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.

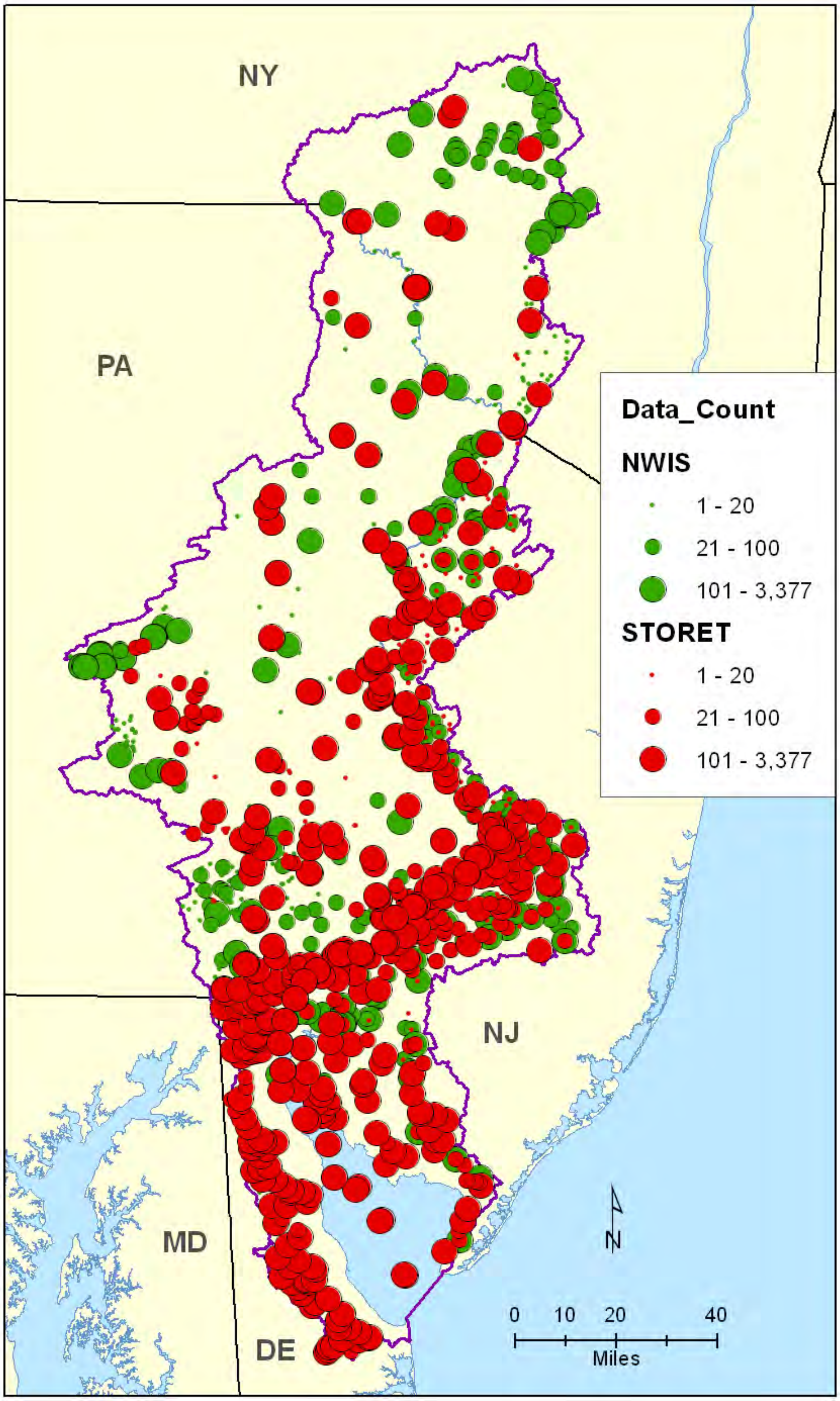

Fig. 3.1. NWIS and STORET Data Count by Location

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.

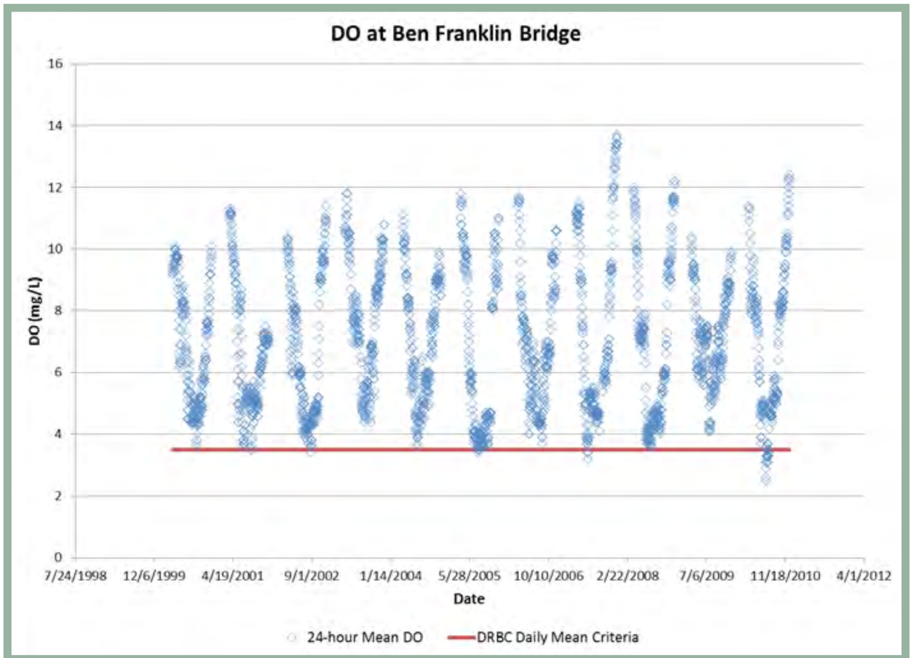

Fig. 3.2. Daily Mean DO Compared to Criteria at Ben Franklin Bridge

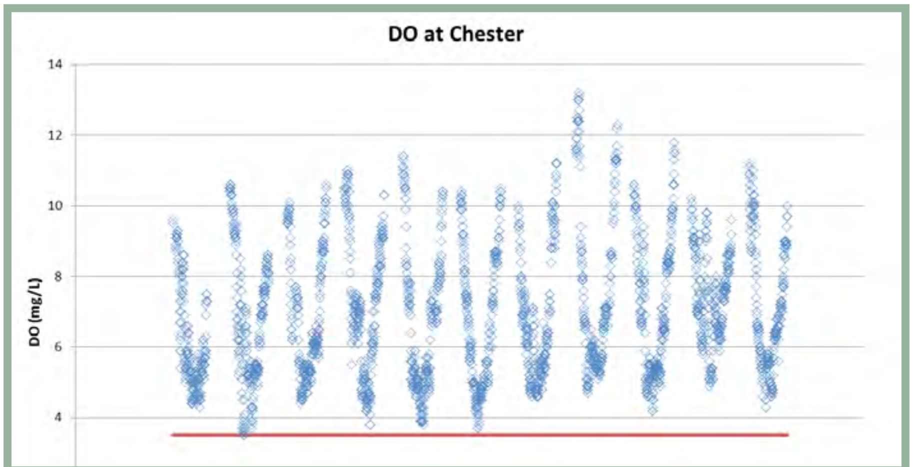

Fig. 3.3. Daily Mean DO Compared to Criteria at Chester

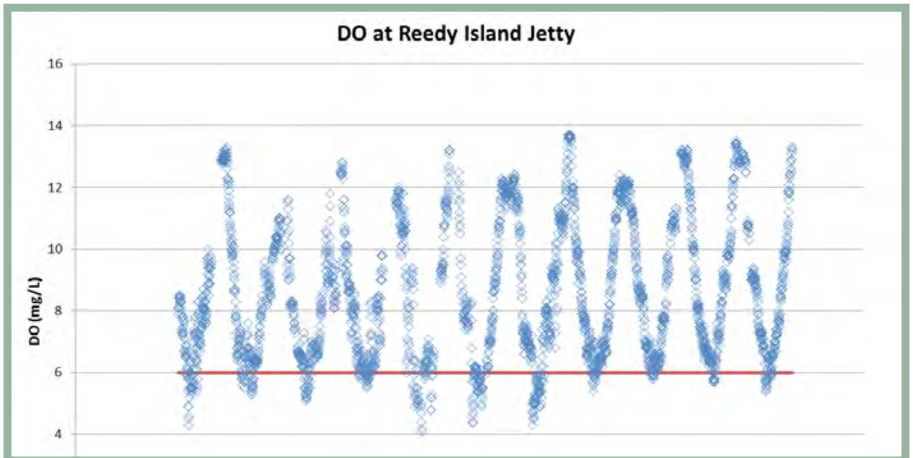

Fig. 3.4. Daily Mean DO Compared to Criteria at Reedy Island Jetty

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.

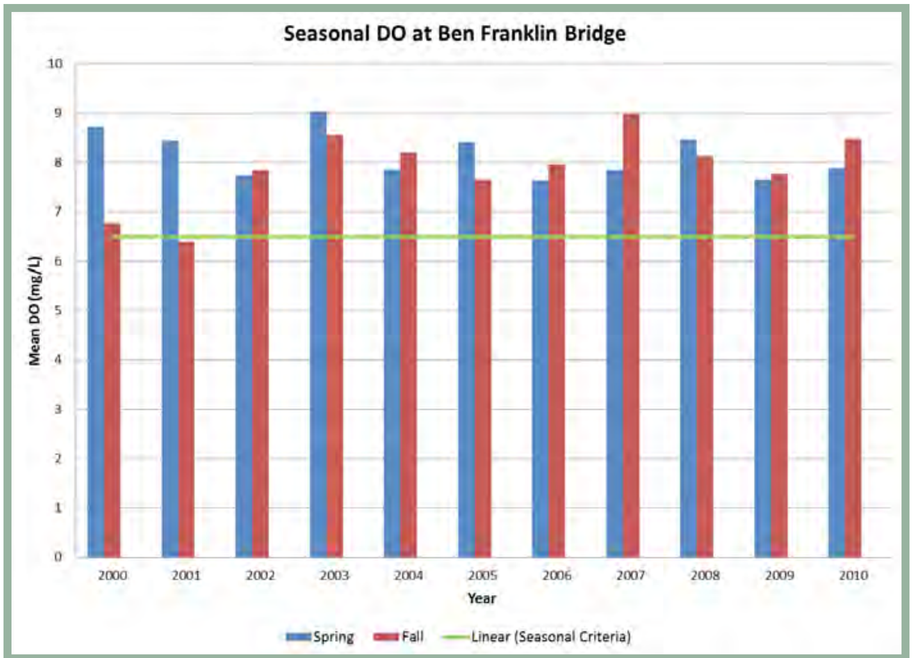

Fig. 3.5. Seasonal Mean DO Compared to Criteria at Ben Franklin Bridge

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.

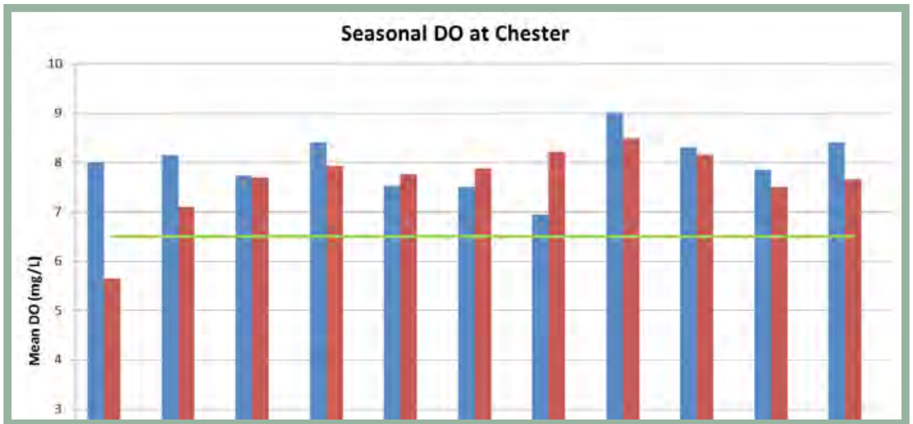

Fig. 3.6. Seasonal Mean DO Compared to Criteria at Chester

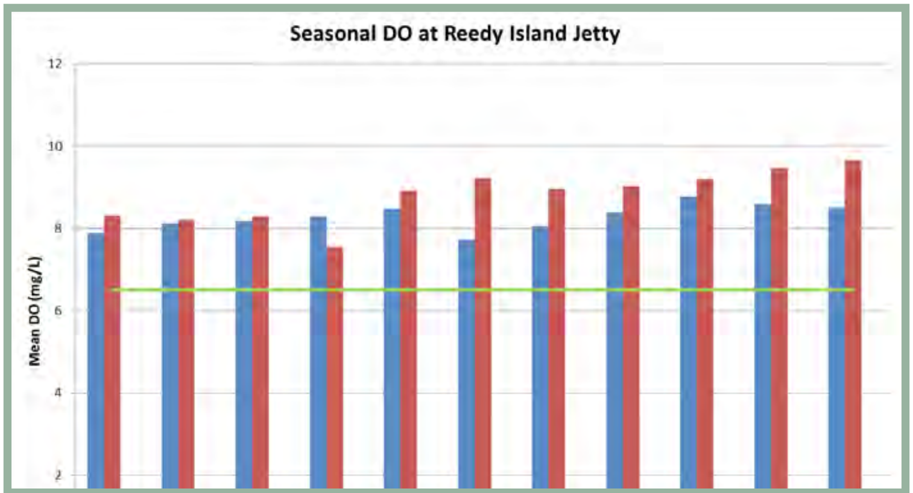

Fig. 3.7. Seasonal Mean DO Compared to Criteria Reedy Island Jetty

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.

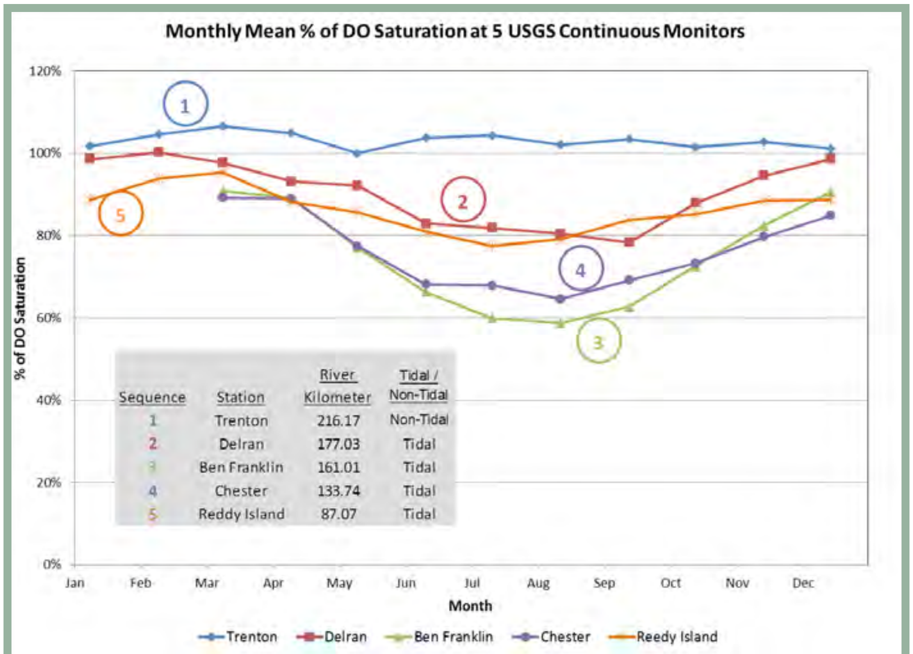

Fig. 3.8. Monthly Mean % of DO Saturation at 5 USGS Continuous Monitors

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.

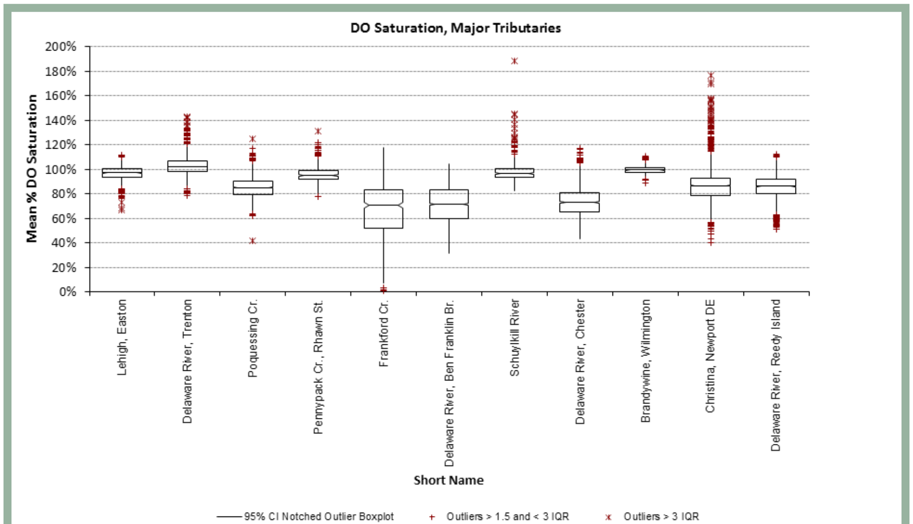

Fig. 3.9. Box and whisker plot of % of DO Saturation for Estuary and Major Tributaries

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.

