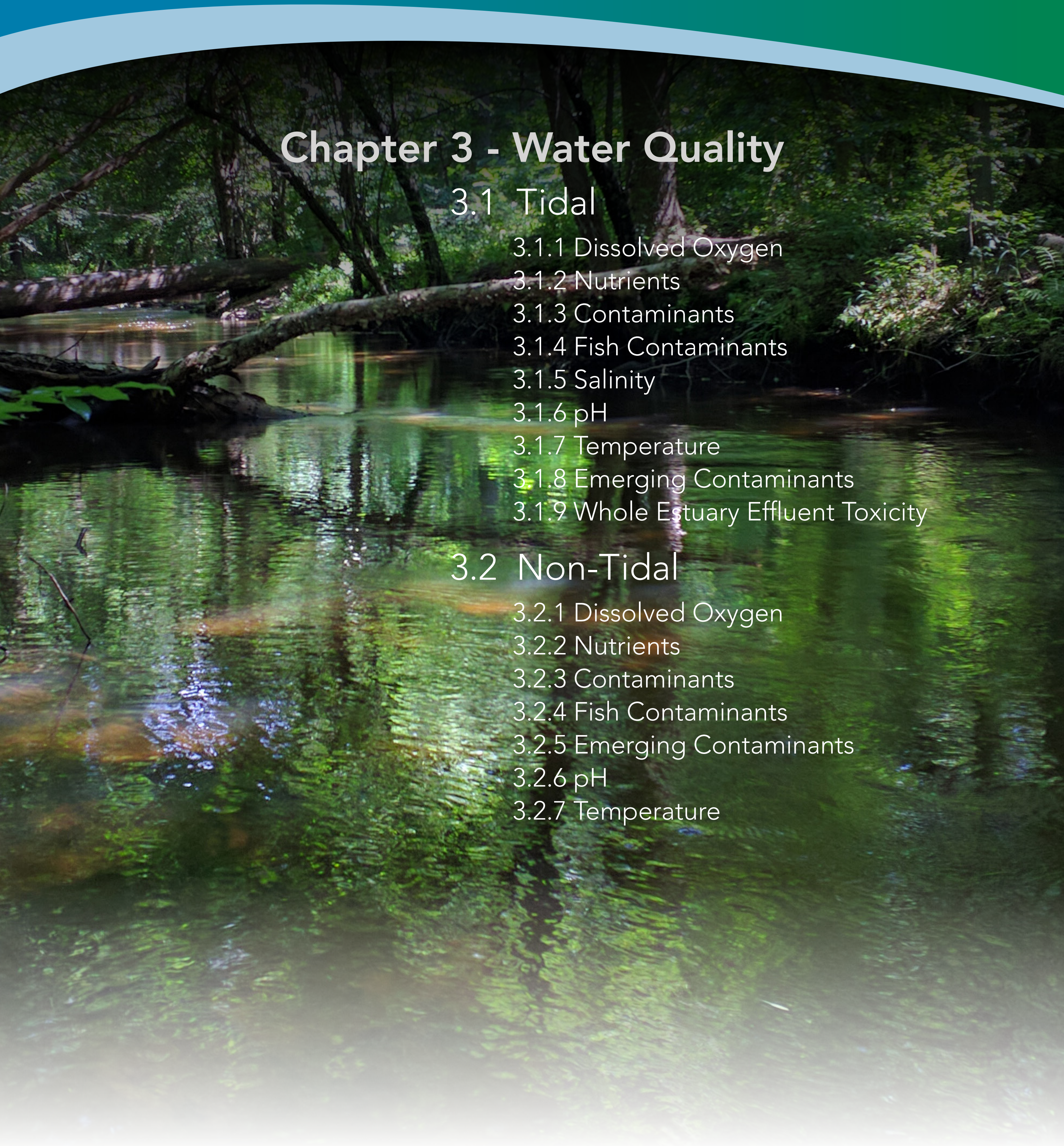

Chapter 3 - Water Quality

Partnership for the DELAWARE ESTUARY

December, 2017 | Report No.17-07

A publication of the Partnership for the Delaware Estuary—A National Estuary Program

3. Water Quality

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Delaware River Basin Commission

3.1 Tidal

3.1.1 Dissolved Oxygen

3.1.1.1 Description of Indicator

Dissolved oxygen (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 and stormwater runoff), 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, dissolved oxygen remains a critical issue for the Estuary because of continued depression of oxygen levels below saturation.

3.1.1.2 Present Status

Dissolved oxygen is measured routinely as part of the Delaware River Basin Commission's (DRBC) Delaware Estuary Water Quality Monitoring Program (formerly the Boat Run) and continuously by the U.S. Geological Survey (USGS) at Reedy Island (01482800), and April through November at Chester (01477050), and the Ben Franklin Bridge (01467200). DRBC's water quality standard for dissolved oxygen in the Estuary is a 24-hour average concentration not less than 5.0 mg/L in Zone 2, 3.5 mg/L in Zones 3, 4, and the upper portion of Zone 5, 4.5 mg/L in the middle portion of Zone 5, and 6 mg/L in the lower portion of Zone 5. In the most recent Delaware River and Bay Water Quality Assessment (DRBC 2016 http://www.state.nj.us/drbc/library/documents/WQAssessmentReport2016.pdf), greater than 98.5% of observations met criteria in Zones 2 through 5, and greater than 90% of observations met criteria in Zone 6.

DRBC has developed a daily near real-time assessment of DO comparing the 24-hour mean concentrations at USGS monitors to the DRBC surface water quality standard available at:

http://drbc.net/Sky/waterq.htm

In addition, DRBC has developed a web app for exploring the Estuary Water Quality Monitoring data at:

https://johnyagecic.shinyapps.io/BoatRunExplorer/

Figure 3.1.1 shows a screen shot of the DRBC Delaware Estuary Water Quality Explorer web application, which allows users to develop their own visualizations of Delaware Estuary water quality data. This selection shows the structure of dissolved oxygen along the profile of the Estuary as measured by the Delaware Estuary Water Quality Monitoring program. As shown, dissolved oxygen saturation levels are higher at the upper and lower ends of the Estuary, with a sag in the most urbanized portion of the Estuary.

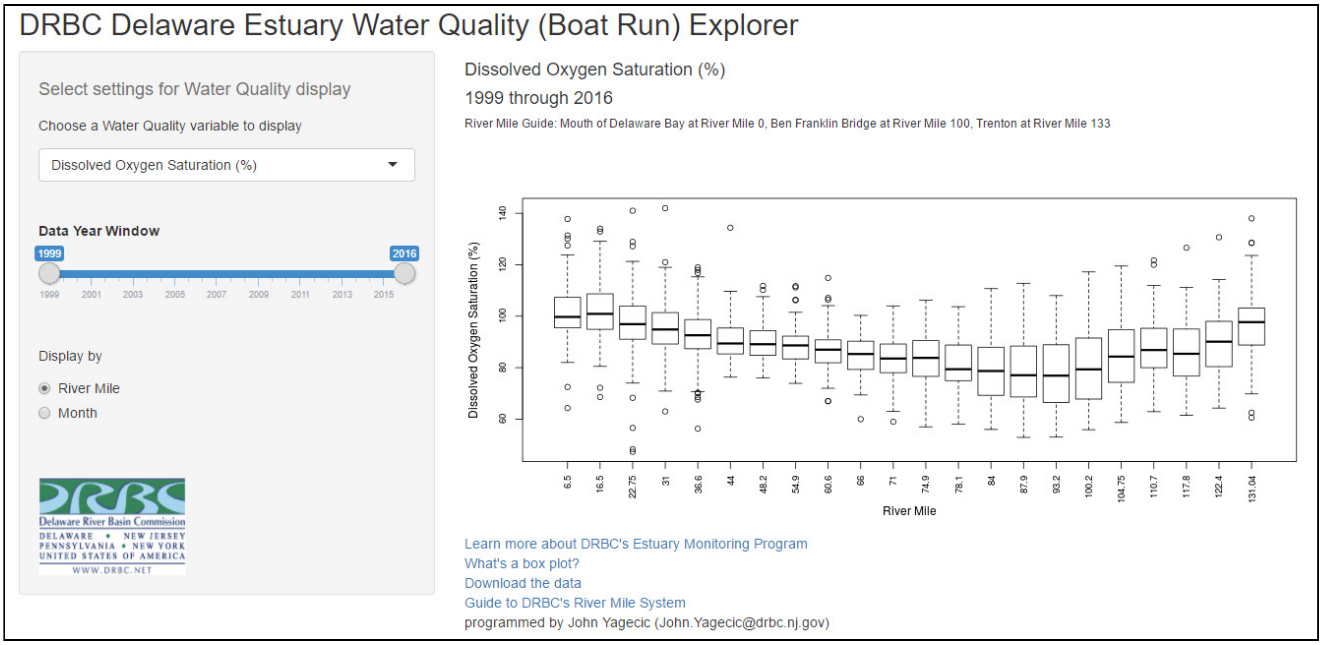

Figure 3.1.1 Delaware Estuary dissolved oxygen saturation measured as part of the DRBC Delaware Estuary Water Quality Monitoring Program, 1999 through 2015.

The USGS continuous monitor data (Fig 3.1.2) shows that dissolved oxygen concentrations are highest at Reedy Island (River Mile 54.1), lower at Chester (River Mile 83.1) and lowest at the Ben Franklin Bridge (River Mile 100.05).

3.1.1.3 Past Trends

USGS' continuous dissolved oxygen measurements began in 1964. Historically, DO concentrations are lowest in mid-summer. As shown in Figure 3.1.3, the July dissolved oxygen concentrations were historically below the current Zone 3 standard of 3.5 mg/L in the 1960s and 1970s. Improvements in DO became apparent through the 1980s as municipal waste water treatment facilities added secondary treatment for sewage. From the mid 1990s onward, criteria were mostly met, although DO concentrations exhibit a high level of variability from year to year. DO at the Ben Franklin Bridge for example was mostly above 6 mg/L in 2014 and 2015, but closer to 5 mg/L in 2016. Figure 3.1.4 shows box plots for daily minimum DO at the same location, over the same time period.

Figure 3.1.5 is a box and whisker plot of all July daily mean % of dissolved saturation values by year for the Delaware River at the Ben Franklin Bridge. Since % of saturation was not historically reported at this location, values were computed using the daily mean water temperature and atmospheric pressure, and assuming specific conductance of 229 uS/cm (the median for this location for this period of record) using the USGS DO Tables application. Although DO measurements are available starting in 1965, atmospheric pressure measured at the Philadelphia International Airport is available starting in 1973 only.

To gain deeper insight into the trends of DO at the USGS monitors in the Estuary, DRBC time series decomposition algorithms were applied to the daily mean DO time series. For winter medians when monitoring is discontinued, 100% saturation values were assumed for missing data. For other missing data, the monthly mean DO was substituted for that location. The time series decomposition tool breaks the overall time series into a repeating seasonal pattern, trend, and remainder (i.e. error not explained by seasonal pattern and trend). By removing the seasonal pattern, time series decomposition helps make clear

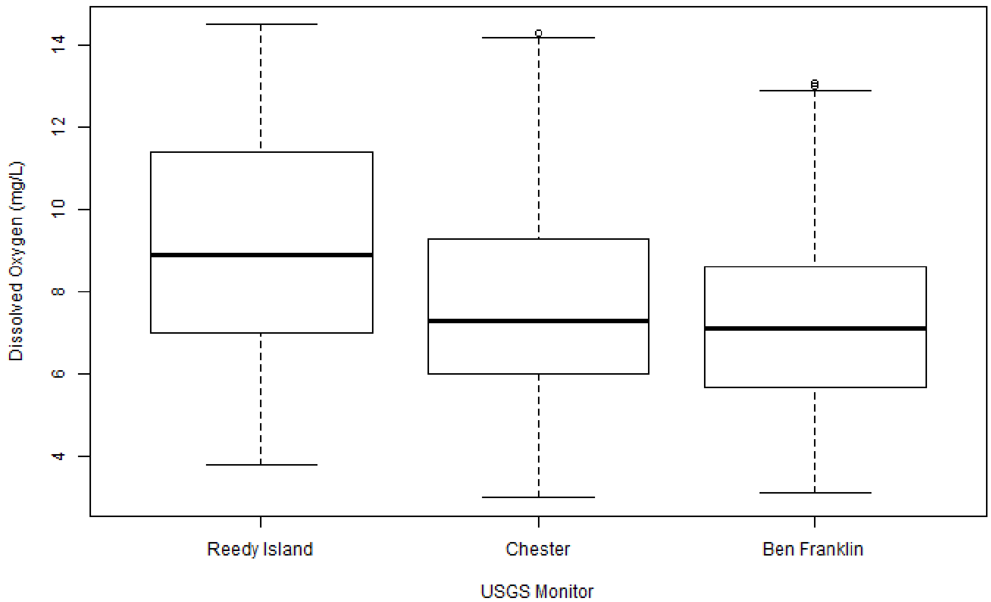

Figure 3.1.2 Delaware Estuary Dissolved oxygen measured by USGS continuous monitors, 2011 through 2016.

the long term trend. Time series decomposition was used to examine DO data from 2000 through 2015 for the USGS monitors at Ben Franklin Bridge, Chester, and Reedy Island (Figs 3.1.6, 3.1.7, and 3.1.8). Ben Franklin seems to show no apparent trend from the mid 2000s through 2015 but with high variability and an apparent dip at the end of the time series reflecting 2016. Chester appears to be characterized by high variability , but with lowest DO levels occurring prior to 2006. Reedy Island appears to show a continuing trend of improved DO concentrations from the early 2000s through 2015.

For each of the time series decomposition plots, the y-axis in the top "data" panel shows the base units, in this case fraction of saturation. The y-axis units for the "seasonal" and "remainder" panels are the same relative units, but centered at 0, thus describing the relative range of these influences. The y-axis units for the "trend" panel are the same units, but limited to the range determined for that component. The gray bar on the right-hand side is a visual reference for the degree of exaggeration of the y-axis, relative to the "data" panel. A gray bar that is much longer than the gray bar in the "data" panel means that the variation attributable to that component has been exaggerated to aid in visual inspection.

3.1.1.4 Future Predictions

Documentation of fish spawning in the Delaware Estuary (Silldorff 2015) and a proposal to designate the Delaware Estuary as Critical Habitat for Atlantic Sturgeon (Endangered and Threatened Species; Designation of Critical Habitat for the Gulf of Maine, New York Bight, and Chesapeake Bay Distinct Population Segments of Atlantic Sturgeon, 2016) have highlighted a gap between the protectiveness of the current dissolved oxygen standard (24-hour mean concentration not less than 3.5 mg/L) in Zones 3, 4, and the upper portion of Zone 5 and the current ecological function of the Estuary. Achievement of higher DO concentrations will likely require tighter controls of the discharge of nutrients, especially ammonia. DRBC is currently in the process of developing a eutrophication model for the Delaware Estuary that will allow us to determine nutrient allocations needed to achieve higher dissolved oxygen concentrations.

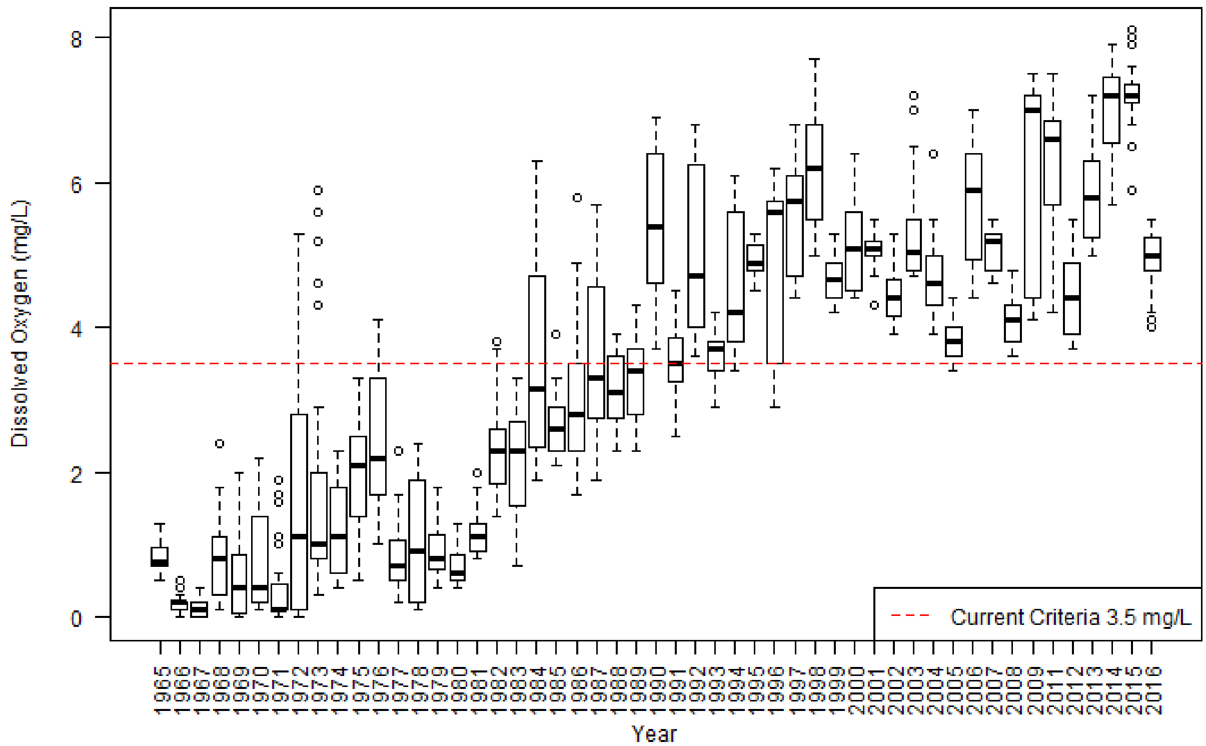

Figure 3.1.3 Delaware Estuary July daily mean dissolved oxygen concentrations by year at USGS at Ben Franklin Bridge, 1965 through 2016.

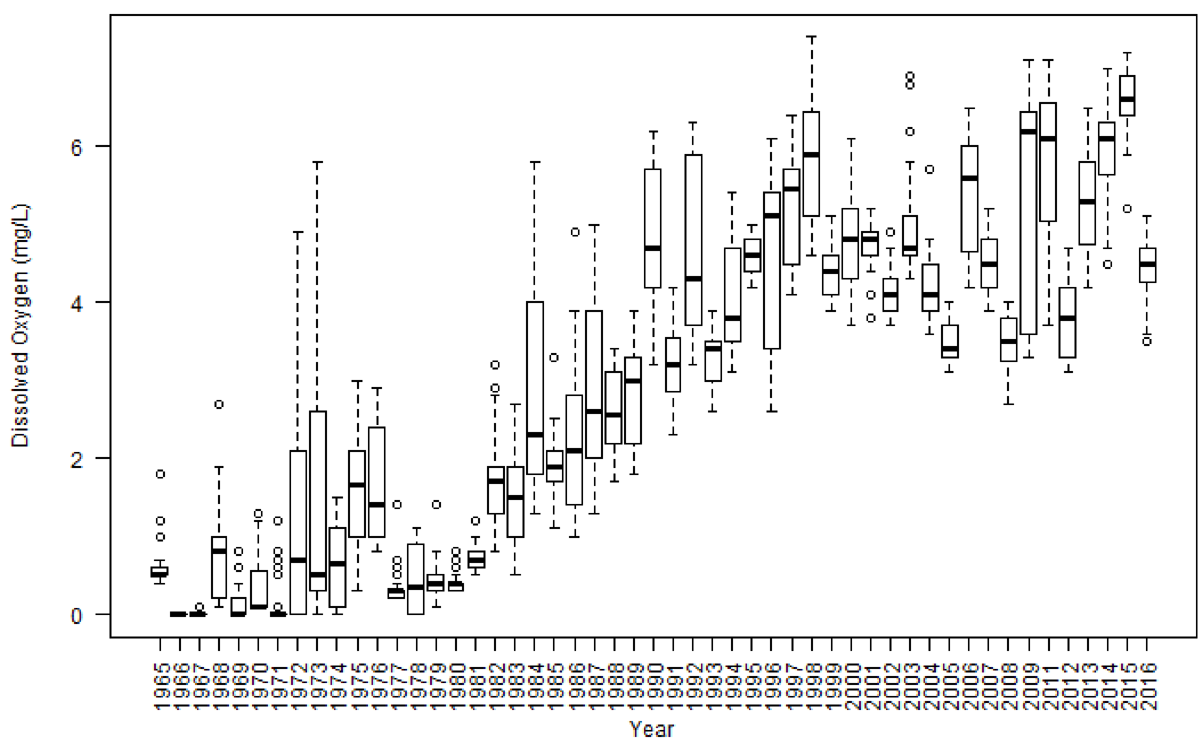

Figure 3.1.4 Delaware Estuary July daily minimum dissolved oxygen concentrations by year at USGS at Ben Franklin Bridge, 1965 through 2016.

3.1.1.5 Actions and Needs

DRBC has identified 2018 and 2019 as monitoring-intensive years in support of the estuary eutrophication model development. During that time period, we are requesting cooperating organizations to temporarily align monitoring initiatives and resources to focus on the Delaware Estuary in support of model development.

3.1.1.6 Summary

The long term trend of DO in the Delaware Estuary shows remarkable improvement from near anoxic conditions in the 1960s and 1970s to nearly always above criteria today. In order to capture and retain the recoveries in fish spawning that have followed the recovery in DO, DRBC is seeking to determine the appropriate designated aquatic life uses of the Delaware River Estuary and the water quality criteria necessary to protect these uses.

