridge by the mid 1990's (Fig. 3.12). The box and whisker plots also reveal the highly variable oxygen conditions in the estuary each year since the peaks of the late 1990s. At this time, it is not clear what the causes are for such highly variable conditions, although high freshwater inflows appear to be one contributing factor to years with higher DO levels.

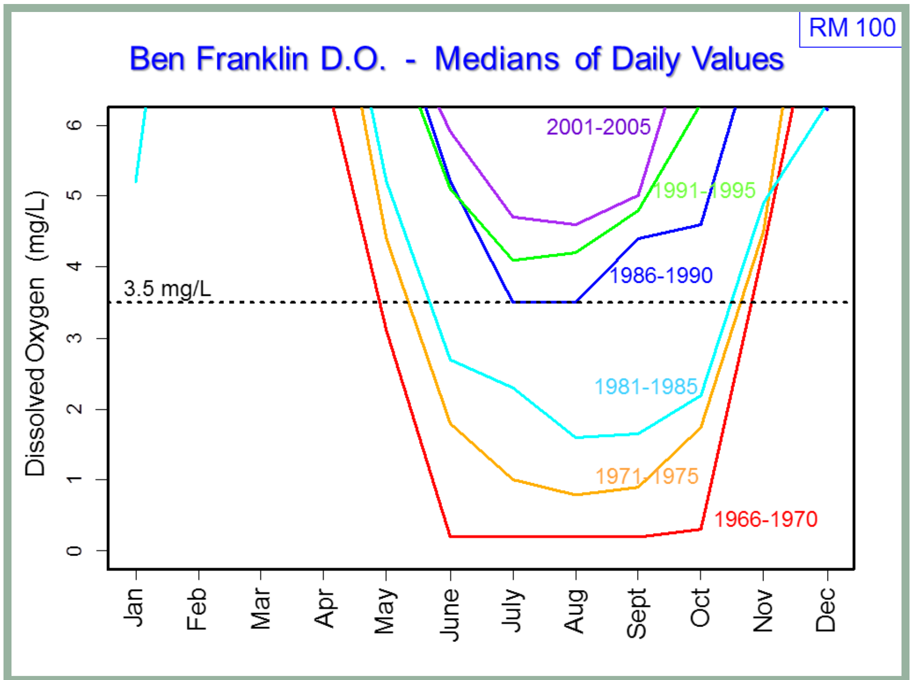

Fig. 3.10. Temporal Duration and Magnitude of Dissolved Oxygen sag at the Ben Franklin Bridge Monitor over time.

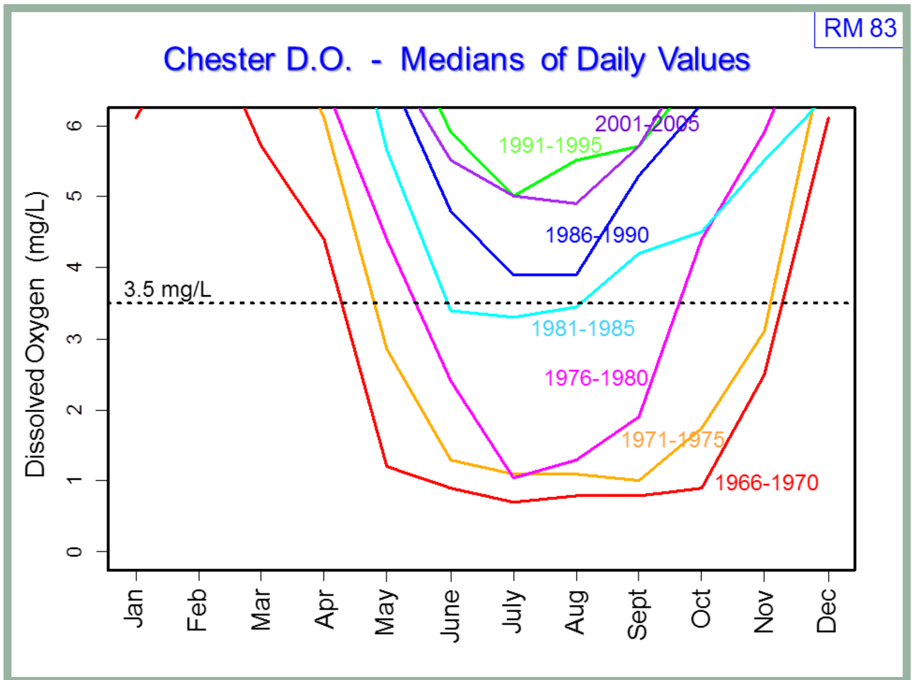

Fig. 3.11. Temporal Duration and Magnitude of Dissolved Oxygen sag at the Chester Monitor over time.

3A – 1.4 Future Predictions

As mentioned previously, DO saturation is a function of water temperature and salinity. Warmer, saltier water carries less oxygen. Global climate change is expected to yield locally increased temperatures and to drive the Delaware River salt front further upstream as a function of sea level rise. Intuitively, this would suggest a lowered oxygen carrying capacity for portions of the Delaware Estuary, if all other factors remain unchanged.

DRBC has advocated model studies to assess the impact of warming water temperatures and rising sea levels on DO concentrations in the estuary. Specifically, it may be necessary to seek additional water quality improvements just to maintain the DO levels already achieved.

In addition, the current water quality criterion of 3.5 mg/L DO has been recognized since its origin in the 1960s as an inadequate goal for the full functioning of a healthy estuarine ecosystem. Particularly noteworthy are the high sensitivities of two endangered sturgeon species (shortnose and Atlantic) in the Delaware Estuary whose juvenile stages experience very high mortality when DO ranges between 3.0 and 3.5 mg/L (Secor and Gunderson 1988, Campbell and Goodman 2004). Thus, in addition to maintaining the DO improvements seen in the estuary to date, there have long been calls to continue the restoration of the DO conditions to levels that would support all indigenous forms of aquatic life in the estuary.

3A – 1.5 Actions and Needs

Current criteria may not be protective of existing uses in the Delaware Estuary. The uses to be protected in Zones 3 and 4, as described in the DRBC Water Quality Standards, include maintenance of resident fish and other aquatic life, and passage of anadromous fish, but not propagation. However, impingement and entrainment studies conducted at power plant water intakes, as well as aquatic living resource assessments, have demonstrated that propagation is occurring in Zones 3 and 4. Therefore, revision of criteria to protect the actual uses is necessary.

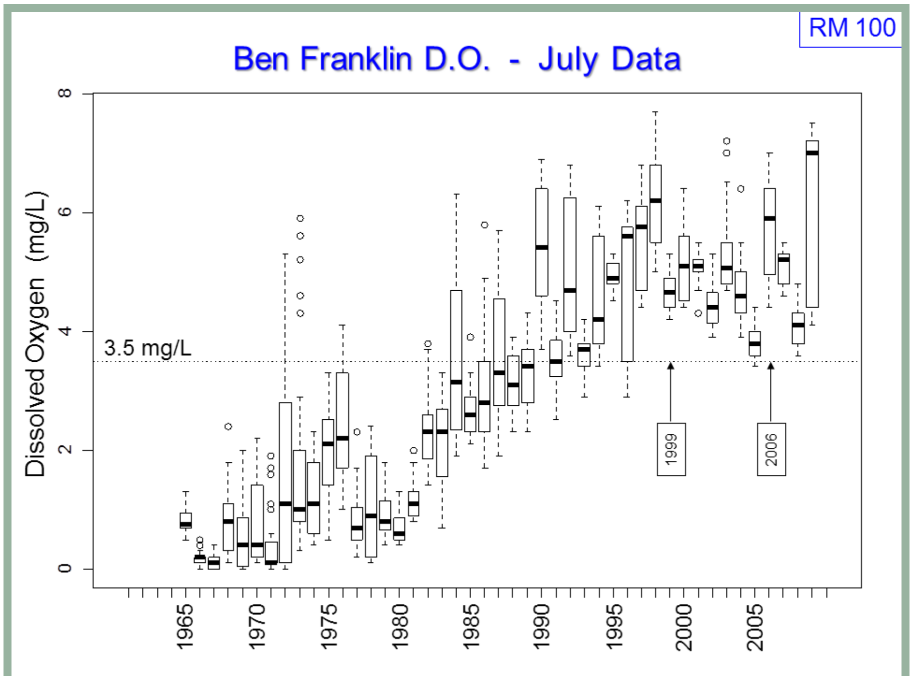

Fig. 3.12. Box and Whisker plot of July Dissolved Oxygen Concentrations at the Ben Franklin Bridge monitor from 1965 through the present.

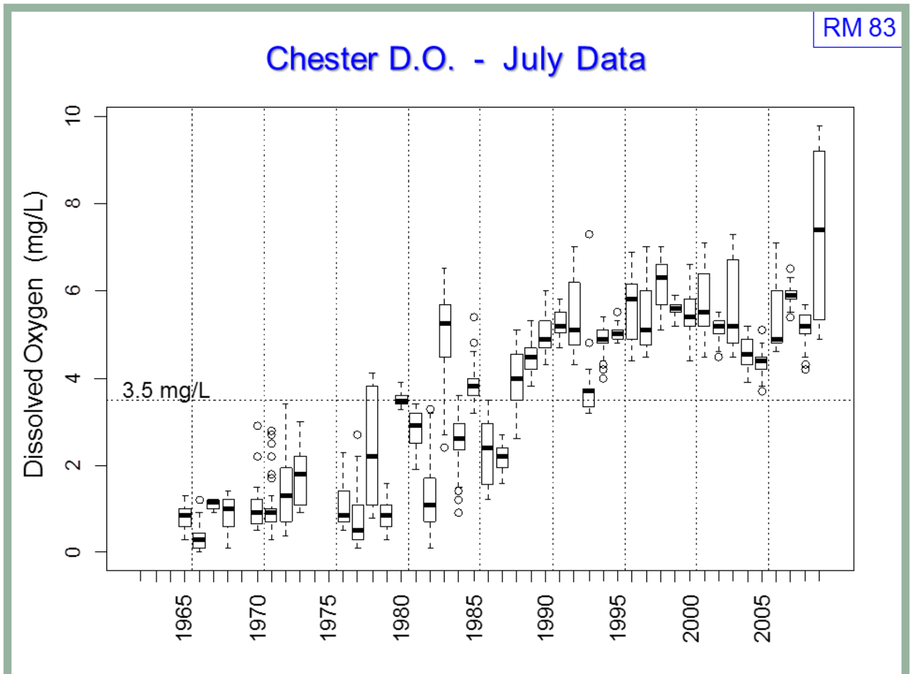

Fig. 3.13. Box and Whisker plot of July Dissolved Oxygen Concentrations at the Chester monitor from 1965 through the present.

In the longer term, we recommend determination of the highest attainable use for the estuary, and subsequent DO criteria protective of that use. This effort would involve coupling estimates of population change and improvements in wastewater treatment technologies, to water quality models which take into account the dynamics of nutrients in the estuary and various forms of oxygen depleting substances, to determine the long term highest use goals.

As mentioned previously, continuous real-time DO monitors provide a better understanding of DO dynamics under a wide range of temporal conditions. The monitors at the Ben Franklin Bridge, Chester, and Reedy Island Jetty have proved instrumental in tracking DO ranges and changes and for assessing the attainment of criteria. USGS has recently installed a DO monitor in Zone 2 (at Delran), but funding for this monitor is temporary. Zone 2 represents a critical linkage between the processes of the non-tidal river, and the historically impacted urban portion of the estuary. As efforts to update criteria and understand the effects of nutrients proceed, dependable long term continuous DO monitoring in Zone 2 is essential.

Currently, important subareas of the Delaware Estuary are not monitored with continuous real time monitors. Near bottom areas, shallows over oyster beds and other important aquatic living resources, and all of Zone 6 are currently not monitored with continuous monitors. Historical spot measurements suggest that DO regimes in these subareas may be substantially different than those measured at the near surface center channel. Therefore, a full assessment of DO requires an expanded network of monitors, including monitors focused on near bottom, oyster beds, and Zones.

3A – 1.6 Summary

Available data suggests that DO is currently above (meeting) criteria, where measured, most of the time. Historical trends in DO document the improvements in water quality in the Delaware Estuary from the 1960's through the present. Retaining the improvements made in DO could be challenged by global climate change, especially through warming water temperatures and sea level rise. Additional improvements to DO condition and refinement of DO criteria may be warranted in the near future. Current monitoring should be augmented to include important subareas, such as near bottom, oyster beds, and Zone 6.

3A – 2 Nutrients

A nutrient is any substance assimilated by living things that promotes growth. The term is generally applied to nitrogen and phosphorus, although it can also be applied to trace nutrients like silica and iron. According to EPA, "High levels of nitrogen and phosphorus in our lakes, rivers, streams, and drinking water sources cause the degradation of these water bodies and harm fish, wildlife, and human health. This problem is widespread—more than half of the water bodies in the United States are negatively affected in some way by nitrogen and phosphorus pollution. (EPA website: http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/problem.cfm)

3A – 2.1 Description of Indicator

The Delaware Estuary has both high loadings and high concentrations of nutrients relative to other estuaries in the United States. The effects from these high nutrients are not well-understood, but monitoring in the estuary shows many signs of poor 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 the poor ecological conditions or the dissolved oxygen sag, high nutrient loading is one of the main candidates for understanding the estuary's poor health.

Although nutrients are high, the most problematic eutrophication symptoms (such as anoxia, fish kills, and harmful algal blooms) are not currently seen in the Delaware Estuary. Yet symptoms of poor health persist in the estuary, with dissolved oxygen levels sagging below both saturation and criteria around Philadelphia, as well as benthic conditions revealing poor diversity in many estuary locations. Through its Water Quality Advisory Committee, DRBC is working closely with stakeholders to identify appropriate nutrient levels for the estuary, and prudent strategies for managing nutrients. Figure 3.14 shows the quantiles of all Total N and Total P observations in the Delaware Estuary.

The general category of "nutrients" is comprised of many different chemical compounds, including several species of nitrogen and phosphorus containing compounds. For this indicator, we considered 5 specific chemical substances as being representative of nutrients. These 5 are:

- Total Phosphorus (or Total P)
- Ortho Phosphorus (Ortho P)
- Total Nitrogen (Total N)
- Nitrate + Nitrite
- Ammonia

3A – 2.2 Present Status

Total Nitrogen concentrations in the estuary currently range from tenths of PPMs to several PPM. The highest concentrations are observed in the urbanized mid area of the estuary, with somewhat lower 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 Fig. 3.14. This pattern suggests loadings originating in the estuary, especially in the urbanized area. As stated previously, although nutrient concentrations in the Delaware Estuary are high, hypoxia and harmful algal blooms are not observed.

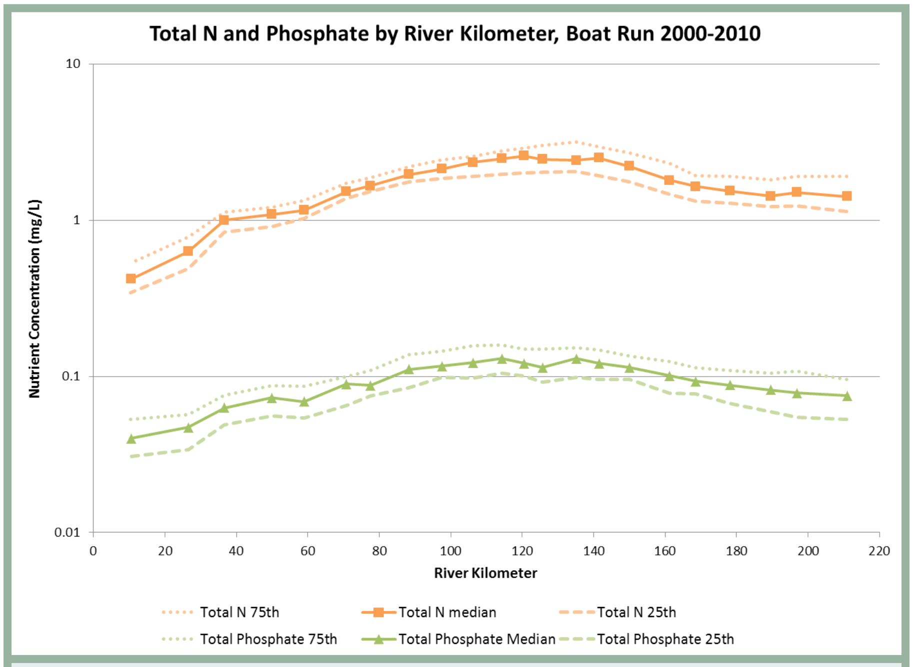

Fig. 3.14. Total Nitrogen and Total Phosphorus Interquartile Range in the Delaware Estuary, Boat Run Monitoring Program 2000-2010

Total phosphorus exhibits a very similar spatial pattern (Fig. 3.14), but with concentrations approximately one order of magnitude lower, such that concentrations range from the hundredths of PPMs to low tenths of PPMs.

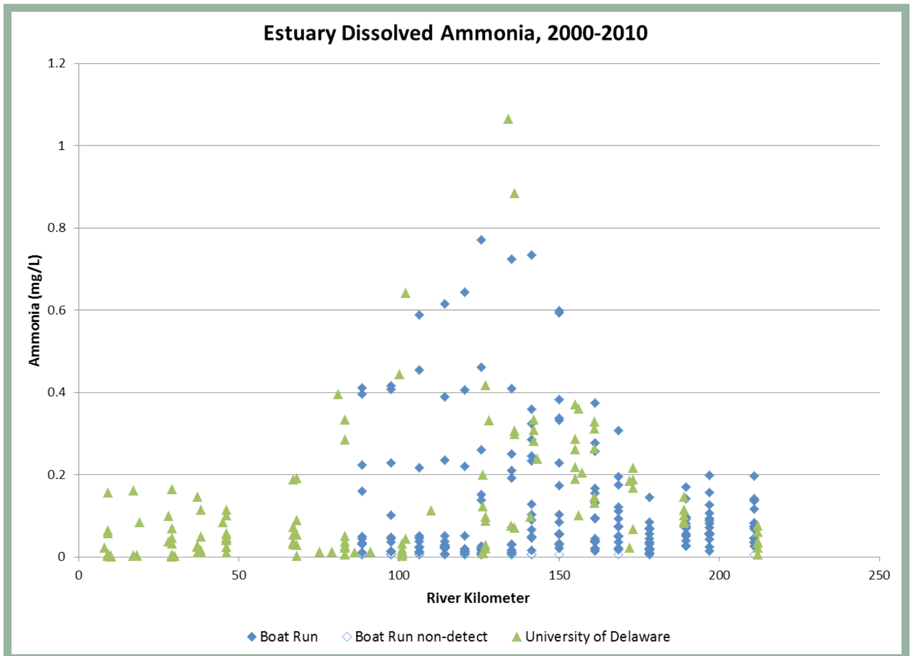

Fig. 3.15. Ammonia Nitrogen in the Delaware Estuary, Boat Run Monitoring Program 2009-2010

Monitoring for ammonia nitrogen has been performed by the University of Delaware and was resumed in the 2009 Boat Run monitoring program, through additional funding from the USGS. Fig. 3.15 shows ammonia results from both programs from 2000 through 2010. These results show highest concentrations near River Kilometer 134, in the vicinity of Chester, PA, tapering down to generally lower concentrations in the upper the lower estuary. A wide diversity of concentrations was observed mid estuary, with concentrations strongly dependent on water temperature. The analytical apparatus used in the Boat Run demonstrated interference caused by salinity. Therefore only freshwater samples from the Boat Run could be quantified.

Nitrate concentrations were lowest but most variable near the mouth of the bay, and relatively higher and less variable mid estuary. Fig. 3.16 shows both total and dissolved nitrate and shows very little difference in concentration between the two, suggesting that most of the nitrate was in the dissolved form.

3A – 2.3 Past Trends

Sharp *et al.* have demonstrated that phosphorus, and to a lesser degree nitrogen concentrations have decreased in the estuary since the late 1960's (Sharp *et al.* 1994) (Fig. 3.17). Phosphorus concentrations in particular have declined substantially since the late 1960's.

3A – 2.4 Future Predictions

US EPA has prioritized nutrient criteria development in the United States for over 10 years, with states, inter-states, and tribes serving as the lead agencies for understanding how nutrients function in their aquatic systems and what nutrient loadings and/or concentrations are needed to sustain healthy biological conditions long-term.

In a 2007 memo, EPA encouraged all states to accelerate the pace of development of numeric nutrient criteria. In August 2009, EPA's Office of Inspector General issued a report entitled "EPA Needs to Accelerate Adoption of Numeric Nutrient Water Quality Standards," which it stated that EPA should prioritize States/ waters significantly impacted by excess nutrients and determine if it should set the standards. In a 2011 memo, EPA reiterated its commitment to accelerating the reduction of nitrogen and phosphorus loads to the nation's waterways, even while the long process of determining numeric nutrient criteria is ongoing.

Until numeric nutrient criteria are developed and implemented, it seems likely that nutrients in the Delaware Estuary will remain at their current levels, lower than historical levels, and elevated relative to other estuaries. When numerical nutrient criteria are developed, some continuing decline in nutrient concentrations, toward a more natural condition, may occur.

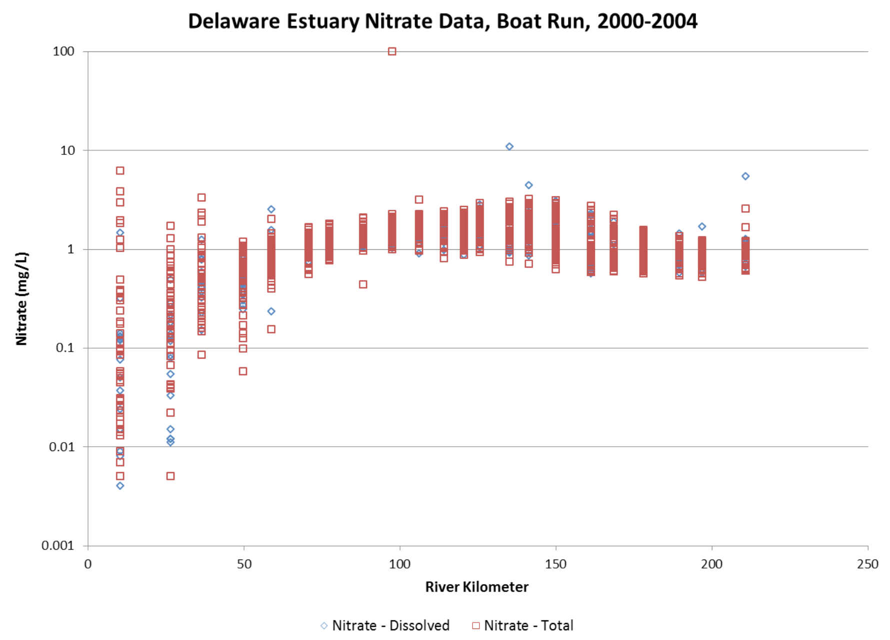

Fig. 3.16. Nitrate Nitrogen in the Delaware Estuary, Boat Run Monitoring Program, 2000-2004

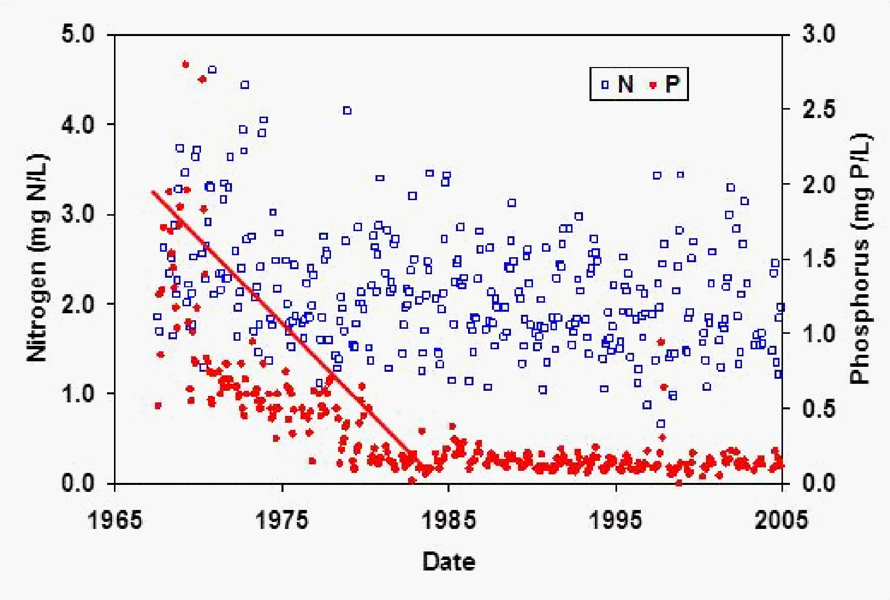

Fig. 3.17. Historic Nitrogen and Phosphorus in the Delaware Estuary

3A – 2.5 Actions and Needs

Stakeholders in the estuary, led by DRBC, need to continue the work of determining the appropriate effects-based nutrient levels for development of nutrient criteria. In addition, DRBC should commit to continuity of nutrient monitoring, to development and maintenance of a long-term record of nutrient concentrations under current conditions.

3A – 2.6 Summary

Delaware Estuary nutrient concentrations are lower than historical levels, but still elevated relative to other estuaries. Determination of appropriate effects-based levels is difficult due to the absence of the most impactful symptoms of elevated nutrients, such as anoxic zones, fish kills, and harmful algal blooms. Stakeholders are working toward the determination of appropriate numeric nutrient criteria for the estuary.

3A – 3 Contaminants

The "Contaminants" indicator is a general category for specific elements and compounds with varying degrees of toxicity to aquatic life and human health.

3A – 3.1 Description of Indicator

To assess the generic category of contaminants, DRBC considered a subset of the EPA priority pollutant metals. These substances have historically been pollutants of concern in the tidal river. EPA has developed recommended criteria for the priority pollutants, which provides a convenient screening level for observed concentrations. The specific contaminants reviewed were:

- Beryllium
- Cadmium
- Chromium(VI)
- Copper
- Lead
- Thallium
- Nickel
- Silver
- Zinc
- Mercury
- Chromium(III)
- Cyanide
- Arsenic
- Antimony
- Selenium

This list is a partial list of the contaminants of concern in the estuary. Some contaminants are better described by their concentration in fish tissue. Section 3A-4 describes fish tissue concentrations in detail, and supplements the water column concentrations considered in this section.

Estuary contaminant concentrations collected from 2000 to 2010 were reviewed using US EPA recommended criteria as screening values and DRBC criteria, as appropriate. Zinc, copper, and nickel provide the most plentiful data sets, as well as some portion of results above the screening values, as shown in Fig. 3.18. Arsenic, cyanide, and mercury also indicate potential exceedances. This evaluation of both the availability of data and the proportion of values exceeding the EPA recommended criteria provides a useful prioritization for looking at estuary concentrations.

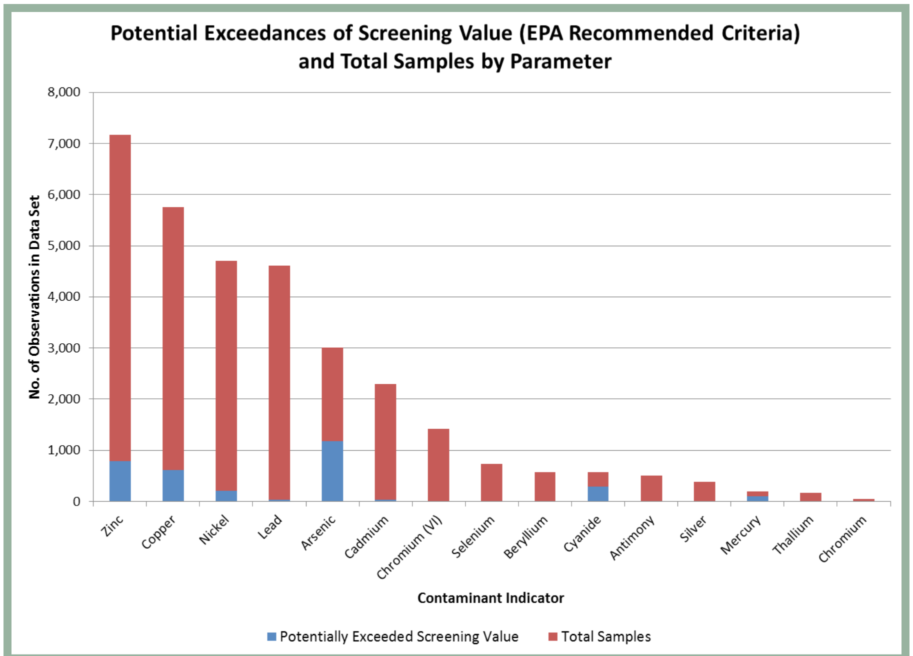

Fig. 3.18. Potential Exceedances of Screening Values for Indicator Contaminants

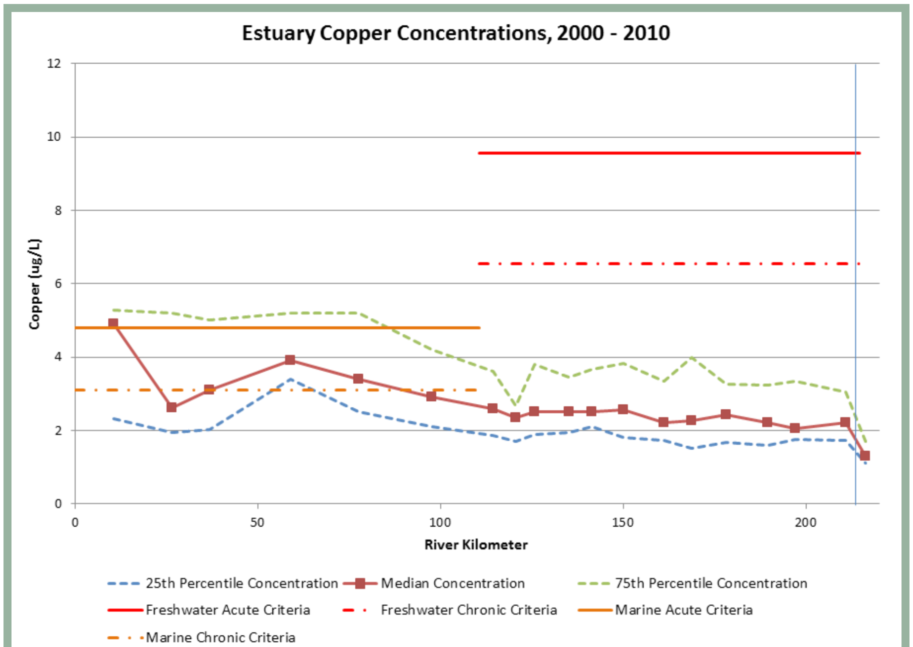

Fig. 3.19. Estuary Copper Concentrations Compared to DRBC Criteria

3A – 3.2 Present Status

DRBC has established criteria for copper. The figure 3.19 shows the Interquartile Range (IQR) of concentrations measured via the DRBC Boat Run monitoring program between 2000 and 2010. Although some values for copper exceed the criteria, more study is required. In the 2010 Delaware River and Bay Integrated List Water Quality Assessment, most copper observations were below criteria, with a few values skirting the criteria. That report indicates:

"Copper concentrations continue to be near water quality criteria with several potential, but inconclusive, exceedances of the marine criteria in the vicinity

of Pea Patch Island (RM 60.6). The potential exceedances are low in both frequency and magnitude. Assessment is complicated by factors such as field sampling and analytical issues with contamination, the applicability of DRBC's freshwater or marine criteria, a need to assess revisions to the current freshwater and marine criteria, and the influence of other water quality attributes that influence the partitioning and toxicity of copper. Therefore, copper levels in Zone 5 should be considered of concern warranting additional monitoring and assessment. Suggested studies include additional synoptic sampling surveys targeted to copper and other metals with finer spatial and temporal scales, and further assessment including the development of water quality models to assess the frequency of criteria exceedances and the factors contributing to those exceedances. Coordination among basin states and agencies should continue to ensure the use of the most appropriate methods and procedures for the conduct of monitoring studies in the Basin, and the harmonization of water quality criteria and assessment methodologies."

DRBC has established criteria for zinc in the estuary. IQR of zinc concentrations measured were measured via the DRBC Boat Run monitoring program between 2000 and 2010. As shown in Fig. 3.20, zinc concentrations are largely below criteria.

Figures 3.21 and 3.22 show similar comparisons for nickel and lead. Again, the majority of observations were below criteria. As the number of available observations decreased, so did the value of the individual element or compound as an indicator. For brevity, the remaining substances will not be shown in detail. An assessment of available data indicates that copper requires attention in the near term due to its concentrations relative to criteria.

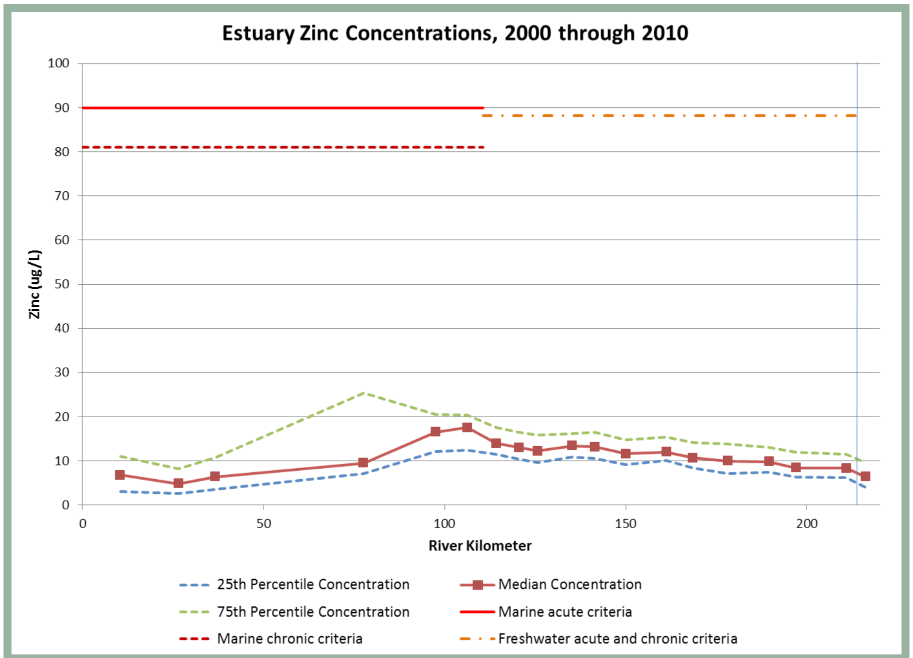

Fig. 3.20. Estuary Zinc Concentrations Compared to DRBC Criteria

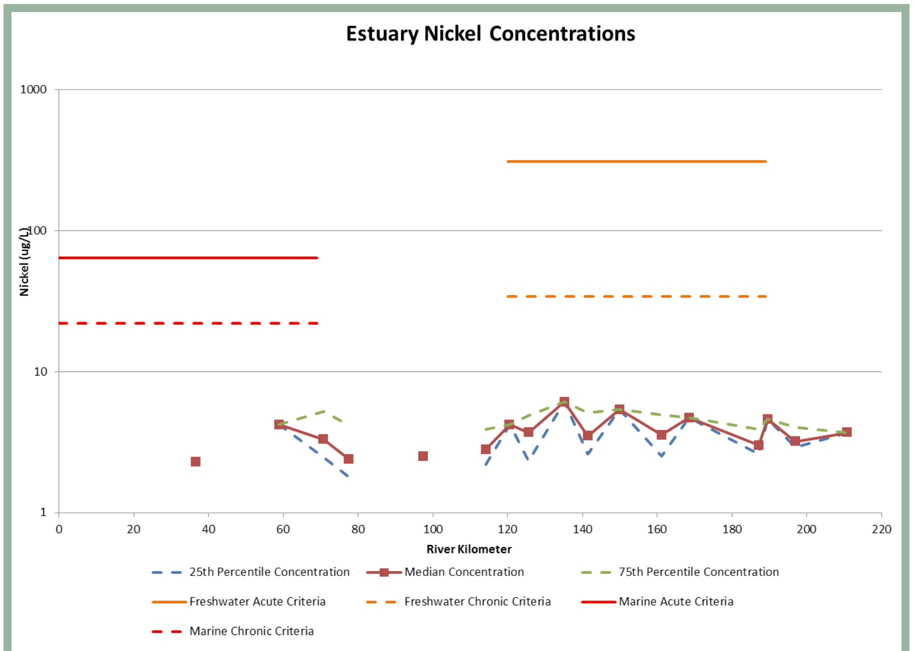

Fig. 3.21. Estuary Nickel Concentrations Compared to DRBC Criteria

3A – 3.3 Past Trends

Data and detection insufficiencies make determination of past trends difficult.

Although water column data are insufficient to assess historic trends, sediment cores may yield some insight into estuary pollution histories. Sediment cores collected in 2001 in marshes bordering the water column in Zone 4 and upper Zone 5 were analyzed for silver, cadmium, chromium, cobalt, copper, tin, and lead. The results indicated for most metals a 2 - 5 fold increase between the early 1950's until the late 1960's or early 1970's, with gradual decreases thereafter. Lead and tin displayed a 10-fold increase after

1950 followed by decreasing levels after the early 1970's (Church *et al.* 2006). It is reasonable to expect that sediment time histories reflect the broader trends that occurred in water column estuary concentrations, with generally increasing concentrations up until peak concentrations in the early 1970's, followed by decreases thereafter.

3A – 3.4 Future Predictions

As monitoring and assessment procedures are refined, and criteria updated to reflect current research, appropriate end points can be defined along with the estuary metal 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. As the local economy continues to transition from heavy industry to mixed commercial and service, it is further reasonable to imagine that isolated sources of priority pollutants will decrease rather than increase. Although some upward pressure is likely to be exerted by population growth, these influences may be more than countered by economic shifts and effective water quality management.

3A – 3.5 Actions and Needs

Continuity in monitoring, continued assessments, and continued updates in criteria are all needed to maintain current contaminant levels and affect decreases where levels are elevated.

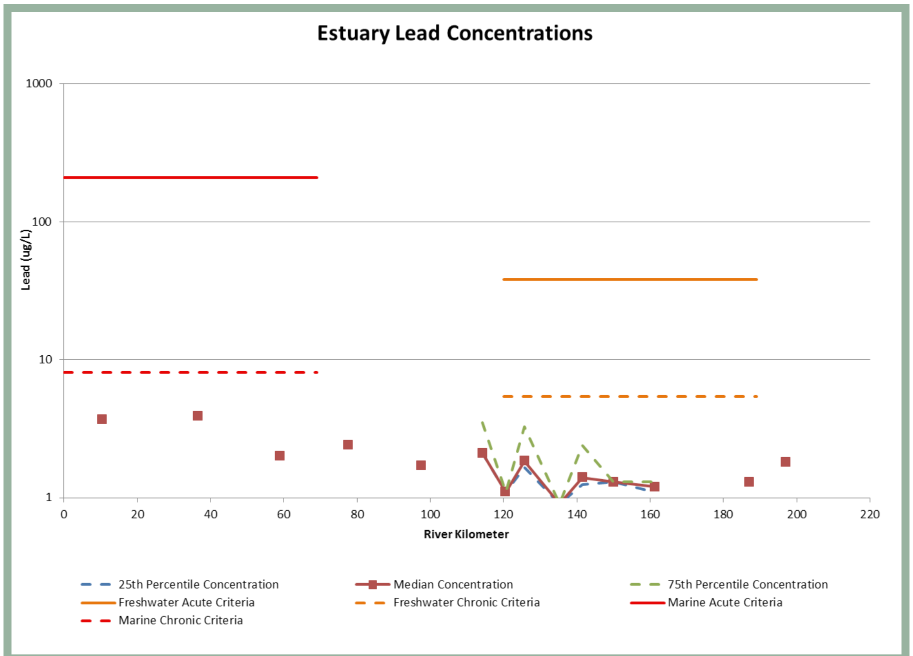

Fig. 3.22. Estuary Lead Concentrations Compared to DRBC Criteria

3A – 3.6 Summary

Contaminants, as represented by the priority pollutant metals, were generally below criteria. Copper may be an exception, but more refined monitoring and assessment is required. Recently, DRBC performed special copper monitoring in the estuary, employing refined field and analytical techniques. At the time this document was prepared, the results of that monitoring were not yet available.

New Jersey has issued more stringent fish consumption advisories for high-risk individuals (pregnant women, infants and children) due to mercury levels in fish tissue. In the Delaware River mainstem, these advisories were generally based upon elevated mercury levels in the non-tidal portion of the river. Mercury levels in fish tissue collected in the estuary were generally lower than fish from most NJ freshwater rivers and lakes (http://www.state.nj.us/dep/dsr/mercury/).

3A – 4 Fish Contaminant Levels

Certain chemicals tend to concentrate (bioaccumulate) in fish to levels thousands of times greater than the levels in the water itself. The resulting concentrations in fish and the attendant health risks to those individuals who consume the fish, such as recreational and subsistence anglers, are of concern to government agencies and the public.

3A – 4.1 Description of Indicator

The DRBC has developed fish tissue screening values (FTSV) for carcinogens and systemic toxicants at a risk level of one in a million (10^{6}) for fish tissue concentrations for specific bioaccumulative toxic pollutants following USEPA's "Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories – Volume 1, 2 and 3 (US EPA 2000b) for establishing fish tissue thresholds. (http://water.epa.gov/scitech/swguidance/fishshellfish/techguidance/guidance.cfm) Screening values are defined as concentrations of target analytes in fish or shellfish tissue that are of potential public health concern and that are used as threshold values against which levels of contamination in similar tissue collected from the ambient environment can be compared. Exceedance of these FTSVs should be taken as an indication that more intensive site-specific monitoring and/or evaluation of human health risk should be conducted. Field data, greater than the screening levels, are worthy of further evaluation. Possible further evaluation would include additional data collection, detailed risk analysis, and potential risk management action. It is important to note that fish tissue screening values are not intended to replace formal risk analysis. Rather, they help the assessor to decide whether a detailed risk analysis is even warranted and how to prioritize several analyses if screening values are exceeded at more than one location.

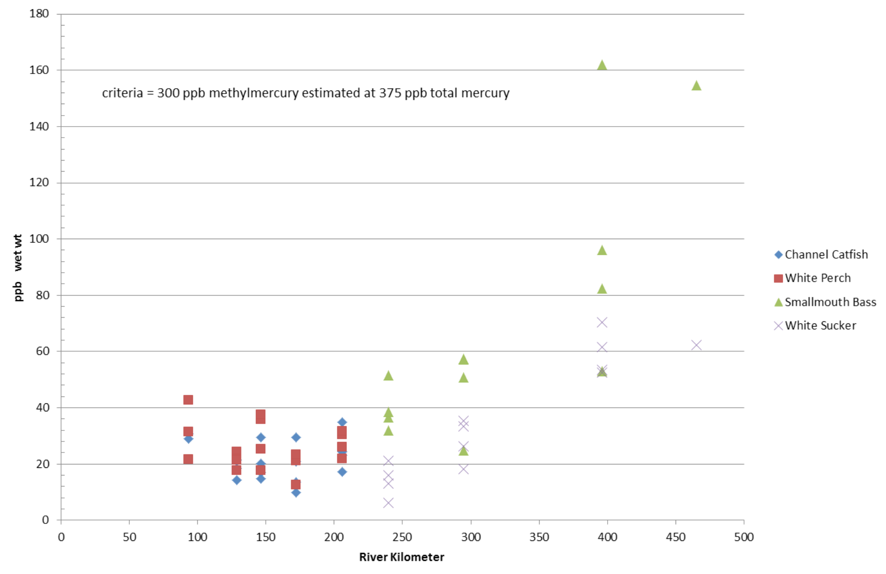

Fig. 3.23. Total Mercury in Fish Fillet 2004 to 2007.

3A – 4.2 Present Status

DRBC FTSVs for carcinogens and systemic toxicants are listed in Tables 3.3 and 3.4, respectively. The bioconcentration factors (BCF), cancer potency factors and DRBC human health criteria (fish ingestion only) used to derive the FTSV are also listed in the tables. Comparable screening values from the EPA, DNREC and NJ DEP are included in the tables. Fish tissue data collected from the Delaware River were compared to the FTSV. Concentrations in fish tissue higher than the FTSV are noted in Tables 3.3 and 3.4. Fish tissue samples from the Delaware River had the carcinogens arsenic, aldrin, chlordane, DDT, dieldrin, and PCBs at concentrations higher than the FTSV for carcinogens. Concentrations of carcinogens heptachlor, heptachlor epoxide, alpha- and beta-BHC, and toxaphene were below the FTSV. A brief summary of the carcinogenic parameters with concentrations higher than the FTSV are described below. None of the systemic toxicants measured (cadmium, mercury, nickel, selenium, zinc, aldrin, gamma-BHC, chlordane, DDT, dieldrin, endosulfan, endosulfan sulphate, endrin, endrin aldehyde, heptachlor, heptachlor epoxide and PBDE) had concentrations higher than the systemic FTSV.

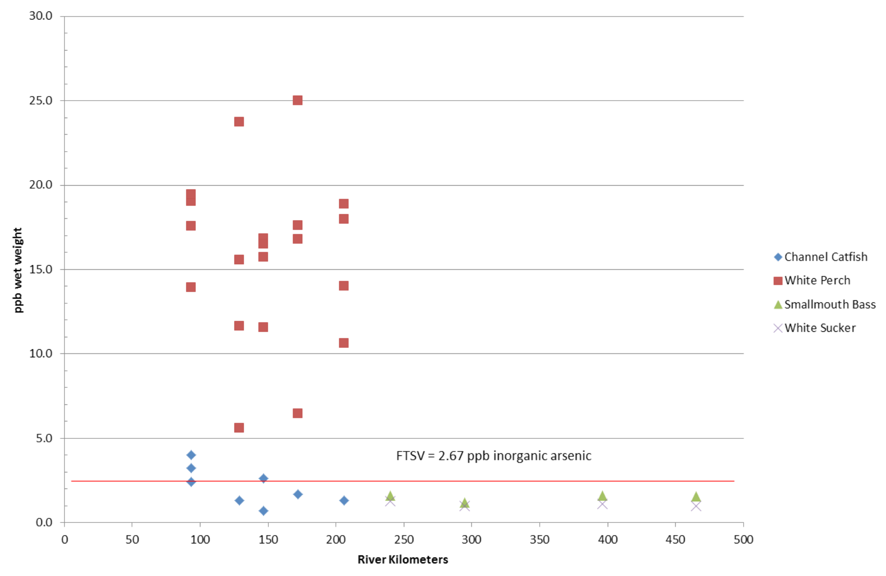

Fig. 3.24. Total Arsenic with Adjustment Factor to Estimate Inorganic Arsenic in Fish Fillet 2004 to 2007.

<u>Mercury</u>

Concentrations of mercury as wet weight in fish fillet from the Delaware River do not exceed a residue based water quality criteria of 300 ppb methylmercury adopted as DRBC criteria assuming methyl mercury is approximately 80% of total mercury measured in the fish tissue (Figure 3.23). This is a residue based criteria not a FTSV. It is worth noting that if calculated based on dry weight, mercury concentrations would exceed the 300 ppb criteria. Fish consumption advisories exist due to mercury contamination in the Delaware River.

Arsenic

Concentrations of arsenic as wet weight in white perch and channel catfish from the tidal Delaware River exceeded a FTSV of 2.67 ppb inorganic arsenic assuming an adjustment factor of 10% to estimate inorganic arsenic from measured total arsenic. Concentrations of arsenic in smallmouth bass and white sucker from the non-tidal Delaware River were below the FTSV (Fig. 3.24).

Aldrin

Concentrations of aldrin as wet weight in white perch and channel catfish from the tidal Delaware River exceeded a FTSV of 0.24 ppb. Concentrations of aldrin in smallmouth bass and white sucker from the non-tidal Delaware River were below the FTSV (Fig. 3.25).

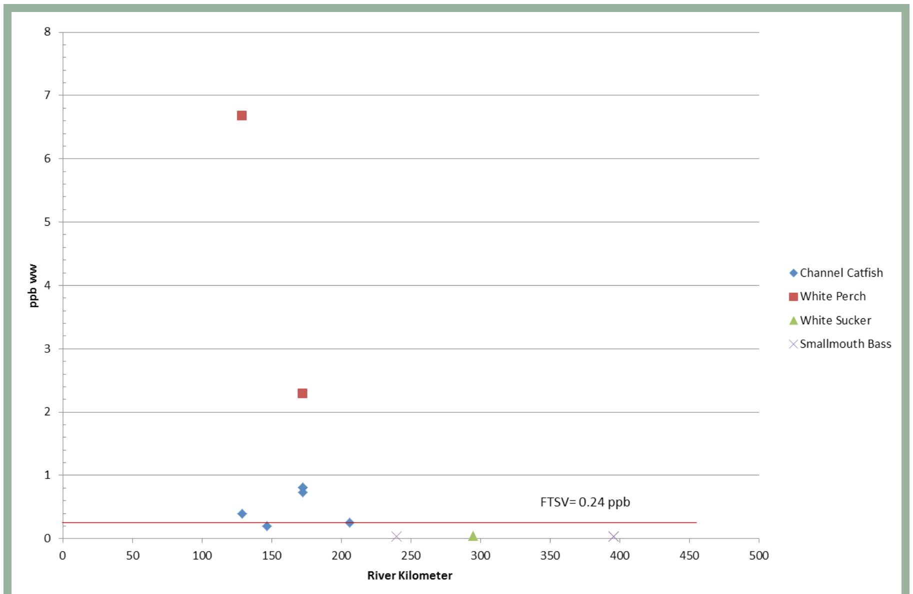

Fig. 3.25. Aldrin in Fish Fillet 2004 to 2007.

Table 3.3. Fish Tissue Screening Values – Carcinogens

DRBC Fish Tissue Screening Values - Carcinogens

Parameter	BCF	Cancer Potency Factor oral slope factor mg/kg/day	DRBC Fish Ingestion Only[a] Regulatory Value ug/L	EPA-SV at risk level 10^{-5} ppb	EPA-SV at risk level 10^{-6} (derived) ppb	DNREC ave adult FTSV risk level 10^{-5} ppb	NJDEP Fish Tissue Based Toxics criteria ppb	**DRBC Fish Tissue Screening Value[b] at risk level 10^{-6} ppb**	Concentrations in fish tissue (wet weight) higher than FTSV?	Notes
Arsenic	44.00	1.50E+00	0.061	26	2.6	36		**2.67**	yes[c]	1
Aldrin	4670.0	1.70E+01	0.000050					**0.24**	yes	2
Chlordane	14100.0	3.50E-01	0.00081	114	11.4	42	11	**11.43**	yes[d]	1
DDT	53600.0	3.40E-01	0.00022	117	11.7	159	86	**11.76**	yes	1
DDE	53600.0	3.40E-01	0.00022					**11.76**		
DDD	53600.0	2.40E-01	0.00031					**16.67**		
Dieldrin	4670.0	1.60E+01	0.000054	2.5	0.25	3		**0.25**	yes	1
Heptachlor	11200.0	4.50E+00	0.000079					**0.89**	no	2
Heptachlor epoxide	11200.0	9.10E+00	0.000039	4.39	0.44	6		**0.44**	no	1
alpha - BHC (HCH)	130.0	6.30E+00	0.004900					**0.63**	no	2
beta - BHC (HCH)	130.0	1.80E+00	0.017000					**2.22**	no	2
PCBs (Total) BCF	31200.0	7.70E+00	0.000045	20	2	27	8	**0.52**	yes	3
Toxaphene	13100.0	1.10E+00	0.00028	36.3	3.63			**3.64**	no	1
Dioxin/furans				0.000000256	2.56E-08		0.00019	**0.000019**	yes	4
2,3,7,8-TCDD	5000	156000	0.000000005					**0.00003**	yes	3
2,3,7,8-TCDD TEQs						0.0004		**0.0004**		4

a) Calculations use consumption rate of 17.5 grams per day and body weight of 70 kg

b) DRBC fish tissue screening value = (RL/CSF)*BW)/CR ; RL-risk level, CSF-oral cancer potency factor(mg/kg-d), BW-body weight (kg), CR-mean daily consumption rate (kg/g)

c) one tenth of measured total arsenic is estimated to be organic arsenic on which the FTSV is based.

d) sum of all chlordane

Comments:

1) DRBC FTSV, EPA SV and DRBC WQ criteria are consistent.

2) EPA SV is not available and the derived DRBC FTSV is used.

3) EPA or basin state derived SV is used.

4) DRBC FTSV is TEQ based. EPA and basin state SV differ.

Concentrations are based on wet weight.

Risk levels at 1 in 1,000,000 (10^{-6}) and 1 in 100,000 (10^{-5}).

BCF = bioconcentration factor; SV = screening value.

Table 3.4. Fish Tissue Screening Values – Systemic Toxicants

DRBC Fish Tissue Screening Values - Systemic Toxicants

Parameter	BCF	Reference Dose mg/kg/day	RSC	DRBC Regulatory Value Fish Ingestion only[a] ug/L	EPA-SV Recreational fishers ppm	EPA-SV ppb	DNREC FTSV average adult ppb	NJDEP fish tissue based toxics criteria ppb	**DRBC fish tissue screening value (FTSV)[b] ppb**	Concentrations in fish tissue (wet weight) higher than FTSV?	Notes
Cadmium	64.0	1.00E-03	0.25	16	4.0	4,000	2,161		**4,000**	no	1
Mercury (methylmercury)		-		0.3 mg/kg (ppm) fish tissue	0.4	400	300	180	**300**	no[c]	1
Nickel	47.0	2.00E-02		1700					**80,000**	no	2
Selenium	4.8	5.00E-03		4200	20.0	20,000	10,803		**20,000**	no	1
Zinc	47.0	3.00E-01		26000					**1,200,000**	no	2
Aldrin	4,670	3.00E-05		0.026					**120**	no	2
gamma - BHC (Lindane)HCH	130	3.00E-04	0.2	1.8	1.2	1,200			**1,200**	no	1
Chlordane	14,100	5.00E-04		0.14	2.0	2,000			**2,000**	no[d]	1
DDT	53,600	5.00E-04		0.037	2.0	2,000	1,080	86,000	**2,000**	no	1
Dieldrin	4,670	5.00E-05		0.043	0.2	200	108		**200**	no	1
Endosulfan (alpha)	270	6.00E-03		89	24.0	24,000	12,963		**24,000**	no	1
Endosulfan (beta)	270	6.00E-03		89	24.0	24,000	12,963		**24,000**	no	1
Endosulfan sulphate	270	6.00E-03		89					**24,000**	no	2
Endrin	3,970	3.00E-04		0.060	1.2	1,200	648		**1,200**	no	1
Endrin aldehyde	3,970	3.00E-04		0.060					**1,200**	no	2
Heptachlor	11,200	5.00E-04		0.18					**2,000**	no	2
Heptachlor epoxide	11,200	1.30E-05		0.0046	0.052	52	28		**52**	no	1
PBDE-47	26,050	1.00E-04		0.0150					**400**	no	
PBDE-99		1.00E-04							**400**	no	
PBDE-153		2.00E-04							**800**	no	
PBDE-209		7.00E-03							**28,000**	no	

a) Calculations use consumption rate of 17.5 grams per day and body weight of 70 kg
b) DRBC fish tissue screening value = (RFD*BW)/CR ; RFD-oral reference dose (mg/kg-d), BW-body weight (kg), CR-mean daily consumption rate (kg/g)
c) Total mercury measured while the tissue based criteria is for methyl mercury. Exceeds FTSV as dry weight.
d) sum of all chlordane
BCF - bioconcentration factor; SV - screening value; RSC = relative source contribution.
Comments:
1) DRBC FTSV, EPA SV and DRBC WQ criteria are consistent.
2) EPA SV is not available and the derived DRBC FTSV is used.

Chlordane

Concentrations of chlordane (sum of all chlordanes) as wet weight in channel catfish from the tidal Delaware River exceed a FTSV of 11.43 ppb. Concentrations of chlordane in white perch from the tidal river as well as smallmouth bass and white sucker from the non-tidal river were below the FTSV (Fig. 3.26).

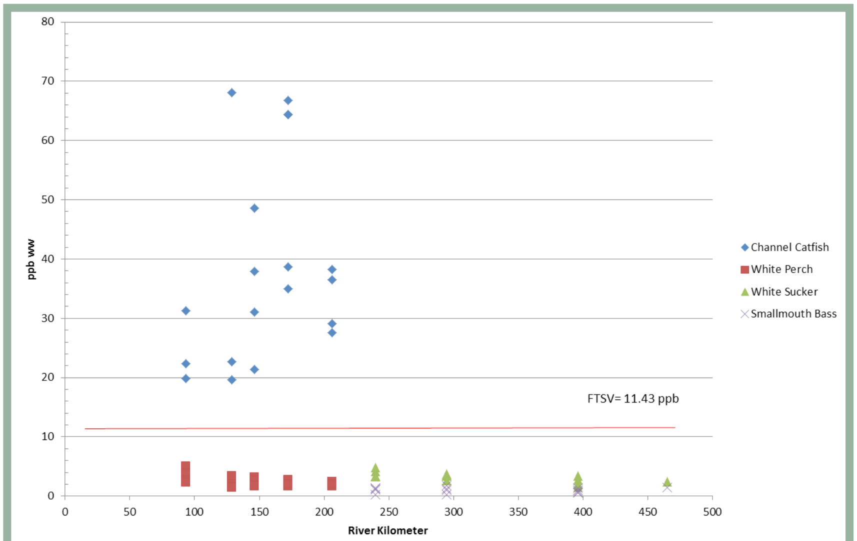

Fig. 3.26. Sum of Chlordanes in Fish Fillet 2004 to 2007.

DDT
Concentrations of DDT and metabolites as wet weight in channel catfish, white perch, white sucker, and smallmouth bass from the tidal and non-tidal Delaware River exceed a FTSV of 11.76 ppb. Concentrations are highest in the tidal species (Fig. 3.27).

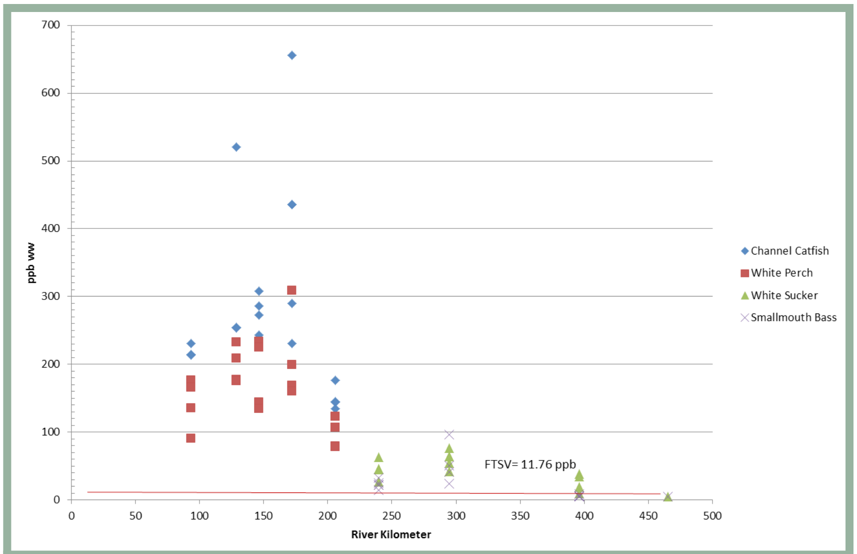

Fig. 3.27. DDT and metabolies in Fish Fillet 2004 to 2007.

Dieldrin
Concentrations of dieldrin as wet weight in channel catfish, white perch, white sucker, and smallmouth bass from the tidal and non-tidal Delaware River exceed a FTSV of 0.25 ppb. Concentrations are higher in the tidal species (Fig. 3.28).

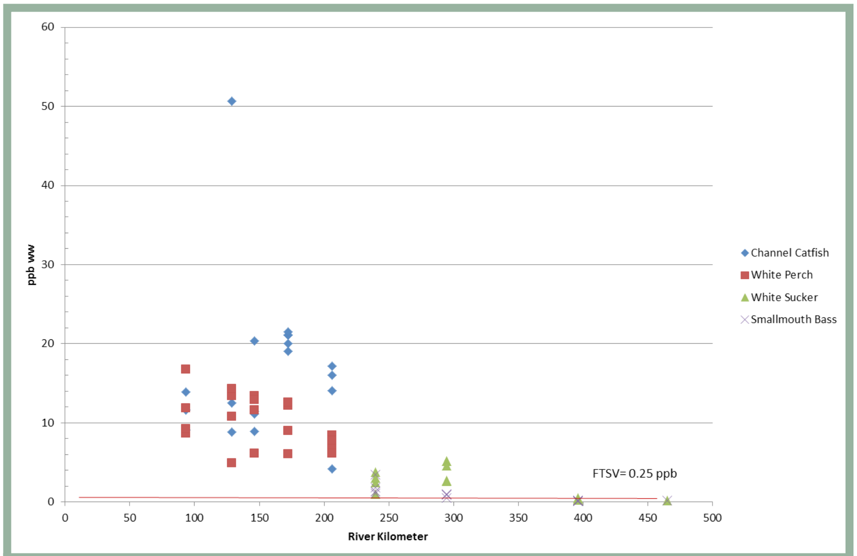

Fig. 3.28. Dieldrin in Fish Fillet 2004 to 2007.

PCB
Concentrations of PCB as wet weight in channel catfish, white perch, white sucker, and smallmouth bass from the tidal and non-tidal Delaware River exceed a cancer FTSV of 1,500 pg/g (1.5 ppb). Median PCB concentrations are 10-100x screening values. (Fig. 3.29).

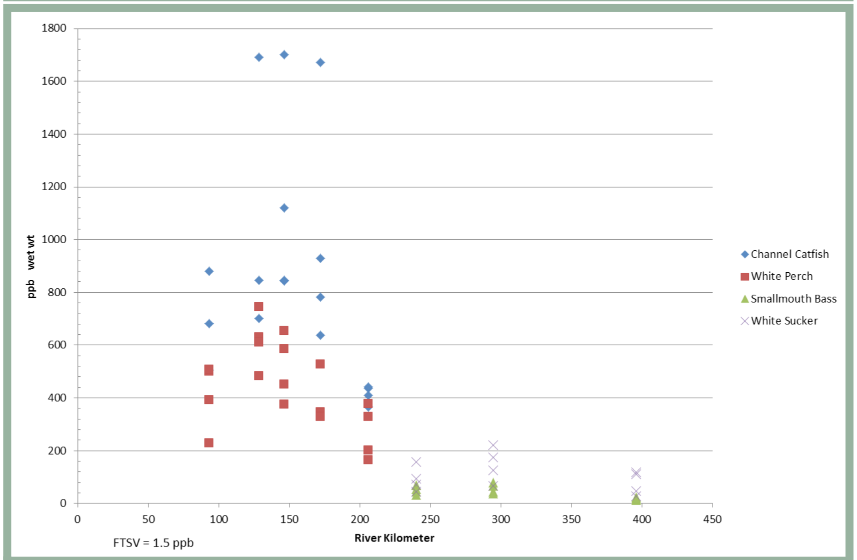

Fig. 3.29. Total PCB in Fish Fillet 2004 to 2007.

DxFs
Concentrations of dioxin and furans as wet weight in channel catfish, white perch, white sucker and smallmouth bass from tidal and non-tidal areas had concentrations higher than the systemic FTSV exceed a cancer screening value of 0.019 pg/g (0.000019 ppb) (Fig. 3.30). EPA recommends basing the fish consumption screening value for DxFs on Toxic Equivalents (TEQs) related to 2,3,7,8-TCDD toxicity. To calculate the TEQ of a dioxin mixture, the concentration of each toxic compound is multiplied with its Toxic Equivalency Factor (TEF) and then added together. Median DxF TEQs are approximately 100x screening values.

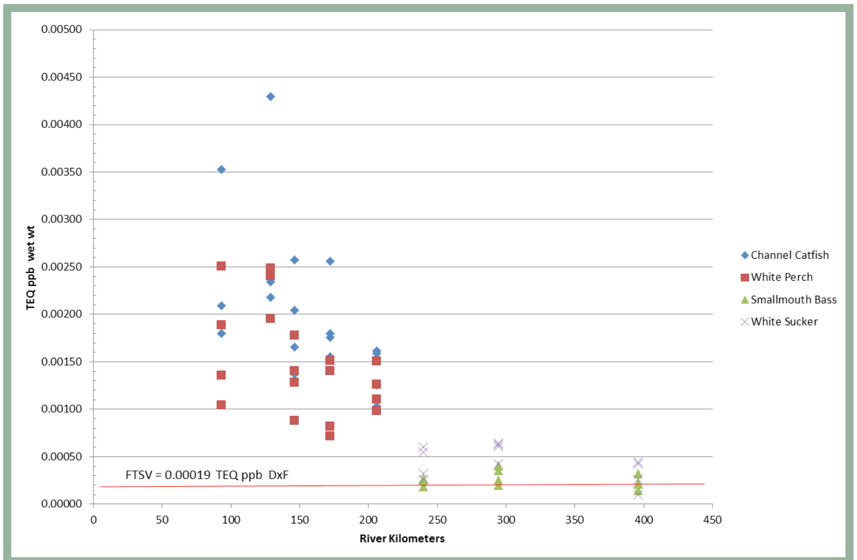

Fig. 3.30. Total Dioxin/Furans TEQs in Fish Fillet 2004 to 2007.

PBDE
Polybrominated diphenyl ethers (PBDE) are flame retardants found in polymers and plastics. Environmental monitoring programs conducted worldwide during the past decade have shown increasing levels of some PBDE congeners in contrast to a general decline in the occurrence of dioxins, PCBs, and chlorinated pesticides. PBDEs, an emerging and unregulated compound, have been observed in whole or fillet fish tissue at concentration from non-detect to 1,300 ppb total PBDE in U.S. waterways (Wenning et al, 2011). PBDE congeners with oral reference dose listed in EPA-IRIS (BDE-47, BDE-99, BDE-153 and BDE-209) were not measured in fish tissue from the Delaware River at concentrations higher than the DRBC calculated systemic FTSV however, a FTSV for carcinogenic effects is not available for comparison because there is insufficient data currently available to determine if these PBDE congeners are carcinogenic. Monitoring of PBDE in water is discussed in Sections 3A-8.1 and 8.2 of this chapter.

3A – 4.3 Past Trends

The contaminant for which the most lengthy and complete historical fish tissue concentration record is available is PCBs. As indicated in Fig. 3.31, some slight decline in fish tissue concentrations may be evident in white perch and channel catfish. While it may be impossible to infer the concentration trajectories of other fish tissue contaminants from the PCB data, it is important to note that PCBs have been the subject of extensive regulatory action, both in terms of domestic production and use, and in the estuary through the PCB Total Maximum Daily Loads (TMDLs).

3A – 4.4 Future Predictions

Given the hydrophobic and lasting nature of the fish tissue contaminants considered here, it is reasonable to presume that concentrations will remain relatively constant. Even the effects of regulatory water quality management efforts will likely take decades to be reflected in tissue concentrations. However, pollution minimization efforts are necessary to bring about the needed reductions in tissue concentrations.

3A – 4.5 Actions and Needs

The fish tissue screening evaluation raises the possibility that some water column chlorinated pesticides are likely exceeding adopted criteria. This conclusion differs from a similar, but less sophisticated, assessment presented to the DRBC Toxics Advisory Committee in 2004. Therefore, direct measurement of water column chlorinated pesticides, with comparison to DRBC water quality criteria, is necessary. Since water quality criteria are the drivers to water quality management, only this direct comparison can initiate the apparatus of reducing the inputs of these contaminants to the estuary.

Similarly, the dioxin/furan assessment suggests that water column concentrations may exceed water quality criteria. Direct measurement and assessment is required.

Future assessments should evaluate the benefits of a tissue residue approach for toxicity assessment and determination of tissue, water, and sediment quality guidelines for aquatic organisms.

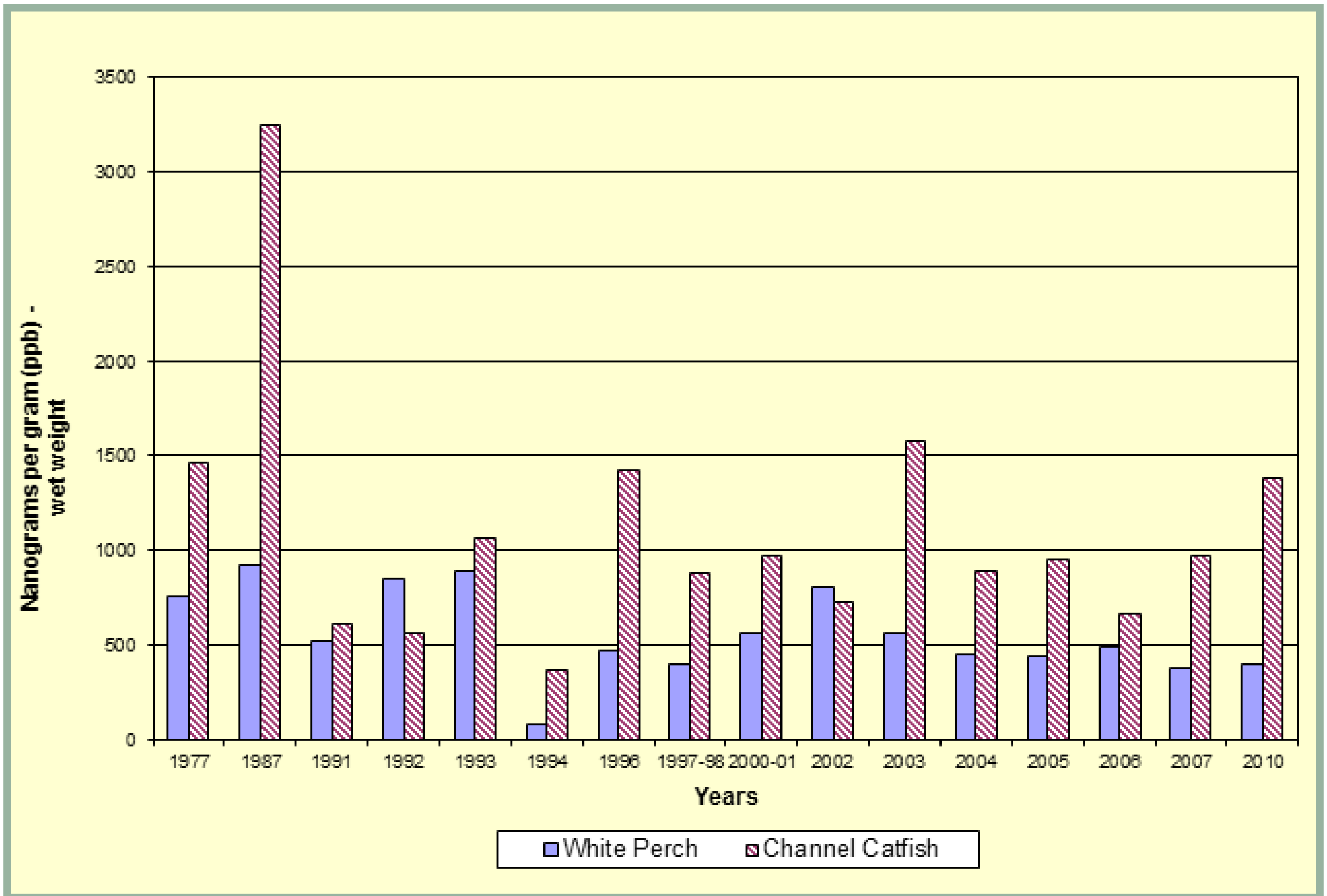

Fig. 3.31. Historical PCB Trends in Fish.

3A – 4.6 Summary

Chlorinated pesticides, PCBs, and dioxin/furans exceed risk-based screening values in fish tissue in the Delaware Estuary. Trajectories for recovery are likely to be long, but effective management is needed to initiate these trajectories. Direct water column measurement is necessary, since water quality criteria are the ultimate drivers for reducing these contaminants in fish tissue and associated environmental matrices. Alternative assessment approaches should be evaluated.

3A – 5 Salinity

The Delaware Estuary is believed to contain one of the largest freshwater tidal prisms in the world and provides drinking water for over one million people. However, salinity could greatly impact the Delaware's suitability as a source for drinking water, if salt water from the ocean encroaches on the drinking water intakes.

3A – 5.1 Description of Indicator

Salinity is usually estimated via direct measurement of other parameters, such as chloride or specific conductivity, with salinity operationally defined in terms of conductivity in standard references such as Standard Methods for the Examination of Water & Wastewater (APHA, AWWA, WEF 2005).

One important metric for understanding the importance of salinity concentrations in the Delaware Estuary is the location of the 250 mg/L chloride concentration based on drinking water quality standards originally established by the U.S. Public Health Service, also known as the "salt line."

The salt line's location fluctuates along the tidal Delaware River as streamflows increase or decrease in response to changing inflows, diluting, or concentrating chlorides in the river. The seven-day average location of the salt front is used by the DRBC as an indicator of salinity intrusion in the Delaware Estuary. The commission's drought plan focuses on controlling the upstream migration of salty water from the Delaware Bay during low-flow conditions in basin rivers and streams. As salt-laced water moves upriver, it increases corrosion control costs for surface water users, particularly industry, and can raise the treatment costs for public water suppliers.

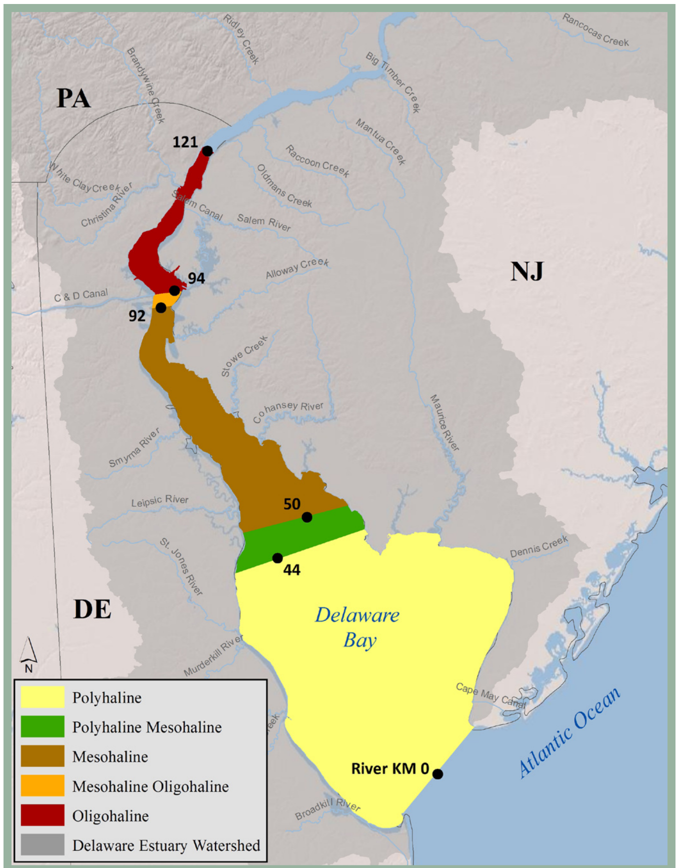

Fig. 3.32. Spatial Salinity Regimes of the Delaware Estuary. (Oligohaline - 90% of observations in the range from 0.5 to 5 ppt; Mesohaline - 90% of observations in the range from 5 to 18 ppt; Polyhaline - 90% of observations greater than 18 ppt)

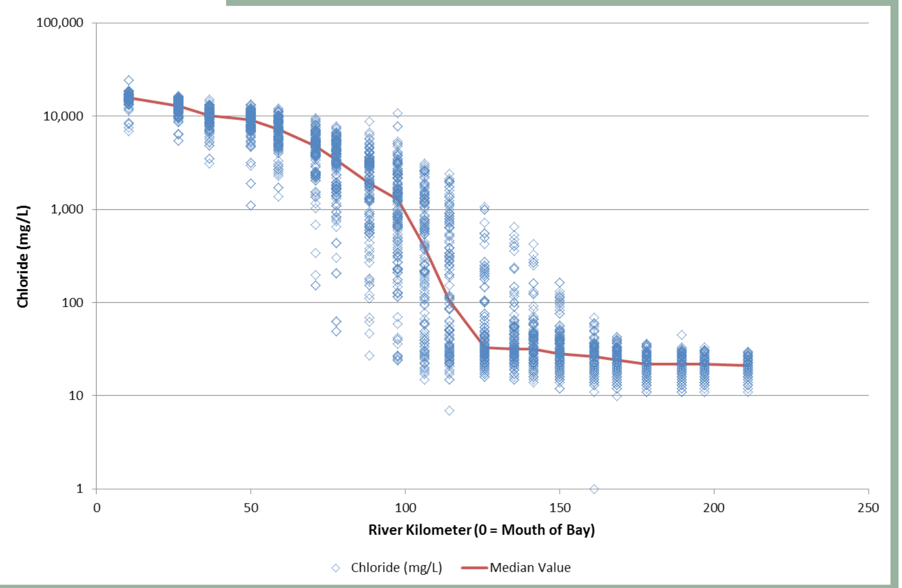

Fig. 3.33. Chloride Concentration Ranges by River Kilometer.

Water releases from five reservoirs are used to help repel, or flush back, the salt-laced water. Three reservoirs -- Pepacton, Neversink and Cannonsville -- are owned by New York City and are located in the Delaware River's headwaters in the Catskill Mountains in New York State. When full, these three reservoirs hold 271 billion gallons (1026 billion liters) of water. Two additional reservoirs -- Blue Marsh and Beltzville -- are located in Pennsylvania along the Schuylkill River in Berks County and the Lehigh River in Carbon County, respectively. These two lower basin reservoirs hold nearly 20 billion gallons (76 billion liters) of water when full.

3A – 5.2 Present Status

By combining data from both the Boat Run monitoring and the University of Delaware water quality cruises, DRBC is able to map the approximate extents of salinity regimes in Delaware Bay. Fig. 3.32 shows the approximate polyhaline (> 18 ppt salinity), mesohaline (5 to 18 ppt), and oligohaline (0.5 to 5 ppt) areas, as well as transitional zones. Upstream of the oligohaline is freshwater, below 0.5 ppt salinity.

Fig. 3.33 shows the chloride concentrations from the Boat Run monitoring program along with the median concentration at each station. A sharp transition near river kilometer 125 (Marcus Hook) is evident in the median value.

3A – 5.3 Past Trends

The best means of assessing historical salinity trends in the estuary is by looking at the long-term continuous specific conductivity results collected by the USGS at the Ben Franklin Bridge, Chester, and Reedy Island. At each of those locations, data back to 1964 are available.

EPA Region 3 developed a long term trend assessment methodology involving binning 10 years of data with subsequent comparison to two-year data windows. DRBC employed this method using box and whisker plots at each of the 3 stations to determine whether trends in salinity (as represented by conductivity) were evident.

Figures 3.34, 3.35, and 3.36 suggest that the drought of record in the 1960's strongly influences the oldest data bin. Since subsequent data bins are standard box and whisker diagrams based on two-year data windows, the drought of record has no impact on the subsequent windows, other than as a point of comparison. None of these assessments make clear a specific unidirectional trend in salinity, but periodic peaks and troughs suggest either longer time period cycles or inter-annual variability.

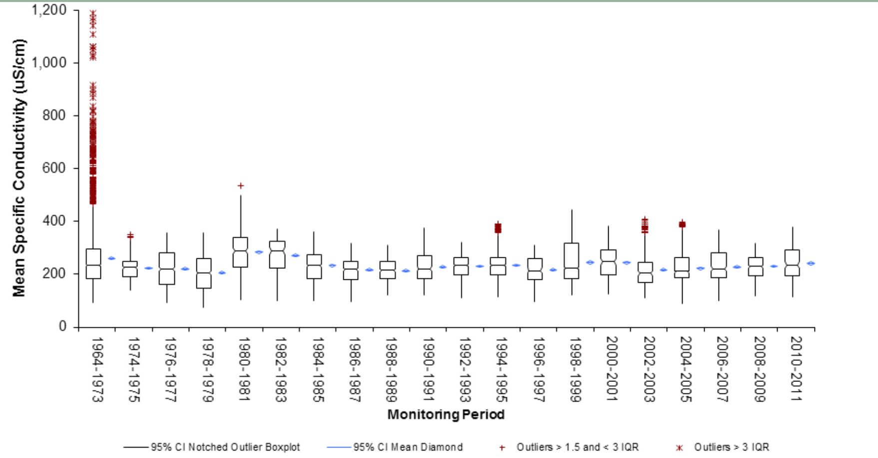

Fig. 3.34. Long –Term Specific Conductivity Box and Whisker Plots at Ben Franklin Bridge

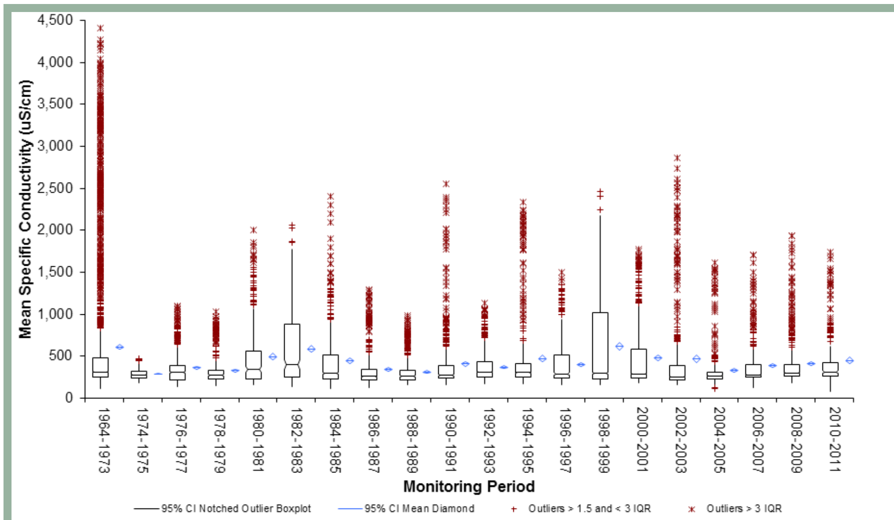

Fig. 3.35. Long –Term Specific Conductivity Box and Whisker Plots at Chester

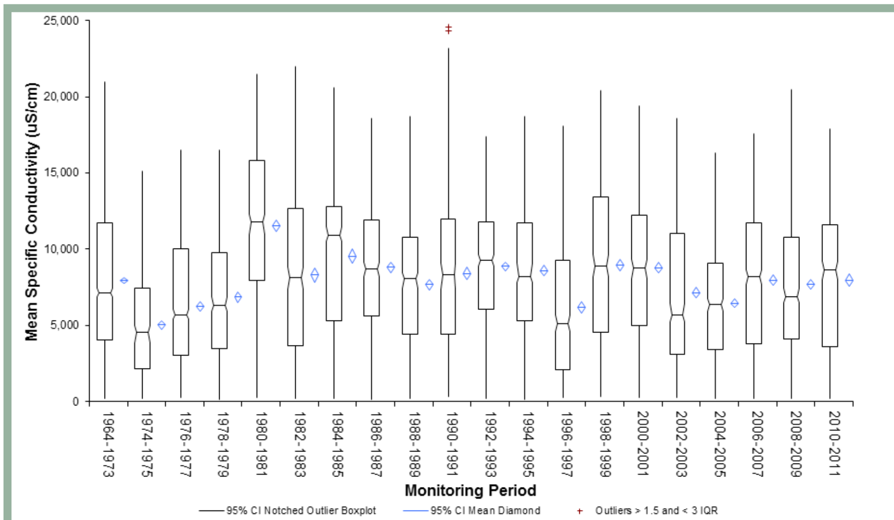

Fig. 3.36. Long –Term Specific Conductivity Box and Whisker Plots at Reedy Island Jetty

3A – 5.4 Future Predictions

Sea level rise associated with global climate change is expected to change the salinity regime of the Delaware Estuary. A model report prepared by the US Army Engineer Research and Development Center (Kim and Johnson, 2007) shows predicted mean increases in salinity between 1996 and 2040 of 14% at Delaware Memorial Bridge, 16% at Chester, PA, and 10% at the Ben Franklin Bridge from sea level rise alone. When combined with other likely drivers, such as channel deepening and changes in consumptive water use over that same period, the forecasted increases in salinity are approximately 22%, 29%, and 18% at the Delaware Memorial Bridge, Chester, and the Ben Franklin Bridge respectively.

That changes in salinity since the 1960's are not evident in the data, in the midst of well document increases in sea level, suggests that more refined assessment and predictive measures are needed to ascertain the expected relationship between sea level and salinity. In addition, management actions involving the release of freshwater from basin reservoirs have likely obscured trends.

3A – 5.5 Actions and Needs

Predictive modeling to establish the linkage between sea level and resultant salinity is needed to assess the expected future salinity spatial regimes. Some level of modeling has been completed and used for this purpose, but longer term forecasts under a wider range of conditions are needed to identify critical conditions and begin to evaluate solutions.

3A – 5.6 Summary

Estuary salinity patterns impact the availability of drinking water and the spatial domains of aquatic living resources. Definitive trends is historic data are not evident from relatively simple assessment tools. Given the importance of salt line, more refined predictive tools are needed.

3A – 6 pH

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 (e.g., metals, ammonia). Among natural waters, both highly alkaline waters and highly acidic waters (like the NJ Pinelands) are known to severely restrict the species of plants and animals that can thrive in particular lakes and streams. Likewise, human alteration of the pH regimen for a water body can alter both the quality of that water and the aquatic life inhabiting that system.

3A – 6.1 Description of Indicator

Although ambient and effluent criteria in the range of 6.5 to 8.5 have been advocated for over 50 years, there has likewise been a long recognition that diel pH fluctuations can occur as a result of primary production and the bicarbonate buffering system of water (Tarzwell 1957, USEPA 1973). As a result, periods of naturally high photosynthesis can produce pH conditions greater than 8.5 during mid to late-afternoon which then subside at night with the reduction in photosynthetic activity. Likewise, naturally acidic and naturally alkaline waterbodies have long been included in considerations of pH requirements and criteria (Ellis 1937, Tarzwell 1957).

Currently, DRBC's criteria for the estuary requires pH to be between 6.5 and 8.5.

3A – 6.2 Present Status

Figures 3.37, 3.38, and 3.39 show the daily minimum and daily maximum pH values measured at each of the estuary USGS continuous monitoring stations, compared to the minimum and maximum pH criteria in DRBC's water quality standards.

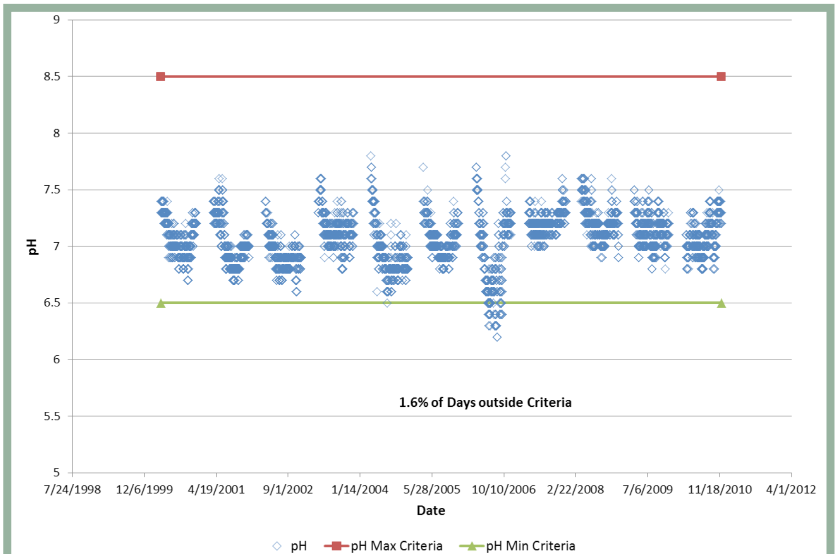

Fig. 3.37. Comparison of Measured pH to DRBC Criteria at Ben Franklin Bridge.

3A – 6.3 Past Trends

To assess temporal changes in pH, we developed box and whisker plots of pH in two-year bins, and compared these results to the initial 10-year bin for the period of record. This approach follows the methodology developed by USEPA Region 3 for looking at long term data. Results for the Delaware River at the Ben Franklin Bridge (Fig. 3.40), Chester (Fig. 3.41), and Reedy Island Jetty (Fig. 3.42), all suggest an increase in pH over the period of record.

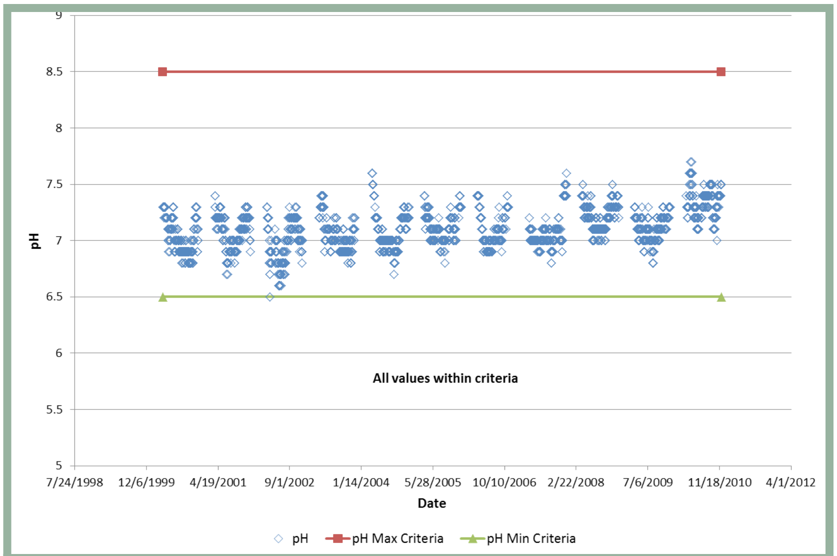

Fig. 3.38. Comparison of Measured pH to DRBC Criteria at Chester.

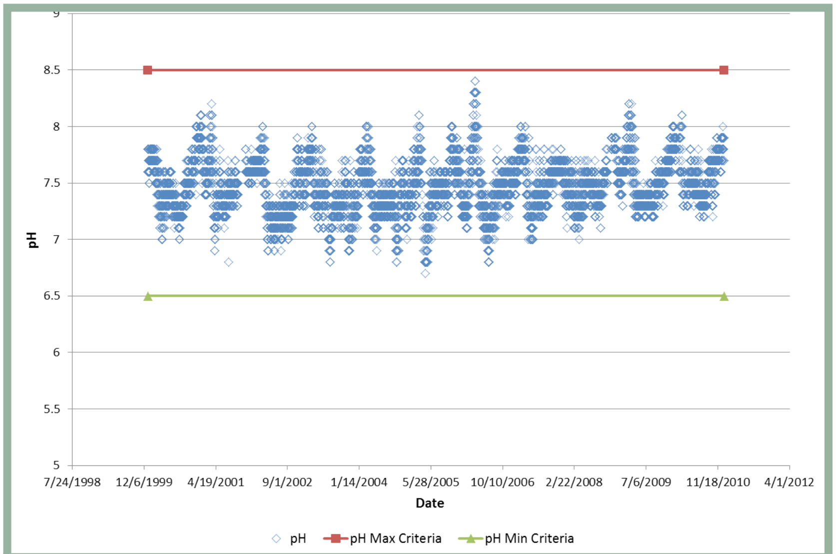

Fig. 3.39. Comparison of Measured pH to DRBC Criteria at Reedy Island Jetty.

This largely unreported 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. Because human and industrial wastes received little or no treatment through the 1960s and 1970s, the carbonaceous and nitrogenous compounds in these wastes were used as food sources for microbes in the estuary, which in turn used up the available dissolved oxygen and created an oxygen block around Philadelphia. In addition to using the oxygen, the waste products from this microbial restoration included carbon dioxide and additional hydrogen ions (acids) which historically caused depression of pH that closely mirrored the sag in dissolved oxygen (Culberson 1988). The improved treatment of both municipal and industrial wasted over the past 40 years has therefore been linked to both improvements in dissolved oxygen and pH for the Delaware Estuary, with stronger trends at both the Ben Franklin Bridge and Chester (the historic zone of anoxia) than further down-estuary at Reedy Island (see Figs. 3.40, 3.41, 3.42). 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.

3A – 6.4 Future Predictions

NOAA and others have documented the occurrence of ocean acidification. In the absence of other reactions, DRBC might expect the pH to decrease at the ocean boundary, with a corresponding decrease in pH propagated from the ocean into the estuary. The more complex dynamic of the estuary, however, suggests that pH levels may be increasing. 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.

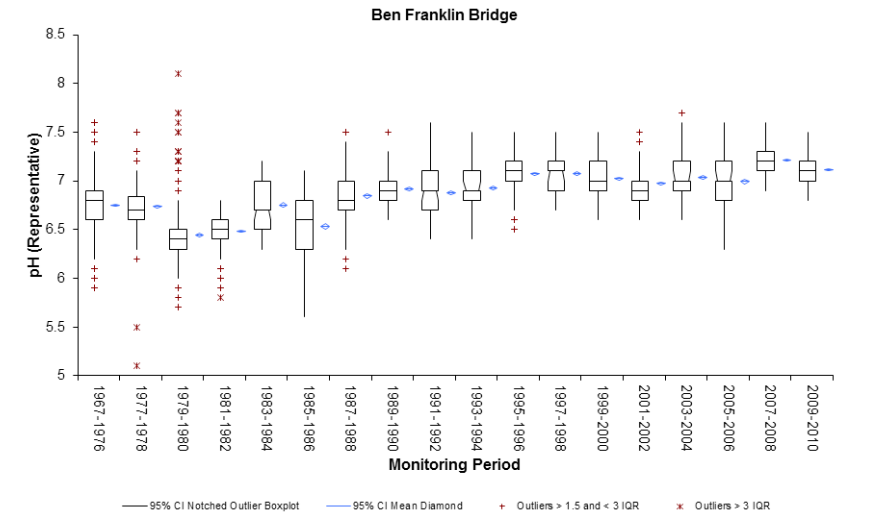

Fig. 3.40. pH Time Series Box and Whisker Plot, Ben Franklin Bridge.

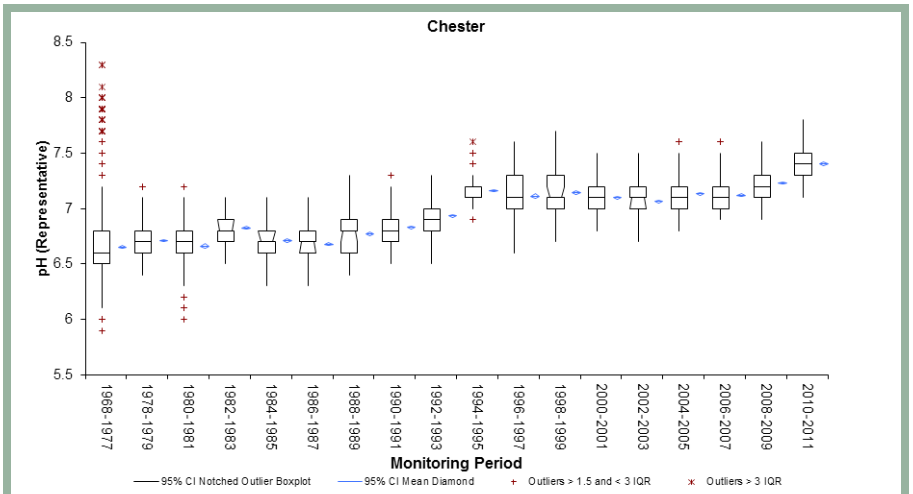

Fig. 3.41. pH Time Series Box and Whisker Plot, Chester.