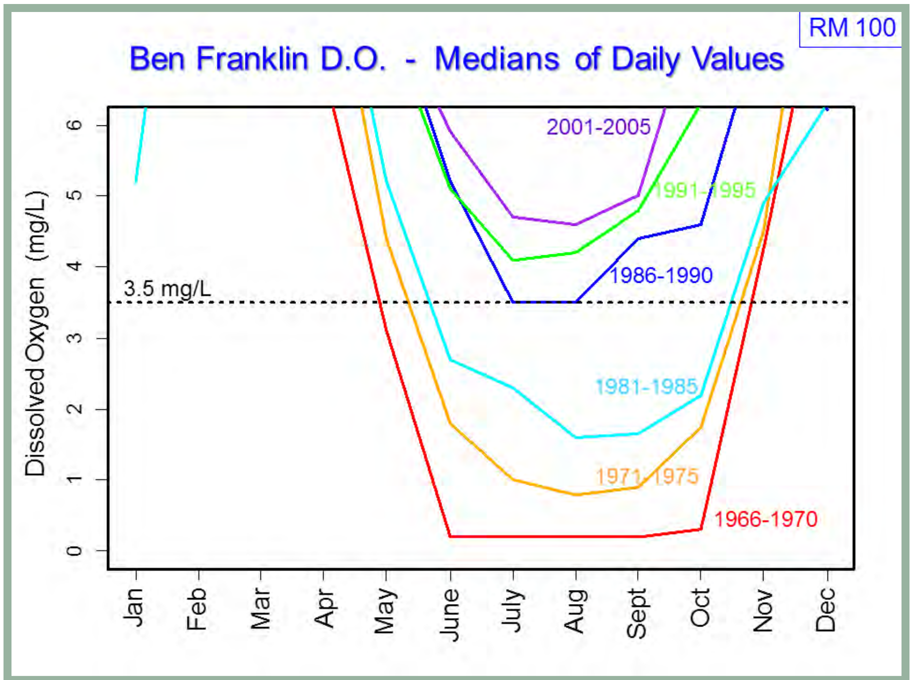

Fig. 3.10. Temporal Duration and Magnitude of Dissolved Oxygen sag at the Ben Franklin Bridge Monitor over time.

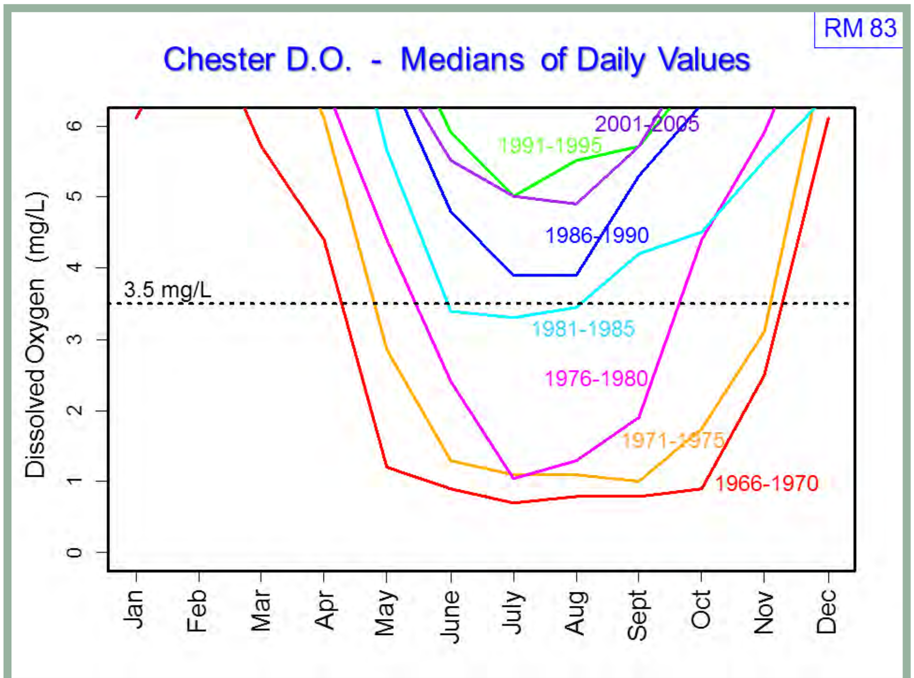

Fig. 3.11. Temporal Duration and Magnitude of Dissolved Oxygen sag at the Chester Monitor over time.

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.

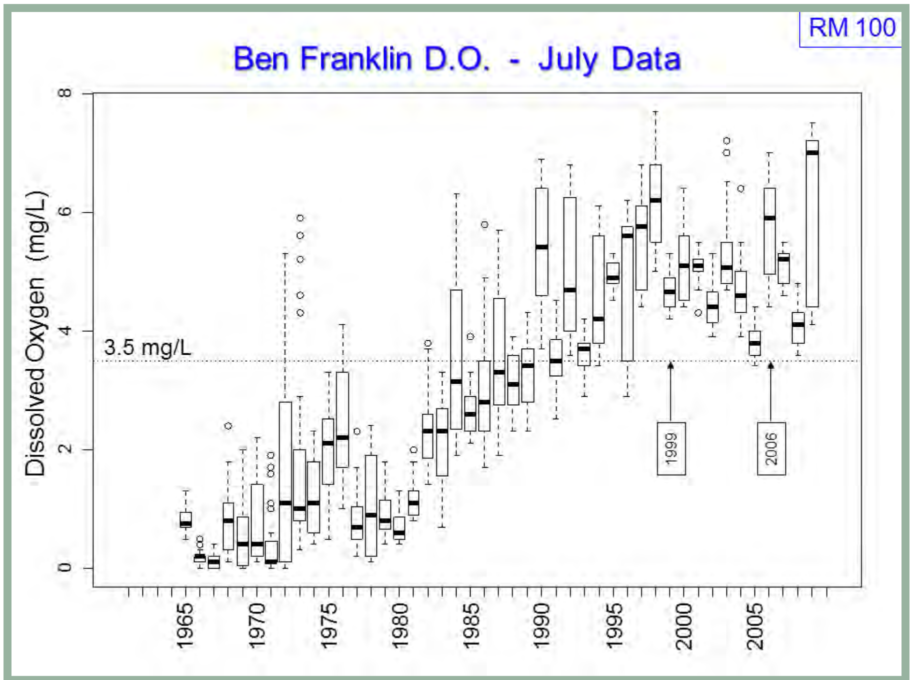

Fig. 3.12. Box and Whisker plot of July Dissolved Oxygen Concentrations at the Ben Franklin Bridge monitor from 1965 through the present.

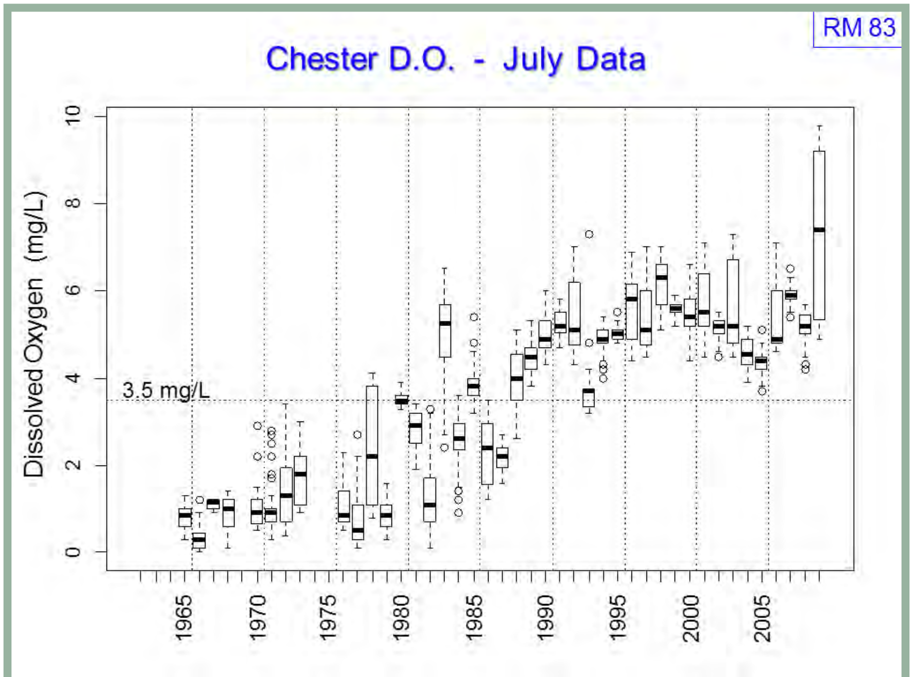

Fig. 3.13. Box and Whisker plot of July Dissolved Oxygen Concentrations at the Chester monitor from 1965 through the present.

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.

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.

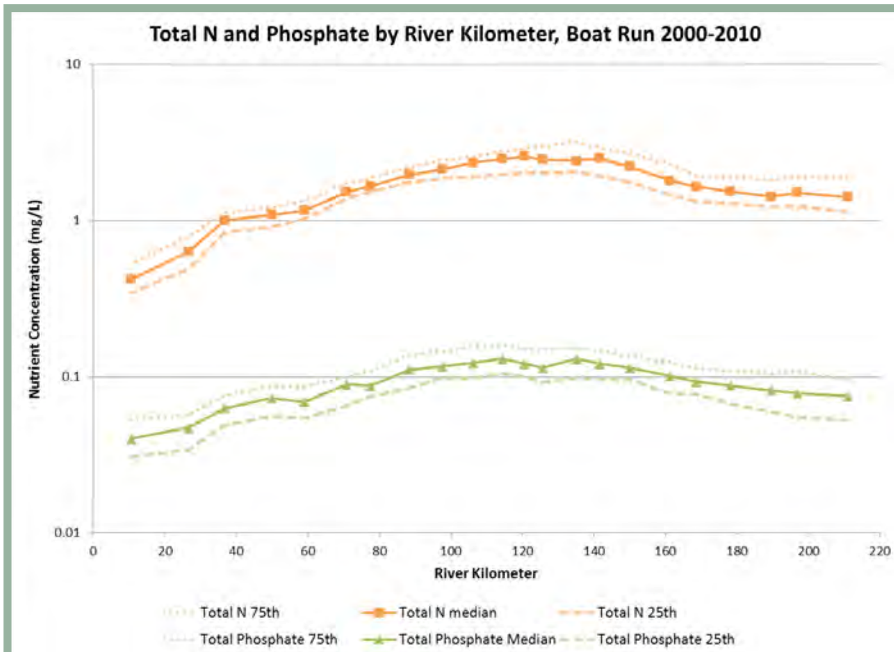

Fig. 3.14. Total Nitrogen and Total Phosphorus Interquartile Range in the Delaware Estuary, Boat Run Monitoring Program 2000-2010

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.

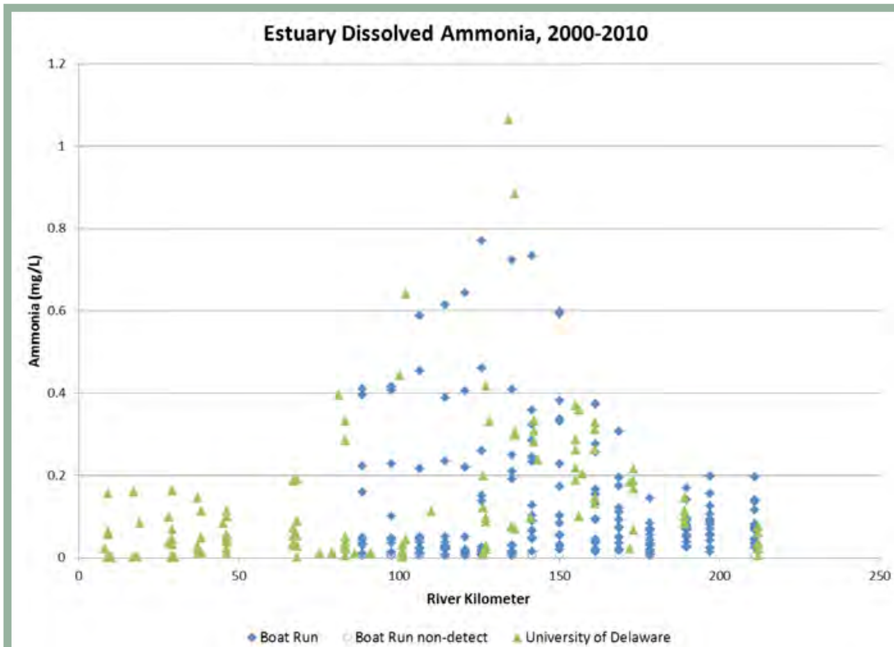

Fig. 3.15. Ammonia Nitrogen in the Delaware Estuary, Boat Run Monitoring Program 2009-2010

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.

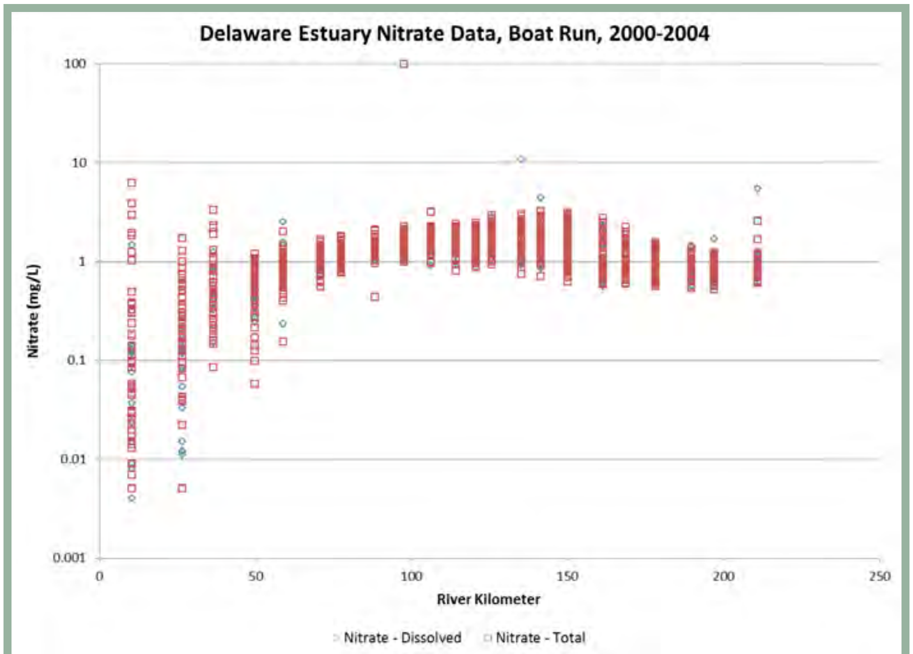

Fig. 3.16. Nitrate Nitrogen in the Delaware Estuary, Boat Run Monitoring Program, 2000-2004

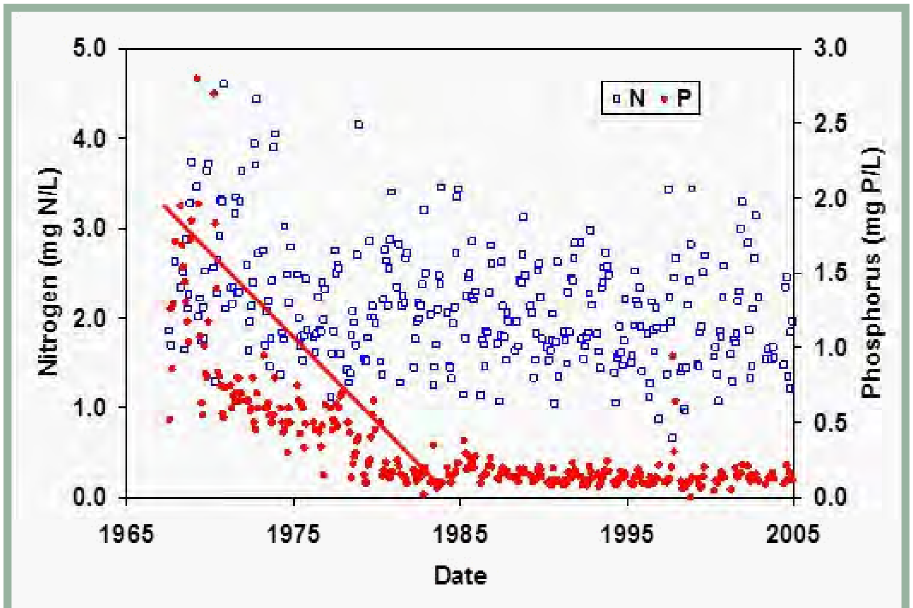

Fig. 3.17. Historic Nitrogen and Phosphorus in the Delaware Estuary

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.