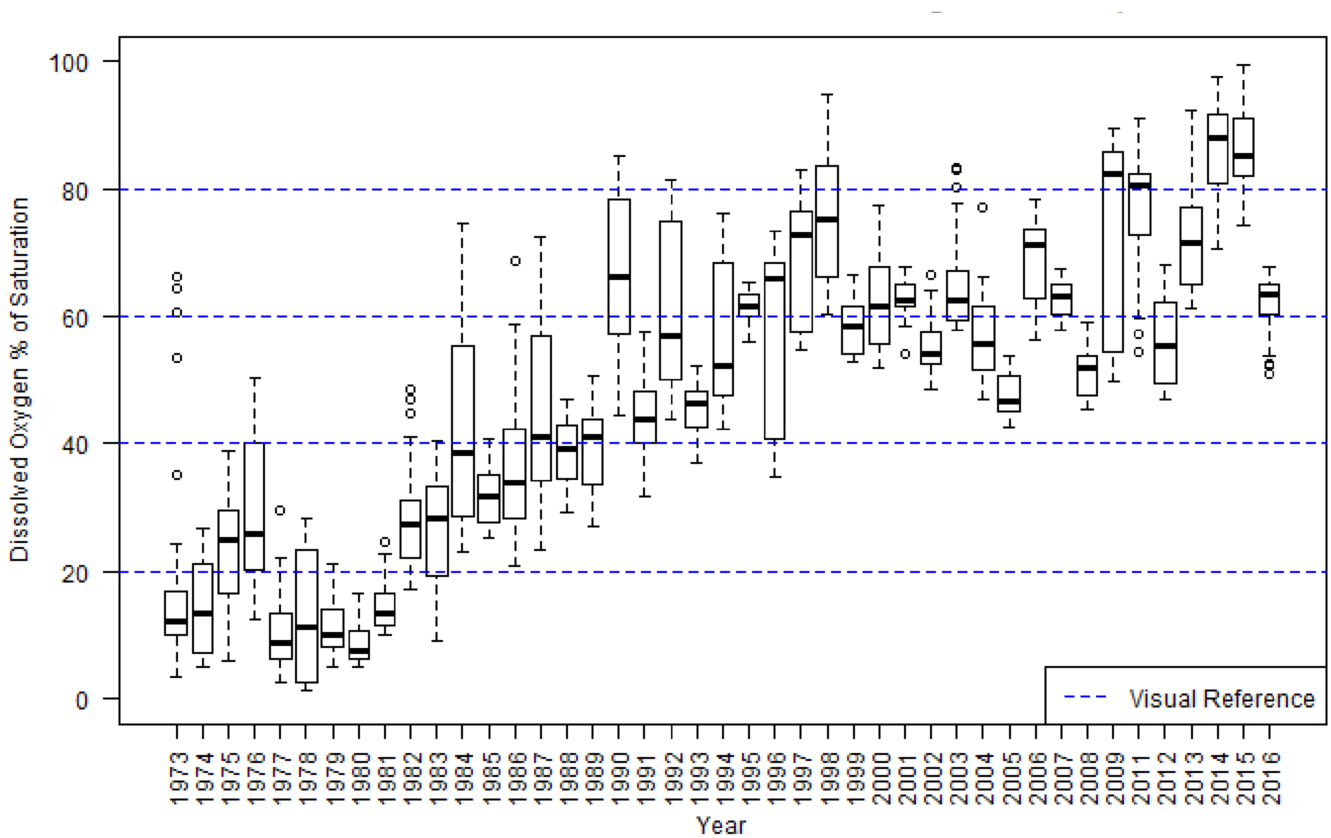

Figure 3.1.5 Delaware Estuary July mean daily dissolved oxygen percent of saturation by year at USGS at Ben Franklin Bridge, 1973 through 2016.

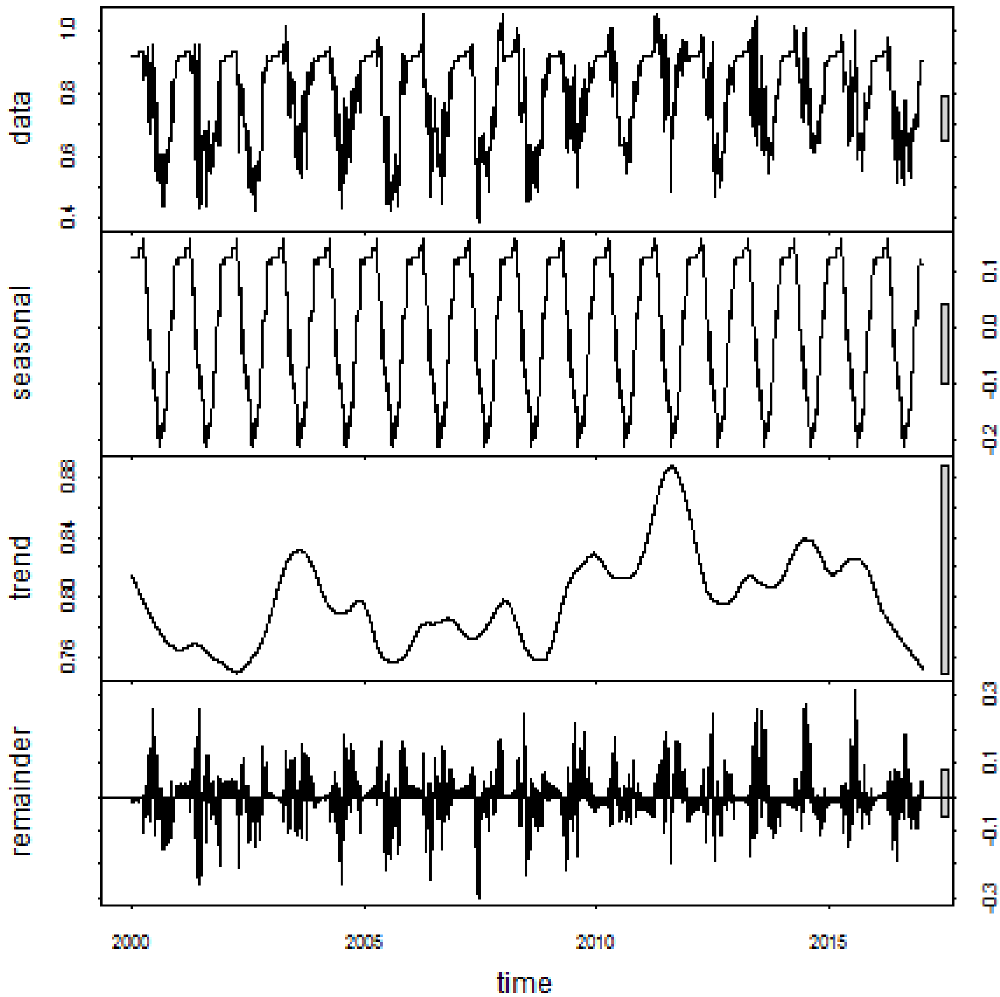

Figure 3.1.6 Time series decomposition, daily percent of dissolved oxygen saturation at USGS 01467200, Ben Franklin Bridge.

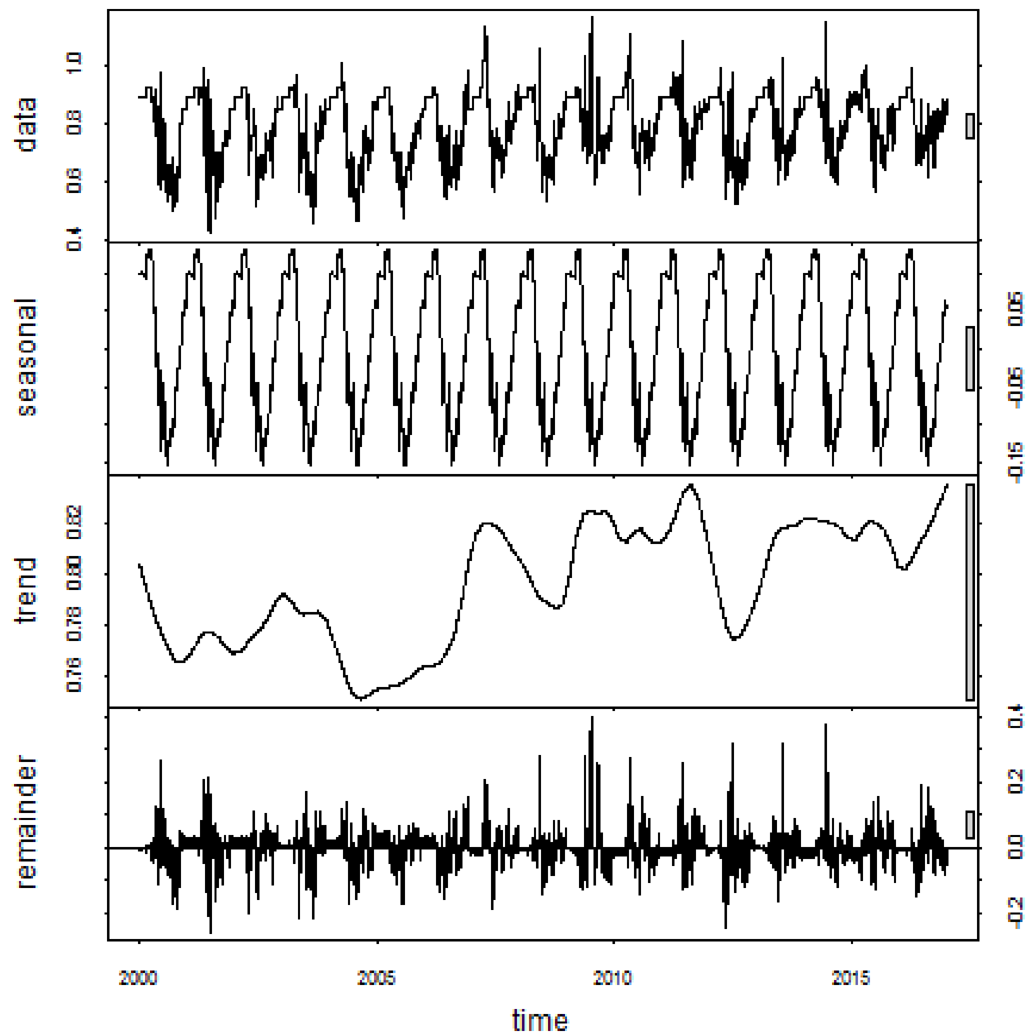

Figure 3.1.7 Time series decomposition, daily percent of dissolved oxygen saturation at USGS 01477050, Chester.

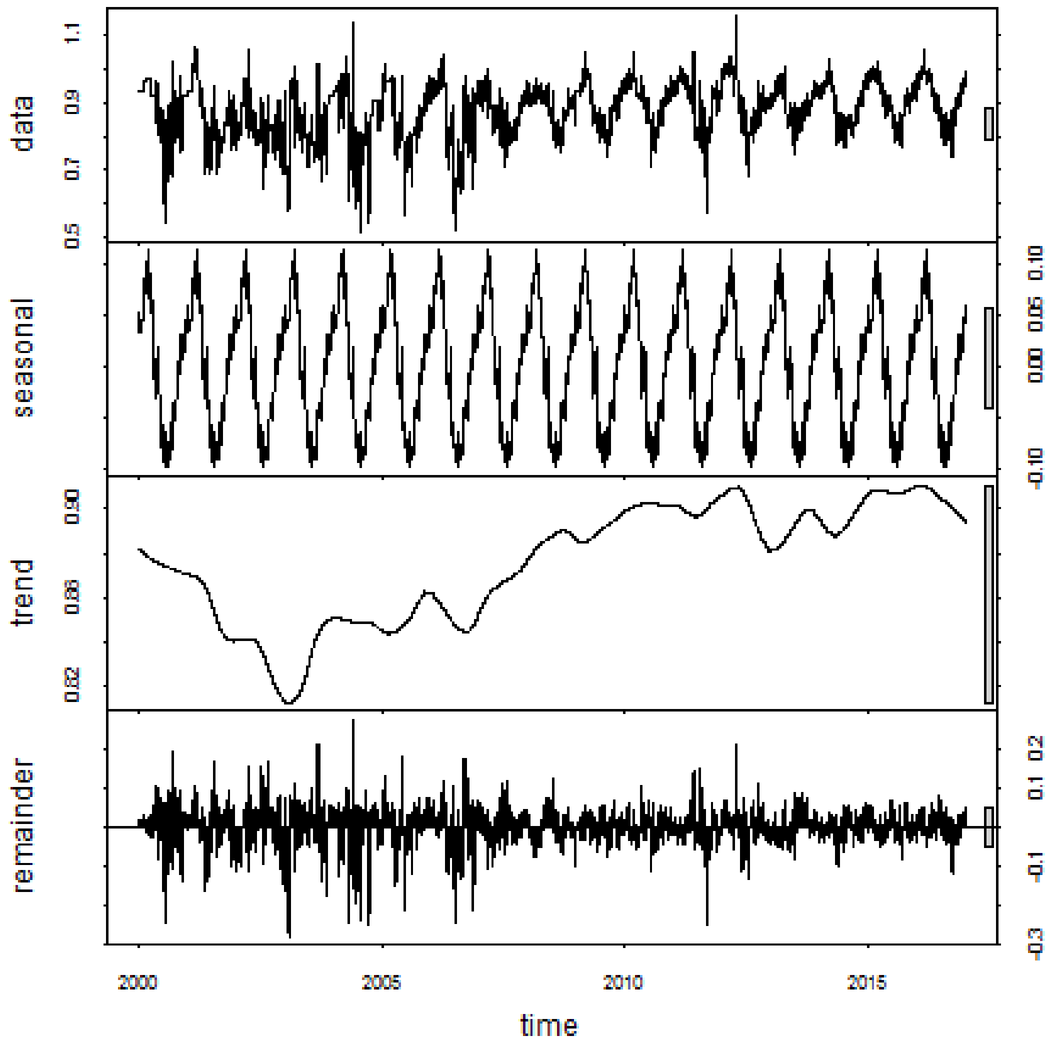

Figure 3.1.8 Time series decomposition, daily percent of dissolved oxygen saturation at USGS 01482800, Reedy Island.

3.1.2 Nutrients

3.1.2.1 Description of Indicator

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 specific chemical substances including nitrate, ammonia, and phosphate as being representative of nutrients. Nitrate and phosphate both have the advantage of being relatively quantifiable in the Estuary and having a long measurement record.

The Delaware Estuary has both high loadings and high concentrations of nutrients relative to other estuaries in the United States (National Estuary Program Coastal Condition Report, 2006). The effects from these high nutrients are not well-understood, but monitoring in the Estuary shows signs of suboptimal ecological health, including a persistent summer dissolved oxygen sag in the urban corridor of the Estuary. Although nutrient loading to the Estuary has not been demonstrated to be the cause of either suboptimal ecological conditions or the dissolved oxygen sag, high nutrient loading is one of the main candidates for understanding the Estuary's ecological health. Although nutrients are high, the worst eutrophication symptoms (such as anoxia, fish kills, and harmful algal blooms) are not currently seen in the Delaware Estuary.

3.1.2.2 Present Status
Phosphate measured as part of the DRBC Delaware Estuary Water Quality Monitoring Program shows highest concentrations near the most urbanized portion of the Estuary with lower concentrations near the head of tide and the mouth of the Bay as shown in Figure 3.1.9.

Ammonia and nitrate concentrations in the Estuary currently are typically less than 1 mg/L for ammonia and typically less than 3 mg/L for nitrate. 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 Figures 3.1.10 and 3.1.11 below. 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.

Monitoring for ammonia has been performed by the University of Delaware, and since 2009 by the Boat Run monitoring program, with funding from the USGS.

Nitrate concentrations in particular, as in Figure 3.1.11 below, show structure suggesting higher loads in the urbanized portion of the Estuary with dilution and possible uptake in the Bay.

3.1.2.3 Past Trends
To assess long term trends, data from the DRBC Delaware Estuary Water Quality Monitoring Program (formerly the Boat Run) were queried, from the late 1960s through 2016.

Nitrate is quantifiable throughout the data record and is expected to be the most prevalent form of nitrogen in the Delaware Estuary, thus providing a good approximation of nitrogen trends over time. Since nitrate in the Estuary has a defined spatial structure (Fig 3.1.11), we selected measurements between river kilometer 104.6 (River Mile 65) and 152.9 (95) as representative of the highest, uniform concentrations in the Estuary. Figure 3.1.12 below, depicting data points and smoothed curve, demonstrate relatively consistent concentrations since the early 1990s, with variable and sometimes higher concentrations in the 1970s.

Since phosphate data are sparse and shows less spatial structure, we selected all Estuary phosphate measurements to generate the long term trend shown in Figure 3.1.13 below. This graph shows much higher concentrations in the 1970s settling toward consistently lower concentrations typically less than 0.25 mg/L in the 2000s, but with a considerable data gap.

Comparison shows that both graphs are in general agreement with and continuation of the trends documented by Sharp et al. 1994.

3.1.2.4 Future Predictions
As mentioned previously, documentation of fish propagation in the Estuary and proposal to designate the Estuary as essential fish habitat for Atlantic Sturgeon compel the identification and adoption or more protective dissolved oxygen criteria. Conceptually, achievement of more protective dissolved oxygen standards will likely need to be achieved through tighter effluent limits on nutrients, especially ammonia.

DRBC is in the process of developing a eutrophication model for the Delaware Estuary. This model will allow DRBC to determine what level of dissolved oxygen is achievable and what limitations on nutrient discharges will be needed to achieve these limits.

3.1.2.5 Actions and Needs
DRBC and its partner organizations need to complete the estuary eutrophication model. The modeling

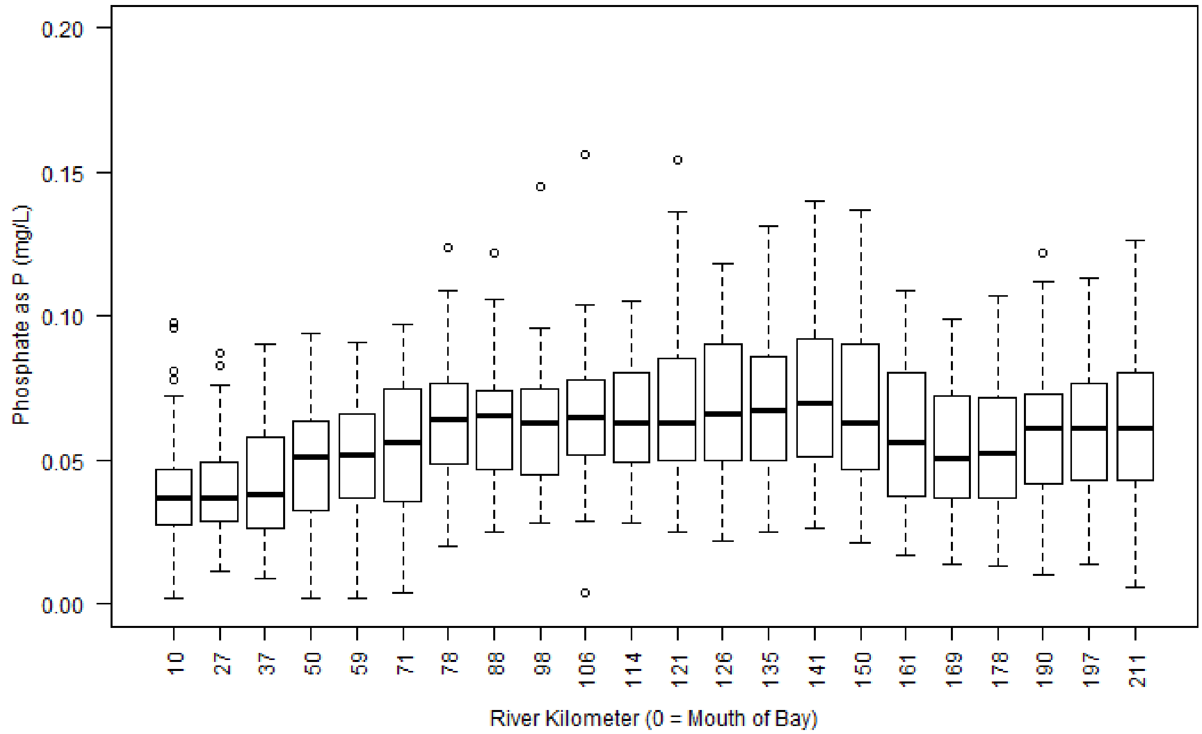

Figure 3.1.9 Phosphate by river kilometer in the Delaware Estuary, 2008 through 2016.

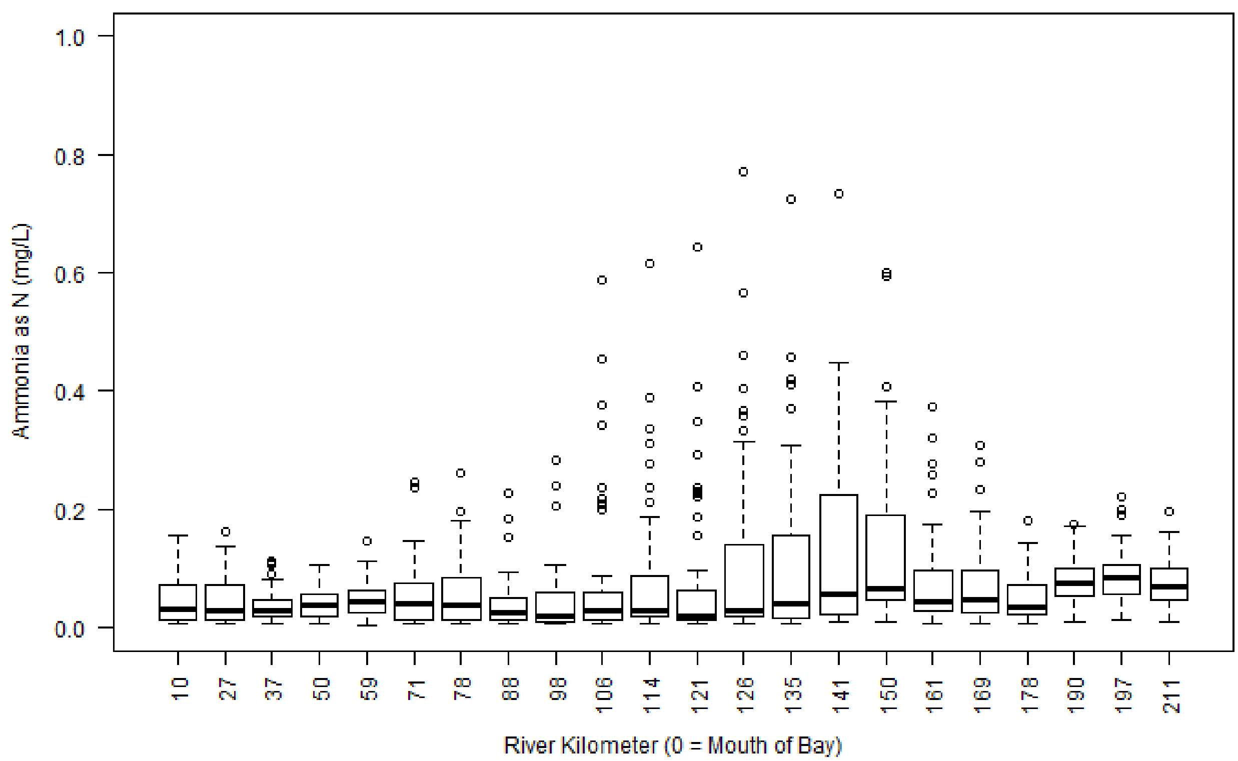

Figure 3.1.10 Ammonia by river kilometer in the Delaware Estuary, 2009 through 2010.