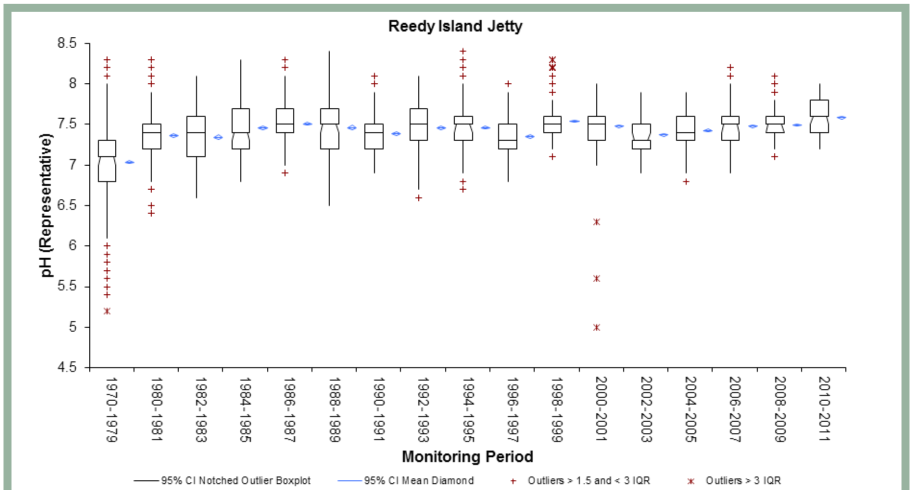

Fig. 3.42. pH Time Series Box and Whisker Plot, Reedy Island Jetty.

3A – 6.5 Actions and Needs

A better understanding of the estuary carbon cycle and its impact on pH is needed. Models that can integrate the countervailing processes of ocean acidification and decreased microbial respiration could help elucidate the short-term and long-term likelihoods of continued changes in pH and carbon availability.

3A – 6.6 Summary

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.

3A – 7 Temperature

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.

3A – 7.1 Description of Indicator

Estuary temperature criteria are expressed in DRBC regulations by day of year. Maximum daily water temperatures recorded at USGS continuous monitors from 2000 to 2010 were compared to applicable criteria. The figures in section 3A - 7.1 show the comparisons between maximum temperature and Zone specific criteria.

3A – 7.2 Present Status

To assess the present status of water temperature in the estuary, DRBC compared temperature observations from the USGS continuous monitors at Delran, Ben Franklin Bridge, and Chester to DRBC's temperature criteria. DRBC's criteria specify upper temperature limits for specific days of the year, and indicate linear interpolation between these criteria points to create a full continuous daily criteria curve. In Zone 2, at Delran Monitor (online only since 2004), 3.1% of the observations were above criteria (Fig. 3.43). At Ben Franklin Bridge (Fig. 3.44), 5.5% of the observations were above (not meeting) criteria, and at Chester (Fig. 3.45), 9.9% of observations were above criteria. Although there is a continuous temperature meter at Reedy Island Jetty, DRBC has not promulgated the same type of criteria at that location.

Determination of the importance of these criteria exceedances is confounded by the strong role played by atmospheric conditions. Work performed for the 2008 Integrated Assessment (http://www.state.nj.us/drbc/08IntegratedList/EntireReport.pdf) suggested that estuary water temperatures were strongly influenced by air temperatures and cloud cover. Brief periods of water temperatures elevated above criteria can have stressful impacts upon aquatic life species, delaying or interrupting spawning, feeding, and development of young. Extremely high temperatures or extended periods above criteria can result in death or detrimental avoidance behavior.

3A – 7.3 Past Trends

Ahother goal of this analysis was to determine to determine whether water temperatures have changed during the period of observational record, in the context of global climate change. One way to begin this assessment is to investigate whether the temperature

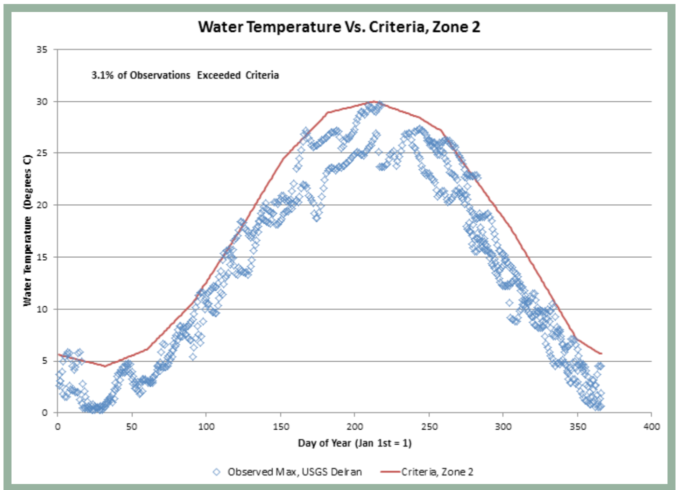

Fig. 3.43. Temperature Observations Compared to DRBC Day of Year Criteria, Delran.

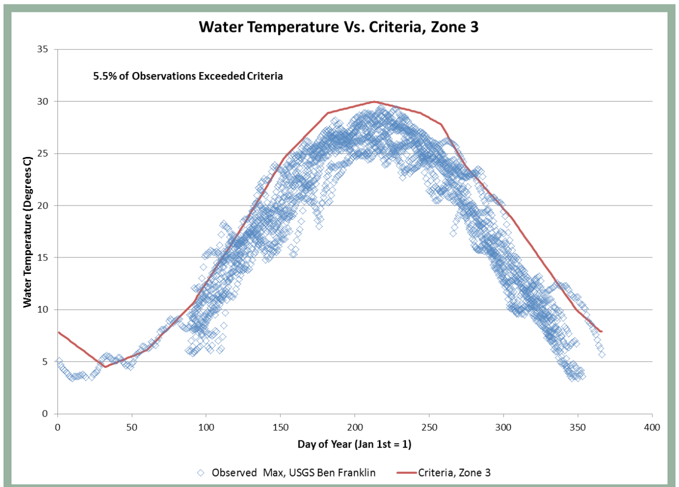

Fig. 3.44. Temperature Observations Compared to DRBC Day of Year Criteria, Ben Franklin Bridge.

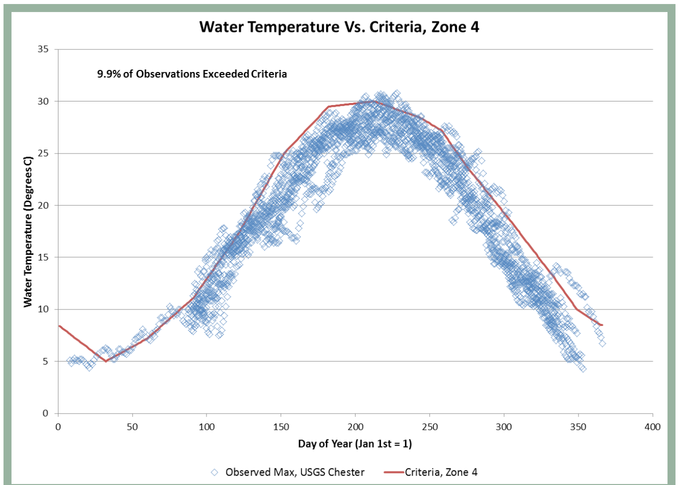

Fig. 3.45. Temperature Observations Compared to DRBC Day of Year Criteria, Chester.

has shifted perceptibly during the period of record. Daily mean water temperatures are available from the USGS monitors at the Ben Franklin Bridge (since 1964), Chester (since 1965), and Reedy Island (since 1970). Minimum and maximum daily temperature records extend back slightly further.

For the entire period of record through 2010 for each of the 3 monitors, it was determined that the median of the mean daily temperature for each day of the year. Daily mean temperature was plotted for each May 15th, for every year from the 1960's or 1970, and medians for each set. Temperature from each May 15th was compared to temperature to the median of all May 15th temperatures at that location, to see if the differences changed over time. Figures 3.46, 3.47, and 3.48 show the mean daily temperature measurements by day of year, and the median for each day of year for the 3 USGS continuous monitors.

Figures 3.49, 3.50, and 3.51 show the residuals (mean daily water temperature – median temperature for that day of year) for Ben Franklin, Chester, and Reedy Island respectively, plotted by date. By this analysis, it was expected that a linear trend of residuals would show an increase if water temperatures were increasing over the period record. Curiously, the results showed a very slight decrease at Ben Franklin, virtually no change at Chester, and a very slight increase at Reedy Island. These results were counterintuitive both from the perspective of any possibility of a decreasing trend, and the likelihood of opposite trends in different parts of the estuary.

Rapid temperature changes in spring and autumn could be confounding the long-term residuals analysis. To minimize this impact, only the portions of the yearly cycle where broad day to day shifts were minimized were looked at (where the slope of the median curve was nearly flat). These flat periods corresponded to winter and summer. From visual inspection of the yearly cycle, winter was defined as the range from day of year 5 (January 5th) to 40 (February 9th). Summer was defined as the range from day of year 195 (July 13th) to 225 (August 12th).

A review of these seasonal residual assessments, however, only deepens the uncertainty. At Ben Franklin Bridge, summer temperatures appear to have decreased slightly over the period of record, while winter temperatures appear to have increased slightly (Figures 3.52 and 3.53). At Chester, summer temperatures appear to have remained unchanged, while winter temperatures appear to have increased slightly (Figures 3.54 and 3.55). At Reedy Island, summer temperatures appear to have increased, while winter temperatures appear to have remained unchanged (Figures 3.56 and 3.57). No site shows the same summer and winter trend as any of the other two sites. Intuitively, this seems to be a problematic result.

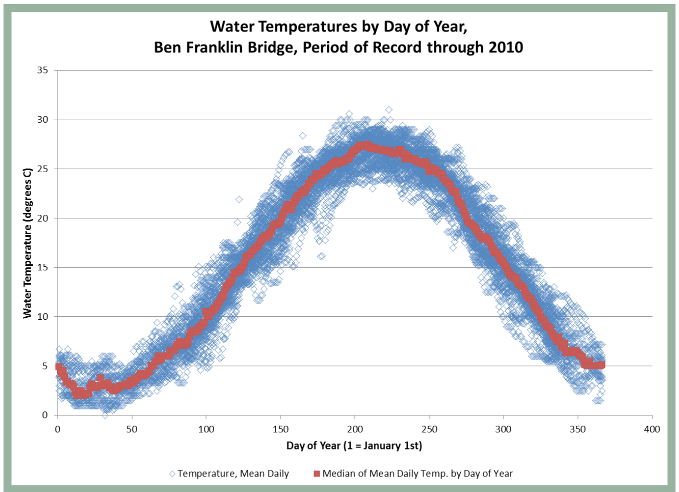

Fig. 3.46. Period of Record Temperature Observations including Median by Day of Year, Ben Franklin Bridge.

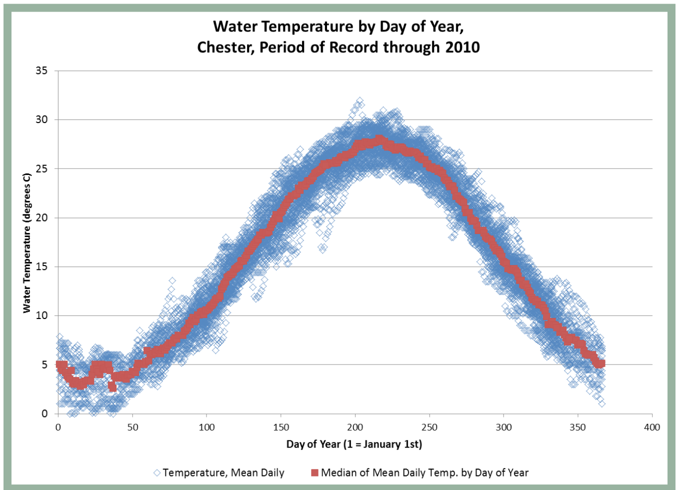

Fig. 3.47. Period of Record Temperature Observations including Median by Day of Year, Chester.

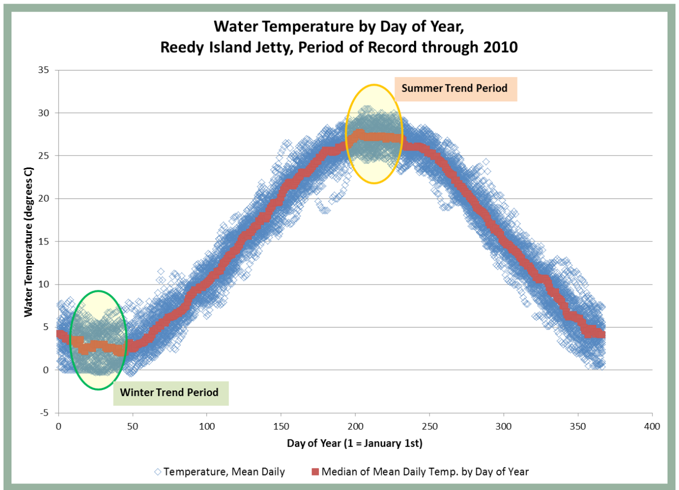

Fig. 3.48. Period of Record Temperature Observations including Median by Day of Year, Reedy Island Jetty.

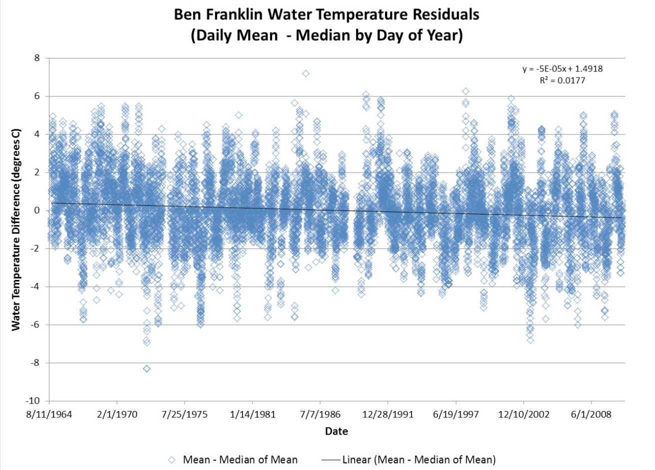

Fig. 3.49. Temperature Residual Trend Analysis, Ben Franklin Bridge.

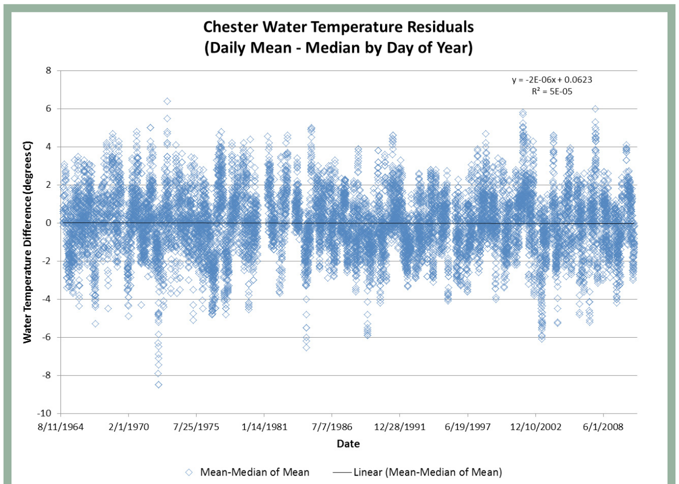

Fig. 3.50. Temperature Residual Trend Analysis, Chester.

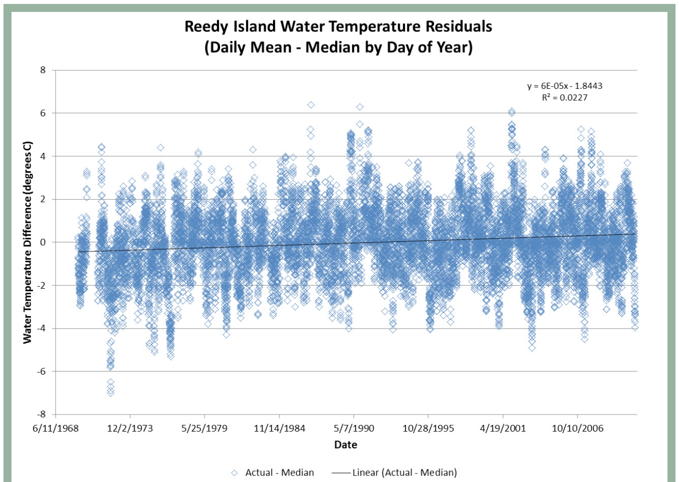

Fig. 3.51. Temperature Residual Trend Analysis, Reedy Island Jetty.

Because trends in water temperature among the three continuous monitor sites are not consistent, either on a gross or seasonal basis, interpretation of these results is challenging. It would appear that multiple overlapping temperature drivers may be at work, with no clear picture as to which dominate. Our intuitive expectation that water temperatures would rise as a result of global warming appears to have been too simplistic. Some influences which may account for seemingly divergent results include the following:

- The shift in industrial activity in the estuary over the period of record away from heavy industry may have resulted in fewer and smaller thermal point loads to the estuary;

- Sea level rise, as well documented at Lewes, DE, may push the influence of the ocean temperature further upstream, counteracting terrestrially driven temperature patterns;

- The drought of record for the Delaware Estuary region occurred between 1960 and 1966. The later part of this drought (1965 and 1966) is reflected in the data sets for the Ben Franklin Bridge and Chester. The regressions that include this period may trend in different directions than a regression from which these years were excluded.

3A – 7.4 Future Predictions

In light of the difficulty in interpreting the historical trends in water temperature, any prediction regarding future shifts is fraught with uncertainty. In their 2008 report, the Union of Concerned Scientists used output from global circulation models to predict that the climate in Pennsylvania would shift toward a climate more similar to Georgia over the next 60 years. Intuitively, this seems to suggest that water temperatures will increase in that same time period. As was seen with historical trends, however, some temperature drivers, such as sea level rise, may impose a counter-acting force which cannot be easily estimated.

3A – 7.5 Actions and Needs

In order to gain a firmer understanding of how different temperature drivers are influencing the Delaware Estuary, and ultimately to understand how global climate change may be manifested in the estuary, a more rigorous evaluation is needed. This evaluation may need to include a temperature model that integrates the various drivers.

3A – 7.6 Summary

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. These inconclusive historical trends confound our ability to make reasonable predictions regarding future temperature changes. A more rigorous assessment, which explicitly accounts for overlapping temperature drivers, is desirable.

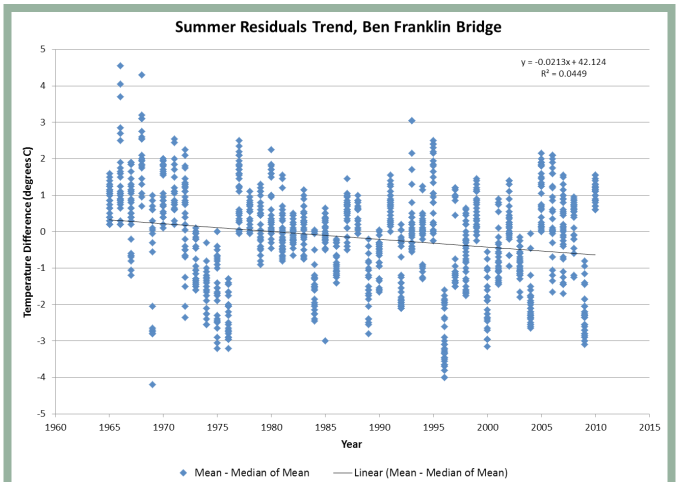

Fig. 3.52. Summer Residuals, Ben Franklin Bridge.

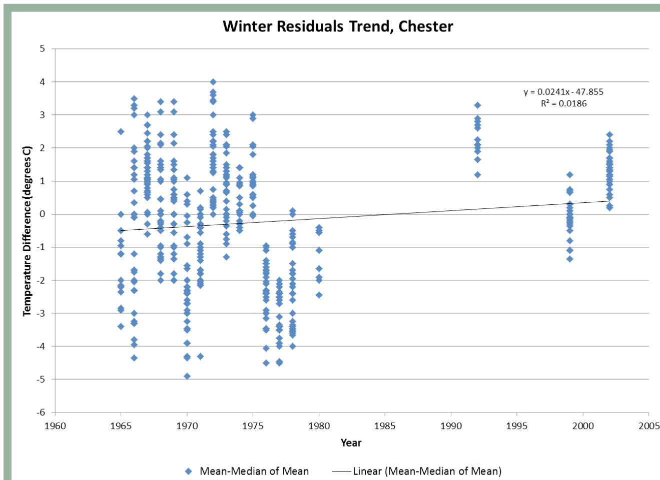

Fig. 3.55. Winter Residuals, Chester.

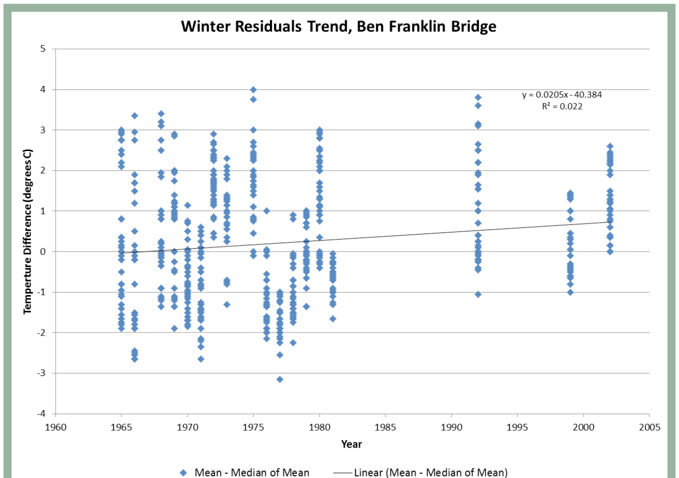

Fig. 3.53. Winter Residuals, Ben Franklin Bridge.

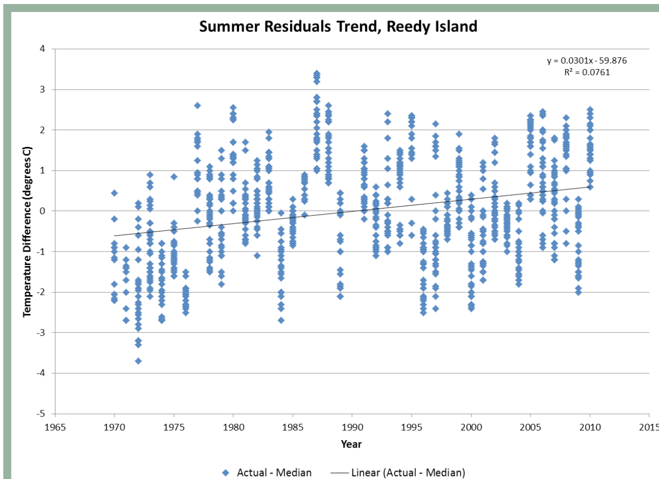

Fig. 3.56. Summer Residuals, Reedy Island Jetty.

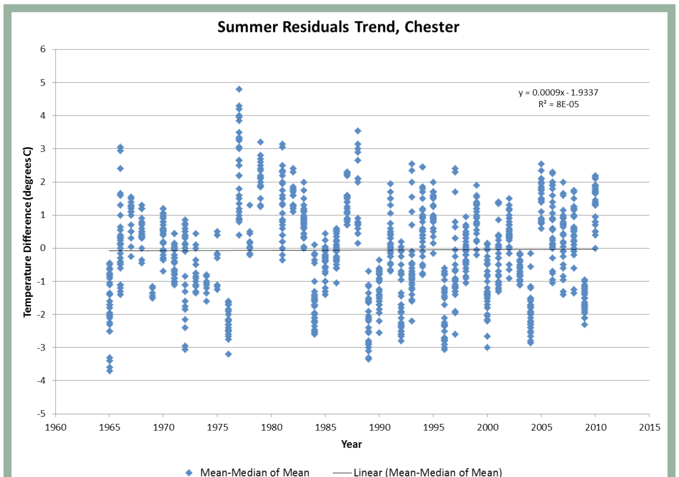

Fig. 3.54. Summer Residuals, Chester.

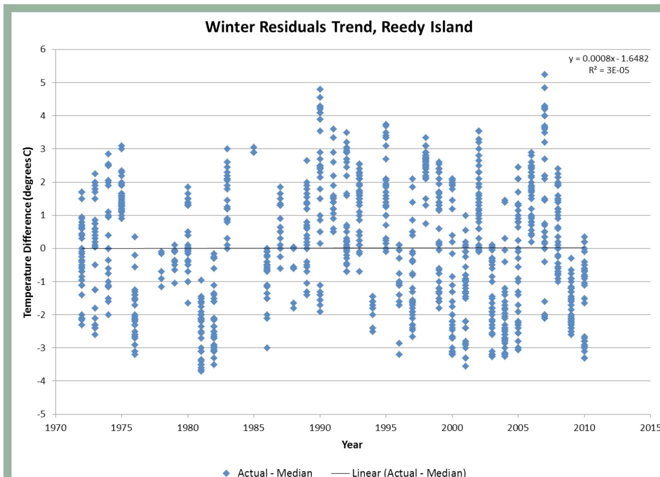

Fig. 3.57. Winter Residuals, Reedy Island Jetty.

3A – 8 Emerging Contaminants

Emerging contaminants are unregulated substances that have entered the environment through human activities, which may have environmental / ecological consequences. Current regulatory approaches are inadequate to address these contaminants and the increasing public concern over their environmental and human health implications.

3A – 8.1 Description of Indicator

The compounds included in a list of emerging contaminants for the Delaware Estuary are pharmaceuticals and personal care products (PPCP), hormones and sterols, perfluorinated compounds (PFC), and polybrominated diphenyl ethers (PBDE) and recently regulated nonylphenol .

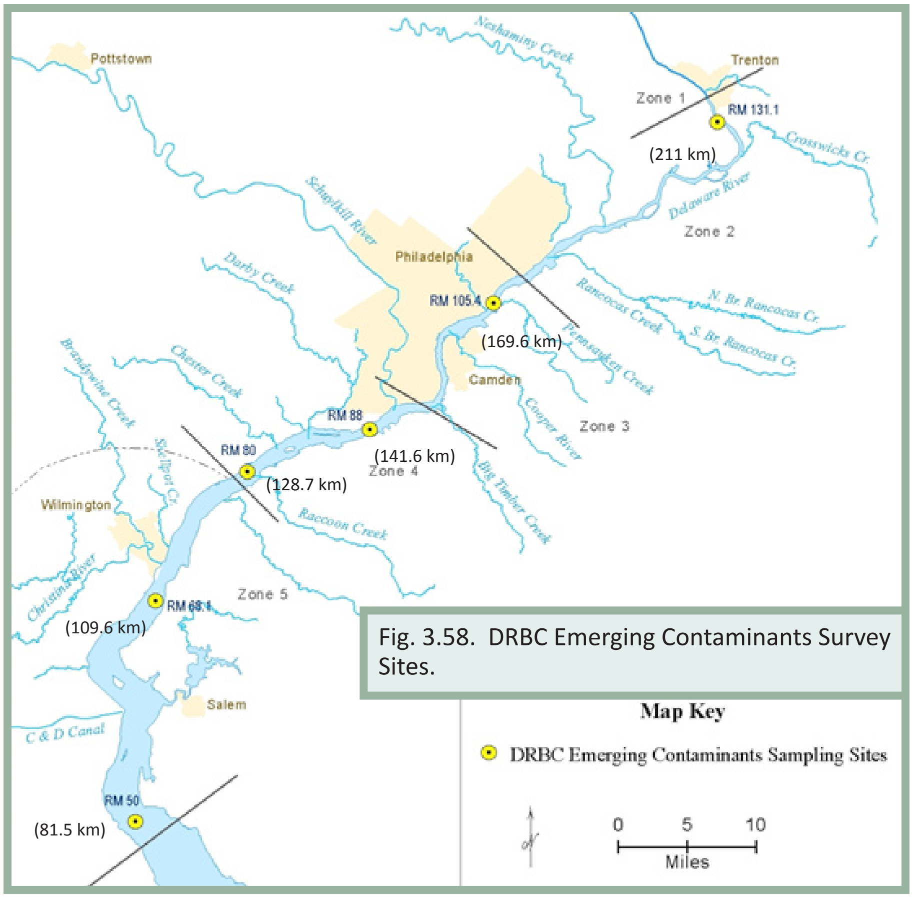

Fig. 3.58. DRBC Emerging Contaminants Survey Sites.

3A – 8.2 Present Status

In 2007, 2008, and 2009 surveys were conducted for emerging contaminants in the estuary. The surveys were conducted because more than 85,000 chemicals are commercially available in the United States. New chemicals are introduced each year and released to the environment and improved analytical methods are available to detect many of these compounds. In addition, there is a growing body of information on adverse effects from some contaminants. Scientists, the public, and regulators have an increased interest in substances and toxic effects not historically monitored or assessed. The survey was conducted in the tidal Delaware River, the part of the river that has tidal flux from Trenton to the head of the Bay. This is an urbanized and industrialized area. Over 6 million residents live in contributing watersheds to the tidal Delaware River creating an area of concentrated consumer product usage (Fig. 3.58). The survey of over 100 compounds provides a snapshot of present status in the estuary.

PPCP, shown in Fig. 3.59, are present in ng/L quantities which are comparable to compounds and concentrations measured in other occurrence studies of ambient water near urban areas. The exception is codeine and metformin found in higher than expected concentrations. In the 2007 and 2008 surveys, both sterols and hormones were included in the list of analytes. In those surveys, the fecal sterols (coprostanol, epicoprostanol, cholestanol) and a cholesterol precursor (desmosterol) as well as the plant sterols (campesterol, stigmasterol and beta-sitosterol) were detected. The fecal sterols indicate the presence of human sewage but are not major contributors to ecotoxicity in the river. In the 2009 survey only hormones were included in the list of analytes. Hormones detected in 2007, 2008 and 2009 at low concentrations and at limited locations include estrone, norethindrone, 17-alpha-ethynyl-estradiol, desogestrel and testosterone. Benchmark values for environmental safety are not available for hormones.

PFC are present in ng/L concentrations with perfluoronanoate measured at the highest concentration (976 ng/L). Although concentrations in water appear to be going down each year, additional ecotoxicology and bioaccumulation information is needed especially on longer chain and sulfonated PFC. For instance, PFUnA (C11) concentrations in the Delaware Estuary were found to be low in ambient water relative to other PFC but were high in fish fillet compared to other PFC (Fig. 3.60).

PBDE are present in pg/L to ng/L concentrations with homolog distributions similar to those observed in other North American locations. Nonyl phenol levels do not exceed current US EPA water quality criteria.

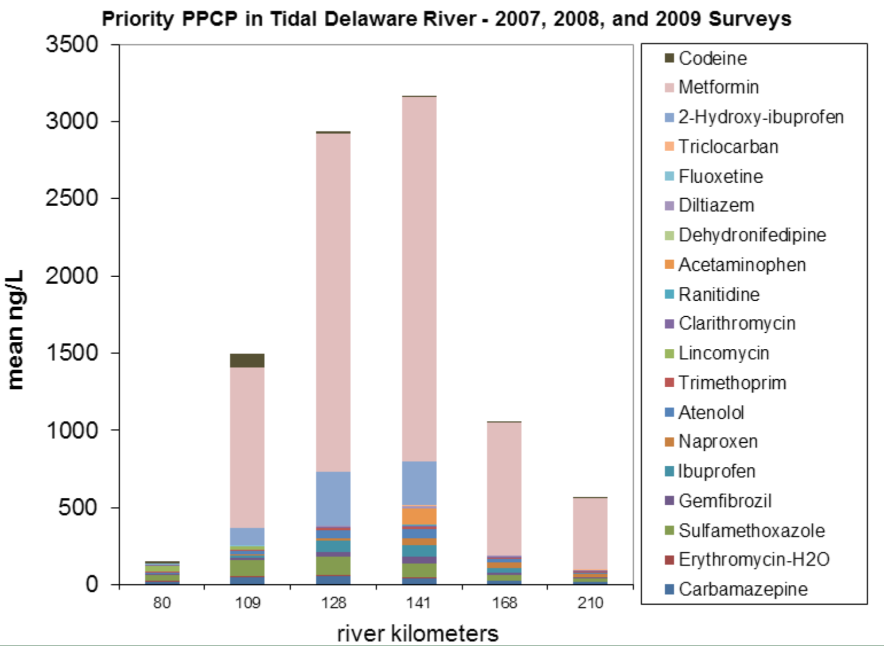

Fig. 3.59. Priority PPCP for monitoring in the tidal Delaware Estuary.

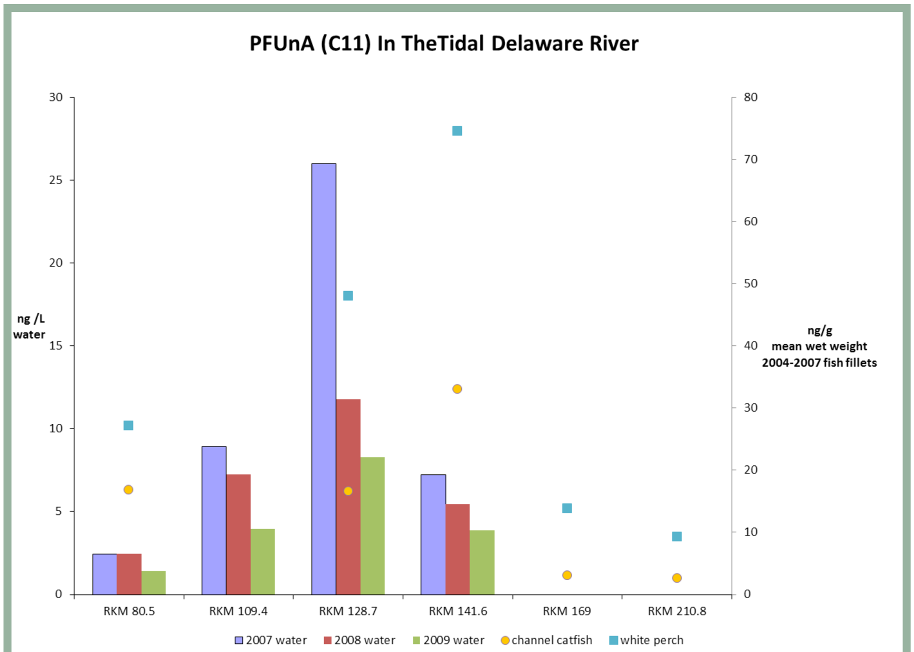

Fig. 3.60. PFC in the tidal Delaware River.

3A – 8.3 Past Trends

Emerging contaminants have historically not been routinely monitored therefore limited information is available on past trends. Previous studies by the US EPA, USGS, basin states and private industry on emerging contaminants in the estuary were identified in the DRBC report titled Emerging Contaminants of Concern in the Delaware River Basin (http://www.state.nj.us/drbc/EmergingContaminantsFeb2007.pdf). However, insufficient data is available to track past trends.

3A – 8.4 Future Predictions

The potential for increased concentrations of emerging contaminants in the environment is predicted. Pharmaceutical production is expected to grow with an aging population and personal care products use should increase with a growing population. Also, U.S. livestock consume large quantities of antimicrobial medications every year, mainly to promote the growth of animals. Concentrations of PBDE concentrations are on the rise in aquatic biota and wildlife worldwide with the Mid-Atlantic , Southeastern and Great Lakes areas having the highest concentrations of PBDE in the United States (Wenning *et al.*, 2011). In contrast, one group of compounds PFCs are predicted to have lower concentrations in the waters of the Delaware Estuary in the future based on available information, although bioaccumulation of PFC in aquatic biota is of concern.

3A – 8.5 Actions and Needs

Nineteen PPCP were identified for focused study based on prioritization criteria such as environmental concentration, toxicity, physicochemical properties, analytical feasibility, consumption, degradation, and persistence (Fig. 3.59). The priority PPCP compounds are triclocarban, fluoxetine, diltiazem, dehydronifedipine, metformin, codeine, acetaminophen, ranitidine, clarithromycin, lincomycin, trimethoprim, atenolol, naproxen, ibuprofen, gemfibrozil, sulfamethoxazole, erythromycin and carbamazepine, and 2-hydroxy-ibuprofen. Assessment priorities include further characterization of persistent and bioaccumulative perfluorinated compounds and a more comprehensive evaluation of potential ecological effects from pharmaceuticals.

3A – 8.6 Summary

Emerging contaminants are unregulated substances that have entered the environment through human activities. Current regulatory approaches are inadequate to address these contaminants and the increasing public concern over their environmental and human health implications. A pilot survey of emerging contaminants in the main stem of the tidal Delaware River ambient waters in 2007, 2008, and 2009 detected emerging contaminants levels comparable to similar compounds and concentrations measured in occurrence studies of ambient water in other urban areas. Assessment priorities in the tidal River include further characterization of persistent and bioaccumulative perfluorinated compounds and a more comprehensive evaluation of potential ecological effects from pharmaceuticals in the estuary.

3B – Non-Tidal

3B – 1 Dissolved Oxygen (DO)

DO refers to the concentration of oxygen gas incorporated in water. Oxygen enters water both by direct absorption from the atmosphere, which is 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 life. Oxygen levels in water bodies can be depressed by the discharge of oxygen-depleting materials (measured in aggregate as biochemical oxygen demand (BOD) from wastewater treatment facilities), from the decomposition of organic matter including algae generated during nutrient-induced blooms, and from the oxidation of ammonia and other nitrogen-based compounds.

3B – 1.1 Description of Indicator

Two different expressions of DO were considered for this review: concentration, as mg/L, and percent of saturation. DO concentration provides a direct comparison to water quality criteria and to aquatic life affects levels. Percent of saturation gives an indication of the oxygen content relative to saturation due to temperature and salinity.

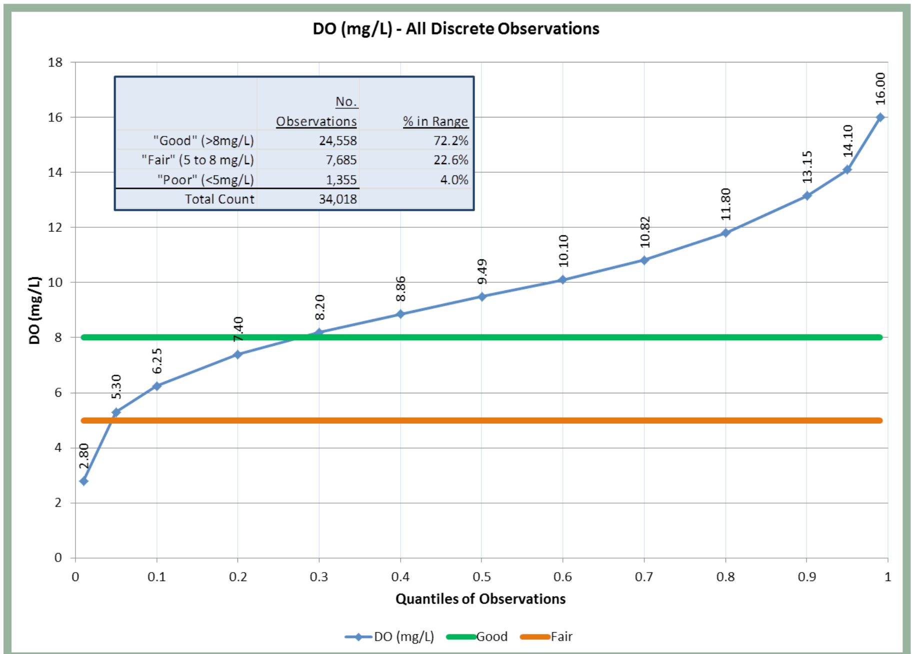

Fig. 3.61. Comparison of Quantiles of All Discrete DO Observations to Ranges

In addition to daytime spot measurements were numerous locations, continuous DO monitors are deployed at the Delaware River at Trenton, the Lehigh River at Easton, Wissahickon Creek and many smaller tributaries to the Delaware. Because DO concentrations 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. In addition, continuous monitors provide a depth and continuity of data that could not be replicated with spot measurements.

3B – 1.2 Present Status

To consider the overall health of basin surface waters in terms of dissolved oxygen, we compared the quantiles of all discrete observations to the generic quality thresholds of “Good” (>8 mg/L), “Fair” (5 to 8 mg/L), and “Poor” (<5 mg/L) defined in the previous State of the Basin reports. This comparison (Fig. 3.61) showed that 72.2% of observations would be indicated as “Good”, 22.6% would fall in the “Fair” category, and only 4% would be listed in the “Poor” category. While these observations do not indicate low DO, it should be noted that these data points represent daytime spot measurements, when DO values are typically at their highest concentration. By contrast, continuous monitors show a persistent DO sag in the urbanized portion of the estuary.

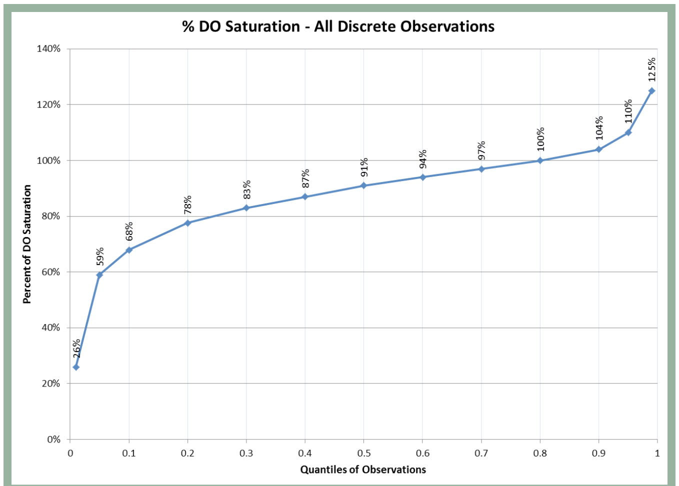

Fig. 3.62. Quantiles of All Discrete % DO Saturation Observations

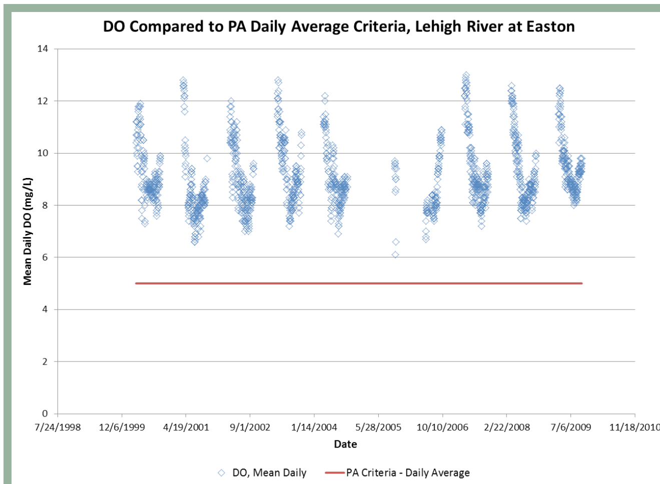

Fig. 3.64. Daily Mean Dissolved Oxygen at the Lehigh River at Easton Compared to Criteria.

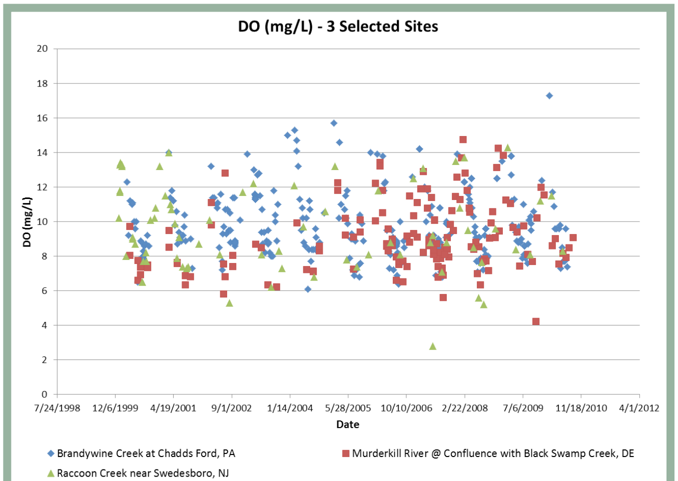

Fig. 3.63. Comparison of Discrete DO Measurements at 3 Locations

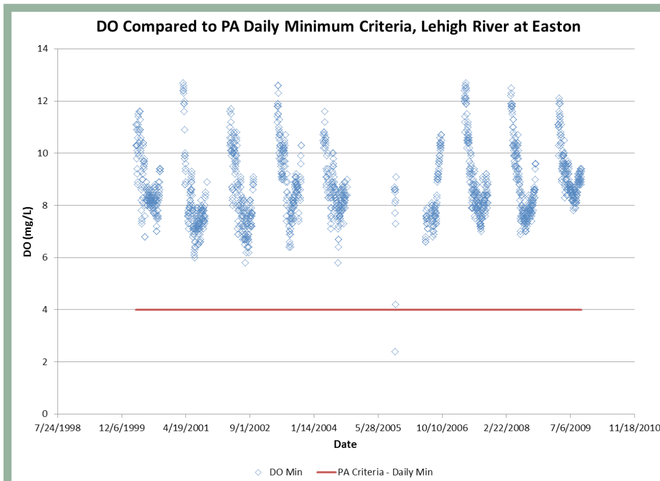

Fig. 3.65. Daily Mean Dissolved Oxygen at the Lehigh River at Easton Compared to Criteria.

A similar evaluation of computed DO Saturation values for all discrete measurements (Fig. 3.62) shows that half of all measurements were at or above 91% saturation, and that only 10% of observations were below 70% saturation.

Fig. 3.63 shows 10 years of DO measurements at 3 different locations in the basin, demonstrating differences between sites and seasonal shifts as well.

Lehigh River at Easton is classified as a warm water fisheries (WWF) by Pennsylvania, and therefore has criteria of a minimum of 5 mg/L DO on a daily average basis, and 4 mg/L on a minimum basis. Figures 3.64 and 3.65 show the results from the USGS continuous real time monitor on the Lehigh River at Easton to Pennsylvania's criteria. All observations were above (met) the daily mean criterion, and all observations except for one were above (met) the daily minimum criterion.

Box and whisker plots were developed for all the USGS continuous DO meters in the Basin. The results are shown in Figures 3.66 and 3.67. It is important to note that Figures 3.66 and 3.67 include both tidal and non-tidal locations. Sites were divided into major and minor sites, although the division was needed primarily to allow a better visual representation of the data, rather than any inherent differences between the site categories. In this data, Frankford Creek at Castor Avenue stands out as having demonstrably lower DO range than the other sites. This tributary is the closest upstream tributary to the Delaware River at the Ben Franklin Bridge, which also shows generally lower DO concentrations.

3B – 1.3 Past Trends

Extended time series data sets are less plentiful in the non-tidal basin than they are in the estuary. However, the Delaware River at Trenton has been monitored with a continuous water quality monitor by USGS since 1962,

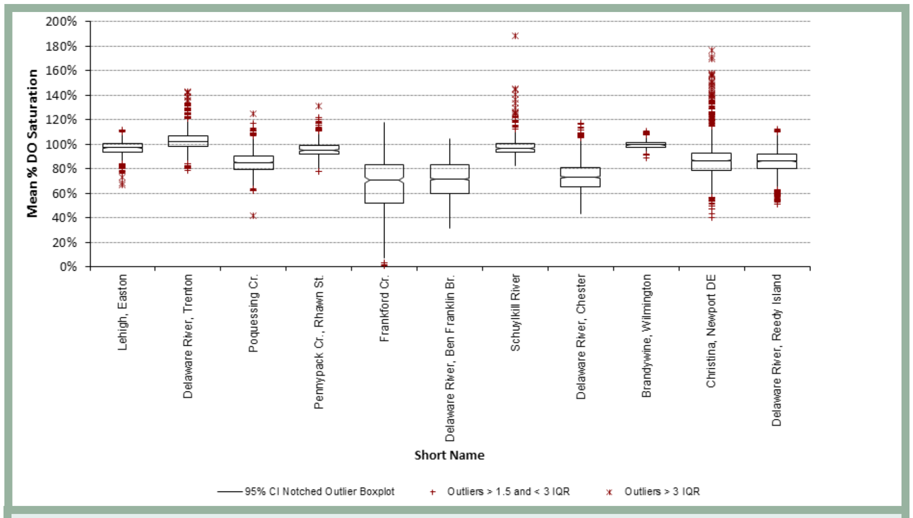

Fig. 3.66. Box and Whisker Plot of DO Saturation from Continuous Meters at Major Tributaries and Delaware River Sites.

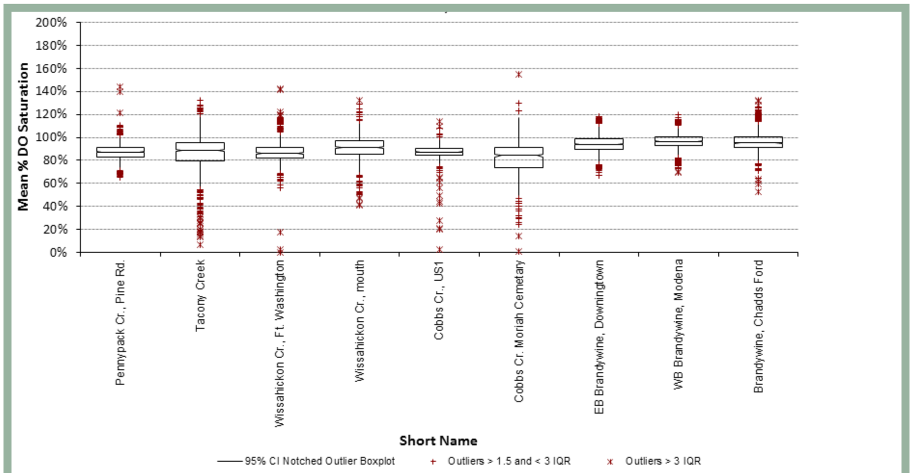

Fig. 3.67. Box and Whisker Plot of DO Saturation from Continuous Meters at Minor Tributaries.

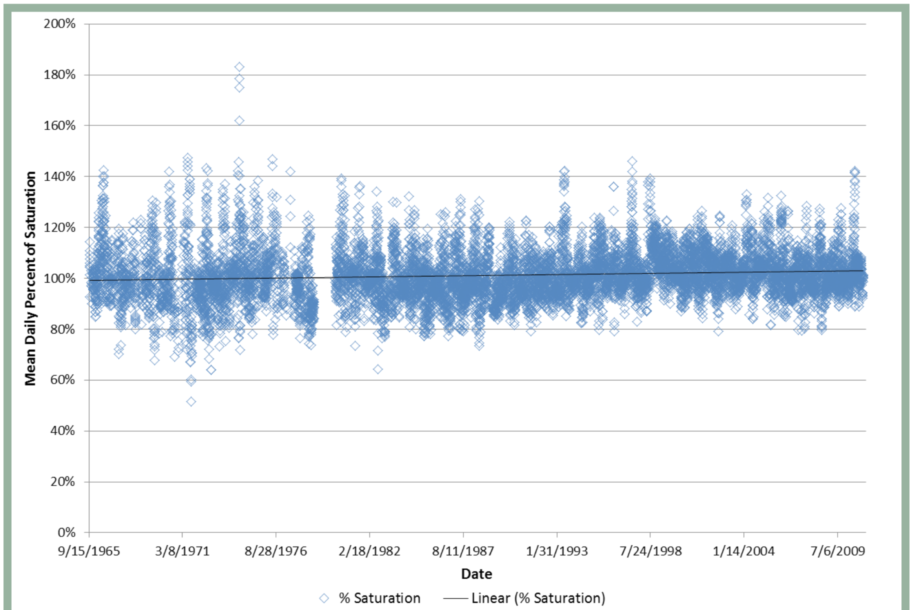

Fig. 3.68. Period of Record Time Series, DO Saturation at Trenton.

with daily mean values recorded since 1965. A review of the DO saturation time series from 1965 to the present suggests stable DO since the early 1990's with some improvement since the late 1960's. As shown in Fig. 3.63, mean daily DO saturation stays primarily in the range between 80% to 120%. This contrasts with the late 1960's and early 1970's, when mean daily DO saturation routinely fell below 80% and more frequently exceeded 140%, possibly indicative of excess algal growth.

3B – 1.4 Future Predictions

Non-tidal DO appeared to be relatively stable. Regulatory programs, such as the DRBC's Special Protection Waters regulations are designed to preserve water quality. Where potential DO problems are indicated (such as in Frankford Creek), long term efforts to minimize combined sewer overflows (CSO) are likely to reduce the frequency and magnitude of exceedances over time.

3B – 1.5 Actions and Needs

Continued monitoring and enhancement of monitoring networks, especially in the realm of continuous real time monitors, will help ensure preservation of water quality and identify reaches where DO is less than optimal.

3B – 1.6 Summary

Available data suggests that DO levels are reasonably good in many locations, with a few areas of localized low DO. The trend at Trenton suggests that DO is stable at relatively high saturation, with some reduction on variability since the late 1960's. We expect good DO levels to persist under current regulations, with improvements at impacted sites over the long term. Expansion of continuous real-time monitoring capability in the basin is recommended.

3B – 2 Nutrients

A nutrient is any substance assimilated by living things that promotes growth. The term is generally applied to nitrogen and phosphorus, although it can also be applied to trace nutrients like silica and iron. According to EPA, "High levels of nitrogen and phosphorus in our lakes, rivers, streams, and drinking water sources cause the degradation of these water bodies and harm fish, wildlife, and human health. This problem is widespread—more than half of the water bodies in the United States are negatively affected in some way by nitrogen and phosphorus pollution. (EPA website: http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/problem.cfm)

3B – 2.1 Description of Indicator

As part of its Special Protection Waters (SPW) regulations, DRBC 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 Delaware River Boundary Control Points (BCPs) and tributary Interstate Control Points (ICPs). 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, using data collected during 2000 through 2004 to define EWQ.

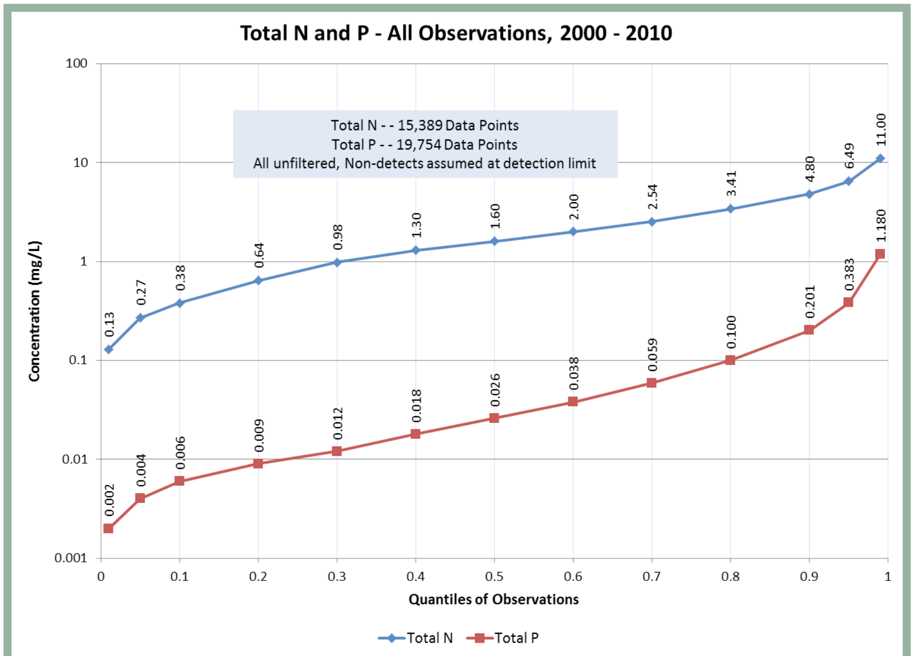

Fig. 3.69. Quantiles of All Total N and Total P Observations in the Delaware River Basin

3B – 2.2 Present Status

The EWQ definitions for nutrients and other analytical parameters are memorialized in DRBC's water quality regulations (http://www.state.nj.us/drbc/regs/WQregs.pdf). At the time of the preparation of this report, DRBC is in the process of collecting new nutrient data at BCPs and ICPs to compare with the EWQ definitions. This effort requires care in data collection, to match the range of conditions under which the original data sets were collected, and care in statistical comparisons between the two data sets. As such, this information is not yet available.

A query was conducted for all Total N and Total P results from NWIS and STORET in the basin, and develop quantiles of those observations, as shown in Fig. 3.69. Total N observations were higher than Total P observations, ranging from one to nearly two orders of magnitude difference across the range.

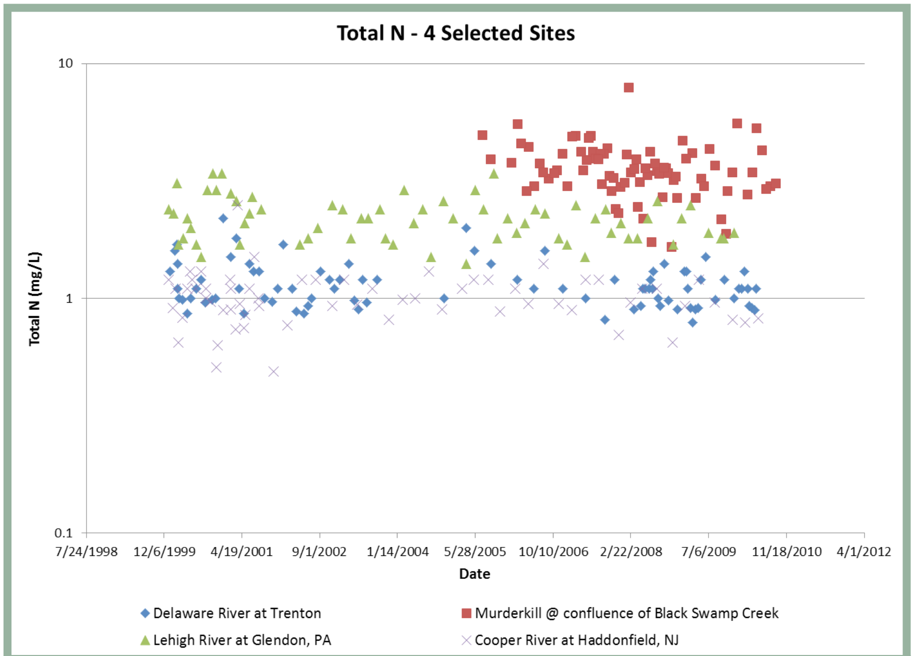

Fig. 3.70. Total N Concentrations from 4 Sites

In addition, total N concentrations from 4 sites throughout the basin were plotted to illustrate the differences in concentrations (Fig. 3.70).

3B – 2.3 Past Trends

The best means of assessing the trend in nutrient concentrations in the basin will be the comparison between the original EWQ definitions, and the new data collected to determine whether EWQ has been maintained. This effort, however, is not yet completed. We therefore defer development of past trends until this effort is completed.

3B – 2.4 Future Predictions

USEPA has prioritized nutrient criteria development in the United States for over 10 years, with states, interstates, and tribes serving as the lead agencies for understanding how nutrients function in their aquatic systems and what nutrient loadings and/or concentrations are needed to sustain healthy biological conditions over the long-term. As this effort to develop criteria comes to fruition, it is reasonable to presume that some subset of tributaries will be above criteria, and actions will be taken to remedy the exceedances. Thus it is reasonable to expect some continued modest decrease in nutrient concentrations.

3B – 2.5 Actions and Needs

The most important actions needed are the completion of the assessment to determine if EWQ has been maintained at BCPs and ICPs. In addition, the continued development of numerical nutrient criteria is needed to ensure ecological health of basin waters.

3B – 2.6 Summary

Efforts are underway to evaluate the current nutrient concentrations relative to the original data derived definitions of existing water quality. This effort will provide a comprehensive comparison between existing and previous conditions, but it is not yet complete.

3B – 3 Contaminants

The "contaminants" indicator is a general category for specific elements and compounds with varying degrees of toxicity to aquatic life and human health.

3B – 3.1 Description of Indicator

To assess the generic category of contaminants, DRBC considered a subset of the EPA priority pollutant metals. EPA has developed recommended criteria for the priority pollutants, which provides a convenient screening level for observed concentrations. The specific contaminants reviewed were:

- Beryllium
- Cadmium
- Chromium(VI)
- Copper
- Lead
- Thallium
- Nickel
- Silver
- Zinc
- Mercury
- Chromium(III)
- Cyanide
- Arsenic
- Antimony
- Selenium

This list is a partial list of the contaminants of concern in the non-tidal zone. Some contaminants are better described by their concentration in fish tissue. Section 3.B-4 describes fish tissue concentrations in detail, and supplements the water column concentrations considered in this section. Non-tidal zone contaminant concentrations were reviewed using US EPA recommended criteria as screening values. Zinc and copper provide the most plentiful data sets.

3B – 3.2 Present Status

Currently the DRBC does not have any criteria for copper concentrations established for the Non-Tidal Zone. The USEPA does not have a set numerical value set for the criteria of copper concentrations, but rather calculates

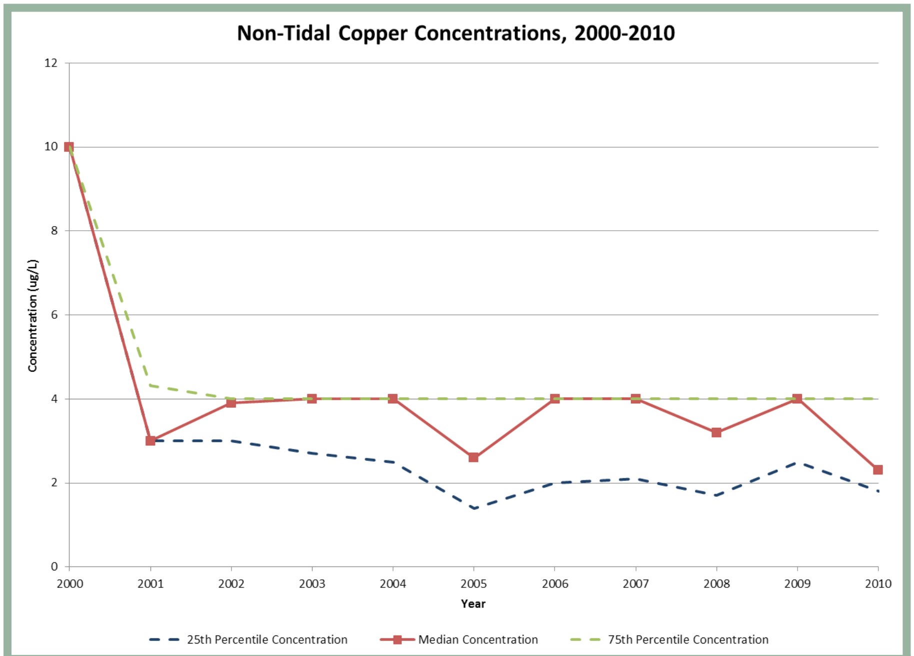

Fig. 3.71. Copper Concentrations in the Non-Tidal Zone from 2000-2010

criteria for concentrations using the Biotic Ligand Model (BLM). Therefore, criteria must be calculated for each sample according to the BLM. Fig. 3.71 displays the Interquartile Range (IQR) of copper concentrations in the non-tidal basin from 2000 to 2010 (including both Delaware River and tributary sites), with data provided by the STORET and NWIS sampling databases.

DRBC does not have set criteria for zinc concentrations in the non-tidal zone. US EPA has recommended acute and chronic criteria concentrations for zinc. Fig. 3.72 displays the Interquartile Range (IQR) for zinc concentrations for samples collected between 2000 and 2010 for both non-tidal Delaware River and tributary sampling locations. The data is provided by the STORET and NWIS sampling databases. As shown in Fig. 3.72, zinc concentrations remained below the USEPA established criteria between 2000 and 2010. Fig. 3.73 shows dissolved and total zinc concentrations at four locations in the basin.

Fig. 3.74 shows a similar comparison for Arsenic, including both non-tidal Delaware River and tributary sampling locations. Again, all of the observations were below criteria. For brevity, the remaining substances will not be shown in detail.

3B – 3.3 Past Trends

Data and detection insufficiencies make determination of past trends difficult.

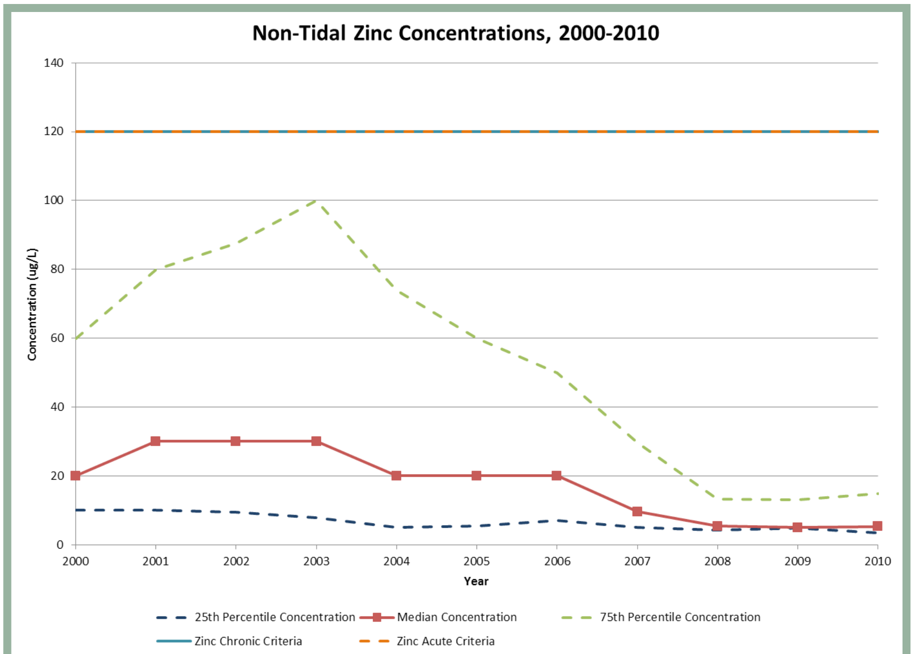

Fig. 3.72. Zinc Concentrations in the Non-Tidal Zone from 2000-2010

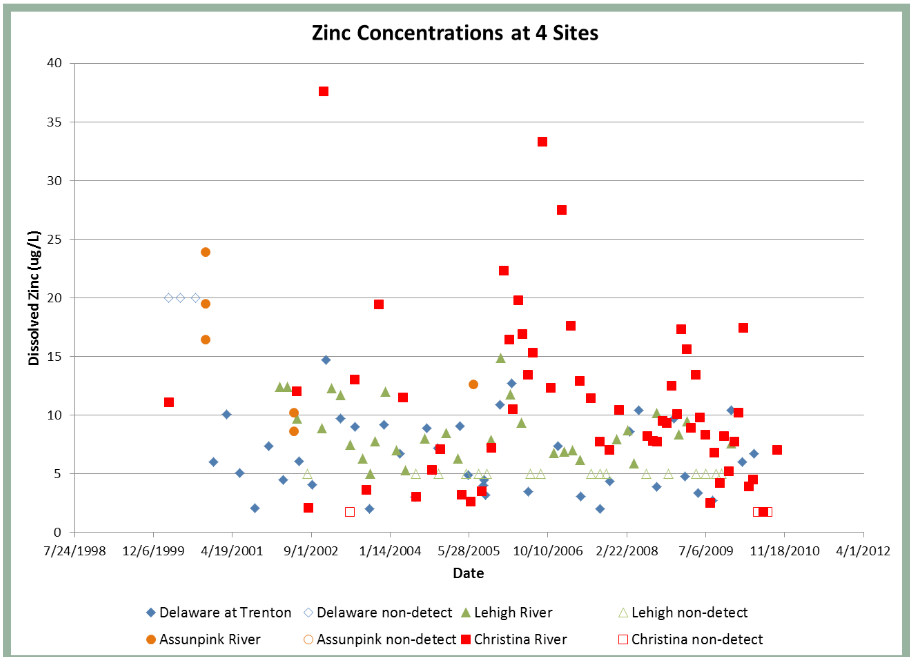

Fig. 3.73. Zinc Concentrations at 4 Basin Sites

3B – 3.4 Future Predictions

As monitoring and assessment procedures are refined, and criteria updated to reflect current research, appropriate end points can be defined along with the non-tidal zone metal 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. Although some upward pressure is likely to be exerted by population growth, these influences may be more than countered by economic shifts and effective water quality management.

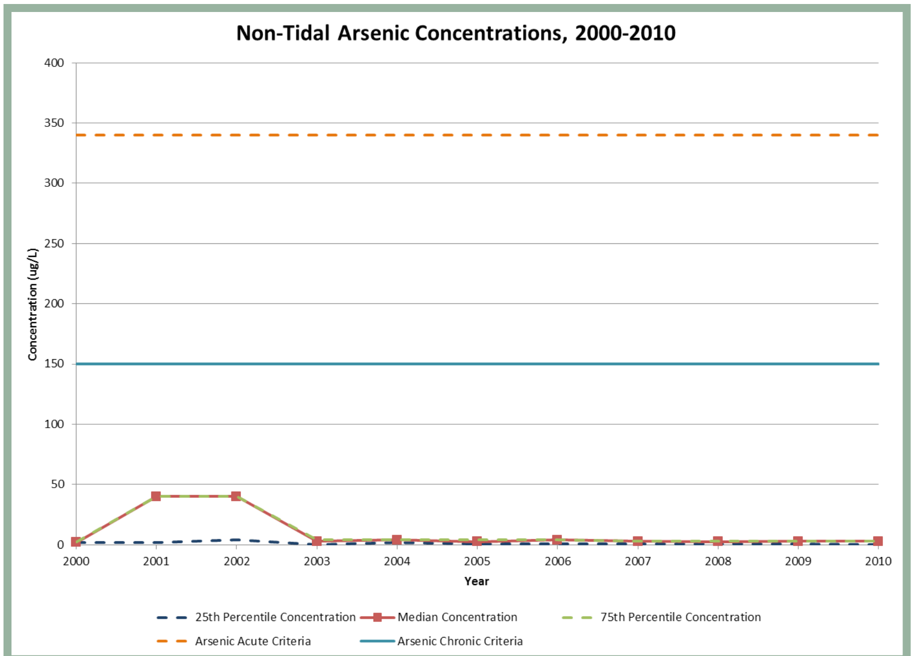

Fig. 3.74. Arsenic Concentrations in the Non-Tidal Zone from 2000-2010

3B – 3.5 Actions and Needs

Continuity in monitoring programs, continued assessments, and continued updates in criteria are all needed to maintain current contaminant levels and effectively decrease levels where levels are elevated. Monitoring should include parameters to assess copper by the BLM. The DRBC Toxics Advisory Committee has recommended development of water quality criteria for toxics in Zone 1 of the Delaware River.

3B – 3.6 Summary

Contaminants, as represented by the priority pollutant metals, are generally below criteria.

3B – 4 Fish Contaminant Levels

Certain chemicals tend to concentrate ("bioaccumulate") in fish to levels thousands of times greater than the levels in the water itself. The resulting concentrations in fish and the attendant health risks to those individuals who consume the fish, such as recreational and subsistence anglers, are of concern to government agencies and the public.

3B – 4.1 Description of Indicator

The DRBC developed fish tissue screening values (FTSV) for carcinogens and systemic toxicants at a risk level of one in a million (10^{-6}) for fish tissue concentrations for specific bioaccumulative toxic pollutants following US EPA's "Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories – Volume 1, 2 and 3 (US EPA 2000b) for establishing fish tissue thresholds. (http://water.epa.gov/scitech/swguidance/fishshellfish/techguidance/guidance.cfm) Screening values are defined as concentrations of target analytes in fish or shellfish tissue that are of potential public health concern and that are used as threshold values against which levels of contamination in similar tissue collected from the ambient environment can be compared.

3B – 4.2 Present Status

DRBC calculated FTSVs for carcinogens and systemic toxicants are listed Tables 3.3 and 3.4 respectively. The bioconcentrations actors (BCF), cancer potency factors and DRBC human health criteria (fish ingestion only) used to derive the FTSV are also listed in the tables. Comparable screening values from the EPA, DNREC and NJDEP are included in the tables. Fish tissue data collected from the Delaware River were compared to the FTSV. Concentrations in fish tissue higher than the FTSV are noted in Tables 3.3 and 3.4. Fish tissue samples from the Delaware River have the carcinogens arsenic, aldrin, chlordane, DDT, dieldrin, and PCBs at concentrations higher than the FTSV for carcinogens. While concentrations of other carcinogens such as heptachlor, heptachlor epoxide, alpha- and beta-BHC, and toxaphene were below the FTSV. A brief summary of the carcinogenic parameters with concentrations higher than the FTSV are described below. None of the systemic toxicants measured (cadmium, mercury, nickel, selenium, zinc, aldrin, gamma-BHC, chlordane, DDT, dieldrin, endosulfan, endosulfan sulphate, endrin, endrin aldehyde, heptachlor, heptachlor epoxide, and PBDE) had concentrations higher than the systemic FTSV. Since figures and tables were developed for both estuary and non-tidal fish samples, the figures and tables are included in Section 3A-4.

Mercury

Although concentrations of mercury as wet weight in fish fillet from the Delaware River do not exceed a residue based water quality criteria of 300 ppb methylmercury assuming methyl mercury is approximately 80% of total mercury measured in the fish tissue (Figure 3.23), mercury is worth noting because the assessment is based on a residue based criteria not a FTSV. If calculated based on dry weight, mercury concentrations would exceed the criteria.

Arsenic
Concentrations of arsenic in smallmouth bass and white sucker from the non-tidal Delaware River were below the FTSV (Fig. 3.24).

Aldrin
Concentrations of aldrin in smallmouth bass and white sucker from the non-tidal Delaware River were below the FTSV (Fig. 3.25).

Chlordane
Concentrations of chlordane in smallmouth bass and white sucker from the non-tidal river were below the FTSV (Fig. 3.26).

DDT
Concentrations of DDT and metabolites as wet weight in white sucker and smallmouth bass from the non-tidal Delaware River exceed a FTSV of 11.76 ppb. (Fig. 3.27).

Dieldrin
Concentrations of dieldrin as wet weight in white sucker and smallmouth bass from the non-tidal Delaware River exceed a FTSV of 0.25 ppb (Figure 3.28).

PCB
Concentrations of PCB as wet weight in white sucker and smallmouth bass from the non-tidal Delaware River exceed a cancer FTSV of 1,500 pg/g (1.5 ppb). Median PCB concentrations are 10x screening values. (Fig. 3.29).

DxFs
Concentrations of dioxin and furans as wet weight in white sucker and smallmouth bass from the non-tidal river had concentrations higher than a cancer screening value of 0.019 pg/g (0.000019 ppb) (Fig. 3.30). EPA recommends basing the fish consumption screening value for DxFs on Toxic Equivalents (TEQs) related to 2,3,7,8-TCDD toxicity. To calculate the TEQ of a dioxin mixture, the concentration of each toxic compound is multiplied with its Toxic Equivalency Factor (TEF) and then added together. Median DxF TEQs are approximately 100x screening values.

PBDE
PBDEs, which are emerging and unregulated compounds, have been observed in whole or fillet fish tissue at concentration from non-detect to 1,300 ppb total PBDE ww in U.S. waterways (Wenning et al, 2011). PBDE congeners with oral reference dose listed in EPA-IRIS (BDE-47, BDE-99, BDE-153 and BDE-209) were not measured in fish tissue from the Delaware River at concentrations higher than the DRBC calculated systemic FTSV (Table 3.2). FTSVs for carcinogenic effects are not available for PBDE. Although BDE-209 has suggestive evidence of carcinogenic potential, an oral slope factor is not listed in IRS. There is insufficient data currently available to determine if BDE-47, BDE-99, and BDE-153 are potential carcinogens.

3B – 4.3 Past Trends

Environmental monitoring programs conducted worldwide during the past decade have shown increasing levels of some PBDE congeners in contrast to a general decline in the occurrence of dioxins, PCBs and chlorinated pesticides.

3B – 4.4 Future Predictions

Declines in concentrations of currently regulated substances such as dioxins, PCBs, and chlorinated pesticides in fish tissue with potential increases in concentrations of emerging and unregulated compounds such as PBDE and perfluorinated compounds.

3B – 4.5 Actions and Needs

Continued and expanded monitoring and assessment of persistent, bioaccumulative, and toxic contaminants in fish tissue, aquatic biota and wildlife.

3B – 4.6 Summary

Exceedance of these FTSVs should be taken as an indication that more intensive site-specific monitoring and/or evaluation of human health risk should be conducted. Field data, greater than the screening levels, are worthy of further evaluation. Possible further evaluation would include additional data collection, detailed risk analysis, and potential risk management action. It is important to note that fish tissue screening values are not intended to replace formal risk analysis. Rather, they help the assessor to decide whether a detailed risk analysis is even warranted and how to prioritize several analyses if screening values are exceeded at more than one location.

3B – 5 pH

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 (e.g., metals, ammonia). Among natural waters, both highly alkaline waters and highly acidic waters (like the NJ Pinelands) are known to severely restrict the species of plants and animals that can thrive in particular lakes and streams. Likewise, human alteration of the pH regimen for a water body can alter both the quality of that water and the aquatic life inhabiting that system.

3B – 5.1 Description of Indicator

DRBC has established minimum and maximum pH criteria for the mainstem Delaware. At Trenton, these criteria are not to exceed 8.5 and not below 6.0. Similarly, Pennsylvania has adopted maximum and minimum pH criteria values of 9 and 6 respectively. Because of the diel nature of pH in most surface waters, continuous pH monitors are the most effective means of measurement for comparison to criteria. USGS maintains real time monitors at Trenton NJ and at the Lehigh River at Eston.

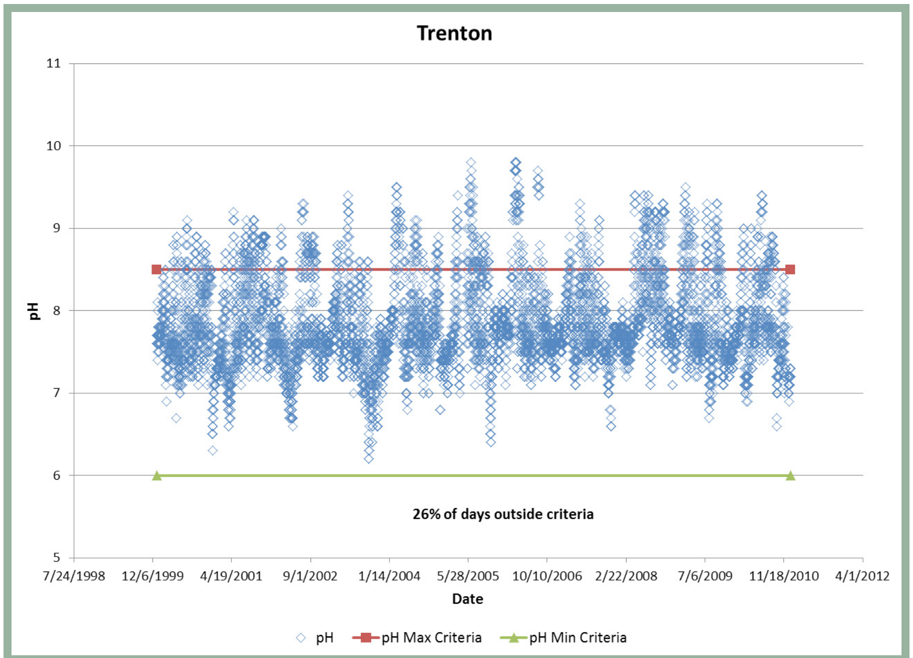

Fig. 3.75. pH Observations at Trenton, Compared to Criteria

3B – 5.2 Present Status

Fig. 3.75 shows the pH at Trenton over a 10-year period compared to DRBC's criteria. Approximately 26% of the observations are outside criteria, exceeding the maximum value of 8.5. No values were below the minimum criterion. However, historic and current pH data suggest natural primary production in the non-tidal river (Zone 1) causes regular and predictable diel fluctuations in pH. Some criteria violations are attributable to naturally high pH conditions during periods of high primary production, although elevated nutrients at Trenton may contribute to the frequency and magnitude of pH exceedances through stimulation of algae and aquatic plants. As such, DRBC is currently reviewing its pH criteria to determine if the current levels reflect the appropriate balance between protection and natural conditions.

Observations of pH at the Lehigh (Fig. 3.76) show values largely within criteria, with only one observation exceeding the maximum criterion value of 9, with the magnitude of this exceedance being relatively small.

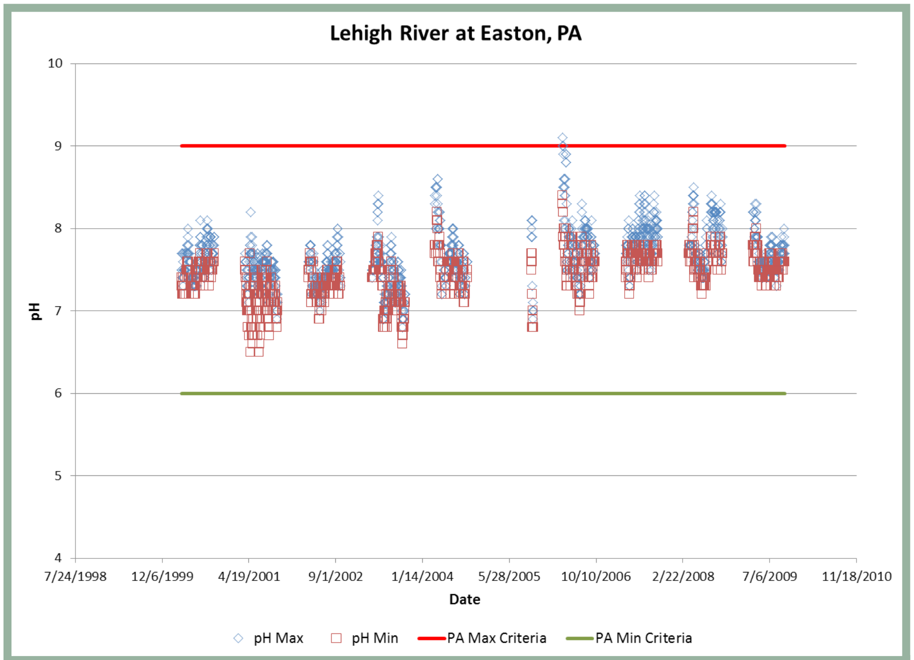

Fig. 3.76. pH Observations on the Lehigh River at Easton, Compared to Criteria

3B – 5.3 Past Trends

We compared 2-year bins of pH data via box and whisker plot to the first 10 years of data from the period of record at Trenton, as shown in Fig. 3.77. No clear trend is indicated, although some periodicity may be present.

3B – 5.4 Future Predictions

Observations of pH appear to be relatively stable in the non-tidal portion of the basin. Continued stable pH, within the already observed ranges, seems likely.

3B – 5.5 Actions and Needs

DRBC is reviewing its current pH criteria, with an effort to address naturally occurring diel pH swings. This effort should continue and new criteria should be adopted. Nutrient criteria development may also assist in the determining whether pH conditions are natural or have been altered through algal and plant stimulation. Continuous monitors provide the best means of comparing pH over the daily cycle to criteria, and efforts to deploy additional pH continuous monitors in the basin should therefore continue.

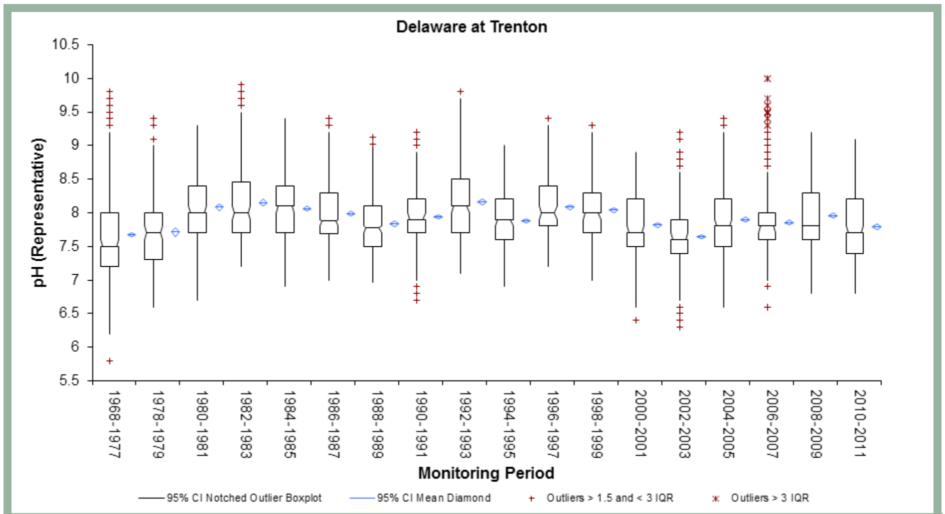

Fig. 3.77. Box and Whisker Plot of pH Period of Record at Trenton

3B – 5.6 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. Efforts are underway to review the current criteria and adopt new criteria that recognize naturally occurring swings.

3B – 6 Temperature

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.

3B – 6.1 Description of Indicator

Currently, DRBC's criteria for temperature in the non-tidal river is oriented toward point discharge thermal mixing zones. As such, we lack specific temperature thresholds protective of the aquatic communities in the river and its tributaries. Pennsylvania, however, has adopted seasonally specific temperature criteria for warm water fisheries, which will be used for comparison in the upcoming section.

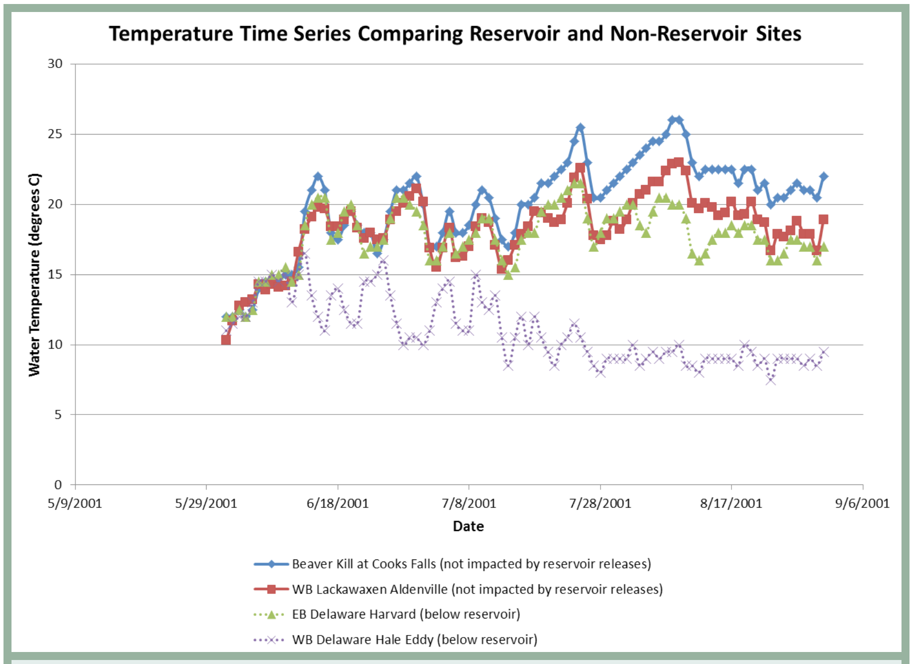

Fig. 3.78. Comparison of Temperature Time Series at Reservoir and Non Reservoir Affected Sites

Continuous temperature monitors are deployed at several stations in the non-tidal basin, including the East and West Branches of the Delaware, and the Delaware River at Callicoon, Barryville, and Trenton. Temperature regimes in the non-tidal Delaware are influenced by reservoir operations. Bottom discharges from the Cannonsville and Pepacton Reservoirs release colder water than would naturally occur. Figure 3.78 shows concurrent temperature time series from summer 2001 for 2 continuous monitors impacted by reservoir releases (East Branch Delaware River at Harvard and West Branch Delaware River at Hale Eddy) compared to two monitors in the same general region not influenced by reservoir releases (Beaver Kill at Cooks Falls and West Branch Lackawaxen near Aldenville).

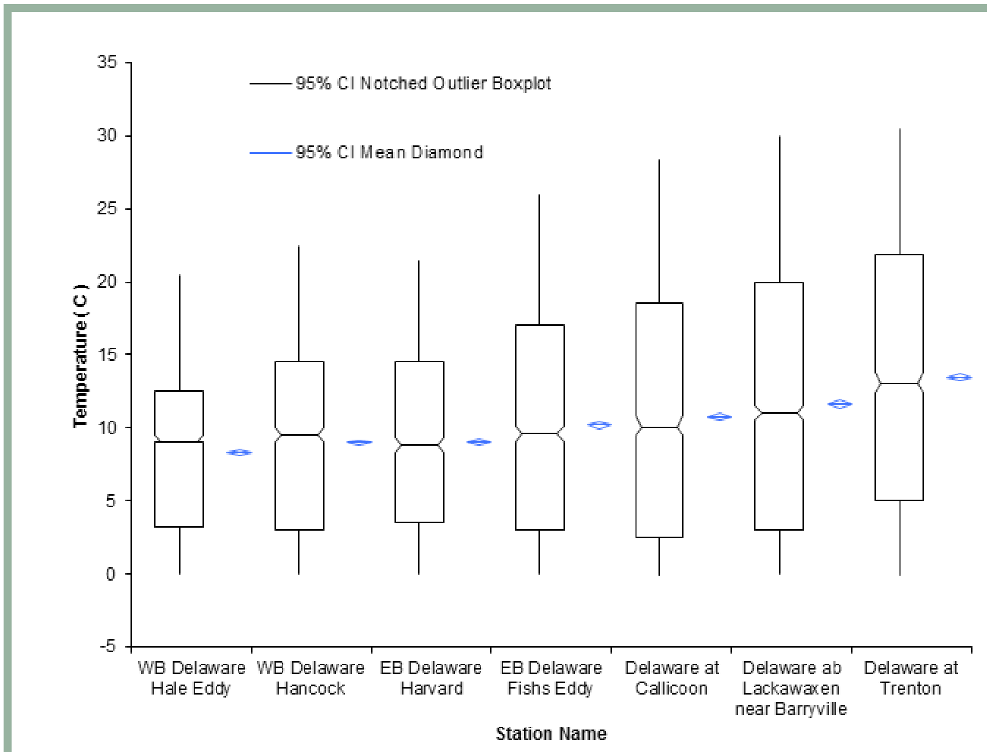

Fig. 3.79. Box and Whisker Plot of Temperature Data Longitudinally along the main stem Delaware River

3B – 6.2 Present Status

Figure 3.79 shows a box and whisker plot of temperature ranges longitudinally along the Delaware River from the East and West Branches down through Trenton, for the most recent 10 years of observations (2000 through 2010). Moving downstream from the reservoir influenced cold water sites on the east and west branches, temperatures increase with the highest range in the non-tidal River at Trenton.

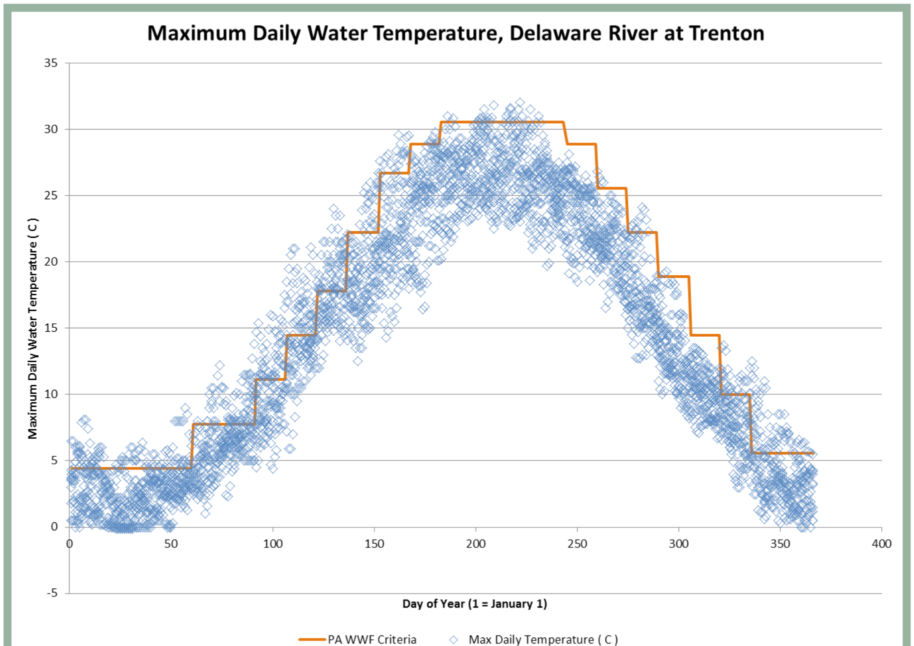

Fig. 3.80. Comparison of maximum daily water temperature by day of year at the Trenton monitor compared to PA warm water fishery temperature criteria

To assess whether the temperature regimes observed in the river were protective of aquatic communities, we compared the continuous measurements at Trenton and near Barryville to the Pennsylvania criteria for warm water fisheries. As shown in Figures 3.80 and 3.81, the number of violations increase from approximately 7% of observations near Barryville (upstream) to approximately 15% downstream at Trenton. In both locations, the violations occur most frequently in the spring.