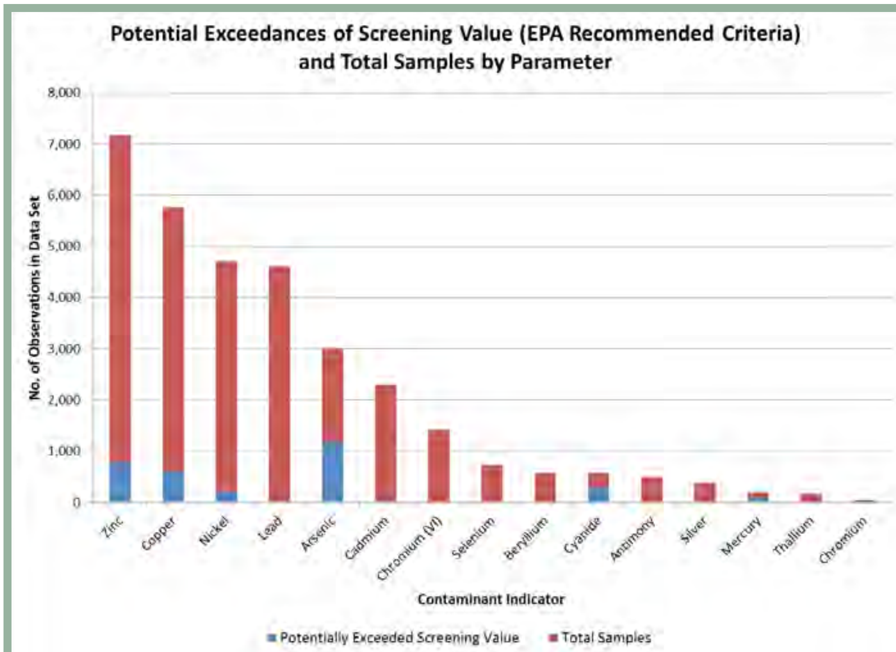

Fig. 3.18. Potential Exceedances of Screening Values for Indicator Contaminants

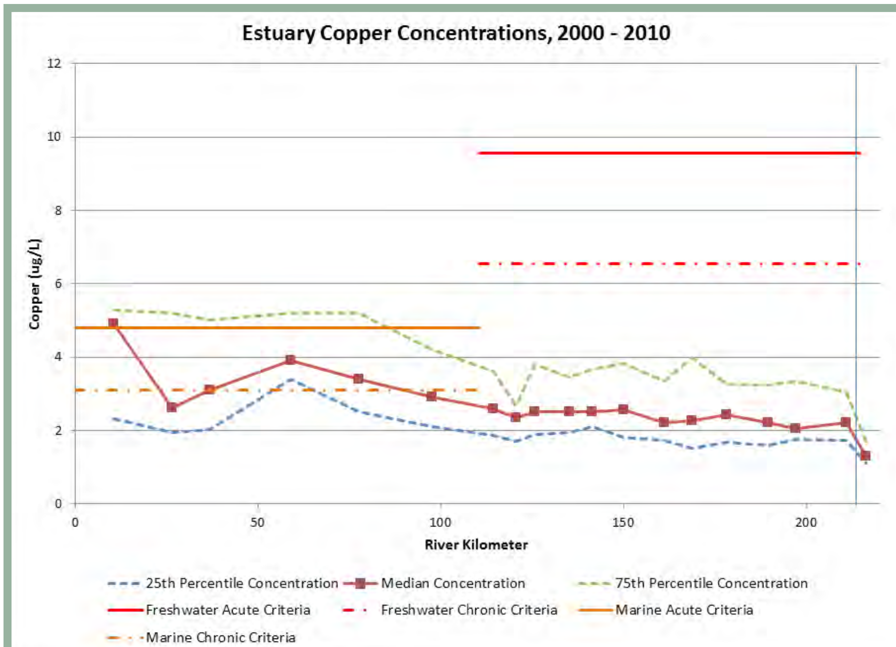

Fig. 3.19. Estuary Copper Concentrations Compared to DRBC Criteria

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.

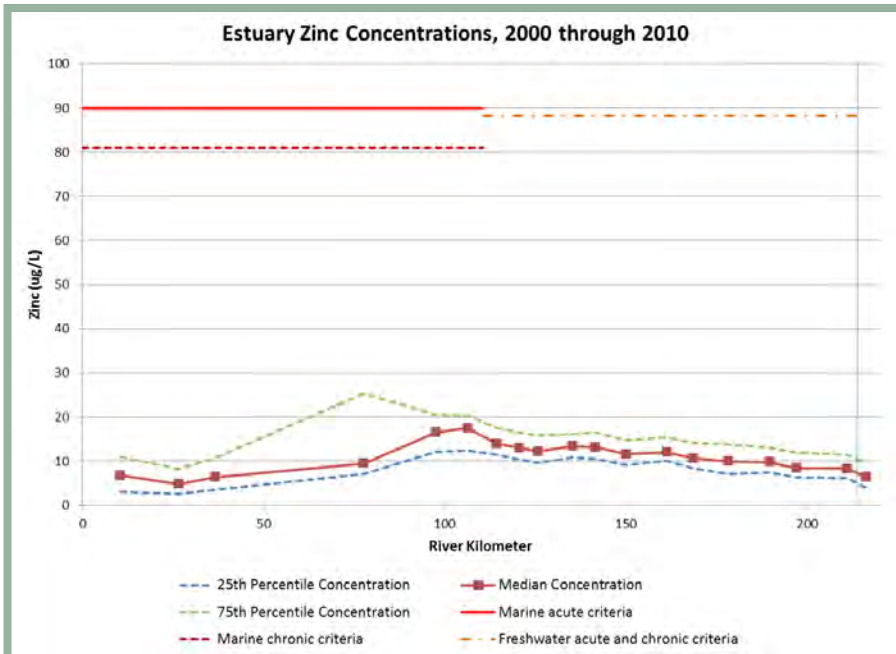

Fig. 3.20. Estuary Zinc Concentrations Compared to DRBC Criteria

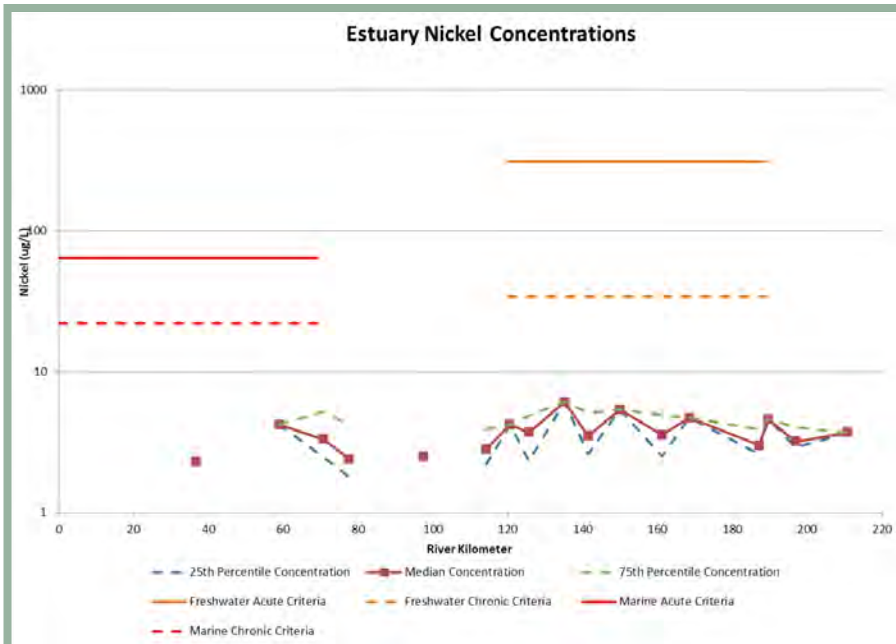

Fig. 3.21. Estuary Nickel Concentrations Compared to DRBC Criteria

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.

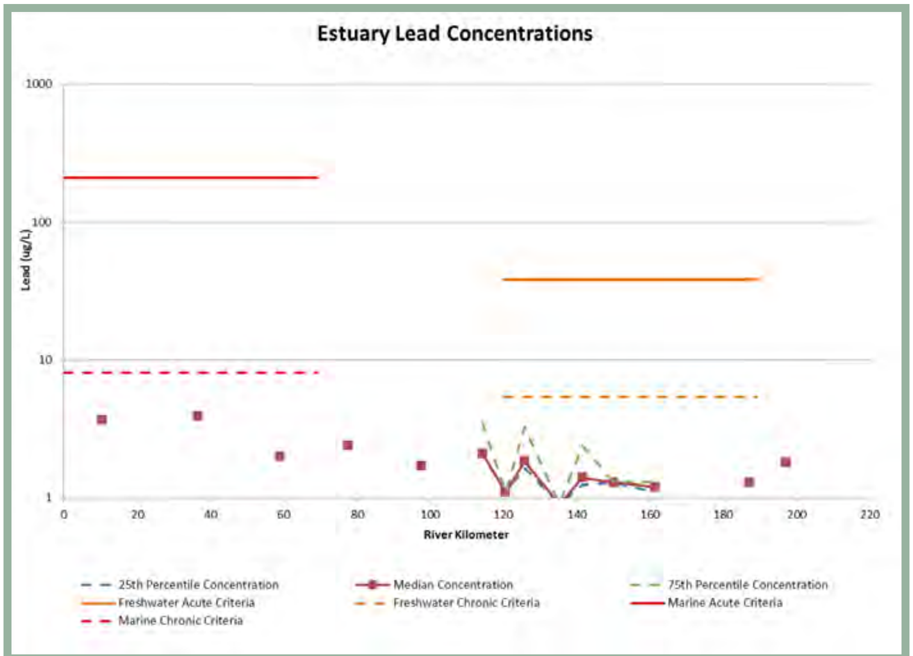

Fig. 3.22. Estuary Lead Concentrations Compared to DRBC Criteria

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.

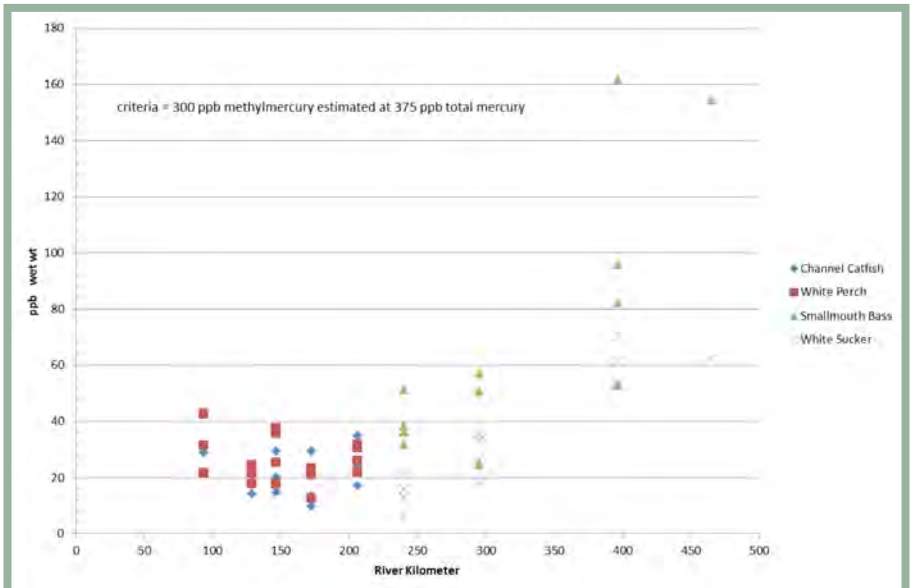

Fig. 3.23. Total Mercury in Fish Fillet 2004 to 2007.

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.

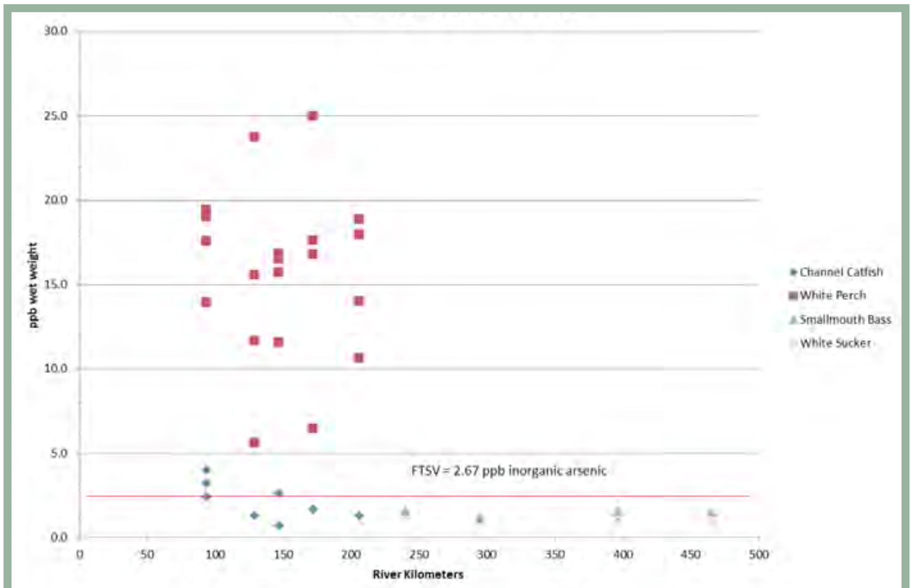

Fig. 3.24. Total Arsenic with Adjustment Factor to Estimate Inorganic Arsenic in Fish Fillet 2004 to 2007.

Mercury

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).

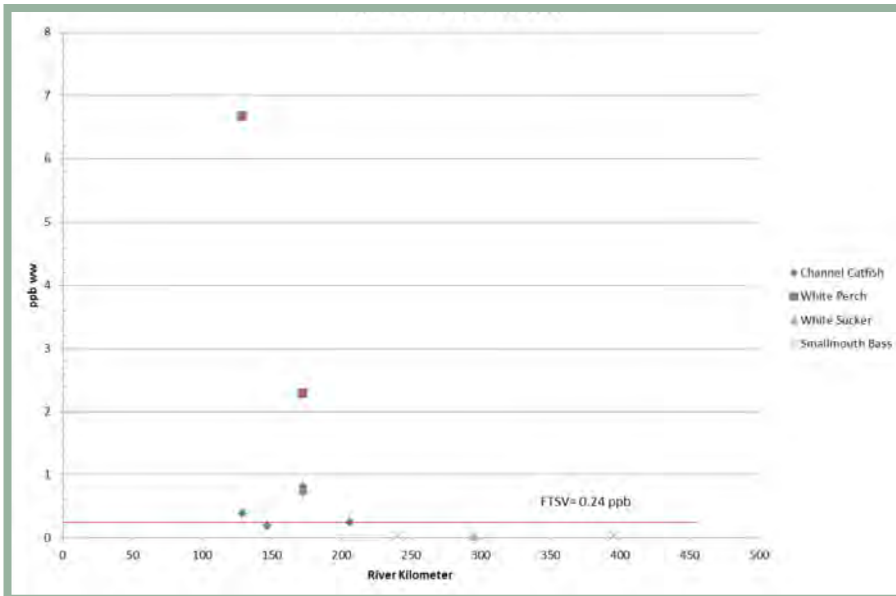

Fig. 3.25. Aldrin in Fish Fillet 2004 to 2007.

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).