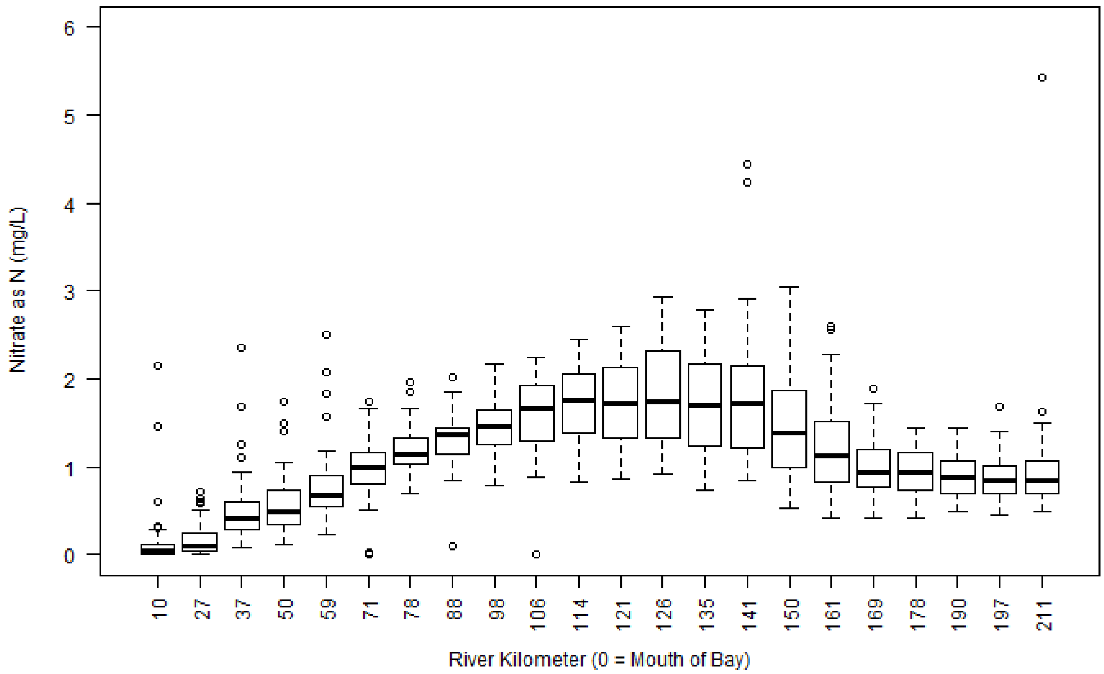

Figure 3.1.11 Nitrate by river kilometer in the Delaware Estuary, 2008 through 2016.

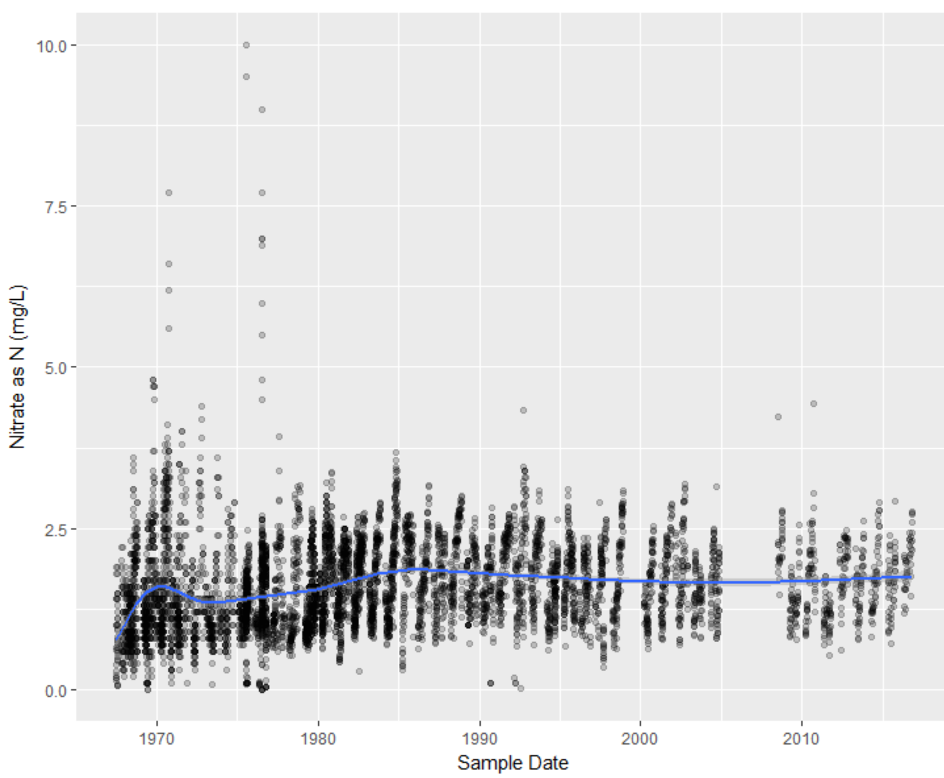

Figure 3.1.12 Historic nitrate in the Delaware Estuary from 1967 to 2016.

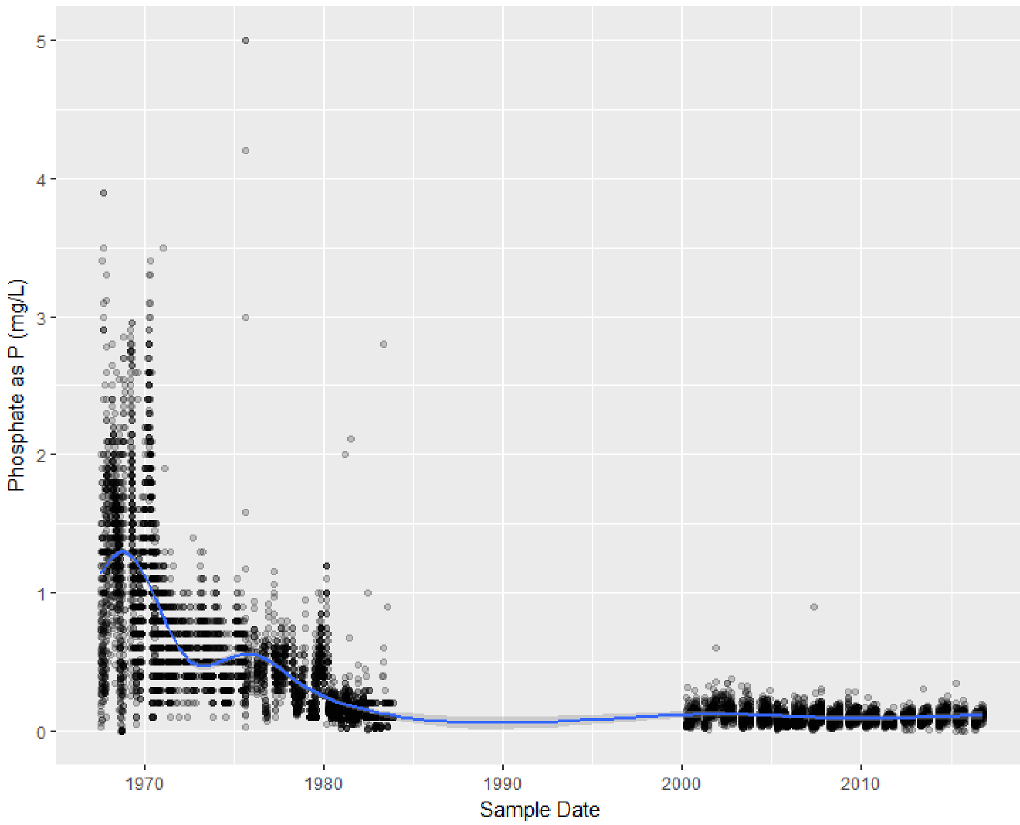

Figure 3.1.13 Historic phosphate in the Delaware Estuary from 1967 to 2016.

effort requires the assistance of partner organizations especially via enhanced data collection during the monitoring intensive period.

3.1.2.6 Summary

Delaware Estuary nutrient concentrations are lower than historical levels, but still elevated relative to other estuaries. DRBC is currently in the process of developing a eutrophication model for the Delaware Estuary that will allow us to determine nutrient allocations needed to achieve higher dissolved oxygen concentrations.

3.1.3 Contaminants

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

3.1.3.1 Description of Indicator

Water quality monitoring data from multiple organizations (DRBC, DNREC, NYSDEC, NJDEP, PADEP and USGS) are compared to stream quality objectives and narrative standard to evaluate water quality. The Delaware River Basin Commission (DRBC) has stream quality objectives for human health and aquatic life used in assessment of the tidal portion of Delaware River Basin from the head of tide at Trenton, NJ to the mouth of the Delaware Bay (Zones 2 through 6) that reflect current scientific information and harmonize DRBC criteria with basin states' criteria. In addition, a narrative standard applicable to waters of the Basin requires that: "the waters shall be substantially free from … substances in concentrations or combinations which are toxic or harmful to human, animal, plant, or aquatic life".

3.1.3.2 Present Status

For a recent report on the extent to which waters of the Delaware Estuary and Bay are attaining designated uses, see the "2016 Delaware River and Bay Water Quality Assessment". (http://www.state.nj.us/drbc/library/documents/WQAssessmentReport2016.pdf.) Some contaminants identified in the report for additional monitoring and assessment efforts to assure water quality in the Estuary and Basin include metals, pesticides and polycyclic aromatic hydrocarbons (PAHs).

3.1.3.3 Past Trends

Data and detection insufficiencies make determination of past trends difficult. See Chapter 4 - Sediment Quality for information on past trends of contaminants in the Estuary.

3.1.3.4 Future Predictions

With increasingly sensitive analytical methods in use, e.g., inductively coupled plasma mass spectrometry (ICP/MS) to measure contaminants and more complex models to evaluate toxicity, e.g., Biotic Ligand Model (BLM) (Fig 3.1.14), there will be an increasing need for coordination of water quality criteria and assessment methodologies in order to prioritize environmental management efforts.

3.1.3.5 Actions and Needs

Coordination among Basin states and agencies should continue to ensure the use of appropriate analytical techniques and assessment methodologies to evaluate the effects of contaminants on water quality.

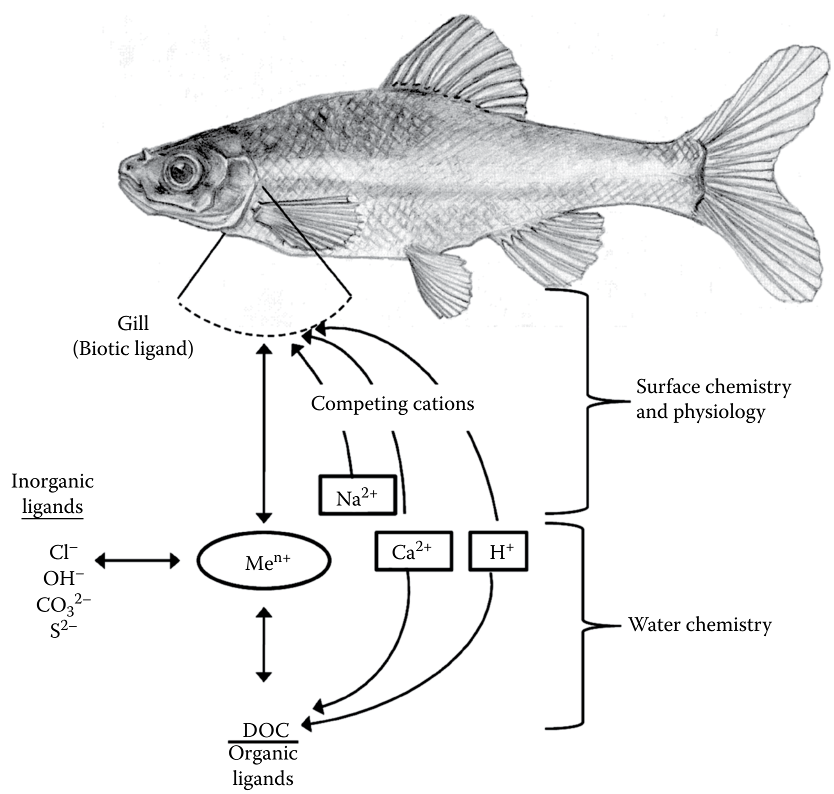

Figure 3.1.14 Conceptual model of the biotic ligand model (after Paquin, P.R. et al., Comp. Biochem. Physiol. C, 133, 3-35, 2002. Art credit Rob Harper, 2009).

3.1.3.6 Summary

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

3.1.4 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.

3.1.4.1 Description of Indicator

Bioaccumulative contaminants have been monitored over an extended period in fish fillet collected from the Delaware River. Bioaccumulation of contaminants in fish tissue is influenced by physical-chemical properties of the contaminant, fish species, age, migration and food habits as well as other environmental factors such as season of fish collection.

3.1.4.2 Present Status

While programs are in place to reduce the concentrations of toxic pollutants that bioaccumulate, Delaware River Basin states issue "advisories" containing meal advice for consumers of recreationally-caught fish and shellfish to minimize the risk to human health. These advisories list the water bodies, fish species, and number of meals recommended to minimize the risk. In some cases, no consumption of any fish species from a water body or more stringent consumption guidelines for pregnant women and children is advised. These advisories are typically revised yearly based upon recent fish tissue concentration data. A summary of recent fish consumption advisories in the Delaware River is available at http://www.state.nj.us/drbc/library/documents/WQAssessmentReport2016.pdf.

The following websites provide additional information on state-issued fish consumption advisories:

Delaware http://www.dnrec.delaware.gov/fw/Fisheries/Pages/Advisories.aspx

New Jersey http://www.nj.gov/dep/dsr/njmainfish.htm

New York http://www.dec.ny.gov/outdoor/7736.html

Pennsylvania http://www.nj.gov/drbc/quality/datum/fish-consumption.html.

3.1.4.3 Past Trends

A number of bioaccumulative compounds are monitored in fish collected from the Delaware River. Trends will differ depending on the contaminant of interest. Dioxins are examples of toxic chemicals observed in the Delaware River that bioaccumulate in fish. The stream quality objective in the Delaware River is based on the most toxic dioxin compound 2,3,7,8-TCDD. A trend of declining concentrations for 2,3,7,8-TCDD (Dioxin) from 2004 to 2015 with concentrations of the lipophilic contaminant normalized to 5% lipid in fish tissue is graphically presented in Figure 3.1.15 and by an ANCOVA comparison of contaminant concentrations by year with the length of the fish as a covariate in Table 3.1.1. Similar assessments indicate that concentrations of other legacy pesticides (chlordanes and dieldrin) are also declining in some estuarine fish species (not shown).

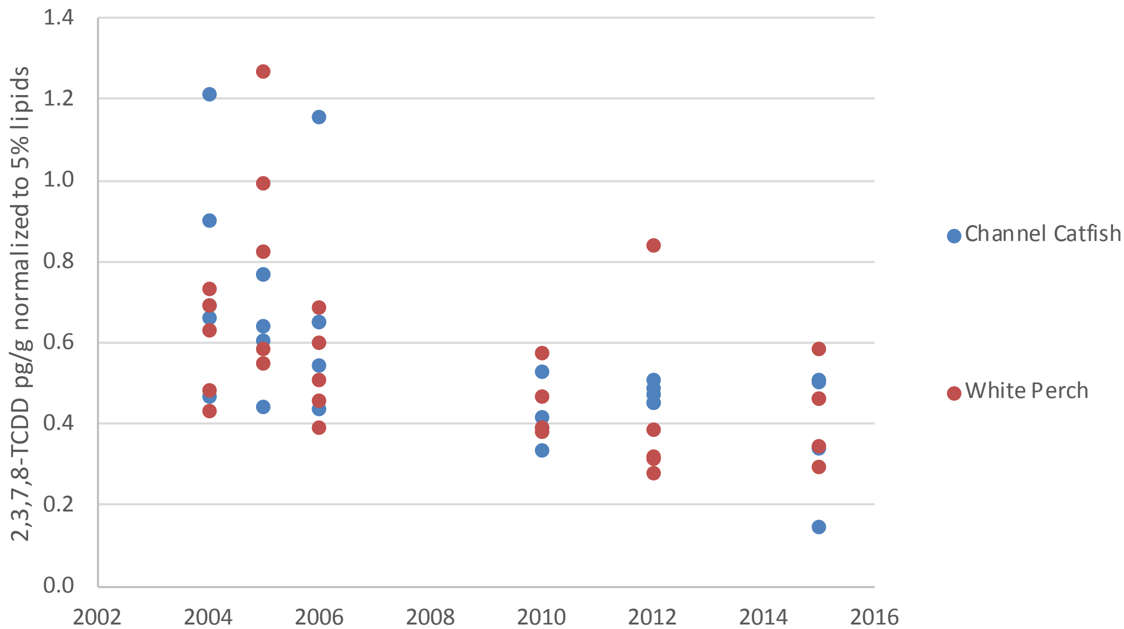

Figure 3.1.15 Concentrations of 2,3,7,8-TCDD in fillet of two tidal fish species by sample year.

3.1.4.4 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 constantor decline very slowly.. Even the effects of regulatory water quality management efforts will likely take decades to be reflected in tissue concentrations.

3.1.4.5 Actions and Needs

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

3.1.4.6 Summary

Trends for specific contaminants may result from regulatory restrictions on use, changes in loading rates or degradation of the contaminant in the environment. Trajectories for contaminant reduction in fish may be long depending on the contaminant of concern, but effective management is needed to facilitate these trajectories.

Table 3.1.1 ANCOVA results of year versus contaminant with weight as a covariate

Contaminant	Species	Water	N	Estimate of Slope	p-value	Trend
2,3,7,8 TCDD	Channel Catfish	tidal	28	-0.04	0.0003	declining
2,3,7,8-TCDD	White Perch	tidal	29	-0.02	0.0143	declining

3.1.5 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.

3.1.5.1 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 streamflow increases or decreases in response to precipitation, 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 higher salinity water moves upstream, it may increase corrosion of the infrastructure of surface water users, particularly industry, and increase the concentration of sodium in treated drinking water which is a health concern for sensitive customers. In the DRBC Water Code Zone 2 location in the Delaware Estuary, where large Pennsylvania and New Jersey drinking water intakes are located, water quality objectives include a maximum 15-day average concentration of 50 mg/L chloride. Salinity repulsion policies, that govern upstream reservoir releases, work to repel the salt line and maintain chloride concentrations below the water quality objective in Zone 2.

Water releases from five reservoirs are used to help dilute the higher salinity water during low streamflow conditions. 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 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 of water when full.

3.1.5.2 Present Status

By combining data from both the Delaware Estuary Water Quality Monitoring Prorgam (formerly the Boat Run) and the University of Delaware water quality cruises, DRBC is able to map the approximate extents of salinity regimes in Delaware Bay. Figure 3.1.16 below 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 approximately below 0.5 ppt salinity during seasonally normal hydrological conditions, but exceeds the 250 mg/L chloride definition of the salt line during seasonally low streamflow conditions.

Figure 3.1.17 below shows the chloride concentrations from the DRBC Delaware Estuary Water Quality Monitoring Program (formerly Boat Run). A sharp transition between river kilometers 121 and 126 (near Marcus Hook) is evident.