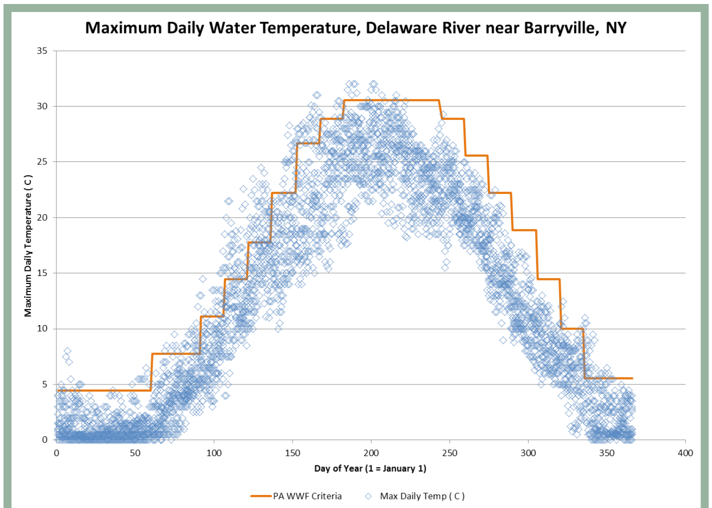

Fig. 3.81. Comparison of maximum daily water temperature by day of year at the Trenton monitor compared to PA warm water fishery temperature criteria

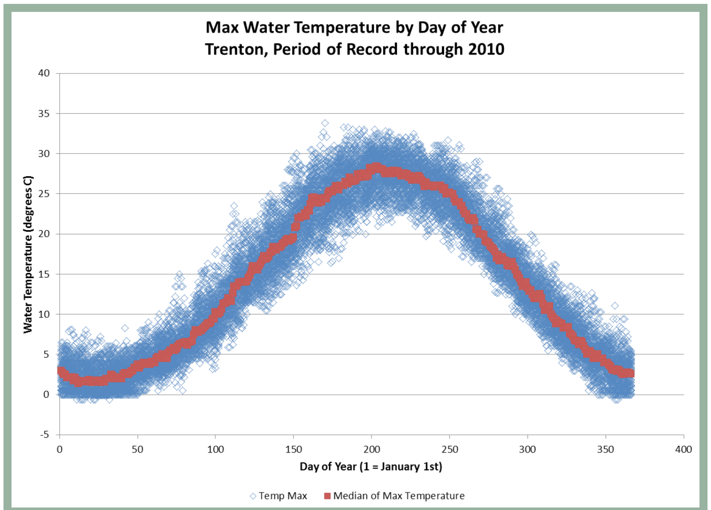

Fig. 3.82. Water Temperature and Median by Day of Year at Trenton

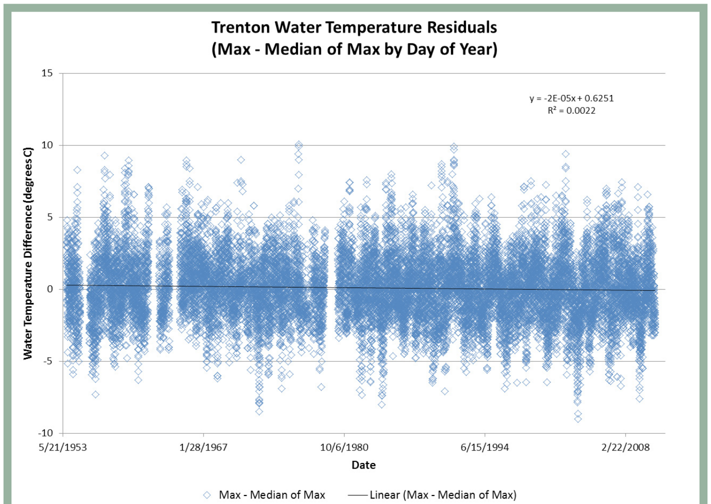

Fig. 3.83. Water Temperature Residual Time Series at Trenton

3B – 6.3 Past Trends

As with the Estuary data, we determined a median concentration for each day of the year at Trenton (Fig. 3.82). We then computed the residuals from this median temperature to see if, over the period of record, water temperatures exhibited a positive or negative shift relative to the day of year median.

As shown in Fig. 3.83, no discernable temporal shift in water temperature is evident from the data.

3B – 6.4 Future Predictions

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. Trenton integrates watershed input from the entire basin. Individual subwatersheds may see increases associated with development, increased impervious cover, and loss of tree canopy. In addition, global climate change could cause a threshold to be passed, resulting in observably higher temperatures.

3B – 6.5 Actions and Needs

We need to continue the development of temperature criteria in the non-tidal portion of the Delaware River, 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.

3B – 4.6 Summary

Temperature assessment in the non-tidal Delaware River is confounded by artificially lowered temperatures from reservoir releases and the lack of protective ambient criteria. A comparison the Pennsylvania's warm water criteria shows exceedances near Barryville and Trenton. The majority of exceedances occur in the spring.

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4

Sediments

1 - Sediment Loading
2 - Sediment Quantity and Budget
3 - Sediment Organic Carbon
4 - Sediment Grain Size
5 - Dredging Activity

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Chapter 4 – Sediments

1 – Sediment Loading

Most estuaries of the world, including Delaware Estuary, are traps for sediment eroded from the watershed above the head of tide. As sea level rose at the end of the last glacial period, beginning about 18,000 years ago, the ancestral Delaware River valley was progressively inundated by the sea until the approximate boundaries of the estuary were established within the past several thousand years (Fletcher et al., 1990). During that period, extensive natural accumulation of both fine- and coarse-grained sediment occurred in the estuary, creating the three-dimensional geometry and distribution of sediments that existed when Europeans first sailed into the Delaware.

The present state of the Delaware Estuary sediment system represents a highly altered condition compared to what existed as recently as a few centuries ago. In the intervening period, land use changes in the watershed above the head of tide have affected the rate at which new sediment is delivered to the estuary. Additionally, portions of once natural estuarine shoreline have been modified by construction of bulkheads, seawalls, piers, and wharves to serve the needs of urban and industrial development. Other portions of the estuary shoreline have been diked and ditched for agriculture and related purposes. The construction and maintenance of a shipping channel through dredging and other activities also have an impact on the system. Dredged sediment has been used as fill to create new land adjacent to the waterway. However, quantitative sediment loading data are available only for the past 60 years.

1.1 Description of Indicator

Sediment loading to the Delaware Estuary occurs principally as the Delaware River and its tributaries discharge their suspended load, and a relatively smaller bed load of sediment, at the head of tide. The rate of sediment discharged depends on a number of factors, including antecedent hydrological conditions over the basin (rainfall and runoff); land use patterns, in particular the degree of disturbed land surface; the number and location of dams on tributaries, which can impound stream sediments above the head of tide; etc. Sediment loading to the estuary has been monitored quantitatively only for the past six decades. Fig. 4.1 presents the annual series of suspended sediment discharged to the estuary from 1950 through 2009. The data represent the combined inputs measured for the Delaware River at Trenton, the Schuylkill at Philadelphia, and the Brandywine at Wilmington, which together include ~80% of the total freshwater discharged to the estuary. The graph shows the large annual variability in sediment discharge, indicative of the fact that sediment discharge is highly correlated to freshwater discharge, particularly peak flow events; the drought period of the mid-1960s has relatively low sediment discharge, whereas the period from 2004 through 2006, with several large flood events in the region, shows relatively higher sediment discharge.

1.2 Present Status

The mean annual sediment discharge over the past six decades at these three locations is 1.28 million metric tons. Together the three gaged locations represent 80% of the drainage area tributary to Delaware Estuary. The remaining 20% of the estuary drainage area that is not gaged for sediment discharge includes smaller watersheds with lower stream gradients. It is concluded that the ungaged watersheds contribute an unknown but negligibly small fraction of the suspended load of the estuary. Other known but unquantified minor contributors of new suspended sediment includes storm and sanitary sewer outfalls.

Consequently, the mean annual sediment discharge to the estuary from the entire basin is estimated as 1.28 million metric tons (1.3 million rounded). For historical perspective, Mansue and Commings (1974) analyzed suspended sediment input to Delaware Estuary and their data show an average annual input from the Delaware, Schuylkill, and Brandywine Rivers of 1.0 million metric tons per year, with a total suspended solids input to the estuary from all sources estimated as 1.3 million metric tons annually. The sediment discharge data in Fig. 4.1 suggest no apparent trend of increase or decrease in sediment discharge over the period of record.

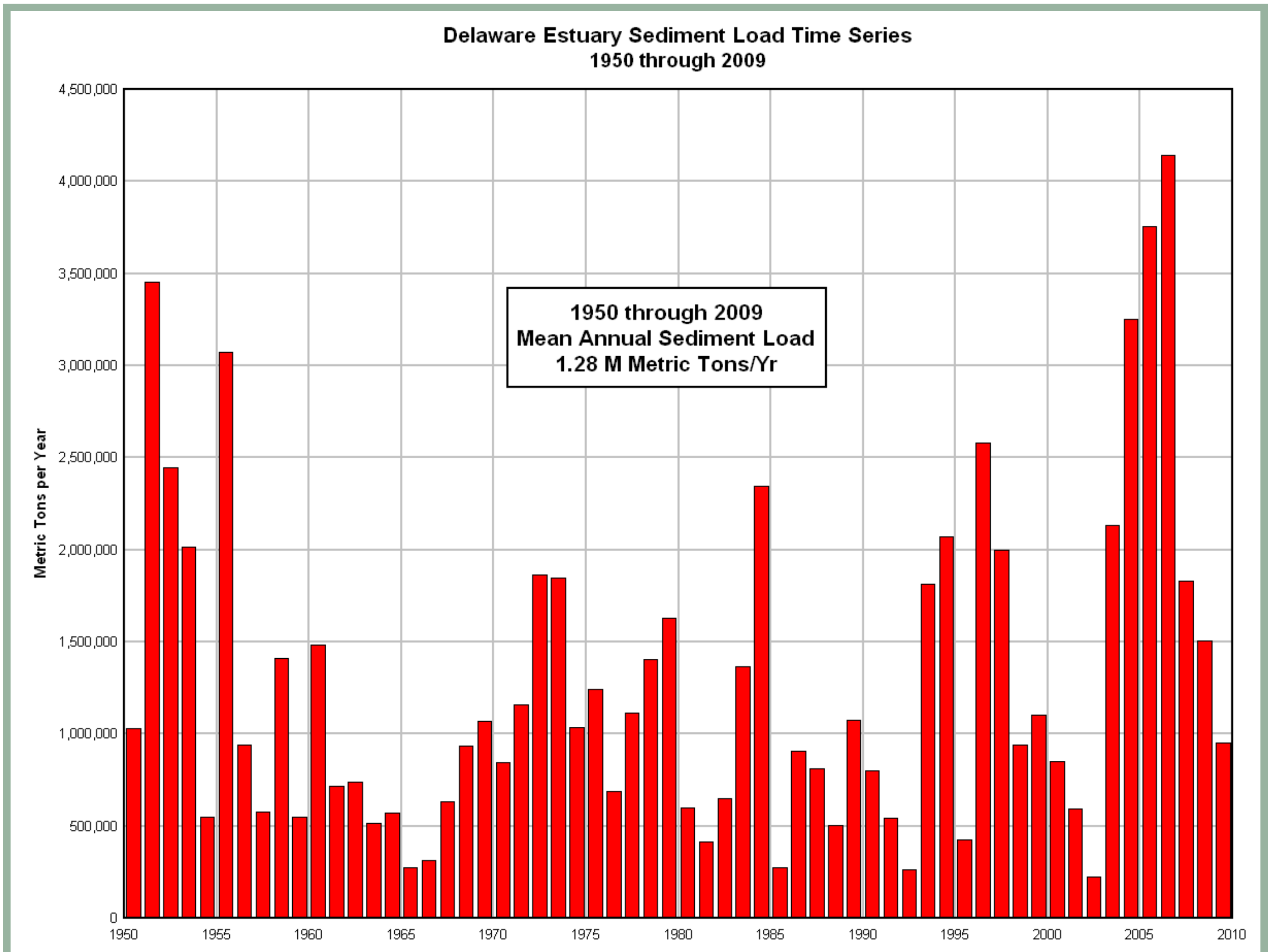

Fig. 4.1. Annual suspended load time series, 1950 through 2009

1.3 Past Trends

There is no apparent temporal trend for increased or decreased suspended sediment loading to the estuary over the past six decades.

1.4 Future Predictions

It is reasonable to expect that sediment loading in the next several decades will resemble the past 60 years. During high-flow events in the watershed, larger quantities of suspended sediment stored in and along streams will be flushed to the estuary, and the sediment load will be small in years with low inflow regimes.

1.5 Actions and Needs

Continued monitoring of suspended sediment discharge at the presently gaged locations is recommended.

1.6 Summary

The mean annual contribution of new sediment to the estuary from the watershed above the head of tide has averaged 1.3 million tons per year over the past six decades. However, the seasonal and annual variability in sediment discharge is large and reflects the underlying natural variability of the hydrologic regime of the Delaware watershed. There is no apparent trend in this record indicating either a long-term increase or decrease in sediment loading to the estuary from the watershed above the head of tide.

2 – Sediment Quantity

2.1 Description of Indicator

The most useful indicator of sediment quantity in an estuary is a spatially complete sediment budget that identifies the principal sources, sinks, pathways, and processes involved in sediment transport and distribution. In an ideal budget, all sediment sources and sinks are identified and quantified, and all processes that add, transport, and remove sediment are also identified and quantified. However, sediment transport processes are highly variable in time and space, and quantifying source and sink terms always involves a level of temporal and spatial averaging. For this reason, system-wide estimates have relatively large uncertainties associated with them. It is also important to note that a system-wide budget need not show sources and sinks being in balance. An estuary may exhibit long-term net accumulation of sediment, or long-term net loss.

2.2 Present Status

The most recent published, quantitative sediment budget for Delaware Estuary was presented in "Anthropogenic Influences on the Morphology of the Tidal Delaware River and Estuary: 1877 – 1987" (Walsh, 2004). The sediment budget data from this report is presented below as Table 4.1.

Table 4.1. 1946-1984 Estuary Sediment Mass Balance.

SOURCES		SINKS	
Bottom erosion	3.4	Maintenance Dredging	2.8
Upland Fluvial Input	1.3	Marsh Accumulation	2.6
TOTAL SOURCES	**4.7**	**TOTAL SINKS**	**5.4**

Quantities in millions of metric tons per year (Walsh, 2004)

Table 4.1 illustrates a number of salient points. First, although the source and sink term do not balance in an absolute sense, they are sufficiently close given the uncertainty of the calculations and measurements involved that they balance to a first order of accuracy. In the list of sources it can be seen that the largest category is "bottom erosion". This indicates that for the period and areas included in the analysis, scour of the bed of the estuary was observed to be the largest source of sediment available to the system, larger by a factor of 2.6 than the average annual input of "new" sediment from the watershed above the head of tide. In the list of sinks, the largest contributor is dredging, followed by sediment accumulation in marshes. This implies that despite the large lateral retreat of fringing marshes of Delaware Bay documented over the past 160 years, tidal marshes may accumulate as much or more sediment mass vertically than they lose to lateral retreat.

Although Table 4.1 represents the latest published sediment budget for Delaware Estuary, US ACE Philadelphia District is working with Woods Hole Group (Falmouth, MA) and Dr. Christopher Sommerfield of the University of Delaware to update this budget. In-progress findings of the sediment budget reevaluation include the following:

- Suspended sediment loading ("upland fluvial input"): 1.3 M metric tons/year
- Inorganic sediment accumulation in tidal marshes: 1.1 M metric tons/year

Additional items related to an updated sediment budget that will be completed by Woods Hole Group and Dr. Sommerfield within the next six months include:

- Suspended sediment inventory in the estuary based on University of Delaware oceanographic surveys
- Analysis of maintenance dredging records provided by US ACE
- Bottom sedimentological data (grain size and bulk density)
- Digital shoreline datasets – analyzed for shoreline change for periods of interest
- Digital bathymetric datasets - analyzed for bathymetric change over several periods

2.3 Past Trends

Previous investigators have compiled the sediment budgets for Delaware Estuary, including Oostdam (1971) and Wicker (1973). However, given the variety of data sources and analytical approaches applied in historic sediment budget research, it is not apparent that a meaningful historic trend can be derived from comparison of budgets created by different researchers at different times. However, the in-progress work by Woods Hole Group and Dr. Christopher Sommerfield, which applies a consistent methodology to several periods from 1890 to the present, will allow a meaningful comparison of estuary sediment budgets over time to identify historic and presumably future trends.

2.4 Future Predictions

[See above]

2.5 Actions and Needs

Sediment budget research in Delaware Estuary has evolved substantially in the past decade in terms of sources of historic data, analytical approaches to the subject, and also instrumentation to directly measure relevant hydrodynamic and sediment transport parameters. Continued efforts to improve our understanding of sediment transport phenomena and the estuary sediment budget in general are recommended, including a reevaluation of localized contribution of suspended sediment from storm and sanitary sewer discharges.

2.6 Summary

Sediment quantity is an indicator that is best represented by an estuary sediment budget. The latest published sediment budget for the Delaware Estuary indicates that the bed of the estuary has eroded at a rate that exceeds the average annual rate at which new sediment is supplied from the watershed, and that maintenance dredging is the principal mechanism by which sediment is "permanently" removed from the estuary. Ongoing research to be completed in the next six months will allow a significant quantitative improvement in identifying the processes and terms of the sediment budget.

3 – Sediment Organic Carbon

3.1 Description of Indicator

Sediment total organic carbon (TOC) is the sum amount of carbon that is bound to organic material. Organic carbon is both natural and anthropogenic in origin. Natural sources include leaf litter, plant and animal waste. Examples of anthropogenic sources of organic carbon include pesticides, municipal and industrial wastewater. It has an affinity for fine-grained sediment particles and its concentrations typically correlate with the percentage of silt and clay in the sediment.

Studies have indicated that the initial increase in organic carbon provides food to the benthos. Too much organic carbon can create an environment where opportunistic species dominate the area. If this occurs over a substantial amount of time, evidence suggests that bacterial mats will dominate the area. Elevated concentrations of TOC commonly suggest greater potential of contaminants to accumulate and impact the aquatic food web. Although the Delaware does not exhibit the typical signs of eutrophication (e.g. fish kills, algal blooms, etc.), TOC remains a useful indicator of contamination by organic pollutants.

3.2 Present Status

Data exists for TOC in two different matrices: sediment and water column. Sediment TOC data was collected and reported in Chapter 3 of the 2007 EPA National Estuary Coastal Condition Report. The existing data indicate that the concentrations of TOC in the Delaware Estuary were rated as "good" for sediment TOC. Sixty-seven percent of the estuarine area was rated "good" for this component, with 19% rated "fair". No portions of the Delaware were rated poor although it must be noted that data was unavailable for 14% of the estuary. In addition, the spatial distribution of sediment TOC was measured in sediment samples obtained in 2008 as part of the Delaware Estuary Delaware Estuary Benthic Inventory (DEBI) effort. The DEBI sample locations are included as Fig. 4.2. TOC sediment data had not been collected in this comprehensive fashion before the DEBI project in 2008 or since. In the Delaware River Watershed Source Water Protection Plan, data collected from 1993 to 2006, indicates that water column TOC are at their lowest in decades. Slight annual fluctuations were noted, especially in the maximum value of TOC detected, but the mean and median values indicated an overall decline in TOC concentrations in mg/L over the course of the last 13 years.

3.3 Past Trends

There isn't enough data regarding sediment TOC to determine a trend. For water column TOC, past trends indicate that TOC was present in greater concentrations than in the past. The system is typically turbid, and the greater the TSS, there is a greater chance of elevated TOC concentrations, especially when the sediment entering the Delaware Estuary is silty in origin. Improvements to wastewater treatment, stormwater control, and the creation of low impact development are a likely to reduce TOC in the water column.

3.4 Future Predictions

Continued improvements in wastewater treatment, storm-water management and smarter land use planning are projected to reduce the amount of TOC delivered to the Delaware Estuary. In addition, total maximum daily loads (TMDLs) associated with nutrient reduction or TSS would also help reduce the amount of water column TOC. Predictions regarding sediment TOC cannot be made at this time.

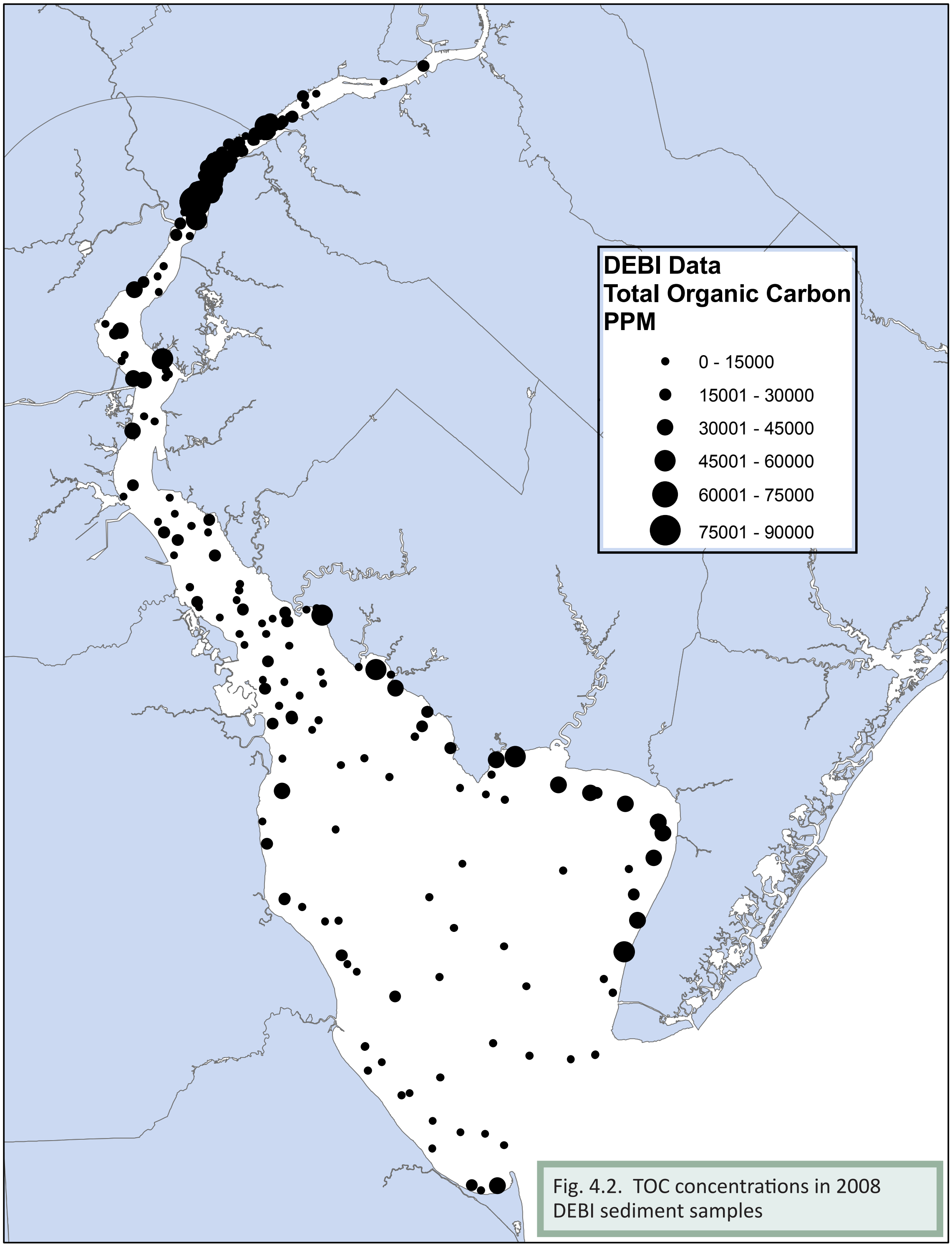

Fig. 4.2. TOC concentrations in 2008 DEBI sediment samples

3.5 Actions and Needs

It is stated in the 2007 National Estuary Program (NEP) Coastal Condition Report that the "regional NEP programs have found that the problems associated with eutrophication are dwarfed by problems from other water quality stressors". This does not mean that eutrophication is not an issue in the Delaware Estuary. It simply implies that greater concerns, such as industrial inputs to the system (i.e. PCBs) are a higher priority at this time. There are still areas of the Delaware Estuary with levels of dissolved oxygen (DO) less than 5mg/L. Although the hydromorphic features of the Delaware are favorable in creating a well mixed system, low DO levels, along with levels of nitrogen and chlorophyll a comparable to the Chesapeake Bay system insinuate that additional data regarding TOC should be collected to better understand the system.

3.6 Summary

TOC is currently being measured in the sediment and water column. A decreasing trend is associated with water column concentrations due to improvements in wastewater treatment and storm water management, while trends in sediment TOC cannot be determined until more data is collected.

4 – Sediment Grain Size

4.1 Description of Indicator

Sediment grain size in the Delaware Estuary varies across a wide range, from gravel to clay. The grain size of sediments on the estuary bottom is an ecological indicator to the extent that many benthic organisms show a preference for specific types of bottom sediments. It is natural, and expected, that different areas within the estuary will exhibit different kinds of bottom sediments. Thus, sediment grain size acts as one of the primary factors influencing the distribution of various benthic organisms and ecological communities. Another way in which grain size is an indicator is that fine grained sediment (i.e. sediment with high TOC) tends to correlate positively with elevated concentrations of industrial contaminants. Thus the spatial distribution of grain sizes contributes to the spatial distribution of contaminants.

4.2 Present Status

The present spatial distributions of sand and silt-clay content are presented in Fig. 4.3 and 4.4, respectively. The sediment grain size samples were obtained in 2008 as part of the Delaware Estuary Program DEBI (Delaware Estuary Benthic Inventory) effort. The two plots indicate the obvious inverse relationship between sand and silt-clay ("mud") fractions of Delaware Estuary sediments. The plots also indicate the heterogeneity of sediment types and patchy distribution at many locations within the estuary, particularly in the reach from Wilmington to Liston Point. In this segment of the estuary, the dominant bottom sediment type is mud whereas downstream of Liston Point, the bottom is dominated by mixtures of sand and gravel with lesser amounts of mud. The zone of dominant muddy bottom corresponds to the estuary turbidity maximum (ETM), which results from the complex interaction of freshwater inflows from upstream sources with denser, more saline water from the Atlantic Ocean.

4.3 Past Trends

Although sufficient data do not exist to assess the degree to which sediment grain size distribution may have changed over time, the 2008 DEBI data are broadly comparable to the bottom sediment distribution that is depicted in Biggs and Church (1984), Fig. 4.1.

4.4 Future Predictions

Although it is plausible to predict that sediment best management practices (BMPs) in the watershed will eventually lead to reductions in suspended sediment supply to the estuary, there is no evidence (see Fig. 4.1) of this reduction having occurred over the past six decades. It is therefore probable that there will be no significant changes in sediment grain size distribution in the estuary within the next few decades.

4.5 Actions and Needs

Sediment grain size data should continue to be collected and archived in future studies and conducted concurrently with other benthic research.

4.6 Summary

Sediment grain size is not intrinsically an indicator of estuary health. There are organisms and ecological communities that productively inhabit the full range of bottom sediment classes that exist in the estuary. Although fine-grained sediment can potentially have higher concentrations of adsorbed pollutants than sand and gravel, fine grained sediment bottom is a natural component of all estuaries and can support a range of "normal" benthic communities.

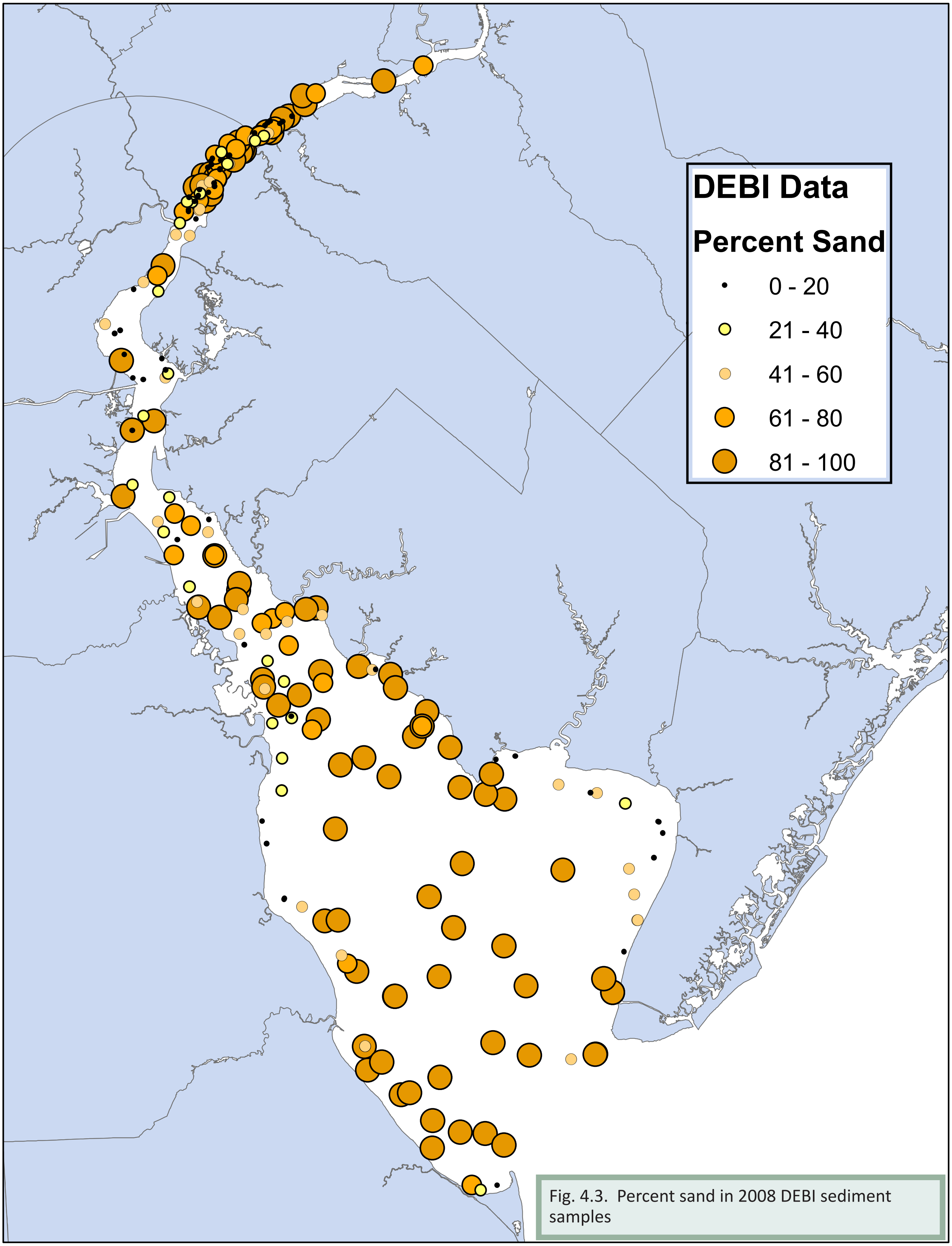

Fig. 4.3. Percent sand in 2008 DEBI sediment samples

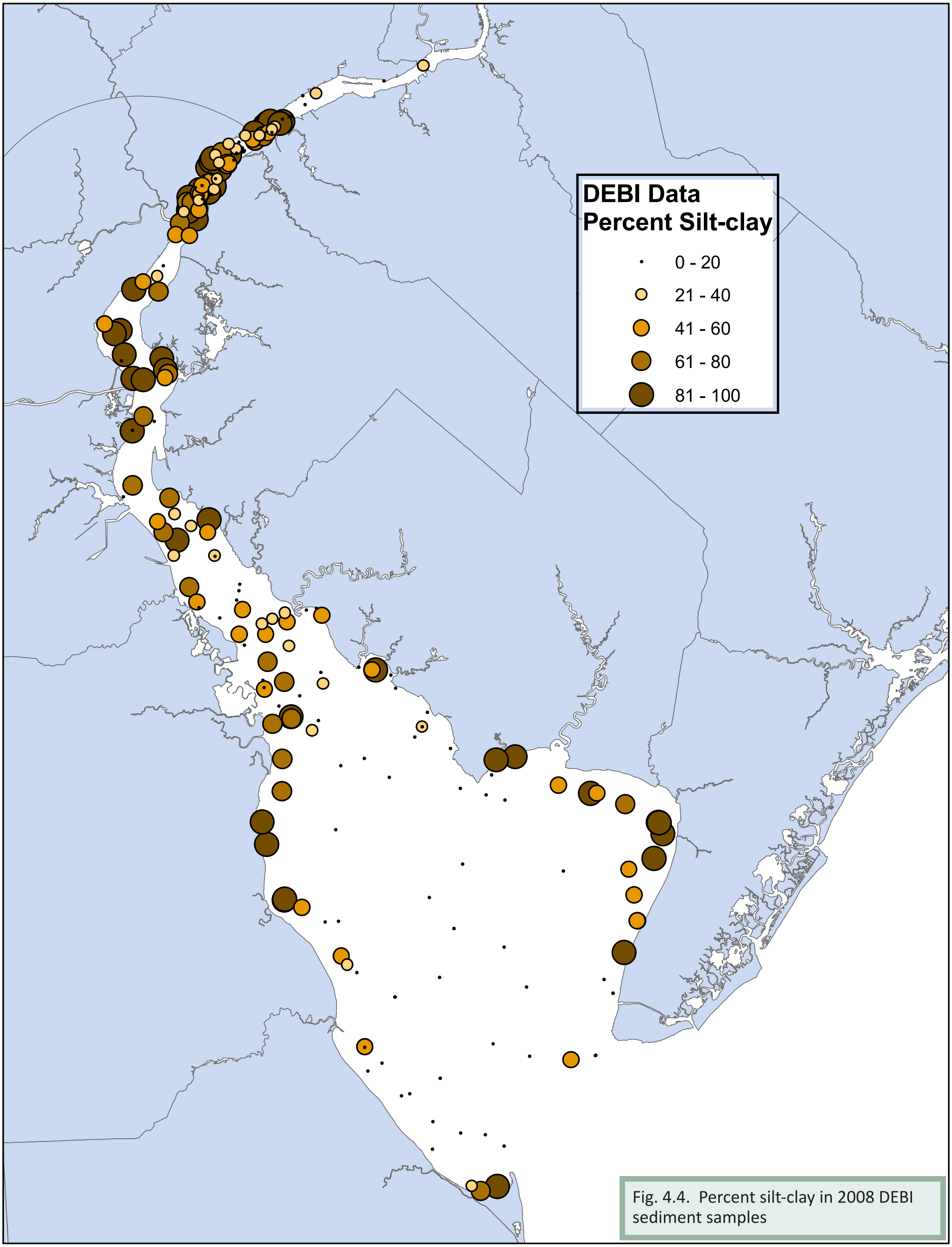

Fig. 4.4. Percent silt-clay in 2008 DEBI sediment samples

5 –Dredging Activity

5.1 Description of Indicator

As shown by the sediment budget information presented in Section 2 of this Chapter, maintenance dredging constitutes a significant component of the source and sink terms of the budget. The earliest navigation improvements within Delaware Estuary that involved dredging began in 1890 in order to meet the growing needs of waterborne commerce in the region. The US ACE has been the principal agency responsible for the construction and subsequent maintenance dredging of federal navigation projects authorized by Congress. The first project was the construction of a 7.9 meter (26 ft) deep channel from Philadelphia to naturally deep water in the bay. Between 1890 and 1942, the Delaware River, Philadelphia to the Sea channel was incrementally deepened to 9.1 meters (30 ft); 11.0 meters (36 ft); and finally to the existing channel depth of 12.2 meters (40 ft). Congress authorized the deepening of this channel to 13.7 meters (45 ft) in 1992, and a portion of that work has been initiated as of 2011. Each successive channel deepening has created a quantity of "new work" dredging. Following completion of dredging to a specified depth, "maintenance" dredging is performed periodically to remove shoaled sediment from the channel in the interest of navigational safety and efficiency. Other deep-draft navigation projects in the estuary include: Delaware River, Philadelphia to Trenton; Wilmington Harbor, Christina River, DE; and Schuylkill River, Philadelphia, PA. The Delaware River, Philadelphia to Sea channel is the longest and deepest of all navigation channels in the estuary, and correspondingly has required the largest dredging effort, approximately 74% by volume, of all Delaware Estuary dredging over the past decade.

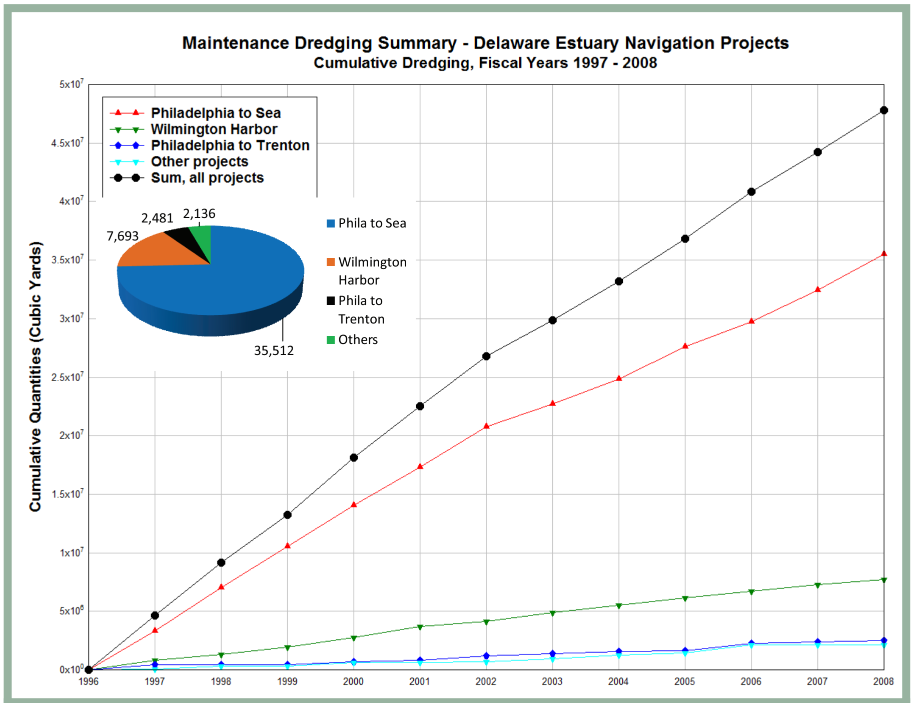

Fig. 4.5. Cumulative maintenance dredging, Federal navigation projects in Delaware Estuary, 1997 – 2009

5.2 Present Status

The cumulative maintenance dredging from all Federal navigation projects in Delaware Estuary for the period 1997 through 2008 is presented in Fig. 4.5, and illustrates the relative portion of Delaware Estuary dredging associated with each project. The average annual total of all Delaware Estuary dredging in this period is 3.1 million cubic meters (4.0 million cubic yards) per year. Channel shoaling, and hence channel dredging, is a highly localized phenomenon. There are four high shoaling-rate locations in the estuary within a 30 km reach between the C&D Canal and Marcus Hook (including the Wilmington Harbor project) that together necessitate about 80% of all maintenance dredging within the entire estuary. Note that since 1955, essentially all sediment dredged from the estuarine system has been placed in upland dredged material disposal sites.

5.3 Past Trends

Maintenance dredging quantities have been compiled in a number of US ACE reports. A 1937 report (US ACE, 1937) states "maintenance dredging amounting to about ten million cubic yards annually" was required over the preceding 25 years. Subsequent US ACE reports (US ACE 1967, US ACE 1984) also present estimated annual navigation project dredging in the estuary. Fig. 4.6 presents the annual dredging rates from these four dates (1937, 1967, 1984, and 2009). Where data were reported for projects in addition to the Philadelphia to Sea channel, these are included in

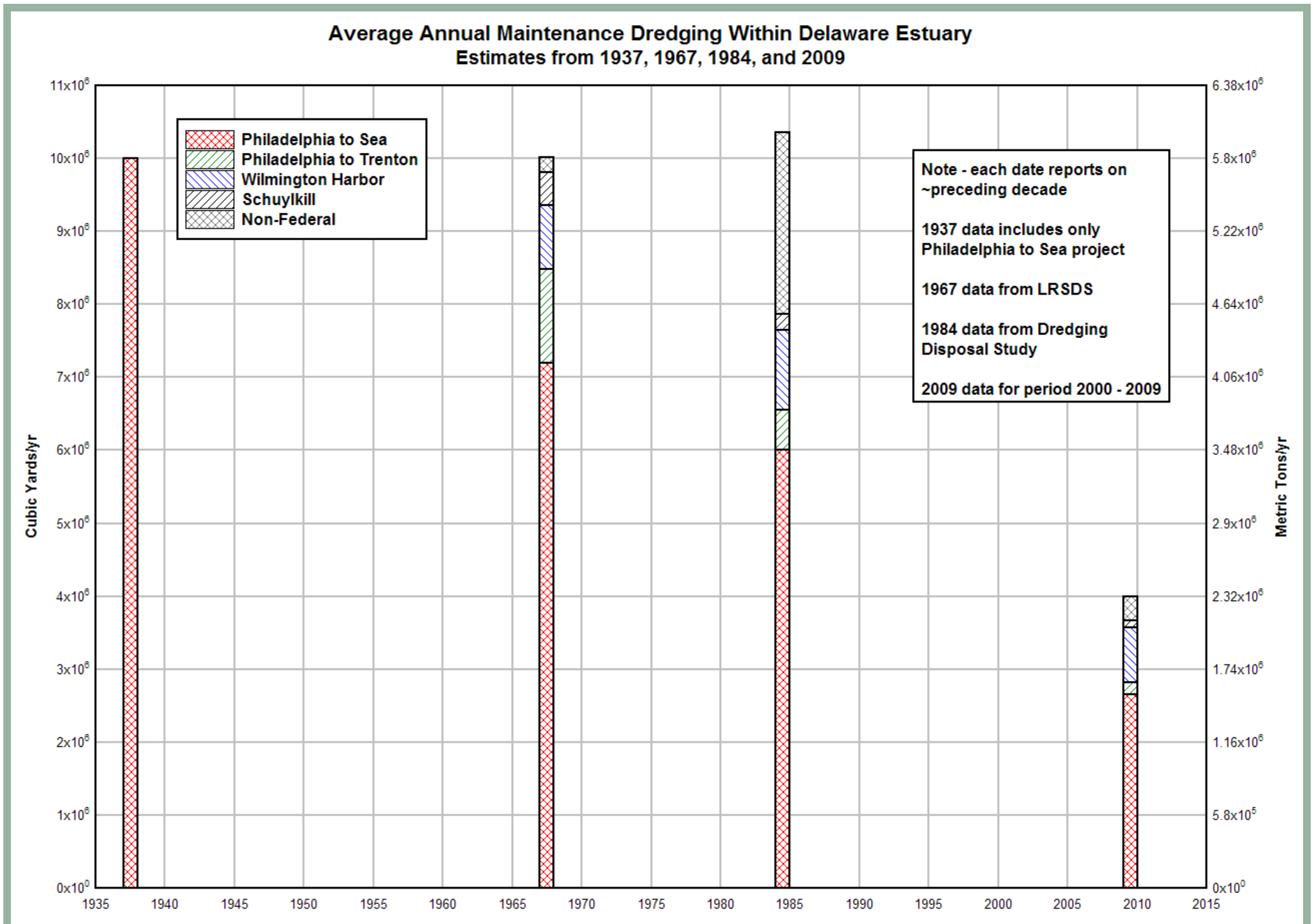

Fig. 4.6. Historic maintenance dredging rates in Delaware Estuary

Fig. 4.6. The quantities are displayed in terms of cubic yards per year on the left axis and are converted to their corresponding sediment mass values of "metric tons per year" (right axis) using the relationship of 753 kg/m3 (see Walsh, 2004). The quantities display the trend of reduced maintenance dredging over the past several decades.

5.4 Future Predictions

The deepening of the Delaware River Main Channel from 12.2 meters (40 ft) to 13.7 meters (45 ft) is expected to lead to approximately a 20% increase in annual maintenance dredging.

5.5 Actions and Needs

Continued monitoring and reporting of maintenance dredging quantities is a routine function of US ACE. It is recommended that future work on all aspects of Delaware Estuary sediment management and sediment budget investigations include regular coordination with US ACE regarding dredging quantities.

Beginning in 2009, US ACE and several other organizations began to work collaboratively to develop a Regional Sediment Management Plan. Prior to this, there had been no systematic approach to dealing with the challenges and opportunities associated with sediment management in the Delaware Estuary region. The Regional Sediment Management initiative is intended to broaden local knowledge and facilitate watershed collaboration about how, where, and when to manage parts of the sediment system differently and more beneficially than has been previously practiced. The Plan is currently under development.

5.6 Summary

Dredging activity is not a conventional ecological indicator. It is a direct measure of the degree to which sediment shoals within navigation projects must be removed in the interest of safe and efficient navigation. The historic trend over the past five decades has been for diminished average annual dredging quantities, but the cause of this decline has not been rigorously investigated to date.

Chapter 4 - References

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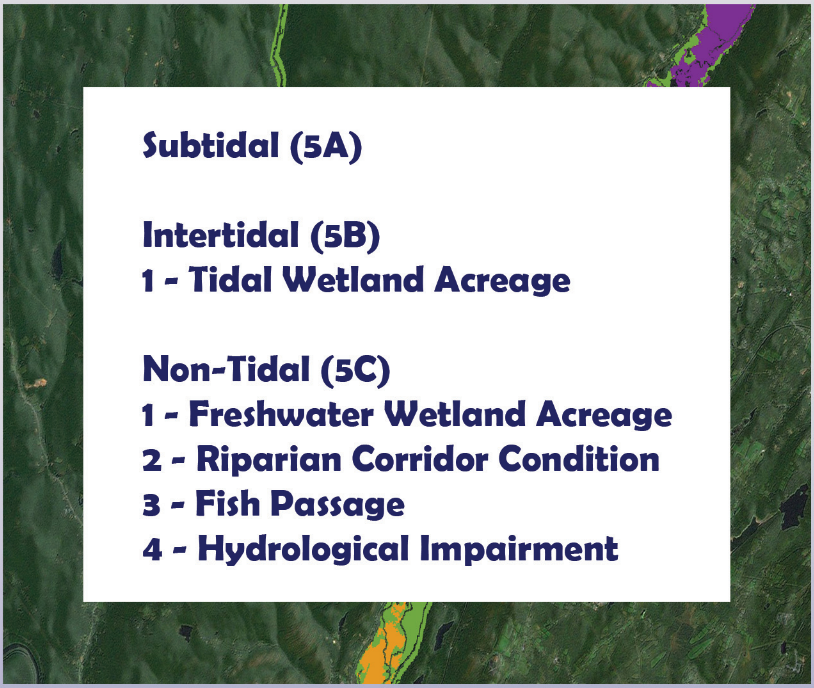
Aquatic Habitats



Subtidal (5A)

Intertidal (5B)
1 - Tidal Wetland Acreage

Non-Tidal (5C)
1 - Freshwater Wetland Acreage
2 - Riparian Corridor Condition
3 - Fish Passage
4 - Hydrological Impairment

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5 – Subtidal Aquatic Habitats

Introduction

While surveys of the benthos have occurred in the Delaware Bay and River since the 1950's (Table 5.2) the recent Delaware Estuary Benthic Inventory (DEBI) is the most comprehensive and intensive ever conducted. Due to the extent of the data produced in the DEBI project, it is the focus, though not exclusively, of this indicator.

PDE

Fig. 5.1. Pictures are from sampling during the 2009 Delaware Estuary Benthic Inventory (DEBI)

The DEBI project was lead by The Partnership for the Delaware Estuary, one of twenty-eight National Estuary Programs. In 2005, The Partnership for the Delaware Estuary recognized a fundamental need for a benthic ecosystem assessment that would inventory the physical and biological conditions of the bottom of the open water tidal system of the Delaware River and Bay. This priority need was articulated in early 2005 when the Partnership convened a science and management conference that brought together more than 250 scientists, managers and science-interested people to summarize the current state of science and to identify and prioritize science and management needs for the Estuary. Consensus views from the conference were summarized in the "White Paper on the Status and Needs of Science in the Delaware Estuary" (Kreeger, et al 2006) that called for a better understanding of benthic conditions.

Soon after the white paper, The Partnership and its collaborators around the estuary designed The Delaware Estuary Benthic Inventory (DEBI) program to fill the vital data gap in our understanding of the estuary's ecosystem by characterizing the biological communities on the bottom. By adding a more spatially comprehensive biological layer to existing maps of physical bottom conditions and historical surveys of benthic communities, findings from DEBI are expected to aid scientists and coastal managers interested in trophic relationships, fisheries, pollutant distributions, water quality, and other topics. These results also furnish an important baseline for tracking future ecosystem responses to changing climate and expanded development in the watershed.

A top priority of this project was to use standard methods to examine the spatial distribution and relative abundance of bottom communities living in soft-bottom substrates that span the broad salinity gradient of the Delaware Estuary. Sediment chemistry and water quality were also examined at the same sample stations. A second priority was to explore biological communities living on selected hard-bottom habitats. Although the RARE-funded project was of foundational importance in launching the program and furnishing base layers, follow-up studies are planned to continue DEBI, such as further exploration and mapping of hard bottom communities and mapping of benthic ecosystem services.

By creating a biological layer, to complement existing habitat and bathymetry layers, insight can be gained to the benthic communities that inhabit the bay and river. Benthic invertebrates tend to live a longer life then most planktonic organisms and can therefore suggest the environmental conditions over time. The Delaware Bay and River consist of both hard bottom and soft bottom, each revealing different knowledge. The soft bottom is a dynamic system that can reveal information about anthropogenic inputs, the history of anthropogenic changes caused to hard bottoms in the lower bay and the legacy that it has left is also of relevance. These changes have possibly lead to compositional and structural changes to the biological communities.

As a first step in launching DEBI, the Partnership for the Delaware Estuary (PDE) partnered with US EPA Regions 2 and 3, US EPA of Research and Development (ORD), and other academic and agency partners to create a technical workgroup affiliated with the PDE Science and Technical Advisory Committee. PDE and this workgroup held workshops and summarized existing benthic data from seven prior bay-wide scientific studies. In addition, specimen collections from surveys by William Amos and colleagues in the 1950's were retrieved from storage and digitalized to augment the growing compendium of existing benthic information.

The soft-bottom survey was completed during the summer of 2008, consisting of 230 sampling sites from the mouth of Delaware Bay to the confluence of the Schuylkill and Delaware River, stratified by three salinity zones and sampled using a probabilistic design. EPA Region 3 provided critical in kind support for the 2008 cruises, including ship time and staffing. Bottom grab samples were taken at each station and split for biological taxonomic examination and chemical analyses. EPA Region 3 analyzed samples for a suite of sediment chemistry parameters, and the Delaware River Basin Commission examined splits samples for PCBs. Macroinvertebrate analyses were conducted via a subcontract to Versar Inc.

Exploratory surveys of selected hard bottom habitats were conducted in 2008, 2009 and 2010. Hard bottoms are more difficult to survey than soft bottoms in the Delaware Estuary because of naturally high turbidity and the ineffectiveness of grab samplers used for soft bottoms. Consequently, much less is known about these areas despite the belief that they are biologically active and ecologically important. Epibenthic sleds, oyster dredges, divers, and ROVs were used, where possible, yielding important new information for areas that were surveyed. For example in the lower bay, extensive "sponge gardens" and worm reefs were found in deeper troughs using the dredge, and divers observed greater fish use of these complex habitats compared to adjacent sand soft-bottoms. In the freshwater tidal zone of the estuary, at least two types of SAV and seven species of scarce or rare unionid mussels were discovered in substantial abundance. Two of the mussel species were considered locally extinct by state agencies. These discoveries of sensitive, rare biota were unexpected considering that they were found in the urban corridor which has had historically poor water quality. Although further work is needed to examine their range and abundance, these beds of freshwater mussels and SAV (which coexisted in many areas) could be important for sustaining fish habitat and water quality in the upper estuary.

Taken together, results from the soft- and hard-bottom surveys have yielded important discoveries and provided the most spatially complete biological layer ever for the bottom of the Delaware Estuary. The new biological layer clearly shows that bottom communities of the Delaware Estuary are spatial complex, spanning the many salinity zones and influenced by the presence and absence of sediment chemistry and stressors. From this layer climate change scientists will have a comprehensive baseline to track future changes in biological communities. The Delaware Estuary has over 200 migrant and resident finfish species that use the Estuary for feeding and spawning, and these new data will also provide managers with a better geospatial understanding of how benthic food resources and habitat support fisheries productivity and/or critical habitat for endangered species such as sturgeon. Maps of filter-feeding organisms may lead to a better understanding of pelagic-benthic coupling and ecosystem services that benefit water quality. Certain hard-bottom communities such as intertidal sabellaria reefs and shallow subtital oyster reefs are also increasingly appreciating for helping offset storm surge and coastal flooding.

The work supported by the RARE grant greatly increased our understanding of the estuary's bottom ecology and will have a direct bearing on diverse management priorities. More effort will be needed to build on the DEBI data to increase our understanding of benthic processes, hard-bottoms, and temporal (seasonal or inter-annual) variability that occurs across the Delaware Estuary. To track anthropogenic and climate driven changes, the benthic biota should also be broadly sampled using comparable methods at least every ten years.

5.1 Description of Indicator

Because of their abundance, diversity, sessile nature and recognized responses to environmental conditions, benthic organisms have long been used to assess the "health" of estuarine systems. In this context, the responses of the benthos to disturbance, organic enrichment associated with eutrophication and pollution, including oil and heavy metals, are of particular interest. To obtain benthic faunal data, typically a grab sampler is used to retrieve a bottom sample, and the sample is subsequently sieved to retain animals, which are then preserved. In the laboratory, macrofauna are identified, enumerated and weighed, allowing metrics such as the number of species, diversity indices or other statistical comparisons of stations to be computed. Examinations of patterns in these metrics are then used to infer the state of, or trends in, the benthic community. Alternatively, direct comparison of assemblages between impacted and reference sites may be used to infer habitat degradation and by extension the overall state of the benthic system. The condition of the benthic community is well known to respond to physical (especially salinity and sediment properties such as particle size) and biological (primary productivity, food web structure, especially predators) factors as well as chemical stressors (e.g., organic enrichment, metals, oil and other organics). Typically, estuaries are spatially and temporally variable in these physical, biological, and chemical factors, and benthic species abundance and assemblage composition is accordingly found to be highly variable in time and space as well. In addition, the faunal or assemblage response(s) to a given factor are often not unique, that is, an observed change cannot always be associated with a single causative agent (i.e., chemical), trend, or process, whether natural or anthropogenic. Polluted sites may have assemblages resembling that of naturally disturbed sites and to complicate matters further, stressors may act in combination, and cause and effect may thus be difficult to resolve using simple measures, especially where observed differences are embedded within the overall natural variability of the estuarine environment.

This is the first time an analysis of the subtidal benthic community has been used as a metric in the Technical Report for the Delaware Estuary & Basin report. We review the most recent and most extensive sampling of the bay conducted under the aegis of the Delaware Estuary Benthic Inventory (DEBI) project and present some preliminary findings and conclusions. These results are then placed in the context of past surveys and followed by some consideration of the use of historical surveys for assessing trends across decadal time scales.

5.2 Present Status

In summer 2008, DEBI was conducted to gather soft-bottom benthic data, with extensive benthic grab and water column sampling. 229 sites were allocated throughout the Delaware Bay and River in a design based on random locations within salinity and bottom sediment strata. Sediments were sampled using a 0.04-m^2 modified Young grab, sieved on a 0.5-mm mesh, and processed as described above. A summary of environment parameters measured during this survey is presented in Table 5.1. Benthic species composition, sediment characteristics, and measurements of metal concentrations as potential stressors were analyzed using diversity indices, multivariate ordinations, and dominance curve techniques.

Table 5.1. Summary of benthic Surveys in the Delaware River and Estuary conducted 1951-2008. (< D.L. means below the detection limit)

Parameter	Mean	Minimum	Maximum	Units
Salinity	13.3	0.2	31.8	‰
Temperature	24.8	17.1	27.8	°C
Dissolved Oxygen	6.8	4.3	11.8	Mg/l
pH	7.7	7.0	8.5	-
Turbidity	41.3	3.4	919.2	NT/U
% Sand	58.4	0.8	98.8	%
Total Organic Carbon	1.6	<D.L.	7.8	%
Arsenic	7.35	<D.L.	330	$\mu g \cdot g^{-1}$
Cadmium	0.44	<D.L.	4.6	$\mu g \cdot g^{-1}$
Chromium	23.7	1.1	132	$\mu g \cdot g^{-1}$
Copper	13.5	<D.L.	112	$\mu g \cdot g^{-1}$
Lead	22.6	1.4	256	$\mu g \cdot g^{-1}$

Overall, 233 benthic species were identified in 112 families and 9 phyla. Five stations had 40 or more species and the mean species richness (number of species) was 13. The most diverse groups were: polychaetes (27 families, 79 species), amphipods (15 families, 35 species), bivalves (17 families, 27 species), and gastropods (15 families, 25 species). The mean benthic invertebrate abundance was 8,800 individuals per square meter. The greatest total abundance was 142,000 individuals per square meter at Egg Island Point; this abundance was dominated by the polychaetes, *Sabellaria vulgaris* (See both feature boxes at the end of the section) and *Polydora cornuta*. The most abundant single species at any station was the bivalve, *Gemma gemma* (71,000 individuals per square meter) near Nantuxent Creek. The dominance by polychaetes, bivalves and amphipods was expected for the estuary's mixed sand-silt sediment as well as from previously published studies, although the abundances reported here are considerably larger than some previous reports (as discussed below). Together, the DEBI data represent the most intensive and comprehensive assessment of the Delaware Estuary's benthic fauna ever conducted, and these data are especially valuable in comparison with surveys of Delaware Bay conducted in the 1950's, 1970's, and more regularly since 1990 (Table 5.2).

Table 5.2. Summary of benthic Surveys in the Delaware River and Estuary conducted 1951-2008 in DEBI final report

Metadata	Amos DRIC	Maurer et al.	EMAP	NOAA S&T	MAIA	NCA	DEBI	Comments
Year(s) and Seasonality	1950's, mostly summer	1972-73, summers	1990-1993, summers	1997, September	1997-98, summers	2000-2006, summers	2008, summers	Summertime for peak abundances, most favorable weather
Spatial Domain	Delaware River and Estuary	Delaware Bay	Delaware Bay	Delaware River and Bay and coastal Atlantic	Delaware River (to Trenton) and Bay	Northeast US, Delaware Bay to Maine	Delaware River and Bay	
Number of Stations	Estimated to be about 130	207	25	81	88	138	230	Remarkably, almost stations 900 over all 7 surveys
Sampling Design	Various, piggybacked on hydrographic and zooplankton projects	Lines running along channels, bathymetry	Probabilistic	Probabilistic with strata	Probabilistic	Probabilistic with strata	Probabilistic with salinity and sediment strata	
Sampling Gear	Grabs, dredges, buoy scrapings, plankton tows	0.1 m^2 Petersen grab and 1.0-mm mesh	EMAP grabs and water quality, 0.5-mm mesh sieve	Young modified Van Veen, 0.5-mm mesh sieve	0.04-m^2 Young-modified Van Veen grab sampler, 0.5-mm mesh screen	0.04 m^2 Young-modified Van Veen, 0.5-mm mesh sieve	0.04 m^2 Young-modified Van Veen, 0.5-mm mesh sieve	Note differences in sampling gear and sieve mesh sizes
Additional Data	Hydrographic	Hydrographic and sediment	Hydro-graphic, sediment and stressors	Hydrographic, sediment and stressors	Hydrographic, sediment and stressors	Hydro-graphic, sediment and stressors	Hydrographic, sediment and stressors	Hydrographic: temperature and salinity; sediment: grain size or % sand, % silt-clay; stressors: DO, heavy metals, organic pollutants
Total Number of Species	≈396, but includes plankton, epifauna species	169	268	239	179	203	235 with Taxonomic Serial Numbers (TSN's)	
Mean Abundance	Not applicable, presence/ absence sampling only, abundances not recorded	722 m^{-2}	[to be computed]	Mean densities: 1412.5 m^{-2} to 26985.0 m^{-2}, but Hartwell and Hameedi report mean of 451 m^{-2}(?)	[to be computed]	770 m^{-2} from all stations [to be computed for just Delaware Bay]	Nearly 9000 m^{-2}	Values to be recomputed to ensure valid comparison
Statistical Methodology	n/a, see below	Cluster analysis	EMAP BI	Cluster analyses	Benthic indices	PRIMER MDS ordination and VPI and B-IBI indices	Diversity indices, ordination plots, dominance plots	
Overall Conclusions	1st survey, data exceeded manual analysis, data awaits analysis (2011)	Low abundance implies low productivity, faunal assemblages better related to sediment than salinity	One-fourth of the Delaware Estuary has impacted benthic communities	Diversity and abundance lowest in low salinity dominated by tubificids and oligochaetes; species richness correlated with grain size	One-third of Delaware Estuary received poor score using Paul, et al (1999) benthic index (EMAP-VP)	Ordination suggests salinity and latitude subregions; NCA data with VPI: 34% good, 29% poor, 37% missing	Salinity drives distribution and diversity overall	Distinct estuarine fauna as in, e.g., Remane diagram, but recent studies discount existence of true "estuary species" and interpret distribution and assemblages in light of salinity, sediment and stressors
Key References	Amos (1952, 1954 and 1956) but largely	Maurer et al. (1978), Kinner et al. (1974)	Billheimer et al. (1997), Billheimer et	Vittor (1998), Hartwell et al. (2001) Tech Memo	USEPA 2002. EPA/620/R-02/003	Hale (2011)	[This report is the first look at these data]	
Web URL for Data	Digitized, awaiting analysis	Results published, availability of raw data unknown	http://www.epa.gov/emap/html/data/geographic.html	http://ccma.nos.noaa.gov/about/coast/nsandt/download.aspx	http://www.epa.gov/emap/maia/html/data/estuary/9798/index.html	http://www.epa.gov/emap/nca/index.html	http://www.delawareestuary.org/science_projects_bay bottom.asp	

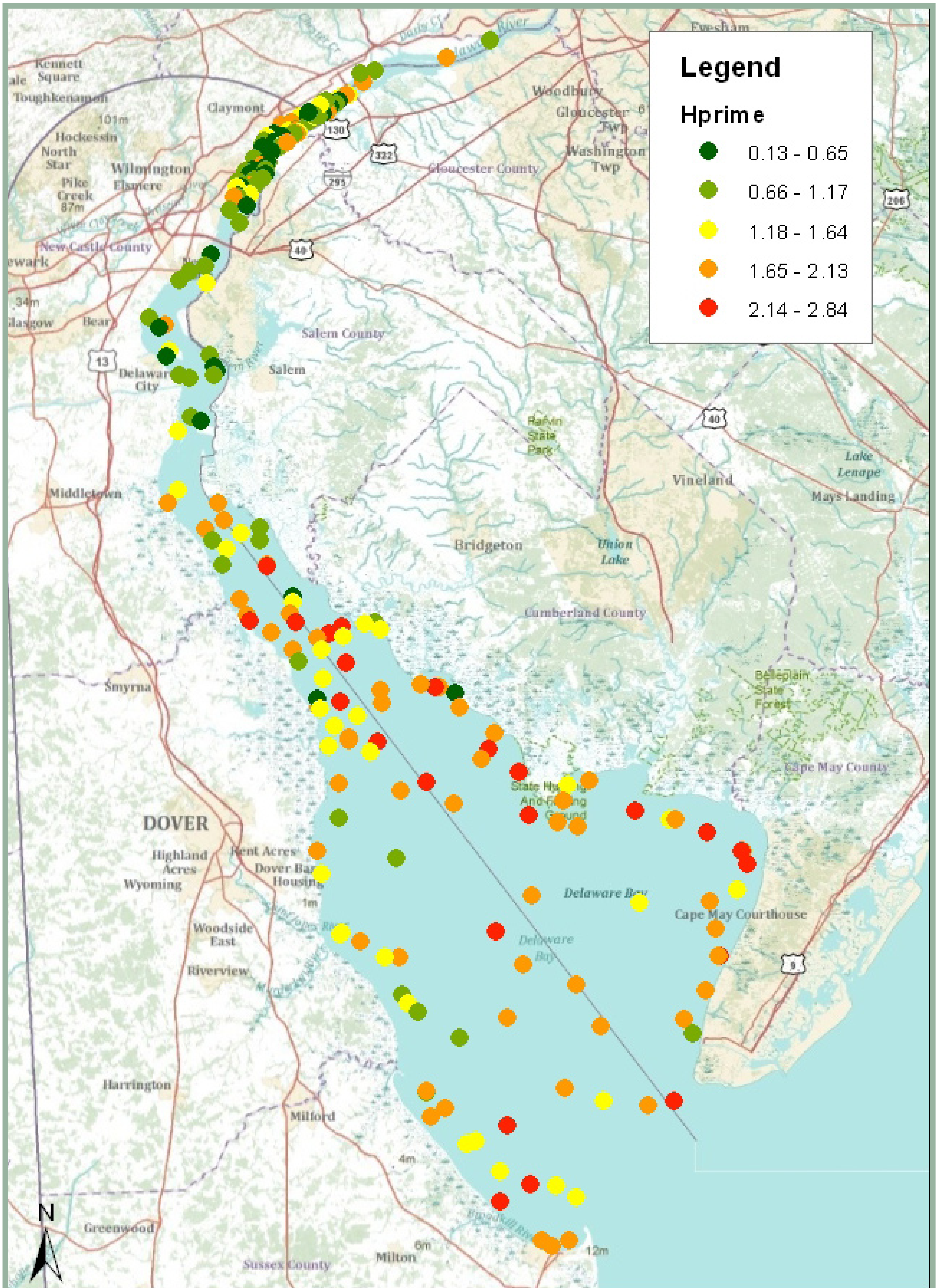


Fig. 5.2. Dots show DEBI sampling locations, and are colored to show benthic diversity in a spatial context, using the Shannon-Wiener diversity index, H'

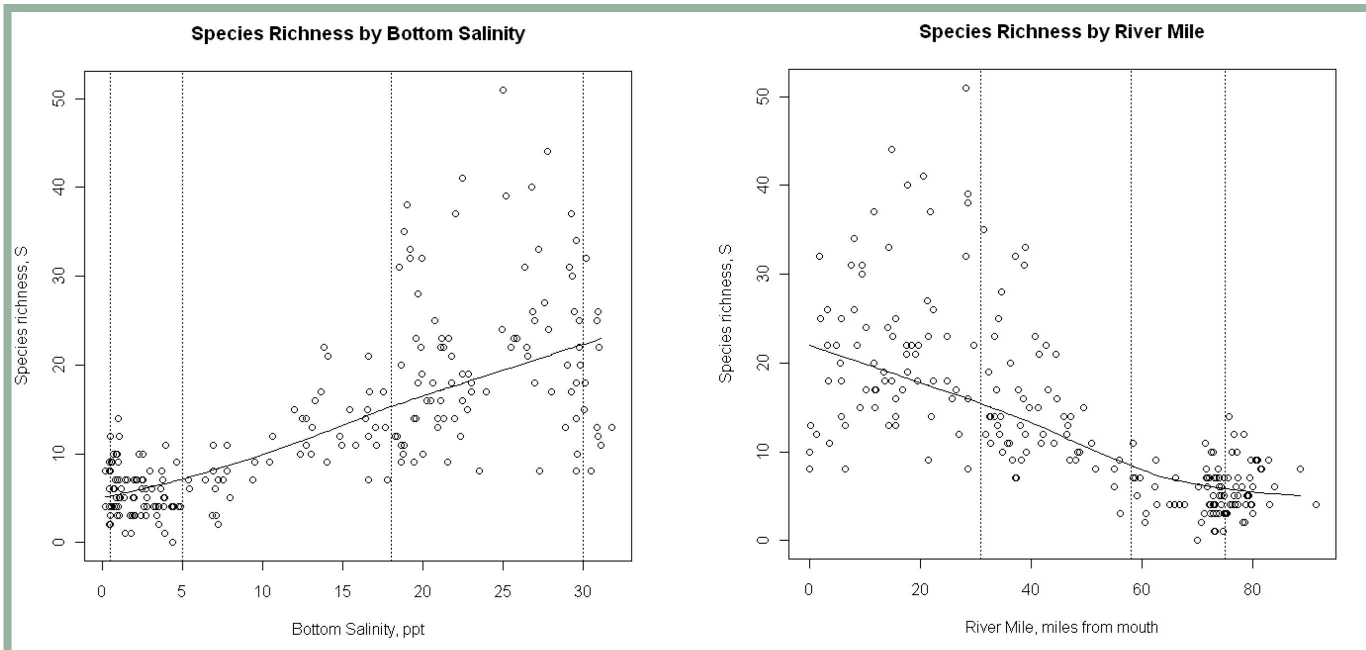


Fig. 5.3. Patterns of benthic species diversity, comparing species richness versus bottom salinity, and comparison of species richness versus river mile.

Figures 5.2 and 5.3 display the estuary-wide patterns of benthic species diversity. Species richness (number of species) versus bottom salinity and river mile, with approximate demarcations of polyhaline, mesohaline, oligohaline, and tidal freshwater zones. Both plots show a characteristic shape of a Remane diagram (Remane and Schlieper 1971) where the pattern is of high diversity at the bay mouth (and at high salinity), decreasing upstream into the mesohaline, reaching a minimum, then higher (and here, more variable) in the oligohaline (near 80 miles from the bay mouth). This is the pattern of benthic diversity commonly seen across estuaries and described in marine ecology textbooks, see Levinton (2001) or Kaiser et al. (2005) and references therein. Figure 5.2 shows benthic diversity in a spatial context using another commonly used metric, the Shannon-Wiener diversity index, H'. The interpretation of this plot is similar to those in Fig. 5.3: the concentration of red and orange dots in the lower bay suggests higher diversity there as compared to the riverine sections of the bay denoted by green and black dots.

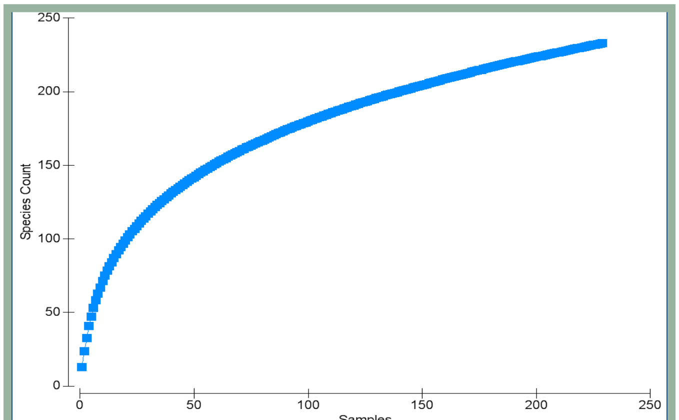


Fig. 5.4. Species accumulation curve, number of species versus number of samples taken during DEBI project.

Figure 5.4 is a species accumulation curve showing the number of species expected versus number of samples taken in the DEBI survey; as more samples are taken, more species are recorded. A leveling off of this curve would indicate that few new species would be recorded by additional sampling, and thus the asymptote represents the total diversity as number of species in the estuary. The shapes of these curves (i.e. initial slope and asymptote) can be compared among studies in order to gauge the effectiveness of sampling and assess the degree to which the full diversity has been sampled. The upward slope at the right of the DEBI curve shown here indicates that even this extensive survey did not capture the full (technically, alpha) diversity of the Delaware Bay soft-bottom benthos. However, the observed diversity of 233 species is generally consistent with other surveys summarized in Table 5.1.

A more detail view of the estuary's benthos is provided using a non-metric multidimensional scaling (MDS) ordination of the full species by assemblage abundance

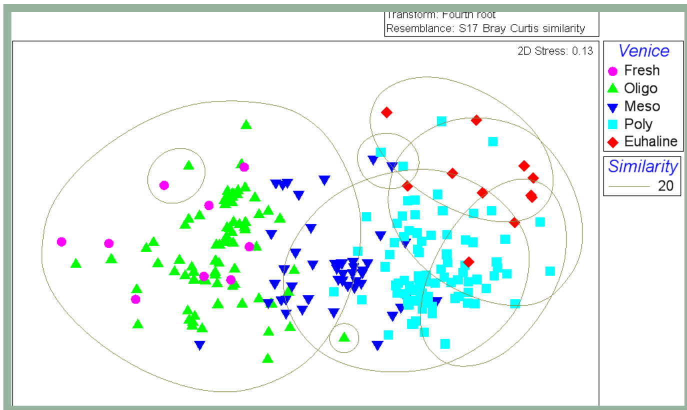


Fig. 5.5. MDS ordination analysis showing species similarities based on salinity zones.

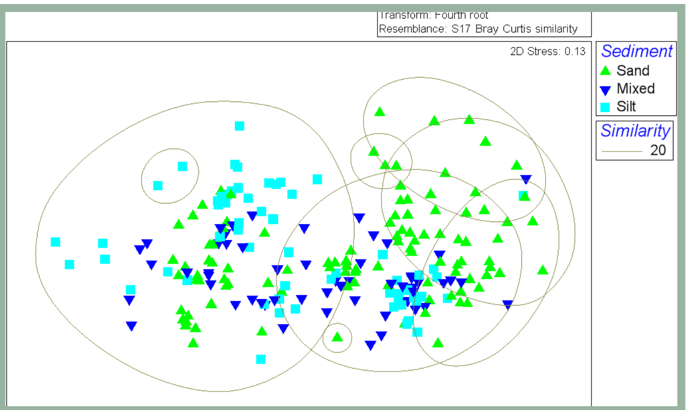


Fig. 5.6. MDS ordination analysis showing species similarities based on sediment type.

matrix. Figures 5.5 and 5.6 show all 299 stations' similarities based on all 233 species using fourth-root transformed abundances and the Bray-Curtis similarity metric, computed using the PRIMER-E package (Clarke and Warwick 2001, Clarke and Gorley 2006). Each symbol represents a station: symbols close together have similar species composition (low dissimilarity), while points far apart differ in species composition (i.e. are dissimilar) in accordance of their separation. The stress value reported here, 0.13, indicates that the two-dimensional plot adequately represents the multivariate (high-dimensional) dissimilarities among stations. The broad ellipses represent groups of stations determined as by a cluster analysis as superimposed on the ordination and are shown here for visual reference. When stations are coded by salinity zone (Fig. 5.5) it is clear that benthic assemblages relate to salinity, with freshwater and oligohaline stations grouped together on the left, mesohaline are concentrated in the middle and polyhaline and euhaline fall together to the right. Figure 5.6 is the same ordination (i.e., the pattern of station points is identical), but the color key represents sediment grain size measured as percent sand. Sandy, silty-sand and silty sites are not separated, but intermixed and not clearly related to species composition, thus sediment composition is not simply associated with broad patterns in species composition. As was found using simple diversity metrics, salinity is the dominant factor correlated with benthic community structure.

Additionally, MDS ordination plots of benthic assemblages can be used to investigate the benthic response to stressors. Figure 5.7 shows four such ordinations (with points identical to those already shown) with the symbol size representing the level of each of four potential stressors: (5.7a) dissolved oxygen near bottom, (5.7 b) total organic carbon, (5.7C) cadmium and (5.7d) chromium. Dissolved oxygen measured near the bottom was in all cases 4.4 mg/l or greater (Table 5.1), and it is not surprising that there is little association of bubble size with stations clusters or broad patterns in the ordination in panel (5.7a). Total organic carbon show larger bubbles associated with stations in the upper and lower bay (5.7b), likely associated with fine sediments (compare

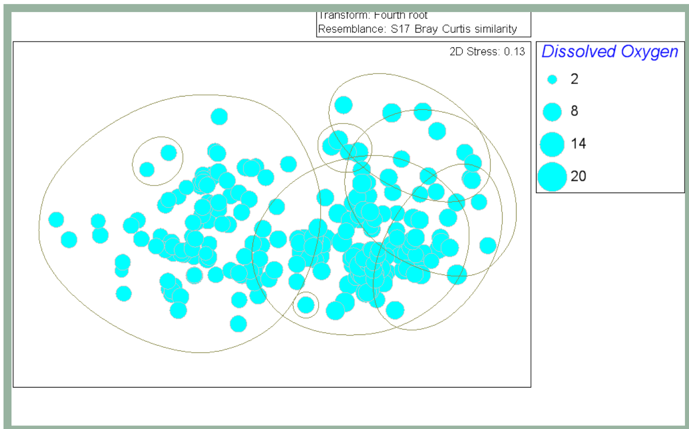


Fig. 5.7a. MDS ordination analysis showing species similarities based on dissolved oxygen.

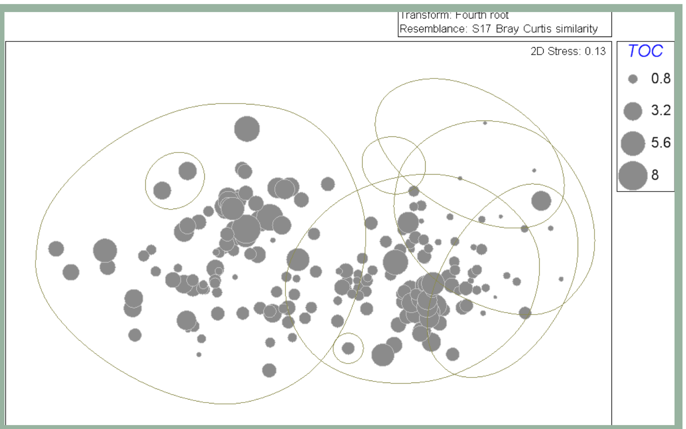


Fig. 5.7b. MDS ordination analysis showing species similarities based on total organic carbon.

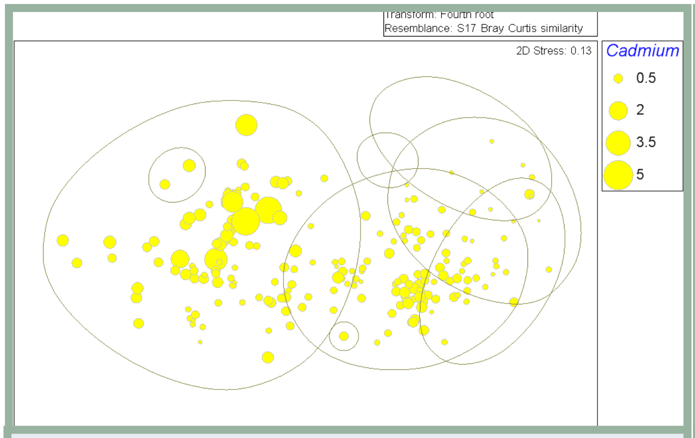


Fig. 5.7c. MDS ordination analysis showing species similarities based on cadmium.

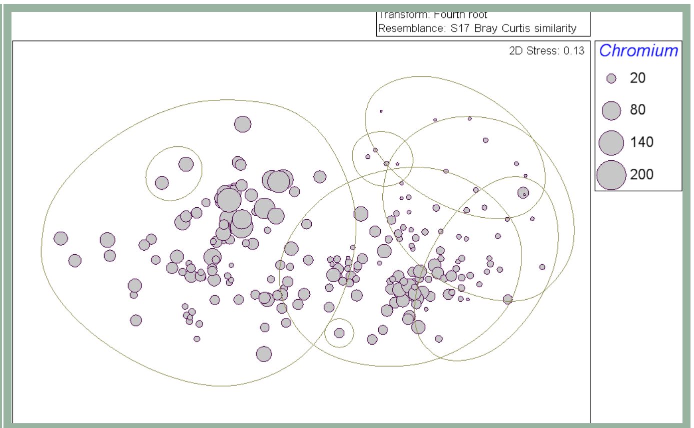


Fig. 5.7d. MDS ordination analysis showing species similarities based on chromium.

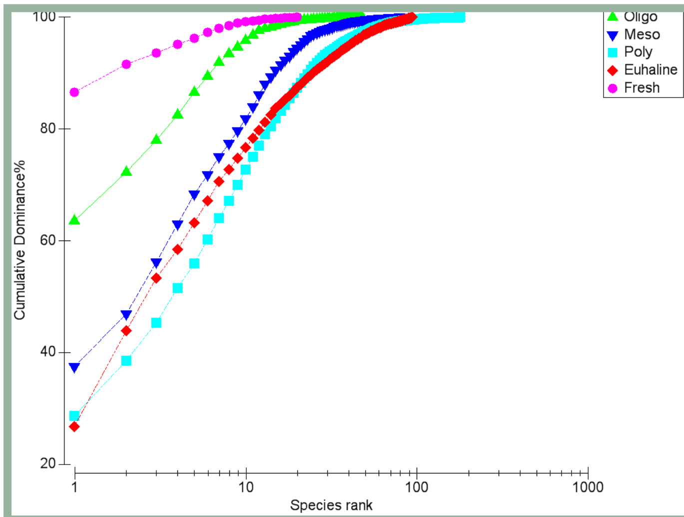


Fig. 5.8a. Dominance curves for DEBI species data, pooled by salinity.

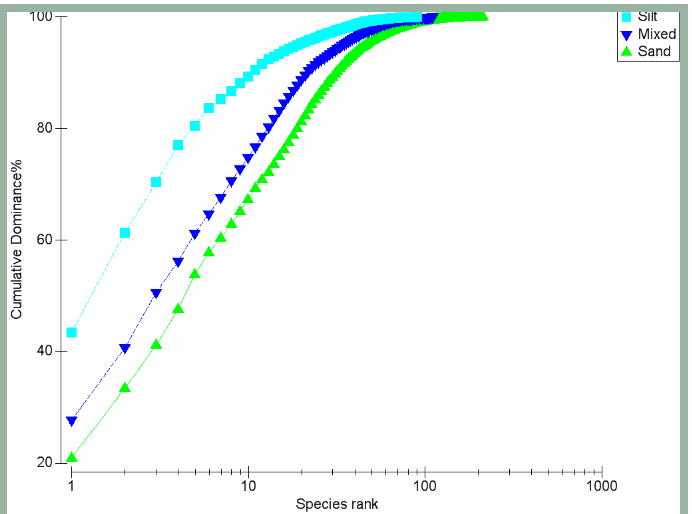


Fig. 5.8b. Dominance curves for DEBI species data, pooled by sediment class.

with Fig. 5.6). A distinct association of high metal concentrations and benthic assemblages and stations is apparent in both panels (5.7 c) and (5.7d) as a knot of large bubbles associated with lower salinity stations (Fig 5.6). This suggests that metal concentrations may be affecting benthic assemblages at these stations and that further analysis is warranted.

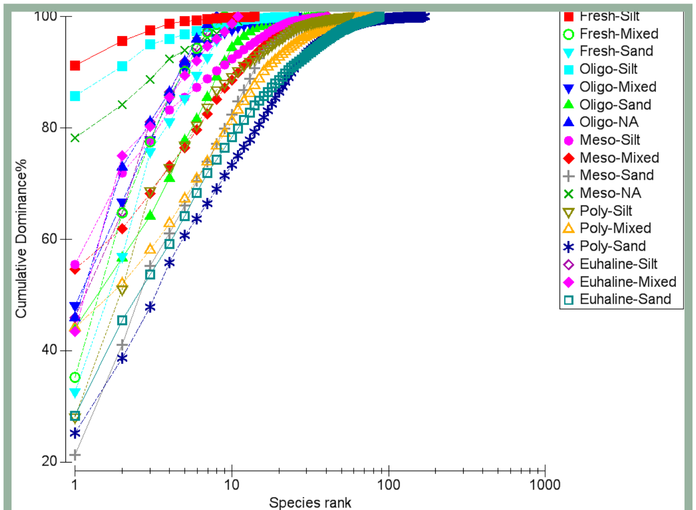


Fig. 5.8c. Dominance curves for DEBI species data pooled by salinity and sediment class.

Dominance curves can likewise be used to investigate patterns in benthic fauna. Potentially disturbed or polluted assemblages have been found to be dominated by few but abundant species (Warwick 1986, Warwick and Clarke 1994, Elliott and Quintino 2007). Figure 5.8 shows these lots for DEBI species data pooled by salinity (5.8a) or sediment class (5.8b) or both jointly (5.8c). The plots show the cumulative percent of individuals for the most abundant species, the second most and so on, by species. A gradual rise to 100% is apparent for these categories, for all sediment classes (5.8b) and mesohaline, polyhaline and euhaline classes, while oligohaline and freshwater curves show higher dominance, higher curve on the left side (5.8a). When jointly classified (5.8c)

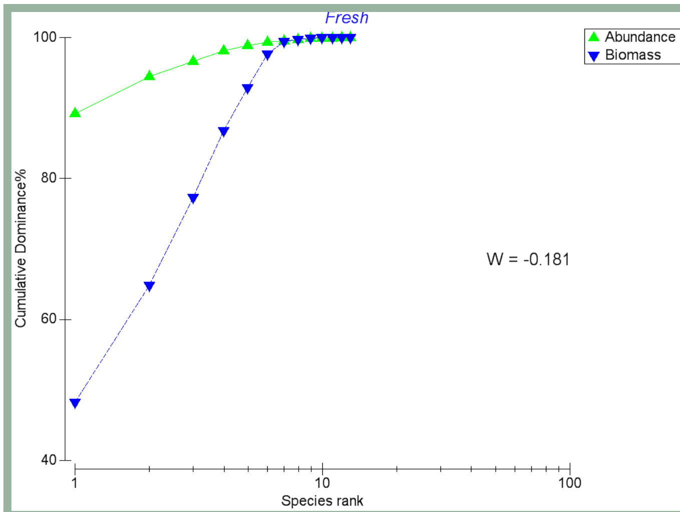


Fig. 5.9a. Abundance-biomass curve for freshwater stations.

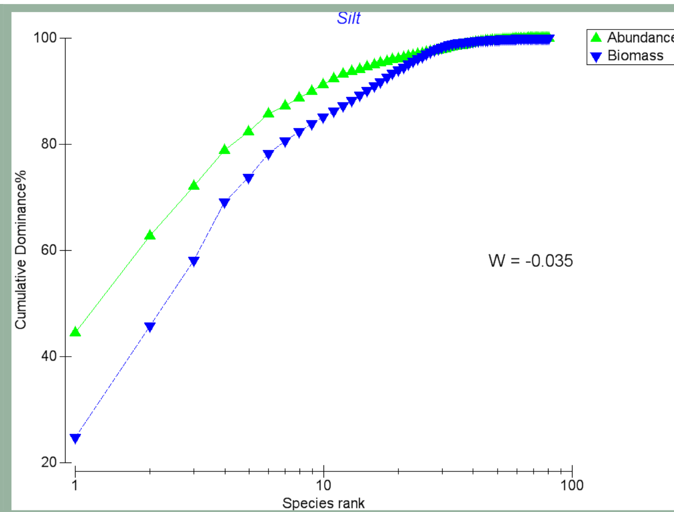


Fig. 5.9b. Abundance-biomass curve for silty sediment stations.

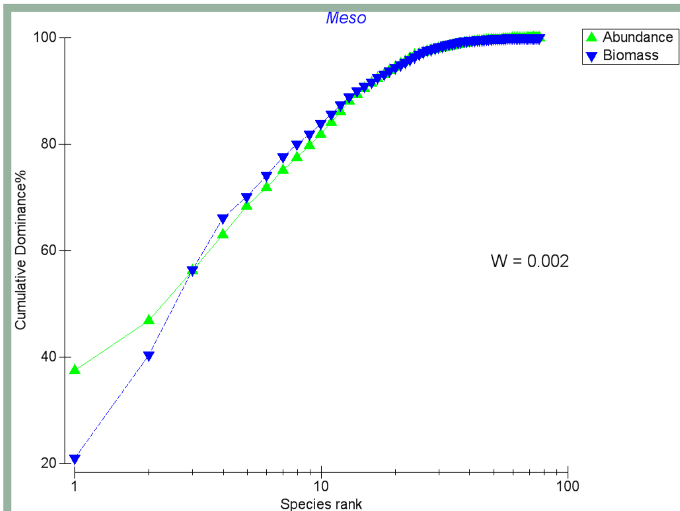


Fig. 5.9c. Abundance-biomass curve for mesohaline stations.

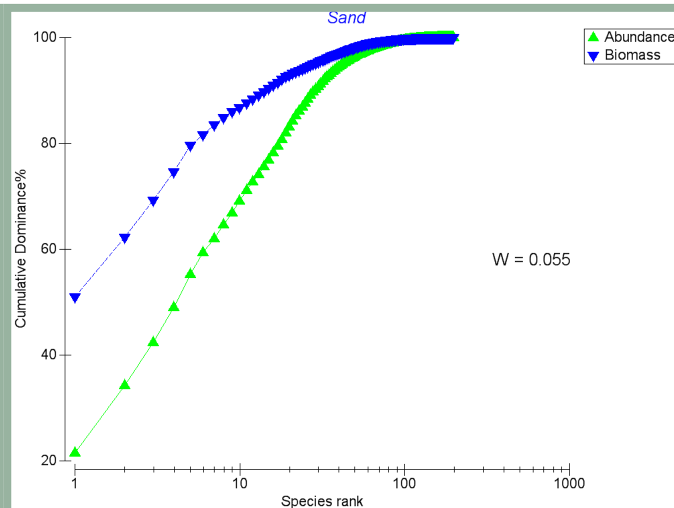


Fig. 5.9d. Abundance-biomass curve for oligohaline and sandy sediment stations.

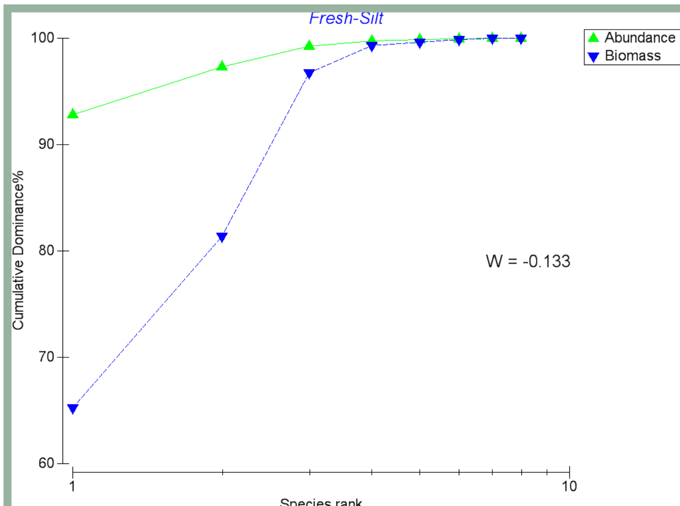


Fig. 5.10a. Abundance-biomass curve for . Oligohaline-silty sediment statinos.

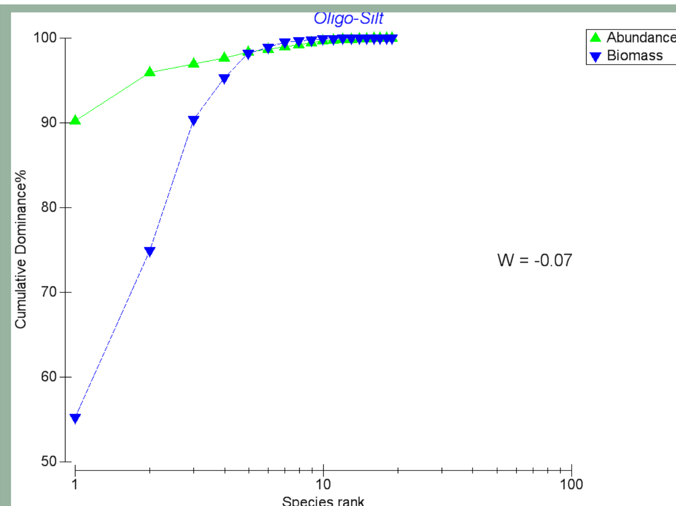


Fig. 5.10b. Abundance-biomass curve for fresh-silty sediments stations.

the oligohaline-silt and fresh-silt stations show high dominance, considerably greater that that of the rest of the salinity-sediment classifications.

Biomass curves can also be used to identify disturbed or polluted conditions: the cumulative percent biomass by species rank is superimposed on the dominance curve in a combined abundance-biomass comparison (ABC) plot. In unpolluted conditions, the biomass curve lies above the abundance curve (Warwick 1986, Warwick and Clarke 1994, Elliott and Quintino 2007), representing an assemblage with many species of moderate abundance and biomass dominated by a few large species, and this interpretation is consistent with that of the classical Pearson and Rosenberg (1978) paradigm (see also Gray and Elliott 2009). In disturbed or polluted conditions, a few but abundant, yet small species dominate (i.e., the large species are eliminated), and the abundance curve lies above that of the biomass. For the DEBI data, fresh and silt ABC curves (Fig. 5.9a and b) are inverted, in comparison to mesohaline and sand (Fig. 5.9c and d). Inversion of the ABC curves is also clearly apparent in the fresh-silt and oligohaline-silt curves (Fig. 5.10a and b), and these stations are located in the C&D Canal to state-line region (and within DRBC's Zone 5) of the estuary. Especially as this area has been characterized as degraded in benthic condition in past studies, these patterns at these stations merit further investigation.

The conclusions from this preliminary analysis are that broad-scale estuarine patterns are as expected for a temperate Atlantic estuary and that the soft-bottom benthic diversity of the Delaware has been sampled to a reasonable though, not exhaustive, extent. Bay-wide, salinity drives the patterns among benthic assemblages to a greater degree than sediment composition, and that high metal concentrations are associated with assemblages at certain stations. Further analysis within salinity and sediment classes reveals assemblages highly dominated by a few, abundant species, which also exhibit inverted abundance-biomass curves, further suggesting disturbed or polluted conditions. In summary, while these overall patterns among the benthic fauna are as expected in terms of abundance, diversity and biomass, stations in the C&D Canal to state line region (DRBC's Zone 5) are distinct in their assemblages, associated with high metal concentrations and have abundance and biomass curves consistent with polluted conditions. This region has been characterized as degraded in past studies on benthic assemblages.

The U.S. EPA recently released the 2011 National Coastal Condition Report IV (U.S. EPA, 2011). The 2006 report divided the analysis not only by region but by estuary as well. Unfortunately, in the 2011 report an assessment was provided only for the Mid-Atlantic Bight and not specifically the Delaware Estuary. The coastal assessment in the Mid-Atlantic Bight of the benthos demonstrates that conditions have remained the same, classified as poor condition, since the last assessment in 2006.

5.3 Past Trends

Starting in the early 1950's, there is an extensive history of scientific benthic study in the Delaware River and Estuary (Table 5.2). Since 1990, surveys have used probabilistic designs for station selection as well as consistent methodologies for sample collection and processing, faunal identification and taxonomy, and data summary and compilation. Specifically, there have been five separate federal programs using the benthos as indicators in Delaware Bay. Conclusions from the early 1990 EMAP survey are reported in Sutton et al. (1996). According to the EMAP benthic index, 93% of the area of the tidal river has benthic communities classified as degraded (68% area) or severely degraded (25 % area). In comparison, only 2% of the bay's area south of the C&D canal was degraded, and no stations were severely degraded. Several benthic indices have been applied to Delaware Bay stations as part of the broader-scale, National Coastal Assessment (NCA) studies beginning in 2000. Using the Virginian Province Benthic Index and 2000-2001 data, 34% of the stations were rated "good," 29% "poor," and 37% "missing," and this mixture of conditions was found throughout the bay and river (US EPA 2006).

In addition to the federal studies, there are "historical" surveys undertaken by Amos in the 1950's and Maurer and colleagues in the 1970's (Table 5.2). In total, sampling has been reported at nearly 900 stations, and the total number of species reported from these studies is consistently 200 or more (cf. Fig. 5.4), with the mean (over stations) total abundances (number of organisms per meter squared) in the expected range of 1000 – 10,000 per square meter, although two surveys reported abundances well below 1000 per square meter. In particular, low abundances were noted by Maurer et al. (1978), wherein they concluded that low abundance reflected low benthic productivity in the Delaware Bay. Low abundance could equally be explained by their use of a 1-mm mesh sieve as compared to the 0.5-mm mesh (a smaller sieve retains more, smaller fauna) used in the present DEBI 2008 sampling as well as other recent federal surveys), although Maurer et al. (1978) discuss this point and explicitly discount this explanation in their report.

The reason(s) for the low mean abundance reported by Hartwell and by Hale are not resolved at present. Future studies by comparing abundance of large species and small (i.e., those not expected to be completely retained by a coarse sieve) selectively, may make it possible to confirm a sieve-bias explanation for at least the Maurer et al. (1978) results.

All or most of the federal data are hosted online although distributed over several federal agency web sites and presented in various data formats. In most cases, data are tabulated as species abundances, and fortunately the consistency of sampling, laboratory analysis, and ready availability of these data will allow synthesis by modern statistical techniques. Any trends in these data over the past 30 years should be resolvable once challenges of data formatting and merging are overcome.

5.4 Future Predictions

Summary plots of diversity, faunal assemblage ordinations, and dominance plots in this section that likely sufficient sampling has been conducted to facilitate development of conclusions and that broad, estuary-scale patterns are as expected based on typical estuarine patterns of diversity. It is important to note that the federal agencies have routinely included stressor variables, such as dissolved oxygen, organic carbon, heavy metals, and organic pollutants in their measurement suite (Table 5.1). These individual surveys have consistently assessed the benthos in light of possible stressors, yet there have been few if any attempts at cross-survey synthesis of these data to assess trends in benthic community structure and condition over time.