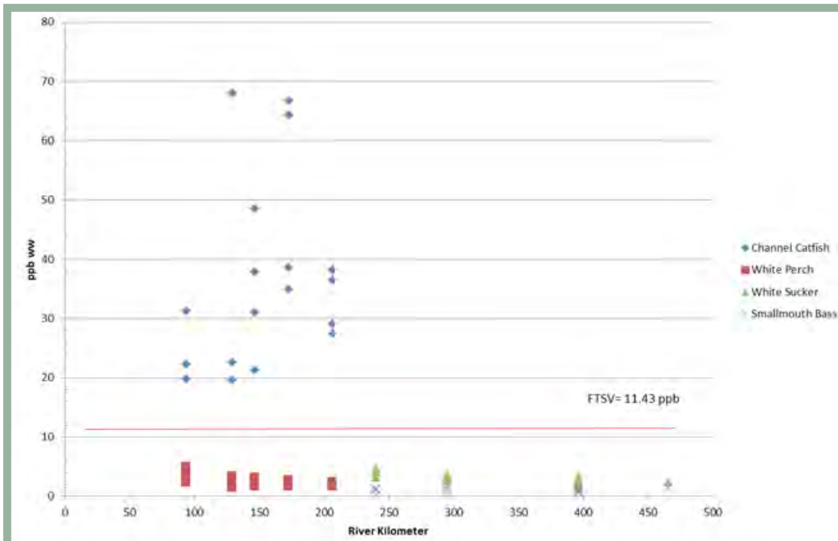

Fig. 3.26. Sum of Chlordanes in Fish Fillet 2004 to 2007.

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).

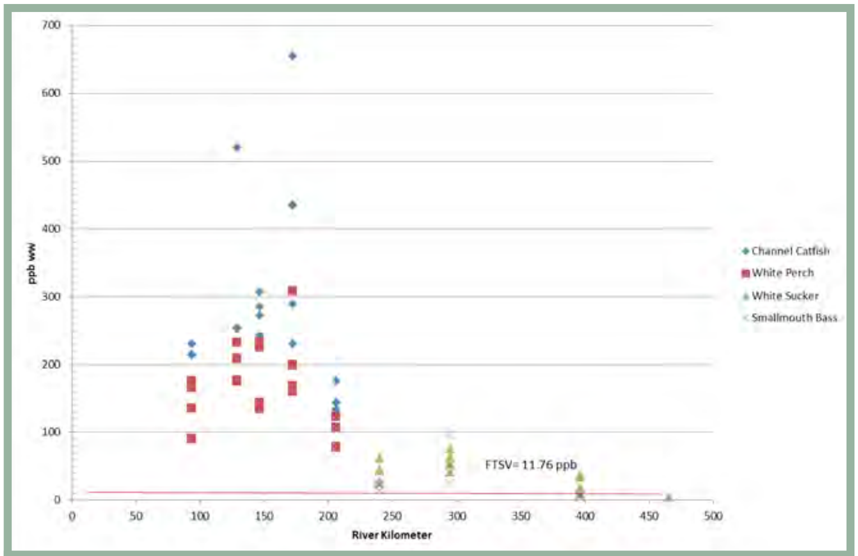

Fig. 3.27. DDT and metabolies in Fish Fillet 2004 to 2007.

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).

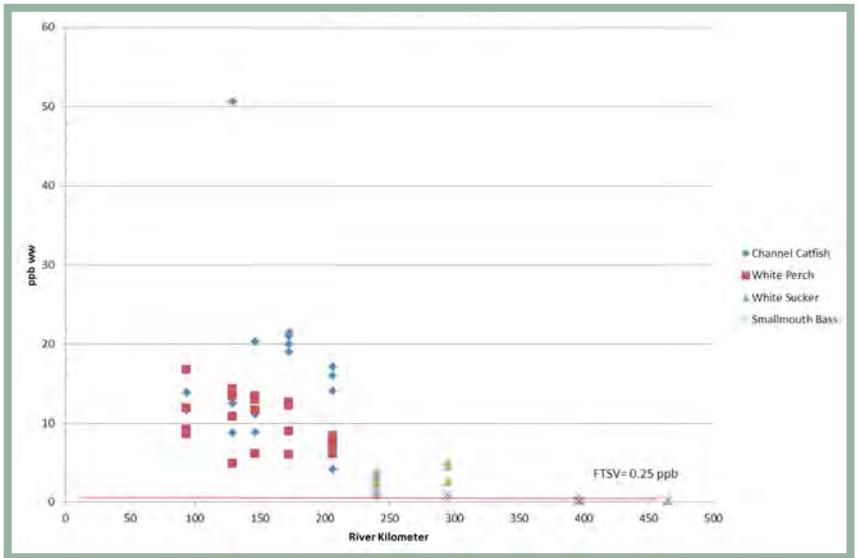

Fig. 3.28. Dieldrin in Fish Fillet 2004 to 2007.

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).

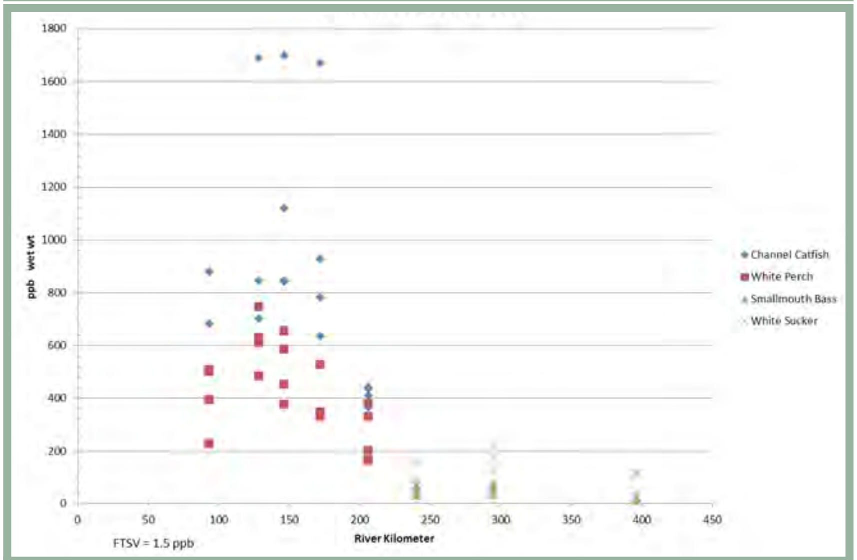

Fig. 3.29. Total PCB in Fish Fillet 2004 to 2007.

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.

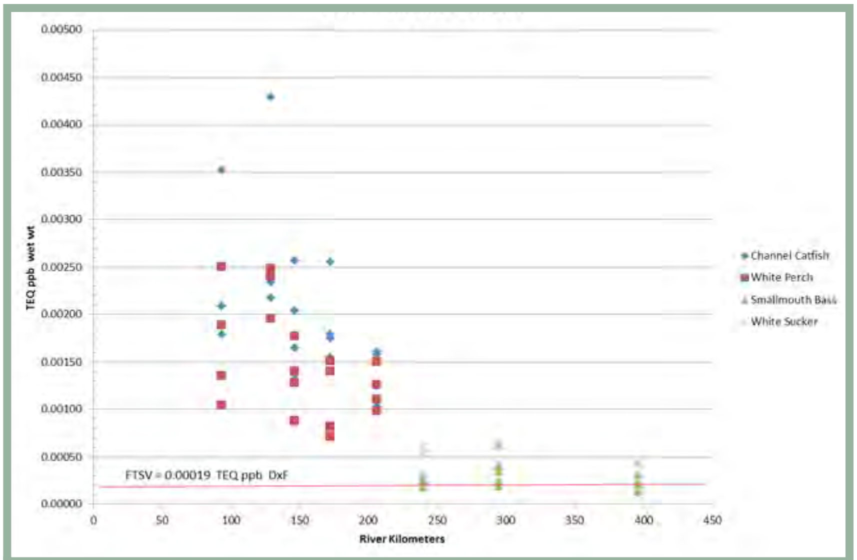

Fig. 3.30. Total Dioxin/Furans TEQs in Fish Fillet 2004 to 2007.

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.

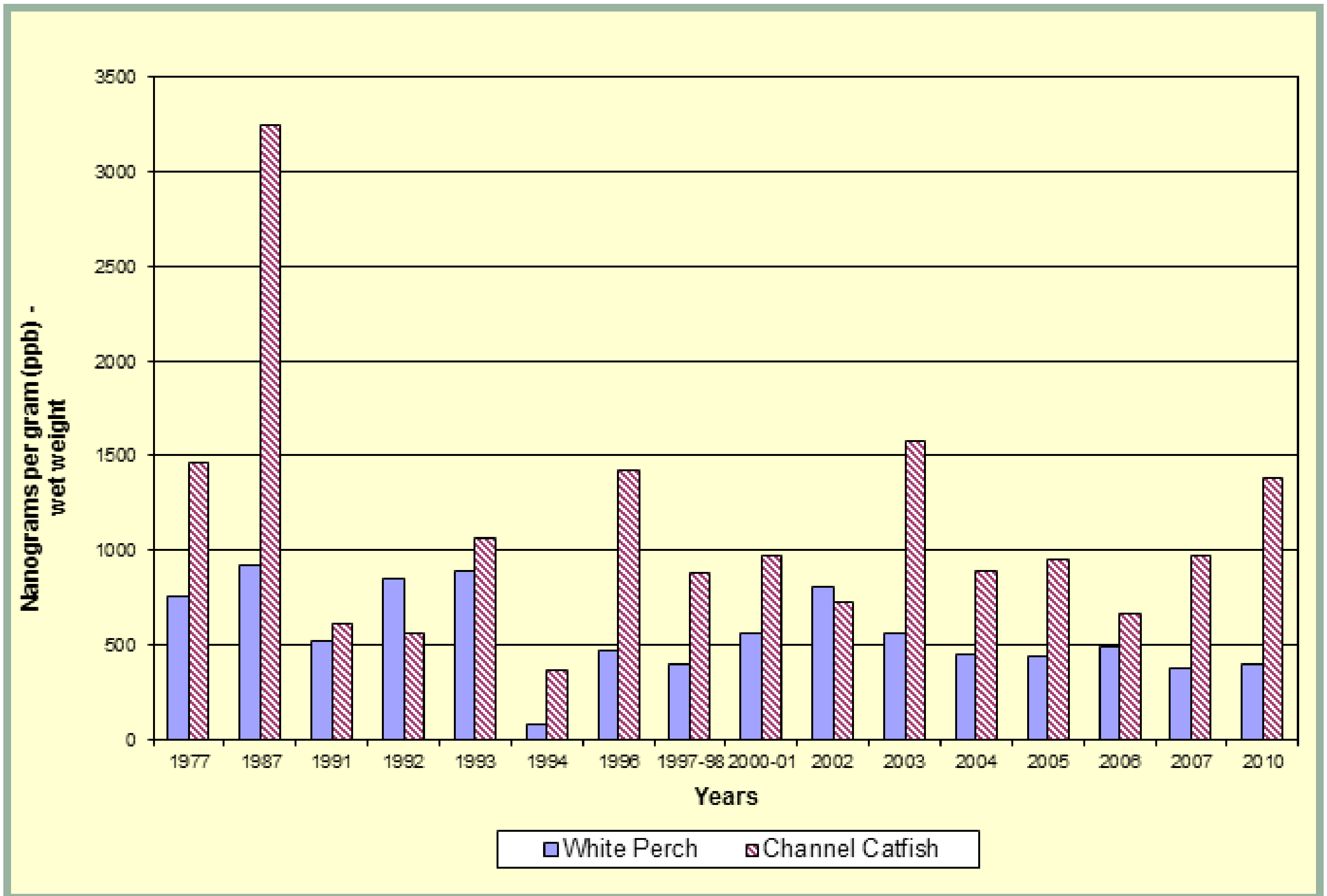

Fig. 3.31. Historical PCB Trends in Fish.

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.

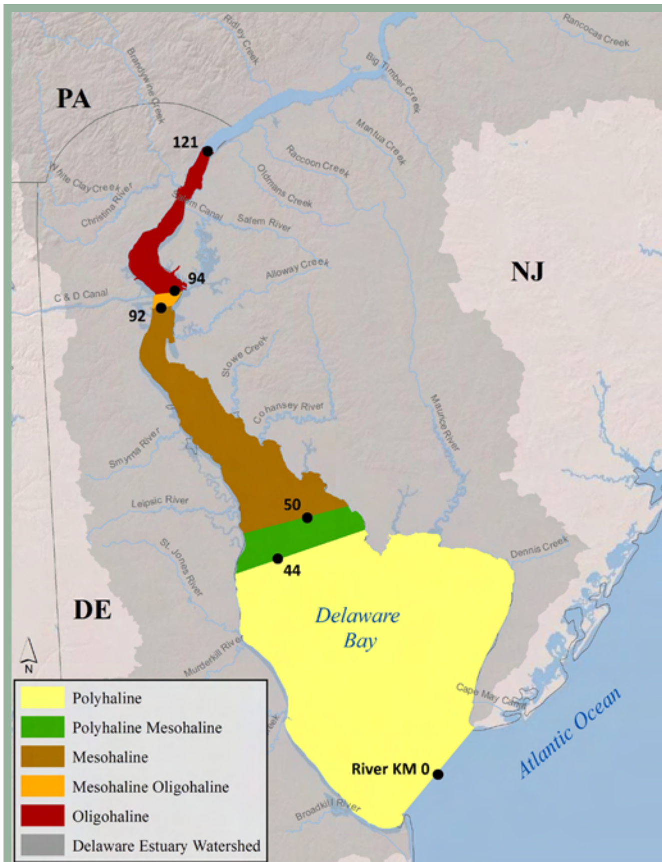

Fig. 3.32. Spatial Salinity Regimes of the Delaware Estuary. (Oligohaline - 90% of observations in the range from 0.5 to 5 ppt; Mesohaline - 90% of observations in the range from 5 to 18 ppt; Polyhaline - 90% of observations greater than 18 ppt)

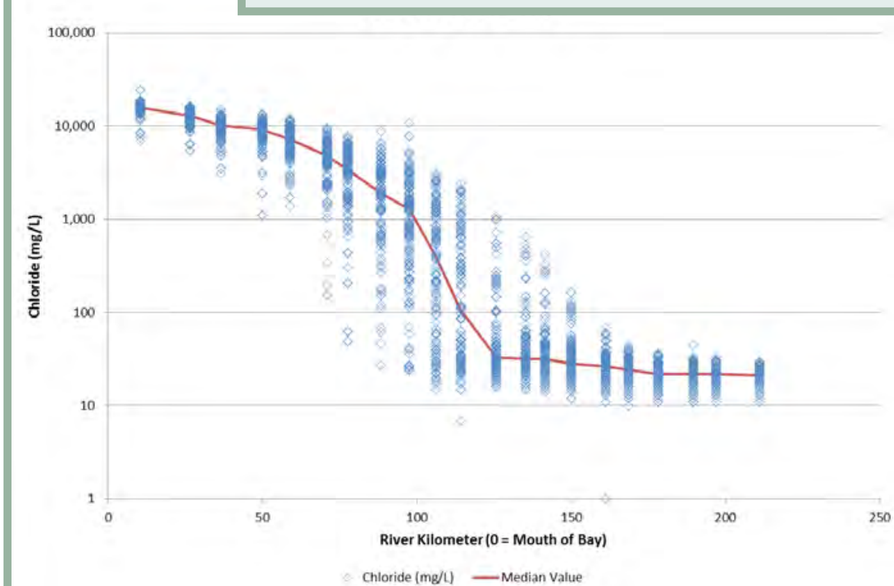

Fig. 3.33. Chloride Concentration Ranges by River Kilometer.

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.