3.1.5.3 Past Trends

To determine whether the recent trends are evident in the DRBC data, we plotted boxplots by year from river kilometer 121 (at the change in spatial structure) and river kilometer 169 (nearest to major drinking water

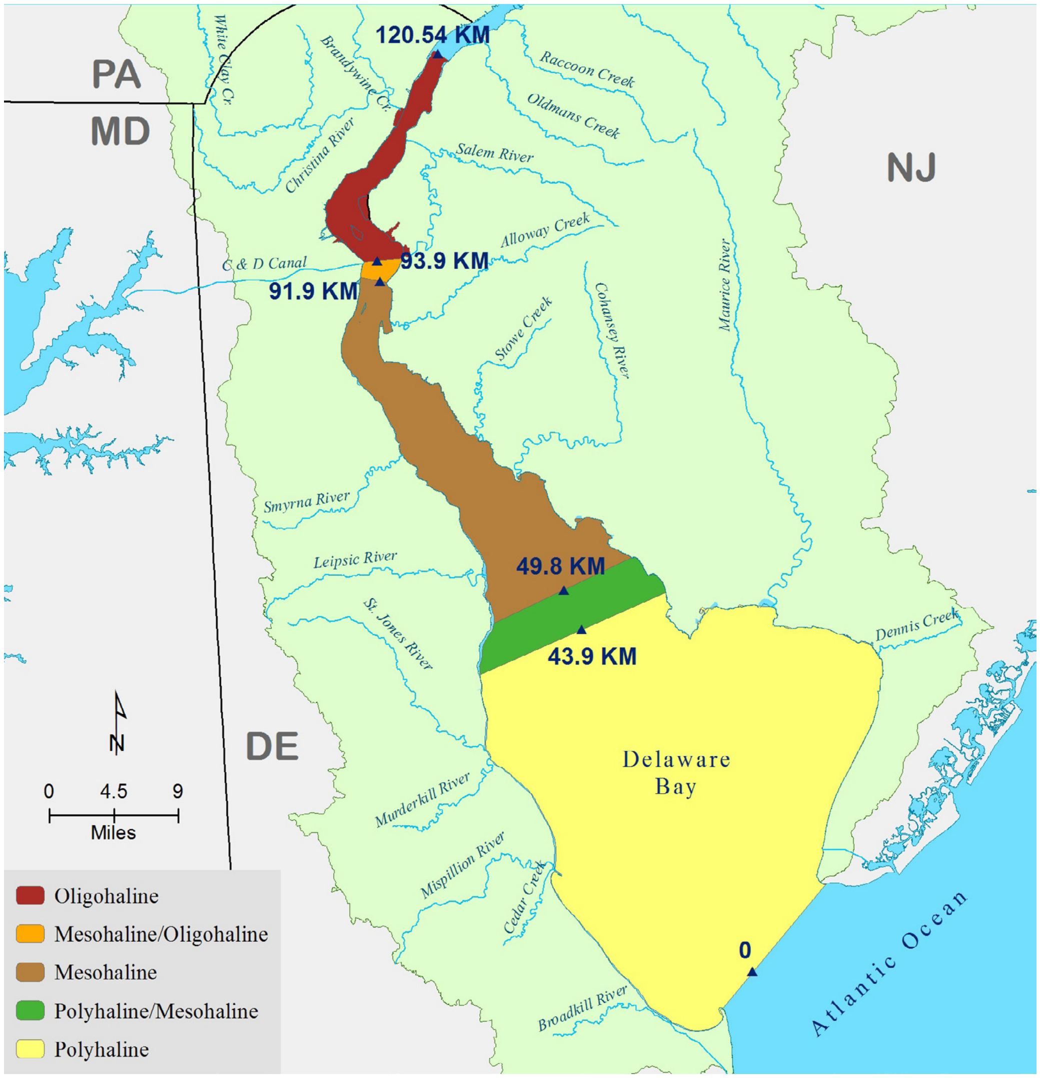

Figure 3.1.16 Spatial salinity regimes of the Delaware Estuary.

intakes). The 2000 to 2016 data at river kilometer 121 (Fig 3.1.18) shows high variability from year to year, but no obvious trend. The same plot for river kilometer 169 (Fig 3.1.19) suggests some slight elevation in 2014 through 2016, but the period of that elevation may be too short to conclude that the data are trending.

The best means of assessing long term 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 are available beginning in 1964.

Figures 3.1.20, 3.1.21, and 3.1.22 below suggest that the drought of record in the 1960s strongly influences the oldest data bin. All plots indicate lower conductivity values than the drought of record and year to year variability (especially at Reedy Island). Ben Franklin and Chester both demonstrate distributions over the last year or two that are higher than those of the recent past.

3.1.5.4 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 U.S. Army Engineer Research and Development Center (Kim and Johnson, 2007) shows predicted mean increases in salinity between 1996 and 2040 of 14% at

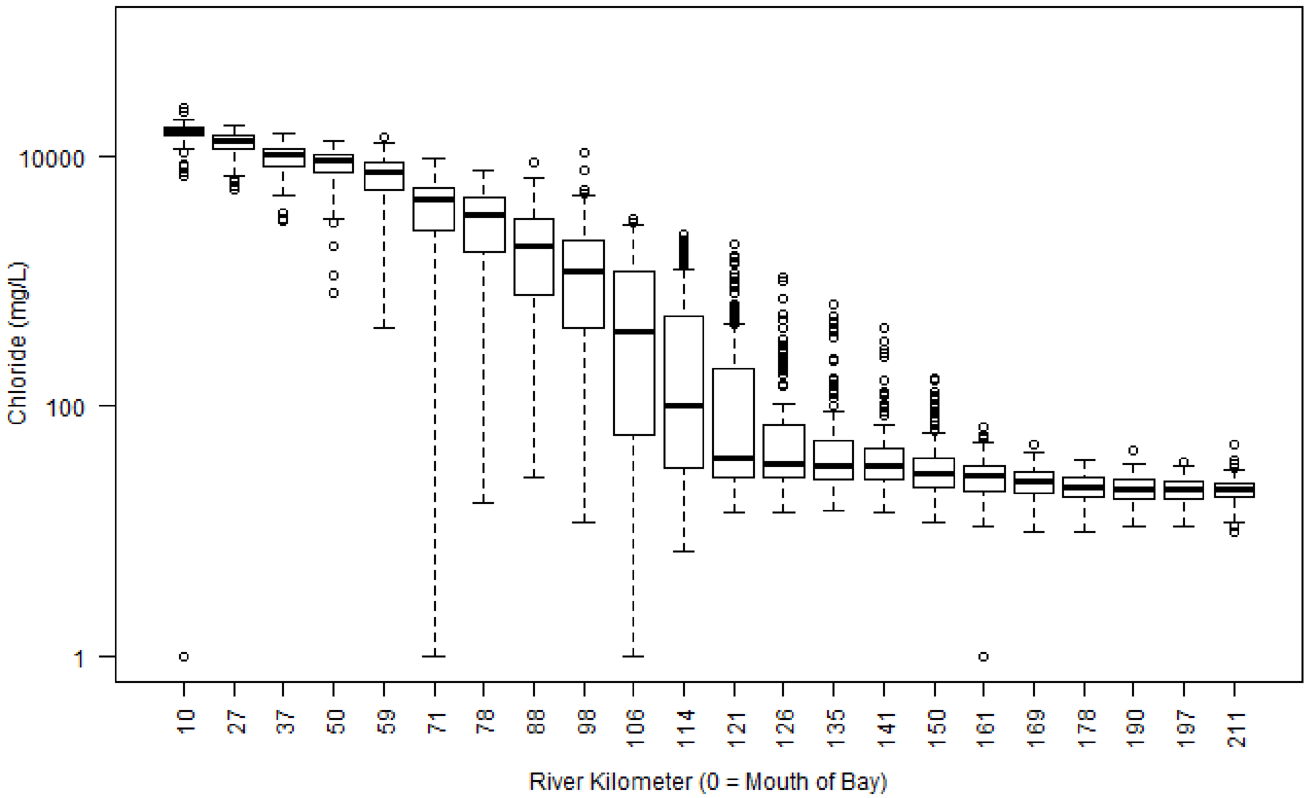

Figure 3.1.17 Chloride concentration ranges by river kilometer in the Delaware Estuary, 2000 through 2016.

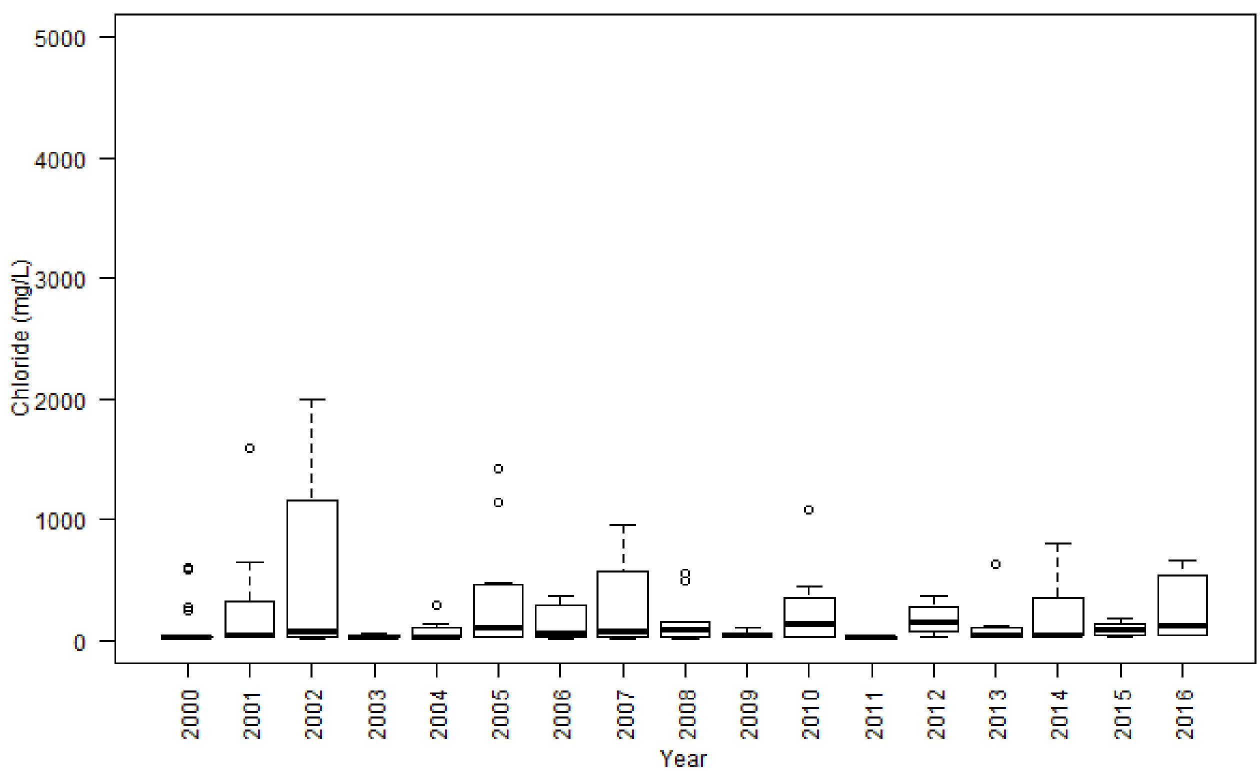

Figure 3.1.18 Recent chloride trends by year at river kilometer 121, 2000 through 2016.

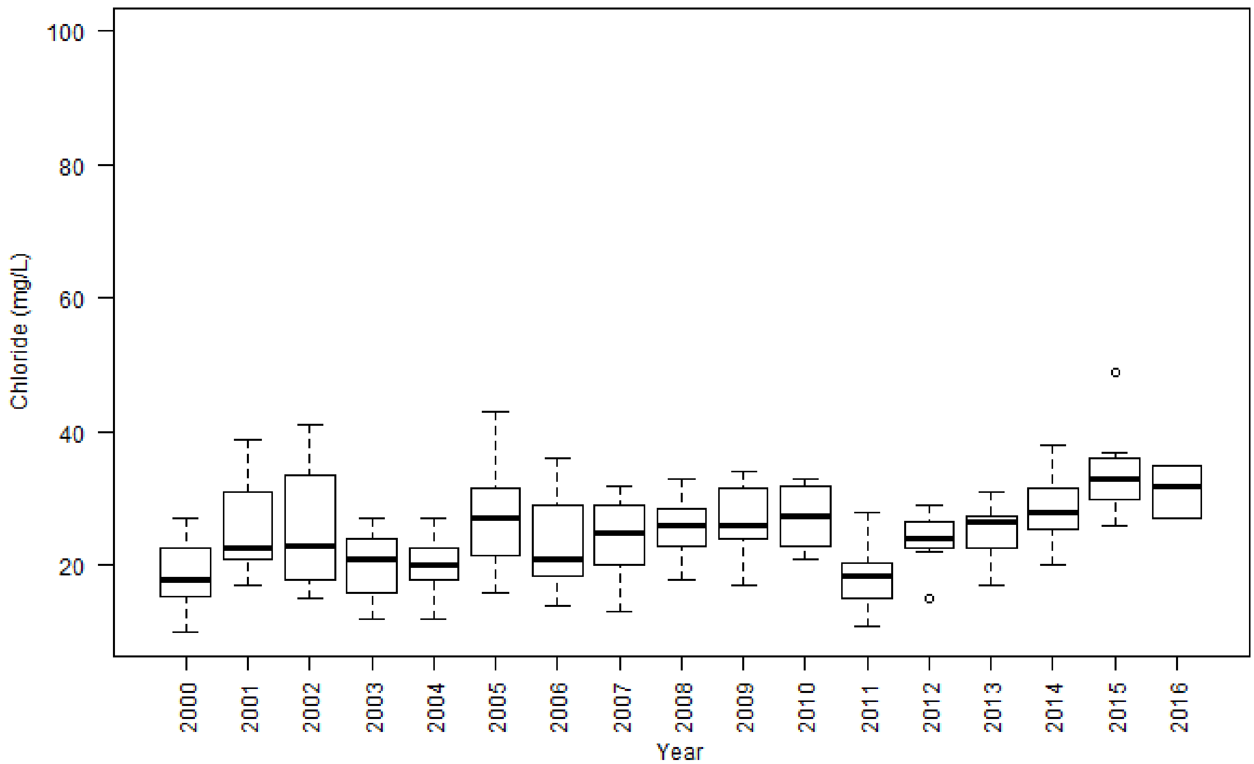

Figure 3.1.19 Recent chloride trends by year at river kilometer 169, 2000 through 2016.

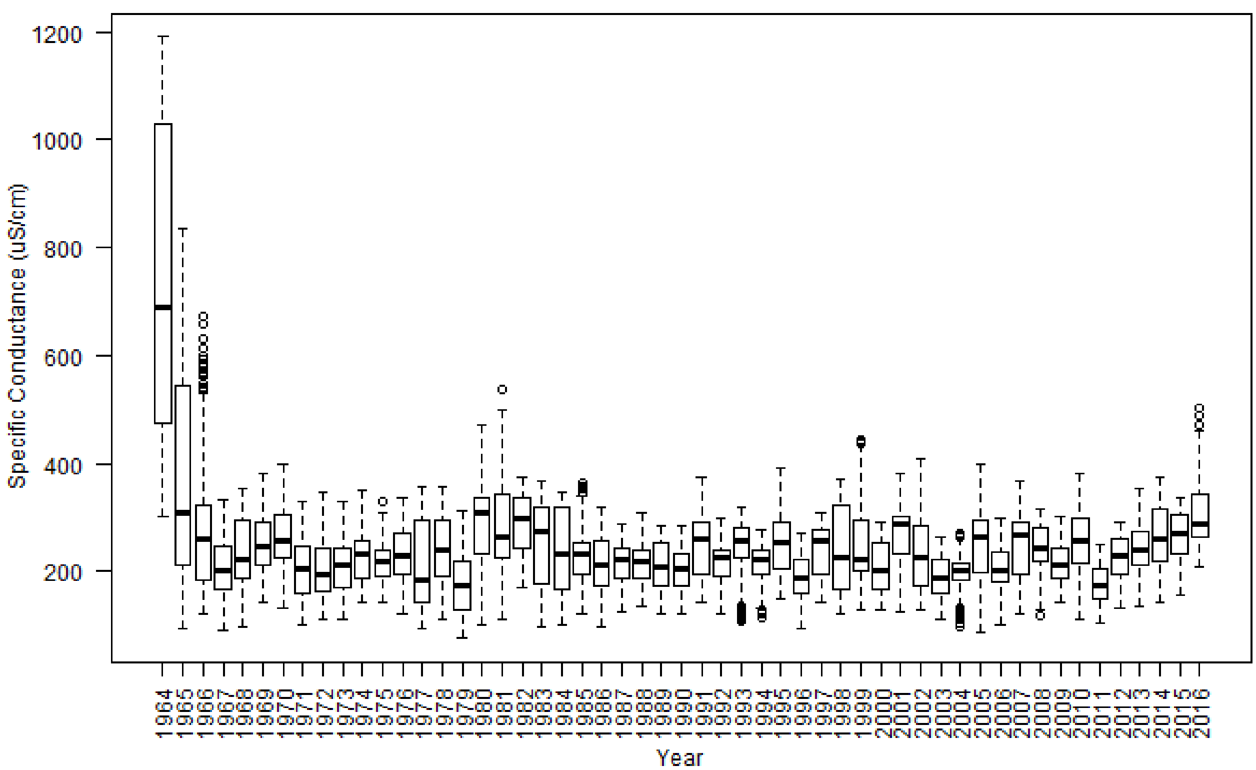

Figure 3.1.20 Long-term specific conductivity box and whisker plots at USGS 01467200, Ben Franklin Bridge.

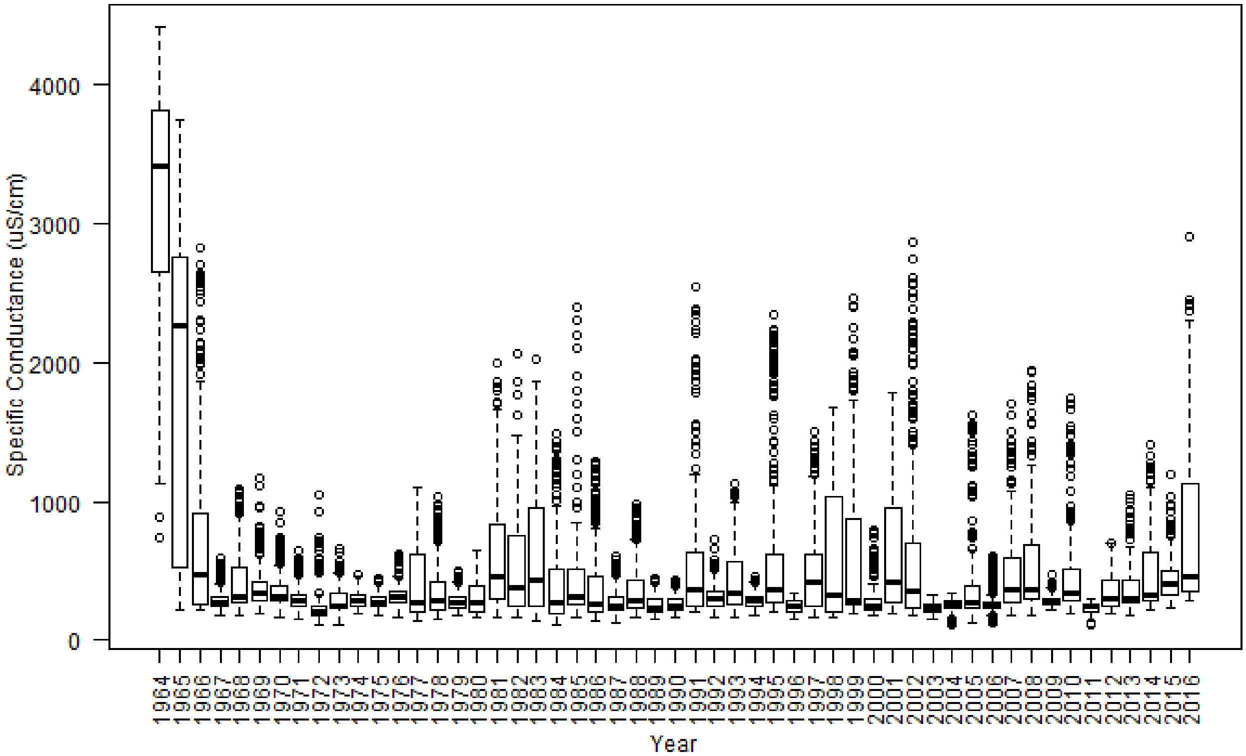

Figure 3.1.21 Long-term specific conductivity box and whisker plots at USGS 01477050, Chester.

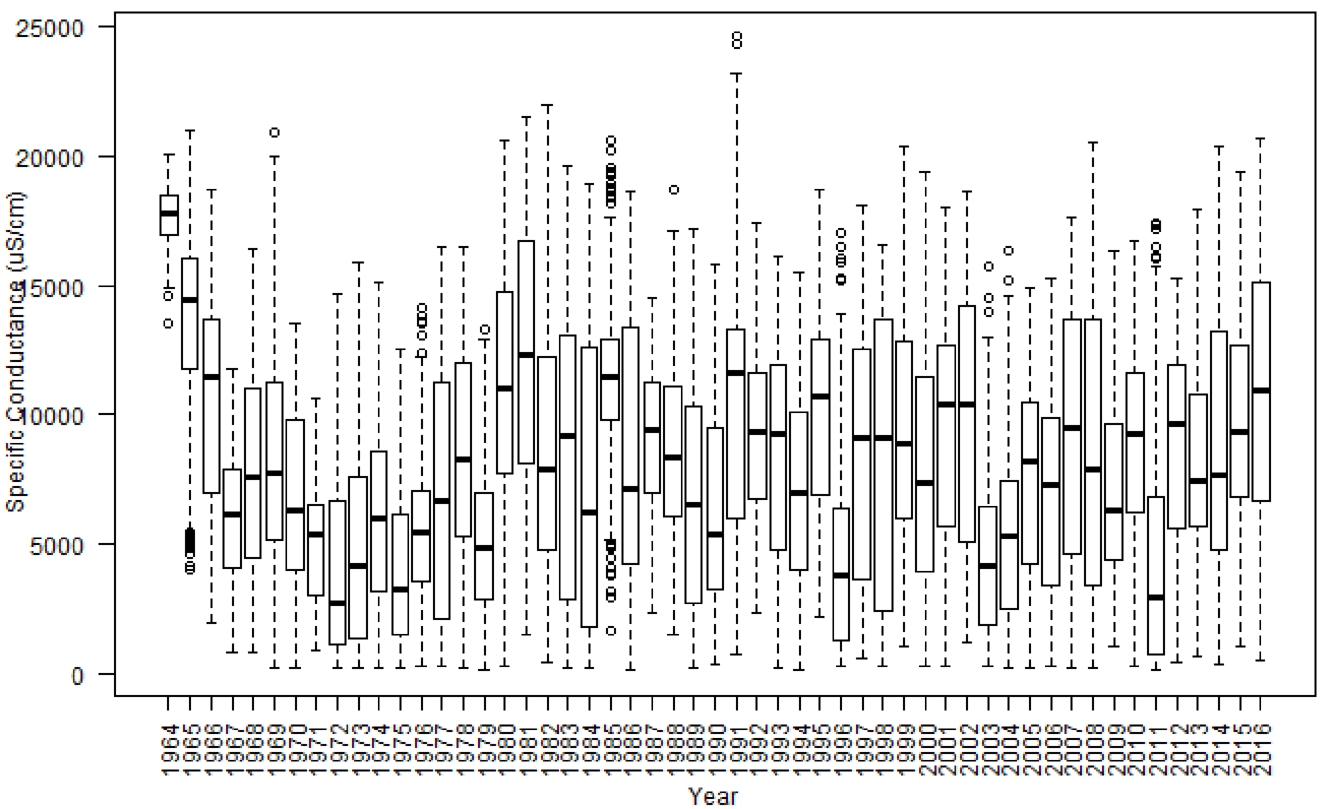

Figure 3.1.22 Long-term specific conductivity box and whisker plots at USGS 1482800, Reedy Island.