5.5 Actions and Needs

The ready availability of extensive data clearly justifies a cross-survey analysis of the past 30 years. Additional effort will be required to determine if differences among data sets are due to a sampling design (spatial allocation of locations) or sampling gear-bias (especially sieve mesh size) or truly represents significant change in estuary conditions. Only limited, broad conclusions can be draw from the simple data summaries and plots presented here. Further analyses using multivariate methods like multi-dimensional scaling and dominance curves may reveal patterns and relationships impossible to discern among multiple possible natural variation and anthropogenic effects. Effective analysis of these benthic data will require additional effort to identify sensitive and tolerant species, reference and control sites (to develop customized and calibrated indices), and the application of more sophisticated multivariate, phylogenetic/taxonomic structural analysis or regression-based species distribution modeling.

5.6 Summary

The benthos of Delaware River and Estuary has been extensively studied and well characterized in surveys conducted over the past 60 years. The most recent, 2008 DEBI survey, represents a firm baseline demonstrating patterns in diversity similar to those found before and typical of temperate estuaries. Overall patterns among the benthic fauna are as expected in terms of abundance, diversity and biomass, but stations in the C&D Canal to state line region are distinct in their assemblages and associated with high metal concentrations. The current DEBI survey data are consistent with other recent studies employing standardized methodology and refute previous conclusions that the bay's fauna is depauperate and unproductive. The availability and congruence of several previous data sets with the current DEBI results clearly justifies a cross survey analysis of all of the data from the past 30 years. Further effort will be required to determine if perceived differences may be due to sampling gear-bias issues, sampling locations differences, or represents real and significant changes in estuary conditions. Effective analysis of these data will require additional effort to identify sensitive and tolerant species, reference and control sites, and the application of more sophisticated multivariate, structural (i.e., phylogenetic/taxonomic) or regression-based species distribution modeling.

Delaware Bay Benthic Mapping Project

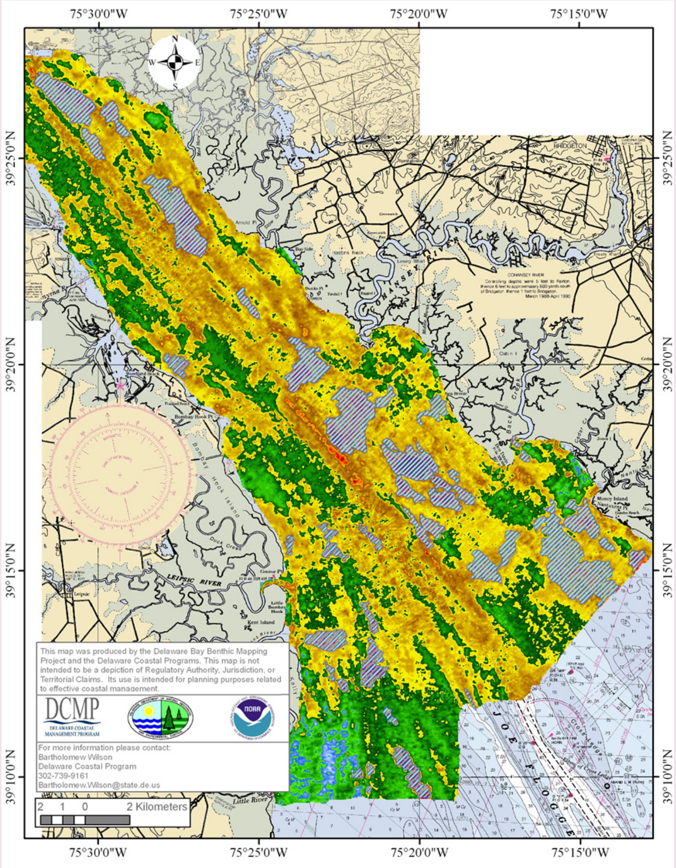
(Author: Bart Wilson)

Through an integrated effort by the Delaware Coastal Programs and the University of Delaware, a benthic and sub-bottom imaging project to identify and map the benthic habitat and sub-bottom sediments of Delaware Bay and River was initiated in 2004. This project would not have been possible without the following partners: University of Delaware Geosciences Department, Delaware Fisheries Section, Delaware Shoreline and Waterway Division, Delaware State University, Partnership for the Delaware Estuary, New Jersey Department of Environmental Protection, and New Jersey Shellfish Bureau.

This project integrates the use of three types of acoustical systems: Roxann Seabed Classification System, CHIRP sub-bottom profiling, and multi-beam bathymetric mapping. Verification of the acoustic data with bottom and sub-bottom sediments is performed through the collection of grab and core samples and underwater video images.

This effort has resulted in many major milestones, which include: mapping over 906 square km, identifying the spatial extent and relative density of the oyster and *Corbicula* beds, identification of borrow sites for beach replenishment, facilitating a greater understanding of the local and regional sediment distribution patterns and pathways, locating key habitats for species (such as: Atlantic Sturgeon, sharks, and *Sabellaria vulgaris*), and starting to understand the relative impact that humans have upon the bay bottom and its living resources. Most importantly integrating the bottom and sub-bottom sediment with species tracking information, in a 3D GIS environment, has provided a new opportunity to assess the habitat relationship between Atlantic Sturgeon and several key regions in the Delaware River.

The program has many accomplishments including an integration of the benthic and sub-bottom data was used to identify sand borrow sites within the Delaware Bay that are located in areas that minimize the impact upon essential fish habitat (especially *Sabellaria vulgaris* habitat). Borrow sites have been located for three coastal communities, and will determine sand resources for 4 additional coastal communities.



DNREC bottom sediment map showing the distribution of sediments and locations of oyster beds over a 620 square kilometers area in the upper Delaware Bay Estuary. In this region, 40 distinct oyster beds were located.

In addition, the project has worked with The Nature Conservancy (TNC) and the Partnership for the Delaware estuary to develop benthic habitat maps for the Delaware Estuary. In September 2011, TNC produced a report entitled; Delaware River Basin Priority Conservation Areas and Recommended Conservation Strategies (http://conserveonline.org/workspaces/nfwfdebasin/documents/all.html). In Appendix V; Benthic Habitats of The Delaware Bay, an attempt was made to create benthic habitat maps using bathymetry, salinity and seafloor substrate. Maps of Ecological Marine Units were created taking into account species data provided by the DEBI project.

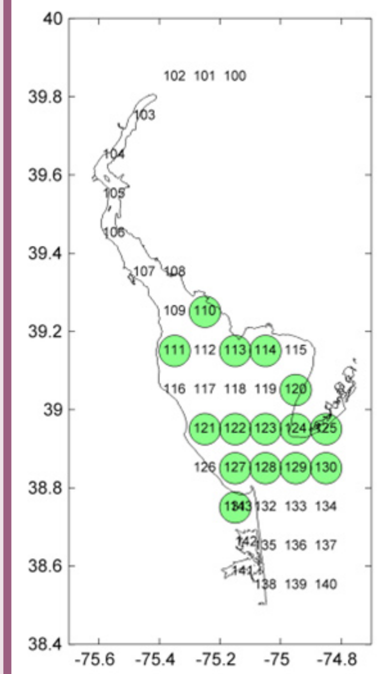
Amos Historical Benthic Collection Analysis

(Author: Douglas Miller)

The Delaware River Invertebrate Collection (DRIC) was the first scientific collection of benthic organisms for the Delaware River and Estuary. William H. Amos' handwritten 5" x 8" data cards along with preserved master specimens from the 1950's are currently housed at the University of Delaware in Lewes. Standing 25 cm (10") high when stacked vertically, these invertebrate cards were scanned for archival purposes in October, 2008 and later digitized.

The Amos DRIC includes over 5,500 records of nearly 400 species from over 130 stations within the Delaware River and Estuary. Information in a locality field in addition to uncovered charts promises to yield much more precise information for sampling locations. These data include collection of benthic organisms by trawl, dredge and Peterson grab, planktonic organisms by net and epifauna as part of the "buoy scrapes" sampling. Chronologically, these data represent mostly the years 1952-54 and 1956, and primarily July and August collections. Many records are included from the Delzoop plankton sampling that occurred several times a year from October 1951 through August 1953.

Amos identified over 400 taxonomic groupings of which about 396 represent species of invertebrates present in the Delaware River and Estuary. This estimate of species number is generally consistent with numbers Amos gave in University of Delaware Marine Laboratory annual reports. Any such "biodiversity" estimate is clearly provisional, depending on updated nomenclature, taxonomic confirmation, and assessment of the influence of sampling effort and gear bias.



Map of Delaware Bay and Amos sector grid, with bubbles showing the number of records of the sandbuilder worm, Sabellaria vulgaris in his pioneering benthic study.

Amos summarize his species distribution data in geographical form using a grid of 40 "sectors" including 37 over the main part of the bay from Philadelphia south, in the bay or just outside, plus Rehoboth Bay, Indian River Bay, and the Lewes & Rehoboth Canal. Samples near Joe Flogger and the Leipsic River have the most records, likely reflecting the intensity of zooplankton sampling in that of the bay. Sectors near Lewes Beach and the Bayside Lab, along the main channel in the lower bay, and at the Shears/Harbor of Refuge have over 200 records each. Most collections are from the main channel and lower Delaware side, and with the exception of the Nantuxent Point area, far fewer are from New Jersey waters.

In addition to representing a time in the history of the Delaware Estuary before major industrialization and development, these data present a uniquely comprehensive picture in terms of the functional group, life habit, and taxonomy of the fauna of the river and estuary. Hopefully now that this historical data set is digitized, scientists around the region will be able to access it and use it in their studies of the benthic ecology of the Delaware River and Estuary.

5 - Intertidal Aquatic Habitats

5 - 1 Tidal Wetland Area

Tidal wetlands are aquatic habitats which lie above the mean low tide line, but below the mean high tide line within an estuary or marine environment. They therefore occupy the intertidal zone between open water and upland areas. Tidal wetlands can be both in fresh water as well as salt water areas.

The traditional definition of a wetland requires that vegetation be present, most typically woody or perennial forms of vascular plants. However, for management purposes, state and federal agencies also consider as wetlands many types of non-vegetated aquatic habitats, such as shallow ponds, mud flats, and some areas dominated by benthic algae (e.g., Cowardin classification system as used by the National Wetland Inventory). For the purposes of this report, the principal focus is on vegetated tidal wetlands, which are a hallmark habitat within the Delaware Estuary.

Tidal wetlands in the Delaware Estuary extend along both shores of the Delaware River and Bay, spanning the broad salinity gradient from the head-of-tide near Trenton, New Jersey, and south to Cape May, New Jersey, and Cape Henlopen, Delaware (Fig. 5.11). The largest portion of tidal wetlands are composed of salt marshes fringing Delaware Bay, which are dominated by smooth cordgrass, *Spartina alterniflora* in the low tidal zone and various (Fig. 5.12) salt-tolerant grasses (e.g., *S. patens* and *Distichlis spicata*) and scrub/shrub vegetation in the "high marsh" zone.

In the upper estuary and in headwater areas of tidal rivers and creeks, nationally rare communities of freshwater tidal vegetation can be dominant wherever salt concentrations are below 0.5 parts per thousand (Fig. 5.13). These freshwater tidal wetlands consist mainly of perennial grasses, sedges and rushes (called emergent marshes), and there are some scrub/shrub and forested tidal wetlands as well.

Typically, freshwater tidal emergent marshes contain greater biodiversity than salt marshes. Species whose presence is diagnostic of this marsh type include wild rice (*Zizania aquatic*), cattail (*Typha sp.*), and low marsh succulents such as spatterdock (*Nuphar luteum*) and arrow arum (*Peltandra virginica*). Like salt marshes, tidal wetlands undergo daily flooding and draining, and are therefore critical components in

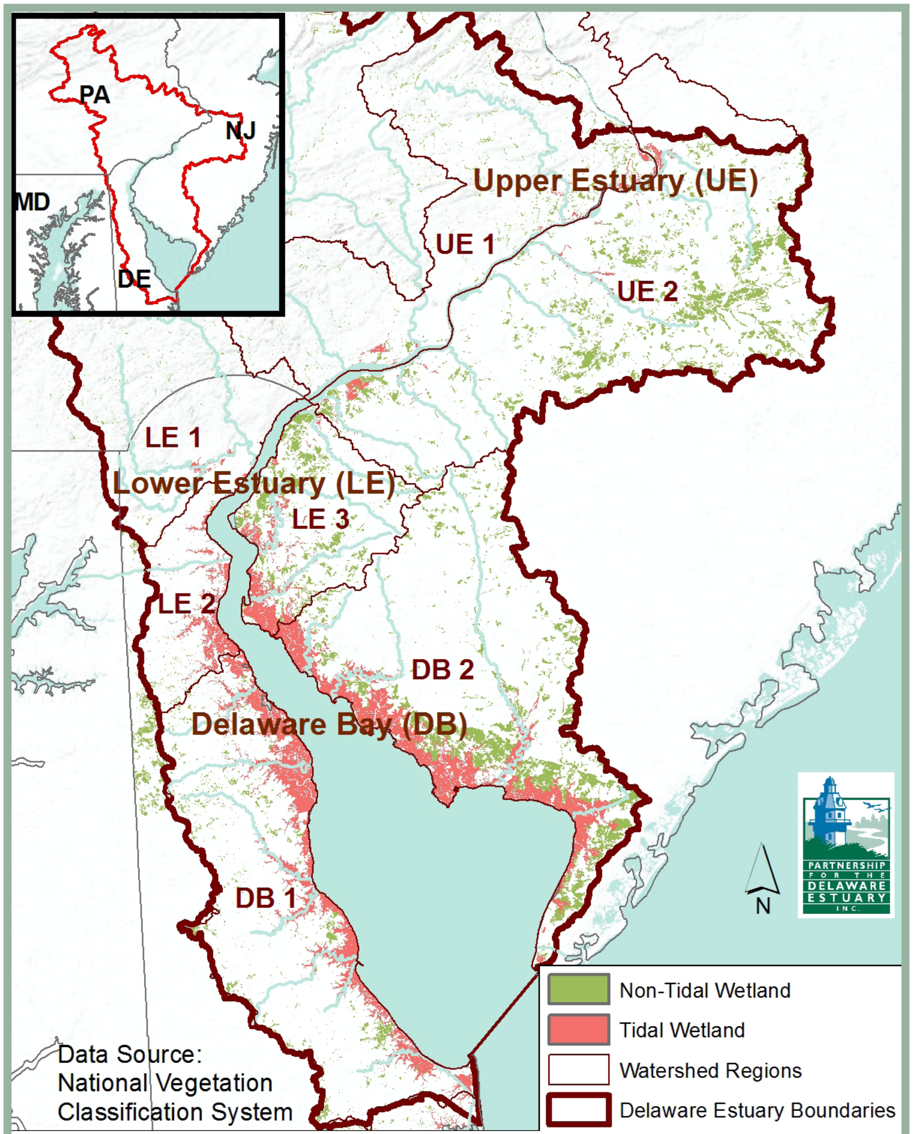


Fig. 5.11. Tidal and non-tidal wetlands in the Delaware Estuary

Key to Watershed Regions

UE - Upper Estuary
LE - Lowever Estuary
DB - Delaware Bay
SV - Schuylkill Valley

David Burke

Fig. 5.12. A characteristic tidal creek salt marsh in Delaware, 2010

Danielle Kreeger

Fig. 5.13. A characteristic freshwater tidal emergent marsh is in Crosswicks Creek, NJ, shown here in July 2011

the sensitive interaction between land and water in the estuary.

Tidal wetlands are among the most productive habitats in the world, and perform a wide variety of vital services. They help protect inland areas from tidal and storm damage; provide water storage to protect against flooding; provide important habitat to a wide variety of wildlife, including waterfowl; serve as a filter to remove contaminants and help sustain water quality; provide spawning and nursery habitat to support commercial fisheries; support active and passive recreation; and provide aesthetic value.

Tidal wetlands are therefore often regarded as the most critical habitat type in the Delaware Estuary for supporting broad ecological health. Assuring that these wetlands remain intact and continue to provide these critical functions is therefore fundamental to the protection and the overall quality of the Delaware Estuary and the Delaware River Basin as a whole.

5 - 1.1 Description of Indicator

The science and management community of the Delaware River Basin has elevated tidal wetland extent and condition as top priorities for monitoring and management, emphasizing that these habitats are one of the leading environmental indicators (Kreeger et al. 2006, PDE 2008). Too little data currently exist to assess the condition of tidal wetlands across the watershed, although efforts are underway via the new Mid-Atlantic Coastal Wetland Assessment (PDE 2011) to fill this data gap for future indicator reporting. Therefore, tidal wetland extent (hectares) is the main environmental indicator that was analyzed for this study.

Despite their importance to the Delaware River Basin, it is difficult to quantify the status and trends in tidal wetland extent due to data gaps and inconsistencies in methods used to track these habitats at different times and in different areas of this large watershed. There are two federal programs, several state programs, and periodic scientific studies that have provided useful data, but to date no data source has yielded a comprehensive, estuary-wide layer at a single pot in time. Furthermore, much of the available data do not differentiate tidal from non-tidal wetlands. The approach here was to inventory the available information on tidal wetland extent and types across the estuary using data that most appropriately reflect wetland areas consistently across each state and the region. The following is a description of the best available data layers for this indicator.

National Wetlands Inventory Data were first gathered for each state from the U.S. Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI). The NWI is a nationwide program which seeks to inventory and assess trends in the nation's wetlands. The US FWS is required to produce a report on the status and trends of the nation's wetlands. The NWI provides detailed, consistent, high-resolution data that enable clear differentiation of wetland types; however, it is of limited value in status and trend analyses for the whole system because of the different dates for which data are collected in different states and areas.

While intended to ensure a consistent and timely picture of wetlands across the country, wetland delineation under the NWI is often highly dependent on funding and input from the states. This leads to a discrepancy in the frequency and (sometimes) methodology of delineation among states. For instance, Fig. 5.14 illustrates the various time periods for the latest NWI data within the estuary, which ranges from the 1970s (in Pennsylvania) through 2009 (in Delaware). The latest NWI data available for New Jersey varies from 2002 in the north to 1999 in the southern coastal areas.

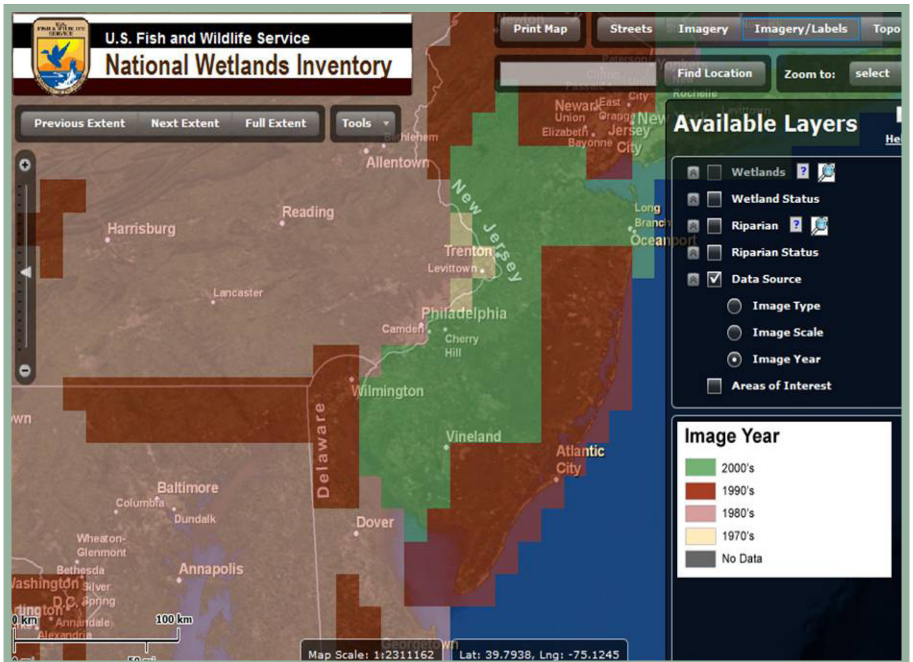


Fig. 5.14. NWI Status in the Delaware Estuary

To determine the current status of intertidal wetlands in the estuary, the latest of each of three state-wide NWI wetlands (Pennsylvania, New Jersey and Delaware) were used. Each of these layers is categorized using the classification scheme developed by Cowardin (Cowardin, 1979). A simplified classification was developed to allow for a synoptic assessment of status and trends of several broad categories of wetlands within the estuary. Table 5.3 lists the classes and the codes used to summarize intertidal wetland types.

Land Cover Data To assess trends in tidal wetland acreage, the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (CSC) land cover datasets were used. These data are available for all coastal areas of the U.S., and have been derived from Landsat satellite imagery at a 30m ground resolution. The data are useful for examination of wetlands since there is a relatively high level of detail differentiating wetland types, and since data for the whole estuary are collected periodically at the same time. Categories of wetlands distinguished by the CSC land cover are: Palustrine Forested, Palustrine Scrub/Shrub, Palustrine Emergent, Estuarine Forested, Estuarine Scrub/Shrub, Estuarine Emergent, Unconsolidated Shore, and Palustrine Aquatic Bed. Dates for the CSC land cover data are (nominally) 1996, 2001, and 2006. (Not all states or regions were delineated using satellite from the same epoch, as interpretation requires high-quality, cloud-free imagery; and the use of photography from varying dates during which these conditions were present.)

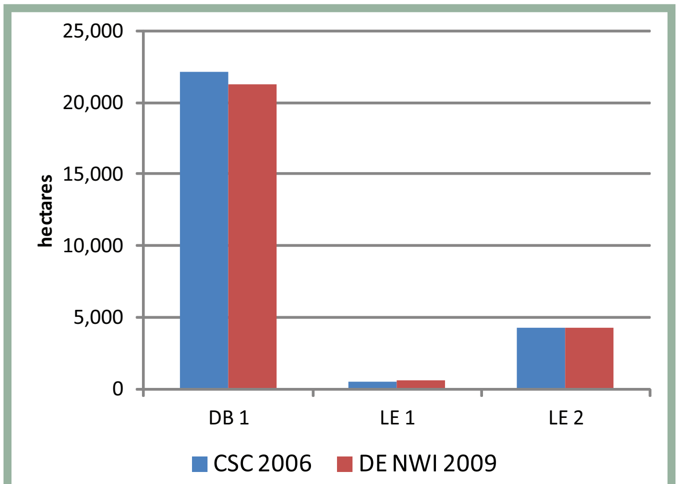


Fig. 5.15. Comparison of measured extent of salt marsh in Delaware watersheds based on CSC and NWI data. Figures agree to within less than 3%. (see map & key on p.133)

Although land cover data are useful because they provide more consistent coverage of the watershed at specific times, land cover data sets do not offer the same degree of resolution as NWI, which is derived from high resolution aerial photography and undergoes more comprehensive ground-truthing. More importantly for our indicator analysis, land cover data used do not distinguish between tidal and non-tidal wetlands. There are six wetland categories distinguished in land cover datasets which include tidal wetlands: estuarine emergent, estuarine shrub/scrub, estuarine forest, palustrine emergent, palustrine shrub/scrub, and palustrine forest. Of these six, only one category (estuarine emergent) consists wholly of tidal wetlands (i.e., salt marshes), which represent dominant and ecologically important landscapes within the estuarine system. In general, however, due to the relative abundance of these six categories in our system, the three "estuarine" categories correspond to tidal wetlands, and the three palustrine wetland types represent largely non-tidal wetlands. Assessment of the comparability of the wetland categories of the CSC land cover data with the NWI data for New Jersey and Delaware indicates that the data are comparable with a relatively small percentage difference, especially for estuarine emergent wetlands (Fig. 5.15). Therefore, we mainly used land cover data to assess status and trends in estuarine emergent wetlands (mainly salt and brackish marshes) because of their consistent spatial coverage and ecological importance within the system.

5 - 1.2 Present Status

Wetlands types cover a significant portion of the lower Delaware River Basin (Fig. 5.16). From expansive salt marsh complexes in the lower estuary, up to isolated wetlands and ponds in the upland reaches, wetlands are an important part of the ecology and hydrology of the watershed. In all, there are 421,137 acres (170,428 hectares) of wetlands (tidal and non-tidal) in the Delaware Estuary study area (lower half of the basin), representing about 10.8% of the total area. This compares to a national figure of 5.5% total area of wetlands in the contiguous U.S. (US FWS). Of these wetlands in the Delaware Estuary, 39.3% are tidal wetlands and most of those are salt marshes.

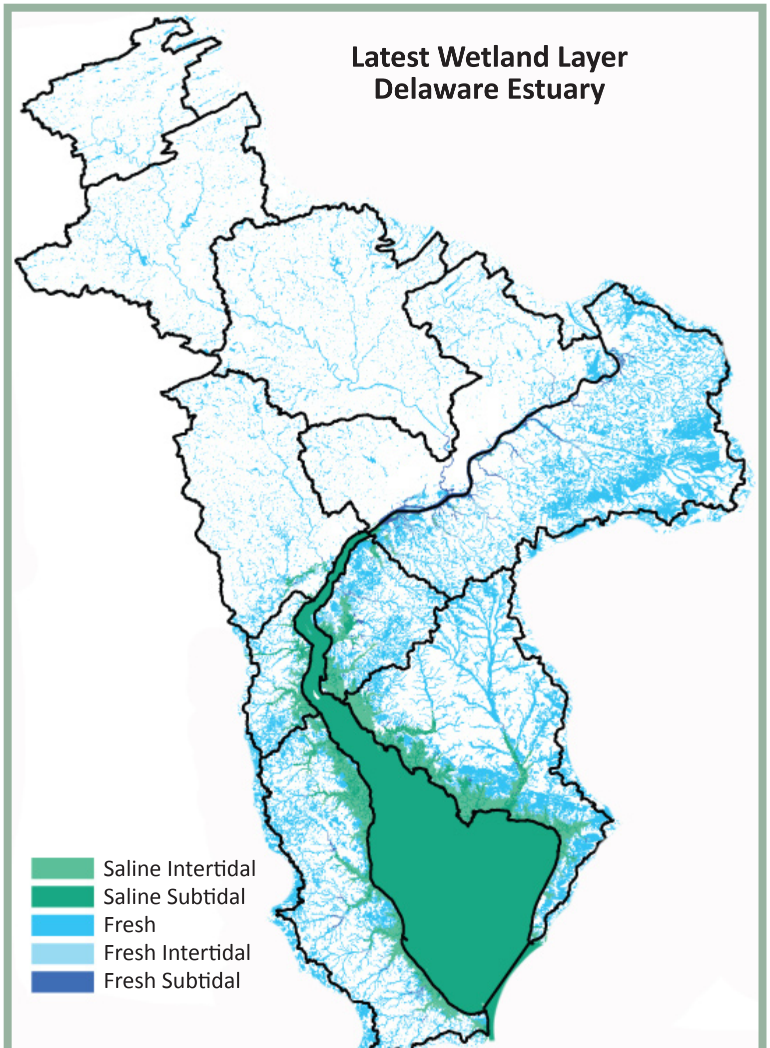


Fig. 5.16. Latest wetland layer for the lower Delaware River Basin based on analysis of both US FWS NWI and NOAA CSC land cover data

Given the disparate dates of the latest NWI data for each of the three states in the Delaware Estuary, total areas of tidal wetlands were considered separately by state. Figures 5.17-20 illustrate the status of wetland acreage based on the latest NWI data for each state. (Note - There is a very small portion of Maryland in the Delaware Estuary, but it is not considered here, particularly since it does not contain tidal wetlands. The New York portion of the Delaware River Basin is not considered here since it also contains no tidal habitat.)

5 - 1.3 Past Trends

It has been estimated that the Delaware Estuary has lost more than half of its wetlands, and more than 95% of our rare freshwater tidal wetlands, since early settlers arrived (PDE 2008). Historical losses occurred primarily because of development and conversion of wetlands for agriculture and other purposes. Despite increased regulatory oversight and "no net loss" policies that have greatly slowed rates of wetland conversion, we continue to lose all types of wetlands within the Delaware River Basin. Indeed, the pace of loss for some types of wetlands might actually be increasing due to a mix of factors (see below). The focus of this analysis was to examine trends in wetland acreage during the past two decades because we do not have data and information to carefully document earlier declines.

To assess trends in the extent of tidal wetlands in the Delaware Estuary, it is important that the data source and classification methodologies be equivalent so that meaningful comparisons can be made. While each state in the estuary has developed programs to map and categorize wetlands, comparing these data across time can be problematic due to differences in source data, interpretation, or methodology. Additionally, since each state has compiled state-wide data layers at different times using different methods, comparison across state boundaries is quite problematic.

Table 5.3. Classification of wetlands in the Delaware Estuary

Category	Code	Description
Saline, emergent vegetation	SAITEM	Typical “salt marsh” characterized by salt tolerant grasses. Predominant intertidal wetland type in the Delaware estuary.
Saline, other vegetation	SAITV	Vegetation other than salt-tolerant grasses, including scrub/shrubs and forest. Typical “high-marsh” habitat.
Saline, non-vegetated	SAIT	Non-vegetated intertidal area, mudflats, pannes, unconsolidated shoreline, beaches. Increases typically accompanies degradation of salt marshes, due to veg. loss, subsidence, and/or Sea level rise.
Fresh, emergent vegetation	FRITEM	Typical freshwater tidal wetlands characterized by emergent vegetation. Generally occur farther up the estuary, or landward of salt marshes in the lower estuary.
Fresh, other vegetation	FRITV	Freshwater tidal wetlands, scrub/shrub and forested wetland.
Fresh, non-vegetated	FRIT	Non-vegetated freshwater tidal wetlands, small portion of wetlands.

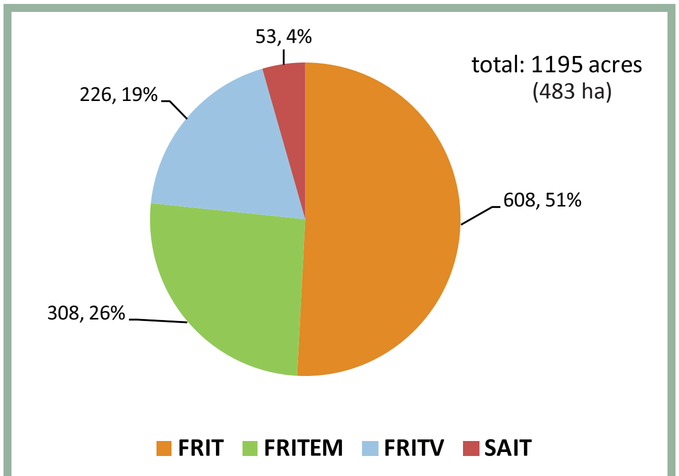


Fig. 5.17. Number of acres (ha) and relative percentage of different tidal wetland types within Pennsylvania based on most recent NWI data (see Table 5.3 for description)

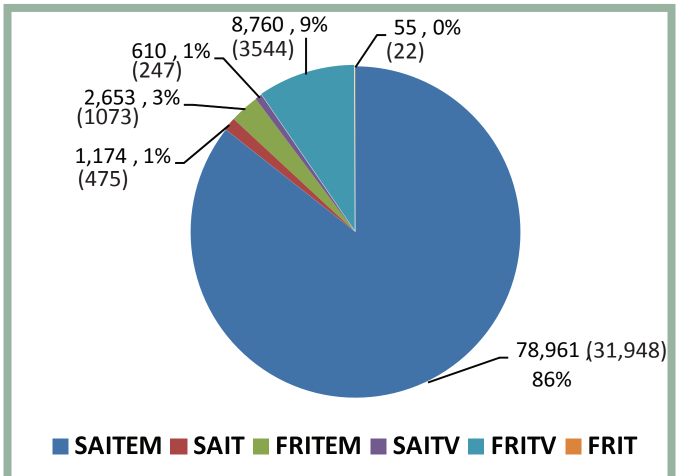


Fig. 5.18. Number of acres (ha) (and relative percentage of different tidal wetland types within New Jersey based on most recent NWI data (see Table 5.3 for description)

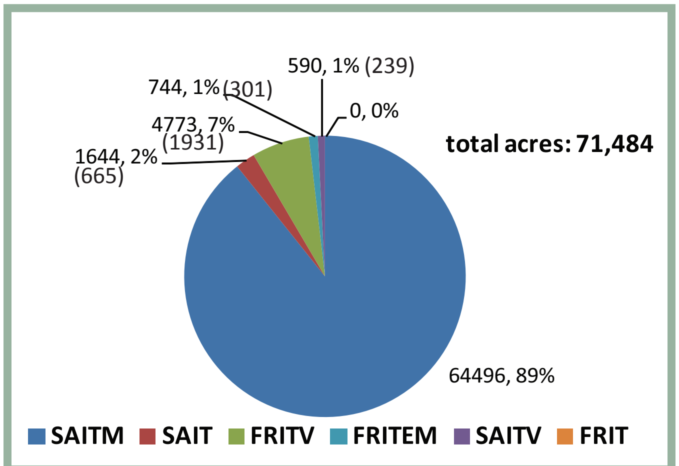


Fig. 5.19. Number of acres and relative percentage of different tidal wetland types within Delaware based on most recent NWI data (see Table 5.3 for description)

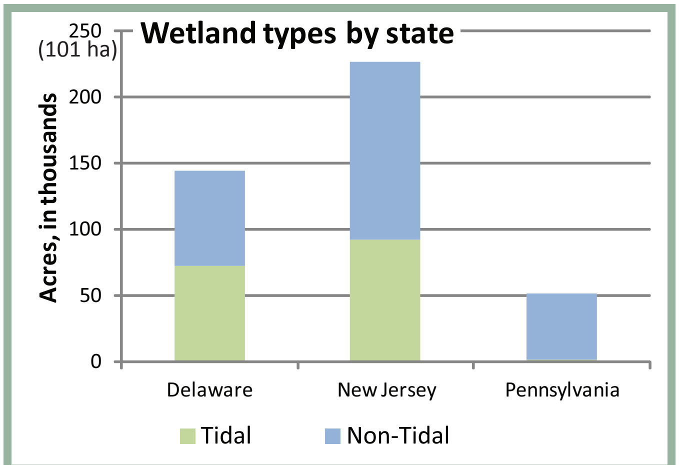


Fig. 5.20. Relative proportion of tidal and non-tidal wetland types within each of the three states in the Delaware Estuary

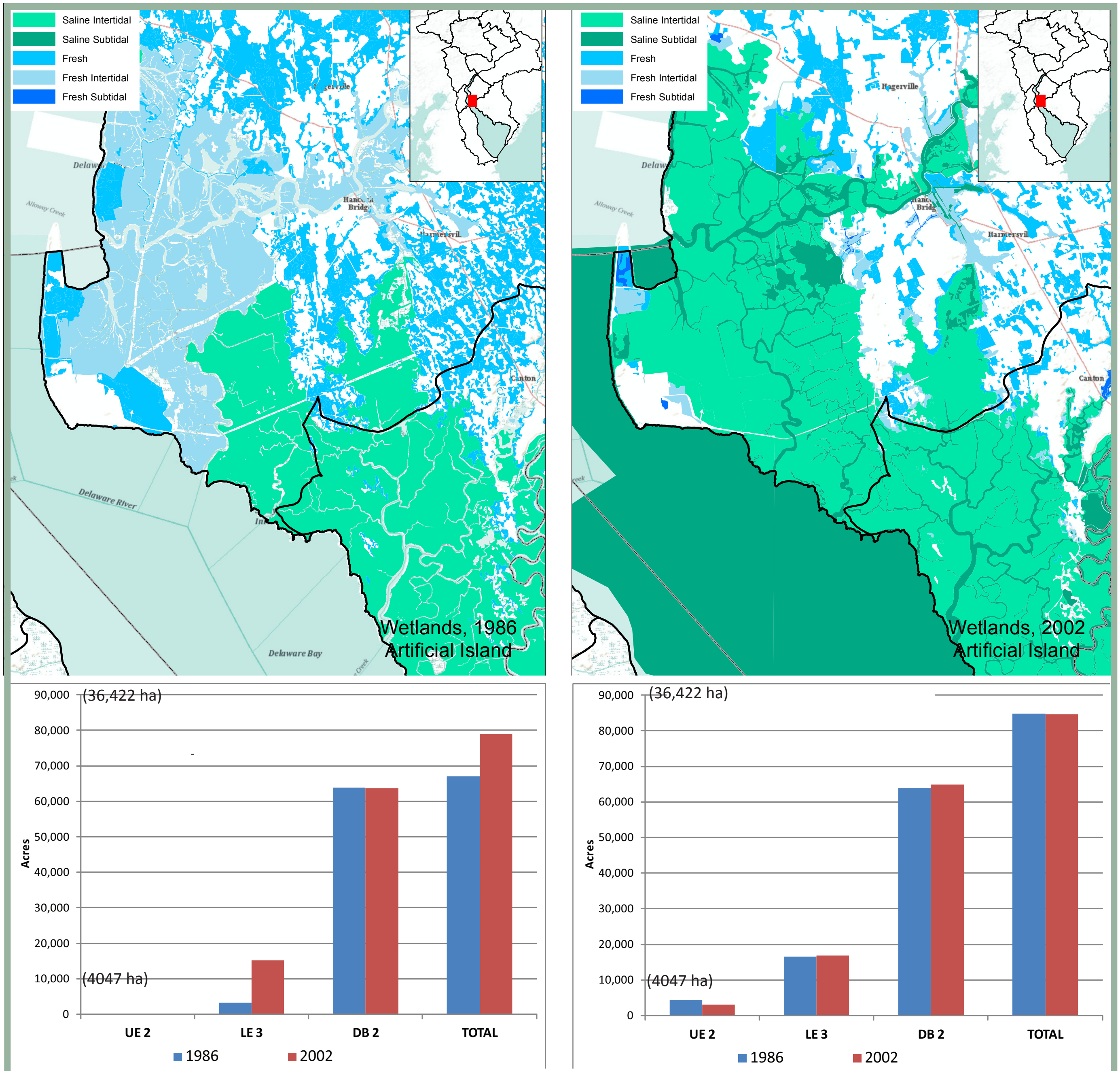


Fig. 5.21. Comparison of wetlands based on NWI classification from 1986 and 2002 for the Artificial Island area, NJ. The increaase in the relative proportion of salt marsh in the lower estuary (LE3) of NJ compare to the total tidal emergent wetlands, might reflect a transition from freshwater tidal marsh to salt marsh due to increasing salinity, or it might have resulted from methodological differences. (see map & key on p.133)

Table 5.4. Categories of wetlands distinguished in NOAA CSC land cover datasets

Palustrine	Forested
	Scrub/Shrub
	Emergent
	Aquatic Bed
Estuarine	Forested
	Scrub/Shrub
	Emergent
Unconsolidated Shore	
Open Water	

Figure 5.21 illustrates this issue. The two charts and maps depict categories of wetlands as identified in 1986 and in 2002, under the NWI program. This area falls near the typical salt line in the Delaware Bay, near Artificial Island, New Jersey. There is a lack of agreement in the delineation of salt marsh versus freshwater tidal wetlands, a difference which may or may not reflect a real change in wetlands of the estuary. The charts indicate that there appears to be an increase in salt marsh acreage in the Lower Estuary watershed of New Jersey (LE3) and a corresponding loss of freshwater tidal acreage, as can be seen in the maps. The chart showing the total amount of tidal wetlands (both fresh

Table 5.5. Change in acres of palustrine wetlands and salt marshes in the Delaware Estuary, 1996 to 2006, based on NOAA CSC C-CAP data. (see map & key on p.133)

Watershed	Palustrine Change	% Change	Salt Marsh Change	% Change
SV 1	36 (15)	463%*	0	--
SV 2	-185 (-75)	-7.7%	0	--
SV 3	-334 (-135)	-2.7%	0	4.9%
UE 1	-288 (-117)	-2.3%	-49 (-20)	-7.6%
UE 2	-514 (208)	-0.5%	-330 (-134)	-8.5%
LE 1	-229 (-93)	-2.3%	-72 (-29)	-5.2%
LE 3	-354 (-143)	-1.2%	-62 (-25)	-0.3%
LE 2	-109 (-44)	-1.3%	-251 (-102)	-2.3%
DB 2	-694 (-281)	-0.6%	-2110 (-845)	-3.4%
DB 1	-582 (-235)	-1.1%	-441 (-178)	-0.8%
TOTAL	**-3252** (-1316)	**-0.9%**	**-3316** (1342)	**-2.2%**

*Due to the small wetland acreage within SV1, this seemingly large percentage increase (from 7 to 43 acres) should be interpreted with caution because it likely falls within the assessment error range.

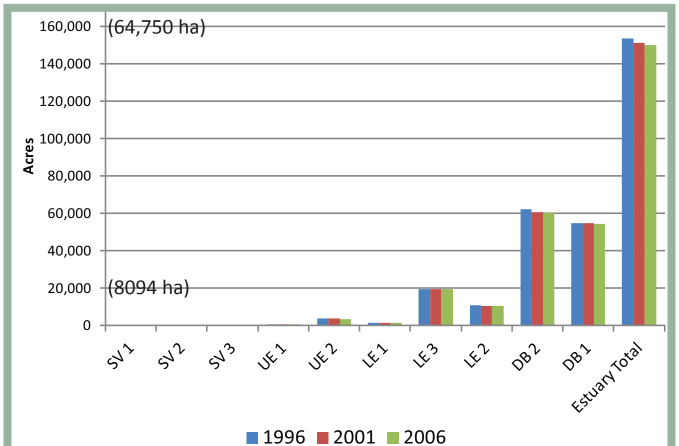


Fig. 5.22. Total acreage of estuarine emergent wetlands (salt marshes) in the watersheds of the Delaware Estuary, 1996 through 2006. (see map & key on p.133)

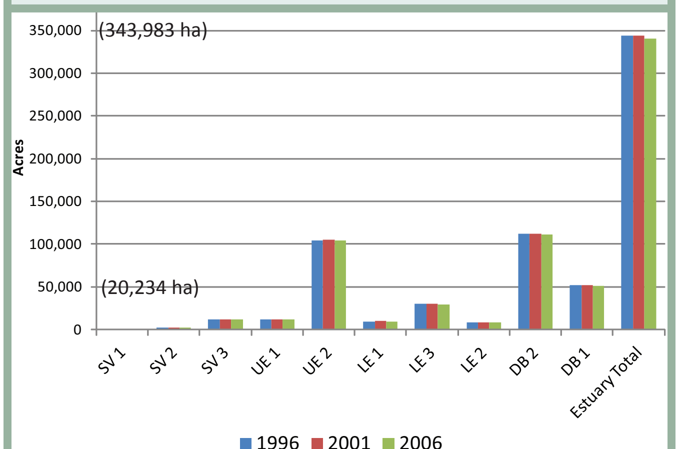


Fig. 5.23. Total acreage of palustrine (vegetated freshwater) wetlands in the watersheds of the Delaware Estuary, 1996 through 2006. (see map & key on p.133)

and salt), indicates that only a very small change in extent occurred when tidal wetlands are considered as a whole. The apparent transition from freshwater tidal marsh to salt marsh might have resulted from increasing salinity in this transition zone due to climate change and sea level rise (see also Chapter 7), but it is not conclusive because of uncertainty in NWI data comparability between the survey years.

To overcome these drawbacks, land cover data from the NOAA Coastal Services Center (CSC) Coastal Change Analysis Program (C-CAP) were compiled for the estuary, as noted above. These data are based on Landsat satellite multi-spectral imagery at a ground resolution of 30 meters. The CSC has derived land cover data for coastal Atlantic states for the years 1996, 2001, and 2006. While focusing on overall land use in the coastal zone, there is a relatively fine level of classification of wetland habitats (see Table 5.4). While the data from the CSC does not differentiate between tidal and non-tidal wetland categories, saline estuarine categories can be analyzed for changes over time. In particular, estuarine emergent wetlands correspond well to tidal brackish and salt marshes (Fig. 5.15).

Across the entire Atlantic seaboard between 1998 and 2004 it is estimated that wetlands have seen considerable losses due to natural and human-influenced causes. Freshwater vegetated wetlands have undergone a loss of 0.5% (from 13,254,960 acres/5,362,957ha in 1998 to 13,188,660 acres/ 5,336,132ha in 2004) (Stedman & Dahl 2008). Over the same period, estuarine emergent wetlands (salt marshes), declined from 1,842,320 acres/745,403ha to 1,822,780 acres/737,497ha, a loss of 19,540 acres/ 7,906ha, or 1.0%. Nationwide for the 6-year period, there was a 0.7% loss of vegetated estuarine wetlands (Dahl,2006).

Compared to these estimates, the rate of tidal wetland loss in the Delaware Estuary was similar or greater over a slightly longer 1-year time period (1996-2006), with a consistent decline in both freshwater wetlands (-0.9%) and salt marsh (-2.2%) (Table 5.5).

The largest losses of salt marsh were in the lower New Jersey bayshore (denoted as Delaware Basin 2, or DB2 in Fig. 5.21), which saw a decrease of 2,110 acres/854ha, or 3.4% (Table 5.5, Fig. 5.22-5.24). Delaware tidal salt marsh wetlands also underwent a significant drop in southern watersheds (LE2 and DB1). Palustrine wetlands (though not necessarily tidal) also saw a consistent decline across the estuary. Fig. 5.25 illustrates the trend for salt marsh (estuarine emergent) and palustrine (vegetated freshwater) wetlands acreage for the years 1996, 2001, and 2006.

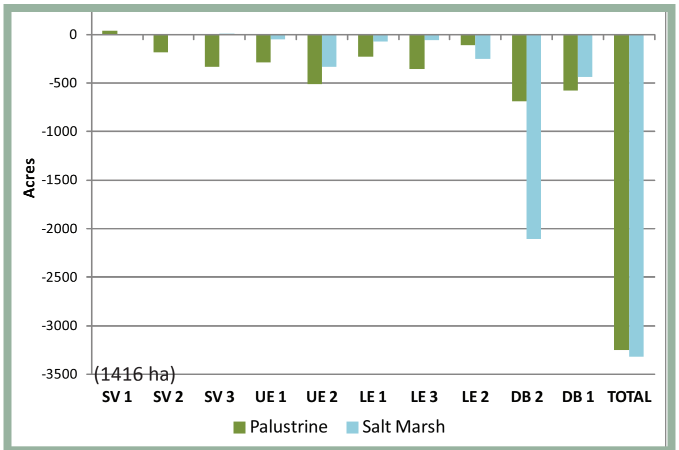


Fig. 5.24. Wetland acreage changes in different watershed regions by type, 1996 to 2006. (see map & key on p.133)

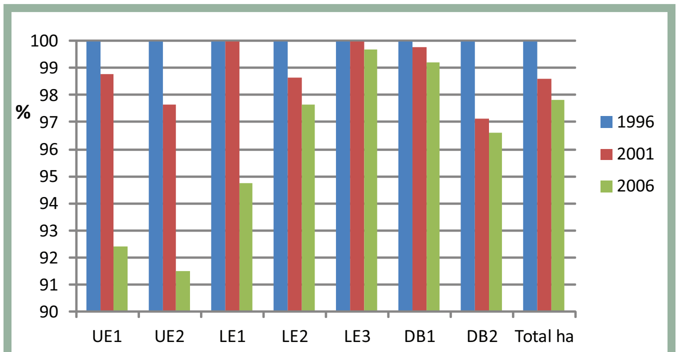


Fig. 5.25. Relative percent loss of wetlands by watershed between 1996 and 2006, with a 1996 baseline at 100%

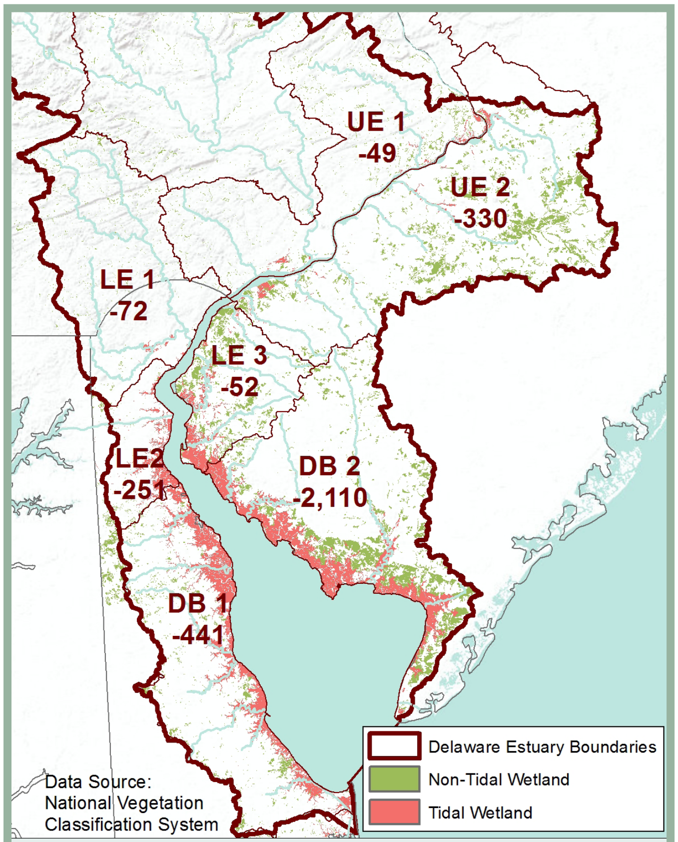


Fig. 5.26. Net change in estuarine emergent wetland acreage in watersheds of the Delaware Estuary, 1996-2006

Taken together, more than 3,200 acres/1295 ha of palustrine wetlands and more than 3,300 acres/1335 ha of salt marsh (estuarine emergent) wetlands were lost in the Delaware Estuary during this 11-year period (Fig. 5.24). The most rapid and sizeable losses occurred in the New Jersey Bayshore area (DB2) where 2,110 acres/854 ha were lost between 1996 and 2006. Percentage of acres lost can been seen in Fig. 5.25, and total acres lost are mapped in Fig. 5.26. These data are supported by on-the-ground observations of rapid, and apparently escalating, erosion and drowning of salt marshes in that area (Fig. 5.27).


Fig. 5.27. High rates of erosion are occurring throughout many areas of the Delaware Estuary as seen here within the Maurice River mouth, New Jersey, 2009

Although losses in the upper estuary are small in absolute terms, they are nevertheless important considering the small amount of tidal freshwater marsh habitat that remains, and their benefits to people, fish and wildlife, and water quality in the urban corridor. In 2009, the Partnership for the Delaware Estuary attempted to assess the health tidal wetland in Pennsylvania by visiting 30 sites at random that were characterized as tidal wetlands in the most recent NWI (1970s-1990s). It was found that many of these sites were no longer wetlands at all; 60 sites were visited until 30 could be found that were still tidal wetlands.This suggests that substantial losses of coastal wetlands continued to occur in recent decades (since NWI data were last collected).

There are many reasons why we continue to lose tidal wetlands in the Delaware Estuary. A recent examination of coastal wetland stressors (EPA 2011) blamed a mix of practices such as mosquito control ditching, continued incremental filling, lack of regulatory oversight, regulatory loopholes for developers, shoreline hardening, hydrological alterations such as dredging, and pollution. Increased rates of sea level rise and the spread of invasive species may also be contributing to the decline of coastal wetlands.

Most tidal wetland losses have converted to tidal open salt water. Nationally, 96.4% of tidal wetland losses were due to conversion to open water, with about 3.5% attributable to human effects in the upland areas (Stedman & Dahl, 2008). Wetland loss to direct human influence is relatively small, but the impacts, particularly on the quality of coastal ecosystems, have undoubtedly been significant. Over 53% of the U.S. population lives in coastal counties, which make up only 17% of the land area of the conterminous U.S. (NOAA Study, 2004). Development pressures and concomitant stresses on estuarine systems in these areas are considerable, and are likely to continue to increase.

As a result of lessons learned from Hurricane Katrina in the Gulf, in recent years attention has turned to assessing sediment dynamics in coastal estuaries and whether channel alterations, dredging, or sediment control projects in watersheds might contribute to coastal wetland losses by possibly starving them of needed sediments. Sea level rise is not a new phenomenon, as evidenced by Figure 5.18 which shows that the shoreline has been retreating with extensive marsh loss since at least the middle of the 19th century. What is not clear is the extent to which an increasing pace of sea level rise will hasten coastal change, possibly pushing tidal wetlands below their maintenance threshold within the tidal prism and relative to sea level.

To maintain themselves, tidal wetlands either need to accrete vertically to keep pace or they need to move horizontally into adjacent landward habitats. Marshes can accrete via the accumulation of organic matter produced *in situ* and/or the passive capture of suspended sediments originating from outside the marsh and brought in by tidal flushing (i.e., mainly rivers). The relative contribution of accumulated organic matter and trapped sediment varies widely from marsh to marsh, but without external sediment supplies most marshes fail to keep pace with sea level rise. Coastal Louisiana was losing a football field of tidal wetland every day for 30 years in part because sediment-laden freshwaters from the Mississippi had been diverted by channels to flow offshore, thereby creating a sediment deficit (Day and Templet 1989, Blum and Roberts 2009). The Delaware Estuary is similar in that it is a naturally muddy, wetland-rich system, and currently more sediments are removed each year through maintenance dredging than enter the system through surface runoff. Although there continues to be high levels of suspended sediments in the water column and the overall sediment budget (inputs and outputs) appears to be in balance (Walsh 2011), these sediment studies also suggest that the budget is currently balanced only because of large inputs of sediments from eroding tidal wetlands.

Another emerging concern is the effect of prolonged, high nutrient concentrations on tidal wetlands. Recent studies indicate that many wetland plants, especially dominant species in salt marshes, are naturally adapted for low nutrient levels and they invest heavily in belowground production of roots and rhizomes as a strategy for scavenging nutrients (Darby and Turner 2008, Turner et al. 2009). This strategy contributes to organic matter in the subsurface and aids in peat accumulation. Nutrient loadings may alter this strategy, resulting in higher ratios of aboveground:belowground production, potentially impairing a marsh's ability to accrete and keep pace with sea level rise. A tell-tale sign of this phenomenon is the presence of taller growth forms of usually short marsh plants, such as *Sparta alterniflora*. across the marsh plain. Paradoxically, a marsh can look its healthiest just before it drowns. Velinsky et al. (2011) reported that many tidal marshes in Barnegat Bay, New Jersey have been significantly degraded by excess nutrients based on careful analysis of diatom chronologies from marsh cores, and areas with highest nutrient loadings are most vulnerable to sea level rise. Increased nutrients can also cause hypertrophic and low-oxygen conditions, affecting the delicate habitats of the marshes and near-shore aquatic beds of the estuary. Since the Delaware Estuary has some of the highest nutrient loadings of any

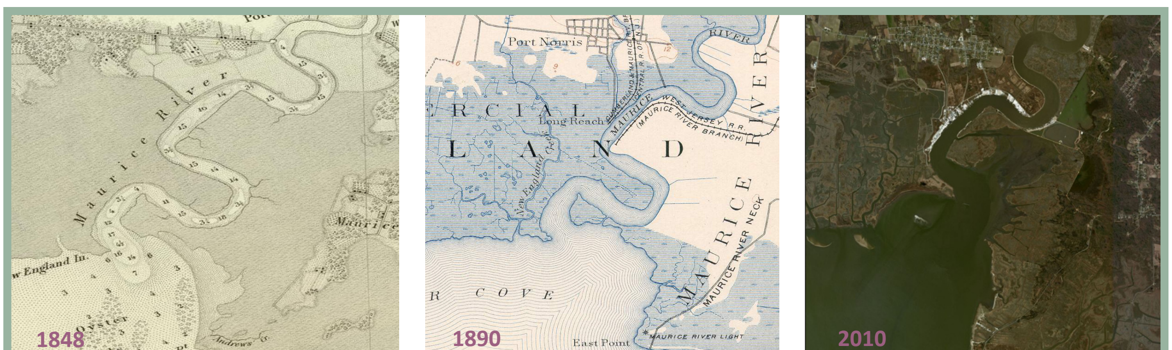


Fig. 5.28. Loss of coastal wetlands in the vicinity of Port Norris and Bivalve, New Jersey, 1848 to present. Although wetland loss has been occurring for a long time, rates of loss may be increasing thereby jeopardizing the safety and economies in coastal towns where these habitats provide flood protection and sustain coastal shellfisheries, fisheries, and ports

coastal area of the United States, it is plausible that these nutrients, especially nitrogen, might be contributing to tidal wetland losses.

Across the country, it has been reported that there has been a net increase in wetlands of approximately 32,000 acres/ 12,947 ha per year between 1998 and 2004 (Stedman and Dahl 2008). Most of these gains, however, are in inland wetland categories, particularly ponds (many on farms). These are not of the same ecological value as natural, vegetated tidal wetlands, and do not provide the same hydrologic and ecosystem services. High quality tidal wetlands, such as those that naturally exist in the Delaware Estuary, are among our nation's most valuable and productive ecosystems.

5 - 1.4 Future Predictions

As discussed above, about half of the pre-settlement acreage of tidal wetlands remain in the watershed, and losses continue to mount every day. Stressors that have contributed to historic and recent losses of tidal wetlands have not gone away in the Delaware Estuary. These include impacts associated with development, including: pollution, shoreline hardening, filling, dredging, ditching, boat wakes, etc. Since the human population is expected to expand by about 80% by 2100 within the Delaware Estuary (PDE 2010), the direct conversion of wetlands for development and the associated environmental pressures by the expanding populace are likely to continue to stress our tidal wetland habitats.

Perhaps even more importantly, increasing rates of sea level rise and associated salinity rise pose mounting threats to tidal wetlands. Although there are limited quantitative data, coastal managers and scientists in Delaware and New Jersey report increasing rates of erosion of seaward marsh edges and rapidly expanding interior open water. Riter and Kearney (2010) reported similar findings from satellite imagery, which suggest that most marshes in the system are showing decreasing amounts of vegetative cover and increasing proportions of open water. Their effort updated the earlier study by Kearney et al. (2002) of both Chesapeake and Delaware Bays, which suggested that more than two-thirds of salt marshes were in a degraded condition.

If the intensity and frequency of storms and associated tidal surges also increase with climate change, this could exacerbate the other threats. Warming trends are expected to boost the incidence of coastal storms, including northeasters and possibly hurricanes. On the other hand, a longer growing season, enriched atmospheric carbon dioxide, and warmer temperatures are likely to enhance primary productivity within wetlands.

In 2010, the Partnership for the Delaware Estuary released a report on the most important changes that are likely to occur as a result of climate change (PDE 2010). Tidal salt marshes were predicted to be highly vulnerable to increasing rates of sea level rise and freshwater tidal wetlands were reportedly highly threatened by salinity rise, among other factors. A panel of wetland experts

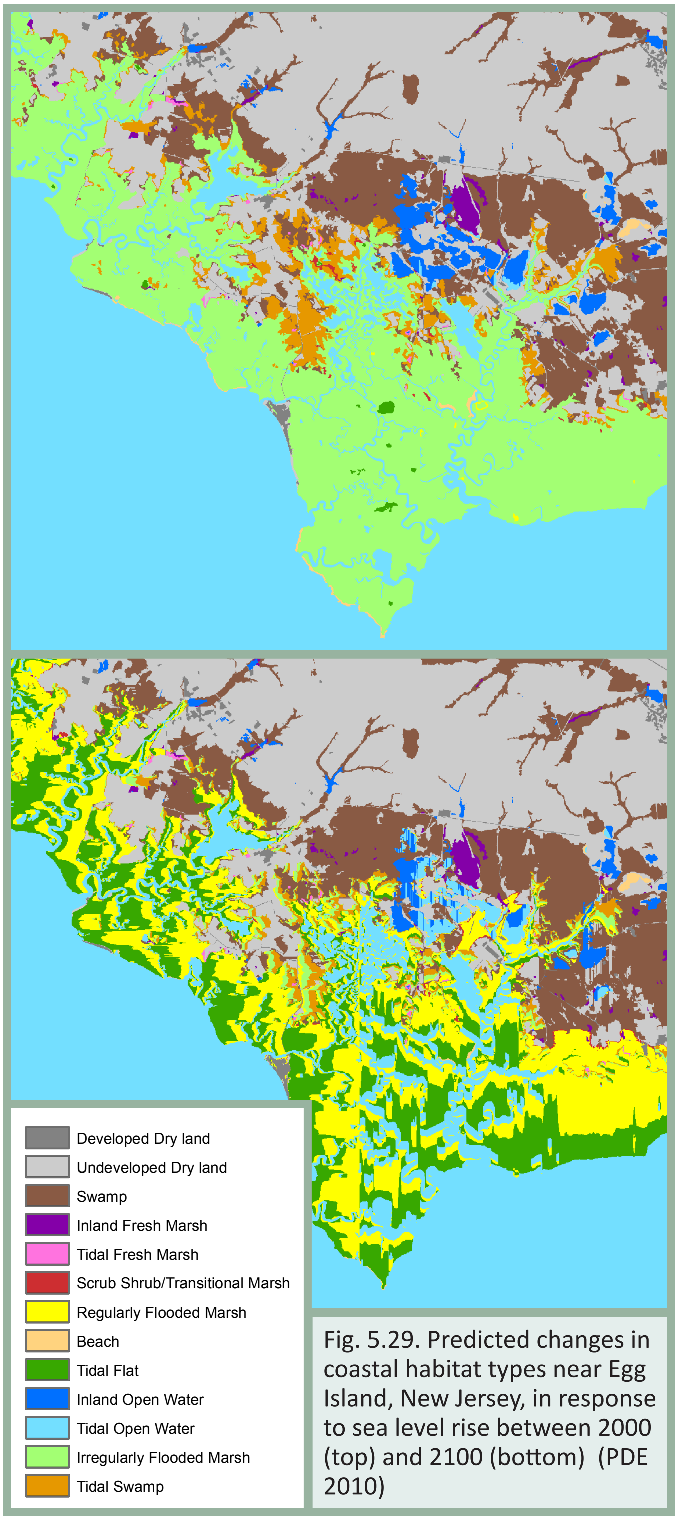


Fig. 5.29. Predicted changes in coastal habitat types near Egg Island, New Jersey, in response to sea level rise between 2000 (top) and 2100 (bottom) (PDE 2010)

predicted that the potential boost to primary production would be dwarfed by the threats posed by sea level and salinity rise (Kreeger et al. 2010).

Moreover, all tidal wetlands face barriers to landward migration within the Delaware Estuary, most significantly in the upper estuary (see PDE 2008, Feature Box). The potential for tidal wetlands to migrate landward is affected by slope, soils, and degree of hardening. Areas with high levels of upland development and shoreline hardening do not allow wetlands to easily migrate landward and thus maintain themselves. In many areas they will need to accrete in place, or face drowning.

With a rise in sea level of one meter by 2100, more than 25% of the system's tidal wetlands are predicted to be lost (PDE 2008). Based on model predictions from the Sea Level Affecting Marsh Model (SLAMM, V.6), this amounts to more than 50,000 acres (20,234 ha) of net loss, resulting from the balance between the landward migration of tidal wetlands into adjacent uplands and non–tidal wetlands (which are expected to >50,000 acres/ 20,234 ha) and a seaward erosion and drowning of tidal wetlands (expected loss of >100,000 acres (40,469 ha). Importantly, since no other habitat types rival tidal wetlands in productivity, the net loss of ecosystem services is expected to be proportionally far more significant than the acreage loss. Based on recent loss trends and revised sea level rise scenarios, we expect total net losses of tidal wetlands by 2100 to exceed 25% (PDE 2010) and perhaps 75% if no action is taken to stem loss. In addition to net losses of acreage, most high marsh in the Delaware Estuary is predicted in this report to convert to low marsh even if it is not eroded.

Sommerfield and Velinsky (2011) reported that accretion rates in tidal marshes are currently greater than rates of sea level rise at sites they studied in the Delaware Estuary. Nevertheless, the Delaware Estuary is experiencing a net loss of these same habitat types. Plausibly, the erosion and loss of some wetlands might be helping to sustain others by subsidizing the sediment supply, but the net balance is still negative per year as determined by decreasing acreage, shoreline retreat, and lower overall vegetative cover.

The current rate of sea level rise in the Delaware Estuary is between 3.5-4.0 millimeters per year, up from about

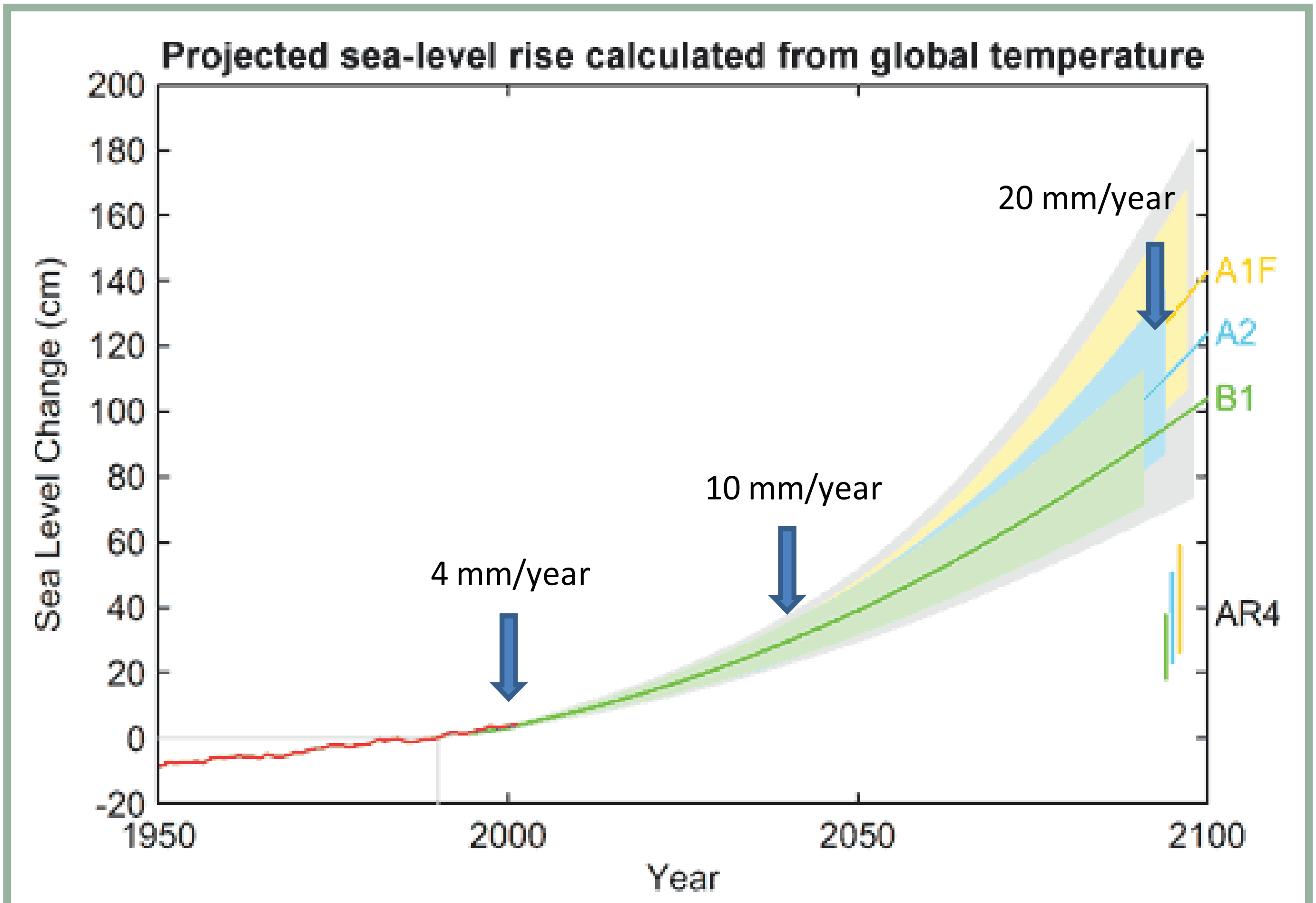


Fig. 5.30. Projected sea level rise calculated from global temperature based on 3 different emissions scenarios (Vermeer & Rahmstorf 2009) with extrapolated rates of sea level rise, assuming a total rise of 1.3m in the Mid-Atlantic region by 2100

1.8 millimeters per year in the early portion of the 20th century (Gill et al. 2011). A one meter rise in sea level by 2100 will require the rate of sea level rise to eventually exceed 10 millimeters per year. The last time that the rate of sea level rise was that high was during the period of post-glacial ice melt up through about 2000 years before present, and during that time period, tidal wetlands were rare along the eastern seaboard, existing only in the most protected areas (Psuty 1986, Psuty and Collins 1996).

In addition, the land is sinking in many areas of the coastal plain due to subsidence from post-glacial rebound. Rates of subsidence appear to be greatest in South Jersey (Sun et al. 1999) where the largest tidal wetland losses have occurred. The interplay between sea level rise and subsidence, compounded by changes in ocean currents (Gulf Stream; see Najjar 2010), will result in greater rates of local "relative" sea level rise than the global forecast models predict. For these reasons, in climate adaptation planning at the Partnership for the Delaware Estuary is expecting 1.3-1.4 meters of relative sea level rise for every 1.0 meter of global sea level rise. To reach 1.3 meters within 90 years, the average annual sea level rise would be 14.4 millimeters if the increase was linear over this period, which it is not. Therefore, the annual rate of sea level rise at the end of the century is likely to be far greater than 14 mm unless significant errors exist in this forecast, or the rise in the rate of sea level slows for other reasons.

Clearly, the rate of relative sea level rise (RSLR) is critically important for determining the fate of tidal wetlands in the Delaware Estuary because of the tipping point that can be breached when the RSLR exceeds the marsh accretion rate. Assuming that this threshold is somewhere between 5-10 millimeters per year for many salt marshes of the Delaware Estuary, and assuming RSLR will reach 1.3 meters by 2100, then a non-linear increase in sea level at the projected rate would likely breach the tipping point within the next 20-25 years for a large proportion of tidal wetlands in the system unless significant actions are taken to aid the vertical accretion of tidal wetlands.

5 - 1.5 Actions and Needs

Sea level rise, salinity rise, development, outdated management paradigms, and pollutants are likely to contribute to the continued degradation and loss of tidal wetlands in the Delaware Estuary unless actions are taken to abate these impacts. Future indicator reporting would also benefit from better monitoring data on tidal wetland extent and condition.

Proactive Adaptive Management

Despite the dynamic nature of the coastline, many regulatory policies continue to treat the landscape as fixed in place. Restoration paradigms set goals based on historic conditions rather than future sustainability. As sea level rises it will be important to update management policies to encourage both the landward migration of tidal wetlands into buffers (Feature Box) and the vertical accretion of tidal wetlands in place (Fig. 5.32). It is still much easier to obtain a permit for a shoreline stabilization project that installs a bulkhead or other hard structurestructure that prevents wetlands from keeping pace with sea level rise and contribute to degradation of tidal wetlands, than it is for a living shoreline (Fig. 5.32). Ditching and filling of tidal wetlands still occur, often without proper monitoring of the effects or understanding of the consequences. To adapt to both climate change and continued watershed development, tidal wetland managers will need to adjust targets, policies and tactics to sustain existing tidal wetland habitat in the future.

In order to address the threats to the intertidal zone in the Delaware Estuary, an approach combining policy and regulatory remedies and actions on the ground is required. The Clean Water Act (1972), Coastal Zone Management Act (1972), and the Coastal Barriers Resources Act (1982), are evidence of the increasing importance of tidal wetlands in the policy and legal arena. Many states and counties have followed the lead of federal agencies and implemented their own regulations covering wetland protection measures such as buffer requirements, impervious cover limitations, and implementation of federal nutrient pollution guidelines. Continued promulgation, refinement, and enforcement of regulations and policies is a critical need, as demonstrated by the various emergency measures that are already underway or being called for in some Delaware and New Jersey areas (e.g. Prime Hook, Delaware; Sea Breeze, New Jersey; Maurice Township, New Jersey) where tidal wetland losses are contributing to the decline of coastal communities. Given accelerating development and population pressures, as well as increases in relative sea level rise, these measures will need to be augmented just to maintain the current integrity of the intertidal zone. In particular, local differences in the extent of regulatory protection provided to wetlands poses a challenge to maintaining consistently high level of wetland quality and function throughout the estuary.

Monitoring Data and Scientific Study

Complete and consistent monitoring data on wetland is a vital need to allow managers to make proper decisions and to enable assessment of wetland status and trends. Such data allows scientists and policy makers to understand the causes of wetland loss and develop approaches to address them. As discussed above, it is still impossible to accurately and consistently report changes in tidal wetland extent because of limited, sustained investment in monitoring. The National Wetlands Inventory is a program designed to address this issue, but differences in the procedures and time frames have made long-term trend analysis problematic. The State of Delaware has developed high-quality datasets, but comparison to New Jersey is not possible. Some areas of Pennsylvania have not been assessed for the NWI since the 1970s. Therefore, basin-wide coordination of NWI assessments is crucial, as is the need to update inventories at least every 5-7 years.

Fig. 5.31. Scientists from the Academy of Natural Sciences, Partnership for the Delaware Estuary, and Rutgers University installing a surface elevation table in a salt marsh in the Dennis Creek watershed, New Jersey, in March 2011 as part of a new sub-regional monitoring initiative targeting tidal wetlands: the Mid-Atlantic Coastal Wetland Assessment

Since the array of ecosystem services furnished by tidal wetlands are proportional to their condition, better health assessments are also needed. For example, restoration and mitigation targets are based on acreage, and realizing small increases in acreage can be very costly; however, investment in enhancement projects (e.g., living shorelines to stem erosion, beneficial use of dredge material to raise elevation) that boost function and save much larger tracts from being lost might yield greater net value (and acres) in the long run. More scientific studies and restoration pilot projects would contribute to knowledge and strengthen management and restoration practices to sustain greatest tidal wetland acreage.

Investment in consistent tidal marsh monitoring and science is difficult to fund at the scale of the multi-state Delaware Estuary. However, the benefits of tidal wetlands are beginning to be captured and capitalized upon (e.g. flood protection, nutrient and carbon capture, fish production). Tidal wetlands are already regarded as the most valuable natural lands (e.g. NJDEP 2007). Managers should carefully consider how a projected loss of 25-75% of the tidal wetlands in the Delaware Estuary might affect coastal communities (lives and property) and regional economies (fisheries and shellfisheries, property values, nutrient criteria). As markets for ecosystem services develop in the future, there will be increasing demand for essential information on trends in tidal wetland extent and condition. Such information will be vital in the development of strategies to protect and enhance tidal wetlands. Until then, there will continue to be a need to collaborate and leverage funds to fill vital information gaps.

<u>On-the-Ground Action</u>

Efforts at preservation, both through regulatory and physical means, have been having some beneficial impacts across the estuary, but many areas are still undergoing degradation or conversion to open water. New policies and tactics are needed to both facilitate the horizontal, landward migration of tidal marshes and to boost the health and vertical accretion of tidal marshes. Given the rapid pace of change in tidal wetland extent and health, swift action to physically protect or enhance tidal wetlands is warranted to stem losses, even if monitoring and scientific information are still in the development phase. Implementation of Best Management Practices (BMPs) using best possible scientific information has already been shown to help to protect tidal wetlands from landward threats such as nutrient loading, sediment deficits, and contamination, both in agricultural and developed areas. Marsh migration plans are needed and will require conflict resolution and education. Seaward protections and marsh enhancements can be just as difficult to implement due to permitting, logistical, and funding challenges. However, there are efforts underway to explore beneficial use of sediments for enhancement (Bailey-Smith 2011), develop new living shoreline tactics appropriate for the Delaware Estuary (Fig. 5.32) (Kreeger et al. 2009; Whalen et al. 2011), and craft an estuary-wide strategy for living shoreline implementation (e.g. Delaware Estuary Living Shoreline Initiative).

PDE PDE Danielle Kreeger Josh Moody

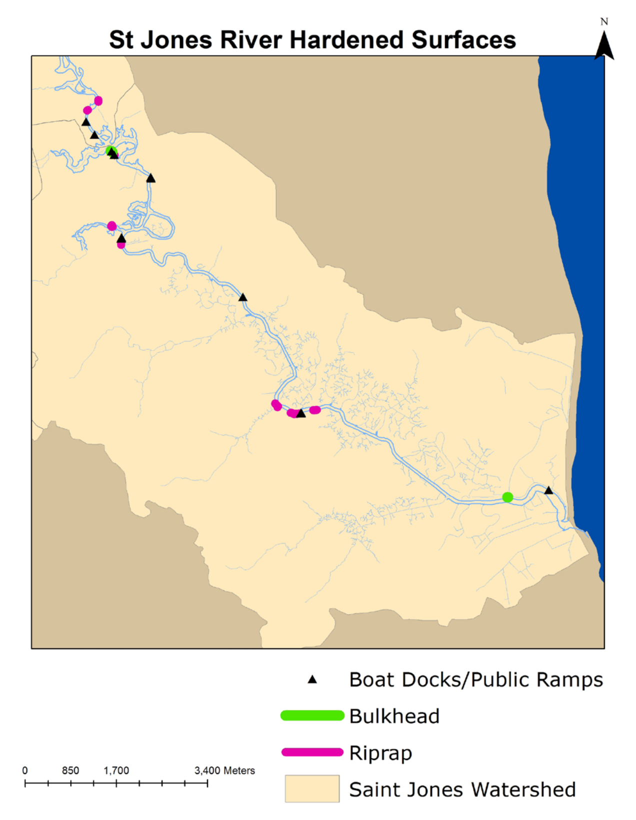
Fig. 5.32. Installation of a mussel and plant-based living shoreline to help stabilize erosion and improve ecological value of a formerly hardened shoreline at Matt's Landing, New Jersey. This new tactic was developed jointly by the Rutgers Haskin Shellfish Research Laboratory and Partnership for the Delaware Estuary. The photo from Sept 2011 was following Hurricane Irene and Tropical Storm Lee

5 - 1.6 Summary

Tidal wetlands of the Delaware estuary are some of the most productive habitats in the world, and they arguably represent the most ecologically and economically important type of natural habitat in the entire Delaware River Basin. By their very nature, they are transient within the dynamic coastal zone. They absorb tidal energy from the open marine environment, and provide a buffer and sink for contaminants from upland areas. They also provide essential habitat for a wide range of organisms, as well as recreational opportunities for people. As long as the intertidal zone remains in a state of dynamic equilibrium, the benefits that they provide are maintained. However, when the processes which threaten the viability of the intertidal zone come to predominate over the processes which maintain equilibrium, this delicate ecosystem becomes unstable and imperiled. Current trends suggest that tidal wetlands, and hence the ecosystem services and direct financial and aesthetic benefits they provide, are being degraded and lost across all areas of the Delaware Estuary, especially salt marshes around Delaware Bay. Future projections suggest that these losses will increase, perhaps rapidly, likely resulting in a dramatic shift in the character and function of the estuary ecosystem. More study and monitoring, along with proactive management and on-the-ground actions, are urgently needed to minimize ongoing losses since no type of replacement habitat will provide the same net level of ecosystem services as these vital coastal areas.

Hardened Shorelines in the St. Jones (by Kelly Somers)

Shoreline armoring or hardening occurs when non-natural structures are added to a shoreline to offset erosion processes. Examples of hardened structures include bulkheads or rock erosion control such as riprap. Recreational structures (such as docks and piers) also can impact the shoreline's natural habitat. Shoreline hardening alters the structural and functional ecology of the wetlands. Hardened shoreline structures disturb natural shoreline processes (such as sediment exchange) and can lead to increased erosion at the base or downdrift from the structure. Hardened structures also do not allow for natural habitats to migrate inland due to sea level rise and flooding (Castellan et al, 2006). An increasing body of scientific evidence indicates that hardened structures particularly bulkheads, are poor habitats for fish and other biota, in comparison to natural edge habitats which function as biological hot spots.



The St. Jones River Watershed is located southeast of Dover, Delaware. In 2007, with collaboration from Delaware Coastal Programs and NOAA, the Virginia Institute of Marine Sciences completed a shoreline inventory of the St Jones River. Recreational structures and erosion control hardened structures were mapped using a handheld GPS unit to determine their extent and location on the river channel. The project looked at various types of structures including bulkheads, docks, piers, boat ramps, and riprap. The data and report show that of the 43.9 kilometers of shoreline along the St. Jones River, 64 meters were bulkhead (in green) and 499 meters had rip rap (in pink). Hardened recreational structures are found along the main channel; 11 docks and 2 boat ramps (black triangles) (Berman et al, 2008).

As an alternative to shoreline hardening, the Partnership for the Delaware Estuary suggests living shorelines, a more natural erosion control method that also enhances ecological conditions, such as by incorporating native plants, reef-building animals, and structural complexity into shoreline protection projects. These tactics enhance the natural landscape, ultimately providing more habitat for plants and animals.

5 – Non-Tidal Aquatic Habitats

5 – 1 Freshwater Wetland Acreage

Non-tidal wetlands, including forested and shrub swamps, bogs, fens, vernal pools, and riverine wetlands , provide habitat for a diverse array of terrestrial, aquatic, amphibian, and bird species (Davis 1993, Mitsch and Gosselink 2000, Faber-Langendoen et al 2008). Wetlands also serve many hydrologic, biogeochemical, and habitat functions, which are strongly influenced by watershed position (Brinson et al. 1995). Headwater wetlands retain and store precipitation, recharging groundwater resources. They are important sources of water and organic and inorganic materials that support downstream aquatic systems. Riverine and floodplain wetlands can store overbank flows, dissipate energy, provide a local supply of large woody debris, and both supply and retain coarse particulate organic matter. Wetland size, density, and landscape context, including condition of adjacent lands and connectivity among riverine, wetland, and upland habitats, are important indicators of condition.

Large wetlands are critical for maintaining suitable habitat for many of the priority species within the state wildlife conservation plans. For example, the Pennsylvania Comprehensive Wildlife Conservation Strategy (CWCS) emphasizes that conservation of large wetland habitat is especially critical for wildlife conservation (PGC and PFBC 2005). While the CWCS definition of "large wetlands" depends on the wetland type and species of concern, it typically defines large wetlands as between 12 and 100 acres (5 and 40 ha) (or larger).

Separating non-tidal wetlands highlights the value and significance of these systems, which have experienced significant losses in the basin. For example, in the state of Delaware more wetlands were lost between 1992 and 2007 than in the previous 10 years; approximately 99 percent of those losses were to non-tidal/freshwater wetlands (Environmental Law Institute 2010).

5 – 1.1 Description of Indicator

Headwater wetland area and the number of large contiguous headwater wetlands (greater than 100 acres/ 40 ha) were calculated for each subbasin within the Delaware Basin. Together, these serve as potential indicators of the degree to which wetlands are providing critical functions in headwater regions, including recharging groundwater and storing and releasing water and organic and inorganic materials to support downstream aquatic systems.

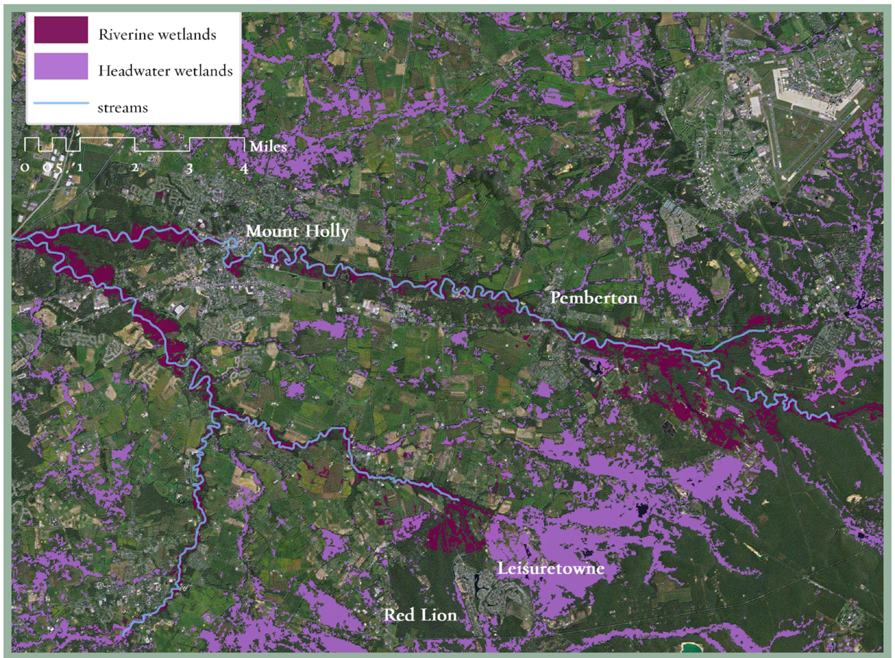


Fig. 5.33. Riverine and headwater wetlands within the Rancocas Creek watershed, New Jersey.

Non-tidal wetlands were defined by first selecting the woody and emergent wetland land cover classes from the National Land Cover Dataset (NLCD 2001). Open water features such as ponds, lakes, and reservoirs were not included. Non-tidal wetlands were then classified according to the National Vegetation Classification System (NVCS) (Westervelt et al. 2006) and further separated into headwater and riverine wetlands (Fig. 5.33). Riverine wetlands were associated with the floodplains of rivers with drainage areas greater than approximately 40 square miles (10,359 ha). Headwater wetlands exist along the riparian corridors of streams with drainage areas less than approximately 40 square miles (10,359 ha).

Within headwaters, contiguous headwater wetlands were defined as areas with connected wetland landcover (i.e., woody or emergent wetland pixels that are connected on a side or on the diagonal). These contiguous wetlands potentially include multiple wetland types according to various existing classifications, but the overall size is one indicator of potential wetland function. The total area of each contiguous headwater wetland was calculated.

5 – 1.2 Present Status

Figure 5.34 illustrates the total headwater wetland area and the number of contiguous headwater wetlands larger than 100 acres (40 ha) within each subbasin. Despite wetland losses, the Delaware River watershed has several subbasins with abundant headwater wetlands. Noteworthy concentrations are located in the Upper Central and Lehigh Valley subbasins and on the coastal plain within Upper and Lower Estuary and Delaware Bay subbasins.

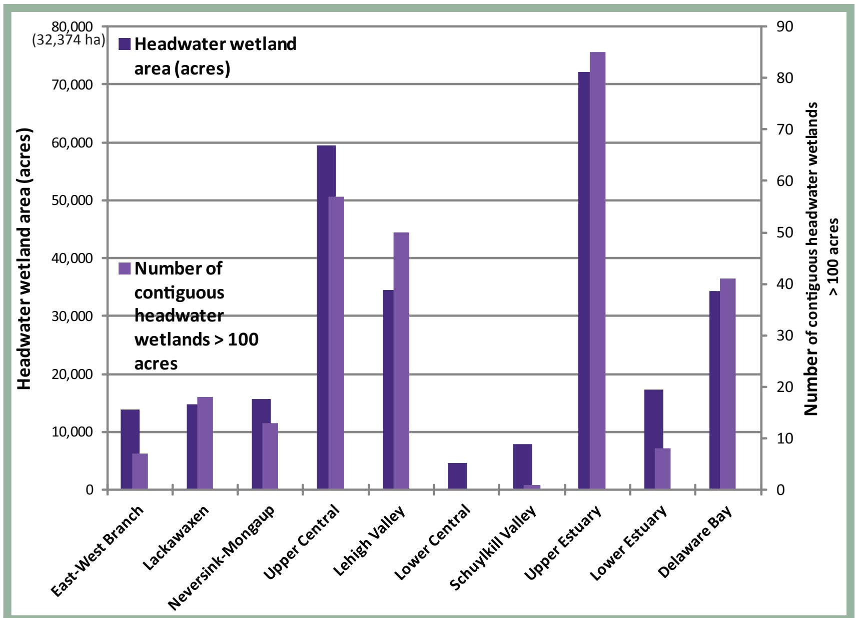


Fig. 5.34. Total headwater wetland area ranges from approximately 4,500 acres (1821 ha) in the Lower Central subbasin to over 72,000 acres (29,137 ha) in the Upper Estuary subbasin. The Upper Estuary subbasin also has 85 headwater wetlands that are larger than 100 acres (40 ha). This is the highest number of any subbasin in the Delaware River watershed.

Both the Upper Central and Lehigh Valley subbasins contain at least 50 headwater wetlands that are larger than 100 acres (40 ha). These subbasins also overlap with the glaciated portions of the Pocono Plateau, which includes the greatest diversity of wetlands in the state of Pennsylvania (Davis 1993). Boreal conifer swamps, oligotrophic kettlehole bogs, cranberry and bog-rosemary peatlands, and acidic broadleaf swamps occur throughout the region. Other unique wetland communities are found along the limestone valley, where mineral-rich groundwater supports calcareous fens, seepage swamps, and limestone wetlands. Cherry Valley National Wildlife Refuge and the Mt. Bethel Fens in Pennsylvania and the Johnsonburg and Sussex Swamps in New Jersey contain examples of these systems. Vernal pools are also scattered throughout the region, with concentrations along the toeslopes of the Kittatinny Ridge.

Although the Upper Estuary subbasin includes Trenton and Camden, NJ, Philadelphia, Pennsylvania, and other urban and suburban areas, this watershed contains over 70,000 acres (28,322 ha) of non-tidal wetlands and 85 wetlands larger than 100 acres. These headwater wetlands are especially abundant on the coastal plain in New Jersey, including along Crosswicks Creek and the North and South Branch Rancocas Creek.

5 – 1.3 Past Trends

Wetlands slow down, capture and cleanse rainwater before releasing it to rivers, oceans, lakes and groundwater. They shelter wildlife and provide breeding and spawning grounds for commercial and recreational fisheries. They store stormwater, releasing it slowly to help prevent floods, and support recreational activities.

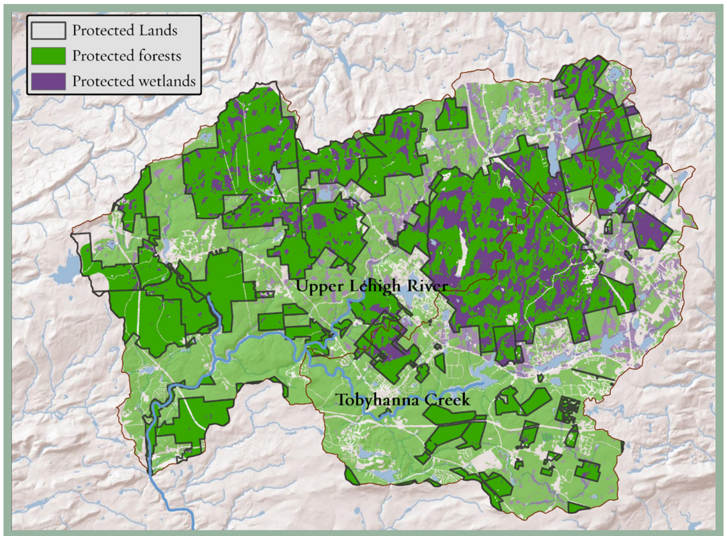


Fig. 5.37. Headwaters within the upper Lehigh Valley subbasin include extensive forests and wetlands within the riparian corridors. Much of this area is also in protected lands.

Yet for much of our history, wetlands have been undervalued. By the mid-1980s half the wetlands in the continental U.S. had disappeared, with losses averaging 500,000 acres (202,343 ha) per year. Regulations to control wetlands loss existed, but were often slow, unpredictable, expensive and frustrating for land owners.

In the summer of 1987, at the request of Lee Thomas, Administrator of the U.S. Environmental Protection Agency, The Conservation Foundation convened the National Wetlands Policy Forum, chaired by Governor Thomas H. Kean of New Jersey, to address major policy concerns about how the nation should protect and manage its valuable wetlands resources.

The goal of the Forum was to develop sound, broadly supported recommendations on how federal, state and local wetlands policy could be improved. In late 1988, the Forum published its final report, a 70-page consensus document that presented approximately 100 recommendations on a variety of issues including promoting private stewardship, improving regulatory programs, establishing government leadership and providing better information. Among the key recommendations was that national policy be guided by a goal of “no overall net loss” of the nation’s remaining wetlands and, over the long term, to increase the quantity and quality of the nation’s wetlands resources.

This goal has guided national wetlands regulatory and non-regulatory programs and policy ever since.

In the years since the Wetlands Forum, the rate of wetlands loss in the U.S. has slowed dramatically to the point where achieving the goal of “no net loss” may be in sight. This is truly a remarkable accomplishment.

Private land owners have made a major contribution, in recent years enrolling an average of 200,000 acres per year in the national Wetlands Reserve Program, one of the programs recommended by the Forum. Total acreage in the program now exceeds a million acres.

Federal and state agencies stepped up and provided increased leadership in numerous ways and in every Administration since the Forum’s recommendations, improving regulatory programs and providing better information. Shortly after the Forum’s report, EPA and the Army Corps signed a Memorandum of Understanding to better coordinate regulatory programs, reducing confusion for landowners.

5 – 1.4 Future Predictions

While filling and conversion of wetlands for agricultural and urban development has generally decreased over time, different stressors in the form of new industrial development seeking a location in small headwater watersheds will have to be carefully managed. In addition, it is likely the precipitation patterns of the next 100 years will be more extreme than the past, resulting in changing water budgets at a watershed scale and even greater ecosystem service values attributed to freshwater wetlands in the future.

5 – 1.5 Actions and Needs

Many positive actions are underway and require continued vigilance by Basin management community:

1. Continued attention to quantifying ecosystem service values.

2. Continued attention to harmonizing state and federal regulatory programs.

3. Continued attention to funding conservation initiatives and wetland reserve programs.

4. Continued effort to quantify feedback loops like the USDA Conservation Effects Assessment Program.

5. Passage of the Delaware River Basin Conservation Act of 2011-- championed by Senators Carper and Coons of Delaware, Senator Schumer and Gillibrand of New York, and Senators Menendez and Lautenberg of New Jersey-- which would establish a federal program at the U.S. Fish and Wildlife Service to coordinate voluntary restoration efforts throughout the Delaware River watershed.

5 – 2 Riparian Corridor Condition

Natural riparian corridors are important for stream and river health because they support physical and ecological processes and provide habitat corridors for river-associated birds and mammals. Depending on position within the watershed, riparian corridors play various functions. In headwater areas, hydrology, sediment input, and channel network formation is largely influenced by riparian corridors. Further downstream, riparian corridors often include well-developed floodplains, which may or may not be confined within steep valley walls. Floodplain condition affects channel and bank stability, water quality, sediment storage, and water storage during overbank flows. Riparian condition is one indicator of headwater and floodplain functions throughout a watershed.