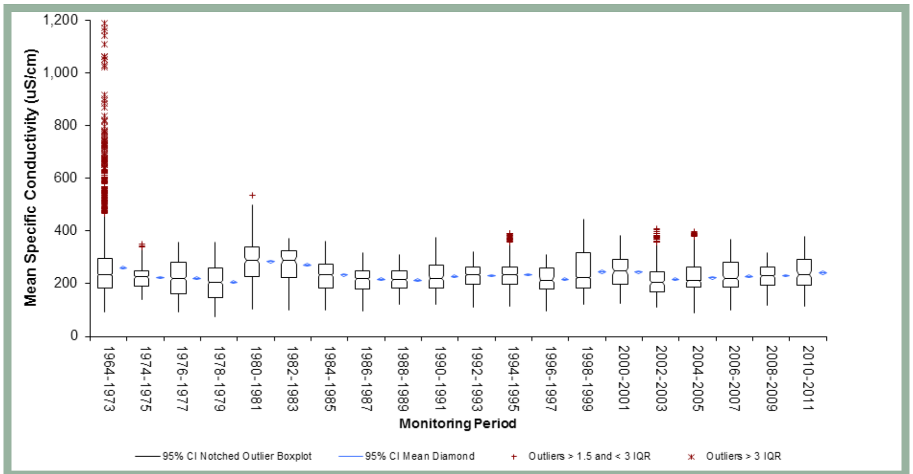

Fig. 3.34. Long –Term Specific Conductivity Box and Whisker Plots at Ben Franklin Bridge

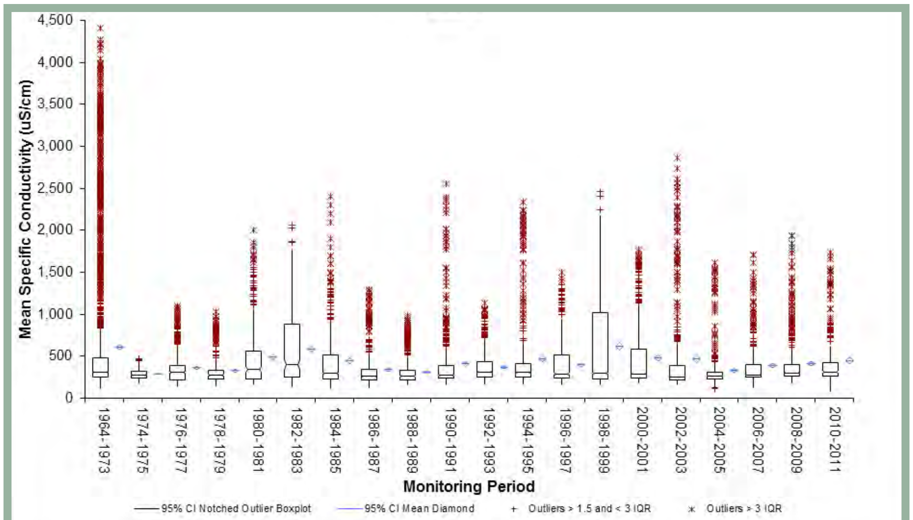

Fig. 3.35. Long –Term Specific Conductivity Box and Whisker Plots at Chester

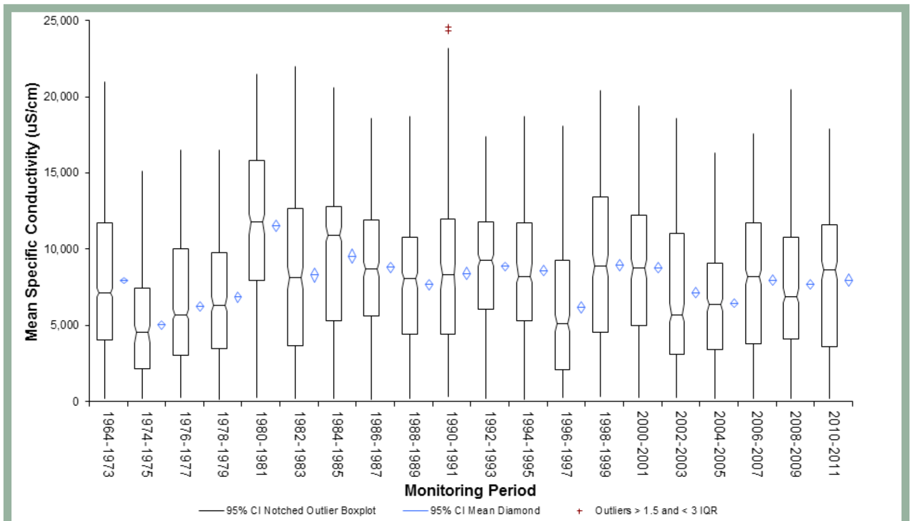

Fig. 3.36. Long –Term Specific Conductivity Box and Whisker Plots at Reedy Island Jetty

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.

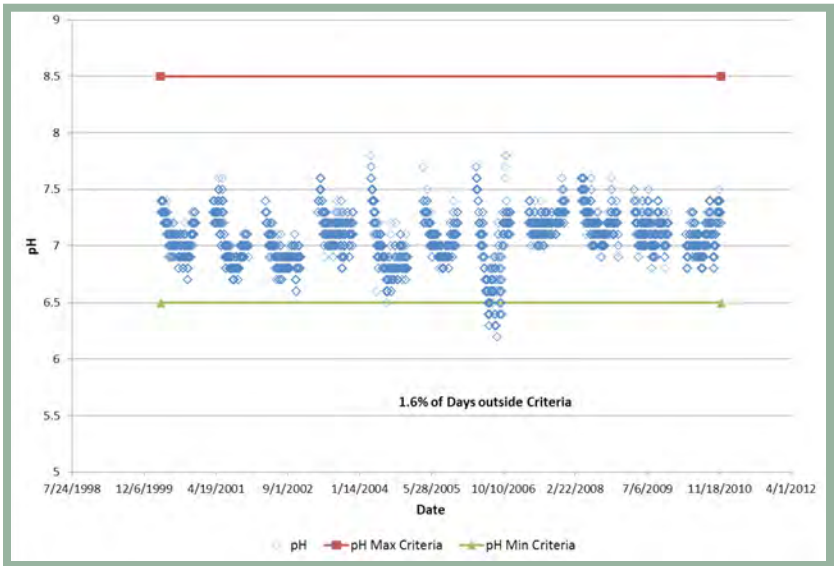

Fig. 3.37. Comparison of Measured pH to DRBC Criteria at Ben Franklin Bridge.

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.

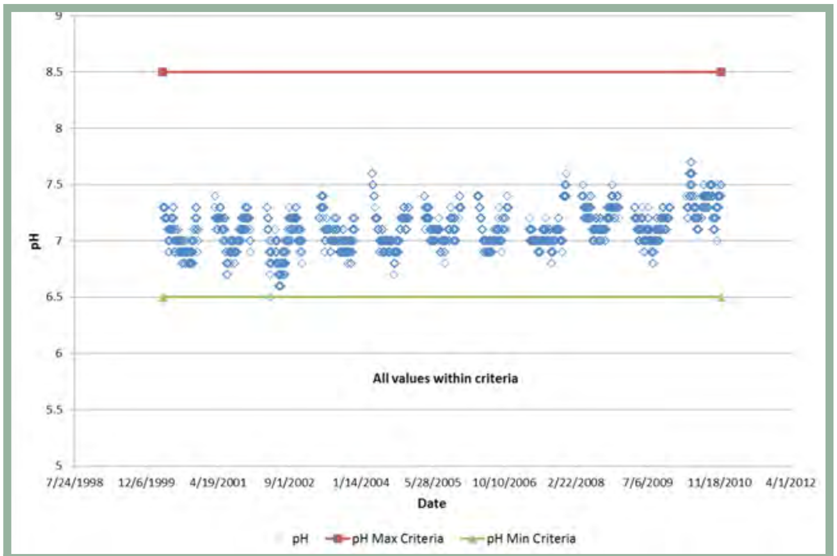

Fig. 3.38. Comparison of Measured pH to DRBC Criteria at Chester.

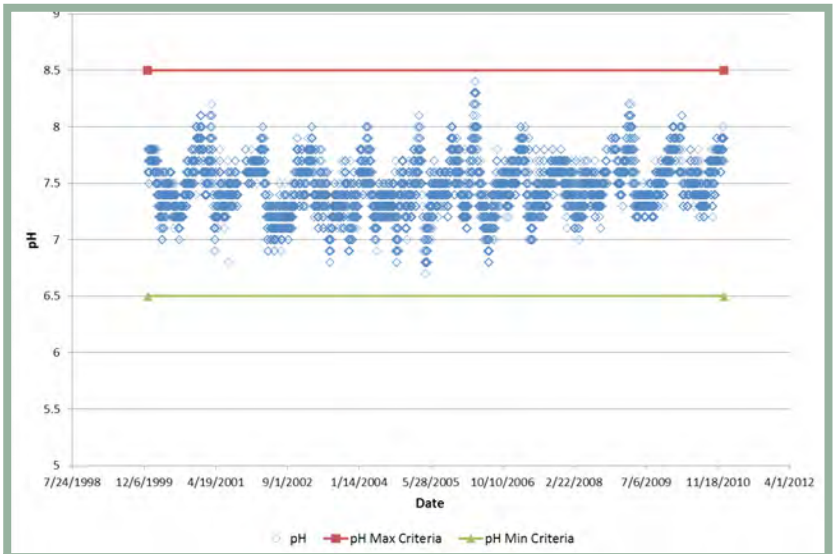

Fig. 3.39. Comparison of Measured pH to DRBC Criteria at Reedy Island Jetty.

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.

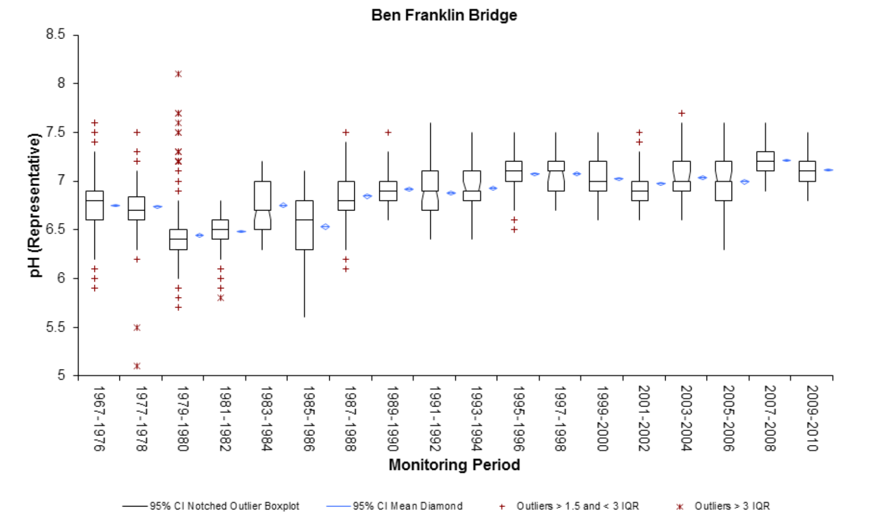

Fig. 3.40. pH Time Series Box and Whisker Plot, Ben Franklin Bridge.

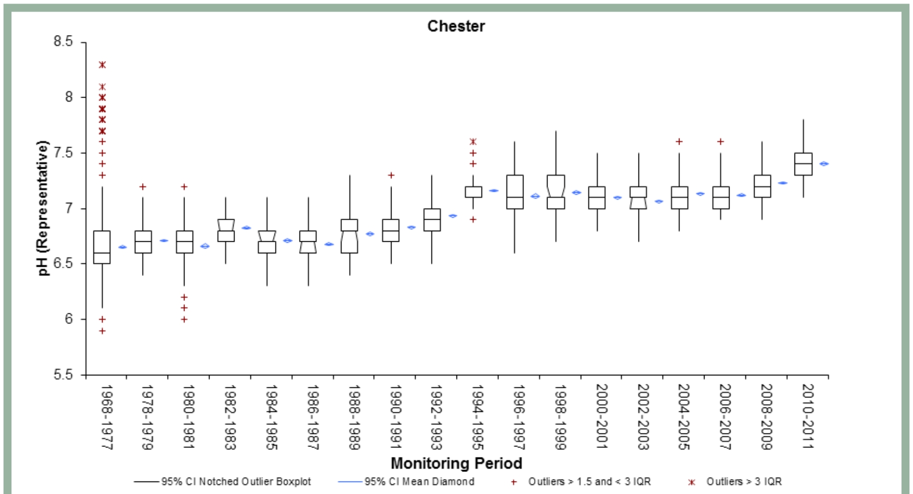

Fig. 3.41. pH Time Series Box and Whisker Plot, Chester.

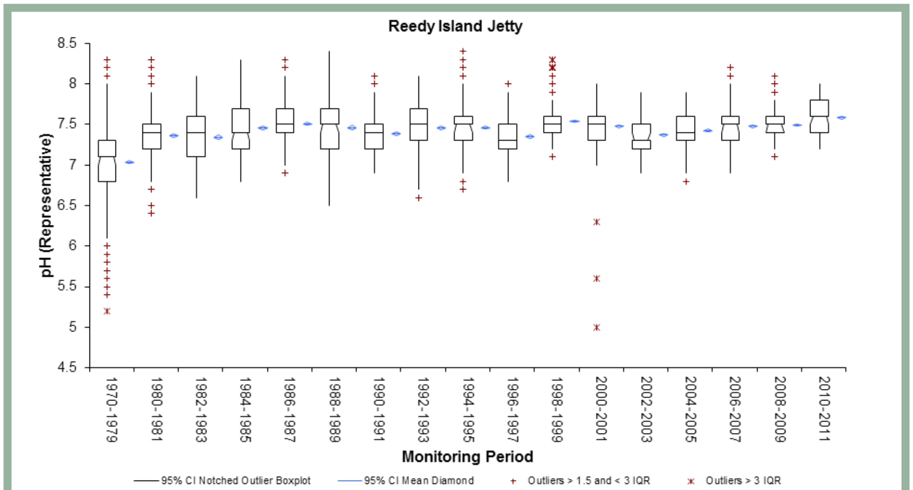

Fig. 3.42. pH Time Series Box and Whisker Plot, Reedy Island Jetty.

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.

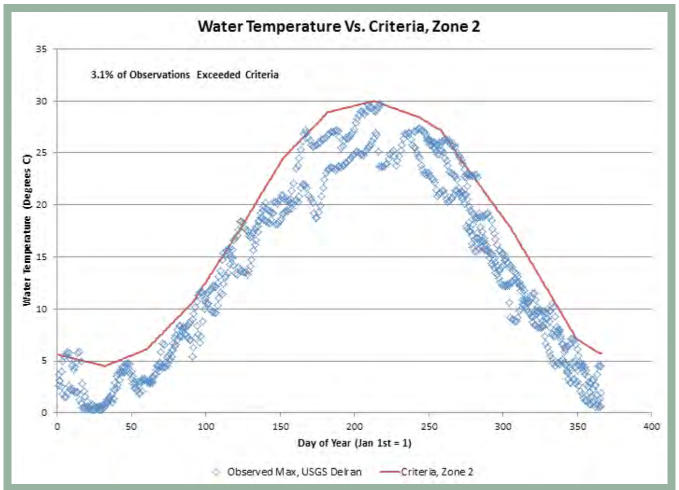

Fig. 3.43. Temperature Observations Compared to DRBC Day of Year Criteria, Delran.

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.

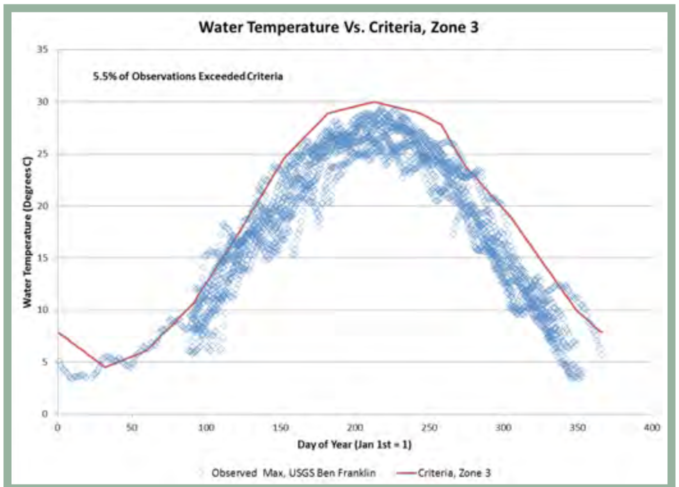

Fig. 3.44. Temperature Observations Compared to DRBC Day of Year Criteria, Ben Franklin Bridge.

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.

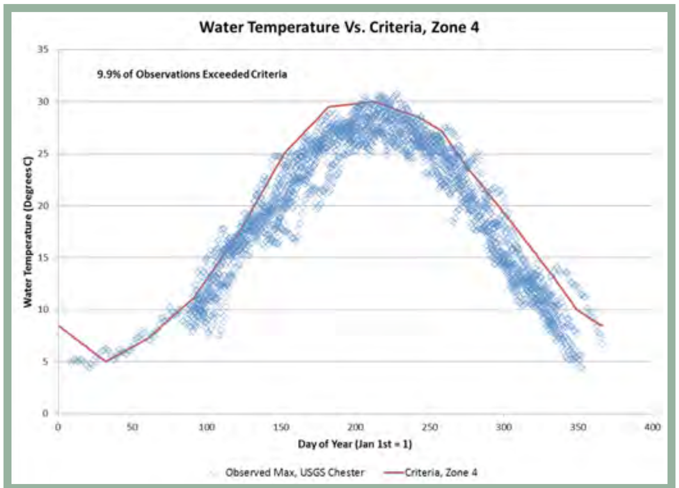

Fig. 3.45. Temperature Observations Compared to DRBC Day of Year Criteria, Chester.

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 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.