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.

3.1.5.5 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.

3.1.5.6 Summary

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

3.1.6 pH

pH is the mathematical notation for the negative log of the hydrogen ion concentration (-log[H+]) and indicates an acid, neutral, or base condition.

3.1.6.1 Description of Indicator

The pH of surface waters can be an important indicator of ecological function and productivity, and pH impacts the bioavailability and toxicity of pollutants such as metals and ammonia. Currently, DRBC's criteria for the Estuary requires pH to be between 6.5 and 8.5.

3.1.6.2 Present Status

Figure 3.1.23 below shows the box and whisker plots of discrete 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. Although the distributions differ by location, all values are within the DRBC criteria.

3.1.6.3 Past Trends

To assess temporal changes in pH, we developed box and whisker plots of pH by year including a dashed blue line at pH=7 for visual reference. Results continue to demonstrate an increase in pH over the period of record at Ben Franklin (Fig 3.1.24) and an even more pronounced increase at Chester (Fig 3.1.25).

This phenomenon was noted in the previous TREB and 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. 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.

3.1.6.4 Future Predictions

NOAA and others have documented the occurrence of ocean acidification. In the absence of other reactions, we 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.

3.1.6.5 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 and long-term likelihoods of continued changes in pH and carbon availability.

3.1.6.6 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.

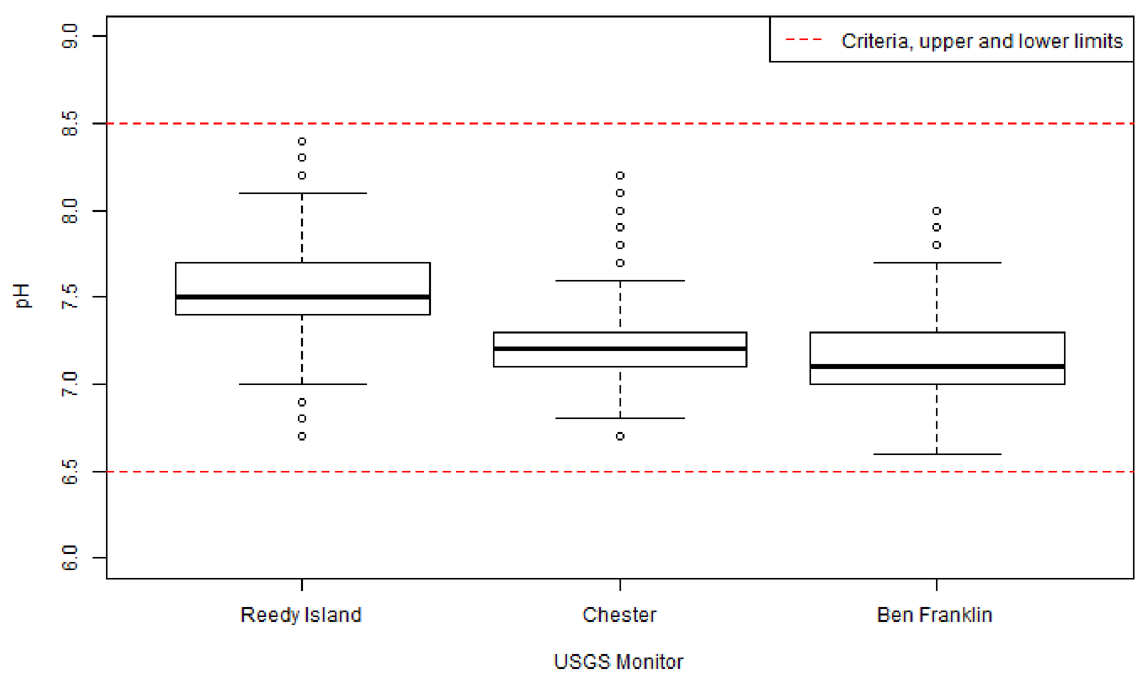

Figure 3.1.23 pH measurements at 3 USGS Delaware Estuary monitors, 2011 through 2016.

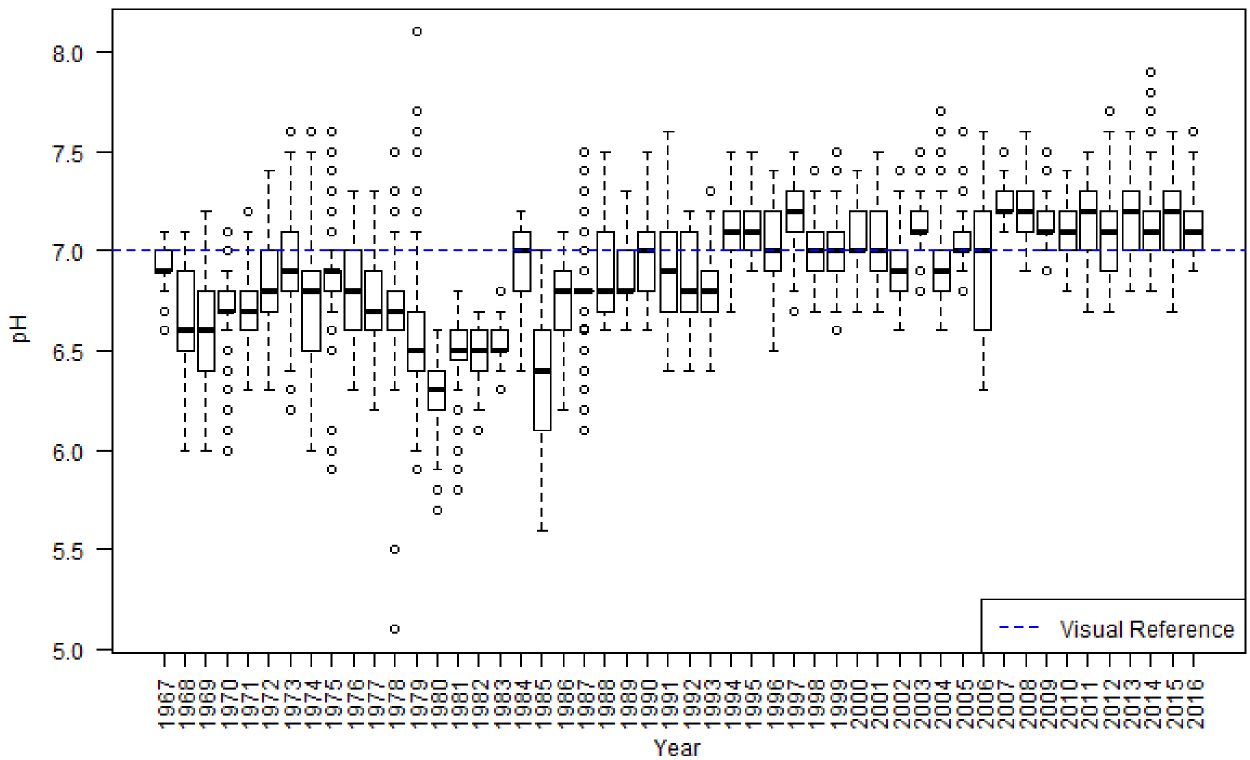

Figure 3.1.24 pH box and whisker plot by year at USGS 01467200, Ben Franklin Bridge, 1967 through 2016.

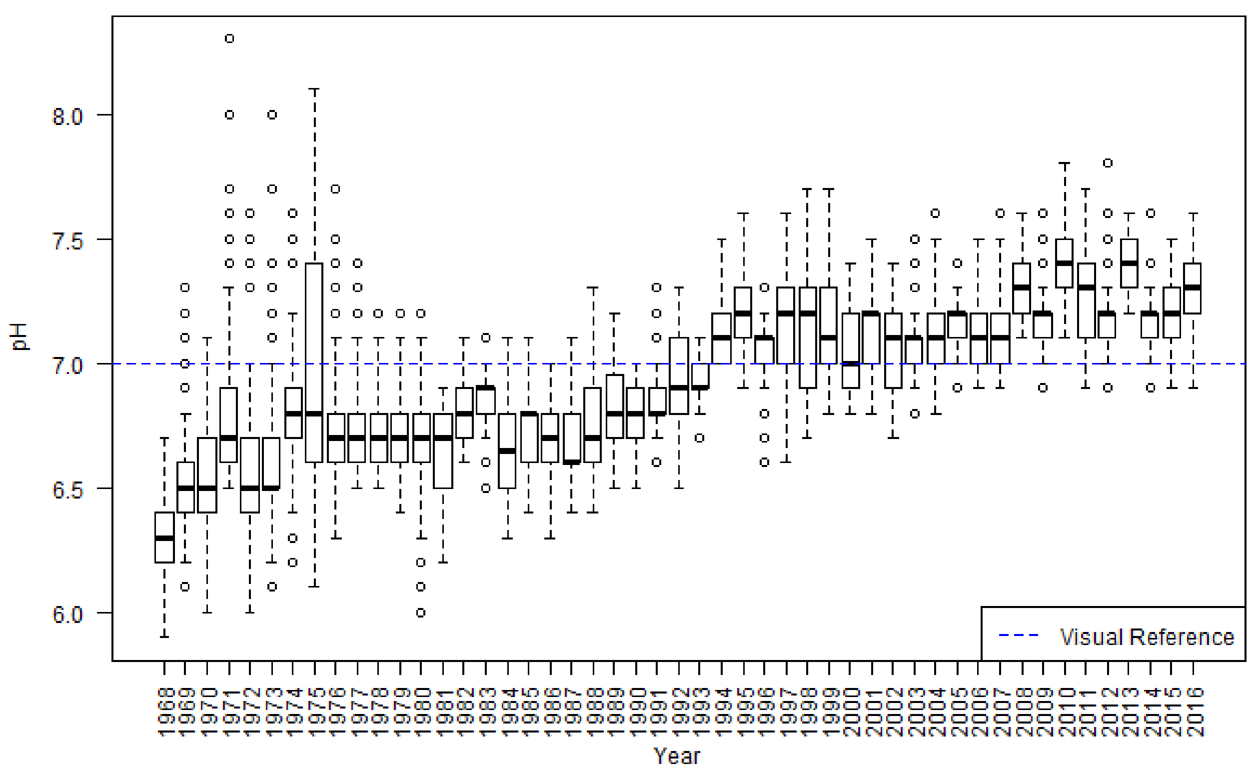

Figure 3.1.25 pH box and whisker plot by Year at USGS 01477050, Chester, 1968 through 2016.

3.1.7 Temperature

3.1.7.1 Description of Indicator

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. Estuary Temperature Criteria are expressed in DRBC regulations by day of year.

Near real-time assessment of temperature criteria in the Delaware Estuary is provided on DRBC's water quality dashboard at http://drbc.net/Sky/waterq.htm, comparing measurements from USGS and NOAA ports monitors to day-of-year temperature criteria.

3.1.7.2 Present Status

Maximum daily water temperatures recorded at USGS continuous monitors at Ben Franklin and Chester from 2011 to 2016 were compared to DRBC's zone specific day-of-year temperature criteria (Fig 3.1.26). Although most observations were below (meeting) criteria, some exceedances were evident.

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.

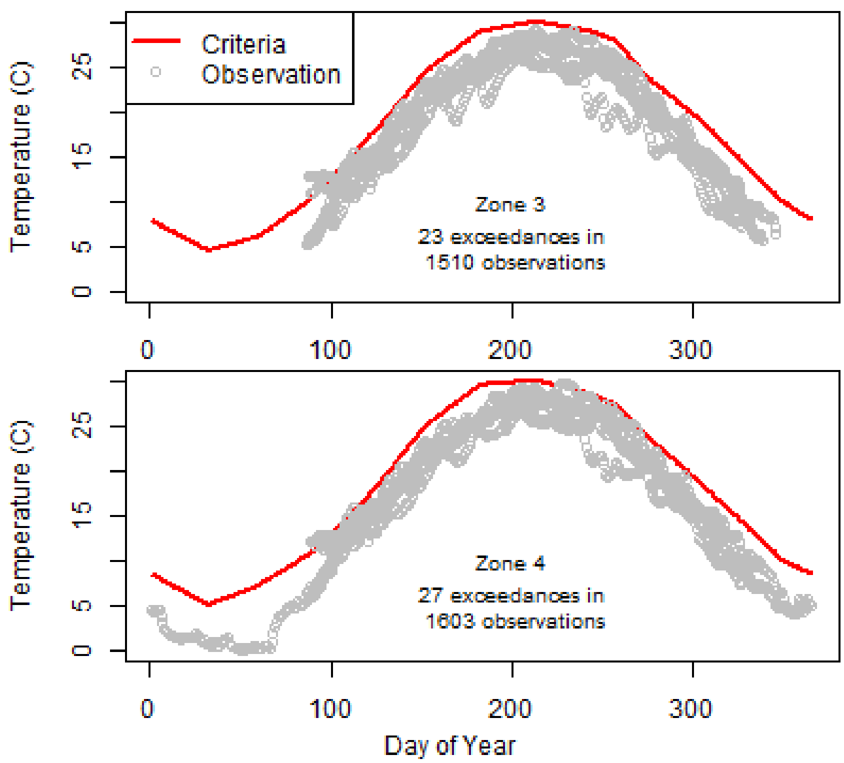

Figure 3.1.26 Temperature observations compared to DRBC day of year criteria, at Ben Franklin and Chester, 2011 through 2016.

3.1.7.3 Past Trends

In the context of global climate change, we want to determine whether water temperatures have changed during the period of observational record. One way to begin this assessment is to investigate whether the temperature 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 2016 for each of the 3 monitors, the median of the mean daily temperature for each day of the year was determined. For example, the daily mean temperature was examined for each May 15th, for every year from the 1960s or 1970, and determined the median of that set. DRBC then compared each May 15th temperature to the median of all May 15th temperatures at that location, to see if the differences changed over time. Figure 3.1.27 shows the mean daily temperature measurements by day of year, and the median for each day of year for the USGS continuous monitor at Chester.

As in the previous TREB, portions of the yearly cycle were examined where broad day to day shifts were minimized (summer and winter). Figures 3.1.28 and 3.1.29 show the residuals (mean daily water temperature – median temperature for that day of year) for Ben Franklin during the summer and Reedy Island during the summer (where the strongest indication for any trend was evident). Consistent with the prior TREB, this analysis suggested a slightly decreasing summer temperature trend at the Ben Franklin station, but an increasing summer temperature trend at the Reedy Island station.

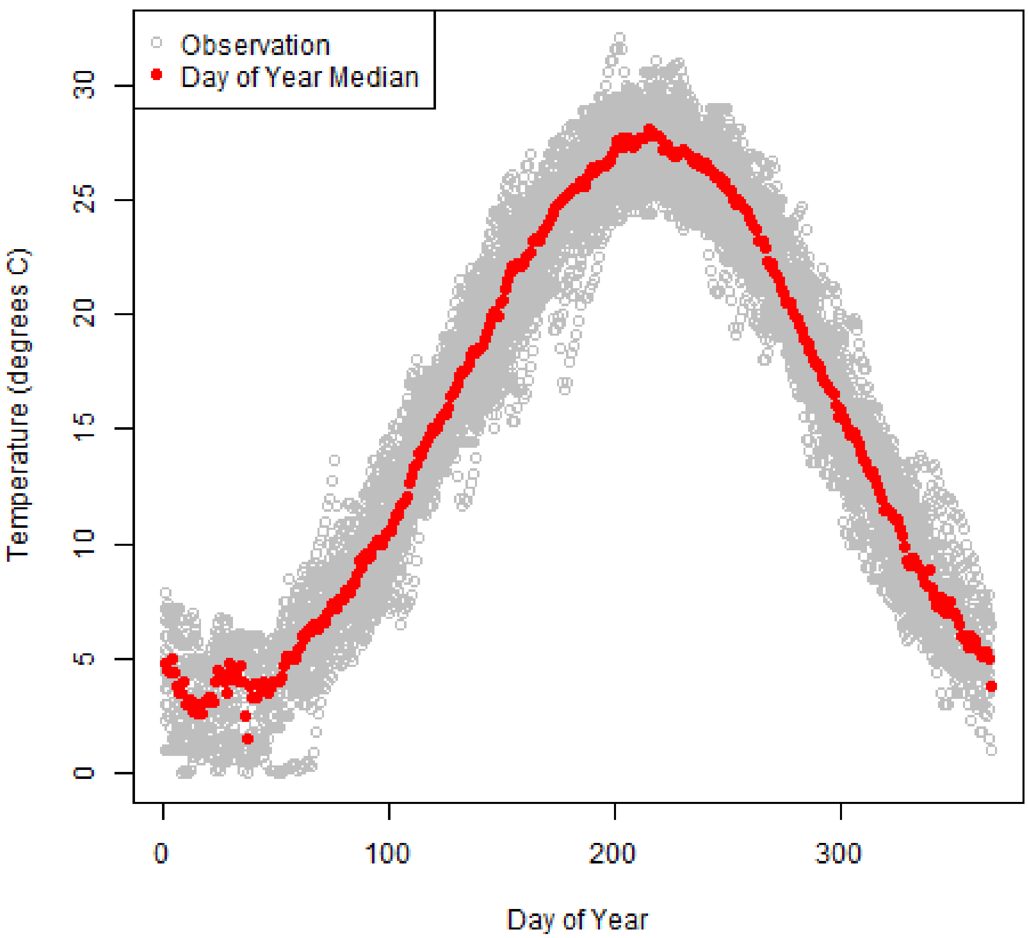

Figure 3.1.27 Period of record temperature observations including median by day of year at Chester, 1964 through 2016.

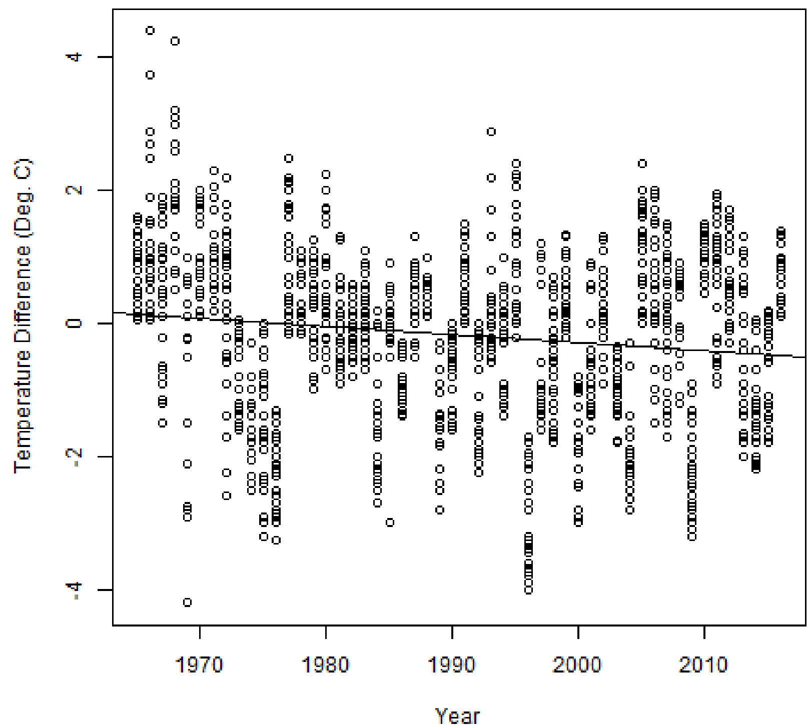

Figure 3.1.28 Delaware River summer residuals at USGS 01467200, Ben Franklin Bridge.

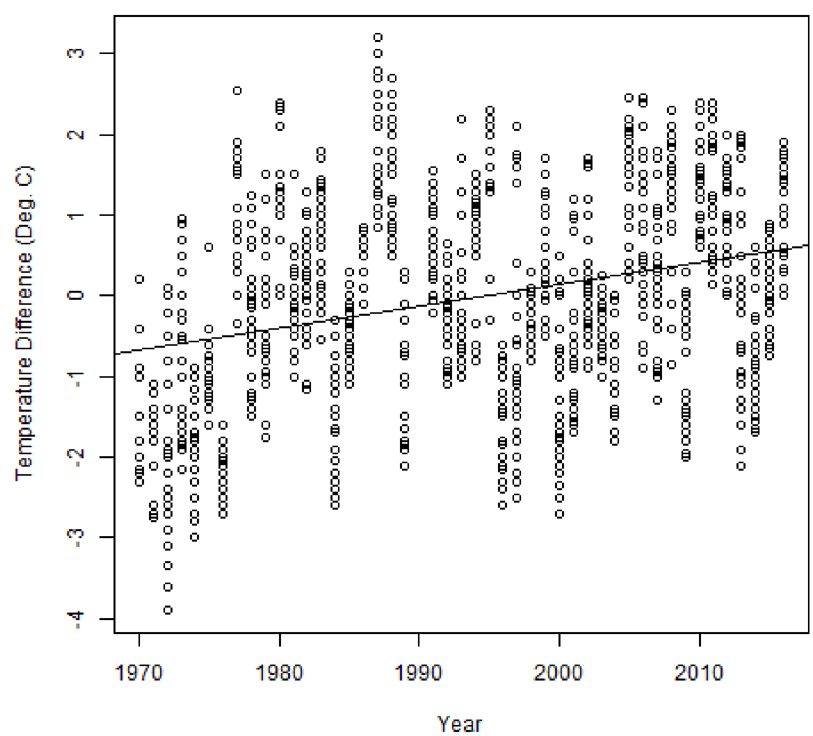

Figure 3.1.29 Delaware River summer residuals at USGS 01482800, Reedy Island Jetty.

As suggested in the previous TREB, these apparently opposite trends could be reflecting different sets of drivers. It seems reasonable to conclude that the Reedy Island increasing temperature trend is reflective of documented climate change, while the Ben Franklin station could be reflecting reductions in industrial thermal loads in the urbanized portion of the Estuary over that same time period.