5 – 2.1 Description of Indicator

The active river area model and land cover data were used to assess riparian corridor condition throughout the non-tidal portion of the Delaware River basin. The active river area framework is a spatially-explicit approach to identifying the areas within a watershed that accommodate the physical and ecological processes associated with river systems (Smith et al. 2008). The spatial model includes three primary components within the riparian corridor: floodplains, riverine wetlands, and riparian areas that are likely to contribute woody debris, coarse particulate organic matter, sediment, and energy to the riverine system. The area and percent of natural land cover (predominately forest

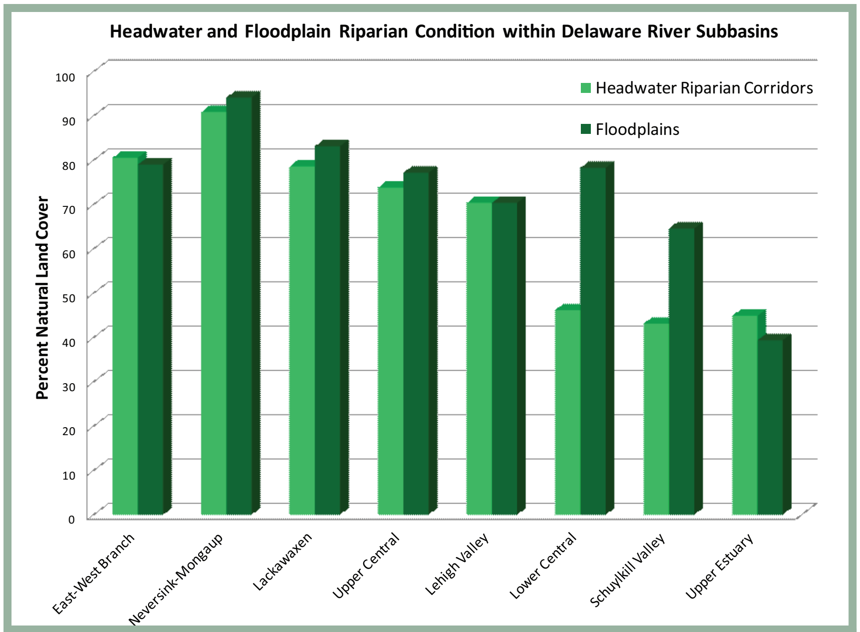


Fig. 5.35. The majority of floodplains and headwater riparian corridors in the Upper and Central Regions of the Delaware Basin contain at least 70% natural cover. Although percent natural cover is lower in the non-tidal portion of the Lower Region, there are still floodplain areas with extensive natural cover, including the portions of the Schuylkill Valley and mainstem Delaware between Allentown, PA and Trenton, NJ (Lower Central subbasin).

and wetland land cover) for headwater riparian corridors (i.e., all streams with drainage areas less than approximately 40 square miles/10,359 ha) was calculated. The area and percent of natural cover within floodplains (i.e., all streams and rivers with drainage areas greater than 40 square miles/10,359 ha) for each major sub-basin was calculated. Comparing riparian condition in headwaters and floodplains is one indicator that reveals how ecological processes may have been altered in various subwatersheds throughout the non-tidal portion of the basin.

5 – 2.2 Present Status

In the Upper and Central Regions of the Delaware Basin, the majority of riparian corridors are at or above 70% natural cover, both in headwaters and in floodplains (Fig. 5.33). The riparian corridors in the Neversink-Mongaup subbasin are in best overall condition compared to any other subbasin; over 90% of the riparian corridors are in natural cover, both within headwaters and within floodplains of larger rivers (Fig. 5.34). Natural riparian corridors in the headwaters, such as those in the Upper Lehigh River and Tobyhanna Creek watersheds, are essential for maintaining water quality and quantity for downstream ecosystems and water users (Fig.5.35). In the Lower Region, riparian corridors are much more developed, although there are still some large areas of natural cover within floodplain riparian corridors in the Schuylkill and Lower Central Subbasins. For example, the floodplain areas along the main-stem between Allentown, PA and Trenton, NJ, are approximately 78% forest and wetland cover. This area includes the Lower Delaware Wild and Scenic River, which is part of the National Wild and Scenic River system managed by the National Parks Service.

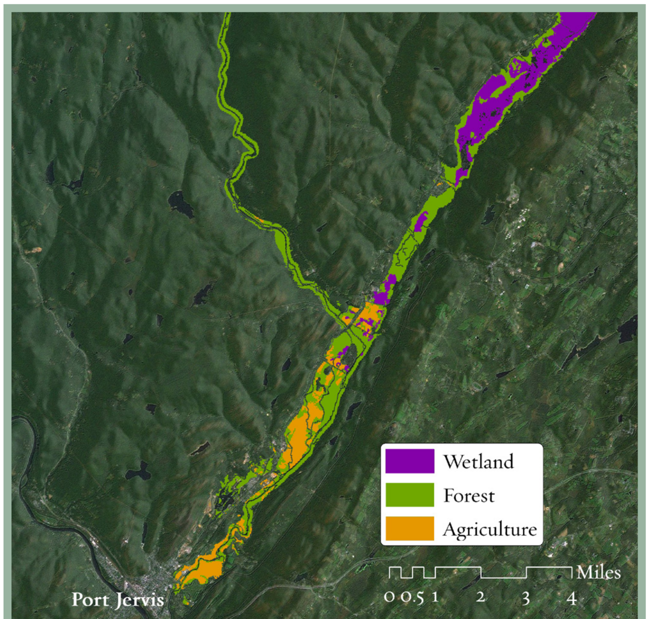


Fig. 5.36. In the Neversink-Mongaup subbasin, approximately 94% of the floodplain area is in forest or wetland land cover.

5 – 2.3 Past Trends

Riparian corridors (floodplains, riverine wetlands and riparian areas) have long been recognized as environmentally sensitive, ecologically diverse, and hydrologically important areas within a watershed. Even though the natural functions of these corridors and the hazards associated with their occupancy are widely known, people have always been attracted to water. Historically, settlements have arisen along waterways because they contain natural features beneficial to human societies (fertile soil, transportation links, water supply, hydropower, and aesthetic beauty). One consequence of human development of riparian corridors is the physical alterations of both stream channels (dams, levee construction, straightening, and dredging) and the floodplain landscape, impacting not only the integrity of the watercourse, but also resulting in significant social and economic consequences. Floods in developed floodplains devastate families, businesses and communities, and cause more damage to life and property than any other natural hazard.

Notwithstanding these problems in many parts of the country, the riparian corridor condition of the Delaware River Basin is relatively good. As noted above, riparian corridors associated with headwater watersheds and floodplains in the Upper Basin enjoy 70% or more natural cover. Similarly, riparian corridor condition associated with the Central Basin Delaware River floodplain has plentiful forest and wetland cover. The national status of the Delaware as the largest free flowing river East of the Mississippi, coupled with high water quality directly attributable to riparian corridor condition have led to inclusion of three-quarters of the non-tidal Delaware River (about 150 miles) in the National Wild and Scenic Rivers System. In contrast, only one quarter of one percent (11, 000 miles) of the 3.5 million miles of rivers in the nation has been included in the System.

5 – 2.4 Future Predictions

In 2004, the four Basin Governors and federal agency Regional Executives signed a forward looking Basin Plan that identified five Key Result Areas, one of which focused on Waterway Corridor Management. Specifically, the Plan specified a Desired Result involving: Waterway corridors that function to minimize flood-induced loss of life, protect property and floodplain ecology, preserve channel stability, provide recreational access, and support healthy aquatic and riparian ecosystems. Work is now underway by many partners to implement the specific goals and objectives enumerated in the plan, including an annual report out of progress at the fall Delaware River Basin Commission meeting.

Another significant milestone in 2011 was realized with the completion of the "Delaware River Basin Priority Conservation Areas and Recommended Conservation Strategies" Report. The report was developed by The Nature Conservancy, Partnership for the Delaware Estuary, and Natural Lands Trust, and funded by the National Fish and Wildlife Foundation. It focuses on Floodplains, Headwaters and Non-Tidal Wetlands and provides a platform for shared conservation and restoration priorities across the basin.

5 – 2.5 Actions and Needs

The Water Resources Plan for the Delaware River Basin ("Basin Plan) Objective 2.3 D called for "Implementing Strategies to protect critical riparian and aquatic habitat" and established milestones for identifying, mapping and prioritizing critical habitats. It also called for development and adoption of protection and restoration strategies.

1. Action: The Final Report for the National Fish and Wildlife Foundation titled "Delaware River Basin Priority Conservation Areas and Recommended Conservation Strategies" was completed in 2011. The report includes detailed maps by Sub-basin showing watershed specific freshwater system priorities. For example, the Upper Delaware River Basin is divided into 22 watersheds and place-specific conservation strategies (Headwater Networks; Floodplain Complexes; Headwater Wetlands; and Riverine Wetlands) are identified and prioritized.

2. Action: The Conservation Plan referenced in Item #1 functions as vehicle for collaborative restoration and protection action.

3. Action: The Conservation Plan also serves as preliminary set of targets for implementation of the Delaware River Basin Conservation Act of 2011, if it is successful in becoming federal law.

4. Need: The Basin conservation community needs to work with its Congressional Delegation to continue to advocate for passage of the Delaware River Basin Conservation Act.

5. Action: The Delaware River Basin Commission Flood Advisory Committee conducted a careful assessment of Floodplain Regulations both in the basin and around the country in 2008 and 2009. In October 2009, they presented a report containing twelve recommendations for more effective floodplain regulations to the Commission. The Committee determined that minimum floodplain regulations, administered by FEMA through the National Flood Insurance Program, do not adequately identify risk or prevent harm. They also found that floodplain regulations are inconsistent from State to State and from community to community. They recommended that floodplain regulations need to be applied more consistently and comprehensively, on a watershed basis that reaches across jurisdictional boundaries.

6. Need: DRBC needs to work with FEMA to advance their Risk Mapping, Assessment and Planning (Risk MAP) strategy to work with local officials to use flood risk data and tools to effectively communicate risk to citizens and better protect their citizens. The DRBC Flood Advisory Committee recommendations could be one component of the FEMA strategy to work with communities at a watershed scale to make the Basin more flood resilient.

5 – 3 Fish Passage

The Delaware River lacks any dams on its main-stem that block passage of fish, a feature which is remarkable for a river of its size. Diadromous fish like American shad, alewife, blueback herring, striped bass, sea lamprey, and American eel can travel over 300 miles (483 km) from the mouth of the river up to its origin (and back out to the ocean) without being blocked by a barrier. Unobstructed stream habitat like this is critical for migratory fish, especially for anadromous fish to be able to access freshwater spawning grounds. Long stretches of connected streams also are important for local movement of resident fish and other aquatic organisms. Some resident species, such as the tessellated darter, also serve as host fish for certain freshwater mussels. Consequently, the ability of fish like this one to move within a stream system is also critical for freshwater mussels, which rely on host fish to disperse their young and colonize new habitats.

Unlike the main-stem, most tributaries of the Delaware River have been dammed over time. Over 1,400 dams within the basin are tracked by various federal and state agencies; additionally, many smaller, unregulated dams that are not captured by these databases exist in the basin. While large dams pose clear barriers to fish passage, small run-of-river dams and even inadequate culverts can impede fish passage. Cumulative effects of barriers can dramatically reduce the amount of accessible habitat for fish within a stream network, although the first few barriers in a stream network have the greatest impact on connected habitat (Cote et al. 2009).

5 – 3.1 Description of Indicator

Using dams in state and Army Corps of Engineers (National Inventory of Dams) databases, as well as a small number of hand-mapped blockages in the Delaware Bay coastal area, we identified the length of each connected stretch of a river network (i.e., portions that have no dams occurring within that stretch) using the Barrier Analysis Tool (BAT, v.1). This tool calculates the total length of a connected stream network by adding the lengths of a river and all connected tributaries between barriers (or between a river origin and the first barrier downstream, or the river mouth and the first barrier upstream). Results of the analysis highlight the longest connected river networks, including those that have no blockages from their headwaters downstream to the Delaware River and out to the Bay.

It is important to note that our analysis included dams that have fish ladders installed on them. These dams were not removed from the analysis primarily because many fishways still pose barriers to fish passage; while they may allow for effective passage of a handful of species similar to those for which they were designed, many fish are still unable to use fish ladders effectively, if at all. Perched, undersized or blocked culverts also can be significant barriers to fish movement; however, this type of barrier was not included in our analysis, due to a lack of a basin-wide culvert dataset.

5 – 3.2 Present Status

The Delaware River is distinguished by being the longest free-flowing river in the Eastern US. Anadromous and catadromous fish species can travel unimpeded through over 500 miles (802 km) of connected rivers and streams, from the mouth of the Delaware River upstream to Hancock, New York and as far upstream on any connected tributary as the first barrier (Fig. 5.38). Many tributaries lack dams in their downstream portions and thus allow migratory fish like river herring to access spawning habitat downstream of any barrier. For example, the Rancocas, Flatbrook, and Neversink River systems all have significant habitat available for migratory fish. A dam removal on the lower Neversink River in 2004 opened up the entire historic habitat available for American shad, while also improving access for American eel and sea lamprey. (In the case of a river like the main-stem Schuylkill River, fish passage structures allow fish like shad to access upstream portions of the river, though our analysis does not recognize this degree of connectivity due to the difficulties in fairly assessing basin-wide where fishways effectively mitigate barriers that dams pose to most fish.)

Despite the fact that the main-stem and connected portions of its many tributaries together provide over 500 miles (805 km) of unblocked aquatic habitat, the Delaware River's tributaries have suffered significant fragmentation from the construction of over 1,400 dams in the 1800s and 1900s. Notwithstanding the fact that they lack a direct connection to the main-stem or bay, some tributary stream networks in the basin still offer significant mileage of connected habitat for resident fish. Some of the largest connected stream networks include the headwaters of the West Branch, the East Branch, the Lehigh River, and the Schuylkill River; a significant section of the middle Schuylkill also lacks tracked dams (Fig. 5.38). The ability to move locally within stream systems like these is important to many species. In particular, potadromous species, such as the white sucker, make instream migrations to complete their life cycles.

It is important to note that while some of the shorter stream systems (e.g, small coastal streams) may not have especially high values in terms of total connected stream length, these streams, which are often highly productive, are 100% connected from their headwaters to the Bay, allowing fish access to their full historic range of stream habitats (e.g., Red Lion Creek or Augustine Creek in Delaware or Oranoaken Creek or Bidwell Creek in New Jersey).

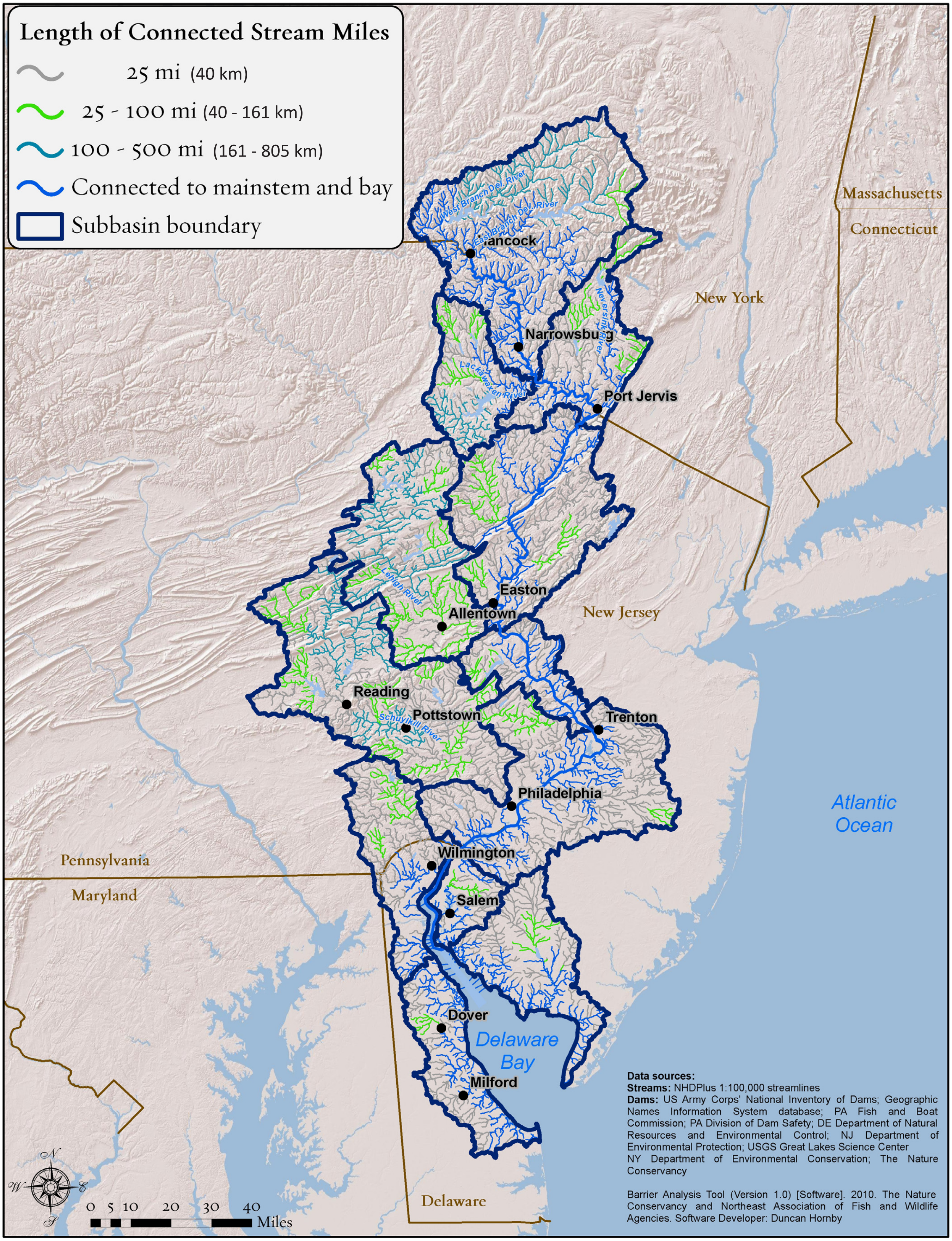


Fig. 5.38. Connected Stream Networks within Delaware River Subbasins.

5 – 3.3 Past Trends

In 1985, the Delaware Basin Fish and Wildlife Management Cooperative identified three priority rivers for fish passage efforts: the Brandywine, Schuylkill, and Lehigh Rivers. How far upstream fish can swim in each of these rivers has changed over time in two of these three rivers as fish passage efforts like dam removal and fishway installation have been implemented (Fig. 5.39).

On the main-stem Brandywine, fish ladders were installed during the mid-1970's on three of the first four dams, all located within the first four miles of the river. However, after several years of monitoring, the fish ladders were found to be ineffective and were removed. The Brandywine Conservancy has published feasibility studies for addressing fish passage for American Shad in the Delaware (2005) and Pennsylvania (2009) portions of the watershed. The studies included the 11 main-stem Brandywine dams in Delaware (~14 miles/23km of main-stem habitat) and 10 of the 28 current dams in Pennsylvania.

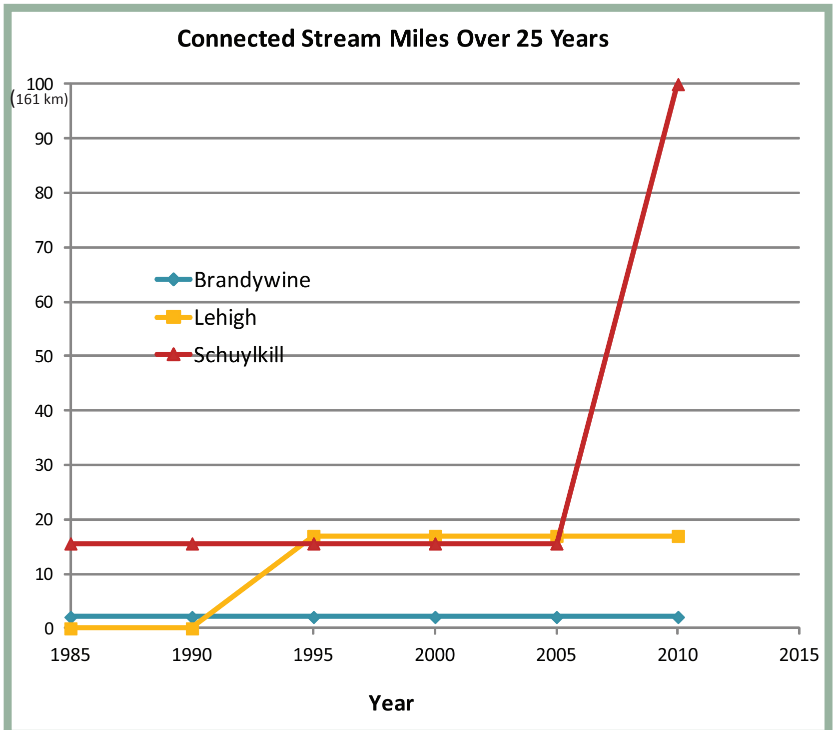


Fig. 5.39. Number of connected stream miles accessible from the mainstem Delaware River or Bay between 1985 and 2010 for each of the three priority fish passage rivers.

On the main-stem Schuylkill, three fish ladders and four dam removals since 2006 have increased access from river mile 15 up to river mile 100, a dramatic improvement. The effectiveness of the three fish ladders is still largely unknown, with only the Fairmount Dam fish ladder having associated long-term monitoring results published. In addition to the main-stem projects, between 2003 and 2007, five dams have been removed on the Perkiomen Creek main-stem, three on the Wyomissing Creek, and one each on the Tulpehocken and Pickering Creeks.

On the main-stem Lehigh, the first two dams had fish ladders (Easton & Chain) installed in 1994 and later retrofitted in 2000. The third dam, Hamilton St., had a fish ladder installed in 1984. A main-stem dam farther upstream, Palmerton Dam, was removed in 2006. After years of monitoring at both Easton and Chain dams, these fish ladders have been determined to be ineffective in passing their target species, American Shad. As a consequence, the Wildlands Conservancy and the PA Fish & Boast Commission recently requested proposals to evaluate the removal of Easton and Chain dams (July 2011) in the hopes of improving fish passage at these locations. Northampton Dam, the last of the lower four dams, is expected to have a fish passage feasibility study initiated in early 2012. In addition to these main-stem Lehigh projects, between 2000 and 2010, a total of 5 dams have been removed on Saucon Creek, East Branch Saucon Creek, Jordan Creek, Little Lehigh Creek, and Mahoning Creek.

In addition to these three tributary watersheds, there are active fish passage efforts underway in smaller tributaries such as Ridley Creek (DE/PA), Pennypack Creek (PA), Bushkill Creek (PA), Lopatcong Creek (NJ) and the Musconetcong River (NJ).

5 – 3.4 Future Predictions

The importance of river connectivity and associated fish passage is being recognized by many water resource agencies and the public and is evident in the recent number of dam removal projects and feasibility studies recently completed or currently underway. In addition to the direct impact on fish habitat, the relationship between keystone species such as freshwater mussels and their dependence on certain fish species for reproduction and colonization should only add momentum to addressing fish passage. Unless Basin prioritization is revisited, fish passage projects will likely continue to be haphazardly located throughout the Basin with more action occurring in tributaries with active watershed- based organizations and cooperative dam owners rather than in strategic locations.

5 – 3.5 Actions and Needs

Financial resources for addressing fish passage within the Basin are limited, and there is a need for an updated comprehensive evaluation of where best to prioritize fish passage. The prioritization needs to consider the best ecological return for each location addressed as well as the suitability of potential new habitat. An effort on-going since 2008 by the Northeast Association of Fish and Wildlife Agencies and The Nature Conservancy (TNC), called the Northeast Aquatic Connectivity (NAC) Project, has developed tools and an initial assessment of opportunities for restoration of stream system connectivity across the Northeastern US. With input from the NAC workgroup, TNC calculated 72 ecologically-relevant metrics for almost 14,000 dams across the region and developed tools to allow for tailored assessment of ecological returns of reconnection projects. Tools and final products (expected by 2012) include two assessment scenarios that rank dams for benefits for anadromous fish and for benefits for resident fish, produced using a subset of metrics weighted by the workgroup. While these products and tools will help inform prioritization efforts, site-specific factors still need to be considered in project selection.

In addition to the forthcoming Northeast Aquatic Connectivity Project, Senator Tom Carper (Delaware) recently introduced the Delaware River Basin Conservation Act of 2011, which would establish a federal program at the U.S. Fish and Wildlife Service (US FWS) to coordinate voluntary restoration efforts throughout the Basin and oversee up to $5 million per year of grant funding. It is envisioned that a basin-wide fish passage prioritization project would be an ideal project worthy of funding through the Act and would help guide future distribution of grant monies.

The fish ladders installed in the Lehigh River have also demonstrated that not all fish passage "remedies" are equal, with some being more successful than others. In cases where a dam no longer serves a critical use such as for public water supply, the first remedial option should be removal. In addition, where regulatory opportunities exist with dam owners during permitting actions, regulatory agencies need to adopt and implement a consistent approach as to when and why fish passage needs to be addressed. Many dam owners have argued that if anadromous fish are not present downstream of their dam, then there is no need to address fish passage. For dam locations that do not have anadromous fish downstream, addressing fish passage is still important for resident species.

From the perspective of both anadromous and resident fish, assessing the degree to which road/stream crossing structures also are creating barriers to fish passage will be important, as well. While we currently lack good data, pilot field surveys conducted by The Nature Conservancy and others will provide some insight on the prevalence of problematic culverts within select tributary watersheds in the Basin. Following ecological standards for culvert design and replacement could be helpful to restore connectivity currently hindered by these small structures.

5 – 3.6 Summary

The Basin has experienced a large number of fish passage projects, primarily targeting American Shad, during the past 10 years. Most of the fish passage projects are occurring in Pennsylvania, with both financial and technical support from the state resource agencies. Although three large tributaries were targeted in 1985 for priority consideration, it appears that the only tributary with significant progress may be the Schuylkill River. Recent fish passage efforts do not appear to be a component of a larger restoration plan. A new Basin-wide reassessment of fish passage priorities is needed to ensure that limited resources are being targeted in an efficient and effective manner.

5 – 4 Hydrological Impairment

Natural variations in hydrologic regime—the magnitude, timing, frequency, duration, and rate of change of stream flow—are critical for sustaining healthy river systems (Poff et al. 1997, Richter et al. 1997). Healthy floodplains also are dependent upon natural flows, as they require interaction with rivers whose flow regimes have sufficient variability to encompass the flow levels and events that support important floodplain processes (Opperman et al. 2010). Alterations to the natural flow regime of a river result from a variety of sources, such as flood control, water supply and hydropower dams, as well as water withdrawals and development in the watershed. Paved and other hard surfaces, collectively referred to as impervious cover, often increase the volume of and rate at which precipitation runs off into the stream channel and can increase the flashiness of streams (Leopold 1968). Impairment of a river's natural hydrologic regime can cause various negative impacts throughout a watershed. Dams that store large amounts of water can significantly change amounts of streamflow downstream of the dam, as well as change seasonal patterns of high and low flows on which many aquatic organisms depend (Poff et al. 1997). In addition, large dams change sedimentation patterns, potentially depriving the river downstream of the dam and causing significant changes in the stream channel and bed. Other impacts include changes in water temperature and nutrient transport, which in turn affect both aquatic and riparian species (Poff and Hart 2002).

5 – 4.1 Description of Indicator

All dams do not have the same effects on downstream rivers, and consequently, using one indicator to predict potential hydrological alteration is difficult across the

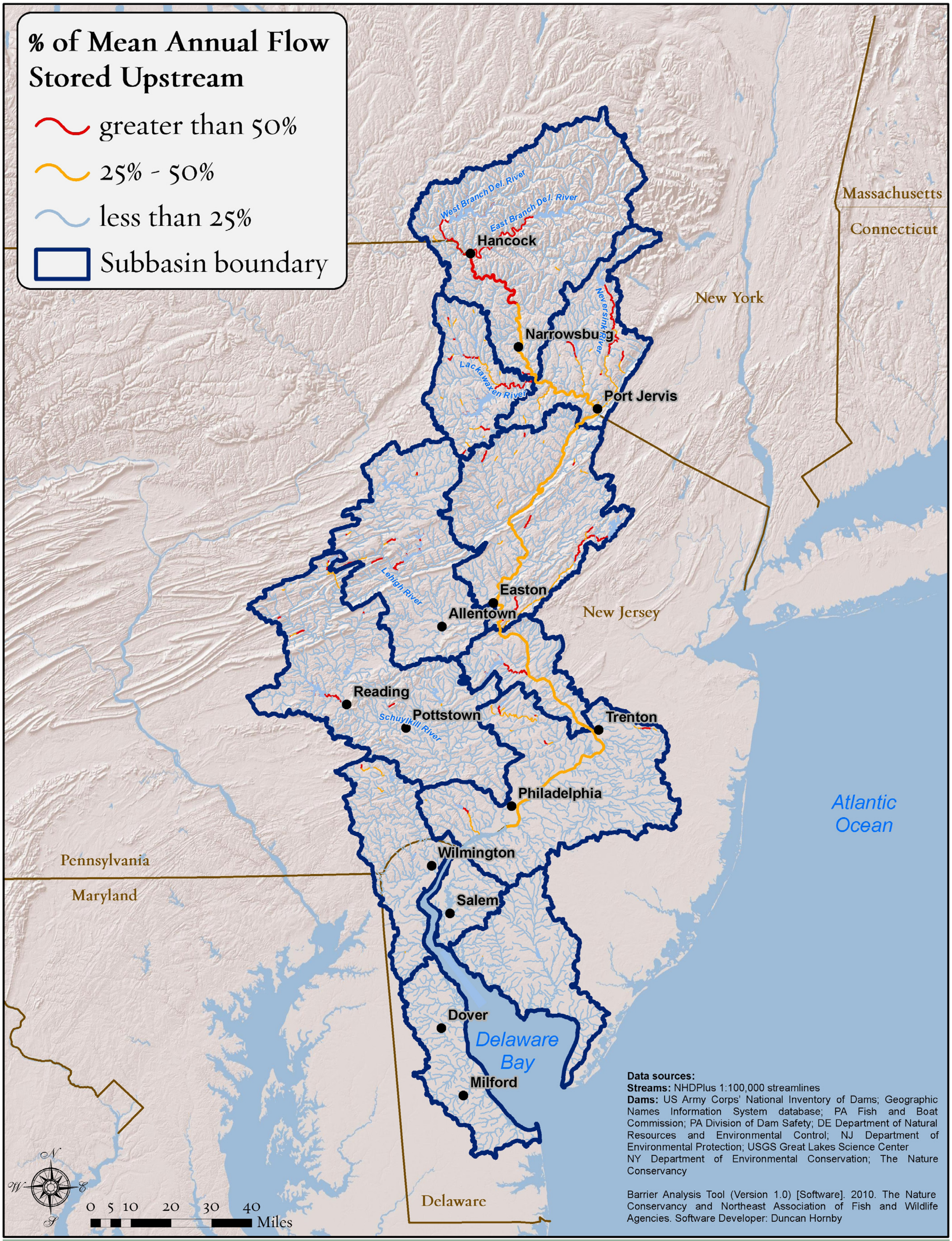


Fig. 5.40. Ratio of upstream dam storage to mean annual flow for river reaches within Delaware River sub-basins.

entire basin. However, one important indicator of potential alteration to the natural hydrologic regime is the ratio of upstream dam storage to mean annual flow downstream (Graf 1999). This ratio is calculated by expressing the cumulative volume of water stored by upstream dams as a percent of the mean annual flow of each downstream river segment. As this proportion increases, so does the likely alteration to natural stream flow. Ratios indicative of a high risk of hydrologic alteration have been demonstrated to be > 50% (Zimmerman and Lester 2006). Using storage values available in state and Army Corps of Engineers (National Inventory of Dams) databases and mean annual flow values associated with NHDplus streamlines, we applied the Barrier Analysis Tool (BAT, v.1) to calculate the percent of mean annual flow that is stored in upstream dams in the Delaware Basin.

This indicator does *not* take into account day to day reservoir operations or specific dam configuration, which can influence the degree of hydrologic alteration in either a positive or negative way. Furthermore, this indicator also does not reflect the effects of other water diversions or withdrawals in the basin, so it is limited to potential impairments to hydrologic regime caused only by dam storage. However, the basin-wide assessment of the risk of hydrologic impairment due to high dam storage is still a useful indicator; across large and small rivers, it can help identify which stream and river reaches may be suffering the hydrologic (and associated ecologic and biologic) impacts of upstream dams and which dams may warrant further investigation to address potential streamflow alteration.

In order to identify places most likely to be suffering hydrologic impairment due to land use change, also examining the percent cover of impervious surface within a watershed can provide a useful complement to the measure of upstream dam storage. The high amounts of impervious cover associated with many highly developed areas are likely to cause hydrologic alteration downstream unless there are adequate stormwater management systems in place. The higher the percent cover of impervious surface across a small watershed, the more likely its streams are to be suffering hydrologic impairment. Because this metric cannot take into account effective stormwater management, it also should be used as a first-cut indicator to identify places that likely would benefit from stormwater management systems if they are not already in place.

5 – 4.2 Present Status

As many dams in the basin are run-of-river dams and have relatively little effect on hydrologic regime, the vast majority of stream miles within the basin are at low risk of hydrologic alteration, as indicated by their ratio of dam storage to mean annual flow value (Fig. 5.40). However, over 300 stream and river miles (483 km) within the basin could be considered at high risk as indicated by ratio values of >50%. Of these 300 miles, over 130 miles (209 km) of high-risk streams and rivers are those which drain less than 38 square miles (9842 ha). High ratios might be expected in these headwater areas where dams occur in small streams that have relatively low mean annual flow values. High risk on larger rivers may be caused by the cumulative storage of many dams upstream or by a major reservoir with significant storage capacity (or a combination of the two). Despite the limitations of the basin-wide analysis of the risk of hydrologic impairment due to high dam storage, this ratio is still a useful indicator of locations where impaired hydrology may be occurring and affecting the health of our streams and rivers. While some significant impacts are occurring in the Delaware Basin, most streams and rivers are at low risk of impairment from dam storage.

Similarly, the vast majority of watersheds within the basin have relatively low (< 10 %) impervious cover (Fig. 5.41). However, streams in or downstream of urbanized areas, particularly those with outdated or insufficient stormwater management in place, are likely to be suffering negative impacts of altered hydrology as well. Most at-risk watersheds are concentrated around the cities of Wilmington, Philadelphia, and Camden, though watersheds along the Lehigh, Schuylkill, and Maurice Rivers also may be experiencing substantial hydrologic impairment due to land use change. Localized land change certainly may also affect hydrology within a watershed, but this basin-wide analysis helps to identify where the greatest impairment is likely to be occurring.

5 – 4.3 Past Trends

Most of the Basin's large reservoirs were completed between 1960-1980 and were not specifically designed to operate with the longitudinal (high and low) and/or the temporal (seasonal) conservation flows that may be needed to maintain native aquatic communities. Recent advances in ecological flow science have resulted in many water resource agencies beginning to factor ecological flow needs into the way that large reservoirs are managed. Some smaller Basin reservoirs currently do not have any conservation release requirements, while most of the larger reservoirs have release requirements based on assimilative capacity needs ("Q7-10" - the consecutive 7-day flow with a 10-year recurrence interval) as opposed to one based on aquatic resource needs. Recent changes adopted by the Decree Parties for the three New York City Basin reservoirs have started to incorporate aquatic resource needs into their reservoir operation plans.

Most of the Basin's existing impervious cover was created prior to modern stormwater management (pre 2000). If any stormwater management did occur prior to 2000, it tended to focus on large storm events (>10 year storm). Modern stormwater management requirements

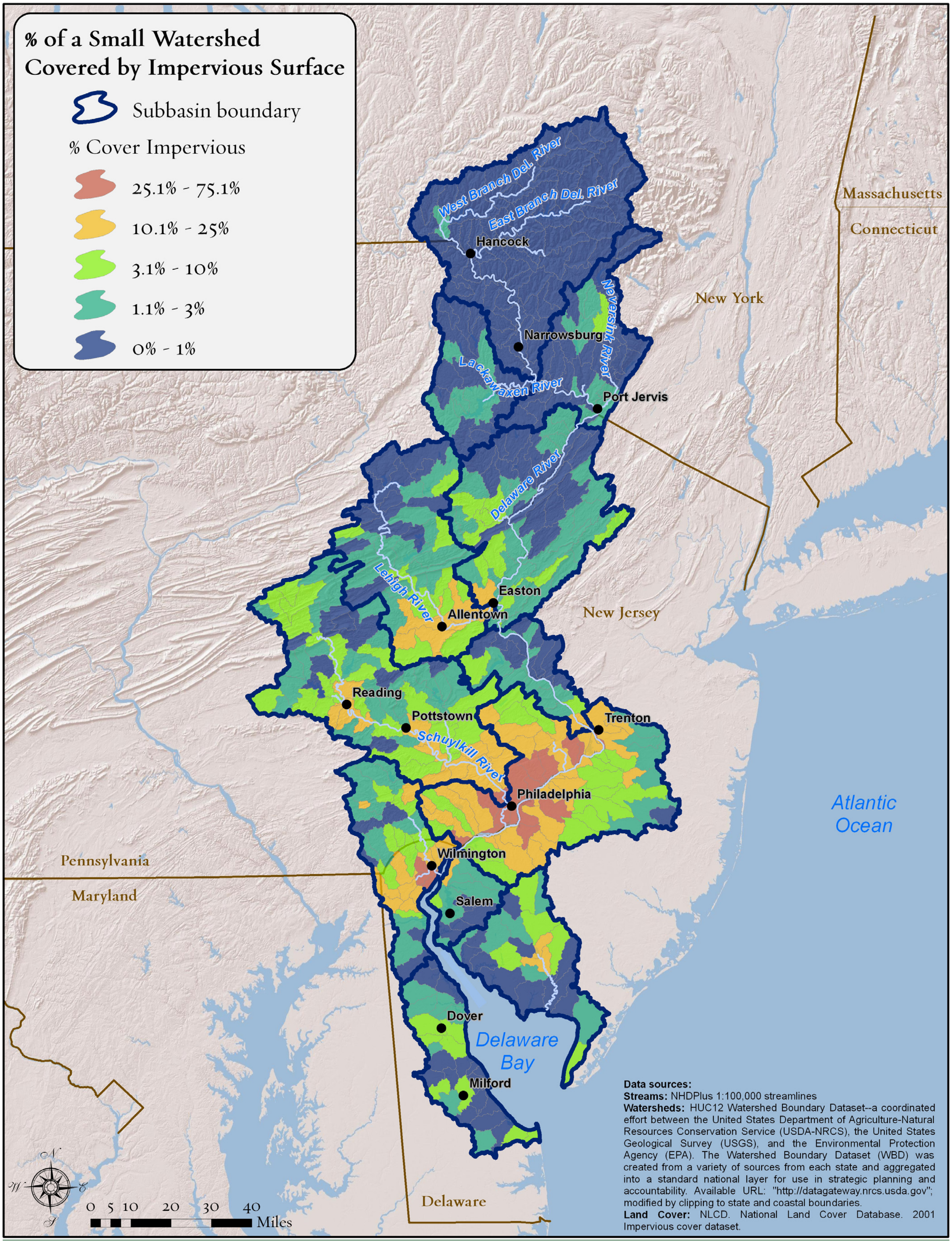


Fig. 5.41. Percent cover by impervious surface across small watersheds in the Delaware River Basin.

have tended to focus on a broader range of rain events (0-100 year storm events), along with minimum infiltration requirements. The modern stormwater management requirements have largely centered on trying to maintain the existing hydrology of a project site from pre to post-development conditions.

5 – 4.4 Future Predictions

As ecological flow science progresses and native aquatic communities' needs are further identified, water resource agencies can start to factor those data into the management of basin reservoirs. New reservoirs will almost certainly be designed and permitted to consider ecological flow needs, while existing reservoirs operations are reviewed during the permit renewal process, which provides opportunities for operational revisions based on the latest science.

Stormwater management will need to focus in two areas – new development and retrofitting existing impervious cover. Almost all new development in the Basin is subject to modern stormwater management requirements. It is anticipated that the level of hydrological impairment due to "new development" will be minimal compared to the existing hydrological impairment caused by existing impervious cover.

5 – 4.5 Actions and Needs

A study of ecological flow needs to protect species and key ecological communities for the range of habitats in the Delaware Basin is necessary in order to provide the scientific basis for any future modifications to reservoir operation plans.

Developing a strategy to deal with existing hydrological impairments due to existing impervious cover is necessary. Options range from mandatory stormwater management retrofits during the redevelopment of a site to voluntary retrofits incentivized by the implementation of stormwater runoff fees.

5 – 4.6 Summary

While most Basin streams are at low risk of hydrological impairment due to dam storage, some significant impacts are occurring in localized areas. The incorporation of ecological flow needs into reservoir management will likely increase in the future as those needs are further identified, which should result in a gradual minimization of impacts in those localized streams.

While most Basin streams are at low risk of hydrological impairment due to existing impervious cover, there are significant impacts in the older urban/suburban areas of the Basin. Implementing stormwater management on existing impervious cover is expensive and may take several decades to address.

Example effects of dam storage and operations on hydrologic impairment: Neversink River

The basin-wide indicator of dam storage ratios does not take into account actual dam operations. For example, this analysis indicates a high level of alteration downstream of the Neversink Reservoir. Indeed, the biologic effects of hydrologic alteration have been documented in the Neversink River, where macroinvertebrate surveys indicated that species composition in the river downstream of the reservoir showed signs of degradation similar to stretches impaired by acidity in other parts of the watershed (Ernst et al. 2008). Altered temperatures and low flow in river stretches immediately downstream of the reservoir appeared to favor Chironomidae taxa over Ephemeroptera, Plecoptera, and Trichoptera taxa, similar to how pH and aluminum in the East Branch of the Neversink River appeared to influence macroinvertebrate composition there. This change in the biotic community of the river downstream of the reservoir likely was caused by adverse effects from dam storage (Ernst et al. 2008). However, more recently, a detailed study of the effects of changes in the management of the Neversink Reservoir just within the past few years illustrates that recent management changes have improved the degree of alteration to the Neversink River's natural hydrologic regime (Moberg et al. 2010). The figure below shows how the natural range of variability in flow on the Neversink has changed with the implementation of the Flexible Flow Management Plan. Whether the biotic communities of the Neversink River downstream of the reservoir have shown any positive response to the return of a more natural hydrologic regime has not yet been studied.

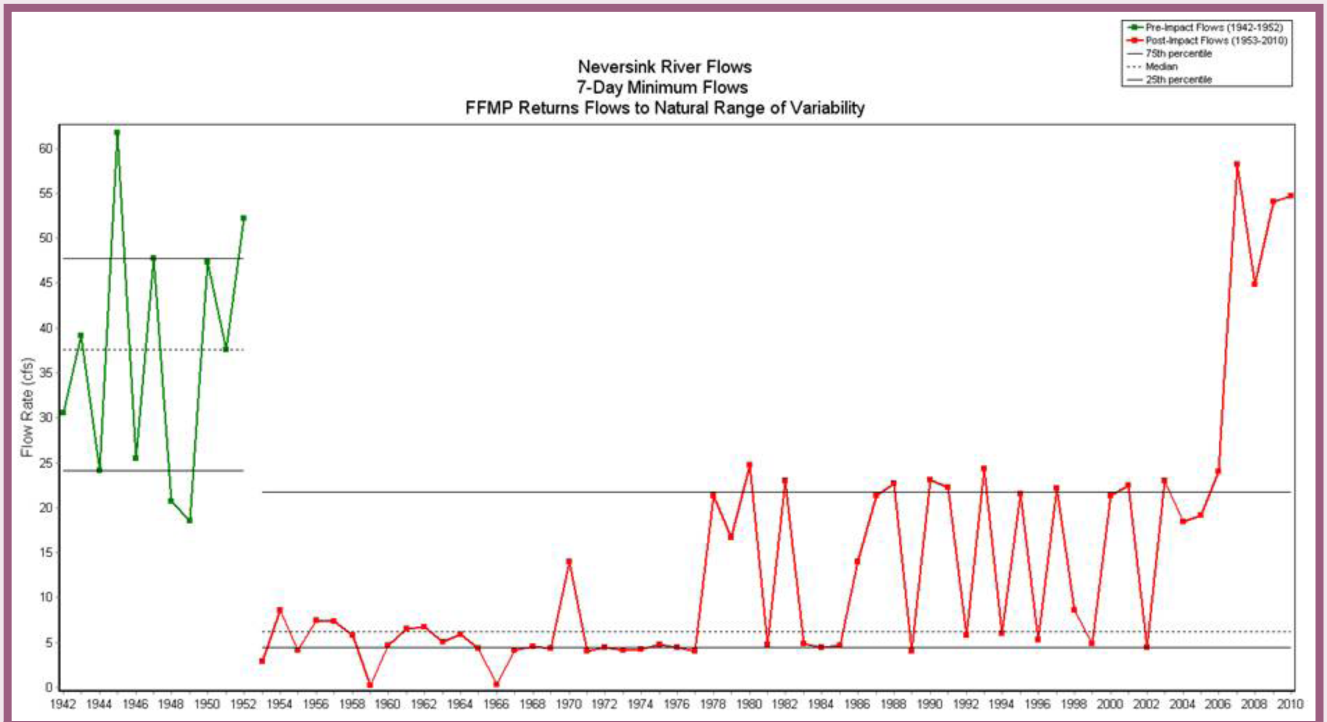


Illustration of the effects of dam operations on the Neversink River, compared to pre-dam conditions. Patterns during implementation of the Flexible Flow Management Plan indicate minimum flows within the range of natural variability.

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6

Living Resources

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6 – 1 Horseshoe Crab

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Horseshoe crabs (*Limulus polyphemus*) are benthic (or bottom-dwelling) arthropods that use both estuarine and continental shelf habitats. Although it is called a "crab," it is grouped in its own class (Merostomata), which is more closely related to the arachnids than blue crabs and other crustaceans. Horseshoe crabs, range from the Yucatan peninsula to northern Maine, with the largest population of spawning horseshoe crabs in the world found in the Delaware Bay.

Each spring, adult horseshoe crabs migrate from deep bay waters and the Atlantic continental shelf to spawn on intertidal sandy beaches. Beaches within estuaries, such as the Delaware Bay, are believed to be preferred because they are low energy environments protected from wind and waves, thus reducing the risks of stranding during spawning events. Spawning generally occurs from March through July, with the peak spawning activity occurring on the evening new and full moon high tides in May and June.

Horseshoe crabs are characterized by high fecundity, high egg and larval mortality, and low adult mortality. Horseshoe crabs spawn multiple times per season, laying approximately 3,650 to 4,000 eggs in a cluster. Adult females lay an estimated 88,000 eggs annually. Egg development is dependent on temperature, moisture, and oxygen content of the nest environment. Eggs hatch between 14 and 30 days after fertilization.

Juvenile horseshoe crabs generally spend their first and second summer on the intertidal flats, usually near breeding beaches. As they mature horseshoe crabs move into deeper water, eventually into areas up to a few miles offshore. Horseshoe crabs molt at least 16 to 17 times over 9 to 11 years to reach sexual maturity. Based on growth of epifaunal slipper shells (*Crepidula fornicata*) on their prosoma, horseshoe crabs live at least 17 to 19 years.

Larvae feed on a variety of small polychaetes and nematodes. Juvenile and adult horseshoe crabs feed mainly on molluscs including razor clam (*Ensis spp.*), macoma clam (*Macoma spp.*), surf clam (*Spisula solidissima*), blue mussel (*Mytilus edulis*), wedge clam (*Tellina spp.*), and fragile razor clam (*Siliqua costata*).

Shorebirds feed on horseshoe crab eggs in areas of high spawning densities such as the Delaware Bay. Horseshoe crab eggs are considered essential food for several shorebird species in the Delaware Bay, which is the second largest migratory staging area for shorebirds in North America. Shorebird predation on horseshoe crab eggs has little impact on the horseshoe crab population since horseshoe crabs place egg clusters at depths greater than 10 centimeters, which is deeper than most shorebirds can probe. Eggs utilized by shorebirds are brought to the surface by wave action and burrowing activity by spawning horseshoe crabs. The eggs brought to the surface not consumed by shorebirds or other predators desiccate in a short time in the sun, so do not contribute to productivity of the horseshoe crab population.

It is believed that adult and juvenile horseshoe crabs may make up a significant portion of the loggerhead sea turtle's (*Caretta caretta*) diet. Horseshoe crab eggs and larvae and adults are also a seasonally preferred food item of a variety of invertebrates and finfish, including sharks.

Human activity probably accounts for the greatest proportion of adult horseshoe crab mortality. Between the 1850s and the 1920s, it is estimated that over one million horseshoe crabs were harvested annually for fertilizer and livestock feed. More recently horseshoe crabs have been taken in substantial numbers (eg. the ASMFC estimated that as much as 299,9491 horseshoe crabs were landed annually between 1995 and 1997) to provide bait for other fisheries, including (primarily) the American eel and conch fisheries.

Horseshoe crabs are also collected by the biomedical industry to produce Limulus Amebocyte Lysate (LAL). This industry bleeds individuals and releases the animals live after the bleeding procedure. LAL is used world-wide to test medical products such as flue serum, pace makers, artificial joints, and other items to help ensure public safety from bacterial contamination. No other known procedure has the same accuracy as the LAL test. If LAL became unavailable, it could take years to find a universally accepted replacement. Mortality associated with this use is estimated to be around 15 percent.

6 – 1.1 Description of Indicator

This indicator uses the spawning survey, which is conducted under the direction of the Atlantic States Marine Fisheries Commission's (ASMFC) Interstate Fishery Management Plan for Horseshoe Crab. The survey provides levels of spatial and temporal coverage that are effective for understanding trends in spawning activity at the bay-wide scale. Begun in 1999, this survey is published annually as a report to the ASMFC.

Beaches are sampled by volunteers using a stratified random approach. Sampling occurs 2 days prior, day of, and 2 days after the peak moon events (full and new moons) and at the highest of the daily high tides, which is the second or evening high tide. Protocol and data sheets and training are provided to volunteers. Each beach is sub-sampled using quadrats along transects that have random starts. Approximately 100 quadrats are sampled per beach. The quadrats are placed at the high tide line and all horseshoe crabs that are at least halfway in the quadrat are counted and differentiated by sex.

The objective of the spawning survey was to estimate an index of spawning activity based on horseshoe crab density. It is important to recognize that this survey gives an estimate of density and should not be used to estimate population size. Instead it provides a useful measure of relative abundance or density of spawners and trends in spawning density.

6 – 1.2 Present Status

The latest report available is the 1999-2010 Spawning Survey Report, published May 30, 2011. In 2010 spawning peaked in late May, and most spawning took place during May. Spawning is well correlated with water temperatures.

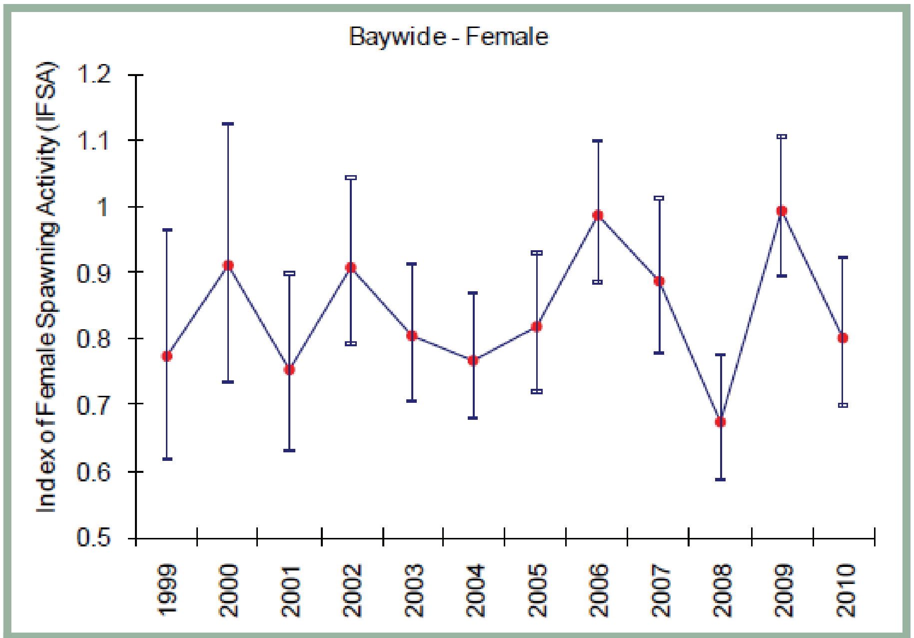

Fig. 6.1.1. Index of female horseshoe crab spawning activity (IFSA) for the Delaware Bay from 1999 to 2000. Error bars are 90% confidence intervals.

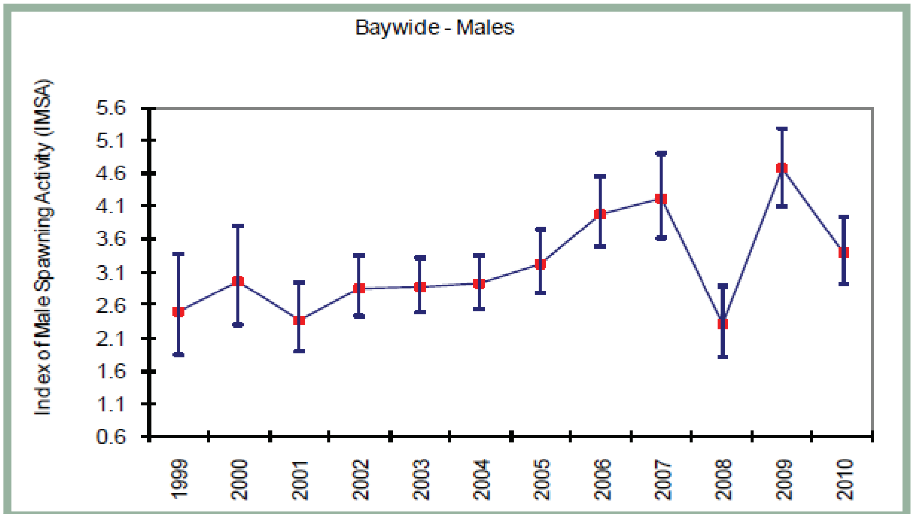

Fig. 6.1.2. Index of male horseshoe crab spawning activity (IMSA) for the Delaware Bay from 1999 to 2009. Error bars are 90% confidence intervals.

6 – 1.3 Past Trends

Little data is available for measuring trends prior to 1990, but the population probably declined in the early 1900s due to overharvest and then increased through the 1970s. Bait overharvest led to another decline in the 1990s. There was no significant trend in female spawning activity between 1999 and 2009. Male spawning activity shows a positive trend during this time period.

6 – 1.4 Future Predictions

The ASMFC has implemented monitoring programs and restricted harvest of horseshoe crab with stated goals of maintaining a sustainable population for current and future generations of the fishing and non-fishing public, migrating shorebirds, and other dependent wildlife, including federally listed sea turtles. The National Marine Fisheries Service has established a horseshoe crab sanctuary off the mouth of Delaware Bay, the Carl N. Shuster Sanctuary. Watermen have voluntarily implemented the use of bait bags that reduce their need for bait by preventing bait from being consumed by non target species. The biomedical industry has voluntarily implemented management practices to reduce stress to animals being held for bleeding. These measures can be expected to allow the spawning population to increase over time by reducing harvest and indirect mortality.

While there are indications that management actions to limit harvests, combined with voluntary reductions in bait use by watermen, are allowing the population to increase, the current population trend for females does not yet show a positive trend and does not appear to be spawning at densities high enough to provide sufficient surface eggs to support historic levels of shorebirds during the spring stopover. Because horseshoe crabs are long-lived and do not reproduce until at they are eight-to-12 years old, it can take a decade or more for management actions to result in a measurable increase in the spawning population.

6 – 1.5 Actions and Needs

In order to better understand horseshoe crab population trends and their interaction with shorebirds, a cooperative effort between the ASMFC, States, US Geological Survey, and the US Fish & Wildlife Service has resulted in an Adaptive Management Framework for recommending harvest levels based upon population models that link red knot populations with horseshoe crab populations. Under this framework, competing models that describe the dependence and interaction of red knots and shorebirds can be evaluated over time by monitoring the populations. Two monitoring programs are essential to implement this framework: The Horseshoe Crab Trawl Survey and the Shorebird Monitoring Program at Delaware Bay. It will be critical to ensure funding for these two monitoring programs in order to increase understanding and reduce uncertainty regarding how these two populations interact.

6 – 1.6 Summary

Management of horseshoe crab harvest coupled with voluntary measures by the bait and biomedical industries can be expected to allow spawning populations of horseshoe crabs in Delaware Bay to increase over time. However, due to overharvest in the past, and the length of time needed (8-12 years) for horseshoe crabs to reach maturity, populations have not yet shown significant increases in terms of spawning densities relative to what were believed to be historical levels. Shorebirds dependent upon eggs that are exhumed by wave action and high densities of spawning horseshoe crabs are still at low levels and it is unclear whether current levels of surface eggs are high enough to support current levels of red knots and other shorebirds during typical weather conditions.

Since a portion of the red knot population that passes through Delaware Bay winters at the tip of South America and breeds in the high Arctic, other factors outside of Delaware Bay can, and probably are, affecting these populations. Work to help better understand the dependence of red knots on Delaware Bay is being carried out, in part, through a cooperative Adaptive Management Framework.

Horseshoe Crab Glossary

Arachnid - terrestrial invertebrates, including the spiders, scorpions, mites, and ticks

Arthropod – animals that have an exoskeleton (external skeleton), a segmented body, and jointed appendages. Arthropods include the insects, arachnids, crustaceans, and others.

Benthic - relating to the bottom of a sea or lake or to the organisms that live there.

Crustacean – a very large group of arthropods which includes animals such as crabs, lobsters, crayfish, shrimp, krill, and barnacles.

Epifaunal - benthic animals that live on the substrate (as a hard sea floor) or on other organisms.

Estuarine – of or pertaining to a semi-enclosed body of water connected to the sea as far as the tidal limit or the salt intrusion limit and receiving freshwater runoff; however the freshwater inflow may not be perennial, the connection to the sea may be closed for part of the year and tidal influence may be negligible.


Greg Breese

Fecundity - generally refers to the ability to reproduce. It can be thought of as fertility, or the actual reproductive rate of an organism or population.

Horseshoe crab - arthropods that live primarily in shallow ocean waters and come on shore for mating. Horseshoe crabs resemble crustaceans, but belong to a separate subphylum, Chelicerata, and are therefore more closely related to spiders and scorpions. The earliest horseshoe crab fossils are found in strata from the late Ordovician period, roughly 450 million years ago.

Intertidal flats - non-vegetated, soft sediment habitats, found between mean high-water and mean low-water and are generally located in estuaries.

Merostomata - class of primitive arthropods of the subphylum Chelicerata distinguished by their aquatic mode of life and the possession of abdominal appendages which bear respiratory organs; the only three living species known today from this group are horseshoe crabs.

Mollusk - a large group of invertebrate animals generally called shellfish. Molluscs are highly diverse, not only in size and in anatomical structure, but also in behaviour and in habitat. Included in this group are squid, cuttlefish, and octopus (among the most neurologically-advanced of all invertebrates); snails and slugs (the most numerous mollusks); chitons (known for their segmented shells); and bivalves including clams, mussels, scallops, and oysters.

Molt - to cast off the outer shell as arthropods do when they grow.

Nematode – this group of organisms, also known as round worms, are the most numerous multicellular animals on earth. A handful of soil will contain thousands of the microscopic worms, many of them parasites of insects, plants, or animals. Free living species play an important role in the decomposition process. Parasitic species includes such well known examples as hookworms and heart worms.

Polychaete - a group of worms, generally marine, in which each body segment has a pair of fleshy protrusions called parapodia that bear many bristles, called chaetae, which are made of chitin. Common representatives include the lugworm and the sandworm or clam worm.

Prosoma – the head or front part of the body in horseshoe crabs.

Quadrats - a square (of either metal, wood, or plastic) used in ecology and geography to isolate a sample for study or measurement.   The quadrat is suitable for sampling plants, slow-moving animals, and some aquatic organisms.

Red knot - a medium sized shorebird which breeds in the Arctic and winters in South America, passing through Delaware Bay where it eats horseshoe crab eggs.

Sanctuary - a place of refuge and protection, for example a refuge for wildlife where hunting or fishing is illegal.

Shorebird – a group of birds characterized by long and thin legs with little to no webbing on their feet, generally found close to water. Shorebirds include the avocets, oystercatchers, phalaropes, plovers, sandpipers, stilts, snipes, and turnstones.

Spatial - relating to, occupying, or having the character of space.

Spawning - refers to the eggs and sperm released or deposited, usually into water, by aquatic animals.

Temporal - of or relating to time.

Transects - a path along which one moves and counts occurrences of the plants and animals.

6 – 2 Atlantic sturgeon

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Historically, Atlantic sturgeon, Acipenser oxyrinchus oxyrinchus, were reported in the Delaware River as well as most major rivers on the eastern seaboard of North America ranging from the Hamilton Inlet on the Atlantic coast of Labrador to the St. Johns River in Florida. Through biological classification, this species is placed in the family Acipenseridae, a category of ancient bony fishes that have been able to survive as a group in contemporary environmental conditions (Detlaff, et al. 1993). Atlantic sturgeon are late-maturing anadromous fish that may live up to 50 years, reach lengths up to 14 feet (4.3 m), and weigh over 800 pounds (364 kg). They are distinguished by armor-like plates called "scutes" and a long snout. They are opportunistic benthic feeders filtering quantities of mud along with their food which consists of aquatic invertebrates (Vladykov and Greely 1963).

U.S. Fish & Wildlife Service

Fig. 6.2.1. Mature Female Atlantic sturgeon.

Mature Atlantic sturgeon (Fig. 6.2.1) migrate from the sea to fresh water in advance of spawning with females, first maturing at ages ranging from 7-19 years old in South Carolina to 27-28 years in the St. Lawrence River. Males can be somewhat younger at first spawning. The Delaware River population of Atlantic sturgeon has been determined to be genetically similar to those of the Hudson River, but through range-wide genetic analysis of nuclear DNA at least 6 sub-populations were suggested including one for the Delaware River distinguishable from the Hudson River stock (King et al. 2001). In the Delaware River, first-maturing females are likely to be at least 15 years old. Spawning occurs in flowing fresh or estuarine waters with a hard bottom. Shed eggs are 2-3 mm in diameter and become sticky when fertilized, frequently becoming attached to hard substrates or submerged detritus until hatching in several days. After hatching occurs, juveniles remain in fresh water for several years but have been documented to out-migrate to coastal areas in their 3rd year (Sweka, et al. 2006) found that juvenile sturgeon preferred soft bottom habitats at depths greater than 6.3 meters in the Hudson River. Once juveniles out-migrate from their natal river they are known to frequent distant estuary systems (Secor et al. 2000); tagged age-0 fingerlings stocked in the Hudson River in 1994 were found in the Chesapeake and Delaware Bays in 1997 (Bain 1998). Mature individuals also frequent estuaries distant from their natal river. Studies performed in the Hudson River using pop-up satellite archival tags showed that the majority of adult Atlantic sturgeon captured and tagged in the Hudson during spawning season eventually out-migrated to the mid-Atlantic Bight but one individual traveled north to the Bay of Fundy and another went south to coastal Georgia (Erickson et al. 2011). Mature Atlantic sturgeons are of great potential commercial value for both flesh and roe, the latter being known as caviar. Although there is an occasional report of Atlantic sturgeons being caught with rod and reel, the species is not known for recreational fishing importance.

6 – 2.1 Description of Indicator

The portion of the Delaware River basin available as habitat extends from the Delaware Bay to the fall line at Trenton, NJ; a distance of 140 river kilometers (rkm). There are no dams within this reach of the river, thus 100% of the habitat is accessible. However, habitat suitability is unknown due to anthropogenic effects on the historic habitat as a result of: industrial development, dredging, and water quality issues. Very little is known about adult stock size and spawning of Atlantic sturgeon in the Delaware river but based on reported catches in gill nets and by harpoons during the 1830s, they may have spawned as far north as Bordentown, south of Trenton, NJ (Atlantic Sturgeon Status Review Team [ASSRT] 2007). The status of this indicator investigated using data from the 2007 Status Review for Atlantic sturgeon (ASSRT 2007) and data provided by the Delaware Department of Natural Resources and Environmental Control, Division of Fish and Wildlife (DE DNREC) which has conducted directed gill net surveys using variable mesh gill nets. Surveys were conducted in 1991-1998, 2001, 2004, and 2007-2011 to assess the abundance of juvenile and sub-adult Atlantic sturgeon in the lower Delaware River. Collections were performed using gillnets at Fort Mifflin (rkm 148), Tinicum Island (rkm 142), Marcus Hook anchorage (rkm 127), Marcus Hook bar (rkm 122) and Cherry Island Flats (rkm 119) (Fig. 6.2.2). These were preferred areas as they were flat- bottom sites free of snags away from heavy ship traffic, near the freshwater-brackish water interface and out of the main channel in 3-8 meters of depth.

6 – 2.2 Present Status

Due to low range-wide population levels, in 1998 a moratorium on all Atlantic sturgeon harvest in U.S. waters was adopted by the Atlantic States Marine Fisheries Commission, enforceable under the provisions of the 1993 amendments to the Atlantic Coastal Fisheries Cooperative Management Act (P.L. 82-721). More recently, a formal Status Review of the Atlantic sturgeon was performed and published in 2007 resulting in recommendations by the status review team that the species be listed as “threatened” in 3 of the 5 Distinct Population Segments (DPS) identified over its U.S. range. The Delaware and Hudson Rivers together were termed the NY Bight DPS and were considered one of the DPS recommended for threatened status by the Status Review Team (ASSRT 2007). Using these recommendations and others, the National Marine Fisheries Service has issued a final rule with the determination that Atlantic sturgeon in four of the five DPS including the NY Bight are “Endangered”, effective April 6, 2012. The only DPS that is considered “threatened” rather than “endangered” is the Gulf of Maine DPS which includes all Atlantic sturgeons that are spawned in the watersheds from the Maine/Canadian border and extending southward to include all associated watersheds draining into the Gulf of Maine as far south as Chatham, MA.

Fig. 6.2.2. 2009 sampling sites (yellow boxes) used as part of an early juvenile Atlantic sturgeon telemetry study by Delaware Department of Fish and Wildlife (DE DFW). Red dots are acoustic receivers. Map courtesy of DE DFW.

Once a species become listed as threatened or Endangered, the Cooperative Endangered Species Conservation Fund provides grants to States and Territories to participate in a wide array of voluntary conservation projects for the listed species. The most current Management Plan for Atlantic sturgeon was written by Taub (1990) and contains recommendations for increasing populations but this plan is somewhat outdated and will be replaced by a recovery plan as required by the Endangered Species Act. http://www.fws.gov/endangered/esa-library/pdf/ESA_basics.pdf.

For the Delaware River, DE DNREC surveys show some apparent decline since 1991 in the relative abundance of late-stage juvenile Atlantic sturgeon (>600 mm TL) in the lower Delaware River (Fig. 6.2.3) but since sub-adults may seasonally wander to non-natal estuaries, these data may not solely reflect fish natal to the Delaware River. However, catches of early stage juveniles (<600 mm total length) increased dramatically beginning in 2009 with the capture of 34 young-of-year fish ranging in size from 178 to 349 mm total length and 51 YOY fish in 2011 (M. Fisher, DNREC, personal communication)(Fig. 6.2.4). This shows that successful spawning took place in the Delaware in 2009 and 2011 and that there is some suitable spawning habitat available. Above average rainfall during the sampling period and a successful spawn as well as targeted sampling in early stage juvenile habitat with small mesh nets likely contributed to the increased early stage juvenile catch rates. Preliminary results of the DE DNREC surveys indicate tagged early-stage juveniles are ranging from New Castle flats, DE to Roebling, NJ with the highest concentration located in the Marcus Hook anchorage (M. Fisher, DNREC, personal communication).

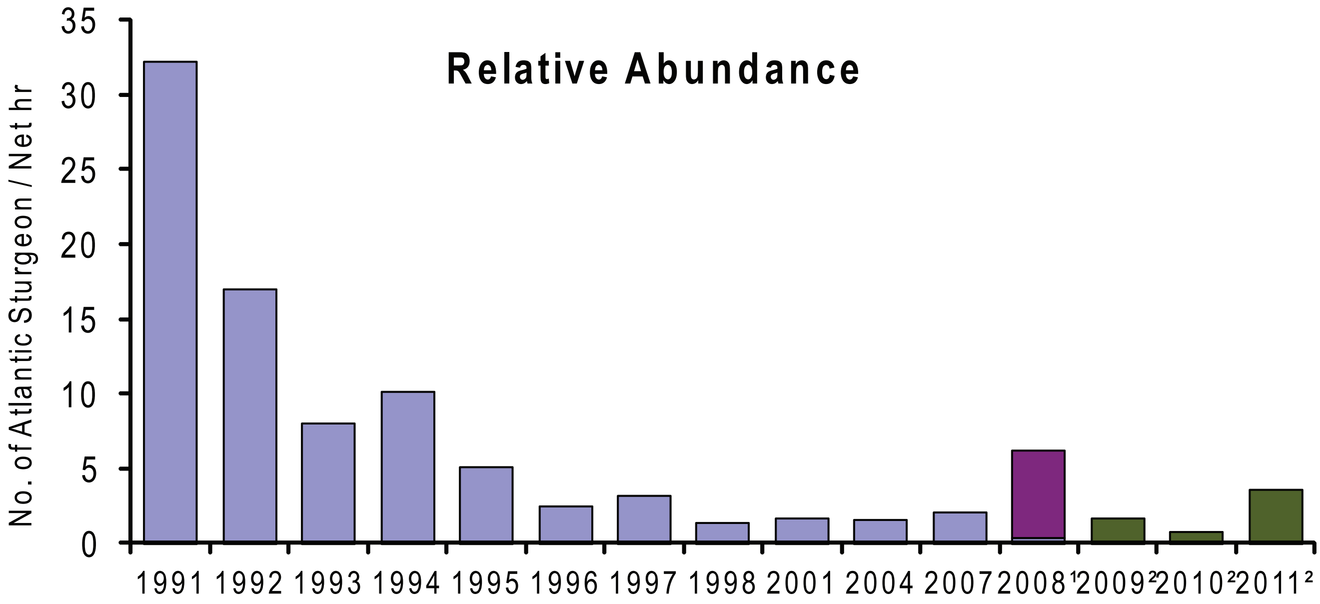


Fig. 6.2.3. Annual catch rates of Atlantic sturgeon in the lower Delaware River from 1991 - 2011 by the Department of Natural Resources and Environmental Control Division of Fish and Wildlife (DE DNREC).

2008[1] overall sampling efficiency increased due to the use of new sampling sites guided by telemetry locations (denoted in red). 2008 abundance at the traditional sites (blue) remained at post 1995 levels. 2009[2] through 2011[2] sampling included new sites and exclusive use of small mesh nets (5, 7.6cm stretch) to target early juvenile sturgeon. Post-2008 data should not be used with earlier data for trend analysis.

The presence of early-stage juveniles in the Marcus Hook anchorage is consistent with findings of Sommerfield and Madsen (2003), that the substrate composition between Marcus Hook and Tinicum Island (Fig. 6.2.2) may represent suitable spawning habitat for Atlantic sturgeon. The majority of the hard-bottom substrate zones, particularly the coarse-grained bedload areas, either neighbor or are within the shipping channel. However, the presence of hard-bottom substrate within the shipping channel may also be a limiting factor in terms of spawning success, potentially exposing adult Atlantic sturgeon to mortality due to boatstrike. Results from tracking acoustically-tagged sturgeon (Simpson and Fox 2006) indicated that the present day lower limit of Atlantic sturgeon spawning is likely the upper limit of salt water intrusion near Tinicum Island (rkm 136) while the upper limit is likely at the fall line near Trenton, NJ (rkm 211). The continued suppression of dissolved oxygen in the Delaware Estuary may also contribute to the limited habitat and spawning success of Delaware populations. With particularly high dissolved oxygen needs of juveniles, (Secor and Gunderson 1998) Atlantic sturgeon recovery may be suppressed by a persistent oxygen sag in the urban estuary corridor.

6 – 2.3 Past Trends

The Delaware River historically supported the largest population of Atlantic sturgeon over its U.S. range. In 1897, 978 fishermen, 80 shoresmen, and 45 transporters were engaged in the Delaware River sturgeon fishery (Cobb 1899).

It is clear that Atlantic sturgeon underwent significant range-wide declines from historical abundance levels due to overfishing in the late 1800s (U.S. Departments of Commerce and Interior 1998). During the season of 1898, the New Jersey fishermen caught 5,060 sturgeons valued at $19,375 and they prepared 1,067 kegs of caviar valued at $76,861. This does not include the catch from Delaware and Pennsylvania since their sturgeon fisheries were not canvassed that year (Cobb 1899). After the late 1800's, Atlantic sturgeon populations did not rebound to any appreciable extent in the Delaware as evidenced by the average annual landings of only 897 pounds (407kg) during the period from 1980 – 1987 (Taub 1990).

Historic habitat for Atlantic sturgeon in the Delaware River has been significantly altered. Large-scale dredging to accommodate commercial shipping traffic has changed substrate composition and tidal flows (Di Lorenzo et al.

1993; Walsh 2004). Within the period 1877 – 1987, the mean depth of the Delaware River increased by 1.6m and the mean cross-sectional area increased by nearly 3,000 m2 (Walsh 2004). By 1973, the US Army Corps of Engineers (USACE) estimated that nearly 154,000,000 m3 of material had been removed from the Delaware Estuary (Walsh 2004). The channel deepening process increased the tidal range in the upper estuary; simultaneously, extensive water removals and diversions were occurring within the non-tidal watershed, resulting in saltwater intrusion in the freshwater-tidal reach of the estuary. This displacement of freshwater habitat may have negatively affected any potential success for the contemporary spawning population (Simpson and Fox 2007).

Fig. 6.2.4. Young-of-year Atlantic sturgeon captured in the Delaware River in 2009.

Delaware Department of Fish & Game

Brundage and Meadows (1982) compiled records of Atlantic sturgeon captured in the Delaware River from 1958 – 1980 and found that out of the 130 reported captures, none were in spawning condition and most were sub-adults (less than the minimum size for sexual maturity). They were most abundant in the Delaware Bay (rkm 0-55) in the spring and in the lower tidal river (rkm 56-127) in the summer.

Due to their migratory nature, high age to maturity, high longevity, and variable spawning periodicity, it is difficult to assess the size of Atlantic sturgeon populations using traditional fishery methods such as mark-recapture. Therefore, there are no detailed past population trends available other than the large decline in harvest levels mentioned previously from the late 19th century to levels in the mid-late 20th century when commercial harvest was still permitted.

6 – 2.4 Future Predictions

Commercial and industrial activity will likely continue to be a factor which limits the growth of the Atlantic sturgeon population in the Delaware River. Since large sub-adult and adult Atlantic sturgeon prefer deep water habitat, they are continually at risk of mortality due to ship strikes since the deepest portions of the Delaware River are typically the maintained shipping channel. Increased shipping traffic and introduction of larger ships will likely increase the risk of ship strike mortalities for large sub-adult and adult fish. Between 2005 and 2008, a total of 28 Atlantic sturgeon mortalities were reported in the Delaware Estuary. Sixty-one percent of the mortalities reported were of adult size and 50% of the mortalities resulted from apparent vessel strikes. For small remnant populations of Atlantic sturgeon, such as that of the Delaware River, the loss of just a few individuals per year due to anthropogenic sources of mortality such as vessel strikes may continue to hamper restoration efforts. An egg-per-recruit analysis demonstrated that vessel-strike mortalities could be detrimental to the population if more than 2.5% of the female sturgeons are killed annually (Brown and Murphy 2010). Since small losses of broodstock can impact Atlantic sturgeon population growth in the Delaware, it is important to work with the shipping industry to develop means for reducing ship strikes.

Even though dredging of the tidal Delaware River will likely continue as maintenance dredging and for increasing channel depth to accommodate larger ships, updated dredging windows have been developed by the Delaware River Basin Fish and Wildlife Management Cooperative (Co-op). Using known life history data, these dredging windows are formulated to reduce impacts on sturgeon and other fish from dredging and related activities and are currently being considered for implementation by the U.S. Army Corps of Engineers in permitting dredging and related activities. To better characterize habitat use in the tidal Delaware River, Delaware River sturgeon researchers are continuing the use of acoustic tags on sturgeon to monitor their movements via an array of stationary acoustic receivers deployed in the Delaware River (Fig. 6.2.2)

Since the National Marine Fisheries Service has issued a final rule that Atlantic sturgeon in the New York Bight (including the Delaware River) are Endangered, a recovery plan for the species must be written that includes specific steps needed for population recovery. The Endangered Species Act also requires the designation of “critical habitat” for listed species when “prudent and determinable.” Critical habitat includes geographic areas that contain the physical or biological features that are essential to the conservation of the species and that may need special management or protection. Critical habitat designations affect only Federal agency actions or federally funded or permitted activities. Federal agencies are required to avoid "destruction" or "adverse modification" of designated critical habitat. Relative to the Delaware River Atlantic sturgeon, this would apply to dredging activities which are currently permitted by the U.S. Army Corps of Engineers in areas known to be utilized by Atlantic sturgeon for completion of their life cycle. Critical habitat may include areas that are not occupied by the species at the time of listing but are essential to its conservation. An area can be excluded from critical habitat designation if an economic analysis determines that the benefits of excluding it outweigh the benefits of including it, unless failure to designate the area as critical habitat may lead to extinction of the listed species.

6 – 2.5 Actions and Needs

Actions that could improve the condition of the Atlantic sturgeon population in the Delaware River include continuation of telemetry studies for discovering areas of the river used by various life stages of the species. Locations of spawning areas and early life stage nursery areas for Atlantic sturgeon in the Delaware River need to be identified so management actions, such as instituting effective dredging windows, can be used to protect fish at times when they congregate in known areas. Expanded study of ship strikes on sturgeon in the Delaware River is also needed to determine the level of population impact occurring and to determine ways to minimize that impact. Since the species is highly migratory, actions to protect, conserve, and enhance Atlantic sturgeon in the Delaware River extend far beyond the geographical limits of the Delaware Basin. These actions include: (1) reducing by-catch from near-shore and ocean commercial fisheries on the east coast by increasing the number of observers on commercial fishing vessels and reducing the use and/or soak time of anchored gill nets, (2) designing and locating future tidal turbines for power generation in a manner which would strive to minimize mortality to distant migrants, and (3) continuing the use of the Coastal Sturgeon Tagging Database as a means to promote data sharing between sturgeon researchers.

In addition, revised dissolved oxygen criteria from the Delaware River Basin Commission and improvements to wastewater treatment in the estuary could significantly improve early-stage juvenile habitat conditions in the core Atlantic sturgeon zone. The need for continued improvements in dissolved oxygen has been articulated since the late 1970s, with the elevated oxygen conditions demonstrated as achievable through a multi-agency study in the 1980s. The listing of Atlantic sturgeon as "Endangered" necessitates immediate implementation of these recommendations.

Currently, there is no funding vehicle specific for protection and enhancement of the Delaware River sturgeon population. However, the Delaware River Basin Conservation Act of 2011 would establish a federal program at the U.S. Fish and Wildlife Service to coordinate voluntary restoration efforts for numerous species and habitats throughout the Delaware River watershed. This legislation is sponsored by Senator Tom Carper (D-DE) and co-sponsored by Sens. Coons (D-Del); Schumer (D-NY), Gillibrand (D-NY), Menendez (D-NJ), and Lautenberg (D-NJ) http://carper.senate.gov/public/index.cfm/pressreleases?ID=c85f7582-af71-400f-8a2c-9e56479e29da. Proposals targeting restoration activities that would benefit Atlantic sturgeon could be considered for use of a portion of these funds should the legislation be passed.

6 – 2.6 Summary

In summary, Atlantic sturgeon of the Delaware River are now considered federally Endangered. The current condition of the Atlantic sturgeon population in the Delaware River is poor compared to the historic condition. Furthermore, the industrialization and related shipping traffic in the very portion of the river which once supported the largest spawning population of this species over its historic range will likely limit the population to a small fraction of its historic size. However, recent discoveries of young-of-year individuals and their habitat along with refinement of information on sturgeon habitat use through acoustic telemetry studies are seen as positive developments concerning this indicator species. The overall condition of the Atlantic sturgeon population in the Delaware River is poor but showing some signs of movement in a positive direction with the capture of 34 and 51 YOY individuals in 2009 and 2011, respectively, proving that successful spawning took place. In addition, the listing of the species as threatened or endangered over all its U.S. range will afford Atlantic sturgeon populations a new layer of protection from which they have not previously benefitted. This will also result in increased funding opportunities for population recovery efforts in the Delaware, a river that is legendary for the size of its historic Atlantic sturgeon population.

6 – 3 American shad

Section Author: Jerre Mohler

Fig. 6.3.1 Mature female American shad captured in the Delaware River

American shad (*Alosa sapidissma*) is an anadromous species that is native to most major river basins on the Atlantic Coast of North America, including the Delaware. The species is in the family Clupeidae, or the herring family. The American shad has a lustrous green or greenish blue back with silvery sides and a white belly. Individuals may live up to 11 years and reach lengths over 20 inches (50.8 cm) (Fig. 6.3.1) They are a popular, hard- fighting sport fish that can be taken on rod and reel using lures known as shad darts and flutter spoons and they also have commercial value.

American shad are opportunistic feeders, whose freshwater diet includes copepods, crustacean zooplankton, cladocerans, aquatic insect larvae, and adult aquatic and terrestrial insects. After emigrating to offshore areas, American shad feed on the most readily available organisms, such as copepods, mysid shrimps, ostracods, amphipods, isopods, euphausids, larval barnacles, jellyfish, small fish, and fish eggs (ASMFC 2010). American shad spend most of their life at sea along the Atlantic coast and enter freshwater as adults in the spring to spawn. Stocks are river specific; that is, each major tributary along the Atlantic coast appears to have a discrete spawning stock due to high fidelity to return to their natal tributary to spawn. In the fall or subsequent spring, juveniles emigrate from freshwater and estuarine nursery areas and join a mixed-stock, sub-adult coastal migratory population. Three primary offshore summer aggregations of American shad have been identified: 1) Bay of Fundy/Gulf of Maine, 2) St. Lawrence estuary, and 3) off the coast of Newfound and Labrador.

After four to six years, individuals become sexually mature and migrate to their natal rivers during the spring spawning period. American shad that spawn north of Cape Hatteras are repeat spawners, while almost all American shad spawning south of Cape Hatteras die after one spawning season (ASMFC 2010). Repeat spawning has been documented for Delaware River shad via analysis of scales. In the Delaware, there can be as many as 5 year classes of adult shad participating in a spawning migration (M. Hendricks, PA Fish & Boat Commission, personal communication).

American shad have ecological, economic, cultural, and social significance (ASMFC 2010). Ecologically, they play an important role in freshwater, estuarine, and marine environments during their anadromous life cycle. They influence food chains by preying on some species and serving as prey for others throughout all life stages. Economically, American shad have 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. The harvest began to decline rapidly in the early 1900s. Severe water pollution, removing oxygen, has been well-documented; there has been no analysis indicating that overfishing has occured, but it could have existed. All major tributaries were dammed. Despite efforts in the late 1800s to increase the shad population through legislation and a massive program of artificial propagation, the shad fishery eventually collapsed under the combined pressures. By the 1940s, the commercial shad fisheries were mainly limited to the lower reaches of the river and bay below Pennsylvania (ASMFC 2007). Culturally, American shad were and are of significance to Native Americans, European colonists and contemporary Americans who reside near and/or fish in rivers that supported or continue to support spawning runs. Many communities celebrated and still celebrate the arrival of shad by holding festivals to mark the occasion. The most comprehensive account of the role that American shad has played in the culture of North America since colonization by Europeans is that written by John McPhee. In “The Founding Fish,” (McPhee 2002) his research documents the relevance of American shad in seventeenth and eighteenth-century America.

6 – 3.1 Description of Indicator

To investigate the status of this indicator, the following data were used:

- Juvenile abundance from beach seining and commercial harvest data from the New Jersey Division of Fish & Wildlife (NJ DFW)
- Gill net catch data at Smithfield Beach and fish passage data at the Easton dam from the PA Fish & Boat Commission (PFBC)
- Commercial harvest data from Delaware Department of Fish & Game(DE DFG)
- Schuylkill River fish passage data from the Philadelphia Water Department (PWD)
- Adult catch rates from the Lewis Haul Seine survey at Lambertville, NJ
- Hydro-acoustic population estimates provided by the Delaware River Basin Fish & Wildlife Management Cooperative (Co-op)

6 – 3.2 Present Status

The portion of the main stem Delaware River available as habitat extends up into the East and West Branches above Hancock, NY representing over 300 miles (483 km) of unobstructed main stem access. However, all major tributaries to the main stem Delaware are dammed creating numerous blockages to historic spawning and rearing habitat. The two major tributaries, namely the Schuylkill and the Lehigh Rivers, do have existing fish passage facilities in place at many of their dams but these are variable in their ability to facilitate upstream passage of American shad.

Tidal reach

There is commercial harvest permitted in the Delaware and New Jersey portions of the estuary with mandatory reporting beginning in 2000. In New Jersey, as of June 20, 2011 there were 86 permits issued (46 commercial and 40 incidental) to allow catch of American shad. Currently, only 76 of these permits are active due to attrition, and only 14 fishers landed shad in 2010. American shad are also caught as bycatch in Delaware's commercial striped bass fishery that has a season beginning on February 15 and extending through May 31. Currently, commercial harvest levels are low with only 5,019 pounds (2277 kg) of shad reported in Delaware and about 7,700 pounds (3493 kg) in New Jersey for 2010 (Fig. 6.3.2). The trend of decreasing commercial harvests is not viewed as a reflection of decreasing stock size but rather the result of fewer commercial fisherman in addition to a shift toward the harvest of the more valuable striped bass by Delaware fishers; stiped bass are present in the estuary at the same time that American shad migrate through (R. Allen, New Jersey Division of Fish & Wildlife and D. Kahn Delaware Dept. of Fish & Game, personal communication).

An additional perspective on the present status of adult American shad in the tidal reach is reflected by fish passage data for the Fairmount dam on the Schuylkill River. Fish passage facilities at the Fairmount Dam have recently been improved along with a concomitant improvement in upstream passage of American shad (Fig. 6.3.3). This is an encouraging trend that not only shows that the fish passage facilities are more efficient, but also shows that the stocking of larval shad, that has been on-going in the Schuylkill since 1985 is having a positive impact. Analysis by the PA Fish and Boat Commission shows that about 96% of the fish returning to spawn on the Schuylkill are of hatchery origin.

A juvenile relative abundance index for the tidal estuary has been developed via New Jersey beach seine surveys. The survey index shows a statistically significant increasing trend in catch-per-unit effort (CPUE) for juvenile American shad in the tidal estuary from 1980-2010 (Fig. 6.3.4). In the early years of this time series, oxygen levels were still low in summer and fall when the survey is conducted. Increases in juvenile CPUE indicate greater numbers of juveniles are available to out-migrate and return as adults 4 to 5 years later.

Non-tidal reach

Above the Trenton fall line there are 3 data sets that reflect the size of the adult American shad run: The Lewis Haul Seine survey at Lambertville, NJ, the fish passage data from the Easton dam on the Lehigh River, and the PFBC Smithfield Beach gill net survey. When data from 1995 – 2010 are plotted together these 3 indices of relative abundance show similar trends. A close correlation exists between Smithfield Beach and Lewis Haul Seine surveys with Easton dam upstream fish passage showing greater temporal fluctuation but a generally similar trend (Fig. 6.3.5). On the Lehigh River, the first three dams (Easton, Chain, and Hamilton Street dams, respectively) have fish passage facilities which can be very inefficient at passing shad upstream due to combinations of poor attraction flow and/or excessive step pool height (R. Quinn, U.S. Fish & Wildlife Service, personal communication). When very high Lehigh River flows coincide with shad migrations, high-water spillage over the Easton dam can mask the attraction flow exiting the fishway and cause poor upstream passage (D.Pierce, PA FBC, personal communication). Thus, the high variability seen in the Easton dam fish passage data is not surprising. The Lehigh River has also been stocked with larval shad each year since 1985 and the percentage of hatchery-origin fish returning as adults is about 74%. There are similarities in the trends of fish passage between the Fairmount dam (tidal reach) and the Easton dam on the Lehigh River (non-tidal reach) suggesting that hatchery fish stocked in both rivers are showing similar trends in survival from larvae to returning adults (Fig. 6.3.3).

6 – 3.3 Past Trends

In the late 1890s, the Delaware River had the largest annual commercial shad harvest of any river on the Atlantic coast having estimates of up to 19 million pounds (8.6 mil kg) in a given year. The harvest began to decline rapidly in the early 1900s. Water pollution was well-documented, eliminating oxygen for months at a time in the mid-lower tidal river; overfishing has not been documented, although it could have occured. All major tributaries were dammed by this time. Despite improved state legislation and regulation, and a massive program of artificial propagation of shad stocks in the late 1800s, the shad fishery eventually collapsed under the combined pressures. By the 1940s, the commercial shad fisheries were mainly limited to the lower reaches of the River and Bay below Pennsylvania. By 1950, the urban reach of the Delaware River was one of the most polluted stretches of river in the world (ASMFC 2007). Pollution continued to be a major factor until passage of the Federal Clean Water Act in 1972. This Act was instrumental in the elimination of the "pollution block" of low or no dissolved oxygen in the region around Philadelphia. By 1973 the majority of spawning took place above the Delaware Water Gap more than 115 river miles (185 km) upstream. American shad can now freely pass through this area during the spring spawning run as well as the fall out-migration.

In 2007, the American Shad Stock Assessment Subcommittee (SASC) completed a coast-wide American shad stock assessment report, that was accepted by the Peer Review Panel (PRP) and the Shad and River Herring Management Board in August 2007 (ASMFC 2007). The stock assessment found that stocks were at all-time lows and did not appear to be recovering to acceptable levels. It identified the primary causes for the continued stock declines as a combination of excessive total mortality, habitat loss and degradation, and migration and habitat access impediments. Although improvement has been seen in a few stocks along the coast, many remain severely depressed compared to their historic levels. In the Delaware River, the American shad is benefitting from continued efforts by the Delaware River Basin Commission and the Basin states to improve water quality and pursue improvements in fish passage on the tributaries.

The Delaware River shad population showed signs of recovery during the 1980s and into the early 1990s, but recent estimates of the adult stock have been well below the target of 750,000 adult American shad at Lambertville, NJ. This target was set by the Delaware Basin Fish and Wildlife Management Cooperative (Co-op) in 1982 as a result of a Peterson population study from 1981 that estimated a population of over 500,000 adult shad. Hydro-acoustic methods were used in 1992, 1995, and 1998 – 2007 to estimate population size at 23,000 to 880,000 individuals (Fig. 6.3.7). However, the hydro-acoustic estimates included wide confidence intervals and are not thought to be precise. There is disagreement as to whether they are reasonable estimates of the Delaware River American shad population. No population estimates have been performed since 2007, therefore the Co-op depends on analysis of trends from the various relative abundance indices to determine the population status. A better method for estimating the size of the shad population is needed for the Delaware River.

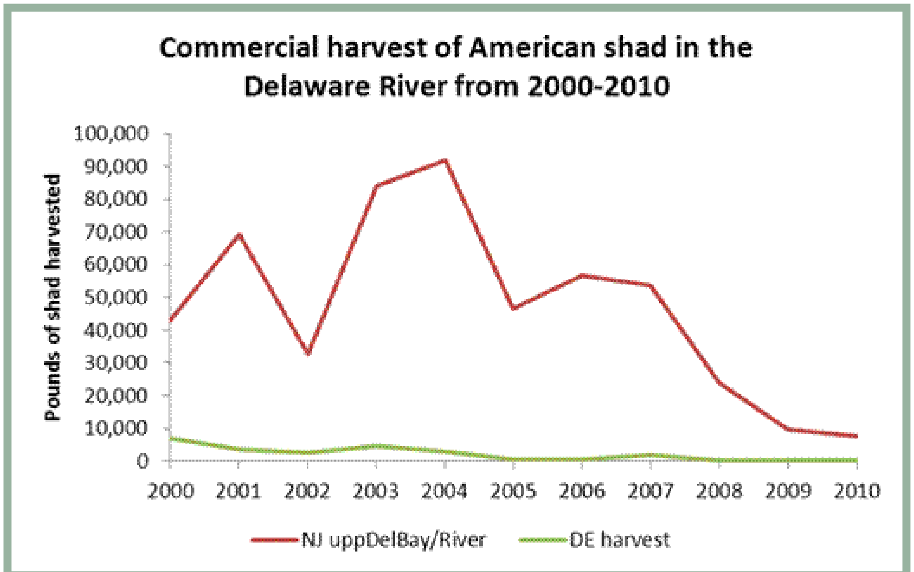


Fig. 6.3.2 A decreasing trend in Commercial harvest of American shad in the Delaware River from 2000-2010 reflecting fewer commercial fisherman in addition to a shift toward the harvest of the more valuable striped bass.

The relative abundance index with the longest time series is the Lewis Haul Seine survey that was first begun in 1890 but did not track catch per unit effort until 1925. This index shows that the Delaware population expanded during the 1980's and early 1990's and has since shown a contraction with some indication of an increasing trend beginning in 2008 (Fig. 6.3.8).

Although habitat degradation was mostly responsible for depleting the initial Delaware River American shad population, anthropogenic factors alone are not responsible for fluctuations in population size, but climatic and other environmental factors can also affect the population. For example, North Atlantic sea surface temperatures have been found to exhibit long-duration variability or oscillation (Schlesinger and Ramankutty 1994; Enfield et al 2001). Kerr (2000) termed this oscillation the Atlantic Multi-decadal Oscillation (AMO). The AMO delineates cool and warm phases that may last for 20 to 40 years at a time and represents a difference of about 1°F between extremes. These changes are probably a natural climate oscillation and have been measured for at least 150 years. A positive AMO indicates a warm phase while a negative AMO indicates a cool phase. The AMO is currently in what is considered a warm phase since the mid-1990s (AMO Kaplan SST V2 data is provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/).

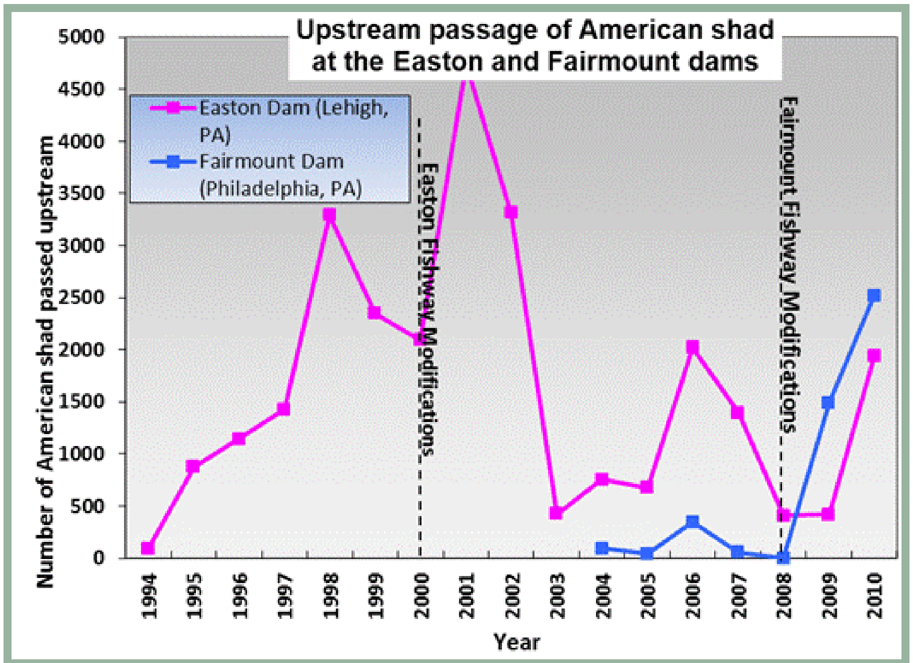


Fig. 6.3.3 Upstream passage of American shad at the Easton Dam (Lehigh River) and Fairmount Dam (Schuylkill River).