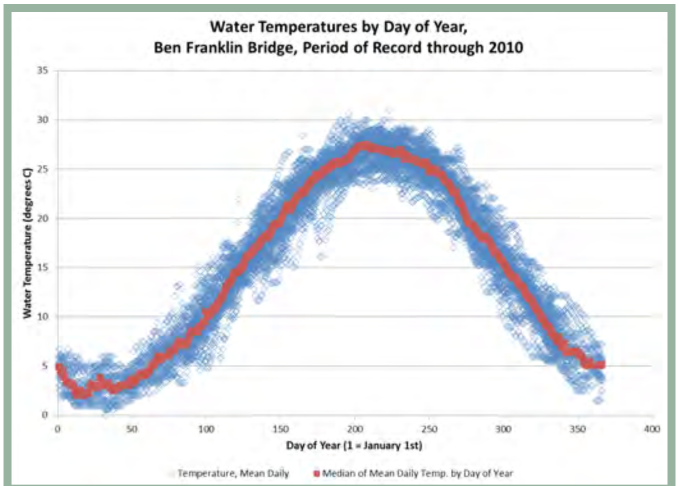

Fig. 3.46. Period of Record Temperature Observations including Median by Day of Year, Ben Franklin Bridge.

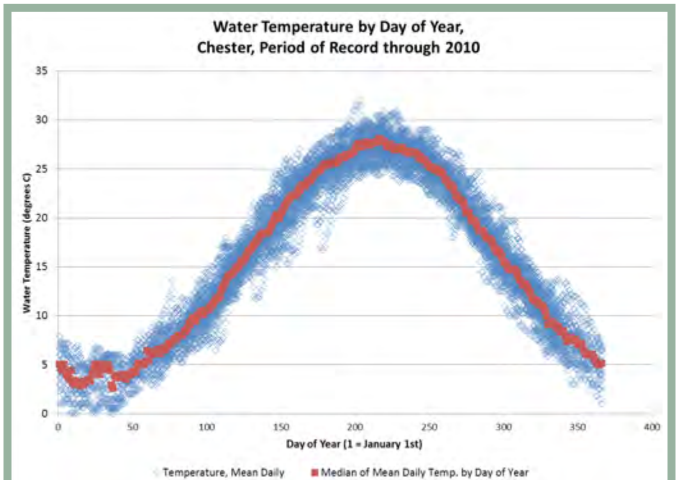

Fig. 3.47. Period of Record Temperature Observations including Median by Day of Year, Chester.

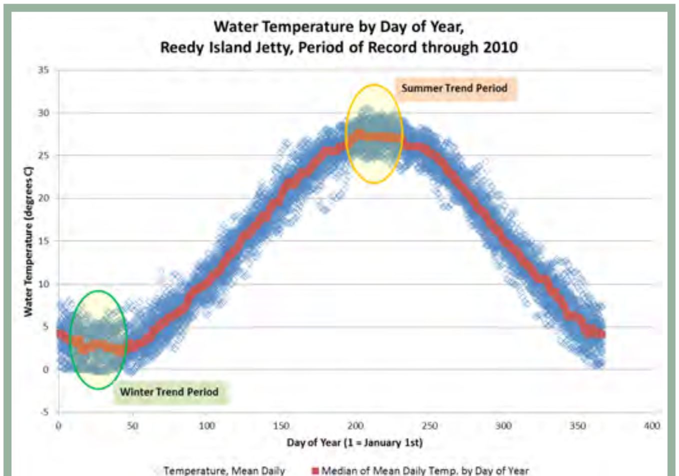

Fig. 3.48. Period of Record Temperature Observations including Median by Day of Year, Reedy Island Jetty.

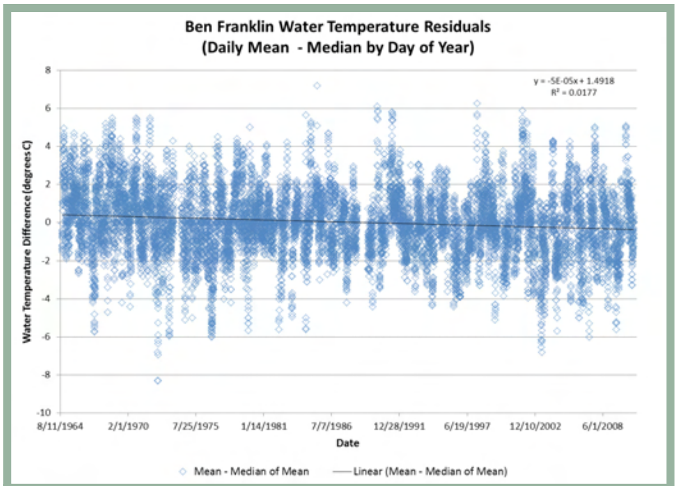

Fig. 3.49. Temperature Residual Trend Analysis, Ben Franklin Bridge.

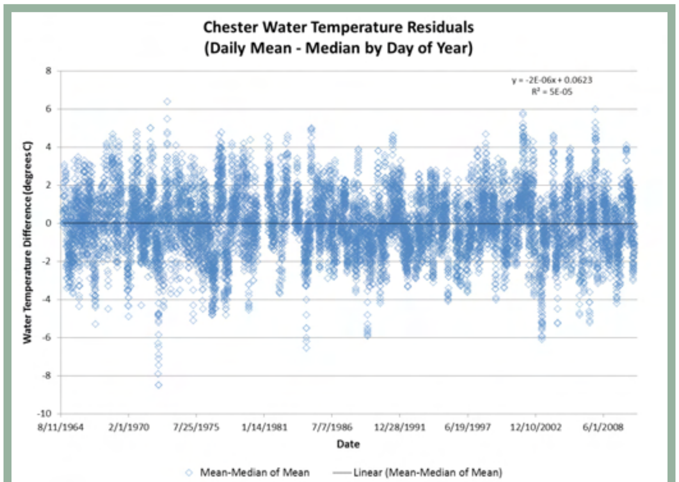

Fig. 3.50. Temperature Residual Trend Analysis, Chester.

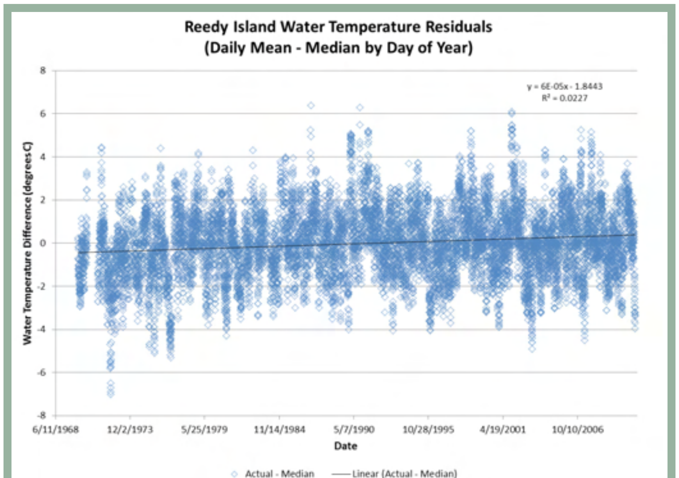

Fig. 3.51. Temperature Residual Trend Analysis, Reedy Island Jetty.

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.

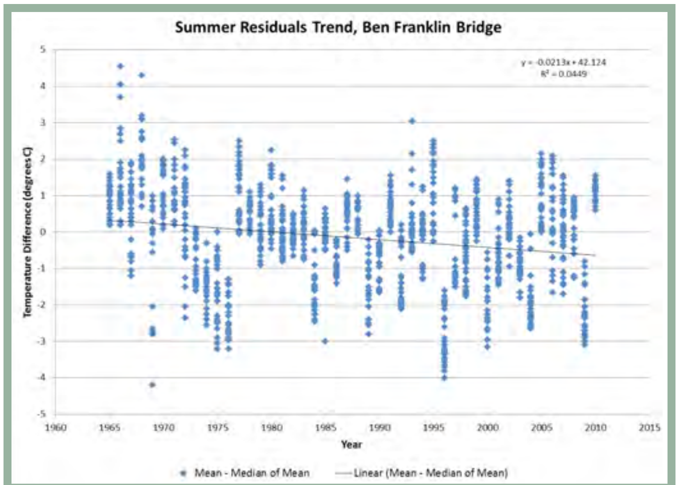

Fig. 3.52. Summer Residuals, Ben Franklin Bridge.

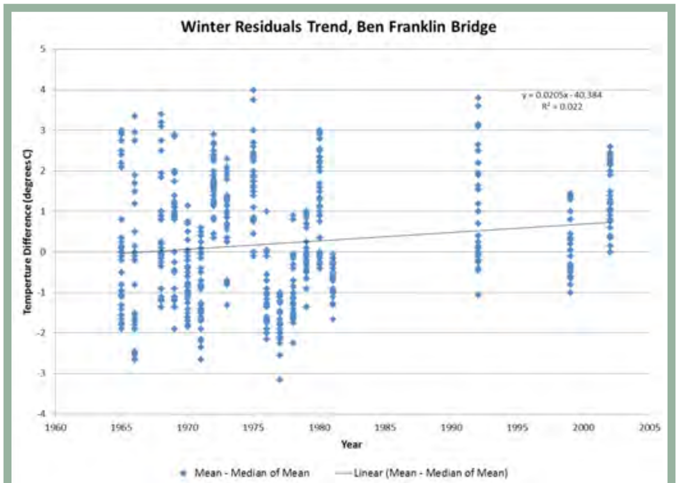

Fig. 3.53. Winter Residuals, Ben Franklin Bridge.

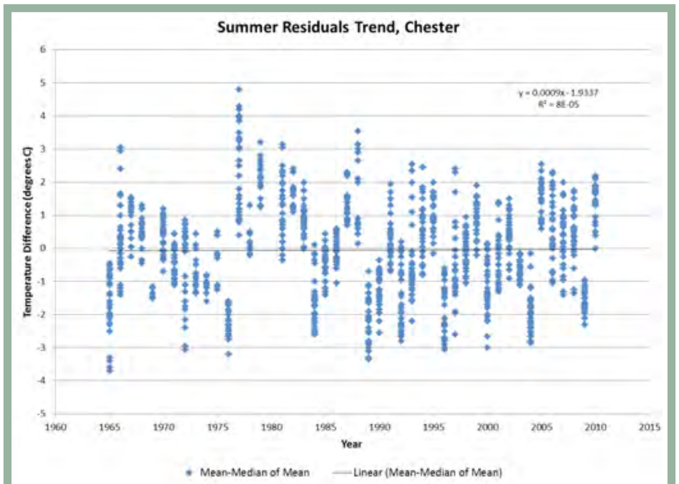

Fig. 3.54. Summer Residuals, Chester.

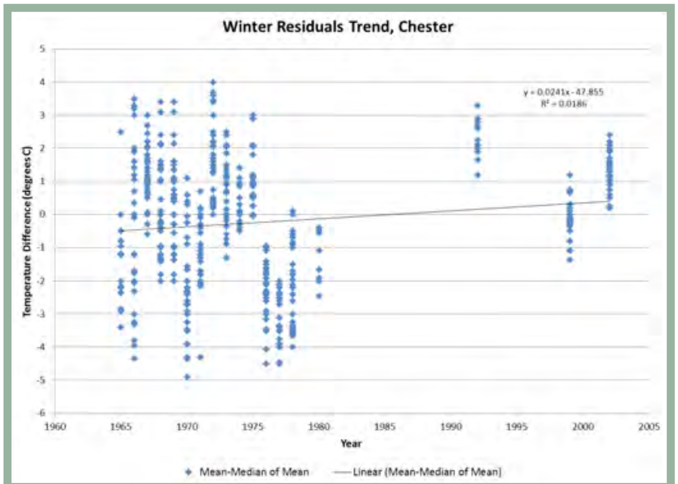

Fig. 3.55. Winter Residuals, Chester.

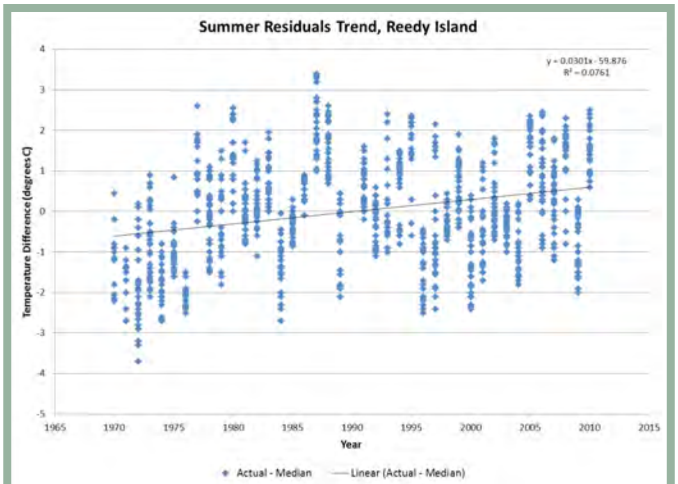

Fig. 3.56. Summer Residuals, Reedy Island Jetty.

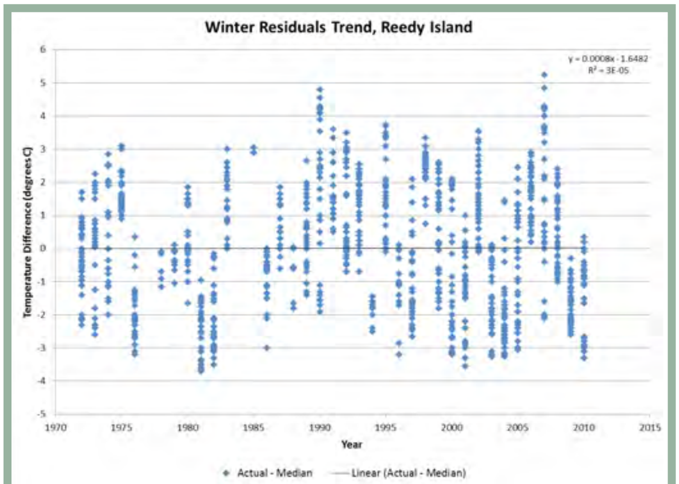

Fig. 3.57. Winter Residuals, Reedy Island Jetty.

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 .

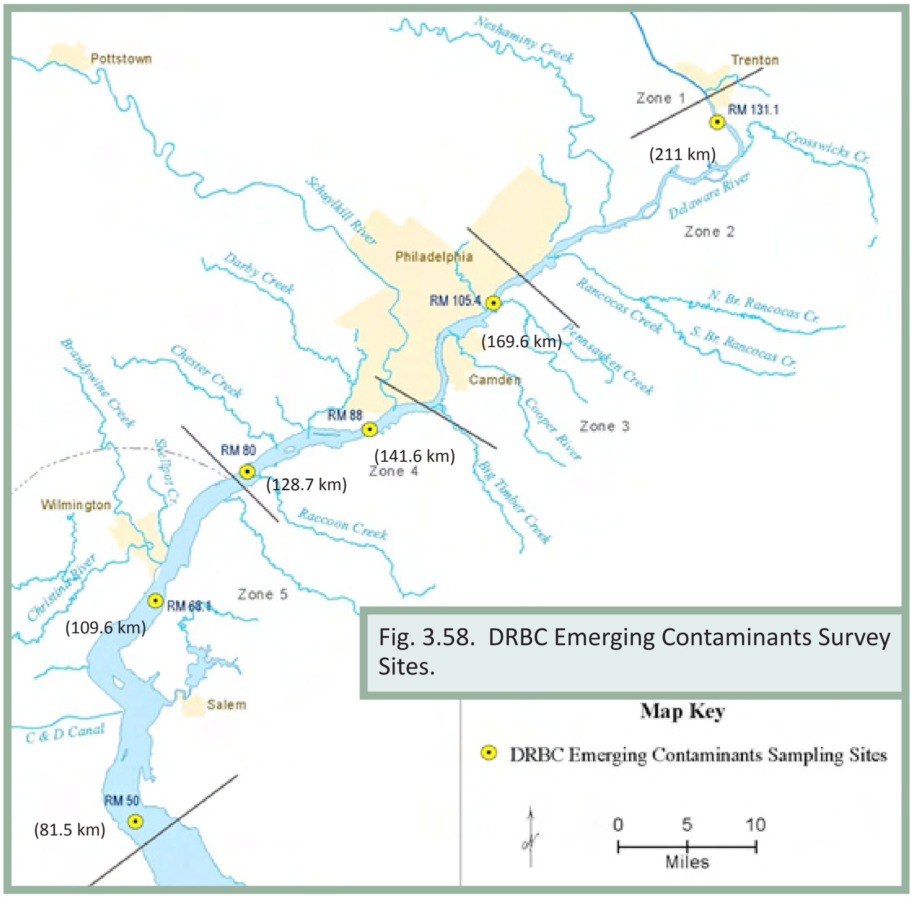

Fig. 3.58. DRBC Emerging Contaminants Survey Sites.

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.