3.1.7.4 Future Predictions
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. Some temperature drivers, such as sea level rise and shifts in industry and landscape may impose counter-acting forces which cannot be easily estimated.

3.1.7.5 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, a more rigorous evaluation is needed. This evaluation may need to include a temperature model that integrates the various drivers.

3.1.7.6 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. A more rigorous assessment, which explicitly accounts for overlapping temperature drivers, is desirable.

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

3.1.8.1 Description of Indicator
Polybrominated diphenyl ethers (PBDEs) are among the emerging contaminants that have been monitored in the Delaware River. PBDEs are flame retardants used on several consumer products such as television and computer casings and the polyurethane foam inside furniture cushions. They are not chemically bound to the products on which they are used, so they can easily shed off of them and into the environment. There are 209 possible PBDE congeners. PBDE's are characterized as persistent, bioaccumulative, toxic compounds (PBTs). Environmental monitoring programs conducted worldwide during the past decade have shown increasing levels of this emerging contaminant. PBDEs have been detected in the water, sediment, and fish of the Delaware Estuary (Ashley, 2007). Indoor dust is believed to be the primary source of human exposure (82-90%) but dietary exposure is also a concern (USEPA, 2010). Although fish is not a primary source of PBDE exposure, consumption of highly contaminated seafood such as catfish and shellfish have been associated with higher serum PBDE levels (Anderson, 2008).

3.1.8.2 Present Status
Four PBDE congeners are listed on USEPA's Integrated Risk Information System (IRIS): BDE 47, 99, 153, and

209. Toxicity information on IRIS includes Reference Doses (RfDs) for all four congeners for neurobehavioral effects and BDE 209 also has a cancer slope factor (http://www.epa.gov/iris/toxreviews).

3.1.8.3 Past Trends

Emerging contaminants have historically not been routinely monitored therefore limited information is available on past trends. Previous studies by the USEPA, USGS, basin states and private industry on emerging contaminants 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 are available to track past trends.

A collaborative project by the DRBC and West Chester University targeting populations that consume fish from the Delaware Estuary evaluated whether there is a declining trend of these four congeners in fish tissue from the Estuary over the years of available data (2004-2012). For each congener, mean lipid-normalized tissue concentrations for each year are presented in line graph form. Sampling sites were combined on the line graphs to show Estuary-wide trends in congener concentrations. Samples were also analyzed by one-tailed Spearman Correlation (on SPSS statistical software) to determine whether fish tissue concentrations demonstrate a significant negative association with sampling year. Declining trends of BDE 209, 153, 99, and 47 in fish tissue were observed. Some fish species have been found to metabolically debrominate certain congeners into other less brominated congeners. Since concentrations of BDE 209, 153, 99, and 47 are less affected by debromination in the catfish, tissue concentration in the catfish may more closely reflect the actual proportions of exposure to each congener. Figure 3.1.30 displays the declining trend in catfish tissue for each of these congeners. All 3 congeners declined 56-59% from their highest measured concentrations (in 2004 or 2005) to their lowest measured concentrations in 2012. BDE 209 levels also showed a moderate, inverse association with sampling year in both catfish ($p=0.045$, $r= - 0.327$) and perch ($p=0.014$, $r= - 0.403$) (Fig 3.1.31).

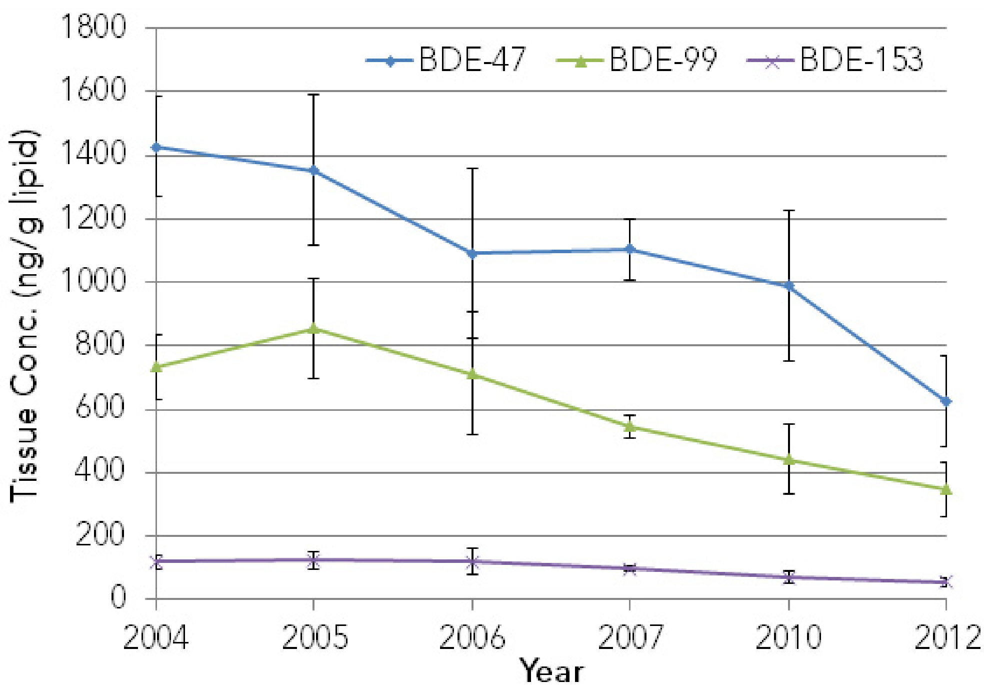

Figure 3.1.30 Lipid normalized tissue concentrations in channel catfish of congeners BDE 47, 99, and 153 by year sampled in Zones 2-5.

3.1.8.4 Future Predictions

While the decline of these congeners in fish tissue is good news and may indicate decreasing environmental contamination by PBDEs, flame retardants currently being used to replace them are not necessarily safe alternatives (Webster, 2012).

3.1.8.5 Actions and Needs

Due to variability of debromination end products by fish species, any future fish surveys should consider common PBDE debromination products in order to assess exposure levels.

Acknowledgement

PBDE trend analysis by Kelly Sand, West Chester University student and her academic advisor Charles V. Shorten, Ph.D., P.E. in collaboration with DRBC staff.

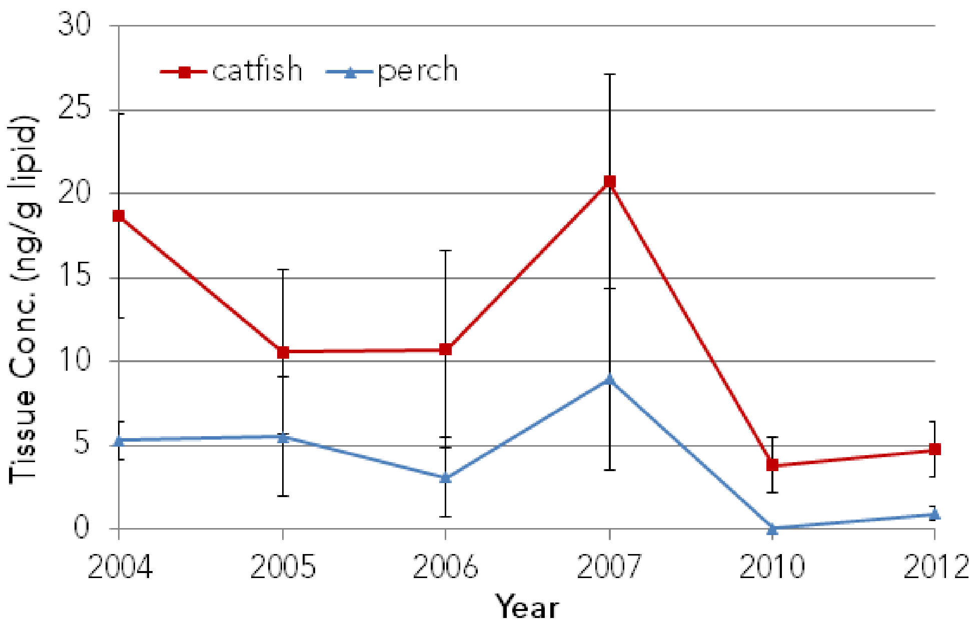

Figure 3.1.31 Lipid normalized tissue concentrations of BDE 209 in channel catfish and white perch by year sampled in Zones 2-5.

3.1.9 Whole Effluent Toxicity

3.1.9.1 Description of Indicator

The tidal Delaware River contains numerous industrial and municipal facilities with National Pollutant Discharge Elimination System (NPDES) effluent discharges (Fig 3.1.32). Whole Effluent Toxicity (WET) testing is a useful approach in the protection of aquatic life by using toxicity tests to measure toxicity of effluents along with the chemical-specific control approach. The two primary advantages to using WET testing over individual chemical-specific controls are: (1) WET tests evaluate the integrated effects of all chemicals in an aqueous sample and; (2) WET tests can measure toxicity caused by other compounds for which a chemical-specific numeric criterion has not been established or do not have an approved parameter specific analytical test method. The WET data used for this trend analysis are of consistent data quality. The trend analysis is based on a chronic toxic unit (TUc) which is (100/IC25) or (100/NOEC) where IC25 is the inhibitory concentration effecting 25% of the test population and NOEC is the no observed effect concentration. Chronic toxicity tests can detect effects at a much lower dose than acute toxicity tests providing a more direct estimate of the safe concentration of effluents in receiving waters. Therefore, chronic toxicity tests have a greater potential to produce more ecologically relevant data.

3.1.9.2 Present Status

Data sets from individual discharges were evaluated by the Mann-Kendall test, a non-parametric statistical procedure. The database was initiated in 1990 as part of the Commission established Toxics Management Program however, data post-2002 was used in the trend analysis because current WET methods were adopted in 2002 and the number of dischargers monitoring for chronic WET increased over time as the monitoring was included in permit renewals and new dockets with most dischargers including biomonitoring after 2002. Of the twelve largest individual dischargers in the Estuary, two dischargers exhibited a decreasing trend for two test species. Four dischargers exhibited a decreasing trend for at least one test species. Six dischargers exhibited no trend. Effluent TUc versus sampling date from 2002 through 2014 for a representative municipal discharge (Fig 3.1.33) and an industry discharge (Fig 3.1.34) are shown.

3.1.9.3 Past Trends

In the 1990s, some dischargers reported toxicity which (estimated after dilution in the receiving water) exceeded the stream quality objective of 1.0 TUc. Available data from recent years do not predict exceedances of stream quality objectives for chronic toxicity by individual dischargers. Determining the cause of a trend is often more difficult than determining the trend. A number of candidates for causes of the observed reduction in chronic toxicity in effluent discharges to the Estuary are efforts by industry to identify and reduce toxicity, pre-treatment and toxics reduction programs for municipal waste treatment facilities, and declining manufacturing in the region.

3.1.9.4 Actions and Needs

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

3.1.9.5 Summary

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

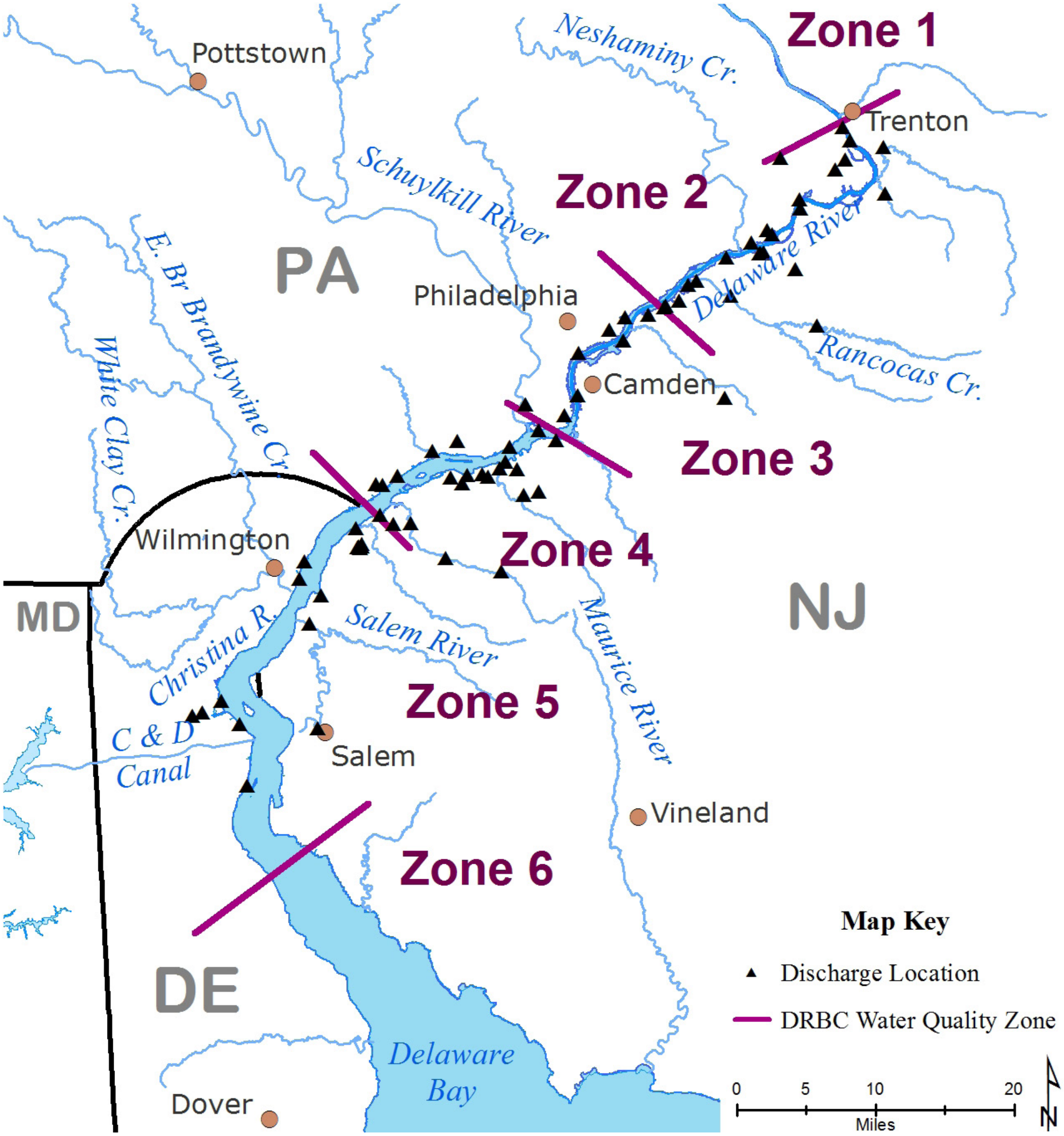

Figure 3.1.32 Delaware Estuary water quality zones and NPDES Discharges.

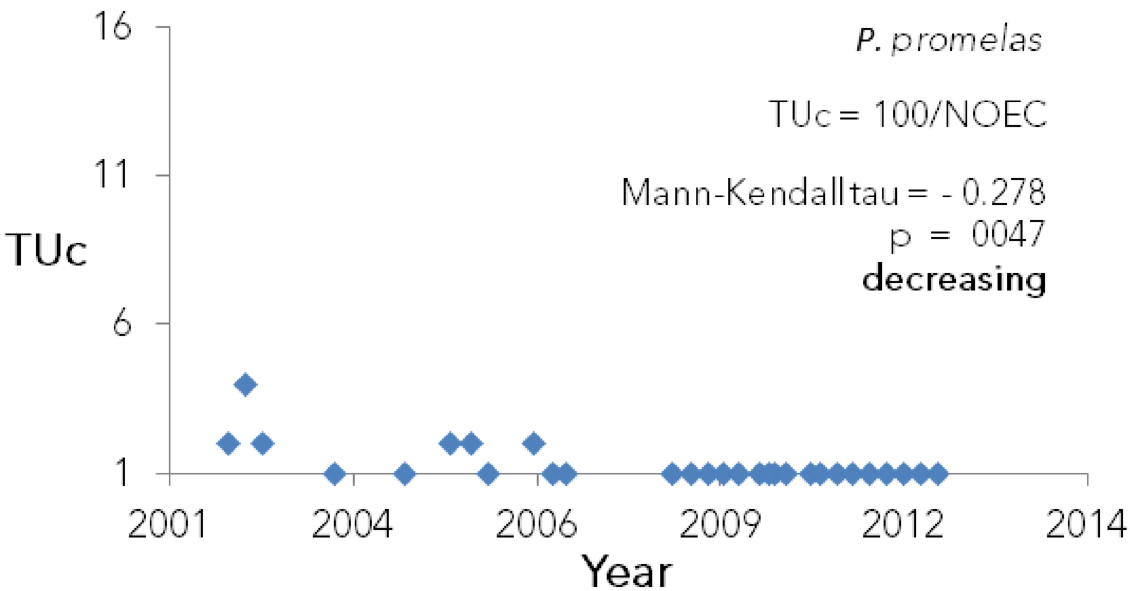

Figure 3.1.33 Municipal Discharge.

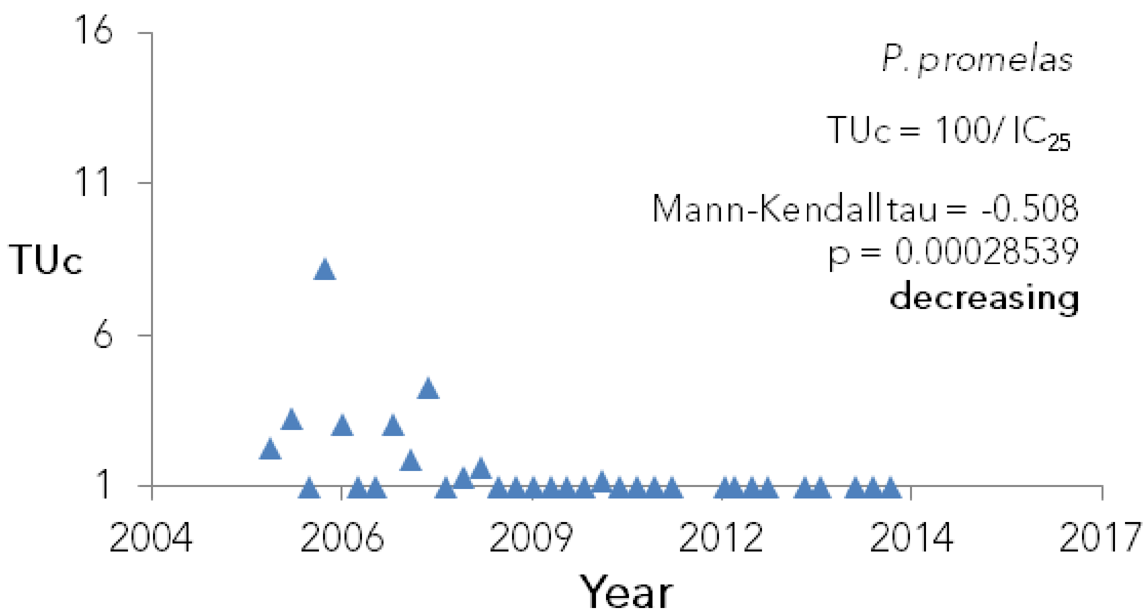

Figure 3.1.34 Industrial Discharge.

3.2 Non-Tidal

3.2.1 Dissolved Oxygen

Dissolved oxygen (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.

3.2.1.1 Description of Indicator

For our review of oxygen values in the Basin, 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 affects levels. Percent of saturation gives an indication of the oxygen content relative to saturation due to temperature and salinity.

3.2.1.2 Present Status

We queried the National Water Quality Data Portal for all summer measurements of DO in the Delaware River Basin from 2011 through 2016 and plotted their location and concentration (Fig 3.2.1). This mapping shows the availability of spot measurements and the concentration.

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. USGS continuous monitors provide a more complete DO distribution, but at fewer locations. We compared box and whisker plots of summer DO from USGS monitors at the Brandywine at Chadds Ford, the Christina River at Newport DE, the Delaware at Trenton, the Lehigh at Glendon, and the Schuylkill River Vincent Dam (Fig 3.2.2). Although the distributions are different at the different locations, the majority of values are above 5 mg/L (the threshold between fair and poor health identified in the previous TREB).

3.2.1.3 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. We applied the same time series decomposition technique from earlier in this report to the daily mean DO % of saturation time series at the Delaware at Trenton from 2000 through 2016 to evaluate recent trends (Fig 3.2.3). This analysis suggests high day-to-day variability, resulting in a noisy seasonal pattern, with no apparent trend. Unlike estuary stations, DO at the Delaware at Trenton is strongly influenced by reaeration due to its wide, shallow, high gradient reaches and photosynthesis from attached algae.

3.2.1.4 Future Predictions

Non-tidal DO appears 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.