In an attempt to determine if there was any evidence of a relationship between the AMO and measures of the American shad stock within the Delaware River Basin, the Co-op compared the AMO to the Lewis haul seine CPUE (Fig. 6.3.8). This data set represents the longest catch per unit effort within the Basin. The Co-op analyzed various portions of the AMO dataset but determined the smoothed January to December average was the best fit for final analysis. A five-year moving average was developed for all data to decrease yearly variability. This was a similar methodology as used for the most recent ASMFC weakfish stock assessment that used a 10-year average (ASMFC 2009).

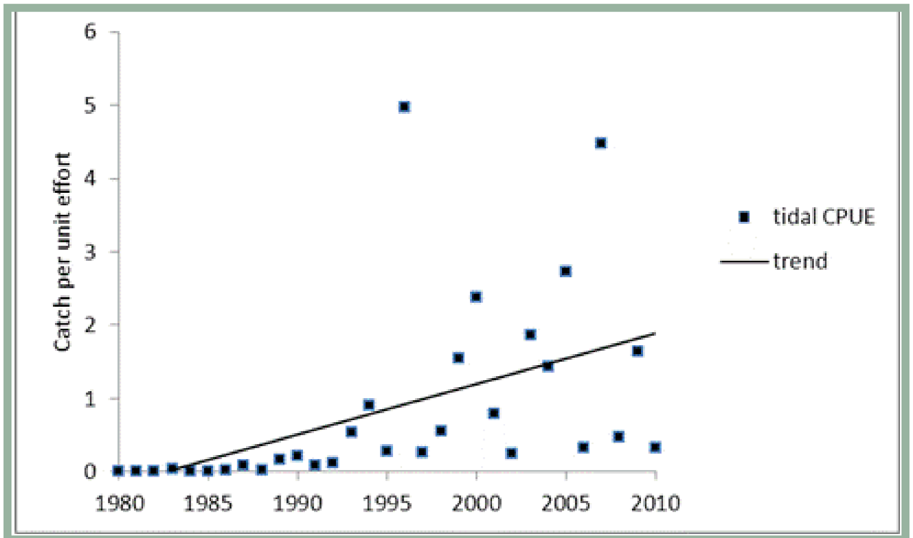


Fig. 6.3.4 Trend in catch-per-unit effort (CPUE) for juvenile American shad in the tidal estuary from 2000 -2010

No correlation is evident between the Lewis haul seine CPUE and the AMO from 1925 to 1971. It should be noted that this period also coincided with very poor water quality within the Delaware River. As water quality improved from the 1970s into the 1990s, the American shad population within the Delaware River also improved. From 1972 to 1989, the smoothed Lewis haul seine CPUE correlated well with the smoothed AMO but the correlation disintegrates during the 1990s suggesting a problem with the stock that should not have occurred according to the relationship with the AMO from 1972 to 1989. The Lewis haul seine to AMO analysis showed a negative correlation for the time period of 1990 to 2010.

In conclusion, this analysis provides evidence that long-term sea surface temperature change may have an impact on abundance of American shad within the Delaware

Basin. The Lewis haul seine CPUE correlates well with the AMO during the AMO index's rise in the 1970s and 1980s but there is a disconnect that occurs during the 1990s that currently is unexplainable. Potential sources of the discontinuity include decline in adults due to overharvest; bycatch discards in ocean fisheries; increased predation from striped bass or other species; or other unknown interruption of the spawning runs during this time period. In recent decades, as oxygen levels improved in the tidal River, indices of relative abundance and commercial landings both increased in the 1980s. During the mid-1990s, however, some decline began which continued to lower levels in the 2000s. A highly significant negative correlation exists between this trend in shad abundance and the trend in abundance of striped bass. The primary prey of striped bass consists of members of the herring family, which includes shad (Fig. 6.3.9). During the peak years for shad in the 1980s, striped bass were at extremely low abundance; as bass recovered during the 1990s, shad began to decline. When bass attained their peak abundance during the later 2000s, shad were at their nadir.

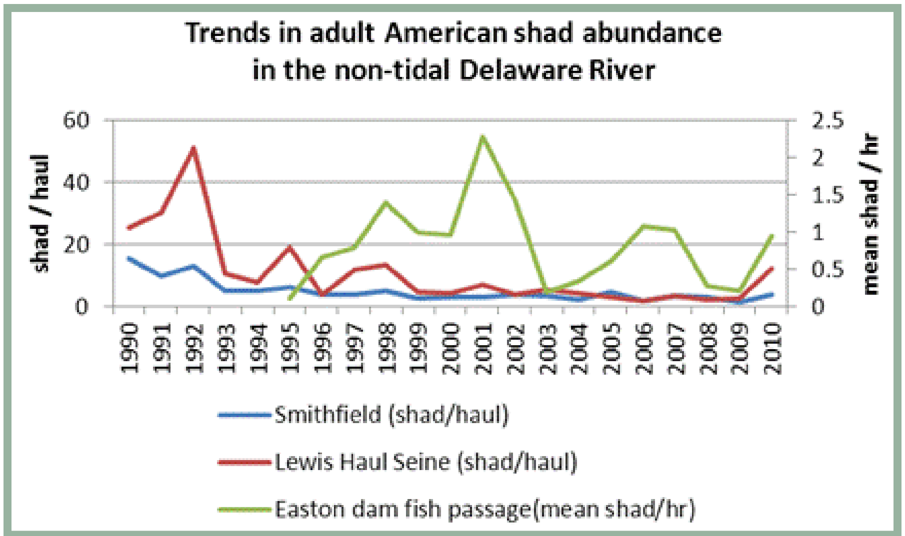


Fig. 6.3.5 Trends in adult American shad abundance in the non-tidal Delaware River: Smithfield Beach gillnet survey; Lewis Haul Seine survey (Lambertville, NJ); and Easton dam fish passage (Lehigh River)

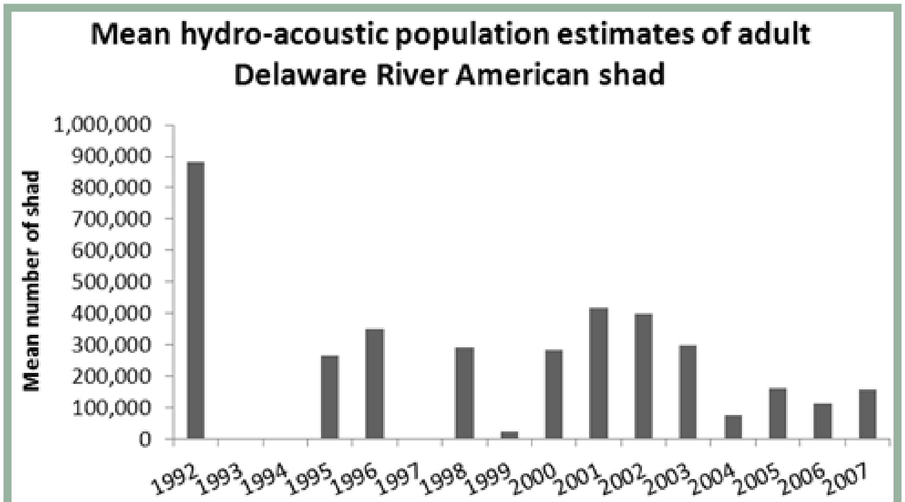


Fig. 6.3.6 Mean estimate of adult American shad population size derived from hydro-acoustic techniques from 1992 to 2007

6 – 3.4 Future Predictions

The Delaware River stock of American shad is currently thought to be sustainable under current recreational and commercial conditions but only with the establishment of benchmarks that would be used to trigger management actions designed to prevent stock collapse. These benchmarks are being established by the Delaware River Basin Fish and Wildlife Management Cooperative (Co-op) and will be used as triggers to elicit any of a number of management changes if juvenile recruitment declines or adult exploitation becomes excessive. An overall population increase should be realized with on-going attempts to improve fish passage on both the Schuylkill and Lehigh Rivers. Dam removal activities also on-going in the Brandywine and Musconetcong Rivers should also be instrumental in providing greater access to historic spawning areas for American shad with a concomitant increase in the population.

6 – 3.5 Actions and Needs

Any improvement in restoring access to blocked habitat through dam removal or improvements in fish passage devices on existing dams would facilitate population increases for American shad in the Delaware River. In that regard, continued negotiation by the PA Fish and Boat Commission to remove dams on the Lehigh River is needed. In order to facilitate restoration of tributaries that have obstacles to fish passage, efforts to spawn wild American shad to produce larvae for stocking should be continued in those areas until shad can access sufficient historic

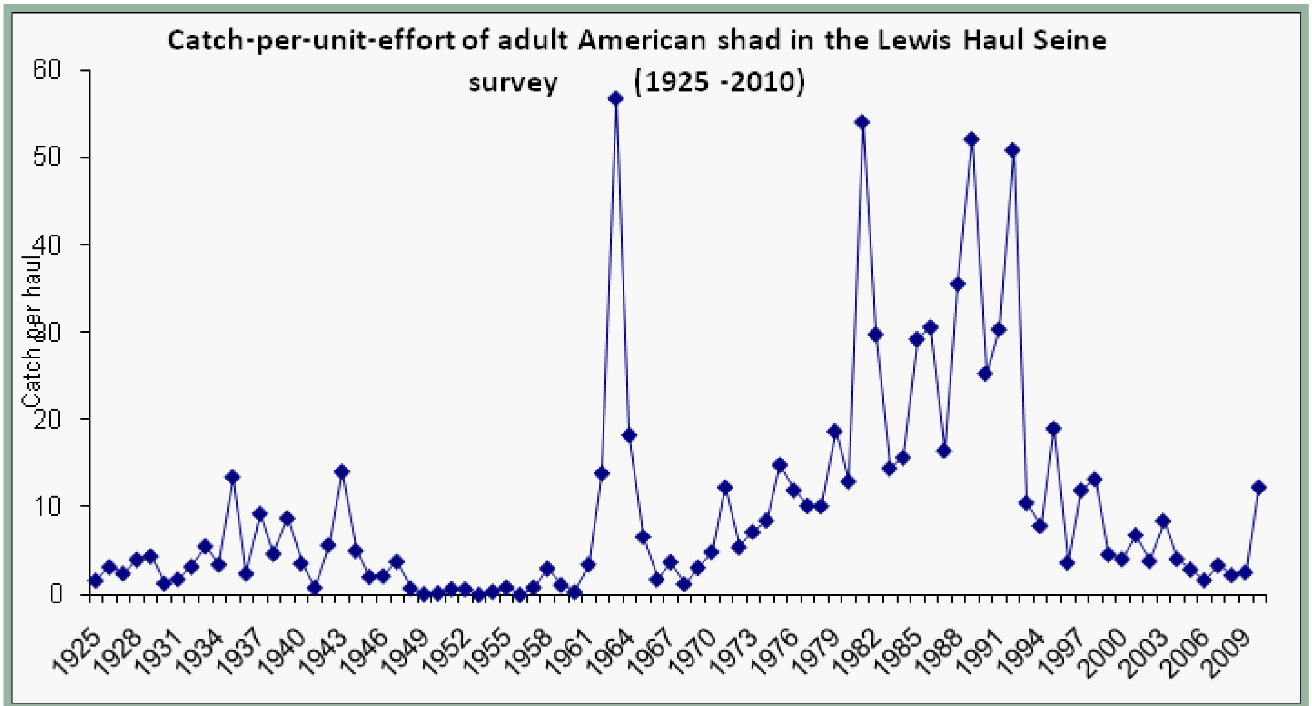


Fig. 6.3.7 Relative abundance of adult American shad reported as catch per haul in the Lewis Haul Seine survey performed at Lambertville, NJ from 1925-2010

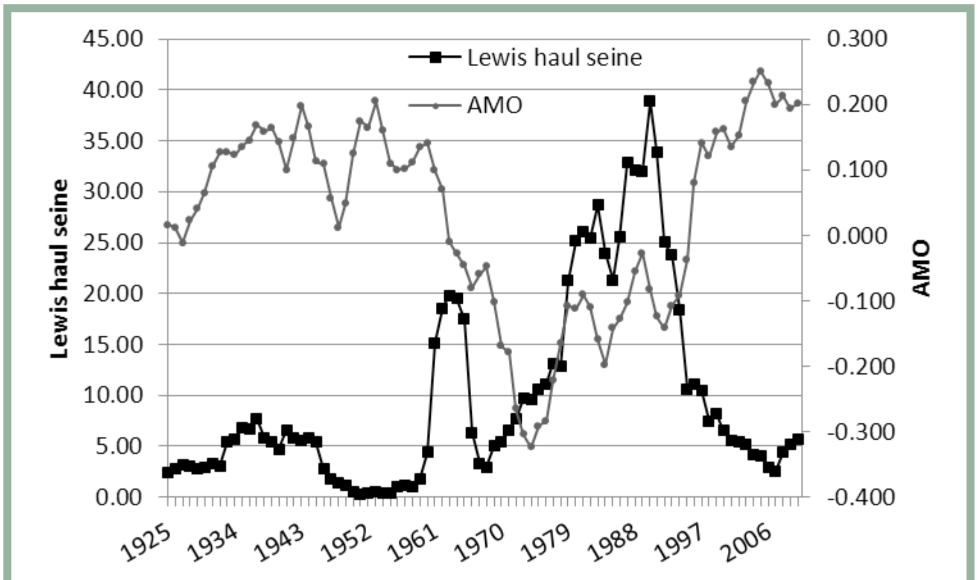


Fig. 6.3.8 Atlantic Multi Oscilation compared to Lewis haul seine catch-per-unit-effort for Amercican Shad (1954-2010). Data are 5-year moving averages to decrease variability.

habitat to reproduce naturally. There is also a need to re-establish the upper river juvenile abundance sampling that was once performed by New Jersey Division of Fish & Wildlife in order to monitor juvenile recruitment and compare it with existing lower river juvenile monitoring efforts. Computer modeling is also needed to determine the level of impact on the population occurring from mortality due to entrainment of eggs and larvae in industrial water intakes in the Delaware Basin. Dredging and blasting activities performed in the Basin under permit via the U.S. Army Corps of Engineers must be limited to those times of year recommended by the Co-op (dredging windows) to prevent excessive adverse impacts on all life stages of shad.

Currently, there is no funding vehicle specific for protection and enhancement of the Delaware River shad population. The four Basin States have allocated some budget resources annually for population monitoring efforts that result in data reported annually to the ASMFC. Recent budget shortfalls in most States have resulted in reduced monitoring efforts, creating a potential discontinuity in numerous population indices that are useful to determine population trends. However, the Delaware River Basin Conservation Act of 2011 would establish a federal program at the U.S. Fish and Wildlife Service to coordinate and prioritize restoration efforts for numerous species and habitats throughout the Delaware River watershed. This legislation will be sponsored by Senator Tom Carper (D-DE) who will be joined in supporting the legislation by Sens. Coons (D-Del); Schumer (D-NY), Gillibrand (D-NY), Menendez (D-NJ), and Lautenberg (D-NJ) http://carper.senate.gov/public/index.cfm/pressreleases?ID=c85f7582-af71-400f-8a2c-9e56479e29da. Study proposals already developed by the Partnership for the Delaware Estuary as well as other proposals targeting restoration activities that would benefit American shad would be valid considerations for use of a portion of these funds should the legislation be passed.

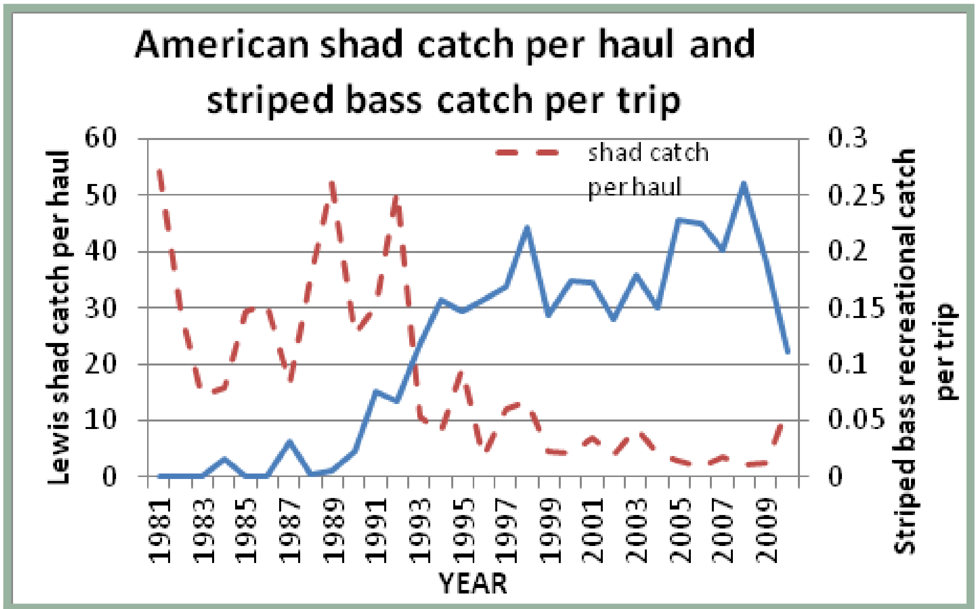


Fig. 6.3.9. Relative abundance trends of striped bass and American shad. Adult American shad catche per haul in the Lewis haul seine fishery, Lambertville, NJ and recreational catch per trip of striped bass in all Delaware waters, 1981-2010: Correlation coefficient, r= -0.757, n=28, P<<0.01.

6 – 3.6 Summary

In summary, the current condition of the American shad population in the Delaware River is low when compared to the original condition of the stock, but relative to other extant populations, the Delaware stock is fairly healthy with numerous indices of relative abundance indicating at least a temporal trend of population increase. In addition to environmental and social benefits, increases in the population of American shad would provide economic benefits through increased revenues for local communities from recreational angling, and commercial fishing. The Delaware River stock of American shad is currently thought to be sustainable under current conditions but only with the establishment of benchmarks established by the Delaware River Basin Fish and Wildlife Management Co-op. These benchmarks are designed to identify declining trends in juvenile recruitment and excessive adult exploitation. The trends are monitored by the Co-op using mandatory commercial harvest reporting from New Jersey and Delaware along with on-going sampling efforts to obtain relative abundance indices.

6 – 4 Striped Bass

Section Author: Desmond Kahn

NY DEC

While female striped bass (*Morone saxatilis*), in particular, are highly migratory, males can be found year-round in the Delaware River and Bay, unlike other potentially large predators such as weakfish, bluefish, large sharks, and sea turtles. The Delaware Division of Fish and Wildlife (DFW) and the PA Fish and Boat Commission conduct tag-recapture studies in the spring on the Delaware River spawning grounds. Tag returns indicate that mature females migrate in summer up the coast to southern New England and eastern Long Island. Some males move into Chesapeake Bay through the Chesapeake and Delaware Canal or out into near-by coastal areas during summer and fall. Migration patterns of immature females are unclear, since they are not tagged in the annual spawning ground survey in the River.

The Delaware River population is now one of the major spawning stocks on the Atlantic coast, along with the Hudson River and Chesapeake Bay stocks. The stock was declared restored by the Atlantic States Marine Fisheries Commission in 1998, based on a report by Kahn et al. (1998). The key to its recovery was the reduction in sewage pollution in the River due, in part, to the federal Clean Water Act. The upgrading of sewage plants was completed in 1987. That upgrade eliminated the anoxia which had existed in 20 or more miles of the tidal River between Philadelphia and Wilmington, the primary spawning and nursery grounds for the stock. Clark and Kahn (2009) reported that catch-per-unit effort (generally proportional to abundance) in the Delaware spring gill net fishery in Delaware Bay and River increased 3,000% to 6,000% between 1987 and 2002-2003.

There is no estimate of population size. Burton and Weisberg (1994) estimated the number of age 0 striped bass in 1990 at 972,937, with approximate 95% confidence limits of 765,916 to 1,241,104, using tagged hatchery age 0 fish stocked in the Delaware River. If this number is considered roughly representative of an average for age 0 fish, and if certain assumptions are made as to the annual survival rate of younger fish, the total stock size could be on the order of roughly three million fish. At any one point in time, however, they would not all be present in the estuary, due to migration.

Striped bass feed primarily on fish, but also consume larger invertebrates. Their predominant prey consists of various species in the herring family, including Atlantic menhaden and river herring. A recent study in the Connecticut River found that large striped bass consumed adult American shad. Striped bass are opportunistic predators, however, and have a broad range of prey. Their habitat includes tidal creeks and rivers, jetties, beaches and relatively open water in the Bay, River and ocean. They are known as rockfish because they are often found near jetties or other rock structures.

The current spawning grounds exist in tidal fresh water in the Delaware River above detectable concentrations of salinity. The spring spawning survey conducted by the DFW usually finds more fish In April in Delaware waters from the Delaware Memorial Bridge up to the Delaware-Pennsylvania line. The New Jersey shore has the majority of spawners, along with the Cherry Island Flats, which are shoals around Wilmington. As the season progresses into May, the temperature and salinity tend to increase, and spawning bass are more commonly collected in Pennsylvania waters up to and including the Philadelphia Navy Yard. Spawning is usually over by the end of May. By September, young-of-year bass are a few inches long. They do not generally exceed four inches by the end of the growing season. Striped bass do not consume fish in any number until their second year of life as one-year olds.

Delaware has a commercial fishery targeting striped bass. Currently, this fishery has the highest economic value of any of Delaware's commercial finfisheries, bringing fishers about $500,000 at the dock in 2010, not including the multiplier effect that economists calculate for such activity. New Jersey has outlawed commercial landing of striped bass. Both states support a recreational fishery, which ranks as one of the top fisheries in both states. Striped bass are one of a few inshore species that can achieve big game size. Fish up to fifty pounds are possible catches.

6 – 4.1 Description of Indicator

The indicator is a measure of the reproductive output of the stock. New Jersey's Division of Fish, Game and Wildlife conducts a beach seine survey in the tidal River from Trenton down to Augustine Beach just a mile above the beginning of Delaware Bay. Results of this survey have been the subject of several peer-reviewed papers. This survey targets young-of-year striped bass, and was begun in 1980, although the first few years were pilot studies. The survey develops a geometric mean catch per haul index, which is the average of catches in August, September, and October.

Catches were low in the first years, with a zero for 1981. Since then a gradual increase in catch-per-haul occurred, building to the first peak in 1989, two years after the upgrade of sewage plants was completed (Fig. 6.4.1). Since that year, the index has fluctuated without trend.

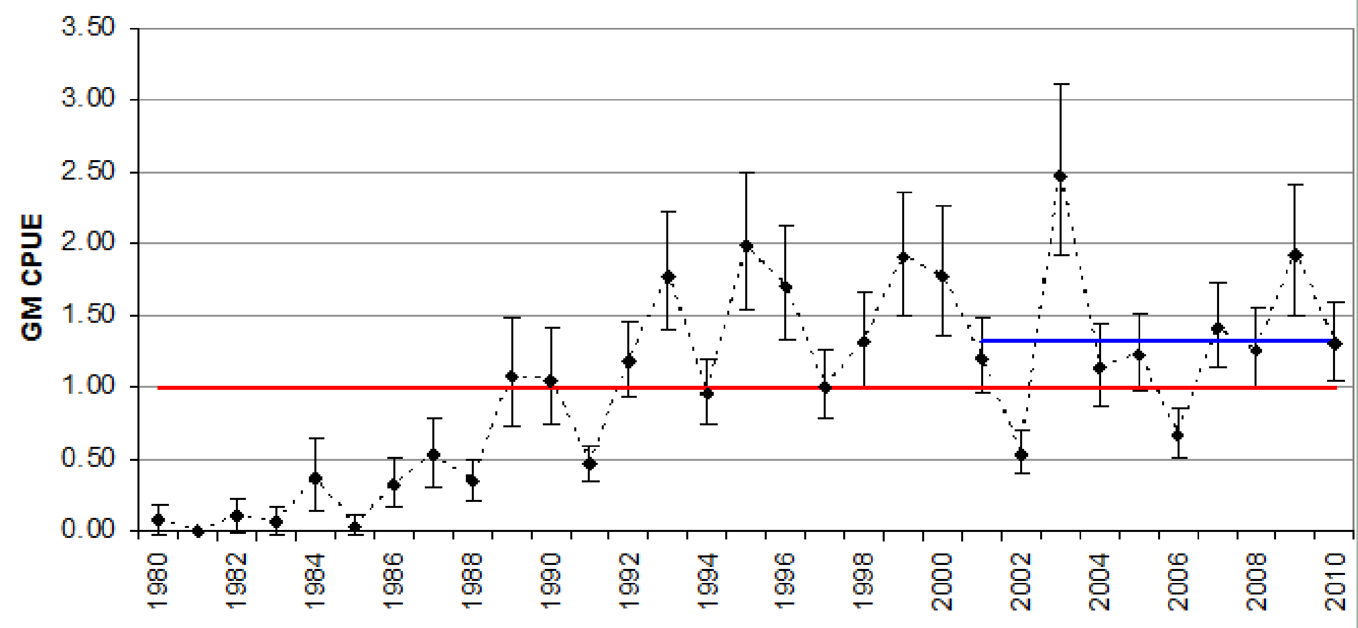


Fig. 6.4.1. The Delaware River striped bass young-of-year index, consisting of the geometric mean of the number caught per seine haul: 1980-2010. The survey is conducted in August, then repeated in September, and October. Survey sample sites are located from Trenton, New Jersey all the way down river to Augustine Beach, Delaware, below the Chesapeake and Delaware Canal. Bars represent 95% confidence intervals. The red line represents time series average (1980–2010). The blue line represents the average for the last ten years (2001–2010).

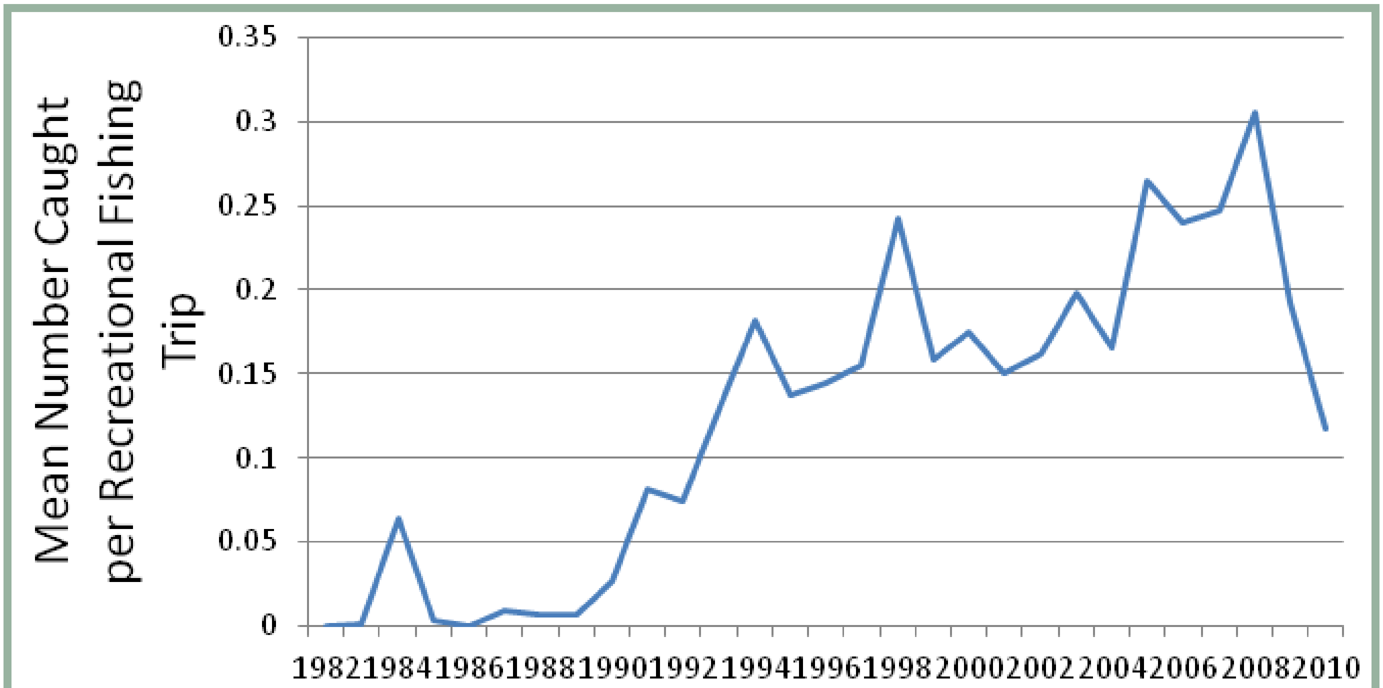


Fig. 6.4.2. Number of striped bass caught per trip by recreational anglers fishing from Delaware ports in the Delaware River and Bay (source: Marine Recreational Fisheries Statistics Survey, National Marine Fisheries Service).

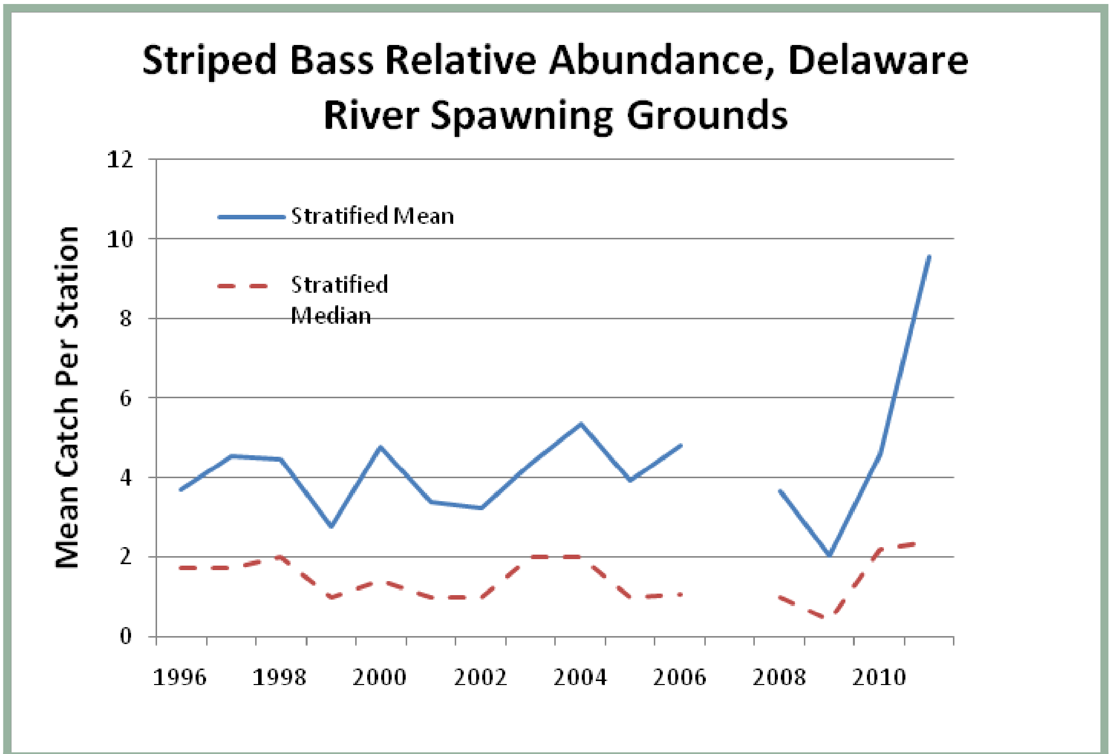


Fig. 6.4.3. Mean number of striped bass caught per station with electrofishing gear in the tidal Delaware River in April and May of each year by the Delaware Division of Fish and Wildlife during the annual Striped Bass Spawning Stock Survey. The survey is conducted from the Delaware Memorial Bridge through the Philadelphia Navy Yard.

6 – 4.2 Present Status

A recent peak in the young-of-year index occurred in 2007, indicating a potentially large year class. Although survival to age one is somewhat variable, a large year class at the young-of-year stage usually eventually recruits into the fishable stock as a large year class.

6 – 4.3 Past Trends

The stock had been considered virtually extinct by some authors in the mid-twentieth century. A remnant probably survived, however. Once water quality improved to the point that adequate oxygen was present in the nursery grounds all summer, the stock rebuilt quickly. It was officially declared restored by the Atlantic States Marine Fisheries Commission in 1998.

6 – 4.4 Future Predictions

The fishery is under fairly conservative restrictions. The abundance coastwide has declined in the last two to three years, reflected in the recreational catch per trip in the Delaware estuary waters in Delaware (Fig. 6.4.2). This index is affected by all the spawning stocks present in Delaware waters, including the dominant Chesapeake aggregation. The latter complex may be the source of the decline, due to an ongoing disease epidemic. The catch per effort index of the Delaware spawning stock survey in April and May does not show a decline in recent years (Fig. 6.4.3). The increase in abundance at the young-of-year stage in 2007 (Fig. 6.4.1) should keep adult stock numbers high in the near future.

6 – 4.4 Actions and Needs

Continue present monitoring and conservation regulations.

6 – 4.6 Summary

Once considered extirpated by some biologists, the Delaware River population is now one of the major spawning stocks on the Atlantic coast. This stock was declared restored by the Atlantic States Marine Fisheries Commission in 1998. The key to its recovery was the reduction in sewage pollution in the River due, in part, to the federal Clean Water Act. Annual surveys by the Delaware Division of Fish and Wildlife, the New Jersey Division of Fish and Wildlife and the Pennsylvania Fish and Boat Commission monitor abundance changes.

6 – 5 Blue Crab

Section Author: Richard Wong

Children's Museum of Indianapolis

The blue crab (*Callinectes sapidus*) is a member of the swimming crab family Portunidae, and inhabits primarily estuarine habitats throughout the western Atlantic, Gulf of Mexico, and Caribbean, from Nova Scotia (although rare north of Cape Cod) to northern Argentina, and along western South America as far south as Ecuador (Williams 1979).

The blue crab is the most valuable commercial fishery species in the State of Delaware. Eighty-two percent of the State's entire commercial landings (shellfish and finfish) came from blue crab harvest in 2009. The 2009 ex-vessel value of 5.4 million dollars was over six times greater than the combined ex-vessel value from all other Delaware fisheries combined.

The Delaware Bay blue crab stock supports commercial and recreational fisheries in Delaware and New Jersey. Since 1973, 2.9 million kg*y-1 (6.4 million lb) of blue crabs are harvested annually from Delaware Bay, with 51% of the total weight landed in the State of Delaware. The commercial fishery is responsible for the majority of the total annual harvest. Recreational harvest accounts for about 3% and 14% of the landings in Delaware and New Jersey, respectively, in 2009.

Total annual Delaware Bay blue crab landings increased by 1,175% from 1978 to 1995 causing concerns of overfishing and the development of fishery restrictions in both states. Total landings peaked at 5.4 million kg (11.9 million lb) in 1995, remained high for the next seven years (averaging 3.7 million kg), and then declined considerably in 2003 and 2004 (2.1 million kg*y^{-1}). Recent landings have rebounded again to historical high levels, averaging 3.8 million kg*y^{-1} since 2005.

Blue crab spawning occurs in the summer months in lower Delaware Bay with peak larval abundance occurring in August (Dittel and Epifanio 1982). Larvae are exported from the estuary into the coastal ocean where they undergo a 3-6 week, seven stage zoeal development in surface waters (Epifanio 1995; Nantunewicz et al. 2001). Quantitative models describe an initial southward transport of zoeae along the inner continental shelf within the buoyant estuarine plume after exiting the estuary (Epifanio 1995, Garvine et al. 1997). Northward transport back toward the estuary is provided by a wind-driven band of water flowing northward along the mid-shelf. Across-shelf transport into settlement sites in Delaware Bay is accomplished by coastal Ekman transport tied to discrete southward wind events (nor'easters) in the fall. These discrete wind events may have a large effect on larval recruitment and settlement success in the bay and strongly influence year class strength through juvenile and adult stages.

The larval crabs settle out as juveniles in late summer though early fall. Females mate immediately after their pubertal molt into sexual maturity, after about one year of life, usually late in their second summer. Females then store the sperm over the winter and produce eggs in the following summer. Prager et al. (1990) estimated fecundity per batch as over 3x106 eggs. Females may spawn twice in their first year of spawning (Churchill 1921; Van Engle 1958).

Juvenile and adult blue crabs hold an important ecological role as opportunistic benthic omnivores, with major food items including bivalves, fish, crustaceans, gastropods, annelids, nemertean worms, plant material, and detritus (Guillory et al. 2001). Post-settled blue crabs have been shown to have a key effect on infaunal community structure, particularly through major predation on bivalves such as the eastern oyster (*Crassostrea virginica*) (Eggleston 1990), *Mercenaria mercenaria* (Sponaugle and Lawton 1990), *Rangia cuneata* (Darnell 1958), *Mya arenaria* (Blundon and Kennedy 1982; Smith and Hines 1991; Eggleston et al. 1992), and other bivalve species (Blundon and Kennedy 1982), and through indirect mortality on infaunal species from mechanical disturbance of sedimentary habitats caused by foraging (Virnstein 1977).

Fish appear to be the primary predators on blue crabs, with more than 60 fish species listed as known predators (Guillory et al. 2001). Blue crabs are known to be a common component of both juvenile and adult striped bass diet in Chesapeake Bay, albeit with great variability in relative importance among studies (Speir 2001). Although there have been recent investigations on the potential negative effect of the recovered striped bass stock on the Chesapeake Bay blue crab stock, no connection with decreasing blue crab population numbers has been supported (Booth and Martin 1993; Speir 2001).

Another very important source of predation on blue crabs occurs from cannibalism, as cannibalized blue crabs make up as much as 13% of the diet (Darnell 1958). Cannibalism appears to increase with increasing crab predator size and is heaviest during the period of juvenile recruitment (Mansour 1992).

6 – 5.1 Description of Indicator

A 16 foot small mesh trawl survey is used to monitor blue crab abundance in Delaware Bay. The survey began in 1978 and is conducted by the Delaware Division of Fish and Wildlife (DDFW). Thirty-nine fixed stations are sampled monthly from April to October. Harvest is also monitored by DDFW from logbook reports submitted by commercial fishermen on a monthly basis. Given annual collections of biological and fishery data, DDFW can estimate the size of the stock, exploitation rates, and how they change from year to year. These stock assessments have occurred annually since 1999.

6 – 5.2 Present Status

Stock abundance can fluctuate widely from year to year. Since 1978, model estimates of annual blue crab abundance have ranged from 31 to 660 million, averaging 165 million. The most recent estimate of abundance was 115 million crabs in 2009 (Wong 2010). More than half of the legally harvestable stock was removed by crabbers, indicating the stock was fully exploited.

6 – 5.3 Past Trends

Severe winters in the late 1970s, especially the winter of 1977, produced high over-winter mortality and a major decline in stock size which persisted for about eight years. A general period of high productivity (i.e. elevated recruitment) occurred for about 15 years from 1985 to 1999 (Fig. 6.5.3). During this period, DDFW crab indices were at or above median levels for 13 of 17 years. In 2002, a very weak year class occurred, beginning a recent period of lower stock abundance.

6 – 5.4 Future Predictions

Blue crabs have been in the midst of a generally low-recruitment period for the past decade. Only two above-average young-the-of-year (YOY) recruitment events have been observed in the past 11 years. As a result, poor spawning stock abundance was observed from 2003 to 2006. A gradual recovery in spawning

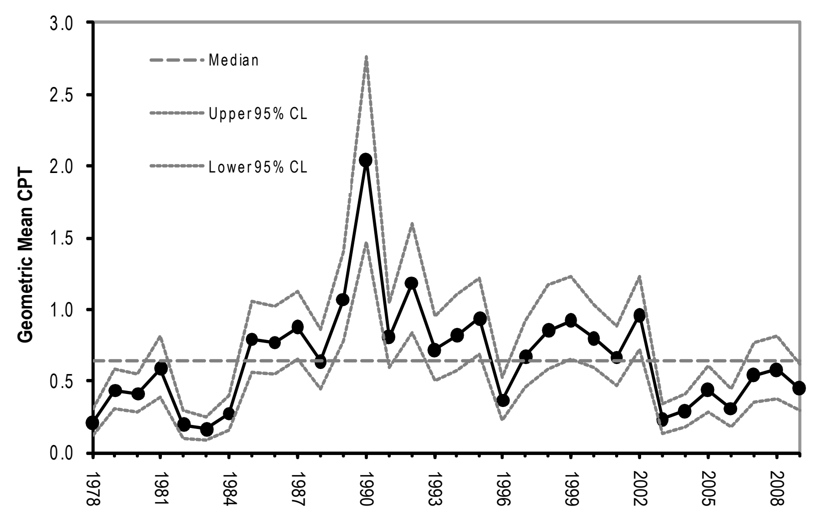


Fig. 6.5.1. Index of spawner abundance. Crabs >=120mm, Apr-May survey.

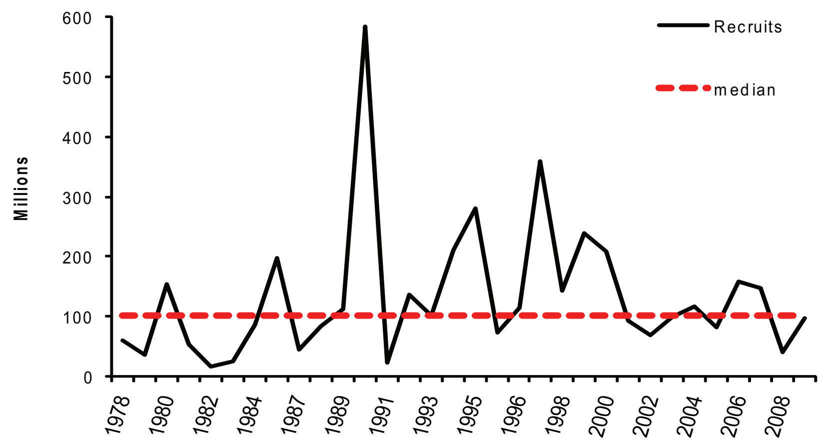


Fig. 6.5.2. Estimated stock size, recruit-size crabs < 120 mm.

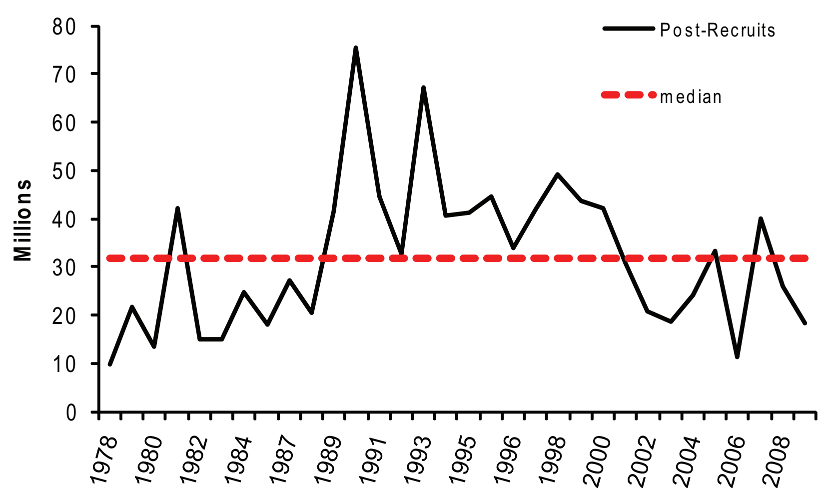


Fig. 6.5.3. Estimated stock size, adult (post-recruit) crabs >=120 mm.

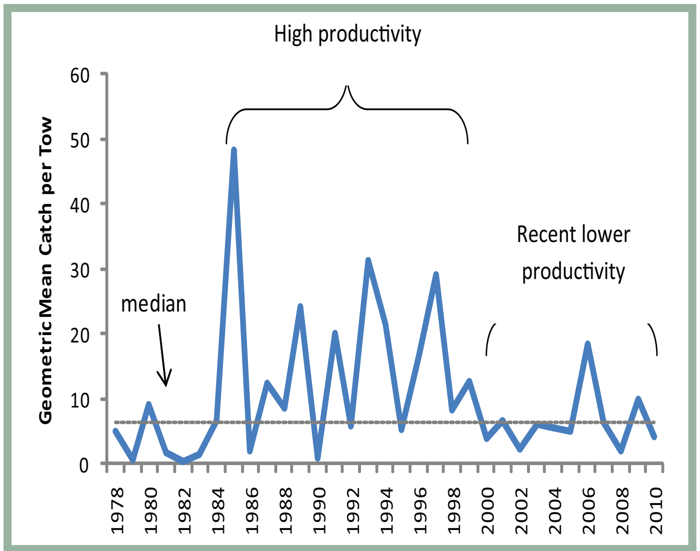


Fig. 6.5.4. Young-of-the-year index of abundance.

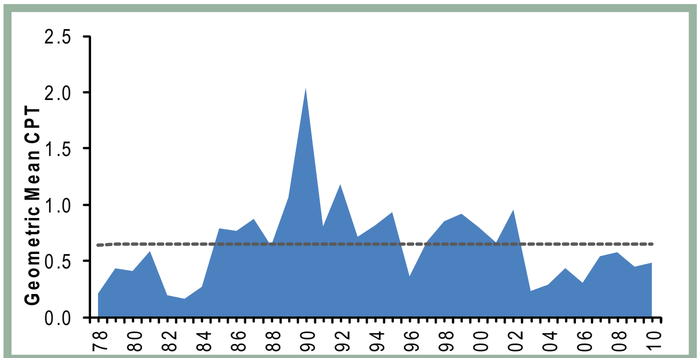


Fig. 6.5.5. Index of spawner abundance. Crabs >=120mm, Apr-May survey.

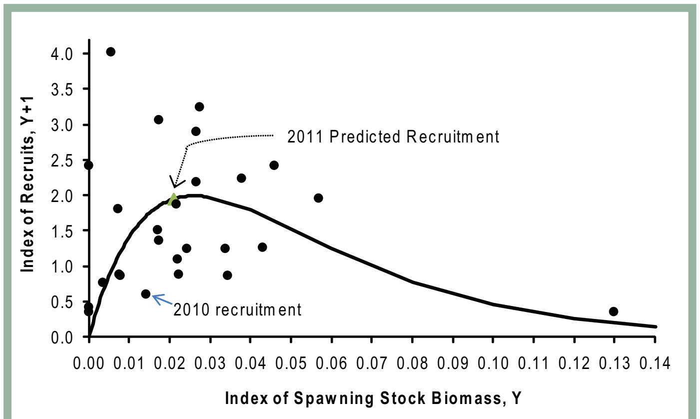


Fig. 6.5.6. Spawner-recruit relationship.

abundance has occurred, although levels remain below the median (Fig. 6.5.5).

Spawning stock biomass has gradually improved to levels that should support high recruitment events based on empirical observations (Fig. 6.5.6). Since environmental factors, particularly weather-driven coastal currents, can profoundly affect larval and YOY recruitment in the bay, it is very difficult to predict future stock dynamics with clarity, even with information about spawning abundance and mortality rates.

6 – 5.5 Actions and Needs

Nothing to report.

6 – 5.6 Summary

A 15-year period of high stock productivity has been followed by a relatively depressed period of low abundance for the past 11 years. Spawning abundance however has recovered enough to support sufficient recruitment in the near term future due to the blue crab's highly prolific reproductive biology. Harvest has remained elevated during this recent period of low recruitment, suggesting a fully exploited stock. Concerns of overfishing however are not yet critical since fishery effort has largely been constrained through caps on commercial licenses since 1994. Future stock dynamics may largely be affected by factors other than spawner abundance, such as oceanographic dynamics and cyclicity. All content in this technical report was taken from "Wong, R. 2010. 2010 Assessment of the Delaware Bay blue crab stock. Delaware Division of Fish and Wildlife, Dover, DE."

6 – 6 Weakfish

Section Author: Desmond Kahn

This member of the drum family (*Cynoscion regalis*) dominated Delaware's recreational and commercial finfish landings in the 1970s and 1980s, to the point that it was named as the State Fish. Weakfish return to the Bay in the spring from overwintering grounds off the North Carolina coast. Spawning occurs in May and then through the summer. The species is an indeterminate batch spawner. Larger weakfish, over several pounds, which were common in the 1970s and 1980s, were believed to spawn in the spring and then leave the bay. Younger, smaller weakfish stayed in the bay all summer, and could spawn more than once. Spawning occurs on shoals in the middle and lower bay. The young-of-the-year (YOY) are found from the lower Delaware bay well up into the tidal River, along with some adults. Young weakfish are first collected in May in most years.

Young weakfish are fast-growing, often reaching a length of six to eight inches by the end of their first summer, before leaving the Bay in the fall to migrate south. They feed heavily on opossum shrimp (known as mysids to biologists), which can be very abundant in mats of grass detritus washed out of marshes. The adults are carnivorous; in a study in the Delaware River in the 1970s, the only diet item found in a sample of adults was YOY weakfish. Other studies have found the preferred prey of adults is Atlantic menhaden, a member of the herring family, which has also been found to be the preferred prey of young and adult striped bass.

Weakfish abundance and catches have declined coastwide beginning in about 2000. A coastwide stock assessment completed in 2006 found that the rate of mortality due to natural factors had increased beginning in 1996, eventually causing the stock to decline. The assessment conducted screening of possible hypotheses to explain the increase in natural mortality. The results were that the impact of increasing striped bass abundance to unprecedented levels could not be rejected as a potential cause of the decline, due to possible impacts of the documented predation and competition for preferred prey. This hypothesis was strengthened by the fact that the boom in weakfish abundance which began in the 1970s coincided with widespread decline of striped bass, to the point that, by the 1980s, some authors worried that bass could go extinct. Striped bass were declared restored shortly before the decline of weakfish in the early 2000s.

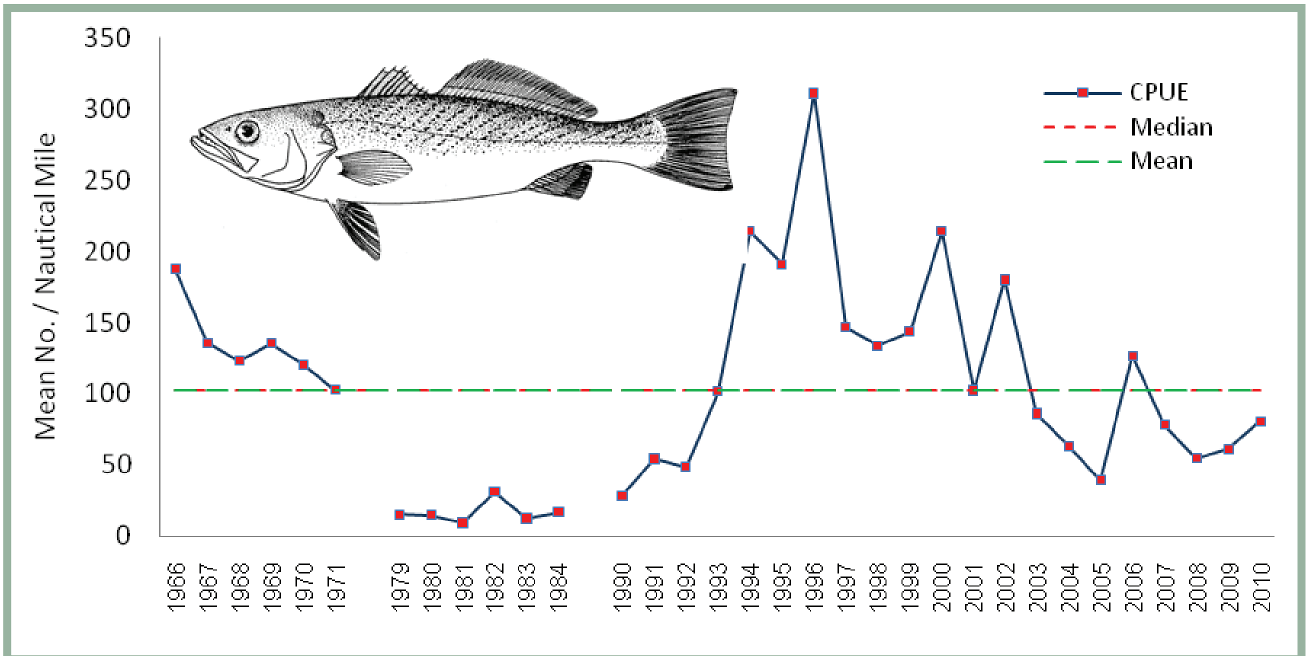


Fig. 6.6.1. Adult weakfish relative abundance (mean number per nautical mile), time series (1966 – 2009) mean and median as measured in 30-foot trawl sampling in the Delaware Bay.

6 – 6.1 Description of Indicator

The primary indicator is the mean catch per nautical mile of weakfish in the adult groundfish research trawl survey, conducted using a 30-foot (9.1 m) otter trawl net in Delaware Bay by the Delaware Division of Fish and Wildlife. This index is reported most recently in Michels and Greco (2011). The index is the mean number of weakfish caught per nautical mile at nine fixed stations in Delaware Bay for the months of March through December.

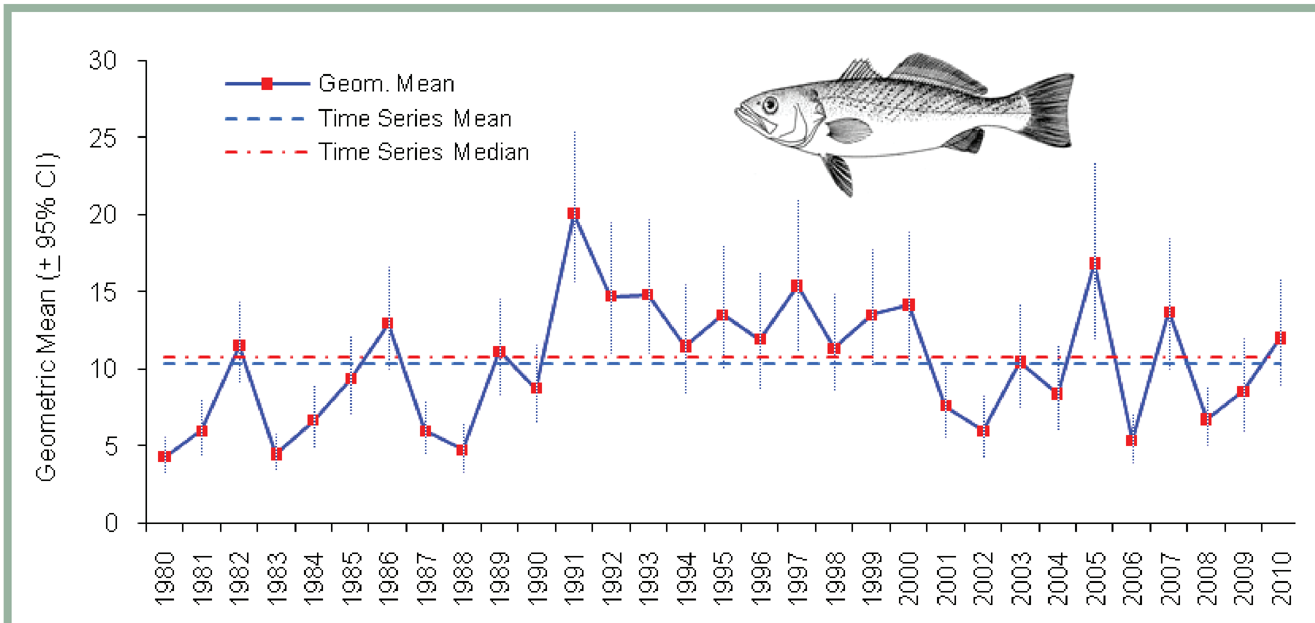


Fig. 6.6.2. Relative abundance of young-of-the-year weakfish from 1980 through 2010 with the mean and median for the last two decades (1990 – 2009) as measured by 16-foot trawl (9.1 m) sampling in the Delaware estuary.

A secondary indicator is the index of relative abundance of YOY weakfish as reported in Michels and Greco (2011), as measured by the Delaware Division of Fish and Wildlife's Juvenile Finfish Research trawl survey (Figure 6.6.2). This survey employs a 16 foot (4.9 m) shrimp try net.at 33 stations monthly from April through October in Delaware Bay and six stations in the lower Delaware River downstream from the Pennsylvania-Delaware border. The net has a 1.3 cm (0.5 inch) knotless stretch mesh liner in the cod-end.

6 – 6.2 Present Status

Weakfish relative abundance in the 30-foot (9.1 m) trawl survey has generally followed a declining trend since 1996 (Fig. 6.6.1) and total mortality estimates have correspondingly increased. The age structure of weakfish has become truncated back to the same level it had been in the early 1990s, with age three the oldest fish detected. In contrast, the age structure in the survey catches in 1999 and 2000 contained weakfish up to age eight. Over 95% of the 2010 catch was less than age two. On the other hand, weakfish was the most abundant finfish species in the survey.

Annual reproduction has continued at relatively high levels in terms of abundance of age zero fish (young-of-year), One reason for the continued levels of production of young weakfish, despite the decline in abundance and age-structure truncation affecting adults, is that 90% of weakfish are sexually mature at age one.

Currently, catches of legal weakfish (thirteen inches) in Delaware Bay are very uncommon, although sub-legal fish are present. The low abundance and truncated age-structure is a coast-wide phenomenon, not limited to Delaware Bay. The 2006 coastwide stock assessment conducted under the auspices of the Atlantic States Marine Fisheries Commission (Kahn et al. 2006) found that the stock was at low abundance due to a large increase in natural mortality. This assessment explored hypotheses concerning the cause of this increase, and found that a negative impact of striped bass was the hypothesis that could not be rejected, through predation, or competition for Atlantic menhaden or both.

A new assessment was conducted coastwide in 2009, and the same status was found, with lower abundance than that in the 2006 assessment. In this more recent assessment, a hypothesis that survived testing was that a combined negative impact of striped bass and spiny dogfish caused the decline through predation, competition or both. A second hypothesis was that the ratio of striped bass to Atlantic menhaden coastwide explained the decline of weakfish, implying competition with striped bass for menhaden, the preferred prey of both adult weakfish and adult striped bass (ASMFC 2009).

6 – 6.3 Past Trends

Weakfish were at moderate abundance prior to the 1970s, when they began an explosive rise in abundance and size. By the late 1970s, Delaware Bay had become famous throughout the Mid-Atlantic region as a destination for catching trophy weakfish in the spring spawning run. By the late 1980s, this fishery subsided. Coastwide fishery restrictions were imposed in the Mid-1990s, and abundance and catches began to increase. The fishery did not attain the high catches and trophy size seen in the 1970-1980 period, but it did produce higher catches of legal size weakfish for many, before it began tailing off in the 2000s.

6 – 6.4 Future Predictions

The 2009 stock assessment indicated that, unless natural mortality declined, even a moratorium would not produce a rebuilding of the Atlantic coast stocks of weakfish.

6 – 6.5 Actions and Needs

none

6 – 6.6 Summary

Currently, weakfish reproduction continues at moderate levels. Survivorship to catchable size, however, has declined greatly, to the point that catches of legal-size weakfish are uncommon in Delaware Bay. The cause of this decline has been determined to be an increase in natural mortality due to predation by, or competition with striped bass and spiny dogfish, possibly mediated by Atlantic menhaden abundance to a greater or lesser extent.

6 – 7 American Eel

Section Author: Desmond Kahn


Ellen Edmonson & Hugh Chrisp

American eels (*Anguilla rostrata*) are unique among fishes of the Delaware Estuary, because to spawn, they must swim to the Sargasso Sea off the southern U.S. coast. They die after spawning. The larvae are leaf-like in shape and are known as leptocephali. Before entering estuaries in late winter, they transform into clear, very small eels known as glass eels. All Atlantic eels are currently believed to spawn in one aggregation, so that no matter how depleted the spawning population from the Delaware estuary may be, the supply of larvae that arrives is not affected. The only potential source of a reduction in larval supply would be severe decline coast wide in the number of spawning eels. The larval eels are not believed to return to the particular waters from which their parents came, but rather to migrate up the coast with the Gulf Stream en masse and to move into the coast in a more or less random order.

Some eels migrate into freshwater non-tidal tributaries, often very small streams. Others remain in brackish water in tidal tributaries of the Bay and River. Some migrate far up the River into New York State and northern Pennsylvania. American eels play an important role in the life history of some species of freshwater mussels. Mussel larvae have evolved to hitch a ride on the gills of eels as a critical part of their life history.

Delaware and New Jersey have significant commercial fisheries for eels, prosecuted in the Bay and its tidal tributaries. Delaware landings have ranged above 100,000 lbs. (45,360 kg) in some years. This is a specialized fishery requiring live tanks because eels must be held alive until buyers arrive to take the eels. There are two markets for eels. One is a market for bait used by recreational fishers targeting striped bass locally, as well as bait for cobia to the south. Even anglers fishing in large southeastern reservoirs use eels for large catfish and striped bass. These eels are small, but must exceed the legal minimum size of 6 inches. The second market is in Europe and Japan for live eels that are flown overseas and are considered to be delicacies.

The eel fishery is dependent on horseshoe crabs as bait; fishers say that much of the year, the only bait that will catch significant numbers of eels in their pots is half of a female horseshoe crab containing eggs. With the restrictions on landings of horseshoe crabs, the price for this bait has increased to about $1 per crab in some cases. This factor has made the eel fishery more difficult.

Coast-wide, the American eel population is managed by the Atlantic States Marine Fisheries Commission. Some populations have declined in recent years, thought to be due to several potential factors, one of which is the introduction of a parasite that lives inside the swim bladder of eels. Other factors could include the long time to reach maturity (8 to 24 years), concentration during certain life stages making them vulnerable to exploitation, fishing mortality occurring prior to spawning, continued habitat loss, and changes in oceanic conditions where they spawn. The US Fish & Wildlife Service is currently conducting a review of the species status in order to determine whether it should be listed under the Endangered Species Act. It is worth noting that the Service closed a previous investigation in 2007, concluding that there was no basis for listing eels as threatened or endangered.

6 – 7.1 Description of Indicator

The index of eel relative abundance is developed from 13 trawl survey stations in the lower Delaware River by the Delaware Division of Fish and Wildlife Juvenile Finfish Trawl Survey. The net is a 16-ft (4.8-m) semi-balloon trawl with a 0.5-in (1.3-cm) cod end liner towed by 62-ft (19-m) R/V First State. Data from April through June is employed. The geometric mean catch-per-tow is the estimator (Fig. 6.7.1). The catch consists of eels from ages 0 to 7, with the most common age about 3 years of age. All eels are juveniles until they migrate to the Sargasso Sea on their spawning run.

6 – 7.2 Present Status

Time series analysis produced a significant fit of a cubic polynomial regression line representing the index as a function of year, which explains a statistically significant portion of the variation ($P < 0.05$, $R2 = 27.4\%$). This fit to a curvilinear line suggests a cyclic pattern of abundance. Such patterns raise the possibility of some type of decadal-scale shifts in weather patterns affecting recruitment into the stock. Since larval eels depend on the Gulf Stream for transport up the coast, wind patterns could possibly affect the variation in the numbers of glass eels that reach the estuary.

Catch-per-tow declined in the later 1980s and increased into the mid-2000s. Recently catch per tow has declined somewhat to moderate levels.

6 – 7.3 Past Trends

Abundance declined somewhat during the 1980s, but increased to higher levels in the mid-2000s. Sykes and Lehman (1957) reported that eel weirs were so numerous on the non-tidal Delaware River that they trapped and killed many, if not most, YOY shad migrating downriver in early fall. These weirs targeted the so-called silver eel stage, which are adults migrating down river and out to spawn in the Sargasso. Smiley (1884) described "hundreds of traps" in the River between Lackawaxen and Hancock. This indicates much heavier fishing mortality on silver eels in the upper Delaware River many decades ago. In recent years, only one weir has been operating in the Delaware River, in New York State. However, even if fishing mortality was high on eels in the upper Delaware River, that would not affect the number of new recruits arriving from the Sargasso Sea annually, because the total coast wide stock would be little affected by reductions in the spawners from the Delaware River.

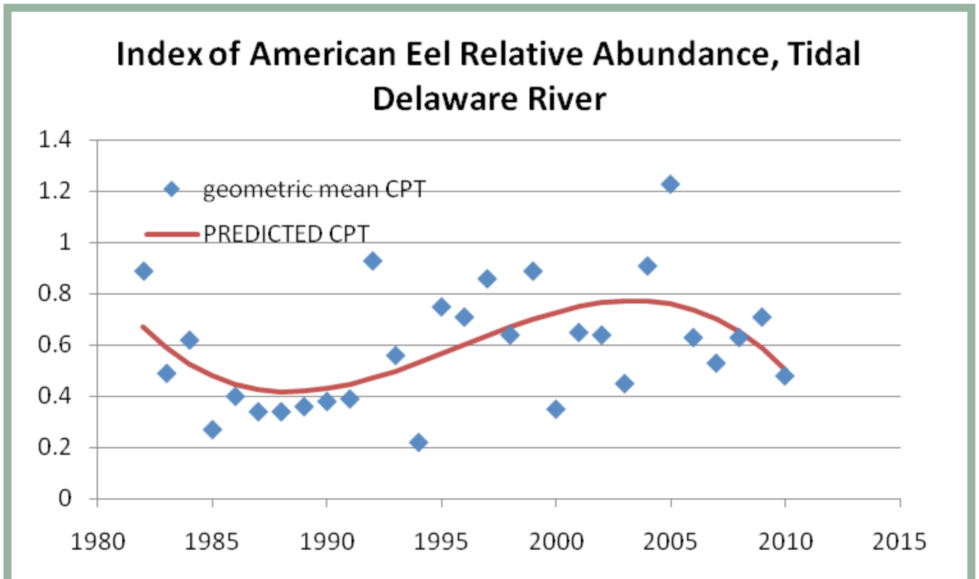


Fig. 6.7.1. Index of relative abundance of American eels in the tidal Delaware River, based on catch per tow at 13 stations from April –June annually. The index is the geometric mean catch per tow. The predicted line was fitted as a cubic polynomial regression, P = 0.0428, R2 = 27.4%.

6 – 7.4 Future Predictions

There are no apparent bases for future predictions, but the coast wide nature of the spawning aggregations (at least that is the current understanding), suggest that even if the Delaware Estuary spawning numbers would decline, the estuary would still get relatively high recruitment annually.

6 – 7.5 Actions and Needs

Although the main stem of the Delaware River is un-dammed, hundreds of dams still block passage along its tributaries; many are low head dams under private ownership and in poor condition. In addition, there are thousands of culverts for roads that cross the tributaries. And in many areas the riparian forested buffer along the streams has been removed, leaving the stream exposed to sun and dramatically increased non-point source sediment and pollution run off. Fish passage and riparian restoration would help improve habitat for eel by increasing connectivity and improving in-stream habitat by providing shade and structure in these tributaries.

6 – 7.6 Summary

Eel populations declined in the late 1980s and increased into the mid-2000s. Recently the population has declined somewhat to moderate levels. Annual recruitment is expected to remain high due to the coast wide nature of eel spawning at sea.

6 – 8 Eastern Oyster

Section Author: John Kraeuter

The eastern oyster, *Crassostrea virginica* (Gmelin, 1791), is a dominant structural and functional member of the Delaware Bay benthos. It supports a commercial fishery, aquaculture and provides a hard substrate in an environment otherwise dominated by sand and mud. In addition to providing structure, which is habitat for many other species, oysters filter large quantities of water thus enhance nutrient cycling within the system. Oysters have been harvested from the bay since pre-colonial times and current harvests are carefully managed.

PDE

The life cycle of the American oyster in Delaware Bay begins with a sperm and egg that are released into the water in the summer. Some years spawning can occur as early as May or as late as September, but most spawns take place in July and August. Females can release all their eggs at once or partially spawn multiple times, but an average female may produce 2 to 60 million eggs during a single spawn. Typical spawns in a hatchery yield 1 to 15 million eggs. The fertilized egg and the free swimming larvae remain in the water column for two to three weeks before attaching to some hard substrate (by setting or settling), preferably clean oyster shell. The subsequent growth rate depends on the temperature and salinity of the site where the oyster attaches. By fall the YOY oysters can range in size from ¾ mm to over 35 mm depending on location and when they set. Little or no growth takes place during the winter, and young oysters are heavily preyed upon by oyster drills, flatworms, small crabs and other predators. By the next fall most surviving oysters reach 30 to 65 mm depending on the location within the salinity gradient. Lower salinity areas have slower growth, but there are fewer predators so survival is better. Average growth to market size (3 inches) typically takes from 3 to 6 years in Delaware Bay, again depending on the location along the salinity gradient. Two oyster diseases are present in Delaware Bay: MSX, *Haplosporidium nelsoni* and dermo, *Perkinsus marinus*. Neither of these organisms affects humans, but they are eventually lethal to oysters. There is evidence that the native oyster population has developed some resistance to MSX. Since 1989 dermo has been a major factor controlling the oyster population levels on the higher salinity seed beds in Delaware Bay.

The oyster and the oyster assemblage are important to the general ecology of the bay. The assemblage of organisms that develop because the oyster provides a hard substrate and irregular spaces for attachment or shelter was recognized in the late 1800s as community and described as a biocoenose by Möbius. This concept was the forerunner of what we now know as community ecology. In addition to the structure provided by the oyster, it is a major functional part of the ecosystem because it filters the water for food. This filtration process removes particulate material from the water column and deposits it on the sediment surface where some of it becomes food for other organisms or is broken down by bacteria. This filtration and deposition is an important pathway for nutrient cycling in estuaries.

6 – 8.1 Description of Indicator

The oyster beds of the New Jersey portion of Delaware Bay have been surveyed in the fall and winter since 1953. In the earlier years the survey took place from September throughout the winter, but since 1989 the period has been reduced to about one week in the last part of October to early November. A random stratified sampling method divides each of the beds into 0.2-min latitude x 0.2-minute longitude grids (~ 25 acres or 10,171 m^2) (Fig. 6.8.1). Each bed is divided into three strata that are defined by surveys of the bed areas that are scheduled on a 10 year rotation. The bed area survey data are then divided into high quality, medium quality and low quality. These represent the areas with 50%, 48% and 2% of the oysters respectively. For the fall survey the grids in the high and medium quality categories are randomly allocated. The number of grids sampled in these two strata is dependent on the variability of the particular bed as determined by the area survey and past sampling.

A grid sample consists of a composite of 3 one-third bushel lots from 3 1-minute tows by a 1.27-m wide commercial oyster dredge on a commercial oyster boat. The length of the tow is measured by repeated (every 5 seconds) GPS positions for the duration of the tow, and the total volume of material brought up by the dredge is measured.

The bushel sample is sorted at the laboratory for total volume, and volumes of oysters, spat, boxes, cultch, and debris. Numbers of oysters, spat, boxes are recorded and all oysters and boxes are measured. Subsamples are set aside for condition index (dry meat weight), and pathology (MSX (*Haplosporidium nelsoni*) and dermo (*Perkinsus marinus*)). Dredge calibration studies are used with the other data to derive numbers per square meter information. Ancillary data are provided by a dock-side monitoring that collects information on the size and number of oysters going to market. A monthly mortality and dermo survey on selected beds along the salinity gradient that begins in April/May and terminates with the oyster survey each year also provides critical information to managers and the industry.

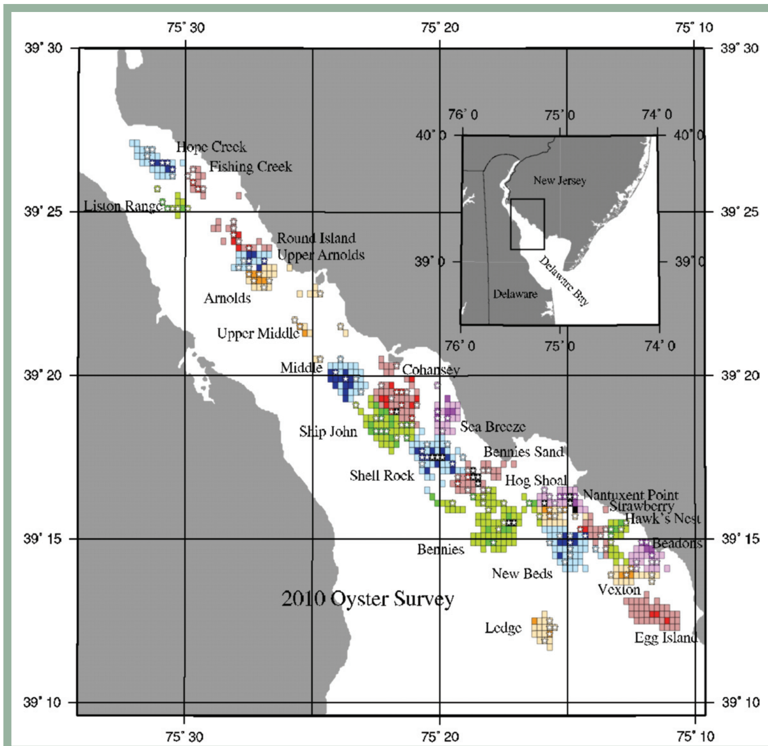


Fig. 6.8.1. New Jersey oyster seed beds. Dark colors represent grids with 50% of the total oysters on the bed, while the lighter colors represent 48% of the oysters. The remaining 2% are not surveyed annually.

These data are combined into a report that is presented to a group of knowledgeable individuals from within and without the area in a stock assessment workshop held each February. The results of the survey are then presented to the New Jersey Department of Environmental Protection and the Oyster Industry at the next Shellfish Council meeting for management consideration and setting of the coming season's harvest.

The oyster resources in the State of Delaware are a fraction of those in New Jersey because the area in the lower bay on the Delaware side is less. The State of Delaware also conducts an annual survey of their oyster resources. It is less intensive than that of New Jersey, but it too relies on dredge samples and counts of live, dead and newly set oysters to set the following year's quota. In recent years representatives from the State of Delaware have presented information from their survey at the stock assessment workshop.

6 – 8.2 Present Status

Population levels and harvest levels have been static at about 1.9 x 10^9 individuals and 70,000 to 100,000 bu (bu = 37 qts = 35 L), respectively, since 2002 in spite of an historically unprecedented period of low settlement that extended from 2000 through 2007. The low recruitment coupled with the oyster disease dermo has reduced oyster stocks on the lower seed beds, but an active management program has sustained the overall levels of oyster abundance while permitting harvest. A welcome increase in settlement in 2009 and even larger set in 2010 should provide for expansion of adult oyster abundance in the next few years.

While per square meter quantitative data from Delaware are not available, data presented by the State of Delaware at the annual New Jersey stock assessment workshop indicate that population dynamic trends on the Delaware side of the Bay mirror those seen in New Jersey.

6 – 8.3 Past Trends

There were substantial oyster harvests from Delaware Bay in the middle 1800's, and by the latter part of that century extensive importation of seed enhanced the numbers of market oysters over what the bay alone could produce. Active survey of the seed bed resource did not take place until 1953, and annual records are available since that date (Fig. 6.8.2). The survey was initiated during a period of low abundance and just a few years before the oyster disease MSX substantially reduced the total numbers of oysters in the bay. The following decade was a period of low abundance, but it was followed, from the late 1960's until the mid 1980's, by a period of high abundance. This was terminated by another MSZ epizootic in 1985, and the emergence of dermo in 1989 which has dominated the population dynamics in the lower seed beds ever since. In the late 1950's the seed bed oyster population averaged 2.8 x 10^9 adult individuals and it currently is 1.9 10^9 individuals. In the peak years of the 1970's to the mid 1980's the average oyster population was ten fold higher at 1.7 x 10^{10}.

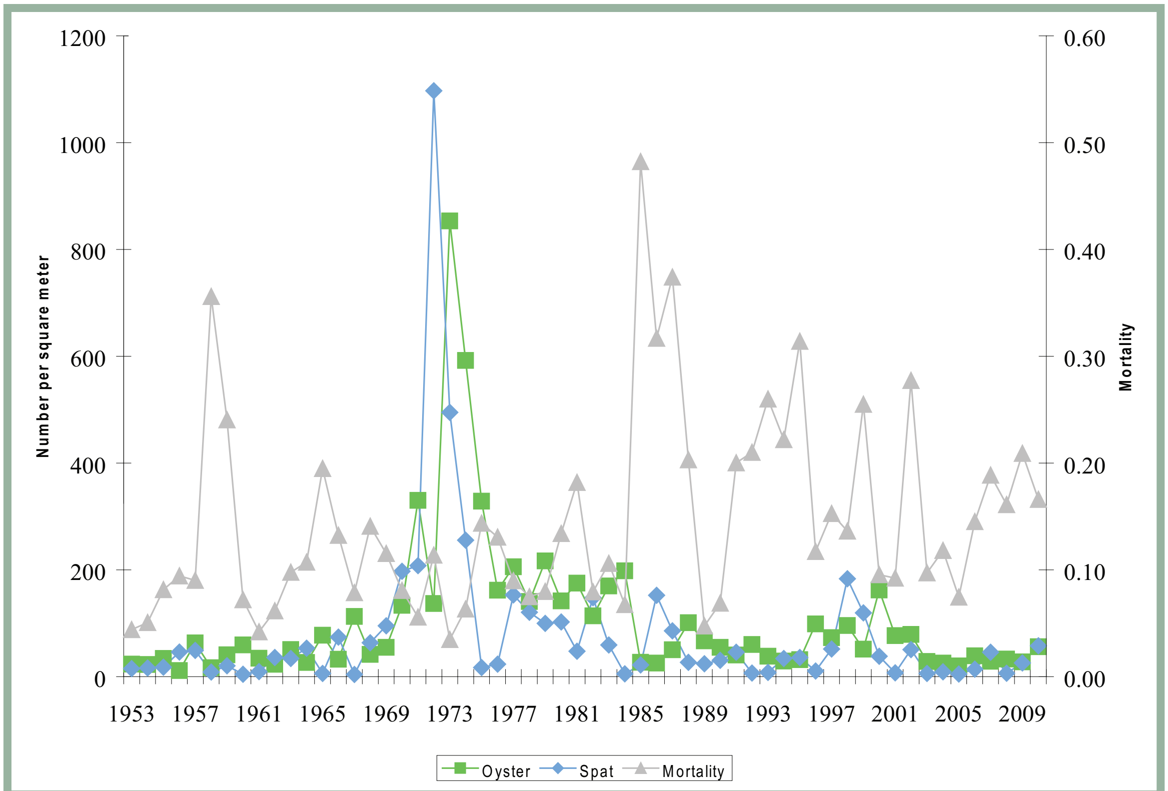


Fig. 6.8.2. Numbers of adult and spat (young of the year) oysters in the fall of each year on the New Jersey Delaware Bay seed beds, 1953 to 2010. Mortality is the fraction of adult oysters dead in the fall of each year.

6 – 8.4 Future Predictions

Management of this resource relies on annual survey data. Because the intensity of oyster diseases and recruitment success cannot be predicted, the only mechanism available for resource management decisions is the annual update of the oyster population information. There is no evidence that harvest has had substantial effects on the population dynamics of oysters in Delaware Bay since at least the late 1960's. Current recruitment levels should bring the population back toward the late 1950's levels. Unless dermo disease in the lower portion of the bay becomes substantially reduced it is unlikely that the higher levels of oysters experienced in the 1970's to the mid 1980's will return. An ongoing study that is attempting to link hydrodynamics and oyster population dynamics with detailed models of oyster diseases and the genetic structure of the Delaware Bay oyster stocks should provide additional information that will substantially inform the management process. The mapping of unutilized oyster beds in the Hope Creek area has offered a new resource for managers to consider.

More detailed data are available through the annual monitoring reports of the Haskin Shellfish Research Laboratory, Rutgers University at the web site: http://vertigo.hsrl.rutgers.edu.

Climate change

As long as the oyster population dynamics in higher salinity areas is controlled by dermo and MSX, changes in the oyster population will be linked to salinity levels. The funnel shape geomorphology of Delaware Bay makes the area available for development of oyster reefs less from the mouth of the bay toward the fall line. Combining this geomorphology with ongoing sea-level rise suggest that the area available for prime oyster habitat will be reduced in the future. Other factors such as channel deepening, extraction of ground water, and consumptive use of Delaware River freshwater supplies all imply that salinity will rise even if climate change causes increased rainfall. Because freshwater in the Delaware River/Bay system is actively managed, man made decisions may have more effects on the oyster population than modest climate change. If the most pessimistic climate change scenarios take place, there are likely to be such profound changes to the Delaware Bay system, and its human inhabitants that any change to the oyster resources will be of secondary or tertiary importance to the maintenance or movement of infrastructure.

6 – 8.5 Actions and Needs

The maintenance of the annual oyster population and oyster disease surveys is essential to management of this resource. Efforts need to be made to evaluate the Hope Creek, Fishing Creek, and Liston Range oyster bed population dynamics. Plans need to be developed to manage the likely continued rise in salinity in Delaware Bay and its importance to the long term viability of key oyster beds. At a minimum, development of a bay wide monitoring system for temperature and salinity should be implemented. As possible additional parameters such as pH, dissolved and particulate nutrients, chlorophyll and total suspended solids could be added. Plans for enhancing recruitment through shell planting need to be continued and expanded.

6 – 8.6 Summary

The oyster is a keystone species in the Delaware estuary in that it provides a habitat, a harvestable resource and a key link in ecosystem nutrient cycling. The oyster population abundance in Delaware Bay is currently controlled by a balance between recruitment and disease related mortality. Both of these processes respond to environmental factors such as the annual temperature cycle and salinity (freshwater input) and thus cannot be predicted. This unpredictability makes annual surveys a key to sustainably managing the resource. Recent good settlement of young indicates that the adult population will increase in the next few years. Shell planting to enhance recruitment is a mechanism for increasing population abundance, and should be continued and expanded.

6 – 9 Osprey

Section Author: Gregory Breese

One of the largest birds of prey in North America, the osprey (*Pandion haliaetus*) eats almost exclusively fish. It is one of the most widespread birds in the world, found on all continents except Antarctica. The osprey is a large raptor (bird of prey) usually seen near large bodies of water. Ospreys arrive in Delaware Bay in early March and begin nesting by mid March. Osprey use a variety of nest sites including: live or dead trees, man-made nesting platforms, utility poles/structures, channel markers, and duck blinds. Young fledge in the early summer. Wintering occurs in the Caribbean, Central America, and South America.

Osprey feed on live fish, which typically make up 99% of their diet. Highly adapted for capturing fish, osprey may plunge underwater in pursuit of their prey. Bald eagles and great horned owls are known to take fledgling osprey. Raptors and other birds will take over osprey nests. Bald eagles are well known to rob osprey of the fish they have caught.

Ron Holmes

6 – 9.1 Description of Indicator

Both New Jersey and Delaware have osprey monitoring and conservation programs. Nest checks by aerial or ground observers are conducted by staff and volunteers to determine active nests and productivity between the end of April and mid July. Each state works independently on their monitoring programs so timing and the survey areas are different (Delaware focused effort in Inland Bays until 2007 and New Jersey surveyed state-wide), and reports are provided separately.

6 – 9.2 Present Status

Ospreys appear to be doing well in Delaware Bay. Productivity, as measured by fledglings observed, is higher than needed for a stable population. Population levels may be close to what is believed to have been the level prior to the widespread use of DDT.

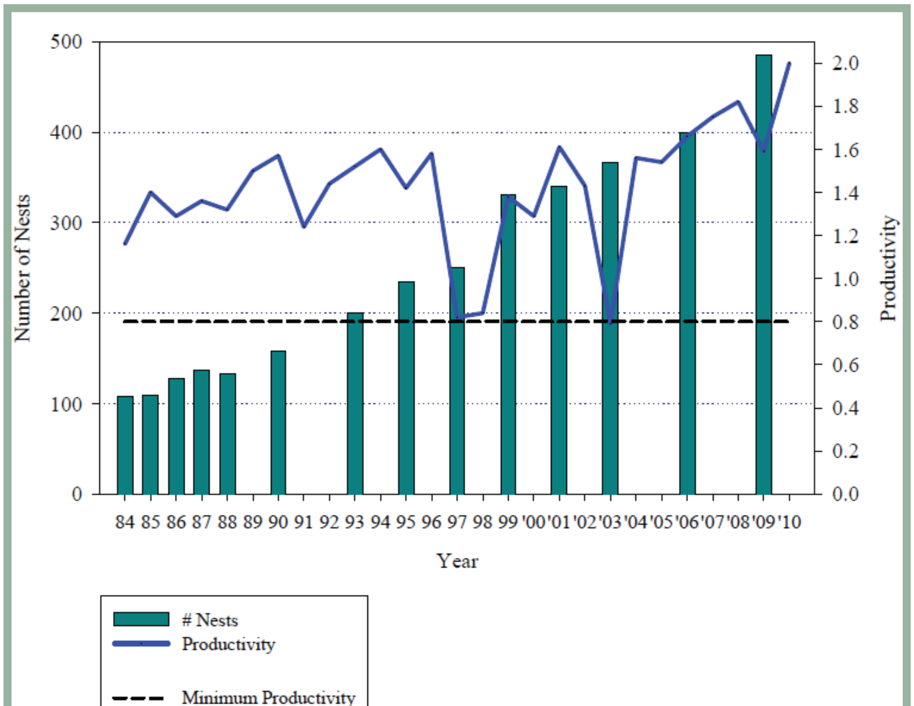


Fig. 6.9.1. Osprey nesting population (bar) and productivity (heavy line) 1984-2010 in New Jersey.

6 – 9.3 Past Trends

Historically abundant, osprey populations declined precipitously in the Northeast from the 1950s through the 1970s, due to the widespread use of DDT to control mosquitoes. Since DDT was banned, osprey populations have been slowly rebuilding, aided by reintroduction programs. Delaware Bay populations remained depressed due to high organochloride and PCB levels into the 1990s. Since then, levels of organochlorides have lowered and productivity has improved.

6 – 9.4 Future Predictions

The outlook for osprey is good in Delaware Bay. Disturbance is generally not an issue, they adapt well to man's activities. Contaminants have been reduced and levels in osprey continue to decline. Expectations are that osprey will continue to show success in Delaware Bay.

6 – 9.5 Actions and Needs

Volunteers are needed for monitoring nests and productivity. Since osprey readily use artificial platforms and structures for nesting, those interested in establishing nesting structures, or that have questions about osprey should contact the State agencies responsible for bird conservation (links to the right).

6 – 9.6 Summary

Osprey populations in Delaware Bay are a success story. They demonstrate the value of reducing contaminants in our environment and taking conservation actions. In addition, the success of osprey conservation shows how volunteers can make a difference.

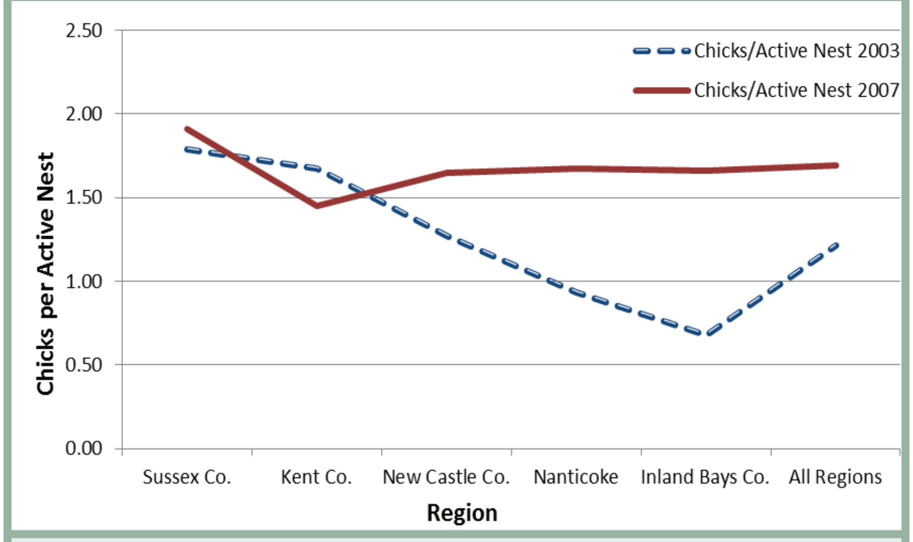


Fig. 6.9.2. Osprey productivity in Delaware by region in 2003 and 2007

NJ:
http://www.njfishandwildlife.com/ensphome.htm

DE:
http://www.fw.delaware.gov/Pages/FWPortal.aspx

6 – 10 White Perch

Section Author: John Clark

Duane Raver, USFWS

White perch (*Morone americana*) are one of the most abundant fish in the Delaware Estuary and probably the most widespread, found in nearly all the waters of the Delaware Estuary, from the Bay and the River to all their tidal tributaries. White perch support important recreational and commercial fisheries throughout the estuary. The Delaware Estuary white perch population is currently in good condition and is not overfished.

White perch are closely related to striped bass, but the white perch is a smaller fish. The Delaware state record white perch was 2 pounds 9 ounces, but any white perch over one pound is considered large. Delaware Estuary white perch display anadromous tendencies in that large numbers of white perch moved into the tidal tributaries in spring to spawn and then out into the deeper waters of the estuary to overwinter, but, unlike striped bass, white perch rarely leave the estuary. White perch numbers in the Delaware Bay and River typically increased during the fall and remained high through winter, then decreased during the spring and summer (Miller 1963, PSEG 1984), while white perch numbers in the tidal tributaries showed the opposite trend (Smith 1971). However, white perch were caught year-round in both the Delaware Estuary (de Sylva et al 1962) and the tidal tributaries (Smith 1971), so these migratory movements are not universal among perch. Landlocked white perch populations have thrived for years in most of the freshwater ponds in the headwaters of Delaware Estuary tidal tributaries (Martin 1976).

White perch spawn in the Delaware River (Miller 1963, PSEG 1984) and most of the Delaware Estuary tidal tributaries (Miller 1963, Smith 1971, Clark 2001). Spawning occurred from early April through early June, but May was usually the peak spawning month (Miller 1963, Smith 1971, PSEG 1984). YOY white perch, like the adults, were found in both the Delaware Estuary (PSEG 1984) and the tidal tributaries (Smith 1971). YOY white perch were found throughout the year in the lower salinity reaches of all sampled tidal tributaries (Clark 2001).

White perch feed almost exclusively on small invertebrates from their larval through juvenile stages, and then add fish to their diet as they reach maturity (PSEG 1984). Almost all male white perch are sexually mature in two years and almost all female white perch are sexually mature in three years (Wallace 1971). Delaware Estuary white perch have been aged to ten years old and some may live longer than that, but white perch older than six years old were rare (Clark 2001).

White perch tolerate a wide range of environmental conditions, as would be expected of such an ubiquitous fish. White perch were caught at water temperatures ranging from 2.2° C (Rohde and Schuler 1971) to 35.5° C (Clark 1995) and salinities ranging from freshwater (Shirey 1991) to 35 parts per thousand (Clark 1995). White perch catch per unit effort was greatest in fresh and oligohaline waters of Delaware tidal tributaries (Clark 2001), which may be explained by pointing out that the freshwater reaches of tidal tributaries are smaller, so the density of perch increases in such water, even if the abundance does not. Smith (1971) caught white perch at a dissolved oxygen level of 2.2 parts per million (ppm) in Blackbird Creek and Clark (1995) caught white perch at a dissolved oxygen level of 2.0 ppm in a high-level tidal impoundment near the Little River, but neither report indicated whether the fish showed signs of stress at these low dissolved oxygen levels.

White perch were among the top five finfish species landed commercially in Delaware during each year of the last decade, which is not surprising since gourmets consider the white perch to be one of the finest tasting fish in the world. Landings averaged 71,909 lbs. (32,618 kg) during 2000 through 2010, with the highest landings, 113,997 lbs. (51,709 kg), reported in 2000. Most fishing effort for white perch was expended during late fall through winter and into early spring. Delaware Bay was the source for most commercially-caught white perch, but substantial landings also came from the Delaware River and several tidal tributaries. New Jersey white perch landings in the Delaware Estuary counties (Salem and Cumberland) averaged 24,333 lbs. (11,037 kg) per year during 1995 through 2000, with the highest landings, 42,000 lbs. (19,051 kg), reported in 2000.

White perch were among the top 10 fish species harvested recreationally in Delaware during each year of the last decade. The mean estimated recreational harvest during 2000 through 2010 was 26,840 pounds, with the highest harvest, 45,626 pounds (45,626 kg), reported in 2010.

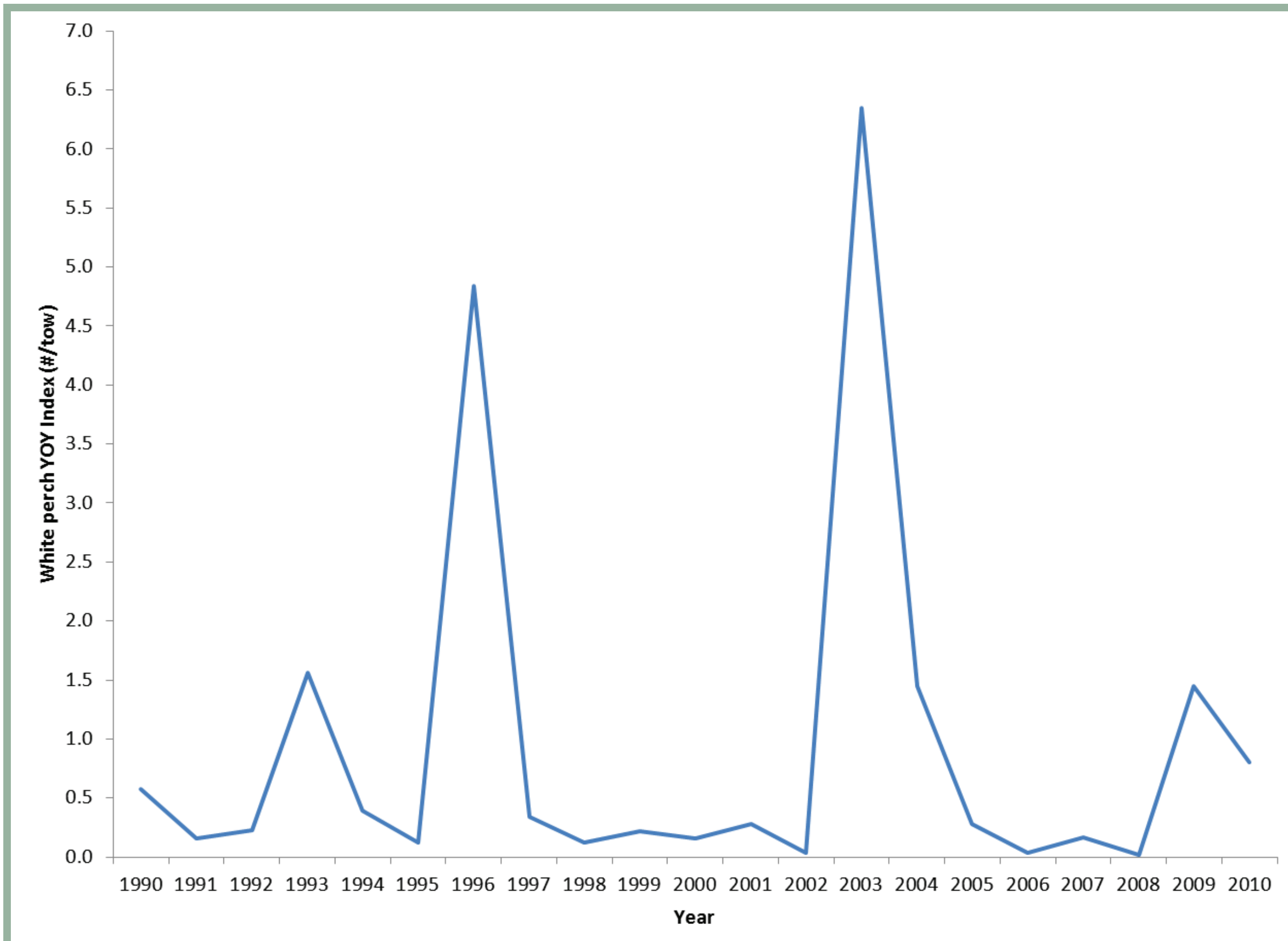


Fig. 6.10.1. White perch YOY index (number of YOY white perch caught per trawl tow) from the DDFW Juvenile Trawl Survey for 1990 through 2010.