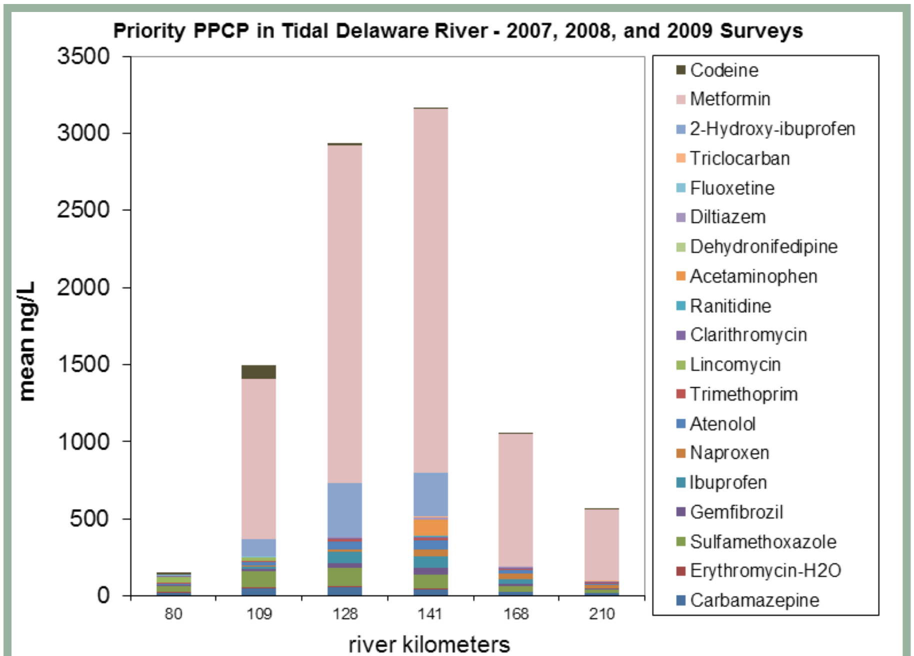

Fig. 3.59. Priority PPCP for monitoring in the tidal Delaware Estuary.

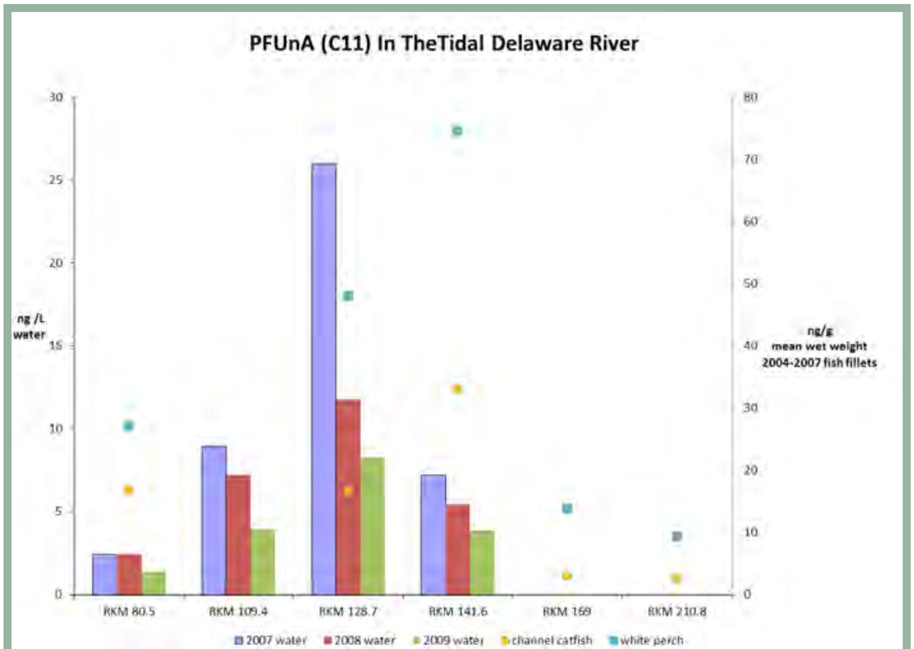

Fig. 3.60. PFC in the tidal Delaware River.

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.

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.

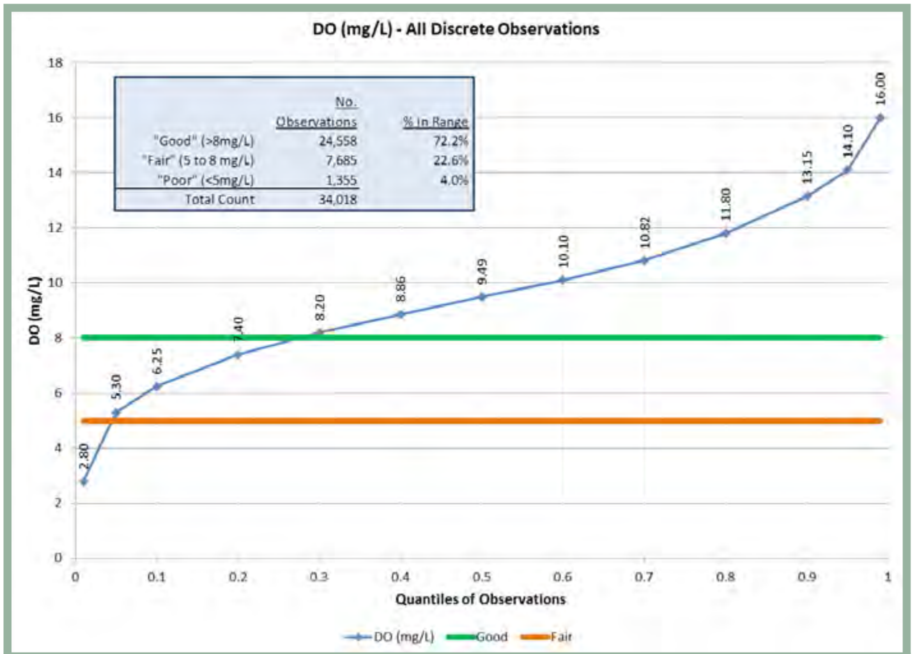

Fig. 3.61. Comparison of Quantiles of All Discrete DO Observations to Ranges

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.

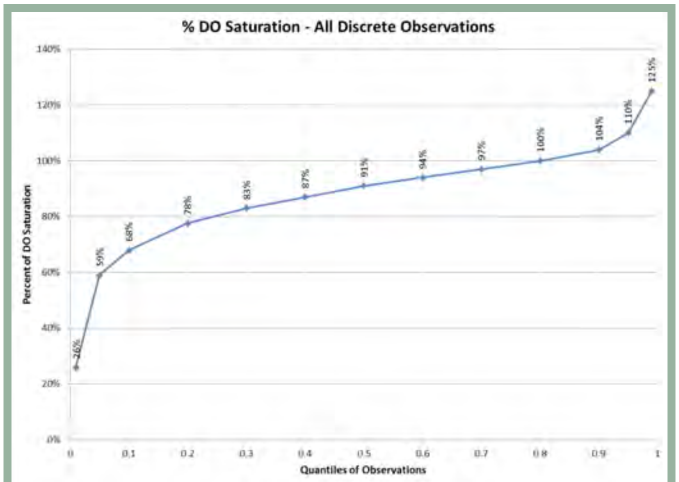

Fig. 3.62. Quantiles of All Discrete % DO Saturation Observations

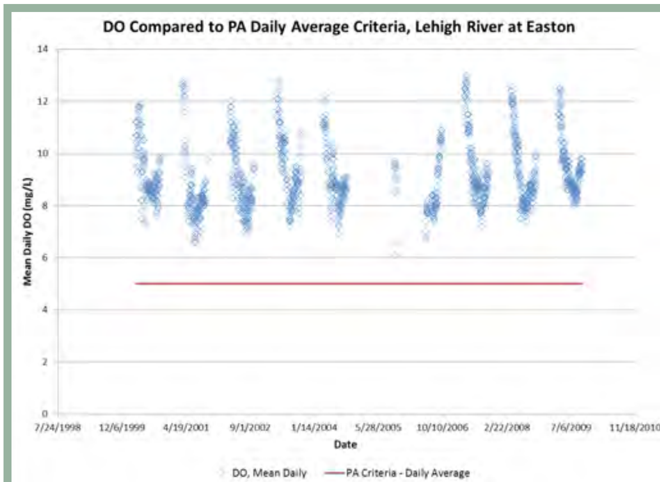

Fig. 3.64. Daily Mean Dissolved Oxygen at the Lehigh River at Easton Compared to Criteria.

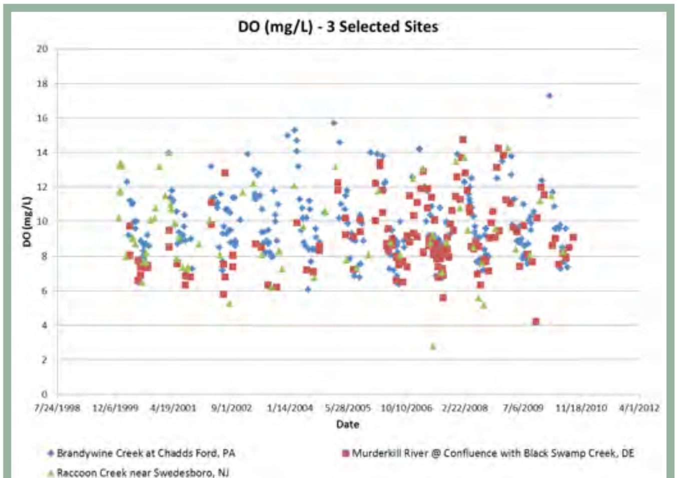

Fig. 3.63. Comparison of Discrete DO Measurements at 3 Locations

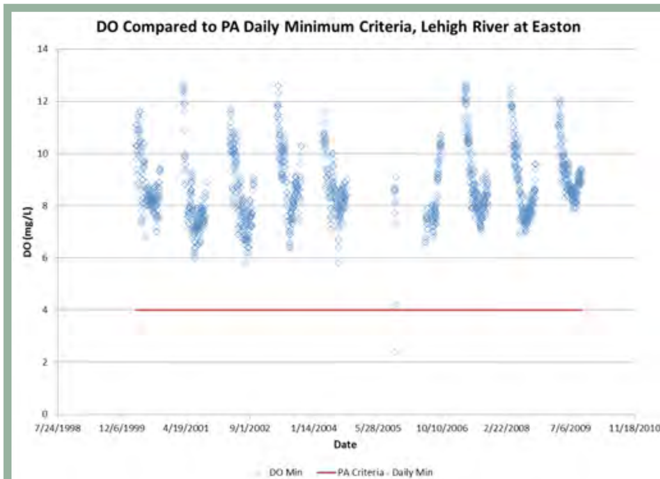

Fig. 3.65. Daily Mean Dissolved Oxygen at the Lehigh River at Easton Compared to Criteria.

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,

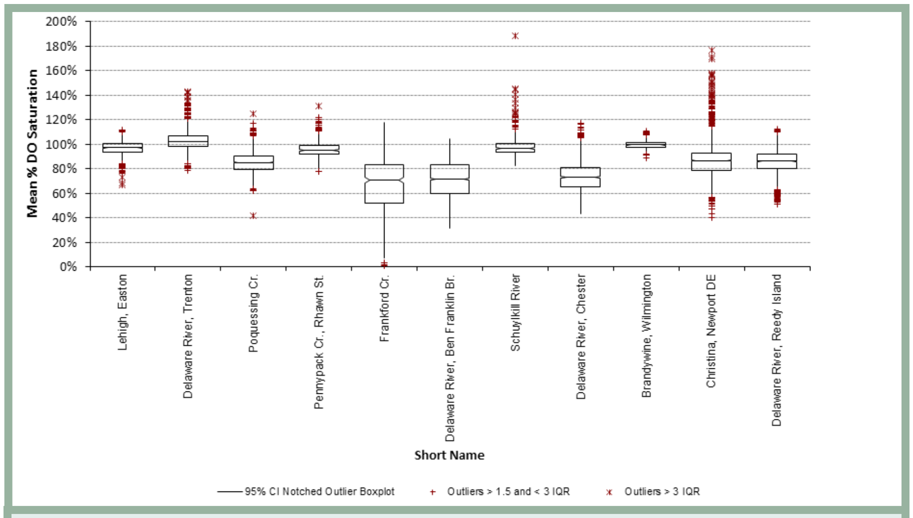

Fig. 3.66. Box and Whisker Plot of DO Saturation from Continuous Meters at Major Tributaries and Delaware River Sites.

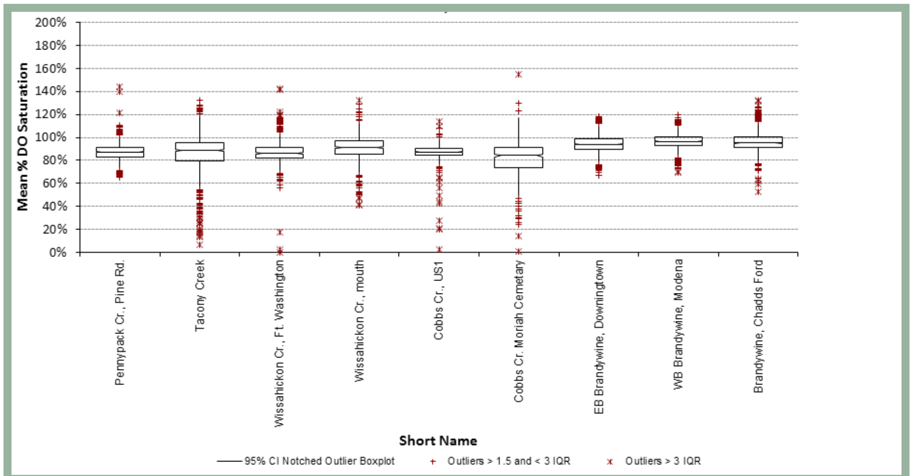

Fig. 3.67. Box and Whisker Plot of DO Saturation from Continuous Meters at Minor Tributaries.

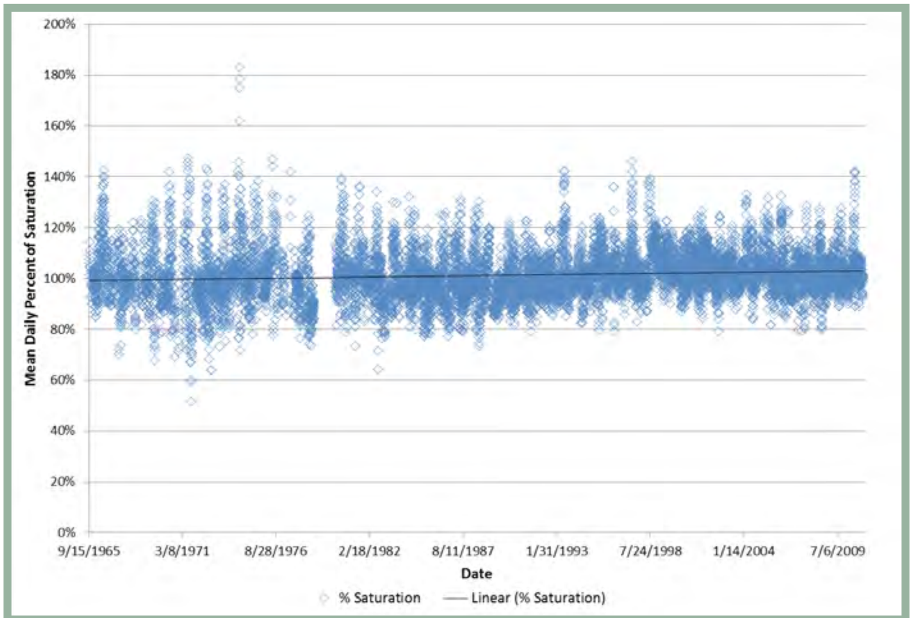

Fig. 3.68. Period of Record Time Series, DO Saturation at Trenton.

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.

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.