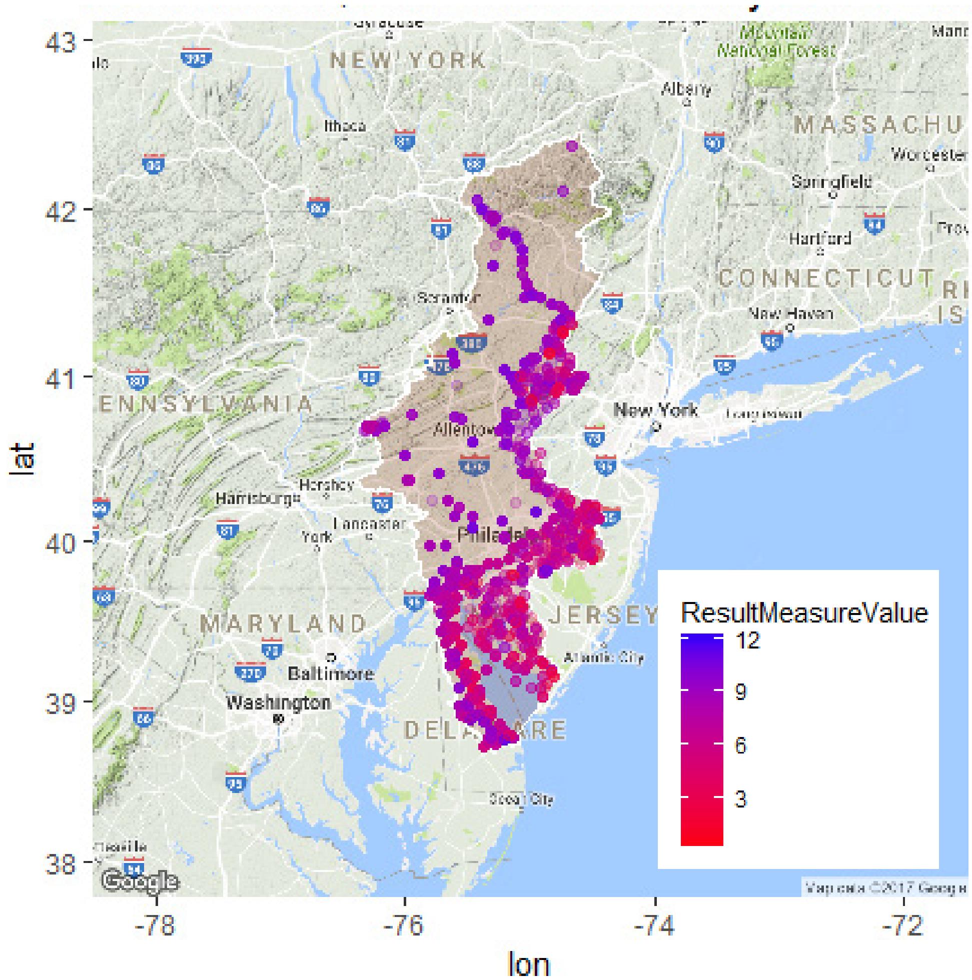

Figure 3.2.2 Summer surface water dissolved oxygen (mg/L) observations in the Delaware River Basin, 2011-2016. From the National Water Quality Data Portal.

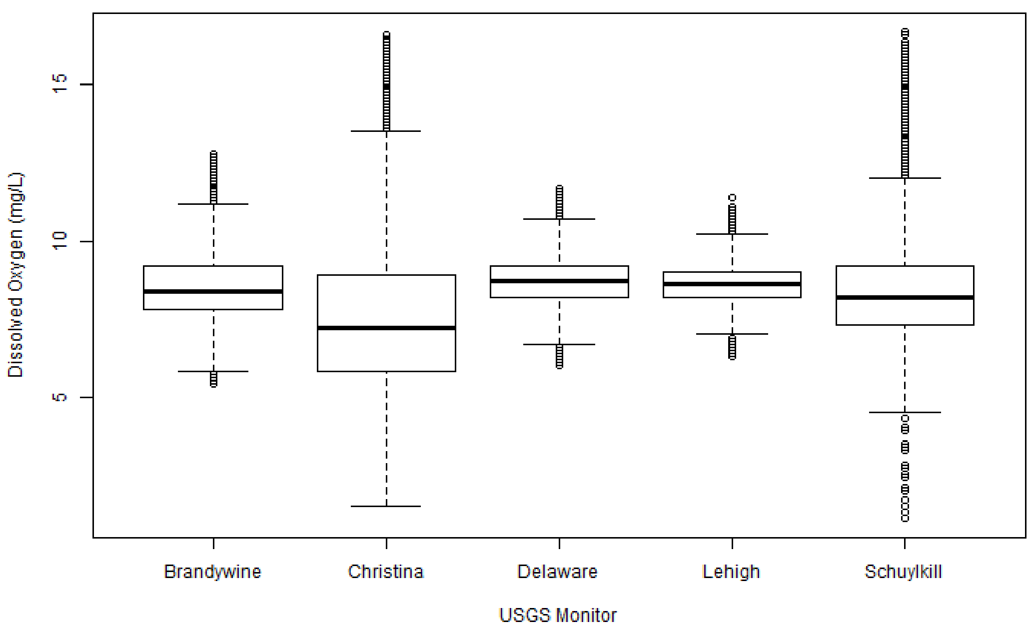

Figure 3.2.1 Box and whisker plot of summer dissolved oxygen (%) from USGS continuous meters in the Delaware Basin, 2011 through 2016.

3.2.1.5 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.

3.2.1.6 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. We expect good dissolved oxygen 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.

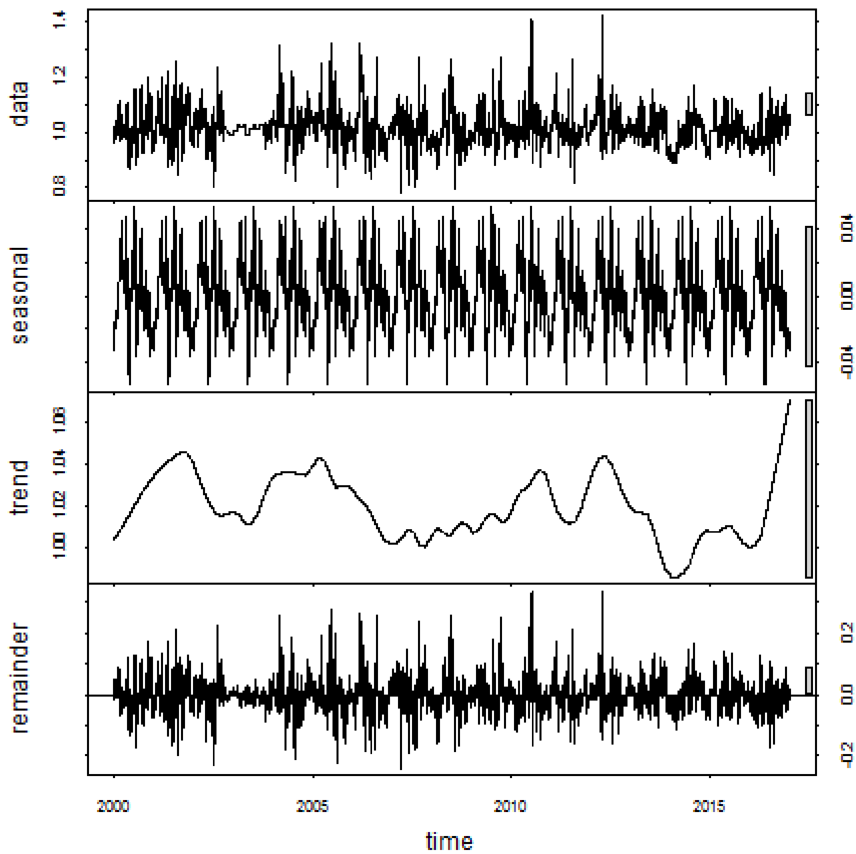

Figure 3.2.3 Time series decomposition, daily dissolved oxygen (%) saturation in the Delaware River, at Trenton, NJ.

3.2.2 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 USEPA, "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. (USEPA website: http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/problem.cfm)

3.2.2.1 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.

3.2.2.2 Present Status

We queried nitrate and phosphate measurements in surface water in the Delaware River Basin from the National Water Quality Data Portal for the period 2000 through 2015. Locations and results are plotted in Figures 3.2.4 and 3.2.5 below. Figure 3.2.4 suggests relatively lower nitrate concentrations in the upper portion of the Basin, with higher values seen lower in the basin and within the Schuylkill sub-watershed. Figure 3.2.5 suggests low phosphate concentrations in many locations with slightly higher levels seen near the urbanized and Estuary portion of the Basin.

For the nitrate basin map, values were limited to those within the range from the first quantile to the 99th quantile, to minimize the scale impact of outliers.

3.2.2.3 Past Trends

In 2016, DRBC completed a project demonstrating that its Special Protection Waters (SPW) program is effective at keeping clean water clean, and has even allowed improvements in nutrient water quality. DRBC

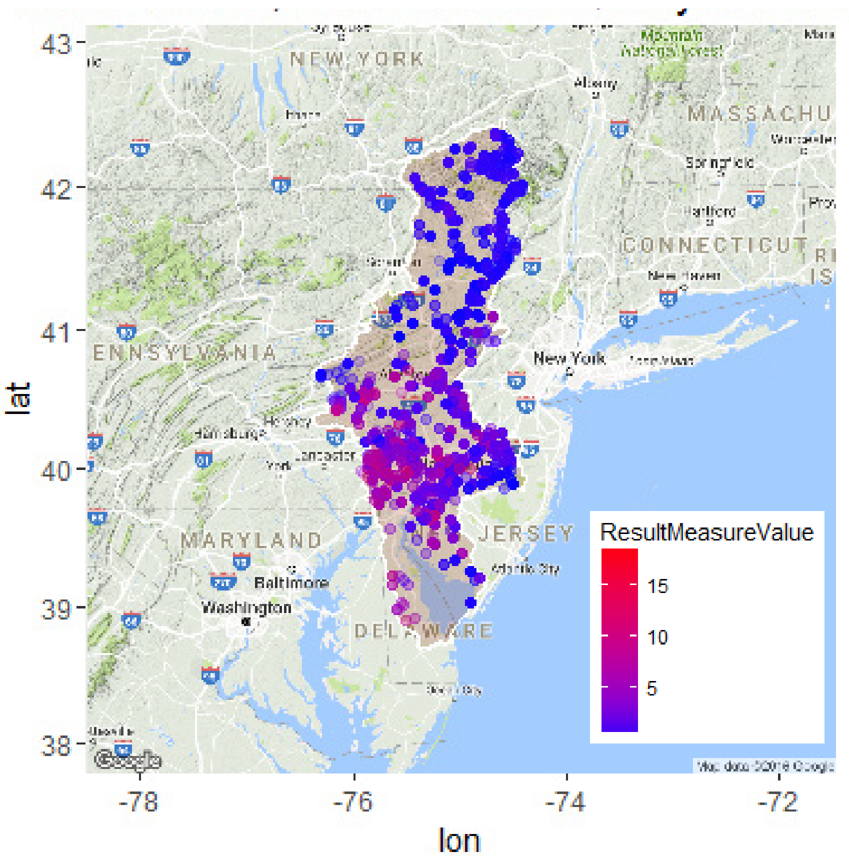

Figure 3.2.4 Surface water nitrate (mg/L) observations in the Delaware River Basin, 2000-2015. From the National Water Quality Data Portal.

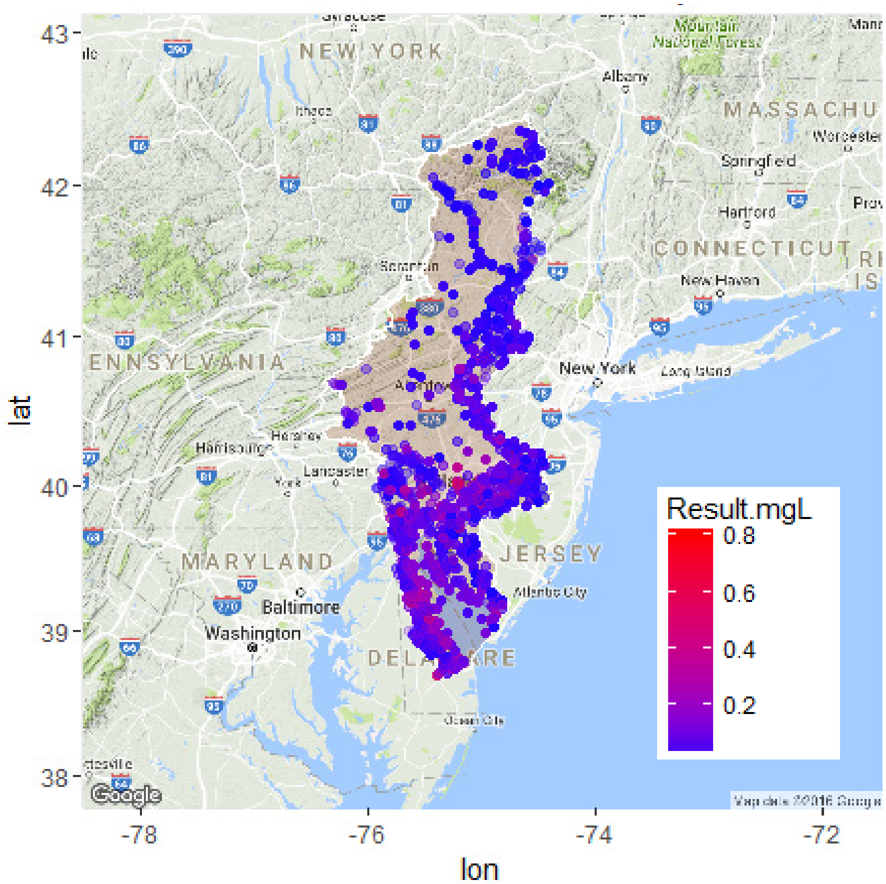

Figure 3.2.5 Surface water phosphate (mg/L) observations in the Delaware River Basin, 2000-2015. From the National Water Quality Data Portal.

compared baseline water quality data initially collected from 2000-2004 to the assessment period of 2009-2011 at 24 sites located on the Delaware River and tributaries. For most water quality parameters at most locations, there were no measurable changes to existing water quality, and nutrient parameters showed improvement at most sites. DRBC's SPW program is designed to prevent degradation where existing water quality is better than the established water quality standards through management and control of wastewater discharges and reporting requirements. Table 3.1.2 below (adapted from the report) shows that all monitoring locations but one demonstrated maintenance or improvement of nutrients for Existing Water Quality. The report and details about the SPW program are available at http://www.nj.gov/drbc/home/newsroom/news/approved/20160808_LDSPW-EWQrpt.html.

For more information on this project contact Robert Limbeck (Robert.Limbeck@drbc.nj.gov).

In 2017 USGS completed an assessment of long term trends in water quality in New Jersey, including stations on the Delaware River and within the Basin. This assessment corroborates nutrient improvements in the non-tidal Delaware River. That report is available at https://pubs.er.usgs.gov/publication/sir20165176

3.2.2.4 Future Predictions

USEPA has prioritized nutrient criteria development in the United States for over 15 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

Table 3.1.2 Results of existing water quality assessment for nutrients.

Site Name	Nitrogen (mg/L)				Phosphorus (mg/L)	
	Ammonia Nitrogen, Total	Nitrate + Nitrite, Total	Nitrogen, Total (TN)	Kjeldahl, Total (TKN)	Ortho-phosphate, Total	Phosphorus, Total (TP)
Delaware River at Trenton						
Delaware River at Washingtons Crossing						
Pidcock Creek, PA						
Delaware River at Lambertville						
Wickecheoke Creek, NJ						
Lockatong Creek, NJ						
Delaware River at Bulls Island						
Paunacussing Creek, PA						
Tohickon Creek, PA						
Tinicum Creek, PA						
Nishisakawick Creek, NJ						
Delaware River at Milford						
Cooks Creek, PA						
Musconetcong River, NJ						
Delaware River at Riegelsville						
Pohatcong Creek, NJ		**	**			
Lehigh River, PA						
Delaware River at Easton						
Bushkill Creek, PA						
Martins Creek, PA						
Pequest River, NJ						
Delaware River at Belvidere						
Paulins Kill River, NJ						
Delaware River at Portland						

Key

(grey)	No indication of measurable change to EWQ
**	Indication of measurable water quality change toward more degraded status

conditions 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.

3.2.2.5 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.

3.2.2.6 Summary

The Assessment of Existing Water Quality performed by DRBC in 2016 suggests that at most of the locations evaluated for most nutrient parameters, conditions are being maintained or improving. The USGS assessment completed in 2017 corroborates these findings for the non-tidal Delaware River in New Jersey.

3.2.3 Contaminants

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

3.2.3.1 Description of Indicator

Water quality monitoring data from multiple organizations (DRBC, DNREC, NYSDEC, NJDEP, PADEP and USGS) are included in water quality assessments of the Delaware River including data from DRBC enhanced studies of non-tidal (Zone 1) metals. Toxic pollutants data are collected using USEPA approved or equivalent methods with the level of monitoring varying by Zone and toxic pollutant.

3.2.3.2 Present Status

To ensure attainment and maintenance of downstream water quality standards and to facilitate consistent and efficient implementation and coordination of water quality-related management actions in shared interstate waters protected for public water supply, the most stringent ambient water quality criteria for human health for New York or Pennsylvania are compared to surface water data in in non-tidal DRBC Water Quality Management Zones Zones 1A and 1B. The most stringent ambient water quality criteria for human health for Pennsylvania or New Jersey is compared to surface water data in non-tidal DRBC Water Quality Management Zones Zones 1C, 1D, and 1E. For waters protected for use by fish and other aquatic life, the most stringent ambient water quality criteria apply in non-tidal shared interstate waters. The report "2016 Delaware River and Bay Water Quality Assessment" describes concerns for the support of human health due to PCB and mercury concentrations and the need for further evaluation of aluminum, cadmium and copper in non-tidal segments of the river. (http://www.state.nj.us/drbc/library/documents/WQAssessmentReport2016.pdf)

3.2.3.3 Past Trends

Data and detection insufficiencies make determination of past trends difficult.

3.2.3.4 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 contaminant concentrations relative to those endpoints. In the face of improving management, it is reasonable to expect improvements in water quality and declines in concentrations of priority pollutants; however it is more likely that levels will remain relatively the same at their current levels. 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.

3.2.3.5 Actions and Needs

Continuity in monitoring programs, continued assessments, and continued updates in criteria are all needed to maintain water quality and effectively decrease levels where levels are elevated. Additional monitoring and assessment of toxic contaminants in the non-tidal portion (Zone 1) of the Delaware River is recommended.

3.2.3.6 Summary

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

3.2.4 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.

3.2.4.1 Description of Indicator

Bioaccumulative contaminants have been monitored over an extended period in fish fillet collected from the Delaware River. Bioaccumulation of contaminants in fish tissue is influenced by physical-chemical properties of the contaminant, fish species, age, migration and food habits as well as other environmental factors such as season of fish sampling.

3.2.4.2 Present Status

While programs are in place to reduce the concentrations of toxic pollutants that bioaccumulate, Delaware River Basin states issue "advisories" containing meal advice for consumers of recreationally-caught fish and shellfish to minimize the risk to human health. These advisories list the water bodies, fish species, and number of meals recommended to minimize the risk. In some cases, no consumption of any fish species from a water body or more stringent consumption guidelines for pregnant women and children is advised. These advisories are typically revised yearly based upon recent fish tissue concentration data. A summary of fish consumption advisories in the Delaware River is available at http://www.state.nj.us/drbc/library/documents/WQAssessmentReport2016.pdf.

The following websites provide additional information on state-issued fish consumption advisories:

Delaware http://www.dnrec.delaware.gov/fw/Fisheries/Pages/Advisories.aspx

New Jersey http://www.nj.gov/dep/dsr/njmainfish.htm

New York http://www.dec.ny.gov/outdoor/7736.html

Pennsylvania http://www.nj.gov/drbc/quality/datum/fish-consumption.html.

3.2.4.3 Past Trends

A number of bioaccumulative compounds are monitored in fish collected from the Delaware River. Trends will differ depending on the contaminant of interest. Dioxins are examples of toxic chemicals observed in the Delaware River that bioaccumulate in fish. The stream quality objective in the Delaware River is based on the most toxic dioxin compound 2,3,7,8-TCDD. A slight declining trend in White Suckers and no trend in Smallmouth Bass of concentrations for 2,3,7,8-TCDD (Dioxin) from 2004 to 2015 with concentrations of the lipophilic contaminant normalized to 5% lipid in fish tissue is graphically presented in Figure 3.2.6 and by an ANCOVA comparison of contaminant concentrations by year with the length of the fish as a covariate in Table 3.2.1. Similar assessments indicate that concentrations of other legacy pesticides (chlordanes and dieldrin) are not indicating a trend in non-tidal fish species (not shown).

3.2.4.4 Future Predictions

Given the hydrophobic and lasting nature of many fish tissue contaminants, it is reasonable to presume that concentrations will remain relatively constant. For many compounds, even the effects of regulatory water quality management efforts will likely take decades to be reflected in tissue concentrations.

3.2.4.5 Actions and Needs

Pollution minimization efforts are necessary to bring about the needed reductions in tissue concentrations. Cooperative efforts among state and federal agencies and other partners to reduce emissions of bioaccumulative contaminants to the Delaware River should continue and be expanded.

3.2.4.6 Summary

Trends for specific contaminants may result from regulatory restrictions on use, changes in loading rates or degradation of the contaminant in the environment. Trajectories for contaminant reduction in fish may be long depending on the contaminant of concern, but effective management is needed to facilitate these trajectories.

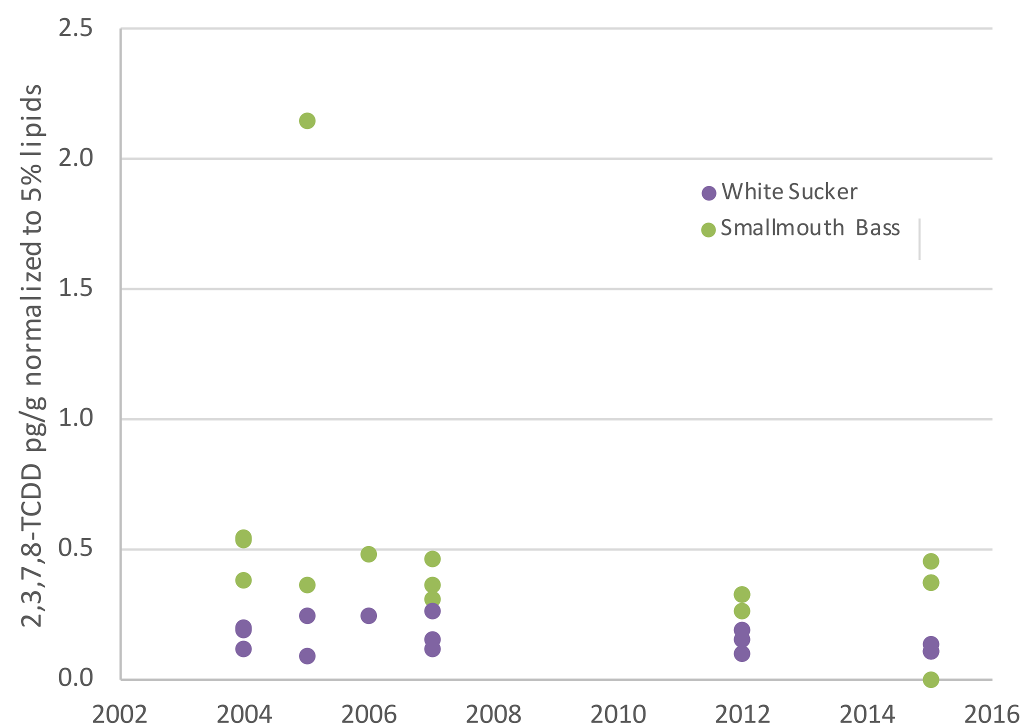

Figure 3.2.6 Concentrations of 2,3,7,8-TCDD in fillet of two non-tidal fish species by sample year.