6 – 10.1 Description of Indicator

This indicator uses the white perch YOY index derived from the Delaware Division of Fish and Wildlife's (DDFW) Juvenile Finfish Trawl Survey. The juvenile finfish trawl survey used a 16' trawl net to sample 39 inshore Delaware Bay and River stations monthly during April through October. The YOY index was calculated as the geometric mean number of YOY white perch caught by the juvenile finfish trawl survey during June through October in Delaware Bay and River (Michels and Greco 2011). The white perch YOY index is an indicator of year-class strength and indirectly an indicator of spawning stock abundance. The white perch YOY index has not been used as a predictor of future population size or future commercial catches. The median white perch YOY index for the 1990 through 2009 time series, 0.26 YOY white perch per tow, was exceeded in 2009 and 2010 (Fig. 6.10.1).

6 – 10.2 Present Status

The white perch YOY index was above the time series median YOY index value during 2009 and 2010, which suggested the Delaware Estuary white perch spawning population was large and spawning success was good. Delaware white perch commercial landings exceeded 100,000 lbs. (45,360 kg) in both 2009 and 2010; the first time landings exceeded 100,000 lbs. for two consecutive years in the 1951 through 2010 time series, which also suggested the Delaware Estuary white perch population was large.

6 – 10.3 Past Trends

Delaware white perch commercial landings were the longest term time series available to assess past trends in white perch abundance (Fig. 6.10.2), but white perch landings were affected by several factors other than the white perch population, such as fishing effort, conditions

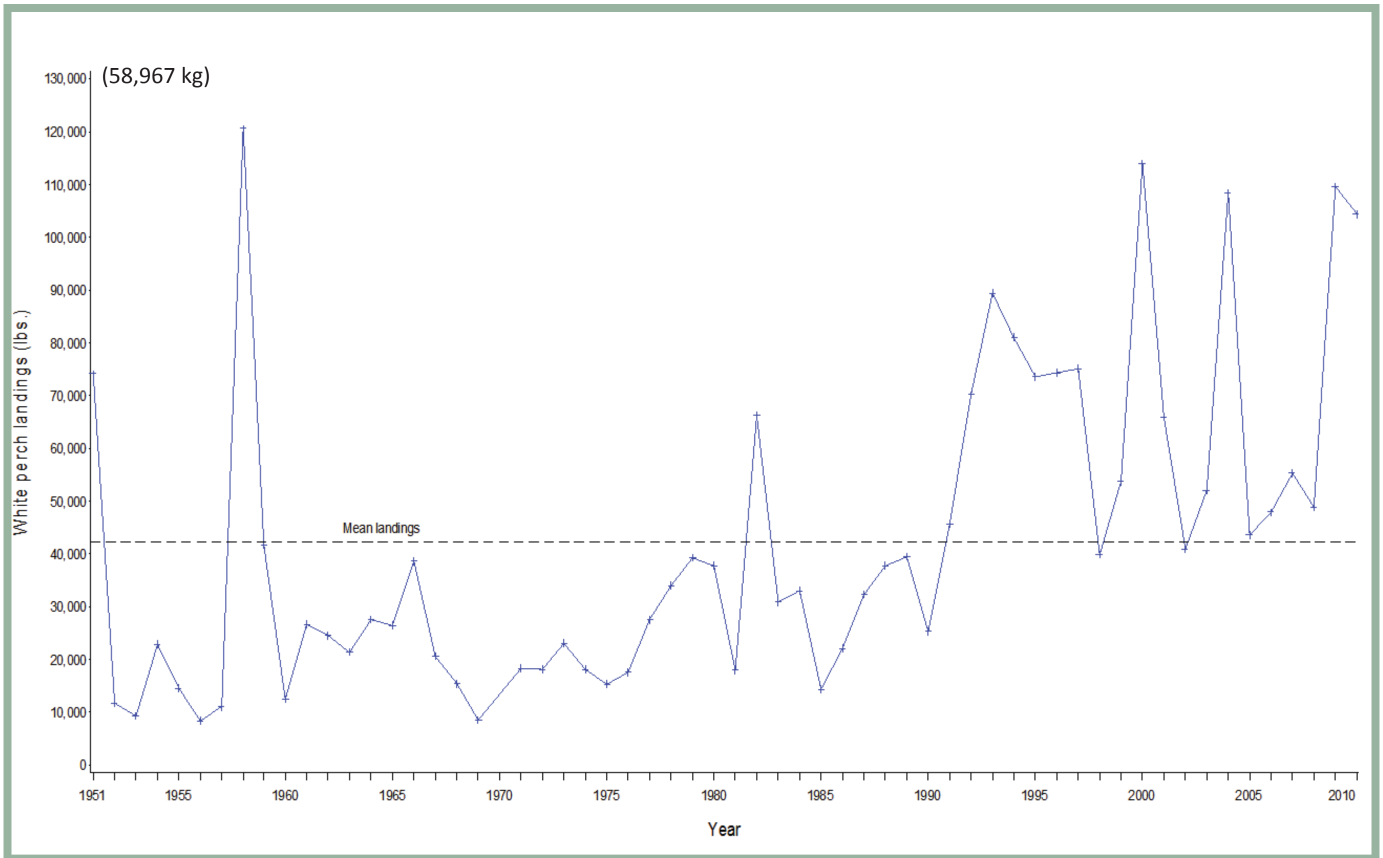


Fig. 6.10.2. Delaware commercial white perch landings (lbs.) during 1951 through 2010.

during the fishing season, gears used, etc. Delaware white perch landings were high for several years during the 1950s, were low during most of the 1960s and 1970s, rose during the 1980s and have been near or above the time series mean during the 1990s and 2000s. Whether the Delaware landings greater than 100,000 lbs. (45,360 kg) seen during 2009 and 2010 are sustainable is unknown.

6 – 10.4 Future Predictions

The white perch's ability to inhabit almost all waters of the Delaware Estuary may buffer it from some of the extreme population fluctuations seen in other species, but habitat protection, particularly for areas of the estuary in which white perch spawn, is important for the continued viability of this fish. Past trends suggest that white perch will continue to support important commercial and recreational fisheries in the Delaware Estuary for the foreseeable future.

6 – 10.5 Actions and Needs

The 8-inch (20.3 cm) minimum size limit for white perch established by Delaware in 1995 has been effective in allowing almost all white perch to spawn once, and for many white perch to spawn several times, before recruiting to the fisheries. White perch often spawn in areas of the Delaware River and in the upper reaches of Delaware Estuary tidal tributaries that have been subject to intense development pressure in the past 30 years. These are spawning habitats for many fish species in addition to white perch and these habitats should be protected.

6 – 10.6 Summary

White perch are one of the most abundant and widespread fish in the Delaware Estuary. The species supports important commercial and recreational fisheries.

6 – 11 Macroinvertebrates

Section Authors: David Burke and Gerald Bright

David H. Funk

Freshwater benthic macroinvertebrates are a useful indicator of the ecological integrity of the Delaware River watershed for several reasons. A variety of macroinvertebrates live in every aquatic environment, and they are functionally important in several ecological roles. They are widely acknowledged to be good indicators of water quality because they are directly impacted by changes in water quality. Furthermore, they have been studied extensively in all parts of the Delaware Basin.

In spite of these facts, it is difficult to aggregate and summarize data about this indicator for a multi-state area like the Delaware Basin. This is because the various organizations that produce data (including state environmental agencies) all use different methods of sampling and analysis. Because of the differences in methods, only an approximate comparability between the data from different sources can be assumed. The best that can be done is take advantage of the fact that all states distill their findings into grades of condition (e.g. "good, fair, poor"). Assuming a rough comparability between these grades of condition, data from various sources can be brought together and presented side-by-side to approximate a basin-wide assessment.

An explanation of how this complex situation came about may help explain what this indicator tells us about the ecology of the Delaware Basin broadly. The discussion may also help readers to appreciate something about benthic macroinvertebrates and their importance, and to understand more about the way environmental agencies perform water quality management in the United States.

6 – 11.2 Description of Indicator

The word "benthic" indicates animals that live on, or in, the substrate at the bottom of a waterbody. The word "macroinvertebrates" designates invertebrate animals that are large enough to be seen without the aid of magnification. In aquatic habitats, benthic macroinvertebrates are a broad group of organisms representing several phyla. The group includes roundworms, flatworms, mollusks, and several kinds of arthropods. Insects are a particularly important class of animals in the group, because of their abundance and diversity in the freshwater biota.

To be more precise, the indicator being discussed here is freshwater benthic macroinvertebrates that live in streams. Thus, those macroinvertebrates that live in lakes, ponds, wetlands, and tidal waters are excluded. These distinctions are primarily made because the nature of the information most easily available, is mostly for "wadeable" streams. Wadeable streams are relatively easy to survey, and these smaller waterbodies are where most states have focused their sampling efforts.

Most states have been sampling and compiling data about benthic macroinvertebrates since the 1970s or 1980s. The reason lies in what these animals say about the water quality of the environments in which they live. Using a procedure called "bioassessment," the biological condition of macroinvertebrate communities is analyzed to provide information about pollution and other water quality problems. In most states, bioassessment is used for multiple purposes, but the most widespread application of bioassessment is for the purpose of assessing a state's streams for the attainment of water quality standards. This program of assessment follows from the states' obligations under the Federal Clean Water Act.

The Federal Clean Water Act (and its amendments through 1987) requires states to develop water quality monitoring programs. States report to the US Environmental Protection Agency (EPA) on the quality of their waters using the biennial "305(b) report" and the "303(d) list." In most states, these biennial reports are now usually merged into a single document called the "Integrated Assessment" or the "Integrated List." The states are charged with assessing their waterways' conditions for various water uses, including, for example, public water supply, recreation, or aquatic life. The condition of macroinvertebrate communities is usually connected specifically to aquatic life uses. Results of bioassessments are used to determine if a waterway is "attaining" or "not attaining" the State's water quality standard, a threshold condition determined by the state.

Over the past 20 to 30 years, bioassessment has become increasingly important to environmental agencies, as advances have been made in the scientific understanding of water pollution and its effects. It is now widely acknowledged that biological indicators represent an essential means of determining the condition of natural waters. Some of the reasons for this are:

• Bioassessments provide information that is directly relevant to the goals of water pollution law (that is, that waters should be able to support aquatic life), and

• Bioassessments provide information about long-term, chronic, or episodic stressors that are otherwise difficult to monitor.

Bioassessment methods can be used to assess fish or periphyton (algae) in addition to macroinvertebrates. However, macroinvertebrates may be the most broadly useful of these biological groups, for reasons that include the following:

• Macroinvertebrates are relatively easy to sample and analyze,

• Macroinvertebrates are less mobile than fish, and thus they provide a better representation of the condition of a particular location, and

• Macroinvertebrates are abundant and utilize diverse niches, which allows for a detailed determination of their condition over a wide gradient.

A bioassessment protocol is a set of standard practices describing how streams should be surveyed to produce data about ecological condition. Methods of collection and analysis must be standardized and consistently applied if data are to be comparable. However, there is no single macroinvertebrate protocol that is universally applicable in all circumstances. Natural variation sometimes dictates that protocols should differ, for the assessment of streams from substantially different environments. In addition, the needs and resources of the organization doing the sampling sometimes determines what protocol will be applied, since there are some protocols that demand more time and resources, while others can be done more rapidly. While there are broad similarities between many of the protocols, they usually differ from one another in their various details. A brief discussion of some of the variables will illustrate the reasons for all of this complexity. Every macroinvertebrate bioassessment protocol must include a description of each of the steps listed below. Within each of these four steps, there can be variations in methodology, as indicated by the following discussion.

1. Sampling: According to most protocols for wadeable streams, benthic macroinvertebrates should be sampled using hand-held nets. The bioassessment protocol specifies details such as the exact shape of the net, the size of the mesh, and how the net should be handled in a stream. The protocol describes how to select sampling sites in the field and how to combine the material from grab samples to make a composite. The protocol further specifies how many organisms are needed to make a representative sample (typically between 100 and 300 individuals), and provides techniques for ensuring that those organisms are picked from the sample using an unbiased randomization method.

2. Identifying organisms: The bioassessment protocol specifies whether a collection of organisms will be identified in the field and returned to the stream alive, or preserved and identified in a laboratory. Field methods usually involve family-level identification, while laboratory methods often provide for identification to genus or to species. Laboratory analysis requires more time and effort, but provides more information. Whether the identification is done in the field or the lab, the product of this step is a list of the macroinvertebrate taxa found at a site, along with the number of individuals of each taxon.

3. Applying bioassessment metrics: The list of organisms produced in the previous step is analyzed by applying bioassessment metrics. This involves various methods of grouping and counting the organisms by types (by taxa). A variety of bioassessment metrics have been presented in scientific literature. Some metrics involve counting the number of different taxa found in a sample (assessing sample diversity); while other metrics involve counting the number of individuals of certain taxa or in certain groups of taxa (assessing community structure). Applying metrics often requires grouping taxa together by what is known about their ecological roles or characteristics. For example, there are several commonly-used metrics that take into account the relative "pollution tolerance" of the various taxa. Applying any metric to the list of taxa for a sample produces a numerical score. It is generally agreed that no single metric provides enough information to stand alone as a means of assessing water quality. Therefore, most states apply a suite of several metrics.

4. Applying an index: An Index of Biological Integrity (IBI) is a method of combining and integrating the information from several bioassessment metrics. It involves applying a series of mathematical transformations to each sample's metric scores and then combining them to give a single numerical index score. Typically, an index score for the so-called "reference condition" is developed using data from sites that are known to be undisturbed and that are judged to be appropriate reference sites

based on regional and ecological considerations. Sample data are compared to reference conditions using the numerical scores calculated using the index. Increasing degrees of disturbance (or pollution) are indicated by scores that range farther and farther from the reference score. For state agencies, one of the main purposes of their bioassessment work is to identify those streams that are divergent enough from the reference condition that they are determined to be "not attaining" the state's water quality standards for aquatic life use. Typically, the threshold that is used to determine attainment are linked to a particular numerical score using the appropriate index.

The "Present Status" (6-11.2) and "Past Trends" (6-11.3) sections of this chapter are based on data from five different sources, namely the four Delaware Basin states and the Delaware River Basin Commission (DRBC). These five organizations all use different macroinvertebrate protocols in their programs for stream assessment. In addition to this interstate variability, there is also intrastate variability, because some states actually use more than one protocol to account for natural variation. A brief description is provided of how each of the organizations that contributed data has designed their respective programs for producing macroinvertebrate data.

Delaware:

Delaware is a small state with relatively little natural variability, but it does straddle a significant eco-regional divide. Delaware's land area is divided between the Middle Atlantic Coastal Plain eco-region and the Northern Piedmont eco-region. In the Coastal Plain, where streams have a low-gradient character, the state's bioassessment program specifies the use of the protocol developed by an EPA-sponsored multi-state workgroup called the Mid-Atlantic Coastal Streams Workgroup (U.S. EPA 1997). In the Piedmont, the state specifies the use of methods documented in EPA's 1999 Rapid Bioassessment Protocols report (Barbour et. al. 1999). The structural and ecological differences between coastal plain streams and piedmont streams dictate several differences between the two protocols. For both stream categories, Delaware specifies that macroinvertebrate samples are to be preserved and identified in a laboratory, with most taxa identified to genus. Both protocols also utilize a multi-metric index. Of the assessment stations that make up the data set for Delaware's Delaware Estuary basin, 46% are from the Piedmont and 54% are from the Coastal Plain.

Pennsylvania:

In 2006, after 10 years of effort, Pennsylvania completed their first statewide bioassessment survey, which was done using a modified version of the EPA Rapid Bioassessment II Protocol from the document referenced above (Barbour et. al. 1999). This method used field identification of organisms and family-level taxonomy. At about the same time, the state decided to refine their biomonitoring program and implement major changes to the bioassessment protocols. Pennsylvania's new program is called the Instream Comprehensive Evaluation (ICE). In it, the State's streams are divided into three major ecological categories, each of which is assessed by a different protocol. Each protocol specifies particular sampling methods, and how metrics and index calculations should be applied. These protocols are briefly described below.

The largest group of streams in Pennsylvania is categorized as riffle-run streams, which are assessed using the "Freestone Streams" protocol. The method specifies making a certain number of collections from shallow gravel-bottom or cobble-bottom riffle habitat, and then compositing and randomly sub-sampling to give a 200-organism sub-sample. The sub-sample is preserved and identified in a laboratory to genus, and a multi-metric IBI is applied to the taxa list. The preferred seasons for sampling are between November and May, so as to avoid sampling during the summer emergence period of many important insects. However, a method for "Freestone Streams, Summer Samples" is also available, for when agency workload requires that stream assessments continue through the summer months. The "Summer Samples" method provides a modified analysis to account for the effects of seasonal emergence on the invertebrate community. (During the summer months, many insects emerge as winged adults, and their aquatic forms are notably absent from stream-collected samples. In light of this, practitioners of bioassessment have two choices. They may avoid sampling during the time of year when the benthic community is likely to be altered by emergence, or they may develop protocols that are specifically tailored to each particular seasonal condition.) Freestone Streams account for 91% of the assessments performed in Pennsylvania's Delaware Basin.

Pennsylvania's second stream category is the low-gradient streams that are lacking in riffle habitat. Pennsylvania uses the phrase "Multi-Habitat" to refer to this stream category and protocol. For Multi-Habitat sites, the sampling methods are designed to provide a means of capturing representative organisms from several specific kinds of habitats (including, for example, coarse submerged debris, submerged aquatic vegetation, and deposits of coarse particulate organic matter). A specific multi-metric analysis and IBI are applied. This category is somewhat similar to the Mid-Atlantic Coastal Plain Streams "Coastal Plain" streams discussed above in the "Delaware" section, as well as to the "Coastal Plain (Non-Pinelands)" category discussed below in the New Jersey section. However, the analogy is not exact, because many of Pennsylvania's Multi-Habitat sites are not in the coastal plain but in low-gradient topography in plateau regions, such as the Pocono region of northeast Pennsylvania. Multi-Habitat assessments account for 7% of the assessments performed in Pennsylvania's Delaware Basin.

The third category of streams, limestone streams, is assessed using the protocol for '"True" Limestone Streams.' This method is specifically for spring-fed streams with high alkalinity and constant year-round temperature. These streams are considered ecologically unique and are important as cold-water fish habitat. The protocol specifies the collection of two samples from riffle habitat, composited and sub-sampled to make a 300-organism sample, followed by laboratory-identification of organisms to genus. A specific multi-metric analysis and IBI are applied. Limestone Streams account for 2% of the assessments performed in Pennsylvania's Delaware Basin.

New Jersey:

From the early 1990s through 2008, New Jersey's biennial Integrated Assessment reports were based on a type of Rapid Bioassessment Protocol that used family-level taxonomy. During this period, all of the state's freshwater streams were assessed using the same index, which was known as the "New Jersey Impairment Score" (NJIS). However, like Pennsylvania, New Jersey revised their bioassessment program in the 2000's to make it more technically rigorous. Stream assessments are now based on genus-level taxonomy; and three different protocols are used, according to the major ecoregions of the state. The three protocols are: the High Gradient Macroinvertebrate Index (HGMI), which applies to the streams of Highlands, Ridge and Valley, and Piedmont ecoregions; the Coastal Plain Macroinvertebrate Index (CPMI), which applies to the Coastal Plain excluding waters considered Pinelands waters; and the Pinelands Macroinvertebrate Index (PMI), which applies to Pinelands waters. Each of these three protocols has particular sampling methods, assessment metrics, and an index. In the network of assessment stations for New Jersey's Delaware Basin, 44% of stations are assessed by the HGMI, 37% by the CPMI, and 19% by the PMI.

New York:

New York's biological monitoring program began in 1972, with the first surveys done on the state's large rivers, using artificial substrate samplers. Since 1984, New York has used a "Rapid Assessment" method in the state's wadeable streams, for both special studies and as part of the statewide ambient water quality monitoring program. In 1987, the statewide program was re-designed, to use a rotating cycle of monitoring and assessments called Rotating Integrated Basin Studies (RIBS). Under the current RIBS schedule, chemical and biological monitoring is conducted in all of the state's 17 major drainage over a five-year period. Riffle habitat is targeted for biological sampling of wadeable streams. Non-wadeable waters are monitored using artificial substrate samplers. The index period for wadeable stream sampling is from July through September. Individual metrics characterizing the benthic macroinvertebrate community are combined to form a multi-metric index called the Biological Assessment Profile. There is no differentiation of streams by eco-region; however, modification of the sampling methods and assessment metrics are used for low-gradient, sandy-bottom streams. Samples are preserved, and identified in the laboratory to genus or species.

DRBC:

As an interstate agency, DRBC takes responsibility for assessing the mainstem Delaware River where it forms a border between states. Since 2001 DRBC has collected benthic macroinvertebrate samples annually at about 25 fixed sites on the Delaware River. These sites range from Hancock, NY (River Mile 331/533 km) to just above the head-of-tide at Trenton, NJ (River Mile 137/220 km). All samples are collected from gravel- or cobble-dominated riffle habitats. Sampling generally occurs in the late summer, with the central sampling window being August and September. The samples are preserved for laboratory identification, and the organisms are generally identified to genus. The analysis methodology used for the 2010 Integrated Assessment is based on a multi-metric IBI with a 100-point range. In their Integrated Assessment report, DRBC discusses how these numerical results can be graded for the purpose of assessing attainment of water quality standards, but they also indicate that this analysis is preliminary. The agency plans to refine it with additional data and additional statistical work.

6 – 11.2 Present Status

For this Technical Report, the status of macroinvertebrates in the non-tidal Delaware Basin is determined using the data produced by the States for their biennial water quality reporting. All four basin states and DRBC report results of water quality monitoring to EPA for the biennial 303(d) list, sometimes called the Integrated List of Waters, or the Integrated Assessment. For this Technical Report, the states have provided the most recent bioassessment data were able to share, and for the most part it comes from the data that they used to prepare the 2010 Integrated List. Some state-by-state details are given in the sections below, and in the accompanying Figures.

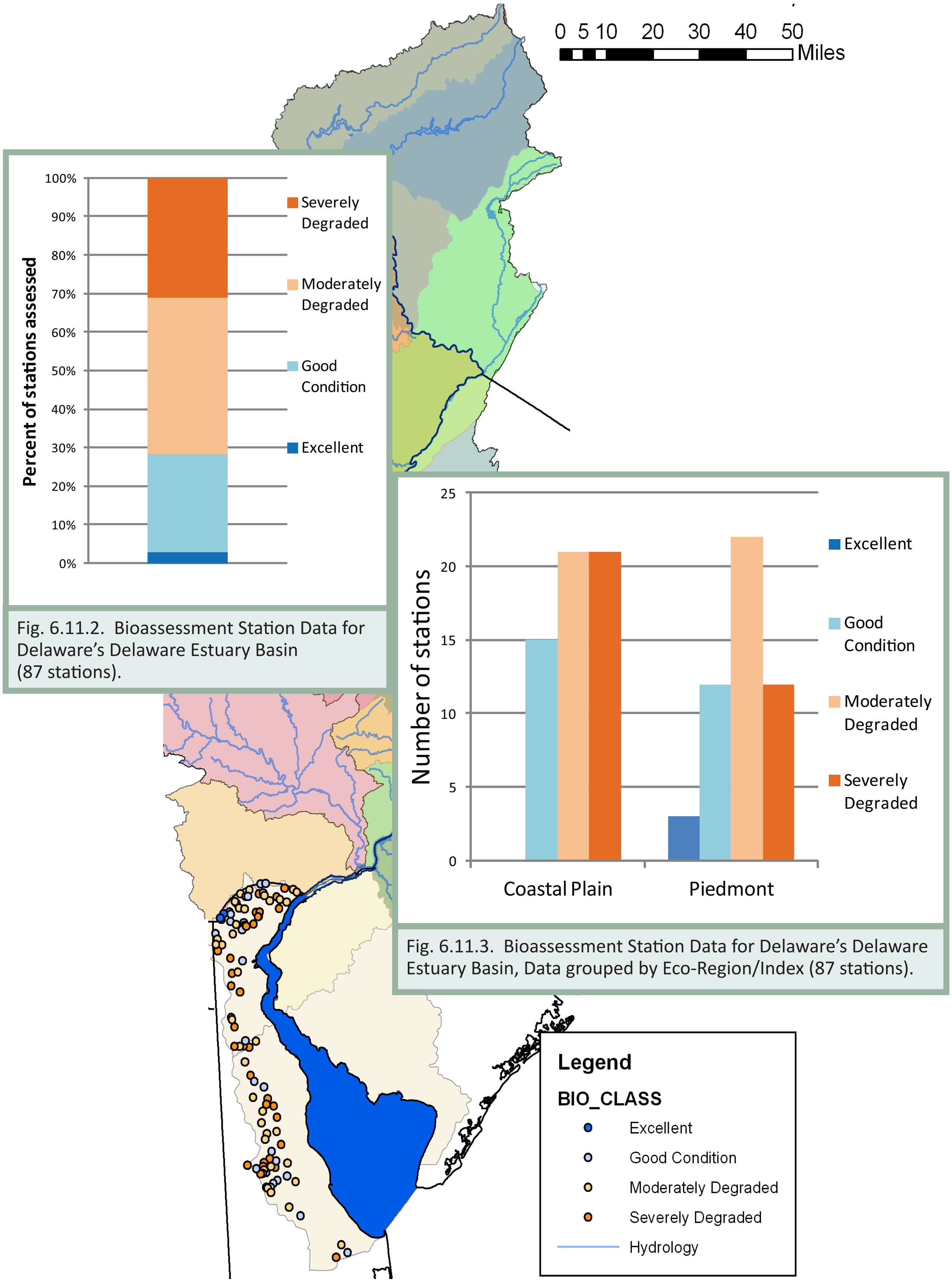
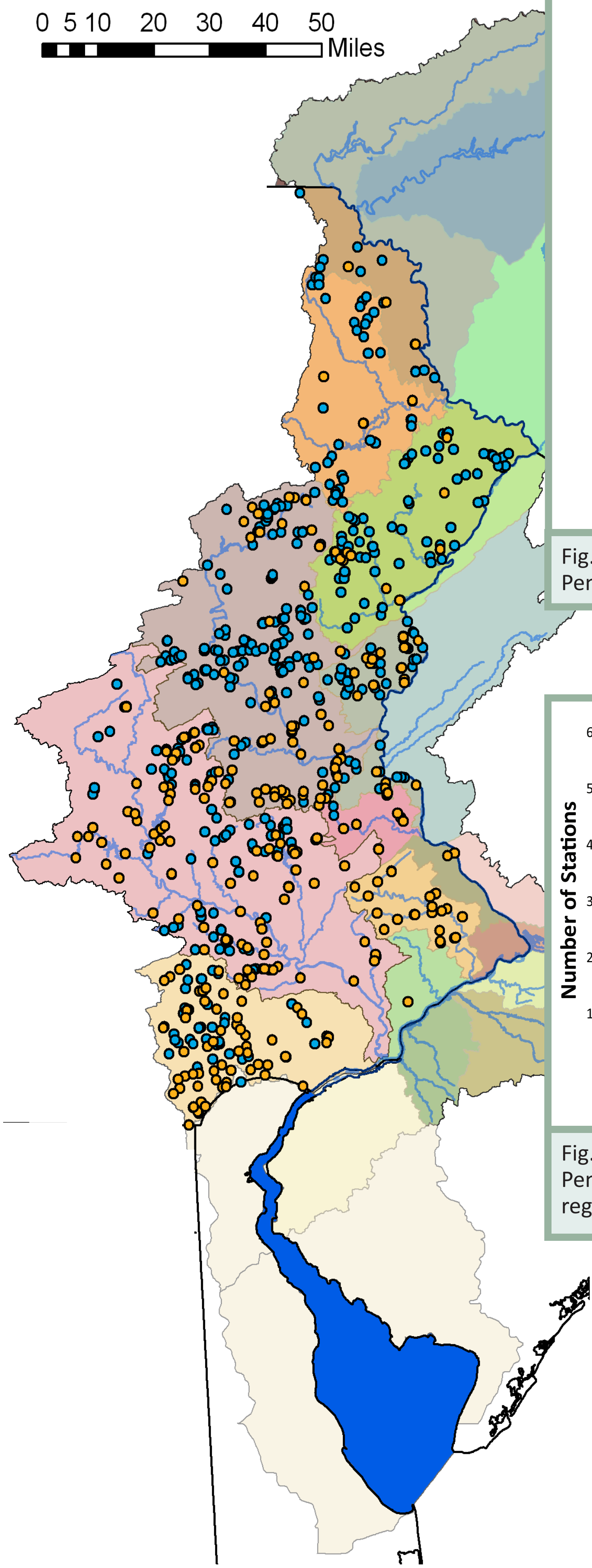


Fig. 6.11.2. Bioassessment Station Data for Delaware's Delaware Estuary Basin (87 stations).

Fig. 6.11.3. Bioassessment Station Data for Delaware's Delaware Estuary Basin, Data grouped by Eco-Region/Index (87 stations).

Fig. 6.11.1. Delaware's Delaware Estuary Basin: Map showing the locations of macroinvertebrate bioassessment stations.



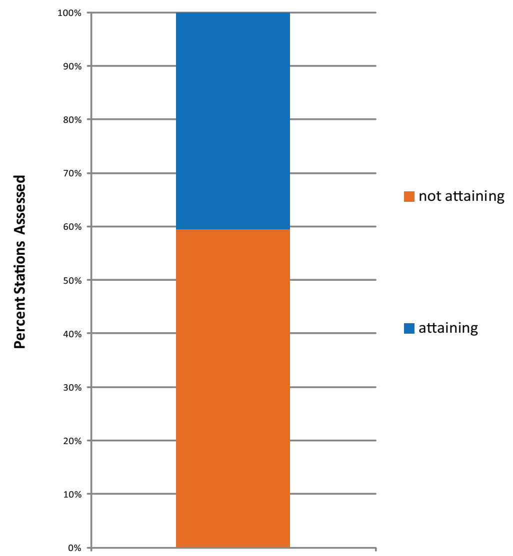


Fig. 6.11.5. Bioassessment Station Data for Pennsylvania's Delaware Basin (914 stations).

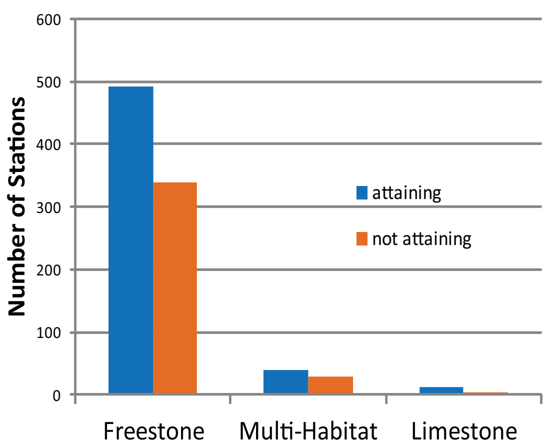


Fig. 6.11.6. Bioassessment Station Data for Pennsylvania's Delaware Basin, Grouped by Eco-region/Index (914 stations).

Fig. 6.11.4. Pennsylvania's Delaware Basin: Map showing the locations of macroinvertebrate bioassessment stations.

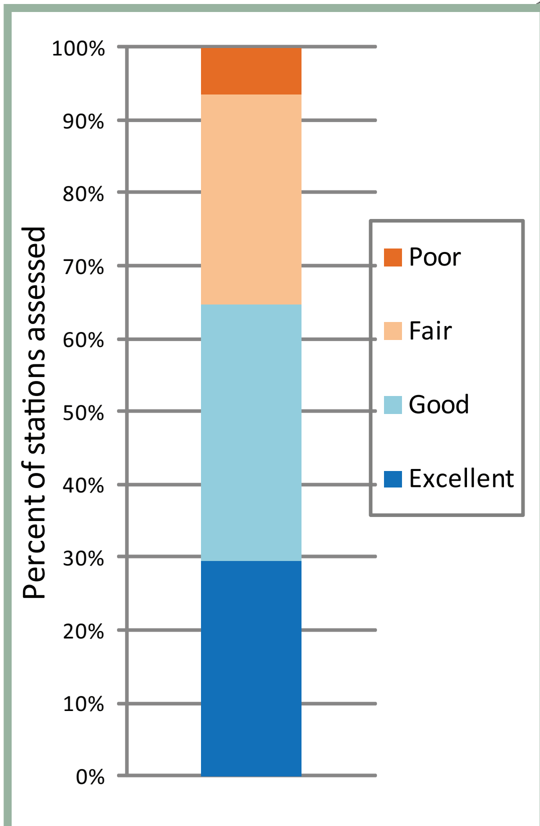


Fig. 6.11.8. Bioassessment Station Data for New Jersey's Delaware Basin, AMNET 4 Survey with 141 stations (2007-present).

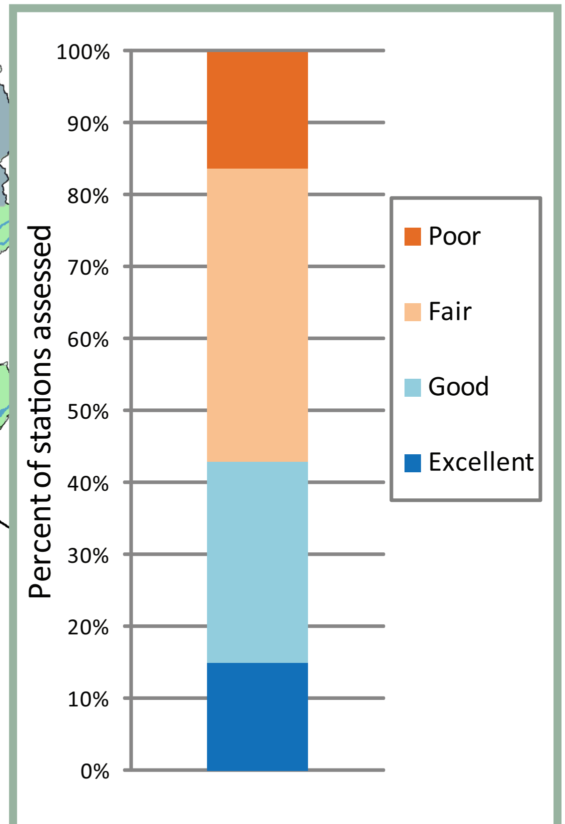


Fig. 6.11.9. Bioassessment Station Data for New Jersey's Delaware Basin, AMNET 3 Survey with 301 stations (2002-2007).

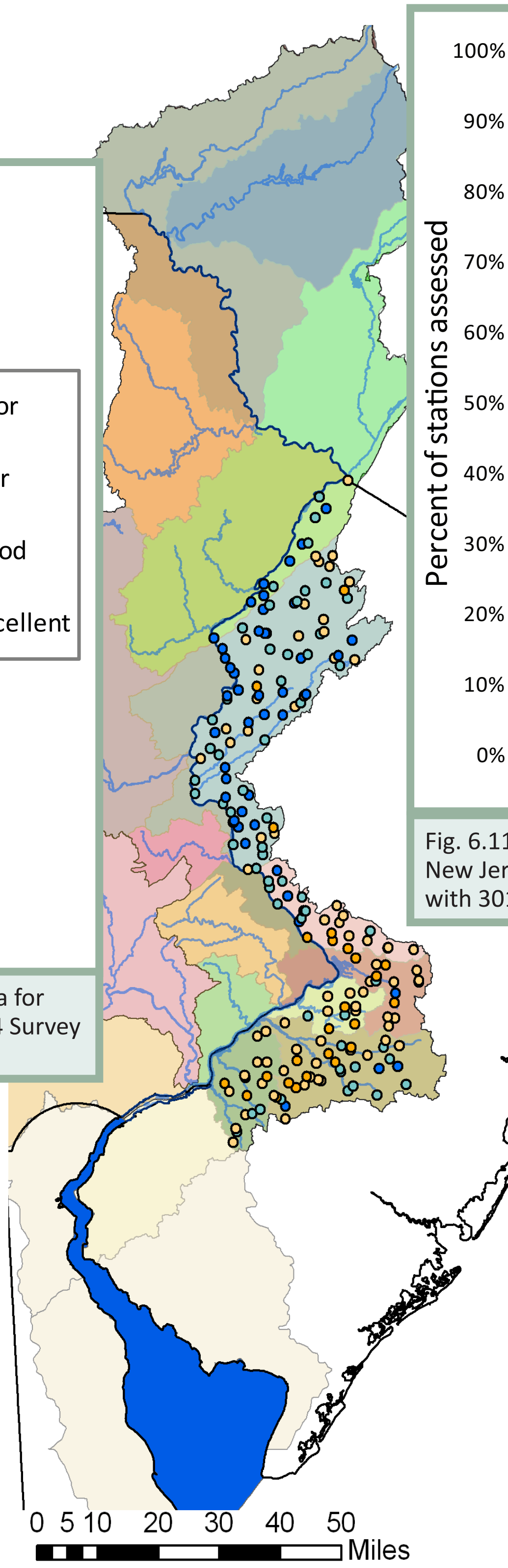


Fig. 6.11.7. New Jersey's Delaware Basin: Map showing the locations of macroinvertebrate bioassessment stations.

Delaware:

Present status is given by data from 87 individual assessments, performed between 2006 and 2009. Four grades of condition are reported: excellent condition, good condition, moderately degraded, and severely degraded. The aggregated data are presented in Fig. 6.11.1 - 3.

Pennsylvania:

Present status is given by data from 914 assessments, spanning more than ten years of time. Each station is reported as either "attaining" or "not attaining" the state-determined regulatory threshold for aquatic life use. The aggregated data are presented in Fig. 6.11.4 - 6.

New Jersey:

Present status is given by data from 301 stations. The statewide program, called "AMNET" (for "Ambient Biomonitoring Network") has produced several rounds of survey results for each of the state's major basins. However, the current survey, known as AMNET Round 4, is not yet complete, and NJ DEP was not able to share the unfinished data for the Lower Delaware Basin. Therefore, this report presents recent data (AMNET Round 4, performed between 2007 and the present) for only the Upper Delaware Basin (141 stations), and older data (AMNET Round 3, performed between 2002 and 2007) for the entire Delaware Basin (301 stations). Four grades of condition are used: excellent, good, fair, and poor. The aggregated data are presented in Fig. 6.11.7 - 11.

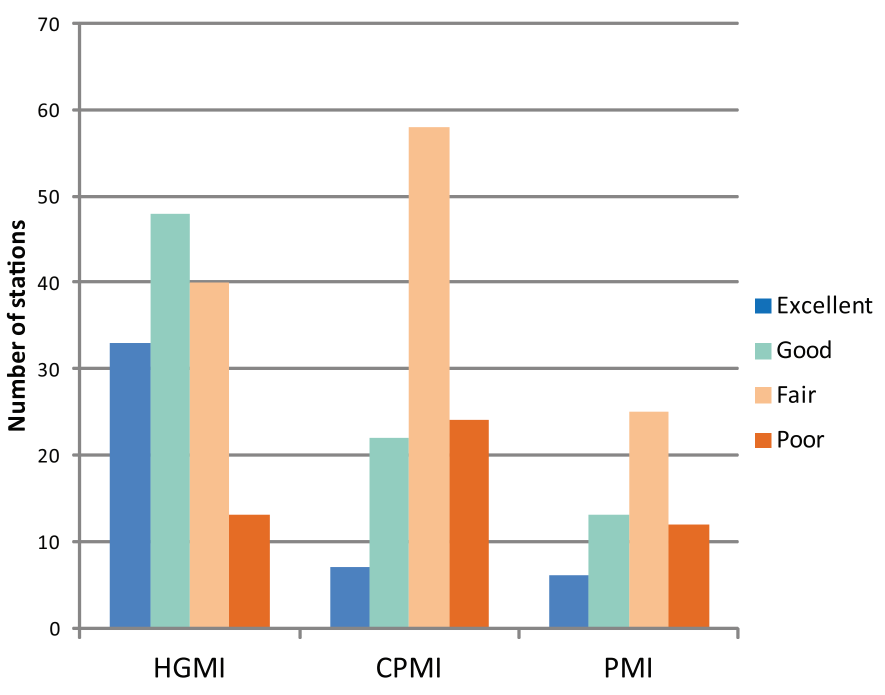


Fig. 6.11.10. Bioassessment Station Data for New Jersey's Delaware Basin, Data Grouped by Eco-region/Index (301 stations)

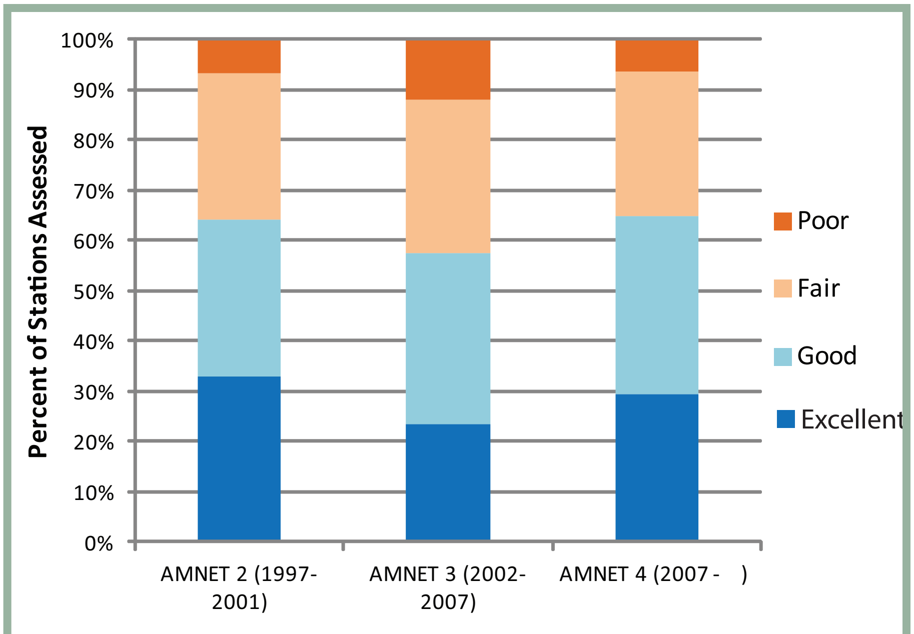


Fig. 6.11.11. Bioassessment Data for Three Successive Surveys of New Jersey's Upper Delaware Basin. (The number of stations is approximately 140.)

New York:

Present status is given by data from 78 stations, collected 10 ten years' time. Four grades of condition are reported: non-impacted, slightly impacted, moderately impacted, and severely impacted. The aggregated data are presented in Fig. 6.11.12 - 14.

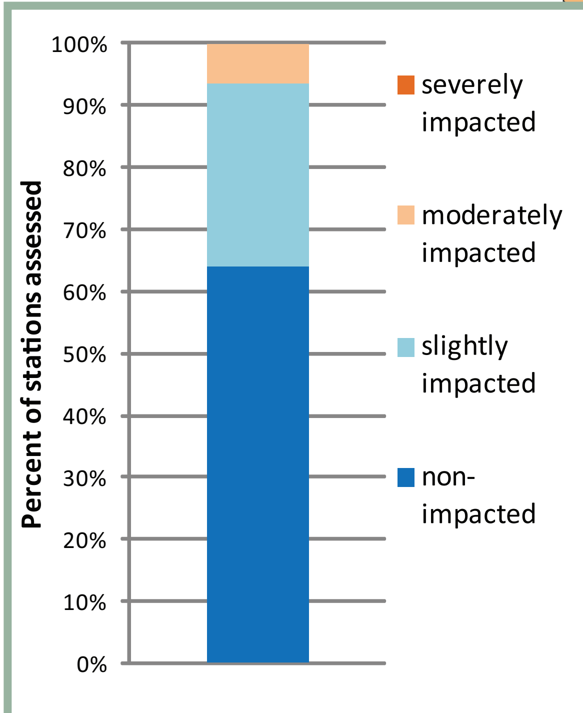


Fig. 6.11.13. Bioassessment Station Data for New York's Delaware Basin. (78 stations)

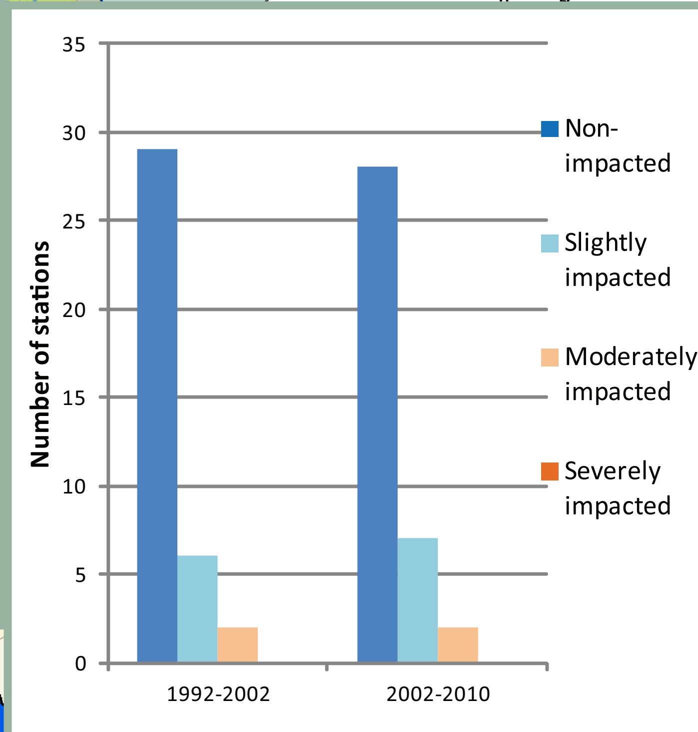


Fig. 6.11.14. Bioassessment Station Data for New York's Delaware Basin, Comparing Data from Two Successive Decades. (37 stations)

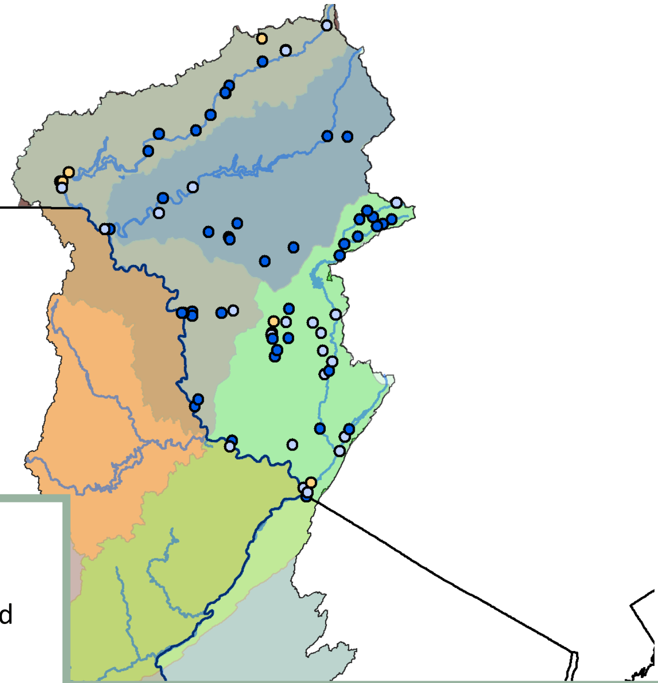


Fig. 6.11.12. New York's Delaware Basin: Map showing the locations of macroinvertebrate bioassessment stations.

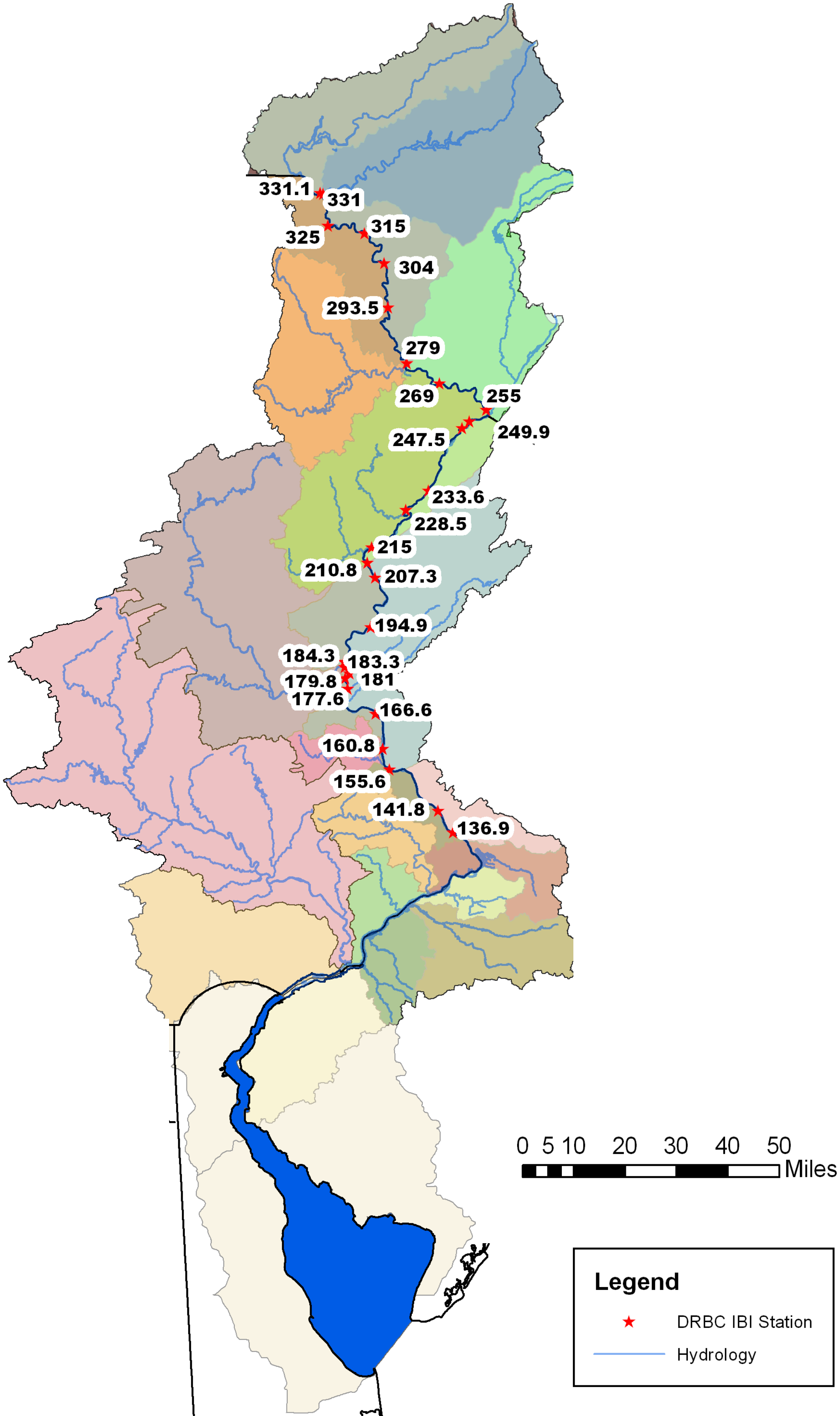


Fig. 6.11.15. DRBC Mainstem Sampling Locations.

DRBC:

Present status is given by data from 23 stations, collected in 2008 and 2009. Stream condition is given as a numerical score according to the IBI that the agency uses. The aggregated data are presented in Fig. 6.11.15. (Certain stations sampled by DRBC are not included in this Figure because they were not sampled throughout the entire period.)

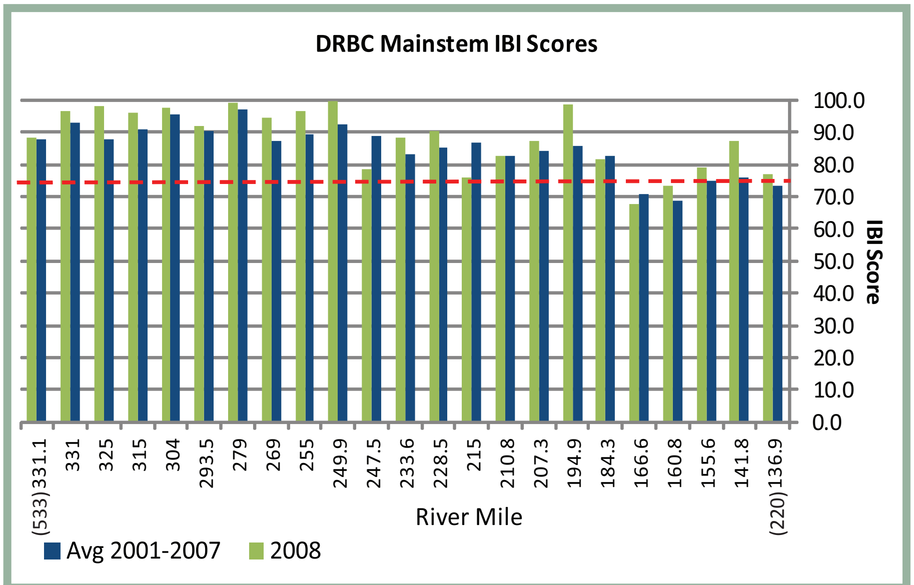


Fig. 6.11.16. Bioassessment Station Data for the Mainstem Delaware River: By River Mile (kilometer)

Considering the Delaware basin as a whole, it appears that there may be some broad regional conclusions that can be drawn from the bioassessment data. New York is the state with the lowest percentage of low-scoring stations, and apparently the best overall condition. Delaware is the state with the highest percentage of low-scoring stations; and New Jersey and Pennsylvania are in between.

For the three states whose bioassessment programs include multiple ecoregional indices, a comparison of the ecoregional differences shows somewhat similar trends in each state. The analogous categories of Piedmont (Delaware), Freestone (Pennsylvania), and High-gradient (New Jersey) have somewhat better conditions than the corresponding low-gradient categories: Coastal Plain (Delaware and New Jersey) and Multi-habitat (Pennsylvania). These observations suggest that the condition of benthic macroinvertebrates is generally better in the upper portions of the Delaware Basin, farther from the coast, and closer to "headwaters." This corresponds to what may be expected based on a general understanding of water quality problems in this basin. Good water quality is generally expected (hence macroinvertebrate quality) to correlate negatively with urban land cover, which is mostly in the lower basin, and positively with forested land cover, which is mostly in the upper basin.

The data suggested the above conclusions, as if the data was from a basin-wide survey, however this is not exactly the case. The data presented in this report, particularly for the states of Delaware and Pennsylvania, may not represent a random selection of sites, as would have been ideal if this had truly been a basin-wide survey of ambient conditions. In Pennsylvania this is due to the fact that the state has not yet completed a full survey of the basin using their revised bioassessment protocol. In Delaware, the available data is skewed towards lower-quality waterways, which were prioritized for monitoring in recent years.

Benthic macroinvertebrate community condition is affected primarily by water quality and habitat disturbance. There are many reasons why conditions at a particular site may appear to be degraded. Furthermore, the basin being discussed is large and diverse. For these reasons, it would probably be inappropriate to draw further conclusions from the data presented. When biomonitoring results cause a state agency to list a stream as "impaired," the agency is supposed to attribute the impairment to a "source" and a "cause." The Integrated List for each state contains information about these "source" and "cause" determinations for each listing, but the terminology that is used is complex. Because of this complexity, an attempet was not made to gather or analyze "source" and "cause" information for the present report. Readers who are interested in examining the sources and causes of impairments listed by the states are referred to the Integrated List documentation for each of the states.

6 – 11.3 Past Trends

Monitoring of trends is one of the stated goals of the biomonitoring program in most of the states. However it is more easily said than done. Reporting trends is difficult at the present time, because of the nature of the available data. In Delaware and Pennsylvania, sufficient data was not obtained to present any kind of trend. Several more years of work will be necessary before meaningful time series will be generated for Pennsylvania and Delaware. We can discuss trends for New Jersey, New York, and for the mainstem Delaware river (DRBC data), based on the collected data.

New Jersey:

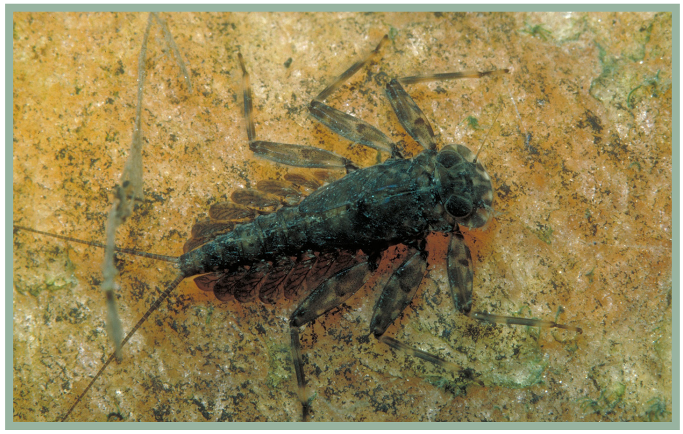
New Jersey's AMNET Program has completed several rounds of sampling at an established set of stream stations. Round 2 of the AMNET program was performed between 1997 and 2002, round 3 between 2002 and 2007, and round 4 began in 2007 and is still unfinished. (There was a round 1 in the 1990s, but it was not as comprehensive as the subsequent surveys, and cannot be compared with the others on a station-by-station basis.) Although results for AMNET rounds 2 and 3 were originally reported using the NJIS index, the New Jersey Department of Environmental Protection (NJDEP) was able to re-analyze the original data from those surveys using the more detailed taxonomy of the new indices. They have prepared a table which shows condition assessments for 144 stream stations in the Upper Delaware Basin for these three rounds of survey. (The agency's analysis of data for the Lower Delaware Basin for AMNET 4 is still incomplete.) These Upper Basin results are presented in aggregate in our Fig. 6.11.11.

Based on the data as shown in Fig. 6.11.11, the general condition of benthic macroinvertebrates in the streams of New Jersey's Upper Delaware Basin appears to have fallen slightly between round 2 and round 3, and then improved again in round 4. However, it would be inappropriate to draw firm conclusions from such a limited set of data. In fact, the data do not necessarily indicate a general degradation of conditions between rounds 2 and 3, followed by a recovery. Instead, it seems likely that the apparent differences between these respective surveys may be within the range of variation that can be expected for repeat applications of the bioassessment method.

New York:

Over the years, New York has collected multiple rounds of data for a certain number of stations in the Delaware basin. In 2004, the state published a report entitled "30-Year Trends in Water Quality of Rivers and Streams in New York State Based on Macroinvertebrate Data, 1972-2002." (The report is available on line at http://www.epa.gov/bioindicators/pdf/NYSDEC30yrTrendsReport.pdf). That report compared the results of surveys conducted between 1992 and 2002 to an earlier set of data collected before 1992.

For the present report, the recent data (2003 – 2010) was compared to the data from the 1990s that appears in the state's "30-Year Trends" report. The comparison reveals that the changes that occurred from the 1990s to the 2000s were very small. The total number of stations with assessment data in both decades was 37. Of those, 28 scored the same both times, while 9 scored differently. Five stations changed from "non-impacted" to "slightly impacted," and four others changed from "slightly impacted" to "non-impacted." Thus the overall difference in the basin appears to be very small. Fig. 6.11.14 presents this comparison as a chart.



David H. Funk

DRBC:

Because DRBC's sampling team has returned to the same stations for several years on a regular basis, their data set appears to offer an opportunity to look at bioassessment data in a time series. Some of this data is presented as a chart in Fig. 6.11.15. Based on the data, there is year-to-year variability, but it appears that there are no clear trends.

DRBC's technical staff believe that some of the variability observed here can be attributed to particular events or conditions. It is thought that a severe summer drought or a major flood can affect aquatic life enough to produce anomalous scores using the bioassessment metrics and index. At least one example of this seems to be evident in DRBC's data. There is a noticeable drop in bioassessment index scores for 2006 at several stations along the River, which may be attributed to the effects of a major flood that occurred in late June of that year, shortly before the macroinvertebrate sampling was conducted (Personal Communication, Erik Silldorff).

6 – 11.4 Future Predictions

The future condition of the benthic macroinvertebrates in the Delaware Basin can be expected to follow the various causes of waterway impairment. Any attempt to project future conditions in the basin would be speculative, particularly in light of the challenges of determining past trends from macroinvertebrate data.

6 – 11.5 Actions and Needs

Bioassessment of macroinvertebrates is a well-established practice in state environmental agencies, and it may be expected to continue for the foreseeable future. Bioassessment has become a core element of the regulatory system for protecting water quality in the United States. Over time, it may be expected that the uses of bioassessment data will be refined as the datasets grow and as organizations gain experience with the interpretation of information produced.

The fact that the states all use different methods is frustrating to anyone who is interested in making interstate comparisons. At present, there is no particular movement towards requiring the standardization of methods. However, as states gather more data and gain a better understanding of how to use it, and with continued improvements in data management, there is reason to hope that meaningful interstate comparisons may become more readily available in time.

6 – 11.6 Summary

Benthic macroinvertebrates are a diverse and important natural resource. They are well known to people who are concerned with water quality and watershed health, but ignored or taken for granted by most people in the general public. Macroinvertebrates are not normally considered for specific management actions of any kind. The management actions that affect benthic macroinvertebrates are essentially the same management actions that affect water quality and aquatic habitats. It is expected that macroinvertebrates can be allowed to thrive by preventing water pollution and by protecting or restoring natural habitat conditions in waterways.

6 – 12 Freshwater Mussels

Section Author: Danielle Kreeger

6 - 12.1 Description of Indicator

Freshwater mussels are filter feeding bivalve mollusks that live in lakes, rivers, and streams (Fig. 6.12.1). Similar to oysters, freshwater mussels benefit clean water, enrich habitats, and furnish other important ecosystem functions such as stabilizing bed erosion (for summaries of ecosystem services, see: Kreeger and Kraeuter 2010; Anderson and Kreeger 2010). For example, freshwater mussels may be abundant enough in the Delaware River Basin to improve water quality by their filtration. Kreeger (2008) measured the abundance of *Elliptio complanata* in the Brandywine River and also used survey data from Dr. W. Lellis (USGS Wellsboro) to estimate that there are at least 4 billion adult mussels of this species across the basin. Based on these numbers and measured physiological processing rates, this species was estimated to filter about 10 billion liters of water per hour across the basin, which is roughly 250 times the volume of freshwater entering the tidal estuary (Kreeger and Kraeuter 2010).

Sylvan Klein, Academy of Natural Sciences

Fig. 6.12.1. Freshwater mussels living *in situ* in the tidal freshwater portion of the Delaware River in June 2011

Freshwater mussels grow more slowly than their marine counterparts. They also live longer (80 years or more) and have complicated reproduction strategies dependent on fish hosts. As long-lived, relatively sedentary creatures that process large amounts of water over their soft tissues, freshwater mussels are particularly sensitive to water quality and contaminants. Freshwater mussels are typically not sampled effectively as part of traditional macroinvertebrate assessments (Section 6-11). The health, population abundance, and species diversity of freshwater mussels therefore represent excellent bioindicators of freshwater systems, particularly over long periods of time.

Fig. 6.12.2. Shells of seven native species of freshwater mussels found in the tidal Delaware River in 2009-2010: Pond Mussel, *Ligumia nasuta* (Ln); Eastern Floater, *Pyganodon cataracta* (Pc); Yellow Lamp Mussel, *Lampsilis cariosa* (Lc), Eastern Elliptio, *Elliptio complanata* (Ec); Creeper, *Strophitus undulatus* (Su); Tidewater Mucket, *Leptodea ochracea* (Lo); and the Alewife Floater*, Anodonta implicata* (Ai).

6 - 12.2 Present Status

Freshwater mussels are the most imperiled of all animals and plants in North America, which has the world's greatest diversity of this taxonomic group (> 300 species). More than 75% have special conservation status (Williams et al. 1993). At least twelve species are native to the Delaware River Basin (Ortmann 1919, PDE 2008, Campbell and White 2010); however, all but one species is reported to now be uncommon (PDE 2008).

The leading causes of mussel decline in the Delaware River Basin are habitat and water quality degradation. Since freshwater mussels rely on fish for successful reproduction, usually species-specific relationships, dams that block fish passage can disrupt reproduction and gene flow (McMahon 1991, Neves 1993).

To assess present status we analyzed survey data for the past 15 years from southeastern Pennsylvania and Delaware. Data were not able to be obtained for the State of New Jersey, therefore, it is not currently possible to examine the status of the freshwater mussel assemblage across the Delaware River Basin. Our analysis suggests that the overall condition of freshwater

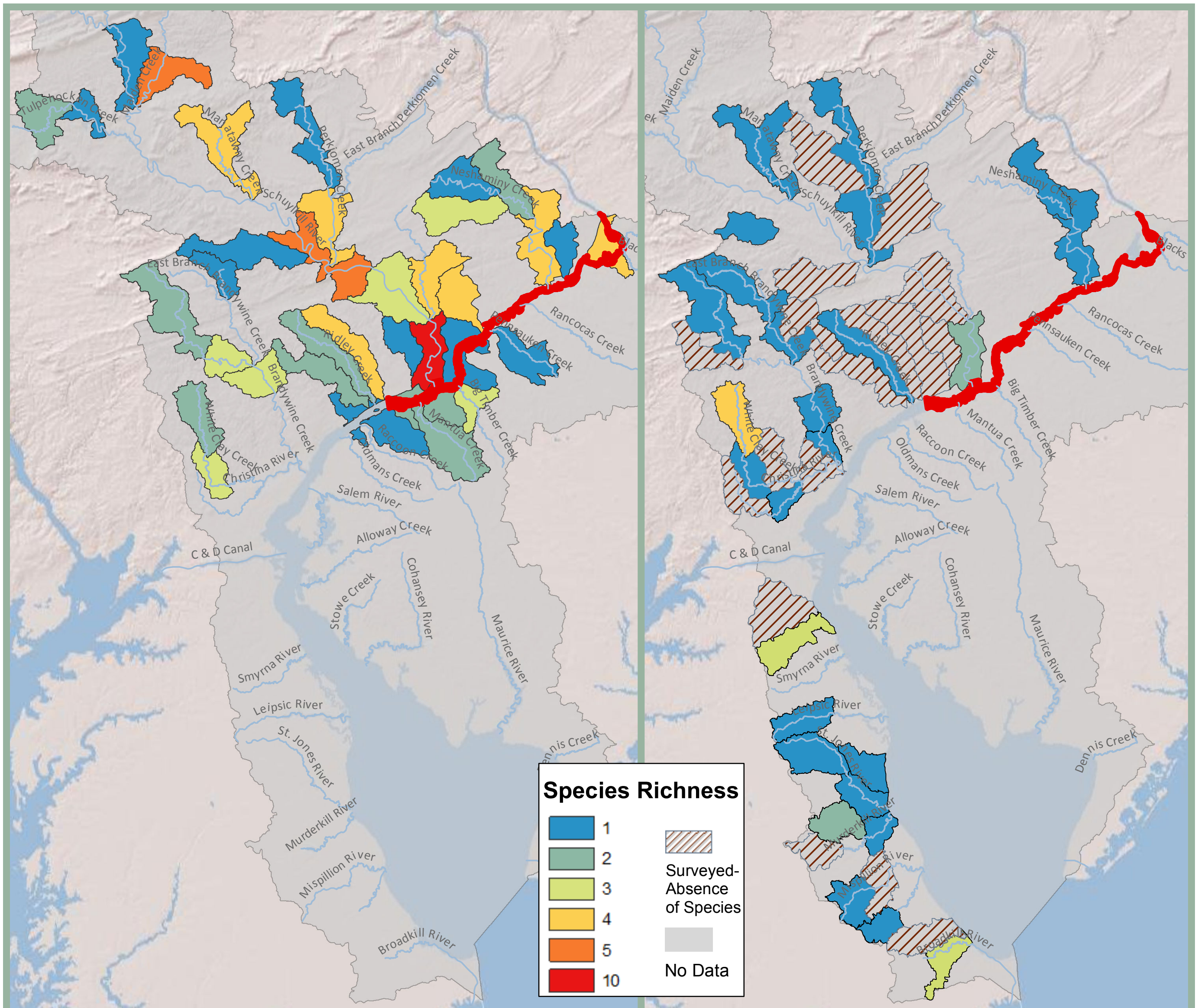


Fig. 6.12.3 Species richness of native freshwater mussels reported in surveys conducted between 1919-1996 in southeastern PA, based on available data obtained by PDE.

Fig. 6.12.4. Species richness of native freshwater mussels reported in surveys conducted between 1996-2011 in southeastern PA. Surveys were conducted by PDE with the Academy of Natural Sciences.

mussel populations is poor in streams where dams and other factors appear to have progressively eliminated or reduced mussel populations over the past 100 or more years (Thomas et al. 2011). Joint surveys in southeast Pennsylvania by the Partnership for the Delaware Estuary (PDE) and the Academy of Natural Sciences between 2000 and 2010 found that only 4 of >70 stream reaches contained any freshwater mussels (Thomas et al. 2011). Even the most common native species are presently patchy in distribution, limited in abundance and may not be successfully reproducing in streams.

In contrast to the low biodiversity, abundance, and limited distribution of native freshwater mussels in streams, recent surveys indicate that the assemblage is still reasonably intact in the undammed and tidal reaches of the mainstem Delaware River (Lellis 2000, 2001, Kreeger et al. 2011). Several species found recently (Fig. 6.12.2) were believed extirpated from the basin because they had not been reported in the published literature since Ortmann's surveys 100 years earlier (Ortmann 1919). Preliminary examination suggests that the beds of mussels in the tidal freshwater stretch of the Delaware River are healthy, having broad size class distribution and lower shell erosion compared to mussel populations in smaller, non-tidal streams (Kreeger and Padeletti 2011).

6 - 12.3 Past Trends

The most comprehensive historical regional mussel survey was conducted in Pennsylvania between 1909 and

1919 (Ortmann 1919). However, even by that time, dams and water quality degradation may have already affected mussel communities. Nevertheless, the study provided an excellent benchmark for gauging long-term trends in the mussel assemblage for the past 100 years.

Ortmann (1919) reported about 12 species of native mussels from the Delaware River Basin, most of which were present at that time in southeastern Pennsylvania (Fig. 6.12.3). Although species richness was highest in the mainstem Delaware River even then, at least five species were present in several tributary watersheds, including the Schuylkill and Brandywine.

In contrast, Fig. 6.12.4 depicts the current species richness of native mussels (Thomas et al. 2011). Although the richness appears to have been preserved in the mainstem Delaware River, only one or no species has been in recent years in most tributary streams of southeast Pennsylvania (Fig. 6.12.4).

A comparison of Fig. 6.12.3 and 6.12.4 also suggests that the range of native mussel occurrence has shrunk significantly in these streams during the last 100 years. This decline appears to be continuing. For example, no mussels have been found since 2002 in the upper White Clay Creek, Pennsylvania, despite annual surveys by PDE; whereas, 2 species were found there as recently as 1998-2001 (leading to the higher richness there in Fig. 6.12..4).

6 -12.3 Future Predictions

Since the decline of native mussel biodiversity has been attributed to habitat development and degraded water quality, the future prospects for freshwater mussels are likely to hinge on careful watershed management. Human population is expected to grow by 80% this century in the basin, which threatens to exacerbate the stressors that have been affecting mussels for probably hundreds of years.

Climate change also threatens freshwater mussels (Kreeger et al. 2011) because of increased thermal stress and stormwater and salinity rise in freshwater tidal areas. Since freshwater mussels depend on fish hosts for larval dispersal, it is unlikely that southern mussel species will be able to expand northward to fill niches that open if northern species are extirpated. The northern pearlshell, *Margaratifera margaratifera,* is an example of a coldwater-loving species that uses brook trout as a host – its present distribution in southeast Pennsylvania is constrained to a few cold headwater streams and below reservoirs in the upper Schuylkill Basin which release colder water from the bottom.

Enhanced conservation and restoration efforts have the potential to offset projected continued declines in freshwater mussels (Kreeger and Padeletti 2011). Although some streams may no longer be as suitable for mussels as they were historically, the carrying capacity for a diverse and abundant mussel assemblage is thought to remain very high. Interest in remediating water quality and habitats has the potential to energize mussel restoration because of the advent of new restoration technologies and growing awareness for the many ecosystem services provided by healthy mussel communities.

6 - 12.4 Actions and Needs

More proactive freshwater mussel monitoring for species presence and population health is needed across the Delaware Estuary and River Basin. Freshwater mussels are not targeted in routine macroinvertebrate assessments, and so mussel surveys are rarely performed despite their value for assessing long term status and trends of aquatic health. Improved coordination and data sharing among states and PDE would also facilitate indicator development and watershed restoration planning. For the mussels themselves, there are numerous new technologies to rebuild native populations (e.g., Kreeger and Padeletti 2011), including surveys, reintroduction via relocation studies, and hatchery propagation of mussel seed for restocking. In addition, critical habitat for mussel beds should be mapped and protected. These types of efforts should be supported to help preserve biodiversity and promote ecosystem services of freshwater mussels (Kreeger 2005), which are the most imperiled of all animals and plants.

6 - 12.5 Summary

A robust community of freshwater mussels should be spread throughout the freshwater ecosystem and include diverse species that fill different ecological niches. Unfortunately, the present status of the 12 or more native species of freshwater mussels is poor across the Delaware River Basin, as judged by the best possible analysis of limited survey data, which show reduced biodiversity, abundance, and range for this taxonomic group. A notable exception is the mainstem Delaware River which appears to retain an intact, remnant community of healthy and diverse mussel species. If carefully protected, this population could be used to restore freshwater mussels throughout much of the lower basin, likely yielding significant improvements for water and habitat quality.

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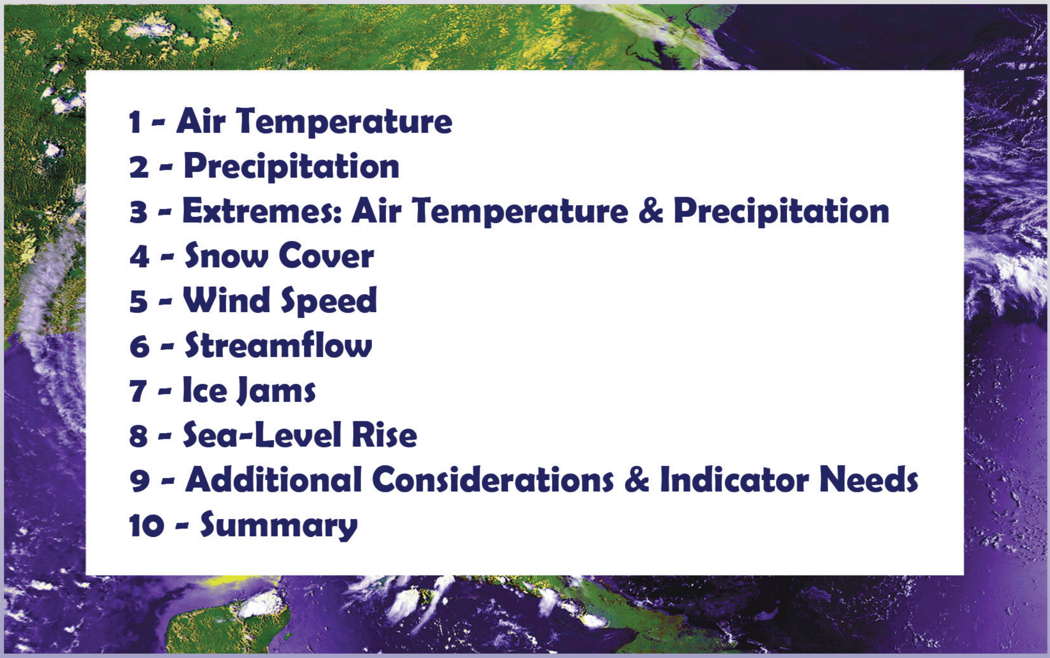
7

Climate Change



1 - Air Temperature
2 - Precipitation
3 - Extremes: Air Temperature & Precipitation
4 - Snow Cover
5 - Wind Speed
6 - Streamflow
7 - Ice Jams
8 - Sea-Level Rise
9 - Additional Considerations & Indicator Needs
10 - Summary

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Chapter 7 – Climate Change

Introduction

This chapter describes how the climate of the Delaware River Basin (DRB) and sea level in the Delaware Estuary have changed and may change in the future. The focus is on air temperature and precipitation throughout the watershed with additional analysis of changes in snow cover, wind speed, barometric pressure, and ice jams in the Delaware River. Trends of water properties including surface water temperature and salinity can be found in Chapters 2 and 3.

1 - Air Temperature

1.1 Description of Indicator

Monthly surface air temperature from the U.S. Historical Climate Network (USHCN), Version 2 was used. The monthly data set is derived from a daily data set. A complete description of the data set and the quality control procedures is given in Menne et al. (2009; 2010a, b); an abbreviated description is presented here. The USHCN is a subset of the National Oceanographic and Atmospheric Administration's (NOAA's) Cooperative Observer Program (COOP). The COOP data stations extracted for the USHCN data set are relatively long, stable, and amenable to adjustments for non-climatic changes (such as station location).

Table 7.1. USHCN stations used in the analysis. The start-end dates shown are defined as the first and last year for which precipitation data passed the 19-day cutoff for calculations of precipitation extremes (see Section 3.1). Some stations have data before 1910, but are not listed as such because the present analysis begins in 1910. Stations in bold are in the lower watershed

#	Name	State	ID #	Latitude (degrees)	Longitude (degrees)	Elevation (m)	Start-end years
1	**Dover**	DE	72730	39.2583	-75.5167	9.1	1910-2008
2	**Milford 2 SE**	DE	75915	38.8983	-75.4250	10.7	1910-2002
3	**Newark Univ. Farm**	DE	76410	39.6694	-75.7514	27.4	1942-1999
4	**Wilmington Porter Res.**	DE	79605	39.7739	-75.5414	82.3	1942-2009
5	Belvidere BRG	NJ	280734	40.8292	-75.0836	80.2	1983-2009
6	**Indian Mills 2 W**	NJ	284229	39.8144	-74.7883	30.5	1910-2008
7	**Moorestown**	NJ	285728	39.9511	-74.9697	13.7	1914-2008
8	Deposit	NY	302060	42.0628	-75.4264	304.8	1963-2009
9	Port Jervis	NY	306774	41.3800	-74.6847	143.3	1910-2009
10	Allentown AP	PA	360106	40.6508	-75.4492	118.9	1948-2009
11	Palmerton	PA	366689	40.8000	-75.6167	125.0	1918-1997
12	**Reading 4 NNW**	PA	367322	40.4269	-75.9319	109.7	1974-2007
13	Stroudsburg	PA	368596	41.0125	-75.1906	140.2	1911-2007
14	**West Chester 2 NW**	PA	369464	39.9708	-75.6350	114.3	1910-2008

The daily portion of the USHCN data has undergone extensive screening for erroneous values; there are 15 individual checks for temperature. For example, if daily data show strong spatial or temporal inconsistency, data are flagged. The daily dataset was not adjusted for biases due, for example, to changes in station location, time of observation, etc.

The monthly data set was derived from the daily data set in several steps. First, means for a given month were computed if no more than nine daily values were flagged or missing for that month. Second, the monthly data set was subjected to further consistency checks that are qualitatively similar to the checks for the daily data. Third, the data were adjusted for time of observation, which has undergone significant change in the U.S. Fourth, a "change-point" detection algorithm was used to adjust the temperature for other inhomogeneities, such as change in station location, change in instrumentation, and change in nearby land use (e.g., urbanization).

These adjustments significantly affect calculated trends. For the U.S. as a whole, the long-term (1895-2007) temperature trend in the unadjusted data is 0.036 °C per decade. Including the adjustment for time of observation increases the trend to 0.054 °C per decade. Remaining adjustments (e.g., station location) increase the trend further to 0.069 °C per decade. The fourth and final step in creating a monthly data set from daily data was to fill in missing days using information from surrounding stations.

The 14 USHCN stations located in the DRB were extracted (Fig. 7.1 and Table 7.1). The analysis distinguished between the upper and lower portions of the watershed. The lower portion of the watershed is defined by those basins that deliver freshwater directly to the tidal portion of the estuary, which is located below Trenton, NJ. The upper portion of the watershed drains to the Delaware River above Trenton. There are eight USHCN stations in the lower portion and six in the upper portion.

The period 1910-2009 was selected for analysis based on the monthly data set because every station during this time period had a value (some being filled in by interpolation). The seasons were defined as December to February (DJF, winter), March to May (MAM, spring), June to August (JJA, summer), and September to November (SON, fall). Seasonal and annual averages were computed for each year and then anomalies were computed with respect to the 1961-1990 reference period. The upper and lower basin averages of the anomalies were then computed. The basin averages of the annual-mean temperature adjustment were also computed; this is simply the adjusted annual-mean temperature minus the raw annual-mean temperature, separate products that were supplied by NOAA.

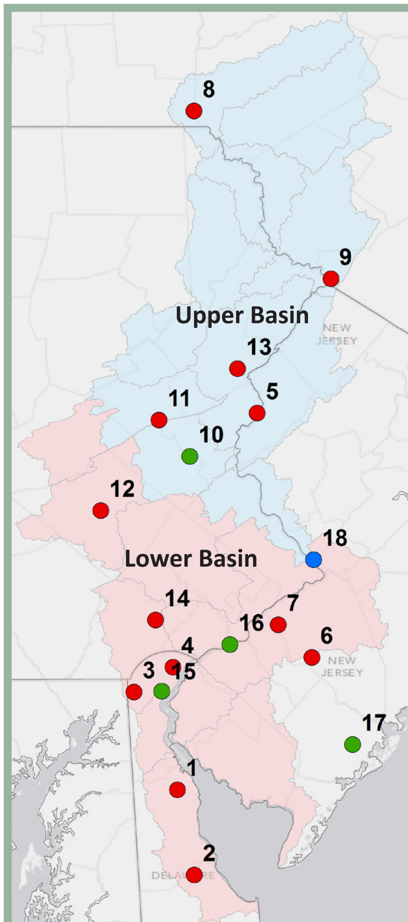

Fig. 7.1. Location of meteorological and hydrological stations used in this analysis. Red dots (1-14) are the USHCN stations; green dots (10, 15, 16, and 17) are the wind stations (Section 5.1); and the blue dot (18) is the stream gauge at Trenton (Section 6.1). The upper watershed is shaded blue and the lower watershed is shaded red

1.2 Past Trends

Annual-mean temperature has increased significantly at the 95% confidence level over the past 100 years, and this trend has increased over the past 30 years (Fig. 7.3. and Table 7.2). In both portions of the watershed, the centennial temperature change given by these trends is about 1.0 °C. The trend over past 30 years for temperature is more than two times the 100-year trend.

Temperature adjustments, which reveal a warm bias in the raw data that has generally decreased with time, are substantial over the past 100 years, accounting for about half of the overall warming trend in the lower watershed (Fig. 7.2). The impact of adjustments over the past 30 years is relatively small. The change in the temperature bias in the late 1960s and early 1970s is likely a result of the change in observation time made at many COOP stations at this time (David Robinson, Rutgers University, personal communication).

The warming observed in the DRB, about 1 °C per century, is consistent with that expected from increases in greenhouse gases according to Najjar et al. (2009), who analyzed temperature observations and global climate model simulations for the region. Table 7.2 and Fig. 7.4 and 7.5 show that significant (95% confidence) warming trends are also evident for individual seasons during the past 100 years, though significant temperature trends over the past 30 years are only seen for fall (warming).

1.3 Future Predictions

In Kreeger et al. (2010) 14 21st-century temperature projections were averaged over the Delaware River Basin from simulations of global climate models (GCMs) under two greenhouse gas emissions scenarios: a higher emissions scenario (A2) in which atmospheric CO_2 is about three times its preindustrial value by the end of the century and a lower emissions scenario (B1) in which atmospheric CO_2 is about twice its preindustrial value by the end of the century. All of the GCMs simulated warming throughout the 21st century, with median warming by late century of 1.9 and 3.7 °C for the B1 and A2 scenario, respectively. The models project more warming in the summer than in the winter.

1.4 Actions and Needs

The large corrections made to the monthly temperature data, particularly in the early part of the century, reveal a poorly constrained uncertainty in the temperature trends in the DRB. Research is needed to better quantify this uncertainty, perhaps through the identification of temperature stations that have required minimal adjustments or can be cross-calibrated.

The cause of the substantial warming observed in the DRB requires further investigation. Though numerous studies have been conducted to determine the causes of long-term temperature trends at continental and global scales, there has only been one study for the DRB (Najjar et al. 2009), which used GCMs from the 2001 Intergovernmental Panel on Climate Change report. Analysis of daily high and low temperatures may provide some insight as to the causes of long-term temperature change as these quantities respond differently to various types of radiative forcing, such as changes in greenhouse gases, aerosols, and cloudiness.

Given the Delaware River Basin's proximity to the sea and its large north-south temperature gradient, the global climate models recently used to investigate climate change in the region (Najjar et al. 2009; Kreeger et al. 2010) may be inadequate. Regional climate model simulations, which have been recently made available by the North American Regional Climate Change Assessment Program (Mearns et al. 2009), represent a substantial improvement over existing GCM simulations in terms of resolution and should be investigated in detail.

1.5 Summary

The DRB has warmed substantially over the past 100 years and the rate of warming appears to be increasing. This change is qualitatively consistent with that expected from increases in greenhouse gases, but the large uncertainty in the temperature data combined with the limited attribution studies indicates that additional research is needed to better understand past temperature change. Future temperature change may paradoxically be more certain: not a single climate model projects cooling even under the low emissions scenario analyzed in Kreeger et al. (2010).

Table 7.2. Linear trends of annual and seasonal temperature and precipitation for the upper and lower portions of the DRB. *p*-values, given in parentheses, are based on an F-test and calculated here and elsewhere in this chapter using the lm function in the programming language R. Trends significant at the 90% and 95% confidence levels are underlined once and twice, respectively. To put the precipitation trends in perspective, the annual and seasonal average totals in the lower & upper watershed for the 1961-1990 period are 112 & 110 cm (annual), 25 & 23 cm (DJF), 29 & 28 cm (MAM), 31 & 30 (JJA), and 27 & 27 cm (SON)

Upper watershed	Temperature trend (°C decade^{-1})		Precipitation trend (cm decade^{-1})	
	1910-2009	1980-2009	1910-2009	1980-2009
Annual	0.09 (2.8×10^{-5})	0.28 (0.030)	1.4 (0.059)	6.6 (0.075)
DJF	0.14 (0.0080)	0.42 (0.20)	0.28 (0.20)	2.5 (0.12)
MAM	0.09 (0.015)	0.08 (0.69)	0.32 (0.17)	-1.9 (0.20)
JJA	0.08 (0.0022)	0.22 (0.21)	0.00 (0.99)	2.5 (0.17)
SON	0.06 (0.045)	0.40 (0.017)	0.83 (0.0027)	3.5 (0.072)
Lower watershed	Temperature trend (°C decade^{-1})		Precipitation trend (cm decade^{-1})	
	1910-2009	1980-2009	1910-2009	1980-2009
Annual	0.10 (3.2×10^{-7})	0.26 (0.031)	1.1 (0.059)	6.3 (0.077)
DJF	0.13 (0.0057)	0.47 (0.14)	0.03 (0.90)	2.0 (0.15)
MAM	0.09 (0.0095)	0.17 (0.39)	0.30 (0.24)	-0.20 (0.24)
JJA	0.12 (9.5×10^{-8})	0.13 (0.38)	-0.21 (0.51)	2.9 (0.12)
SON	0.09 (0.0039)	0.28 (0.079)	0.94 (0.00081)	3.4 (0.074)

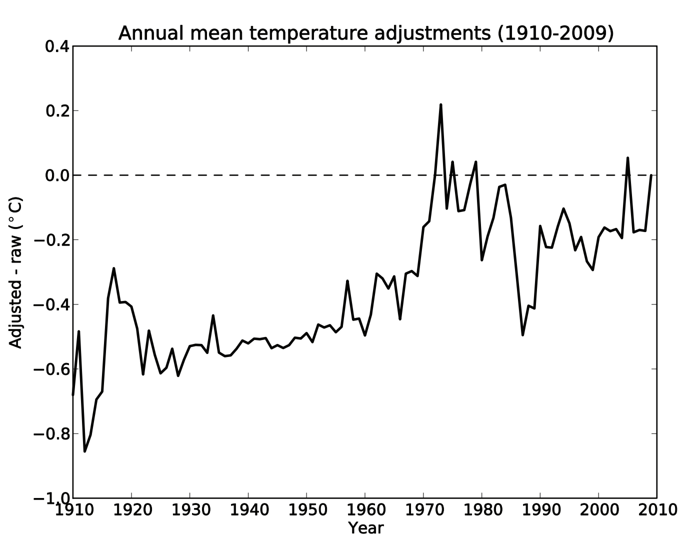

Fig. 7.2. Adjustments made to monthly temperature data. Shown is the adjusted temperature minus the raw (unadjusted) temperature for the lower portion of the watershed

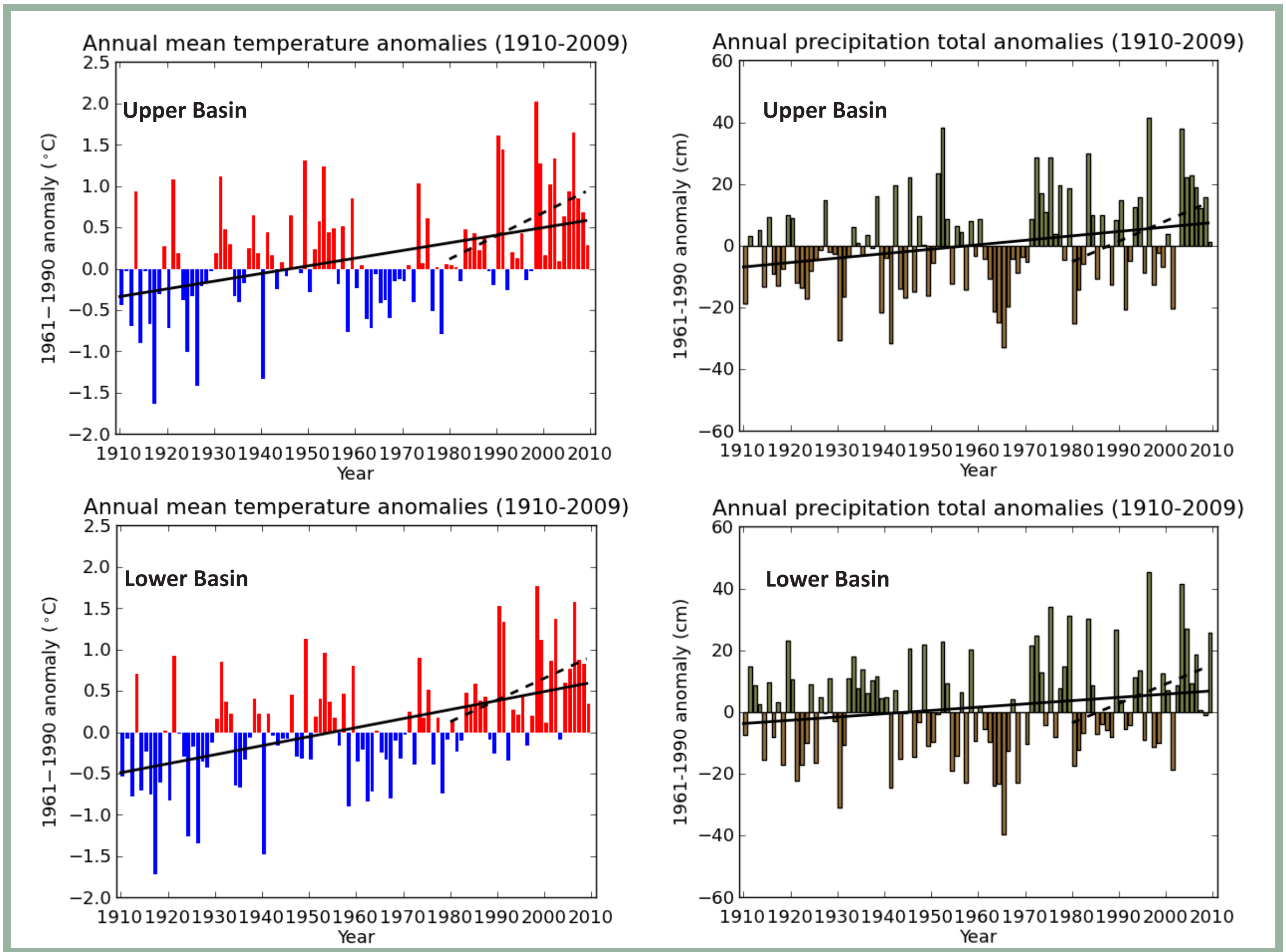

Fig. 7.3. Anomalies (with respect to the 1961-1990 average) of annual-mean temperature (left panels) and annual totals of precipitation (right panels) for the lower (bottom panels) and upper (top panels) portion of the DRB. The solid and dashed lines are the linear fits to the data for the 1910-2009 and 1980-2009 periods, respectively. To put the precipitation trends in perspective, the annual 1961-1990 avg. precipitation for the lower and upper watershed is 112 and 110 cm, respectively

2 - Precipitation

2.1 Description of Indicator

As with temperature, monthly precipitation from the USHCN, Version 2 was used. The data set description and screening procedures are the same as for temperature (Section 1.1), except that there are 12 screening checks for precipitation and no time-of-observation correction.

2.2 Past Trends

Annual-mean precipitation in the DRB has increased significantly at the 90% confidence level over the past 100 years, and this trend has increased over the past 30 years (Fig. 7.2 and Table 7.2). In both portions of the watershed, the centennial precipitation change given by these trends is about 10%. The trend over the past 30 years for precipitation is more than five times the 100-year trend. Seasonal precipitation trends (Table 7.2 and Fig. 7.4 and 7.5) are positive but these are only significant in the fall, which has gotten dramatically wetter (more than 10% per decade over the past 30 years). Though a warmer atmosphere is expected to hold more moisture and have greater precipitation, Najjar et al. (2009) found that the precipitation increase over the 20th century in the Delaware River Basin was not captured by GCMs forced by the observed increase in greenhouse gases. Similarly, Seager et al. (2012) examined the cause of the 1960s drought and the subsequent rapid increase in precipitation in the Northeast U.S. They, too, found that simulations with GCMs forced by increased greenhouse gases were not able to capture these important hydrological changes. Seager et al. (2012) also found that GCMs forced from below by surface ocean temperature change did not reproduce the observed precipitation changes in the Northeast U.S. Together, these studies suggest that internal variability of the atmosphere (as opposed to variability forced from the

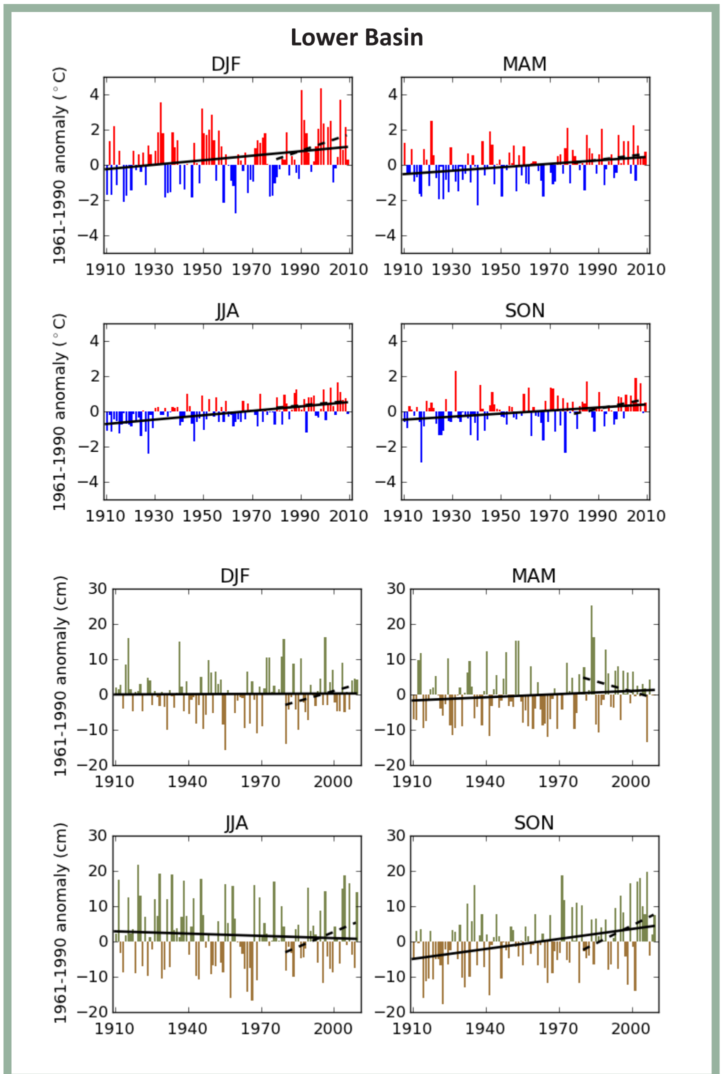

Fig. 7.4. Anomalies (with respect to the 1961-1990 average) of seasonal-mean temperature (top four panels) and seasonal totals of precipitation (bottom four panels) for the lower portion of the DRB. The solid and dashed lines are the linear fits to the data for the 1910-2009 and 1980-2009 periods, respectively

ocean or greenhouse gases) is the dominant influence on precipitation in the Delaware River Basin.

2.3 Future Predictions

Precipitation projections come from the same source as temperature projections (Kreeger et al. 2010). These show the DRB getting progressively wetter throughout the 21st century, particularly in the winter and spring. There is less consensus, however, than the temperature projections, as some models project precipitation declines. Median projected precipitation increases by the late 21st century for the B1 and A2 scenarios are 7 and 9%, respectively.

2.4 Actions and Needs

The understanding of long-term changes in DRB precipitation is poor. Greenhouse gas emissions, at least

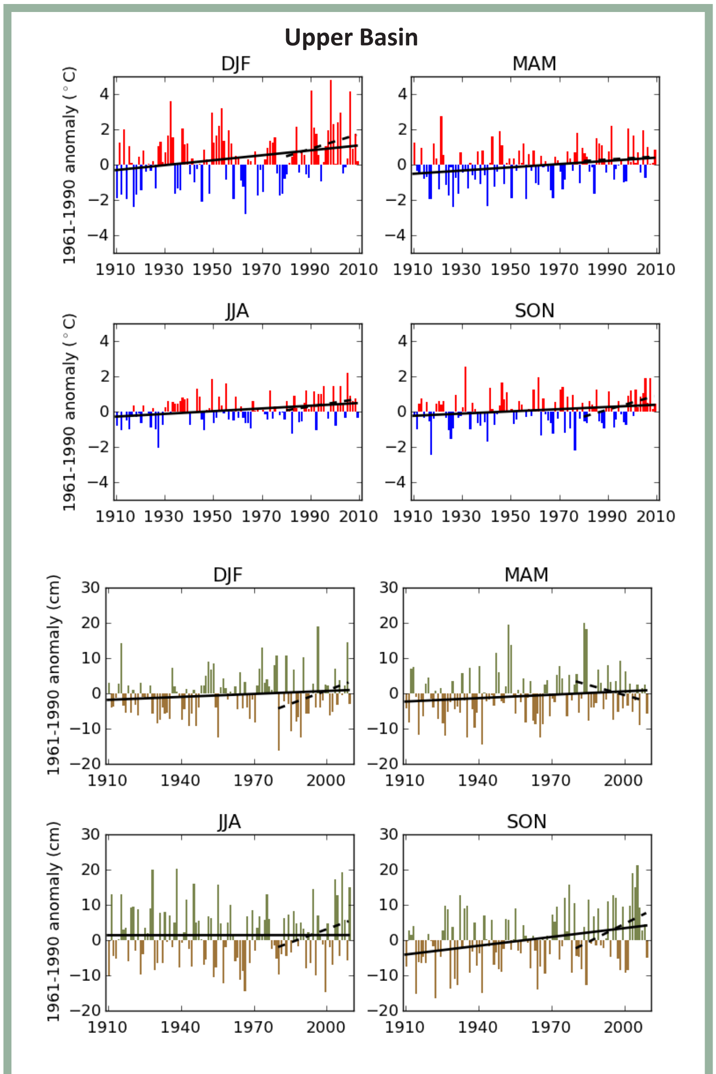

Fig. 7.5. Same as Fig. 7.4, except for the upper portion of the DRB

according to the limited studies available, do not appear to be the cause of such changes. However, as noted for air temperature (Section 1.3), climate simulations that have been analyzed are of very coarse resolution and are unable to capture the fine-scale processes, particularly in summer when convective activity is high, that drive the precipitation process in the DRB. Therefore, regional climate models or statistical downscaling techniques should be considered as tools for investigating past and future precipitation change.

2.5 Summary

Precipitation has increased in the DRB, mainly during fall, and is projected to increase in the future, mainly during winter and spring. Projected precipitation changes are well within natural interannual variations (Najjar et al. 2009), which is possibly why the greenhouse gas signal has not been detected at regional scales, in contrast to studies showing a signal at continental and global scales (e.g., Hegerl et al. 2007).

3 - Extremes: Air Temperature and Precipitation

3.1 Description of Indicator

Trends in five extreme event indices were used: (1) the number of days per year with the high temperature above 90 °F (0°C), (2) the number of days per year with the low temperature below 32 °F (32.2°C), (3) the maximum number of consecutive dry days per year, (4) the annual maximum five-day precipitation total (cm), and (5) the number of days per year with heavy (>4.5 cm) precipitation. The USHCN daily data set was used for this analysis. Precipitation data that were flagged during screening were not used nor were any temperature data for a given day if the high, low, or average temperature was flagged. For the high-temperature metric, years from a given station were not used if it had more than 23 days of flagged or missing data during May-September of that year; the same threshold was used for the low-temperature metric during October-April. For the three precipitation extremes, a year from a given station was not used if it had more than 19 days of flagged or missing data. A day was deemed dry if precipitation was less than 1 mm; missing days were assumed to be wet. For the maximum five-day precipitation total, precipitation for any day with missing or bad data was assumed to be 0. Thus, the maximum five-day total period could include a missing day, though this was rare.

Plots of extreme event index anomalies were averaged over the watershed as follows. First, using only data from years that met the cutoff, time series of extreme index anomalies were created for each station, using 1974-1992 as the reference period (chosen subjectively based on data availability). Those stations were then averaged in a given year that passed the cutoff for that particular year.

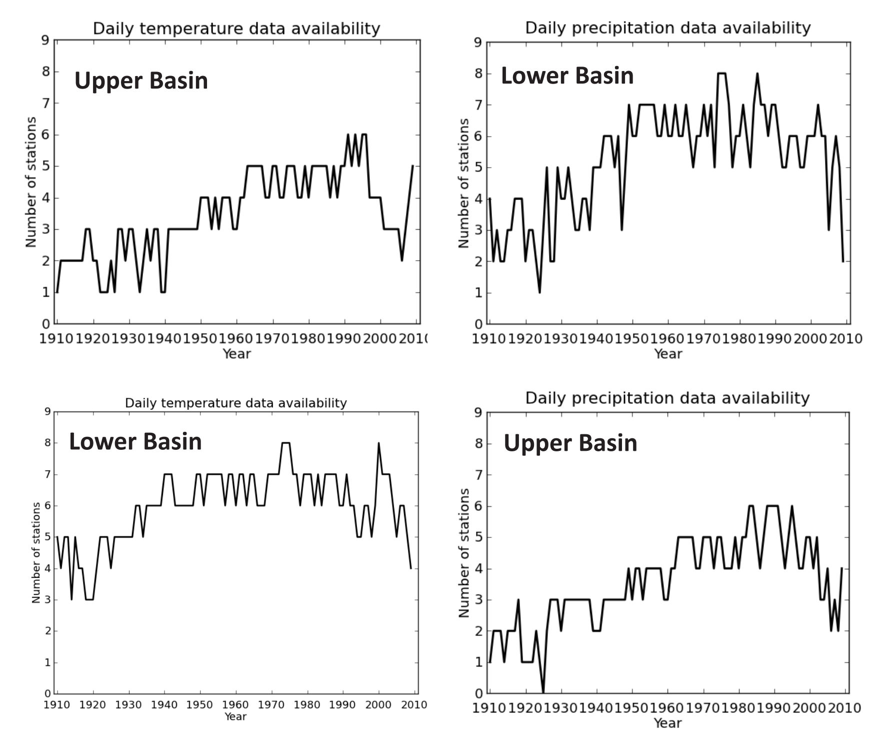

Fig. 7.6. Number of stations that passed the cutoffs for extreme event index calculations for temperature (left panels) and precipitation (right panels) in the lower (bottom panels) and upper (top panels) portion of the watershed

Table 7.3. Linear trends of extreme event indices for the upper and lower portions of the DRB. *p*-values are given in parentheses. Trends significant at the 90% and 95% confidence levels are underlined once and twice, respectively

Upper watershed	1974-1992 average	Trend (per decade)	
		1910-2009	1980-2009
# days per year above 90° F	10	-0.22 (0.42)	0.19 (0.91)
# days per year below 32° F	125	-0.43 (0.20)	1.5 (0.39)
Annual max # consecutive dry days	18	-0.097 (0.51)	-0.94 (0.20)
Annual max 5-day precip. total	10	0.10 (0.35)	1.2 (0.12)
# days/yr with precip. >4.5 cm	2.5	0.13 (0.0078)	0.47 (0.062)
Lower watershed	1974-1992 average	Trend (per decade)	
		1910-2009	1980-2009
# days per year above 90° F	18	0.37 (0.21)	-1.2 (0.59)
# days per year below 32° F	97	-0.84 (0.013)	-2.3 (0.16)
Annual max # of consecutive dry days	19	0.11 (0.50)	0.04 (0.96)
Annual max 5-day precipitation total	11	0.11 (0.30)	1.0 (0.04)
# days per year with precip. >4.5 cm	3.0	0.13 (0.0024)	0.47 (0.030)

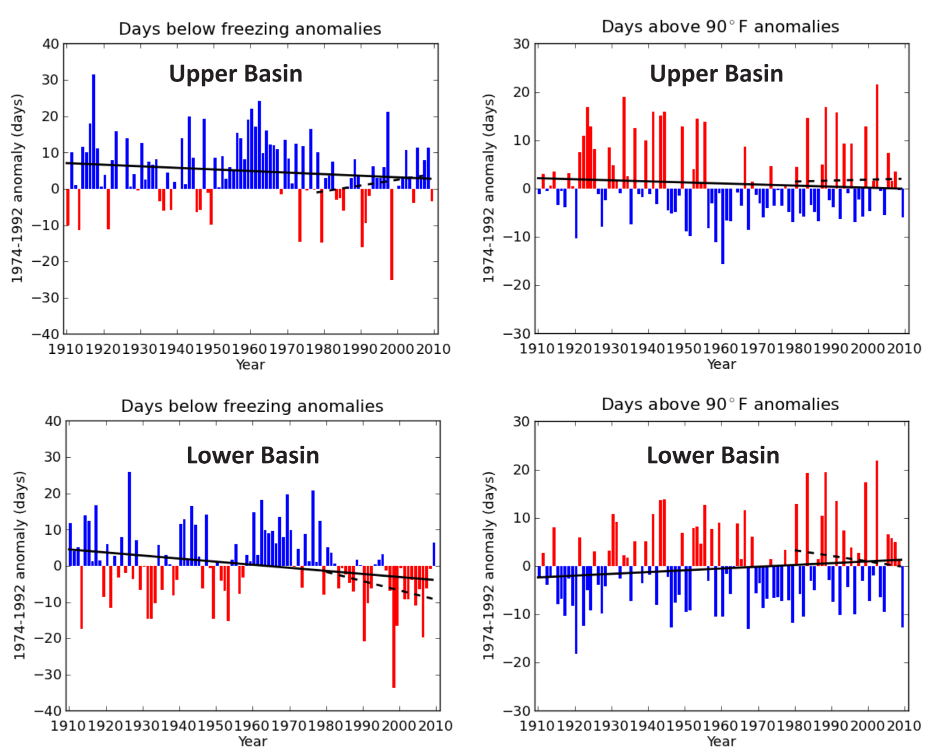

Fig. 7.7. Time series of the anomalies (with respect to the 1974-1992 average) of the number of days per year with low temperature below 32° F (0°C) (left panels) and high temperature above 90° F (32.2°C) (right panels) in the lower (bottom panels) and upper (top panels) portion of the watershed. Lines are least-squares linear fits to the 1910-2009 (solid) and 1980-2009 (dashed) periods

3.2 Past Trends

Fig. 7.6 shows the number of stations that passed the cutoffs for temperature and precipitation described in Section 3.1. In most years, more than half of the stations meet the cutoffs. The greatest rejection rates are early in the 20th century and during the past few years; these are due, at least in part, to the start and end dates of the stations (Table 7.1).

Many of the trends in the five extreme event indices analyzed are insignificant, with the notable exception of the days per year of heavy precipitation, which shows a significant upward trend of 0.1 day per year per decade or 1 day per year per century in the upper and lower watersheds (Table 7.3 and Fig. 7.7 and 7.8). This may appear to be a small change but is, in fact, substantial, because there are so few days of heavy precipitation. Compared to the average for the 1974-1992 reference period (3.0 days per year),

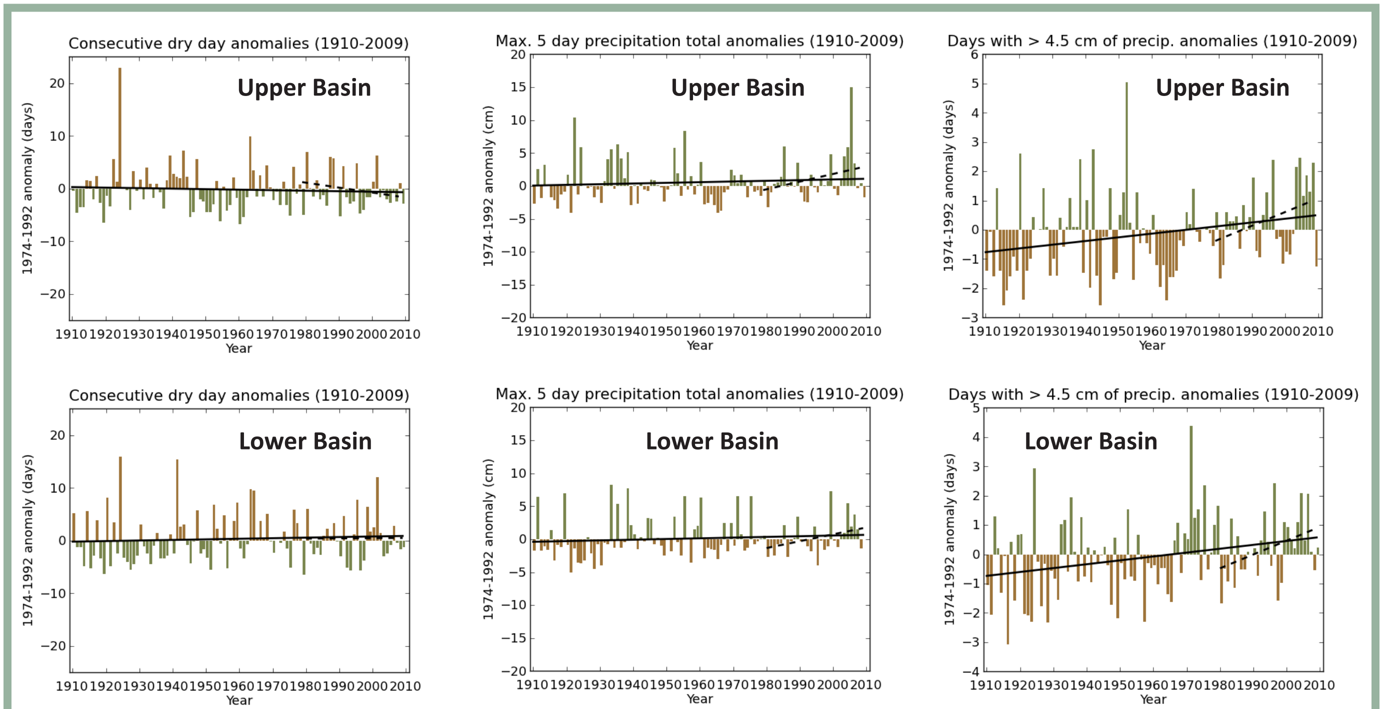

Fig. 7.8. Time series of precipitation extremes anomalies (with respect to the 1974-1992 average): annual maximum number of consecutive dry days per year (left panels), annual maximum 5-day precipitation total (middle panels), and number of days per year with precipitation exceeding 4.5 cm. Upper watershed is shown in upper panels and lower watershed in lower panels. Lines are least-squares linear fits to the 1910-2009 (solid) and 1980-2009 (dashed) periods

the increase is about 30%; an earlier reference period would give an even larger fractional increase. Also, in the lower watershed, we find a significant decline in the number of freezing days over the past 100 years, which is consistent with a similar decline found by Brown et al. (2010) throughout the Northeast U.S.

3.3 Future Predictions

Although there is considerable uncertainty in predicting future climate extremes, the current consensus is that the increased annual-mean precipitation (Section 2.3) projected for this century will be associated with more frequent extreme events. Three quarters of the climate models analyzed by Kreeger et al. (2010) predicted increases in the frequency of extreme hydrological metrics, including heavy precipitation and consecutive dry days. The U.S. Global Climate Research Program also predicted increases in extreme weather events and associated risks from storm surges (GCRP 2009).

3.4 Actions and Needs

A more thorough analysis and literature review is needed for past trends in extremes in the DRB. A central issue is bias adjustment in daily precipitation and mean, minimum, and maximum temperature. Other studies, with different treatments of the data and different metrics (DeGaetano and Allen 2002; Brown et al. 2010) show some substantial differences with our analysis, and these need to be resolved. The science and management community in the DRB should stay abreast of regional and national climate studies that predict extreme events and storm intensity and frequency. Understanding of complex global and regional climate cycles and oceanic feedbacks is rapidly evolving but is still very limited. Nevertheless, warmer and wetter air masses are expected to provide suitable conditions to fuel stronger and more frequent weather events.

3.5 Summary

The intensity and frequency of extreme temperature and precipitation events are difficult to examine directly and even harder to predict. Despite increased overall temperatures in the DRB over the past century, no significant increase in high temperature extreme events was detected in this analysis. There was, however, a significant decrease in the number of extreme cold events in the lower watershed. On the other hand, heavy precipitation events increased in frequency in both the upper and lower basin. This upward trend in extreme precipitation events was more striking for the recent past (1980-2009) than over the past century (1910-2009). Similarly, 5-day rainfall totals increased during the last 30 years in the lower basin, which also had less frost days. Most climate scientists predict increasing extreme events in the future, but there is still a lot of uncertainty in this facet of climate science.

4 - Snow Cover

4.1 Description of Indicator

The snow cover product used here, The Northern Hemisphere EASE-Grid Weekly Snow Cover and Sea Ice Extent Version 3, is from the National Snow and Ice Data Center (NSIDC, Armstrong and Brodzik 2005). This 25-km resolution product was created by the NSIDC by re-gridding data products from the Rutgers University Global Snow Lab (much of which actually has a resolution coarser than 25 km). Data are binary, with 0 indicating no snow and 1 indicating snow. Continuous data are available for the period 1967-2006. For each of the approximately 60 grid points in the DRB, the fraction of weeks each year with snow cover was computed. Those fractions were then averaged to arrive at the DRB-wide snow cover fraction for each year. The anomaly of the snow fraction was computed relative to the 1974-1992 average (for consistency with the extremes metrics) and expressed as a percent difference.

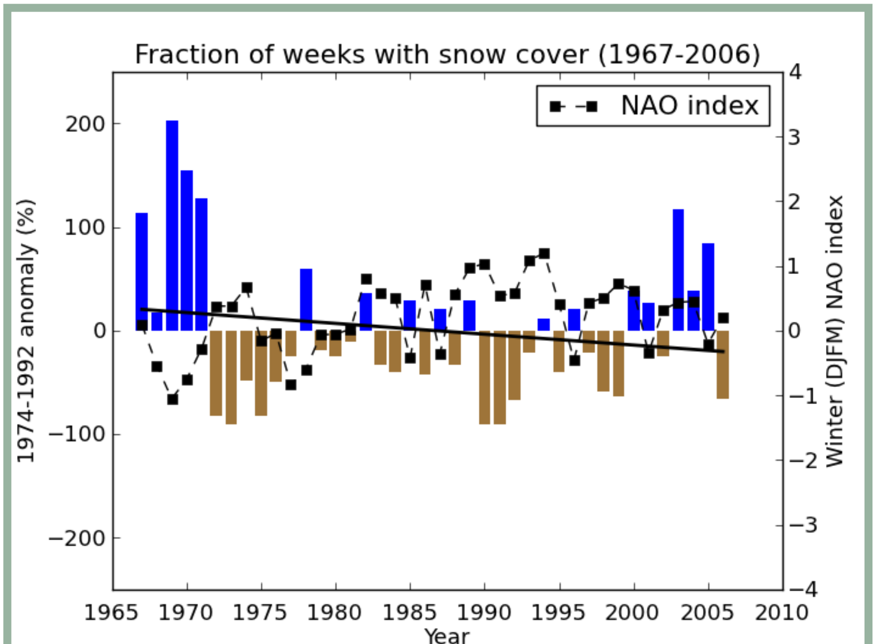

Fig. 7.9. Time series of snow cover anomaly (with respect to the 1974-1992 average) in the Delaware River Basin (bars) and the winter NAO index (squares). The solid line is a linear fit to the snow cover data

4.2 Past Trends

Figure 7.9 shows that snow cover in the DRB has varied dramatically, with some years having twice the mean snow cover and some years with essentially zero snow cover. The linear trend is negative and about 10% per decade but is not significant (p = 0.029). The winter North Atlantic Oscillation (NAO) index, acquired from the Climate Prediction Center, is significantly (p = 0.001) negatively correlated (r = -0.50) with DRB snow cover (Fig. 7.9). This result is consistent with analyses showing a negative correlation between the winter NAO index and snowfall in the eastern United States (Seager et al. 2010).

4.3 Future Predictions

Approximately 20 fewer frost days per year are predicted by mid-century and 40 fewer frost days by the end of the century under a "A2" emission scenario (Kreeger et al. 2010). With fewer frost days, the snowpack in DRB is predicted to be smaller and melt earlier (UCS 2008). The reduction or loss of the winter snowpack, combined with higher winter precipitation, will contribute to greater winter flooding and lower amounts of springtime snowmelt runoff.

4.4 Actions and Needs

Snowfall depends on many factors in addition to temperature, such as the status of the NAO; therefore, the understanding of how climate affects snowfall would benefit from a more robust analysis of how local and regional weather events are affected by changing climate and associated weather patterns. For example, stronger winter storms such as occurred during the winters of 2010 and 2011 were sufficient to entrain cold air into the DRB, resulting in record snowfall despite overall warming conditions.

4.5 Summary

Snowfall is highly variable from year to year, influenced by many factors that govern upper air movements, storm intensity, and temperature of course. It is just as related to short-term weather patterns as it is to long-term climate patterns. It is plausible that snowfall could actually increase in the future if deeper winter storms more routinely entrain cold northern air that would normally stay north of the Delaware River Basin. On the other hand, warmer winters are predicted to cause a decrease in the depth, range and duration of the snowpack. Therefore, it may snow just as much in the future but it may not stick around for as long as in the past, leading to faster freshwater runoff in streams and rivers.

5 - Wind Speed

5.1 Description of Indicator

Wind speed data were acquired from the National Climatic Data Center for four stations in the region (Fig. 7.1): Wilmington, DE (1948-2009); Allentown, PA (1948-1994); Philadelphia, PA (1955-1994); and Atlantic City, NJ (1971-2010). The methods of analysis are similar to those of Vautard et al. (2010). Hourly averages at four times per day were acquired (00, 06, 12, and 18 UTC). To compute a seasonal average, at least 63 observations were required from each of the 4 hours. Annual averages were computed when all seasonal averages were defined. Statistical quality control procedures of Vautard et al. (2010) were followed to eliminate outliers. Anomalies were computed with respect to the 1974-1992 average and then averaged

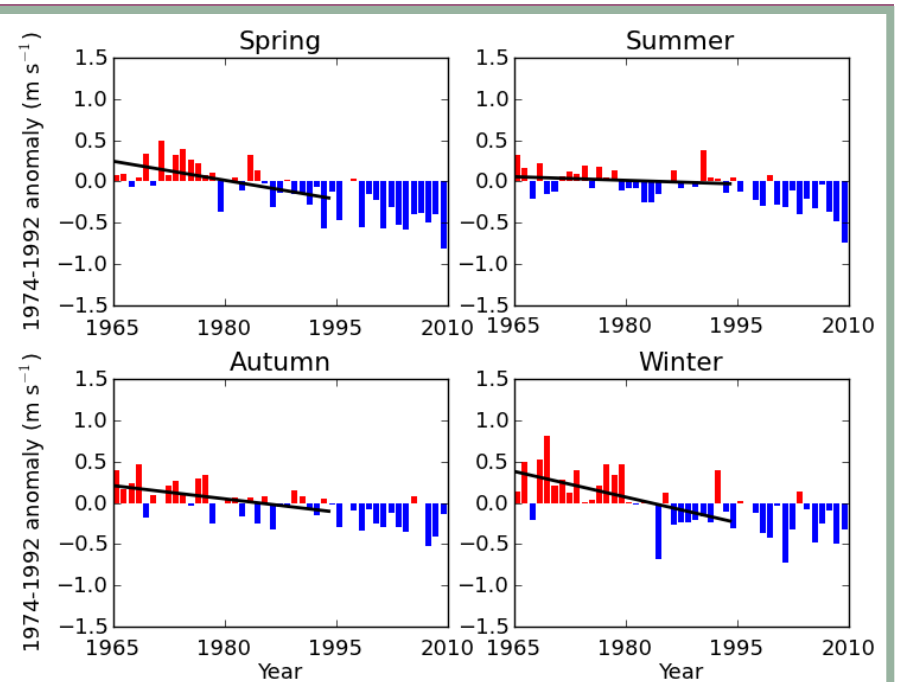

Fig. 7.10. Time series of wind speed anomalies (with respect to 1974 -1992 average) for each of the seasons averaged over the four wind stations (see text). Solid lines show least-squares linear fits between 1965 and 1995

over the four stations. The analysis was restricted to the period after 1965 because of a change in the reporting of low wind speeds in the early 1960s (DeGaetano 1998). A change in instrumentation occurred in 1995, when the stations became part of the Automated Surface Observing System (ASOS) of the National Weather Service. According to McKee et al. (2000), such a change resulted in low winds reported lower and high winds reported higher; calm wind reports nearly doubled. Post-1995 data are presented, but the trend analysis is restricted to 1965-1995.

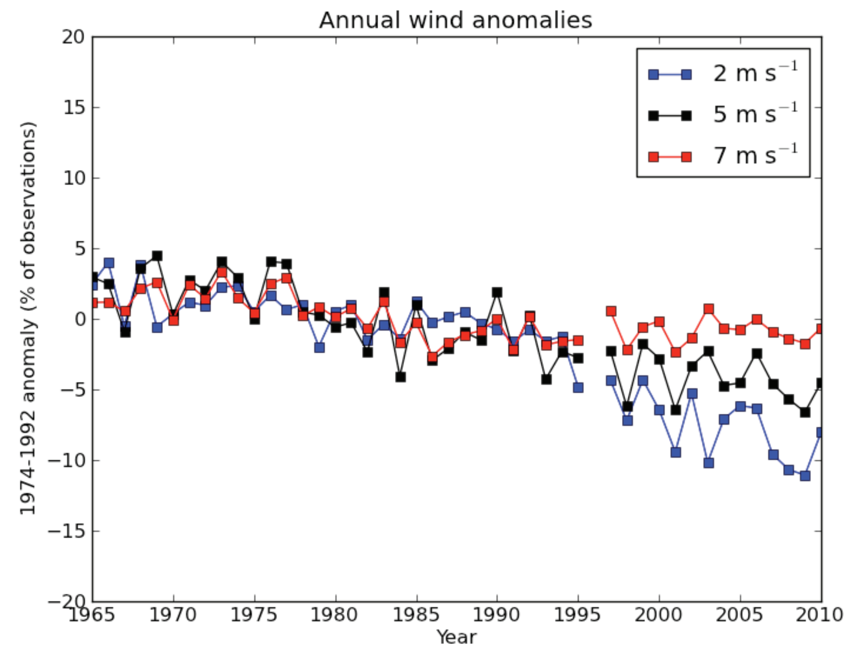

Fig. 7.11. Time series of the four-station average (see text) of the annual anomaly (with respect to the 1975-1992 average) of the percent of observations exceeding wind speed thresholds of 2, 5, and 7 m s^{-1}

5.2 Past Trends

Annual-mean wind speeds in the region decreased 0.12 m s^{-1} per decade between 1965 and 1995, a decline of 9% in 30 years (Table 7.4 and Fig. 7.10). Winter and spring declines are even larger. Declines are relatively uniform across the wind speed distribution (Fig. 7.11). The divergence in the trends for different wind speeds, which begins in 1995, is likely a result of the switch to the ASOS network. Over the past 30 years, long-term wind speed declines have occurred over much of the Northern Hemisphere's land masses, and such declines are not matched by wind declines aloft, suggesting that surface roughness changes, perhaps resulting from land-use change, were responsible for the surface wind declines (Vautard et al. 2010). In fact, winds above the surface (at a pressure of 850 mb), have increased over much of North America, including the northeastern U.S. (Vautard et al. 2010). Pryor et al. (2009) found differences among U.S. wind speed trends in observations, regional climate models, and reanalysis products (a blending of models and data), and were not able to determine the cause of the observed wind speed decline.

Table 7.4. Means and linear trends (1965-1995) of annual and seasonal wind speed averaged over the four wind speed stations (see text)

	Mean (m s^{-1})	Trend (m s^{-1} $decade^{-1}$)
Annual	4.0	-0.12
DJF	4.4	-0.21
MAM	4.6	-0.15
JJA	3.5	-0.03
SON	3.7	-0.11

5.3 Future Predictions

Future predictions of wind speed have not been analyzed in the DRB. However, if recent trends are any indication, future winds may depend more on land use management than climate.

5.4 Actions and Needs

Since wind speeds are decreasing, this could have diverse effects on weather, agriculture, and other topics important to people and the environment. More study is needed to examine, for example, whether weaker winds might reduce evapotranspiration, promote slower moving thunderstorms and more persistent fog, thereby affecting the water budget and growing conditions for plants and animals.

5.5 Summary

Wind speeds have been declining across the Delaware River Basin. The cause of the wind speed decline is not known, but it may result from changes in surface properties, such as land use. Augmenting the current wind speed analysis with data on land use change and a regional climate model should be helpful in determining the cause of wind speed change in the Delaware River Basin.

6 - Streamflow

6.1 Description of Indicator

Daily streamflow at Trenton, NJ was obtained from the United States Geological Survey (USGS) and was averaged by season and year. Anomalies were computed with respect to 1974-1992 averages.

6.2 Past Trends

Streamflow at Trenton, NJ has varied substantially over the past century, with many years departing from the long-term mean by more than 50% (Fig. 7.12). Trenton streamflow is highly correlated with DRB precipitation (Najjar et al. 2009) and shows increases of 4.2 m^3s^{-1} per decade over 1913-2009 ($p = 0.16$) and 47 m^3s^{-1} per decade over 1980-2009 ($p = 0.015$). Seasonal trends over 1913-2009 and 1980-2009 are positive and significant at the 90% level for autumn and winter but not for the other seasons (Fig. 7.13).

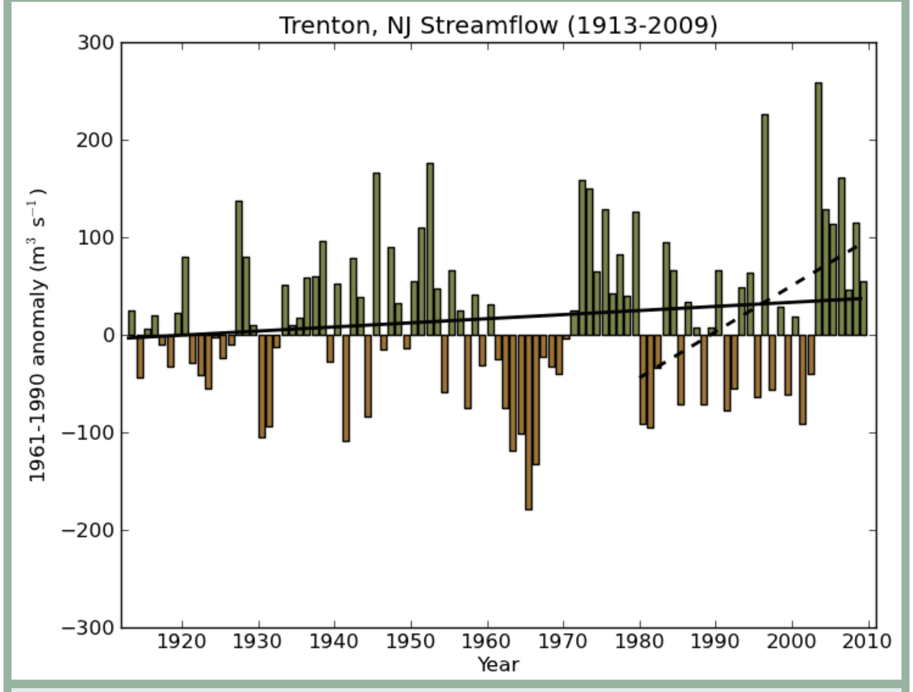

Fig. 7.12. Time series of annual average streamflow anomaly (with respect to 1974-1992 average) at Trenton, NJ. Lines are linear fits over the periods 1913-2009 (solid) and 1980-2009 (dashed). The anomaly is the departure from the 1961-1990 average, which is 320 m^3s^{-1}

6.3 Future Predictions

Streamflow is tightly correlated with precipitation even though much of the runoff in the DRB is regulated by reservoirs. Future predicted increases in precipitation may lead to greater runoff, particularly if less water infiltrates because of reduced snowpack and more flashy storm events. However, increased temperature will increase evapotranspiration, making less water available for runoff. Therefore, annual streamflow changes are highly uncertain in the mid-Atlantic region (Najjar et al. 2009); increases in winter and spring flow, however, are likely.

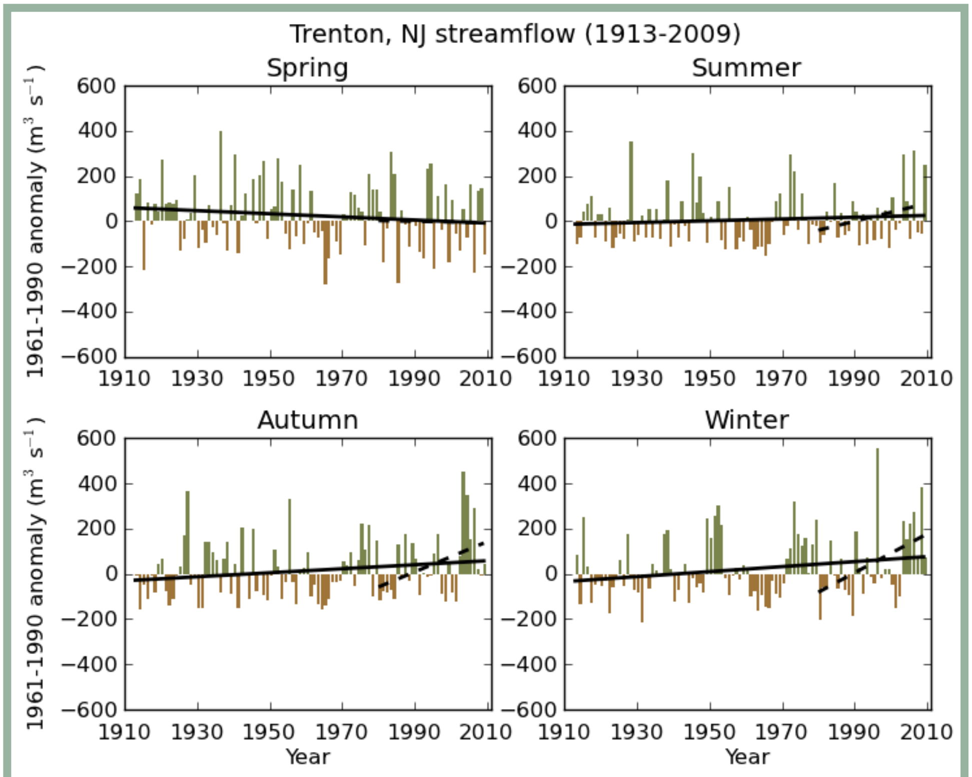

Fig. 7.13. Time series of Trenton, NJ streamflow anomalies (with respect to 1974-1992 average) for each of the seasons. Lines are least-squares linear fits to the 1910-2009 (solid) and 1980-2009 (dashed) periods

6.4 Actions and Needs

Funding cutbacks threaten to diminish USGS monitoring capabilities for streamflow. Continued monitoring of stream and river flows is critically important to track changes in the water budget of the DRB, which affects estuarine salinty and freshwater availability for people and the environment.

6.5 Summary

Increased fall and winter streamflow has occurred across the Delaware River Basin, particularly in recent decades, due to increases in precipitation (Section 2). In the future, this upward trend in runoff, particularly in the winter, is expected to continue as a result of predicted further increases in precipitation, more episodic events, and reduced snowpack.

7 - Ice Jams

7.1 Description of Indicator

Occurrences of ice jams were obtained from the Ice Jam Database of the U.S. Army Cold Regions Research and Engineering Laboratory (White 1996). The data base contains occurrences of ice jams in numerous rivers of the northern United States. This section summed the occurrences in the DRB and in the Delaware River alone.

7.2 Past Trends

The top panel of Fig. 7.14 shows that the number of ice jams that have been reported over the past 80 years in the DRB and in the Delaware River has been declining. This is possibly a result of underreporting of ice jams in the more recent past (White 1996). However, winter warming of the watershed has occurred during this time (Fig. 7.4), which is expected to lead to fewer ice jams. Indeed, as the bottom panel of Fig. 7.14 shows, there is a strong negative correlation between the number of ice jams and the mean winter temperature.

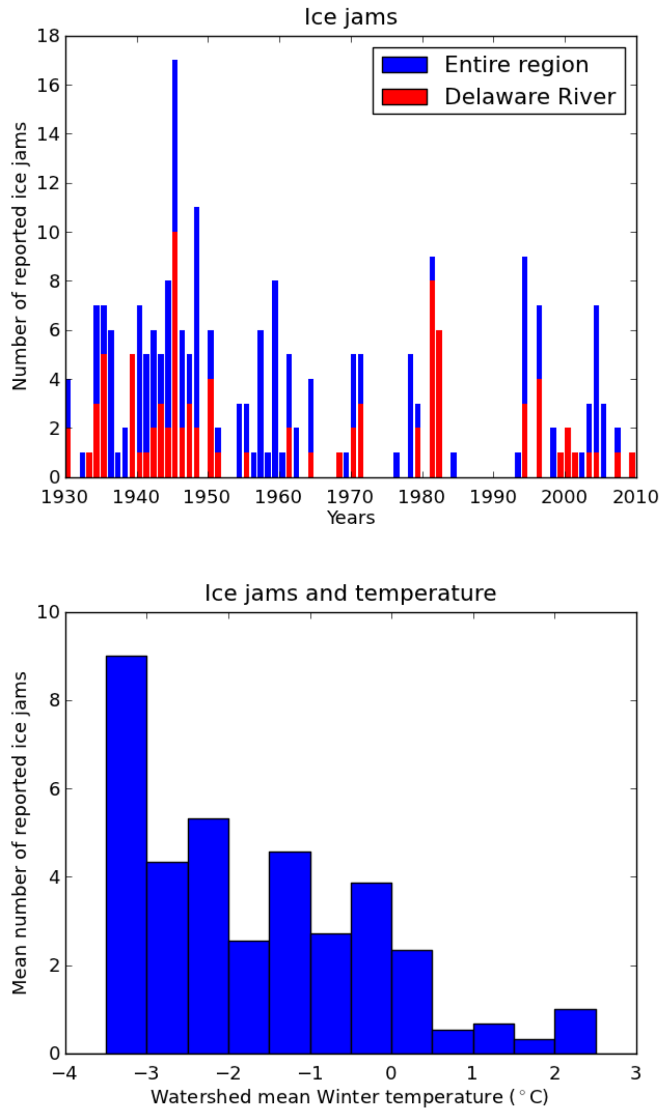

Fig. 7.14. Top panel: annual ice jam reports in the entire Delaware River Basin and in the Delaware River. Bottom panel: the number of reported ice jams binned into mean watershed temperature intervals of 0.5° C. Watershed-mean winter temperature is taken to be the average of the upper and lower watershed temperature

7.3 Future Predictions

It is reasonable to expect fewer ice jams in the future due to predicted higher winter temperatures. Ice jam frequency shows a strong inverse correlation with mean winter temperatures in the DRB.

7.4 Actions and Needs

More analysis is warranted to understand the connection between temperature, river flow, snowfall, and ice jam data quality and consistency. This indicator appears to serve as a useful indicator of a climate change “outcome” and should be further explored.

7.5 Summary

Ice jams represents an interesting “outcome” indicator for tracking climate change effects, but the tracking of ice jams has potentially been inconsistent and so the analysis here should be considered as preliminary. Nevertheless, the frequency of ice jams in the Delaware River Basin has appeared to decrease significantly, and the decline is directly associated with the mean winter temperature across the watershed. Since winter temperatures are predicted to increase markedly in the future, ice jams are expected to become still less frequent.

8 - Sea-level Rise

8.1 Description of Indicator

The coastline around the Delaware Estuary extends from Trenton, New Jersey, to Cape Henlopen in Delaware and to Cape May in New Jersey. Rising sea level is a growing concern with some Delaware and New Jersey Bayshore communities already calling the associated flooding an emergency situation. When combined with prospects for an increased frequency of intense storms (e.g., Lambert and Fyfe 2006), coastal flooding will become even more severe. Increased sea level is also expected to lead to greater loss of coastal wetlands, increased intrusion of saltwater into groundwater, and higher salinities, all of which threaten many important natural resources (Kreeger et al. 2010).

Sea-level rise is a natural phenomenon and natural resources and people have long adapted; however, an increase in the rate of sea-level rise will force more rapid adaptation in the future. This is why sea-level rise rate is the focus of this section.

8.2 Past Trends

The current rate of sea-level rise in the Delaware Estuary is 3.5-4.0 mm yr^{-1}, up from about 1.8 mm yr^{-1} in the early portion of the 20th century (Gill et al. 2011). In the geologic history of the region, rates as high as 6-8 mm yr^{-1} have been estimated (Psuty 1986; Psuty and Collins 1996). Dr. Norbert Psuty (Rutgers University, Personal Communication) notes that during the Holocene when rates were most recently that fast, there were few tidal wetlands along the Mid-Atlantic coast. Reconstructions in the Delaware Estuary indicate that sea-level rise was approximately 1-2 mm yr^{-1} for the past 1,500 years until it more than doubled over the past 100 years (Engelhart et al. 2009).

8.3 Future Predictions

Absolute sea-level rise refers to the global rise of water resulting from melting ice sheets and expanding water as it warms. In the Delaware Estuary, two other factors will contribute to relative sea-level rise, which refers to the sea-level rise an observer fixed to the land surface would experience. These two factors are changing ocean currents and subsidence.

Regional variation in absolute sea level occurs because of gravitational forces, wind, and water circulation patterns. A decrease in current velocity of the Gulf Stream is an example, whereby less water will be pushed offshore by abated Coriolis Effect forcing. Under a “A2” greenhouse gas emissions scenario, changing water circulation patterns such as this are expected to increase sea-level by approximately 10 cm by 2100 in coastal regions of the northeast U.S. (Yin et al. 2009).

Subsidence is the sinking of the land surface due to post-glacial settling, which has occurred in the Delaware system since the last Ice Age. This settling causes a steady loss of elevation. Withdrawals of groundwater for irrigation and other uses are believed by some scientists to increase subsidence. Through the next century, natural subsidence is estimated to hold at an average 1-2 mm of land elevation loss per year (Engelhart et al. 2009), but perhaps greater if water withdrawals increase.

For these reasons, the Mid-Atlantic States are anticipated to experience sea-level rise greater than the global average (GCRP 2009). In its 2010 report, the Partnership for the Delaware Estuary noted that sea-level projections are being updated frequently and it decided to plan for an increase in sea level of 0.5 m, 1 m and 1.5 m without predicting the date. Most agencies in the region are currently planning for either 1 or 1.5 m by 2100. For every 1 m of global absolute sea-level rise, it is plausible to expect 1.2 m (or more) of relative sea-level rise in the Delaware Estuary.

Sediment accretion from accumulated plant matter and trapped sediments can act locally to offset this sinking and help land keep pace with sea-level rise. However natural accretion rates are rarely more than 5 mm yr^{-1}. If sea level rises 1 m by 2100, at some point the rate must become greater than 10 mm yr^{-1}, and so accretion is unlikely to be sufficient to offset sea level rise and subsidence in most areas.

8.4 Actions and Needs

Predicting rates of sea-level rise is critically important for coastal planners and resource managers due to the tremendous consequences for people and the environment, which depend on the timeline. Natural ecosystems and living resources all have tolerance limits for the rate of change to which they can adapt. Tipping points might be breached for some habitats such as salt marshes, a hallmark feature of the Delaware Estuary.

More research and monitoring is needed to track whether sea-level rise is contributing to or will contribute to increased salinity in the estuary and intrusion into groundwater. Since relative sea-level rise differs from absolute sea level rise, some of the elevation benchmarks may need to be replaced around the estuary due to past subsidence causing potential inaccuracies.

8.5 Summary

Sea levels in the Delaware Estuary have risen by about a foot in the last century (~0.3 m), which was a faster rate of increase than the previous 15 centuries when it was about half a foot per century. Over the next 90 years, most agencies are now planning for at least a 3 foot (0.9 m) rise, perhaps more. The science is still evolving, and scientists and managers will need to stay abreast of new developments and plan carefully and accordingly because of the potential severe effects of this scenario on coastal flooding and natural resource sustainability.

9 - Additional Considerations & Indicator Needs

9.1 Storm Intensity and Frequency

Climate change is expected to lead to environmental conditions that would support more frequent intense storm events, including both warm-season tropical cyclones (Kerr 2010) and cool-season extratropical cyclones (Lambert and Fyfe 2006). However, there is considerable scientific uncertainty in predicting future storminess. Looking at past trends, it is unclear whether storm intensity or frequency have increased, although as noted previously there is some evidence from surrogate indicators (extreme precipitation events) that storms may be on the increase.

As a proxy for storm intensity, barometric pressure data was examined from Atlantic City for the period 1947-2010 (except for 1965-1972 when data were not available). Daily mean atmospheric pressures were adjusted to sea-level, which is done to standardize pressure data collected from different stations that have different altitudes (Atlantic City station is located at 18 m elevation). The number of days per year with mean pressures below 1000, 990, and 980 millibars (mb) were counted, as well as the number of two-day events below 1000 mb. The number of days per year with low pressure was then contrasted among decades. No trends were apparent in any of these low-pressure proxies for storm intensity or frequency (e.g., Fig. 7.15). Since Atlantic City is not situated within the DRB and the long-term dataset is incomplete, it may be worth identifying and analyzing other relevant long-term datasets for atmospheric pressure or other direct indicators of storm severity for the Mid-Atlantic region.

9.2 Biological Indicators of Climate Change

This chapter summarizes past and predicted changes in physical conditions that are related to climate because these have generally been monitored and reported for a long time and because they serve as ecological drivers that govern biological activity. However, there is also a need to identify and develop biological indicators of climate change, which document ecological responses to changes in physical conditions. Biological indicators of climate change can take the form of altered species-species relationships (e.g., pollinators, shorebirds/horseshoe crab eggs), altered functionality and ecosystem services (e.g., water filtration by suspension-feeders, carbon sequestration by wetlands), and shifting species ranges (all major taxa), life history strategies (e.g., subtidal versus intertidal oysters) or physiological ecology (e.g., thermal stress, and oxygen consumption rates).

The Delaware Estuary and River Basin have high biodiversity, and preservation of this diversity is important for many reasons. However, a limited subset of plants and animals are often the functional dominants in terrestrial and aquatic habitats. These dominant biota and their associated habitats perform numerous life-sustaining services to people and natural resources (e.g., clean air and water, fish and wildlife habitat, nutrient and carbon sequestration, primary production of food, and microbial remineralization). Therefore, it will become increasingly important to sustain these key resources despite changing climate conditions and increasing pressures from human population growth and continued development.

To report the status and trends of future biological indicators of climate change, investments are needed in research and development of the indicators and associated monitoring infrastructure in cases where appropriate metrics are not currently being tracked.

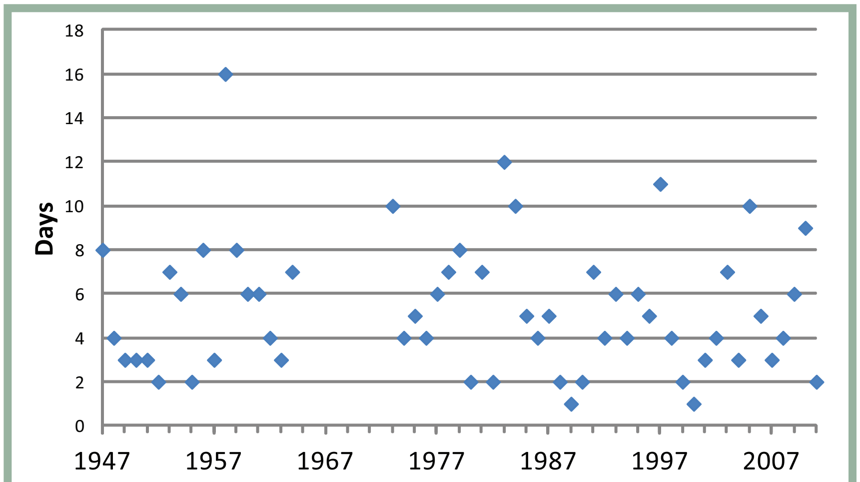

Fig. 7.15. Number of days per year for which the mean atmospheric pressure was less than 1000 mb at Atlantic City, NJ

9.3 Interactions Between Climate Change and Watershed Change

The consequences of future climate change for people and natural resources in the DRB are expected to vary in severity and rapidity. Some changes are expected to occur gradually, whereas others will appear suddenly when thresholds are breached. At the same time, the human population is expected to increase by 80% by 2100 (Kreeger et al. 2010). Until improvements are made to tracking of status and trends, it may be challenging to attribute specific changes to climate change because of complex interactions in the region's ecosystem. Living resources and habitats that are stressed because of direct anthropogenic impacts (e.g., development and pollution) are likely to be more vulnerable to the negative aspects of climate change. On the other hand, the longer growing season and increased plant productivity could impart some added resilience to buffer changes.

To discern between watershed change and climate change as drivers for future changes in environmental conditions, it will be increasingly important to monitor key ecosystem conditions. Currently, resource managers in the Delaware Estuary and River Basin are hampered by a lack of an ecosystem-based, watershed-based model that describes the basic physical, chemical and biological interactions that currently exist. Although cross-sector communication has increased in recent years, managers continue to focus on particular aspects of the system without a holistic context that would be provided by an ecosystem model. Development of an ecosystem-based model would help today's and tomorrow's managers more effectively address and discern the effects of climate and watershed change and to strategically respond to negative stressors with countermeasures.

10 – Summary

An analysis has been conducted of changes in a wide variety of climate metrics in the Delaware River Basin and sea level in the Delaware Estuary. It was found that the watershed is getting warmer and wetter, as expected given the observed increase in greenhouse gases. However, the magnitude and timing of the precipitation change is not consistent with climate model simulations and thus may be a result of natural variability. Some metrics of extreme temperature and precipitation are following changes in mean conditions. For example, decreases in ice-jam and frost day frequency and an increase in the number of heavy precipitation days were found. However, many metrics of extremes, including storminess, do not show significant trends. Wind speeds have declined substantially but the causes are not well understood. Streamflow is generally on the increase, and is consistent with the precipitation change. Finally, sea level is on the rise in the Delaware Estuary, exceeding the global average rate due, at least in part, to local subsidence. In summary, many aspects of the climate of the Delaware estuary and its watershed are undergoing change, and there is some understanding of these changes. A modeling framework that links the atmosphere to the watershed and its estuary will not only help to improve understanding of past change but allow for more robust future predictions.

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8

Restoration

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Chapter 8 – Restoration

Introduction

The objective of this section is to provide information on restoration efforts and progress in the Delaware Estuary. Whereas Chapters 1 to 7 review the status and trends of environmental indicators, this chapter is a first attempt to gauge the success of our collective efforts to *improve* environmental conditions via management actions that protect, enhance, and restore the system. To date, no entity has quantified the cumulative management and restoration progress across the basin. The indicators presented in this chapter should therefore be regarded as baseline measures to be strengthened in future expanded assessments of management progress. Restoration data from multiple states and programs are challenging to collect and analyze, and for this pilot attempt the indicator analyses are based on limited project tracking data routinely collected for the National Estuary Program and which were available at the time of this report. Future efforts to assess management and restoration progress are expected to be enhanced with the advent and implementation of new tracking tools being developed at the Partnership for the Delaware Estuary (PDE), some of which are discussed in this chapter.

The term restoration can be thought of in several ways. Ecological restoration indicates that degraded and destroyed natural systems will be reestablished to sites where they once existed. Restorationists have considered this at length and addressed them in the current definitions of restoration and restoration-type activities. A simple and useful definition of restoration was developed by the National Research Council (NRC). In its 1992 report, *Restoration of Aquatic Ecosystems*, NRC defined restoration as the "return of an ecosystem to a close approximation of its condition prior to disturbance." Also, the Society of Ecological Restoration defines ecological restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.

The concept of restoration is further clarified by defining many types of restoration-related activities. There are many "non-point" management actions that can be considered as restoration activities, such as land and habitat protection, flow management and pollutant regulation. However, for our purposes here "restoration" is used to mean on-the-ground actions that create, enhance, or restore natural resources. In the future with better data, management progress should be broadened to include any actions or decisions that lead to improvements in environmental conditions as assessed by the indicators in Chapters 1-7, such as by the elimination or reduction of stressors that degrade natural conditions. In addition to traditional restoration of past natural conditions, the following terms describe activities that are considered as part of restoration for the purposes of this chapter.

Fig. 8.1. Example of reestablishing a riparian buffer along a tributary in the Delaware Estuary

Establishment (also referred to as "creation") is the manipulation of physical, chemical, or biological conditions to facilitate development of a target habitat that is representative of natural conditions but that did not previously exist at the project location. Establishment results in a gain in acres for the target habitat. For example, establishment occurs when a wetland is placed on the landscape by some human activity on a non-wetland site (Lewis, 1989). Typically, a wetland is created by excavation of upland soils to elevations that will support the growth of wetland species through the establishment of an appropriate hydrology.

Reestablishment is the manipulation of physical, chemical, or biological characteristics of a site with the goal of returning natural/historic habitat types and functions to the site. Reestablishment results in the rebuilding of a former habitat and a gain in acres for that target habitat.

Enhancement is the manipulation of physical, chemical or biological characteristics of a site to strengthen ecological conditions and functions, such as for the purpose of improving water quality, flood water retention, or wildlife habitat. Enhancement typically results in improvement of structure and/or function without an increase in acreage.

Rehabilitation is similar to enhancement and is defined by the EPA as the manipulation of the physical, chemical or biological characteristics of a site with the goal of repairing natural/historic functions of a degraded habitat. Rehabilitation results in a gain of habitat function but does not result in a gain of acres for that habitat.

USDA-NRCS-NJ

Fig. 8.2. Example of enhancement: Streambank erosion on Walnut Brook. Left April 2007, Right August 2009

In all types of restoration, changes in ecosystem conditions should result in a net gain or improvement in those targeted natural goods and services that are deemed of highest value by managers. Since the environmental conditions at any location never have zero value, scientists and managers must recognize that any manipulation results in tradeoffs in habitats, living resources and functions. Efforts to control mosquito populations and improve fish habitat by digging ditches in wetlands could result in decreased vegetation cover and carbon sequestration services. Restoration activities therefore ultimately reflect value judgments that can differ among different sectors of the scientific and management community. Our goal is to quantify restoration progress that reflects the current consensus view on ecological priorities, focusing on key natural resources that typify the Delaware Estuary and River Basin.

Activities that might be considered restoration progress but which do not necessarily fit the definition of restoration given on the previous page include the following:

Protection is defined as the removal of a threat to, or preventing the decline of, natural healthy environmental conditions. This includes management actions such as land acquisition, conservation easements, deed restrictions, etc. or other designations to prevent alteration of natural site conditions. This term also includes activities commonly associated with the term "preservation". Although protection efforts are critically important for sustaining natural goods and services, they do not result in a net gain of hectares or habitat function relative to past conditions

Mitigation refers to the "restoration, creation, or enhancement of wetlands to compensate for permitted wetland losses" (Lewis, 1989). Here, we also extend that definition to include other natural habitats. For example, under Section 404 of the Clean Water Act, wetlands may be legally destroyed, but their loss must be compensated by the restoration, creation, or enhancement of other wetlands. In theory, this strategy should result in "no net loss" of wetlands. Other programs that are similar include the Natural Resource Damage Assessment (NRDA) Process and Supplemental Environmental Projects (SEPs). Whether mitigation is successful or not, the goal is to simply replace or repair injured natural resources, meaning that these activities do not (and in some cases legally cannot) result in net gain in habitat acreage or functions relative to pre-injury conditions.

The approach taken in this chapter was to develop new indicators that reflect restoration activities across the Delaware Estuary and Basin, focusing on metrics that can be quantified such as hectares, locations, and types of habitats restored and available data. It's important to note that in contrast to these restoration activities, many important habitats are continuing to be lost or degraded (see other chapters).

1 – Hectares Restored Annually

1.1 Description of Indicator

Many important resources are found in the Delaware Estuary and Basin. For example, the estuary contains more than 163,897 hectares of wetlands, more than 50,990 of which are recognized as internationally important (PDE 2006). The tidal portion of the system is also one of the largest freshwater tidal estuaries in the world, and despite losing >95% of rare freshwater tidal wetlands the system still has more hectares of this habitat type than anywhere else in the United States. The Delaware Estuary also has 185 natural vegetation community types encompassing 35 broader-scale ecological systems. Delaware Bay contains the largest breeding population of horseshoe crabs in the world. The watershed also contains critical habitat for endangered populations of dwarf wedgemussels, two species of sturgeon, and bog turtles.

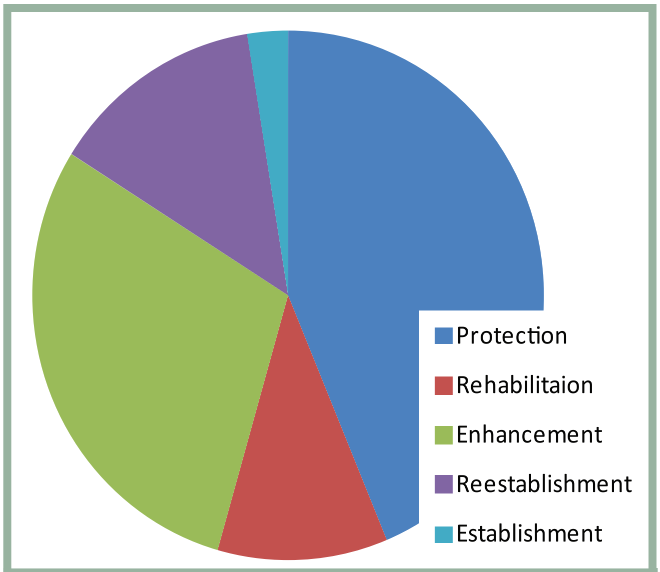

Fig. 8.3. Comparison of the land area protected versus restored by between 2000 and 2011, as reported in NEPORT

Considering the tremendous habitat diversity, numerous geopolitical boundaries, and large size of the watershed, efforts to track restoration progress are hampered by limited data availability among the many different agencies and programs that are responsible for restoration. One of the most straightforward ways to track habitat restoration is to determine hectares restored annually, focusing on voluntary actions (and not reparative, regulatory based actions such as mitigation projects). However, tracking the loss of habitat is also helpful to put restoration into context. Ideally, restoration activities should also be assessed for specific habitat types. In the future, it would be beneficial to also assess the functionality of restored habitats, since a particular site could be "restored" significantly without any net increase in acreage. However, at present, finding information about all of these activities is difficult. For this pilot effort, we relied on acreage data that has been reported as restored (and also protected) by each state (New Jersey, Pennsylvania, and Delaware) annually using the EPA's National Estuary Online Reporting Tool (NEPORT).

NEPORT is a web-based database that EPA has developed for National Estuary Programs (NEPs) to track annual acreage of habitat improvement efforts. This is a part of the goals of the 1996 Comprehensive Conservation and Management Plan (CCMP) for the Delaware Estuary. The Partnership for the Delaware Estuary has been collecting data on completed restoration projects from partners (mainly state agencies and PDE initiated projects) since 2000 to report to the EPA each year. The EPA then provides the project information for every National Estuary Program on this website: http://www.epa.gov/owow_keep/estuaries/pivot/mapping/sat.htm .

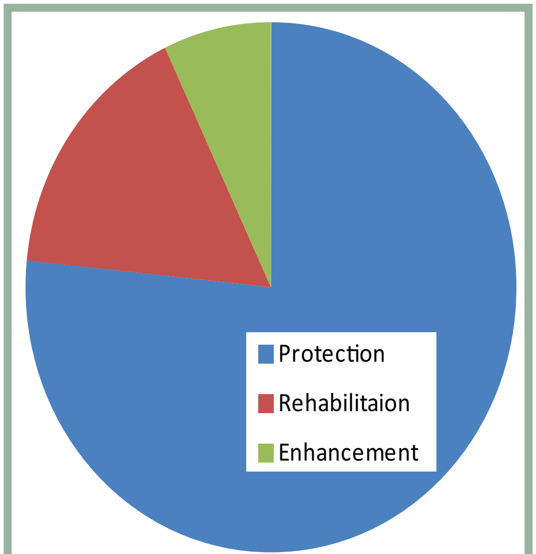

Fig. 8.4. Comparison of land area protected versus restored in 2011 as reported in NEPORT

Unfortunately, there is no coordinated tracking system at this time to determine how many *net* hectares have been restored or gained/lost in the watershed, and NEPORT is not comprehensive due to it only showing project data that has been voluntarily provided from partners of the Partnership for the Delaware Estuary. These data therefore represent only a fraction of restoration progress at the watershed scale. Since a similar approach has been followed for more than ten years it is possible to examine trends in restoration progress using NEPORT data alone as an indicator. However, it should be noted that EPA does occasionally make changes from time to time on how NEPORT data is reported. Another advantage of NEPORT data is that the tracking program excludes actions associated with mitigation (e.g. NRDA, SEP), which are designed simply to correct for discrete injuries. Although protection efforts are not the focus of this chapter (see above), NEPORT data for protected acreage are also shown here for comparison purposes.

1.2 Present Status

Since quantitative data on the number of hectares restored is best considered temporary (see trends, Section 1.3), the present status was examined qualitatively by contrasting the types of restoration progress made in the Delaware Estuary according to NEPORT. NEPORT tracks restoration as: protection, rehabilitation, enhancement, reestablishment, or establishment. The relative balance of these activities for the entire reporting period is 2000-2011 (Fig. 8.3) and indicates that considerably more land area has been protected than restored. Among the four types of restoration tracked in NEPORT, more area was enhanced than rehabilitated or reestablished, and newly created acres (establishment) represented a very small portion of overall efforts.

As noted above, protection does not improve ecological conditions. Therefore, summing acreage data from NEPORT does not give a clear representation of actual net ecological improvement since so much of what is reported took the form of protection (Fig. 8.3). This finding is even more important for the most recent NEPORT data from 2011 (Fig. 8.4), which shows that protection accounted for more than three-quarters of total proportional activity types.

1.3 Past Trends

As a National Estuary Program, the Partnership for the Delaware Estuary is responsible for setting restoration goals (including protection) every year, and since the advent of NEPORT tracking in 2000 this annual goal has been about 1012 hectares. As noted above, tracking restoration is challenging because PDE must rely on voluntary reporting by partners. Year to year variation in restoration investment also tends to vary greatly because projects are typically grant-funded and thus subject to funding fluctuations. Despite these caveats, restoration progress since 2000 has been considerable (Fig. 8.5). The annual progress is shown in Fig. 8.5 in comparison to the annual target of 1,012 hectares for the combination of protection and restoration. This target was met in eight of twelve years, and the overall amount of area protected or restored for the twelve-year period was 26,658 hectares. (Reported by Pennsylvania, Delaware, and New Jersey, City of Philadelphia and projects funded through the National Fish and Wildlife Foundations Delaware Estuary Watershed Grants Program to the Partnership). In most years since 2000, protection efforts surpassed restoration efforts, largely due to data reporting from programs such as New Jersey Green Acres that provides funding for land acquisition.

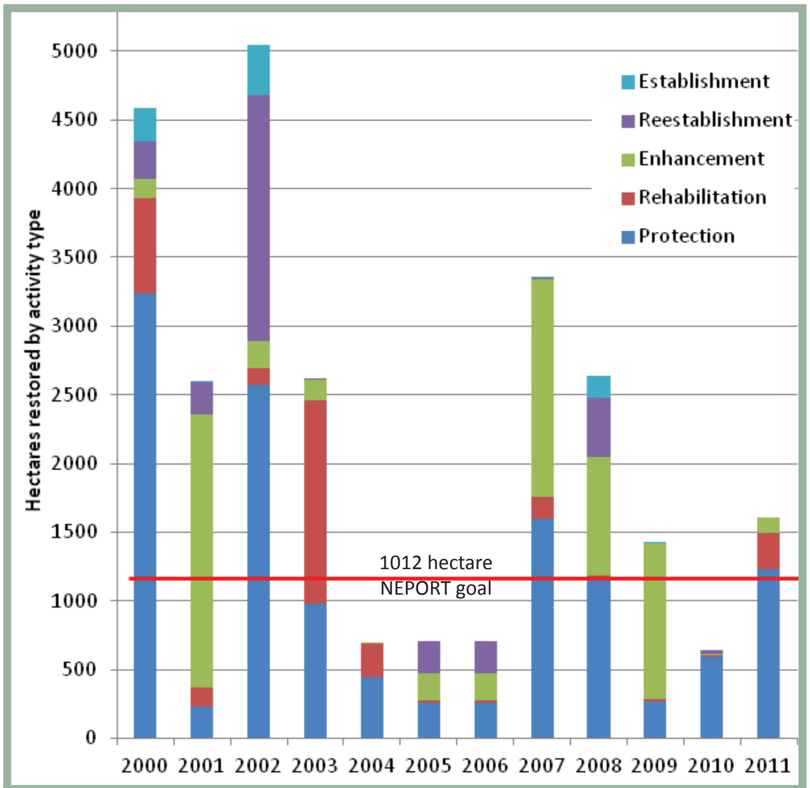

Fig. 8.5. Hectares restored and protected annually between 2000 and 2011, with four types of restoration reported separately, in relation to the annual NEPORT goal set by the Partnership for the Delaware Estuary

1.4 Future Predictions

The amount of area restored per year in the Delaware Estuary (per NEPORT) through non-mitigation, voluntary actions is dependent on funding, especially from state and federal agencies. The restoration need is high (as judged by the continuing losses of critical habitats, see Section 1.5) and funding for restoration is limited. However, we are optimistic that in the long term the pace of restoration will hasten as our understanding of the ecological and economic consequences of inaction increases. In the short-term, we anticipate that the recent trend in restoration investment will be sustained and that the Estuary Program will continue to meet the annual 1012 hectare goal. This progress could be undermined with continued reductions in funding, especially for open space protection.

1.5 Actions and Needs

Unfortunately, hundreds of thousands of hectares of natural habitats have been destroyed or significantly altered in the Delaware Estuary watershed during the past 10-15 years despite many governmental protections (see other chapters). Losses of forest area due to development (Chapter 1) and erosion of coastal wetlands (Chapter 5b) appear to far exceed any gains from restoration. Since these natural habitats purify our water, provide clean air to breathe and furnish other critical goods and services enabling the survival of both humans and natural communities, this trend in net loss of natural habitats is unsustainable, especially considering projections for human population growth (chapter 1). The Comprehensive Conservation Management Plan (CCMP) requires that restoration, protection and enhancement of natural habitats be a primary program objective of the Partnership for the Delaware Estuary, and a critical need will be to sustain funding for implementation of the CCMP as well as other core management programs that seek to reverse the declines in natural capital for the region, and to boost investment in voluntary restoration and protection of our remaining natural habitats.

Considering the limited restoration funding and high need, careful prioritization will be essential so that projects that get implemented target the most critical needs for maintaining core estuarine functions (PDE 2005, 2007, Kreeger et al. 2006). The Delaware Estuary Regional Restoration Initiative (RRI) is an example of a prioritization program that seeks to identify the most ecologically significant species and habitats in a geospatial framework and then to direct restoration efforts to pivotal places and activities that lead to the greatest "uplift" of these resources. Ecologically significant is a designation given to natural resources which supply critical ecosystem goods and services, such as by a functional dominant species or habitats (or if they are rare then they must be threatened or a hallmark feature of the watershed). The RRI also intends to build efficient collaborations to spatially map and track restoration actions and build science-based consensus on restoration priorities.

Future monitoring and assessment reports would also be strengthened by development of enhanced tracking tools for restoration data, enabling better comparisons with land use data on habitat losses such as associated with development. One example of how tracking data can be used to inform habitat prioritization from the Schuylkill Watershed is a project by the Schuylkill Action Network and Delaware Valley Regional Planning Commission (DVRPC). The Schuylkill Watershed Priority Lands Strategy uses GIS modeling to identify areas within the Schuylkill Watershed that are the most important to preserve for both ecological and drinking water source protection, further defined by development threat over the next 20 years. Because developed land in the Schuylkill Watershed is expected to increase by 40% over the next two decades, this strategy can be used to direct inappropriate uses away from high priority resource areas as well as a guide to where restoration efforts can be most effective. The model is a series of maps that can be viewed on-line at http://www.schuylkillprioritylands.org/index.html. DVRPC has used this model to set goals for protection. See also Chapter 1, section 3.5, for actions and needs regarding land protection based changes in land cover trends.

1.6 Summary

Quantitative measures of land area restored annually in the Delaware Estuary can be an effective way to track management progress, and analysis of limited data suggests that some progress has been made since 2000. However, the current tracking system used by the Partnership for the Delaware Estuary (NEPORT) is not designed to be comprehensive for the watershed, and it gives a biased estimate of the amount and type of restoration in the estuary because of the limited voluntarily-contributed data that it is based on. It is useful as a progress indicator because annual data collection has been consistent for a sufficient period to examine trends, showing that some management targets set by the National Estuary Program have been met. Improvements in such reporting would be to strengthen future status and trends reporting on management progress. Although NEPORT data significantly underestimates actual restoration investment across the entire Delaware Estuary and Basin, the amount of land area restored between 2000-2011 was certainly dwarfed by mounting losses of natural lands due to development and other factors, as demonstrated by land use land cover changes described in Chapter 1. This clearly suggesting that management progress via restoration is not keeping pace with overall needs to sustain core habitats.

2 – Balance of Restoration Project Types

Introduction

In addition to the assessing the amount of area restored, it is helpful to track the types of habitat that are being restored to ensure that restoration progress reflects the balance of habitats that have suffered the most degradation and/or are currently being lost most rapidly. For example, coastal wetlands are a hallmark feature of the Delaware

Estuary, are critical for supplying diverse benefits to people and the environment, and we have lost more than half of our coastal wetlands mainly because of direct filling and development (Chapter 5b). Deciduous forests are similarly vital for sustaining source water quality and other services, and forest losses continue to be swift due to development (Chapter 1). Has restoration (and protection) investment over the past decade targeted these (and other) crucial habitats that are in decline? Similar to Section 8.1, data from the National Estuary Program Online Reporting Tool (NEPORT) was examined to discern what types of habitats have generated the greatest restoration attention since 2001.

2.1 Description of Indicator

Healthy estuaries depend on a complex mix of habitats, and every estuary has its unique character and habitat assemblage. Although the Delaware Estuary and Basin is home to dozens of different habitats and ecological communities, it is most distinct because of its abundant, protective forests in the headwaters, broad freshwater tidal area that supports rare biotic assemblages, and a wealth of coastal wetlands that fringe the tidal estuary. Hundreds of thousands of hectares of natural habitats have been destroyed or significantly altered in the Delaware Estuary watershed. These systems purify our water, provide clean air to breathe and furnish other critical goods and services enabling the survival of both people and natural communities. To get the greatest benefits, voluntary (non-mitigation) attempts to rebuild these habitats should reflect the natural balance of types that characterizes the watershed.

2.2 Present Status

Fig. 8.6 shows a comparison of all the hectares restored between 2000 and 2011 by habitat type. Tidal wetland and forests have been the focus of management attention since 2001, judging from the combined data for protected and restored habitat types (Fig. 8.6). Most of this was via protection (see Section 8.1) and efforts to protect and restore tidal wetlands represented the greatest progress.

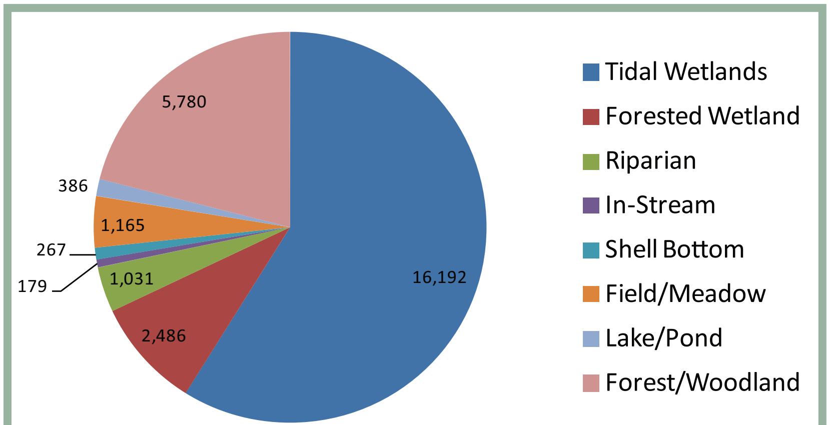

Fig. 8.6. Comparison of hectares restored by habitat type between 2000 and 2011 as reported in NEPORT

In general, the relative balance of protection and restoration progress compared among habitat types does therefore match the types of habitats that have been experiencing the greatest losses, tidal wetlands and forests. As noted in Chapter 5b, it is believed that more than half of our tidal wetlands have been lost in the Delaware Estuary compared to pre-settlement acreage, acreage losses between 1996 and 2006 exceeded 2%, and future projections suggest that a minimum of 50,000 more hectares will be lost by 2100 with a sea level rise of one meter. Forests continue to be lost at an even faster clip, and the cumulative impacts from natural gas drilling and other contemporary challenges threaten to hastenloss rates in the upper basin. In the future, continued focus on tidal wetlands and forests is therefore warranted. Some other habitats that have been prioritized such as bivalve shell reefs are arguably even more vital, but they are also smaller in size and harder to capture in terms of hectares.

2.3 Past Trends

The amount of area protected and restored varies widely among years and among habitat types (Fig. 8.7). There is considerable variability among years and habitats due mainly to fluctuations in available funding from year to year, as well as shifts in reporting from various state and local partners who report data to NEPORT. Although it is difficult to draw any conclusions from these limited data, there is an apparent downward trend in the total acreage restored and protected. There also appears to be an increase in the diversity of project types reported to NEPORT. It is possible that these differences simply reflect variability in reporting rather than real patterns.

2.4 Future Predictions

Several analysis and planning initiatives currently exist to prioritize protection and restoration activities at the watershed scale in the interests of targeting key species, habitat types, and places to more effectively increase not only the acreage restored but the overall health and functionality of the estuary's key ecosystems. For example, in November 2011, The Nature Conservancy and partners completed a set of protection and restoration strategies to conserve the Delaware River Basin from the headwaters to the Bay. Their prioritization report (TNC 2011) included various strategies to target high value places in the landscape for protection and restoration. Floodplains, shellfish populations, and habitat for migratory fish were some of their focal resources.

PDE's Regional Restoration Initiative, introduced in 2009, similarly attempts to guide future decisions on restoration, protection and enhancement by focusing on habitat types and living resources that furnish key ecosystem goods and services, and identifies for places in the landscape where restoration action can yield the greatest return on investment. As part of the RRI, a technical workgroup (Regional Restoration Workgroup of the STAC) and a decision-maker group (PDE Alliance for Comprehensive Ecosystem Solutions) have been formed to help implement the regional restoration approach using an iterative, science-based approach. Current habitat priorities for the RRI are urban waterfronts, tidal wetlands, headwater streams, and bivalve shellfish. As part of this effort, an online Project Registry helps to identify and fund priority restoration activities, and as this registry further develops it is expected to also be useful for gathering data future indicator reports such as this. Both efforts hold great promise for increasing the quality and quantity of restoration in the Basin, but only to the extent that funding is available to do the work.

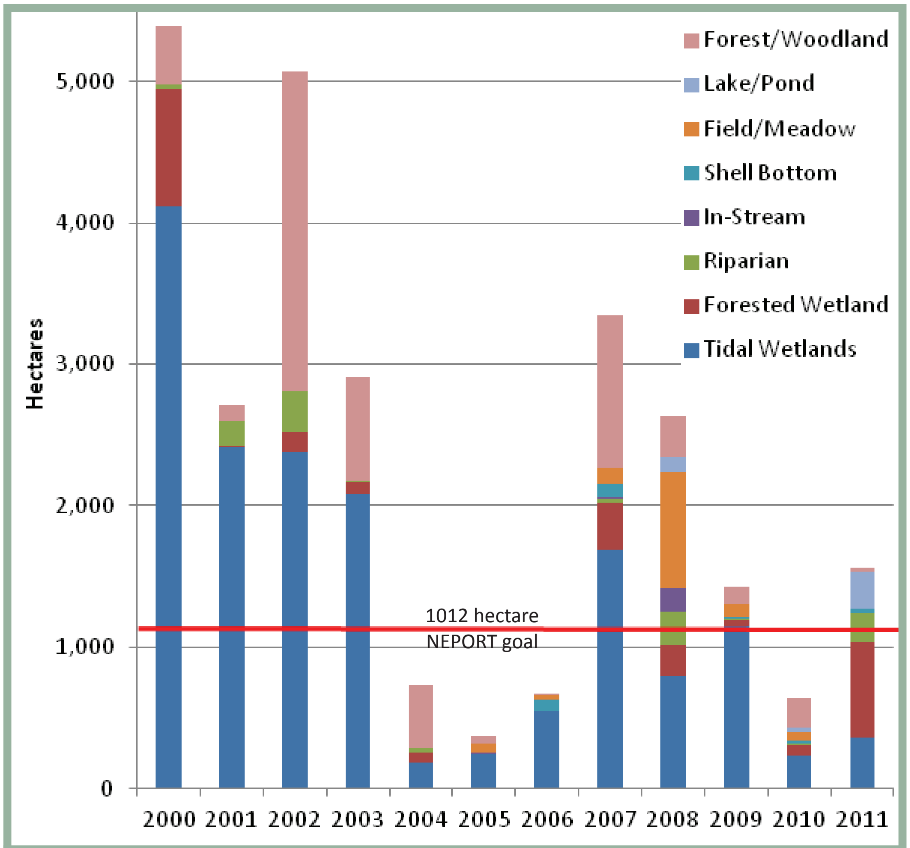

Fig. 8.7. Hectares restored annually by habitat type

2.5 Actions and Needs

In addition to setting overall goals for the amount of habitat to be restored, restoration investment should target habitat types that are deemed most critical for preserving the character and functionality of the unique Delaware Estuary watershed. New conservation and restoration prioritization tools that specify habitat types and places to be targeted should be used to guide strategic investments. To facilitate smarter restoration as well as progress tracking, data for completed projects should be entered into the PDE project Registry, along with data on unfunded project needs. Increased promotion, use, and maintenance of the PDE project registry could provide additional valuable information for continuing this effort in the future.

2.6 Summary

The balance of habitat types restored and protected in the past 12 years can be analyzed with data from the National Estuary Program Reporting Tool. Although results from this analysis should be interpreted with caution because the dataset is limited, restoration progress in the Delaware Estuary appears to be targeting the appropriate habitat types that are considered most vital and which are experiencing greatest losses.

3 – Restoration Need

Introduction

The need for more restoration in the Delaware Estuary and Basin is sizeable and plain to see judging from the disparity between the historic and recent losses in acreage of natural lands (see other chapters) and the relatively small gains in acreage from restoration efforts over the past decade (see Section 8.1). Although science-based planning tools have been recently developed to guide strategic restoration and protection investment at the watershed scale, these tools will be useless without funding to implement new projects to offset losses that go well beyond site-specific, regulatory-based mitigation. In the future, PDE and partners intend to further clarify the restoration need by developing new metrics and indicators. In this section, we provide a foundation for this future effort by gathering limited data on our restoration need, contrasting this with the level of current investment, and comparing results to some other large American "Great Waters".

With the continuous loss of habitat from development and sea level rise and lack of funding for environmental conservation, strategic measures need to be taken to implement restoration actions aimed at reaching the maximum ecological function for priority habitats while using scarce resources wisely and developing future funding sources. PDE's Regional Restoration Initiative establishes the framework for a watershed-wide ecosystem based approach to management and restoration using some basic tools. There are a vast array of projects and actions that impact the restoration status of the estuary at a local, regional, and estuary/coastal stage, it is very challenging to catalogue and evaluate the cumulative effect of all these actions.

Better tools need to be developed to be able to track completed restoration projects throughout the estuary, to prioritize restoration and know restoration project gaps, and to monitor completed restoration projects to ensure that the ecosystem function is being restored and to gain knowledge in order to improve future restoration. A sustainable funding source will likely be required. However, progress has been made in ecosystem based approaches including an evaluation of the economic value of the Delaware Estuary (in terms of ecosystem services and economical benefits) by the University of Delaware. The report found that by using economic activity as a measure of value, the Delaware Estuary contributes over $10 billion in annual economic activity from recreation, water quality and supply, hunting and fishing, forests, agriculture and parks (Kauffman 2011). This information can be used to evaluate restoration actions and identify the ecological and economic benefits in addressing community needs.

The PDE Project Registry, part of the overall Delaware Estuary Regional Restoration Initiative, includes regional restoration needs in terms of submitted restoration projects and could serve as a clearinghouse for restoration projects across the watershed if well populated and maintained.

In addition to assessing restoration on a regional scale, restoration can also be assessed at a site, media, and or event level of scale. For instance, if a contaminated site or Brownfield property is cleaned up and/or restored, this is restoration at a local level. Often there is restoration of habitat as part of a cleanup and/or natural resource damage assessment. These types of projects, especially in a cumulative fashion, can support the restoration goals of the CCMP if the goals are considered and integrated. An example is ecological restoration of a shoreline area or tidal wetland as part of a removal or stabilization/containment remedy. The Clean Water Act through its permitting and enforcement provisions can support restoration efforts related to increasing water quality and obtaining targeted water quality uses, as well as protecting wetlands and other aquatic habitats. Through this process there can be cumulative permitted losses of aquatic habitat and functions for which mitigation projects are required. The cumulative impacts of both losses and mitigation benefits need to be evaluated on a more comprehensive basis in order to evaluate the impact of regulatory programs on estuarine restoration goals.

3.1 Description of Indicator

One approach to assessing restoration needs is to examine the present status for other indicators in this technical report, relative to past conditions. As a whole, this information is useful for managers who must establish restoration goals since they can frame realistic or stretch goals better when they are grounded in tangible data on ecological trajectories of change. But for the exploratory purposes of developing restoration specific indicator of restoration need, we can simply tally the total dollars required to fund pending projects in the new Delaware Estuary Project Registry. The registry is less than three years old and new projects are being added continually as restoration practitioners and managers learn about the registry and its dual purposes (matching projects with funders, tracking needs and implementation); therefore, the total need is substantially underestimated by the Registry. However, with increased promotion and use over time, the usefulness of this as an indicator should improve.

3.2 Present and Past Status

Currently, the project registry contains 90 unfunded projects totaling over 60,000 hectares of possible restoration throughout the Delaware Estuary and Basin. The projects currently in the registry that need funding have requested budgets totaling more than $10,500,000. These projects represent only a fraction of total watershed needs to reverse net losses and achieve no net loss of natural lands. Even if completely funded and implemented, continued annual restoration investment would be needed beyond the initial investment because of mounting development pressures from human population growth and changing climate conditions (e.g. sea level rise). This estimate of restoration need is tremendous, especially considering the difficult current financial situation. However, it represents only about 1.5% of the annual worth of the natural resources of the basin, which were recently valued as contributing over $10 billion in annual economic activity associated with recreation, water quality and supply, hunting and fishing, forests, agriculture and parks (Kauffman 2011).

The Delaware Estuary and Basin is also not unique, and other large American estuaries likely have similar needs. Another way to assess restoration progress is to look at how restoration investment here compares with investments in other large American "Great Waters". The Northeast-Midwest Institute recently reported (Strackbein and Dawson 2011) that the level of investment from one example federal agency, the US EPA, was considerably lower in the Delaware Estuary and Basin than eight of the other most significant aquatic systems that are managed discretely. This analysis suggests that federal environmental investment in the Delaware system is far less than 10%, perhaps even 1%, of that invested in the Chesapeake system (Fig. 8.8), despite having a similar human population.

Restoration investment can also be examined on a geospatial basin and contrasted with consensus views on restoration needs, using data from NEPORT (see Sections 8.1, 8.2), and this can then be compared with human population in those areas (Fig. 8.9).

Typically, restoration needs are higher in areas where human population is higher due to habitat degradation associated with pollution, development and other anthropogenic disturbances. Although most people live in the upper estuary region (Fig. 8.9), most protection and restoration progress between 2001 and 2011 has been made in other watershed regions (Fig. 8.10). For example, the Delaware Bay and Upper Estuary had more investment likely because larger tracts of land can be acquired and protected in these watersheds. This information can be useful for directing the funding for future priority projects, such as by focusing on identifying new opportunities to restore areas in urban landscapes. Further analysis of NEPORT and other data is needed to discern the locations of actual restoration projects. In general, protection is prioritized in less developed areas whereas restoration is prioritized in more developed areas.

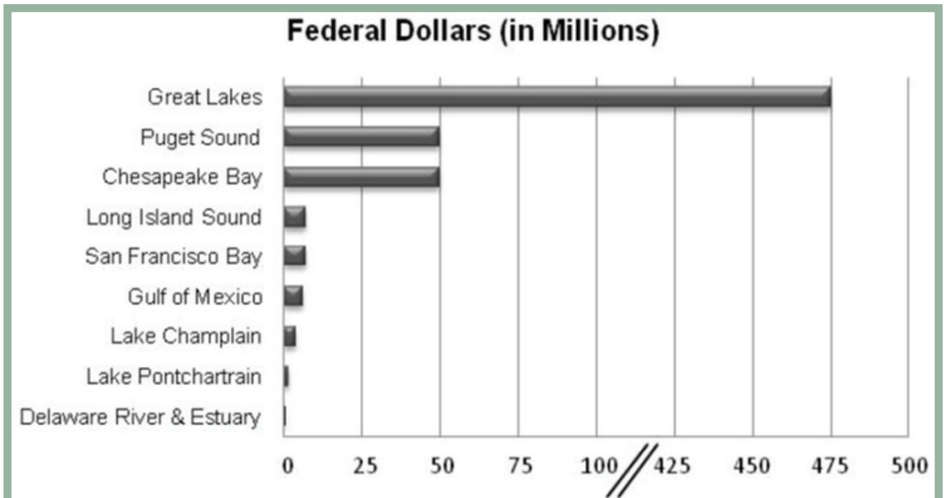

Fig. 8.8. Comparison of US EPA federal spending in FY2010 on environmental management and restoration in nine major water bodies in the United States (from Strackbein and Dawson 2011)

3.5 Actions and Needs

Until sufficient funding can be generated to materially stem losses of natural lands and restore critical habitats in the Delaware Estuary and Basin, management targets will need to be tempered and continued net losses of vital habitats will unfortunately still occur. There are a number of current efforts (PDE and others) to increase efficiency, implement strategic science-based priorities, and coordinate restoration activities. These include PDE's Regional Restoration Initiative and The Nature Conservancy's Delaware River Basin Conservation Initiative. However, these efforts will have limited benefits if restoration needs continue to be largely unmet because of stagnant and low levels of restoration investment across the Delaware Estuary and Basin.

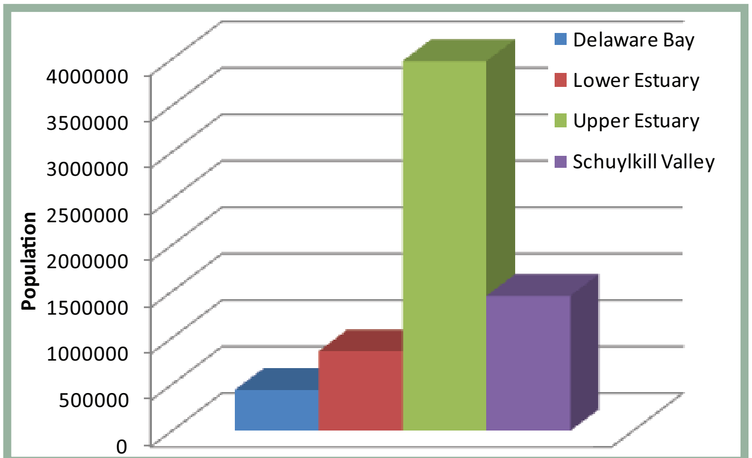

Fig. 8.9. Comparison of human population in the four watersheds of the Delaware Estuary

Therefore, the top restoration need is funding, which can be justified by the economic value of the resources that are being eroded every day. There are several efforts underway to raise awareness of the need and to build support for directed federal investment, including an effort to pass the Delaware River Basin Conservation Act mentioned in previous sections of this report. If successful and authorized, this would provide $5 million for the entire basin. Whether these efforts will be successful and how these funds will be used/prioritized to meet the needs of the estuary and basin is not clear.

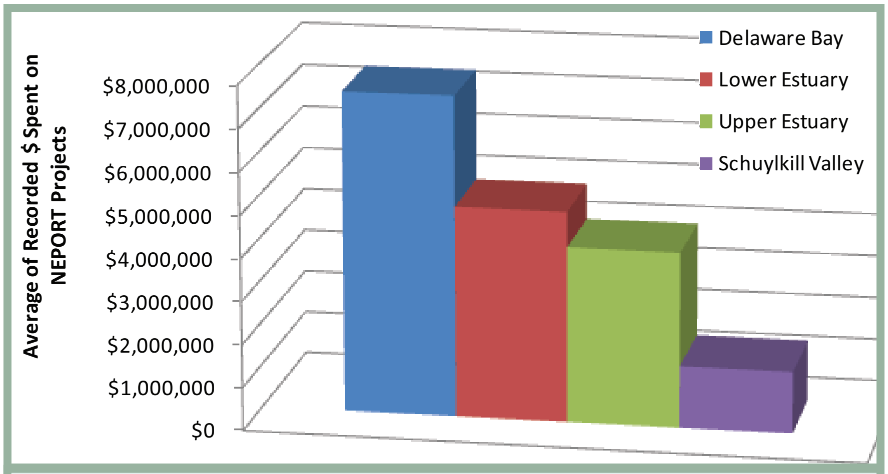

Fig. 8.10. Comparison of average $ spent between 2001 and 2011 in each watershed

In its Regional Restoration Initiative, the Partnership for the Delaware Estuary proposed the concept of a *Delaware Estuary Basin Science & Restoration Trust* (Kreeger et al. 2006, PDE 2009), that with sustainable and significant funding, would be capable of addressing diverse restoration needs associated with key living resources, habitats and water resources and which is science-based and guided by strategic monitoring and assessment data. Such a Trust would be maintained and operated by Trustees representing federal and state agencies and other groups that have worked together to develop shared, consensus-driven regional restoration priorities. In 2010 the PDE Alliance for Comprehensive Ecosystem Solutions was created based on this model, but without a designated source of funding. This public-private Alliance meets annually to assesses, prioritize and begin promoting a set of priority restoration projects for the Delaware Estuary each year. Without a designated source of funding it relies entirely on the existing resources of its partners to support projects, and so has mainly been successful at drawing attention and pooling existing resources to focus on priority projects. However, it is a framework that can be quickly and easily adapted and expanded into the more comprehensive funding Trust originally envisioned, in the case that a source of funding emerges or is created.

Sources of financing for a Trust were explored by PDE with help from the Delaware Community Foundation, the Environmental Finance Center (EFC 2007), the Global Environmental Technologies Foundation, and the Keystone Conservation Trust. The funding mechanisms identified by those efforts require more policy capacity and influence that PDE has – a challenge PDE has been working to address but which has been exacerbated by economic and political conditions in recent years.

In brief, the Trust would provide a new vehicle for accepting and pooling funding from a variety of sources to meet diverse needs, including funding priority restoration and protection projects elevated through the Regional Restoration Initiative. It could include numerous operating centers where contributions could be earmarked for specific protection, restoration, monitoring or scientific activities. The vision is for the Trust to direct and fund wise investments in the future of the Estuary.

3.6 Summary

The Delaware Estuary has significant restoration needs related to restoration of both ecosystem services, including those having significant economical consequences, and the health of local and regional communities. The main need in the Delaware Estuary is a regional restoration approach that can prioritize restoration needs, track restoration projects, identify and fill project gaps, and supply funding for high value projects. This will require coordination and sharing among various sectors and most importantly, development of a sustainable source of funding for restoration. Ideally, a broad-based Science and Restoration Trust is needed that would fund substantially more restoration and protection while also providing support for the science and monitoring that is needed to strengthen the scientific basis for restoration decision-making and outcome tracking.

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