Table 3.2.1 ANCOVA results of year versus contaminant with weight as a covariate.

Contaminant	Species	Water	N	Estimate of Slope	p-value	Trend
2,3,7,8 TCDD	Smallmouth Bass	non-tidal	6	-0.03	0.40	none, slight
2,3,7,8-TCDD	White Sucker	non-tidal	2	-0.0016	0.02	declining

3.2.5 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.

3.2.5.1 Description of Indicator

Pharmaceuticals and Personal Care Products (PPCP) include a wide suite of active ingredients in prescription and over-the-counter medication such as antibiotics, anti-inflammatories and anti-hypertensives as well as personal care products such as anti-bacterials. Concentrations of PPCPs have been shown to be generally higher in urbanized and industrialized areas.

3.2.5.2 Present Status

A recent collaborative research project was carried out by Temple University and the DRBC to increase our understanding of the loading of emerging contaminants by sampling tributaries in a specific area of the Delaware River watershed that is urbanized and significantly impacted by wastewater treatment plant effluents. Fifteen target compounds were selected for analysis based on their frequency of detection in a previous multiyear study conducted on the Delaware River main stem. The analytes measured in surface water included clarithromycin, trimethoprim, carbamazepine, diphenhydramine, dehydronifedipine, diltiazem, erythromycin, gemfibrozil, ibuprofen, triclocarban, metformin, guanylurea, ranitidine, sulfamethoxazole and thiabendazole. Ten sampling sites were chosen on tributaries receiving municipal and industrial discharges. Tributaries sampled were East Perkiomen Creek, Perkiomen Creek, Schuylkill River, Wissahickon Creek and Neshaminy Creek. Sampling locations were above and below potential source discharges. Sampling was designed to assess seasonal differences in emerging contaminant loadings.
The measured environmental concentrations of the target compounds present a detailed picture of urban and industrial impacts on subwatershed receiving waters. An "index of concern" ranking system is in development for the sample locations by comparing measured environmental concentrations, existing target compound water quality criteria or predicted no effects levels and developing a concern summary parameter.

3.2.5.3 Actions and Needs

Because of concerns about potential effects of PPCP on aquatic life, future work should evaluate the sources as well as the fate and effects of PPCP in the Delaware River water column, sediments and biota.

3.2.6 pH

pH is the mathematical notation for the negative log of the hydrogen ion concentration (-log[H+]) and indicates an acid, neutral, or base condition.

3.2.6.1 Description of Indicator

The pH of surface waters can be an important indicator of ecological function and productivity, and pH impacts the bioavailability and toxicity of pollutants such as metals and ammonia. Currently, DRBC's criteria for the Delaware River requires pH to be between 6.5 and 8.5.

3.2.6.2 Present Status

Boxplots of summer pH from USGS monitors at the Brandywine at Chadds Ford, the Christina River at Newport DE, the Delaware at Trenton, and the Lehigh at Glendon from 2011 through 2016 show different distributions in pH by location (Fig 3.2.7). Since pH can react to productivity, summer was selected to capture this influence.

DRBC's criteria for the Delaware River requires pH to be between 6.5 and 8.5. Figure 3.2.8 below shows the boxplot of pH instantaneous measurements by year at the Delaware River at Trenton from 2008 through 2016. The applicable criteria are plotted as red lines, and the plot shows that during many years, as many as 25% of the measured values exceed the upper limit criteria of pH = 8.5. Exceedances of the criteria are permissible when due to natural conditions, but more work is needed to evaluate what proportion of these exceedances are attributable to natural conditions. Some criteria violations are attributable to high pH conditions during periods of high primary production, although nutrients concentrations may contribute to the frequency and magnitude of pH exceedances through stimulation of algae and aquatic plants.

3.2.6.3 Past Trends

We developed a box plot of the daily median pH values at the Delaware River at Trenton by year for the period 2000 through 2016, shown in Figure 3.2.9 below. No clear trend is indicated.

3.2.6.4 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.

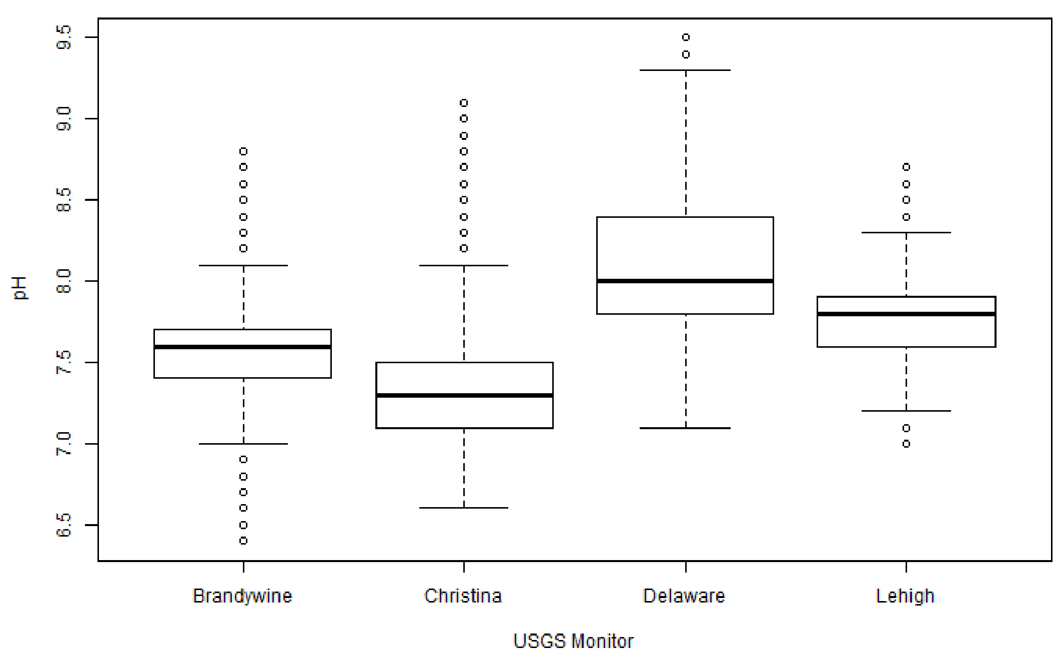

Figure 3.2.7 Summer pH observations at 4 USGS continuous Delaware Basin water quality meters 2011 through 2016.

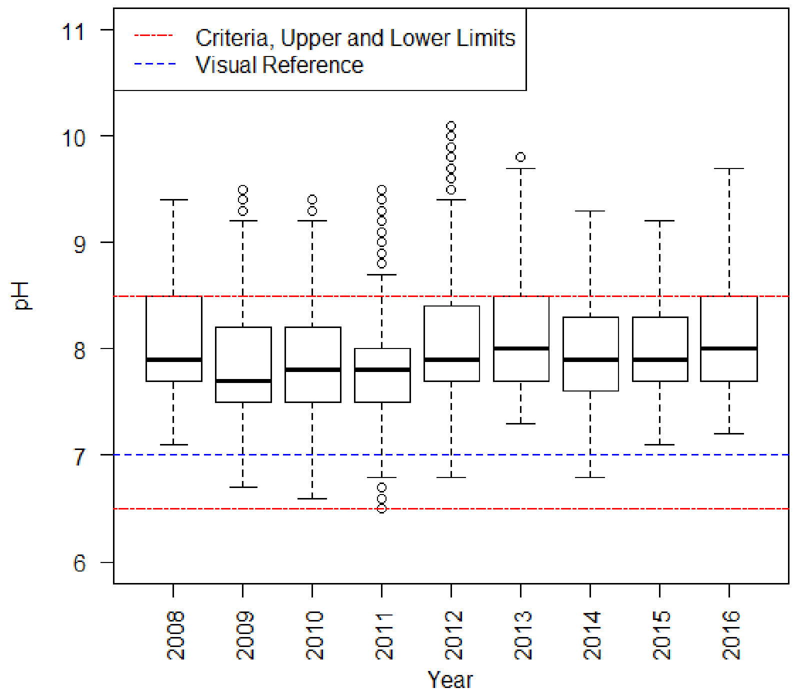

Figure 3.2.8 Instantaneous pH measurements by year, Delaware River at USGS 01463500, Trenton, 2008 through 2016.

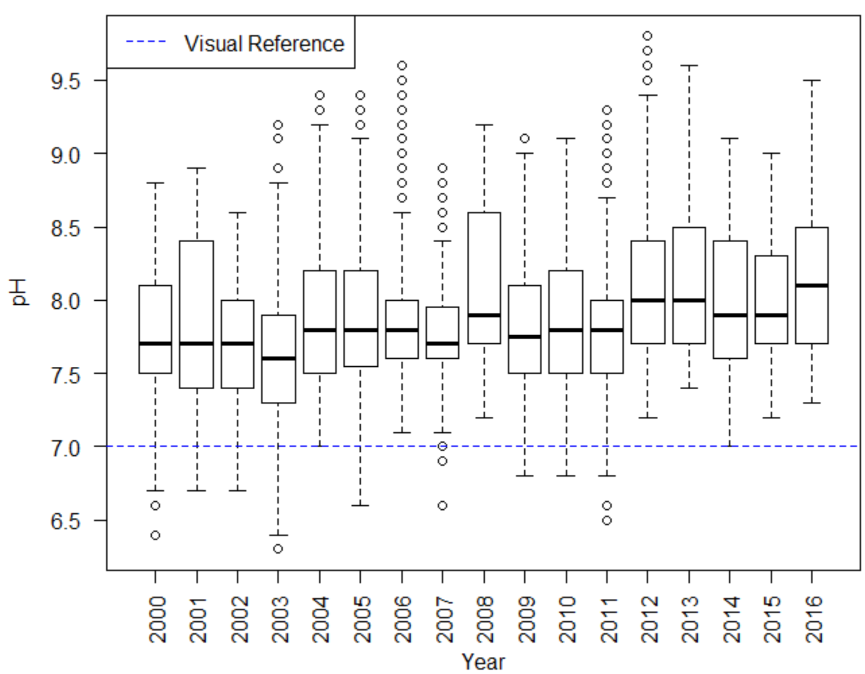

Figure 3.2.9 Daily median pH box and whisker plot at USGS 01463500, Trenton, 2000 through 2016.

3.2.6.5 Actions and Needs

More effort is needed to understand and evaluate routine excursions above a pH value of 8.5 at Trenton. Although this could be a violation of the surface water quality standard, it would be permissible if due to natural conditions. While nutrients may play a role, we have also observed pH excursions above 8.5 in the upper portion of the River, where nutrient concentrations are substantially lower and considered to be oligotrophic.

3.2.6.6 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.

3.2.7 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. Temperature assessment in the non-tidal Delaware River is confounded by artificially lowered temperatures from reservoir releases in the upper portion of the River and the lack of protective ambient criteria.

3.2.7.1 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.

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.

3.2.7.2 Present Status

Figure 3.2.10 shows the summer temperature distributions at four USGS monitors in the mainstem Delaware River at Lordville (river KM 517.6), Callicoon (KM 487.1), above Lackawaxen near Barryville (KM 449.3) and Trenton (KM 216.2), from 2011 through 2016. This plot demonstrates the shift in temperature from the reservoir influenced cold water upstream to warmer temperatures downstream.

To assess whether the temperature regimes observed in the river were protective of aquatic communities, we compared the continuous measurements at Trenton to the Pennsylvania criteria for warm water fisheries. As shown in Figures 3.2.11 below, although the majority of observations are below (meeting) criteria, there are numerous violations, most frequently in the spring.

3.2.7.3 Past Trends

Long term temperature record at Trenton (1954 through 2016) were evaluated to determine if the number of 'violations' would have increased over time (had those criteria been in place). As shown in Figure 3.2.12, no discernable trend in the number of violations per year is evident from the data.

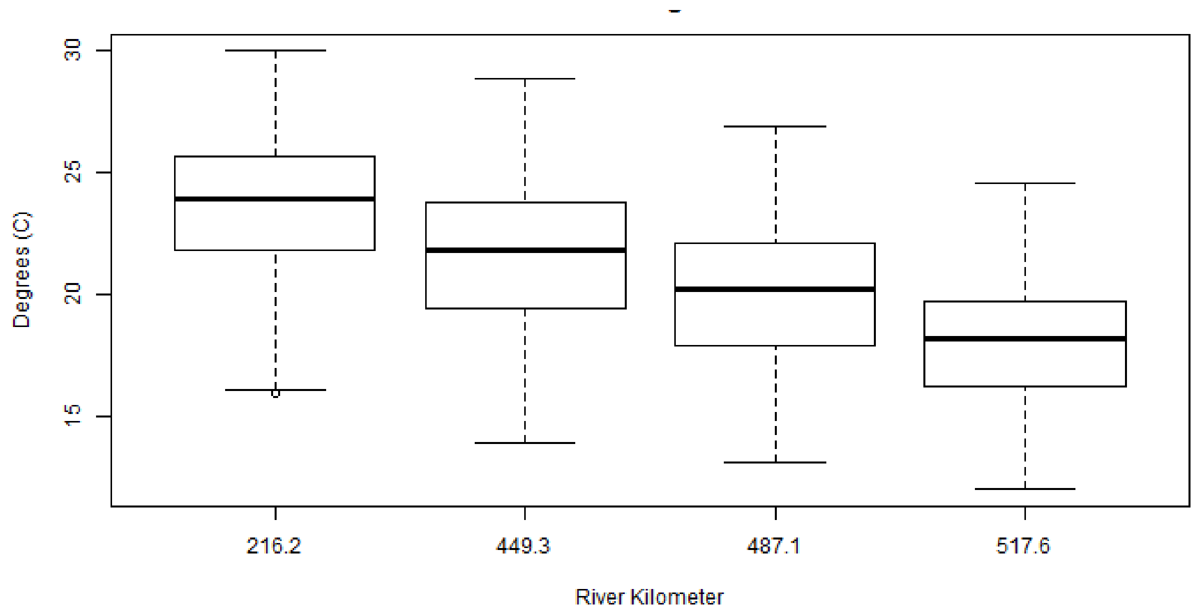

Figure 3.2.10 Summer water temperature box and whisker plot along the main stem of Delaware River, 2011 through 2016.

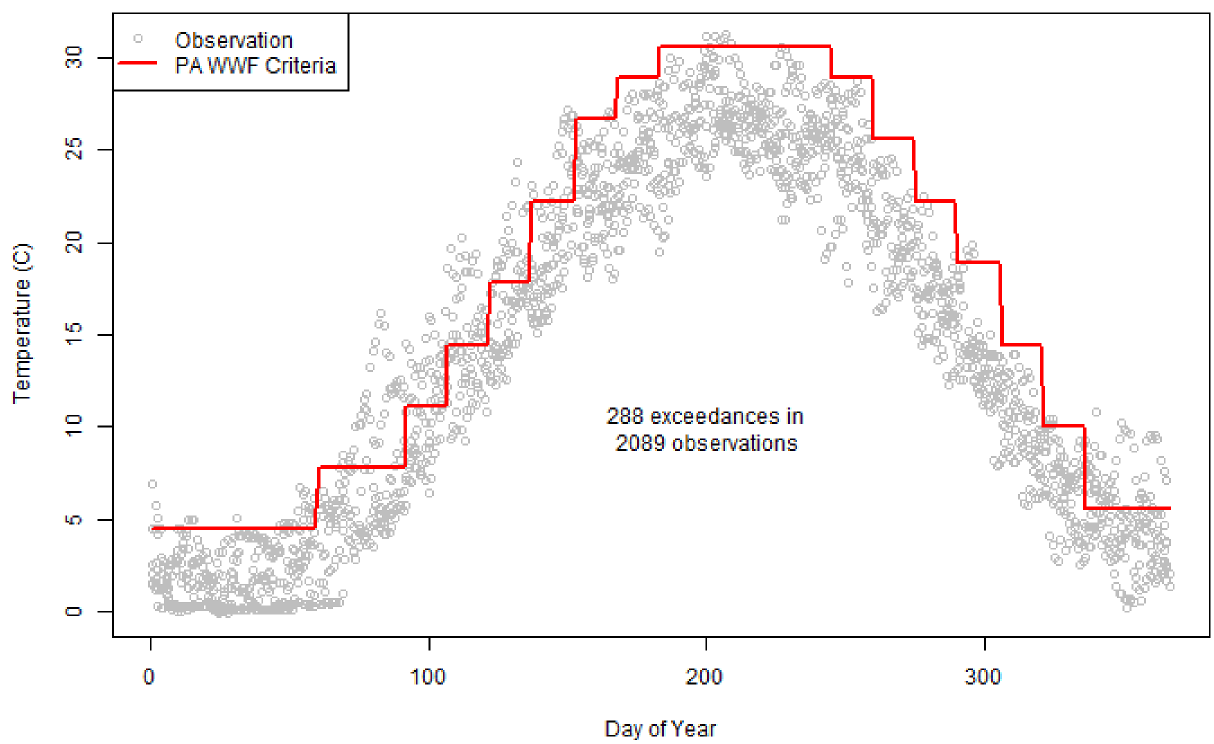

Figure 3.2.11 Comparison of maximum daily water temperature by day of year at USGS 01463500, Trenton to PA Warm Water Fishery Temperature Criteria, 2011 through 2016.

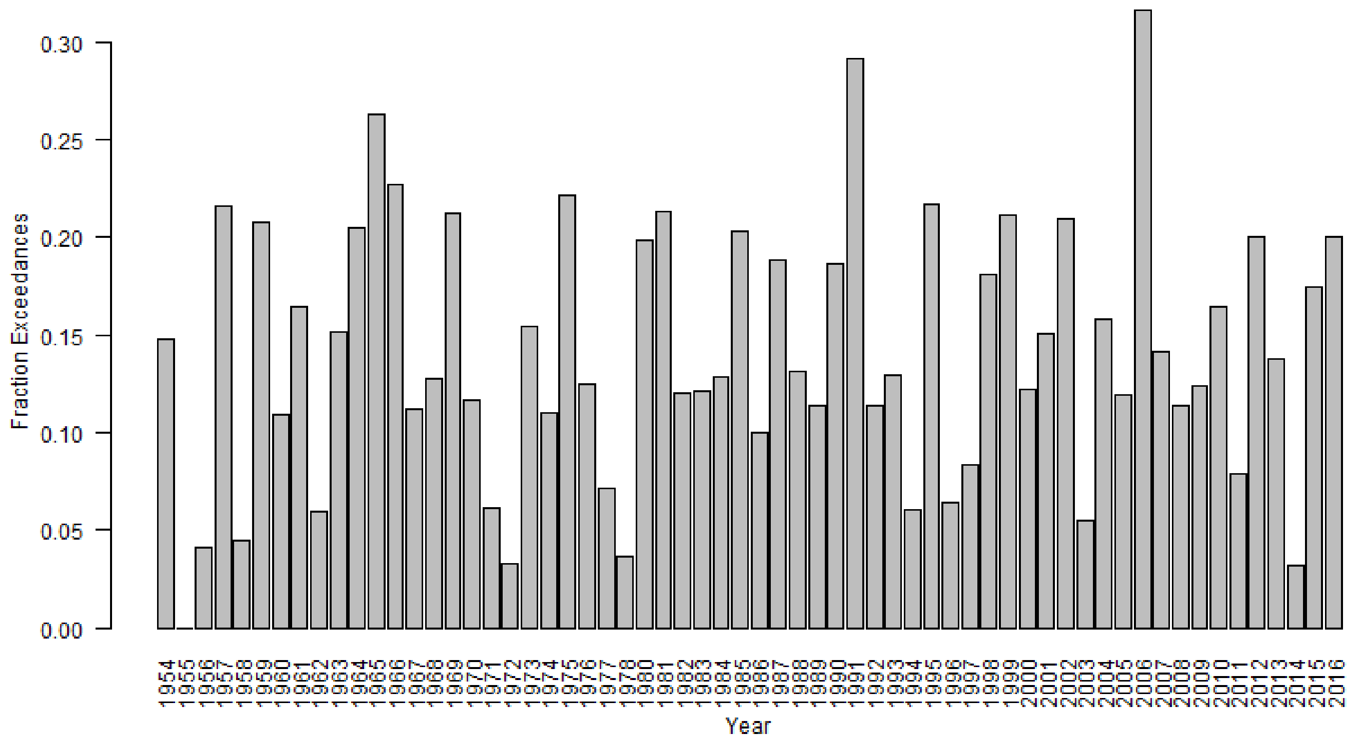

Figure 3.2.12 Water temperature exceedances over PA WWF criteria by year along Delaware River at USGS 01463500, Trenton.

3.2.7.4 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 is expected to exert upward pressure on water temperatures.

3.2.7.5 Actions and Needs

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

3.2.7.6 Summary

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

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Suggested Citation for this Chapter

Yagecic, J., R. MacGilivray. 2017. “Chapter 3 - Water Quality” in the Technical Report for the Delaware Estuary and Basin. Partnership for the Delaware Estuary. PDE Report No. 17-07, pp. 97-145.

Data Sources and Processing

Data used in this TREB update comes primarily from USGS continuous monitors, USGS discrete monitoring, and DRBC monitoring programs. Aggregated available data sets were also queried via the National Water Quality Data Portal. Where multiple data sets exist, the authors relied on data for which we had the best first-hand knowledge of quality assurance and quality control.

There are unlimited options available for sub-setting data and presenting it graphically. The authors chose data periods and graphical representations in each instance that conveyed the best understanding of the data.

Back to Table of Contents