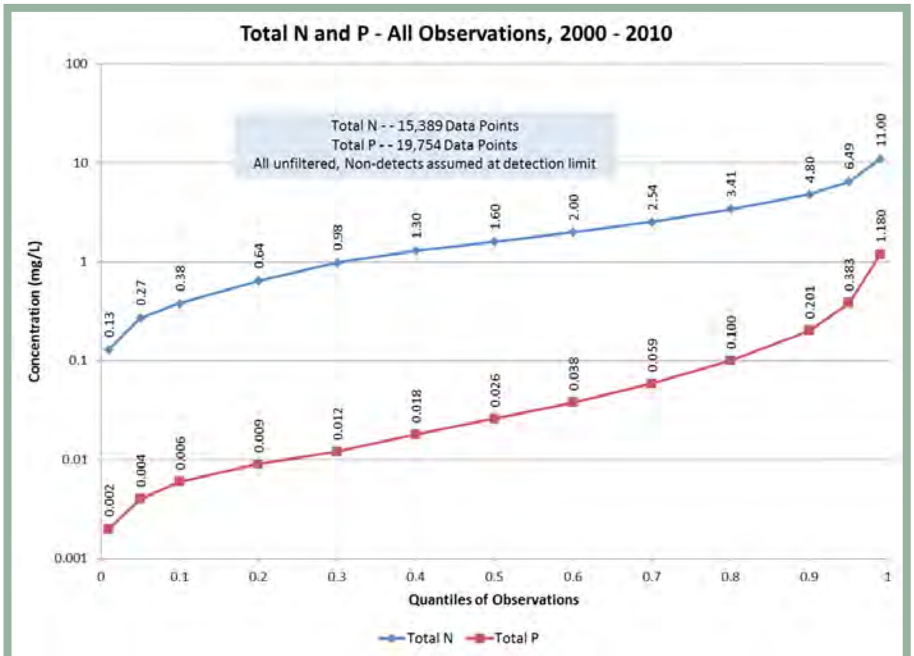

Fig. 3.69. Quantiles of All Total N and Total P Observations in the Delaware River Basin

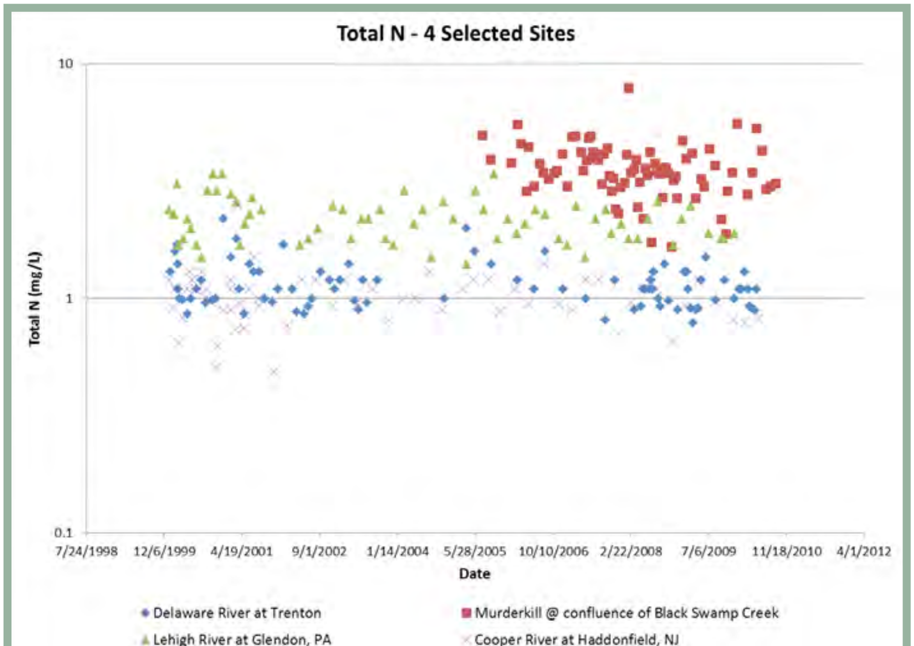

Fig. 3.70. Total N Concentrations from 4 Sites

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

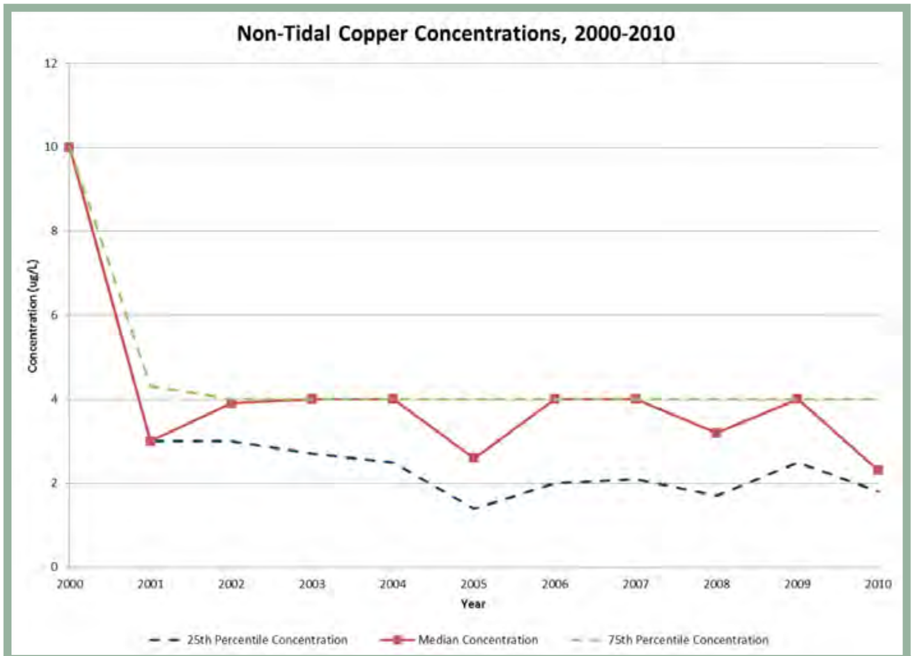

Fig. 3.71. Copper Concentrations in the Non-Tidal Zone from 2000-2010

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.

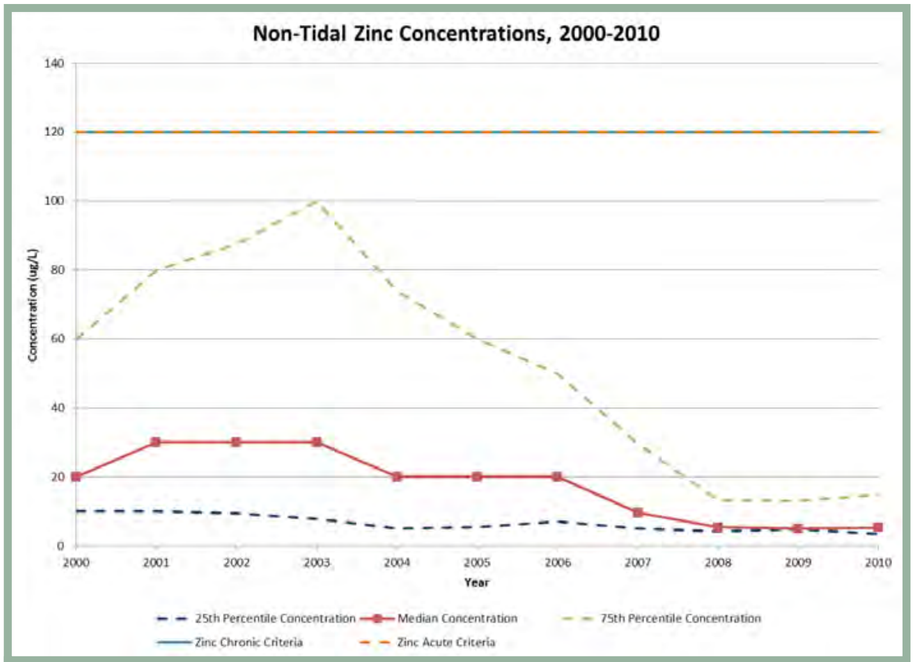

Fig. 3.72. Zinc Concentrations in the Non-Tidal Zone from 2000-2010

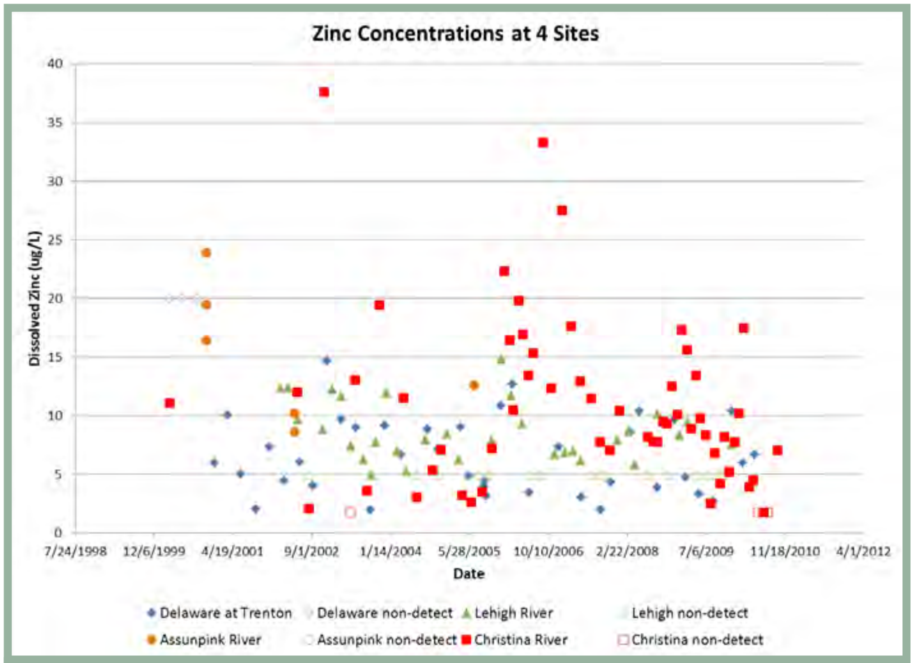

Fig. 3.73. Zinc Concentrations at 4 Basin Sites

3B – 3.3 Past Trends

Data and detection insufficiencies make determination of past trends difficult.

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.

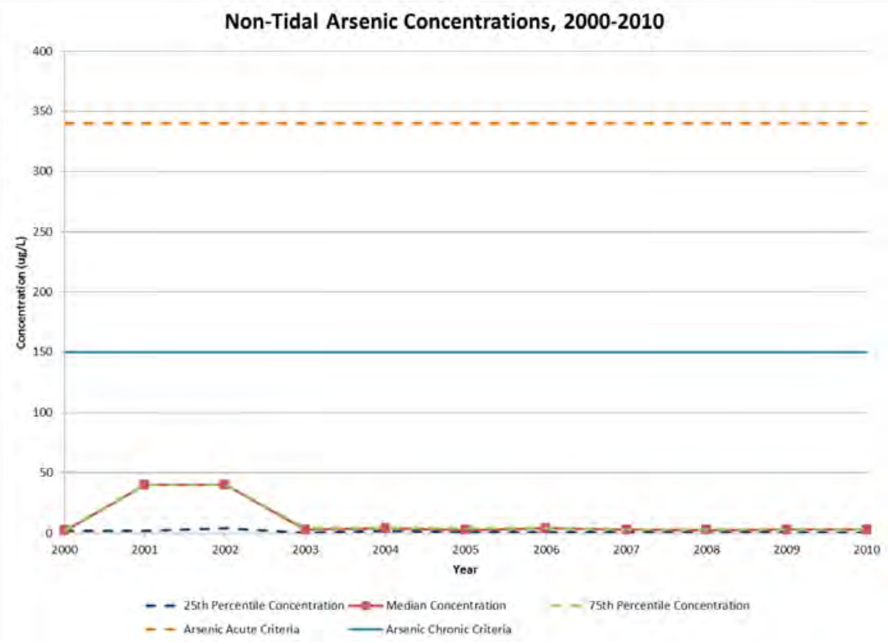

Fig. 3.74. Arsenic Concentrations in the Non-Tidal Zone from 2000-2010

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.

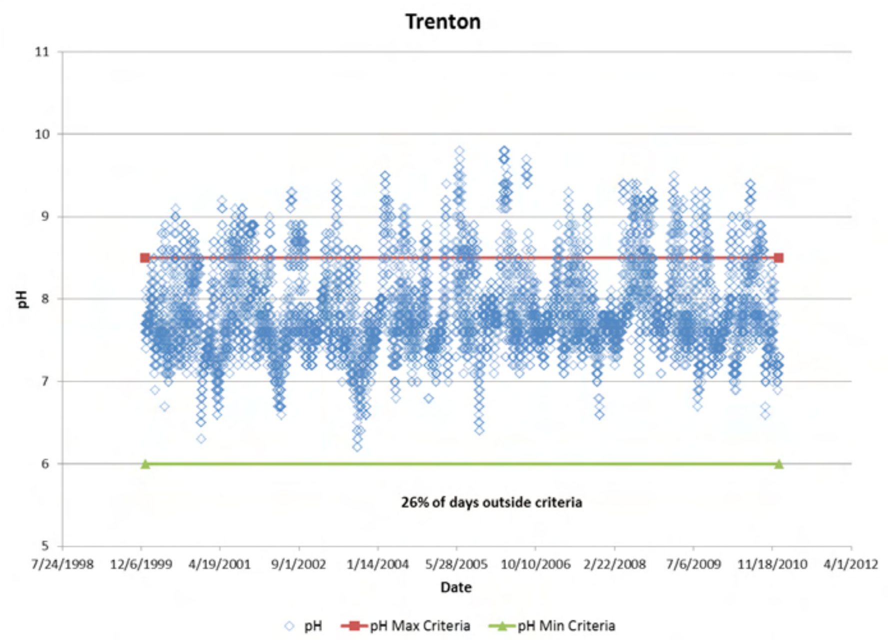

Fig. 3.75. pH Observations at Trenton, Compared to Criteria

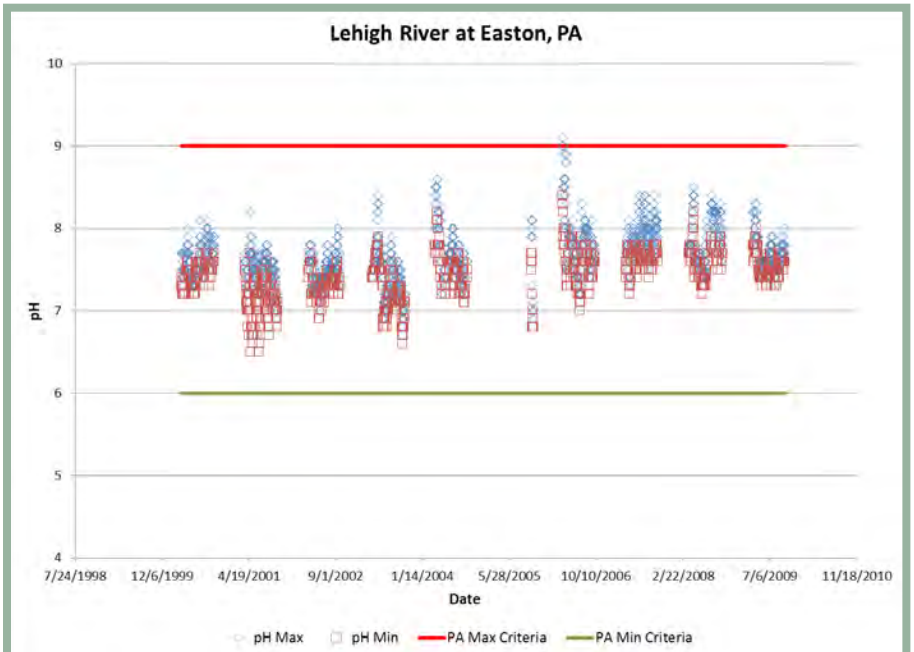

Fig. 3.76. pH Observations on the Lehigh River at Easton, Compared to Criteria

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.

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.

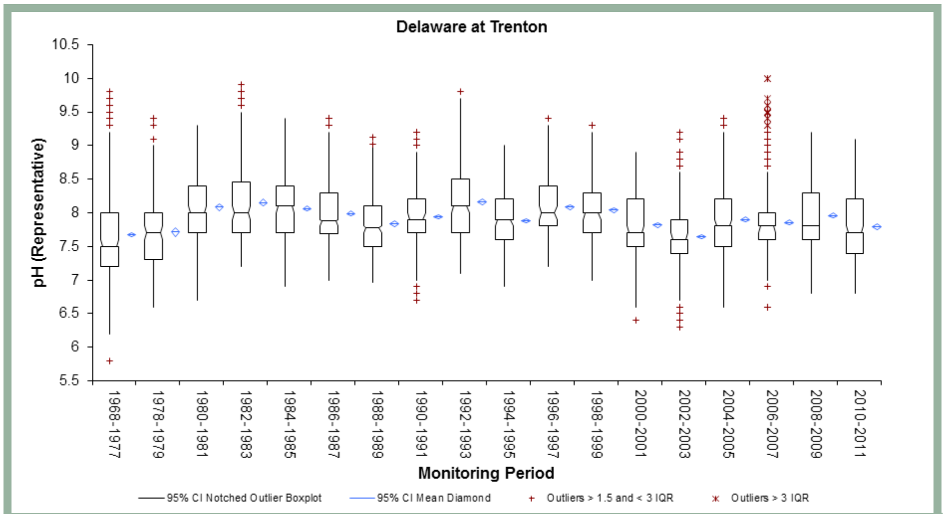

Fig. 3.77. Box and Whisker Plot of pH Period of Record at Trenton

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.

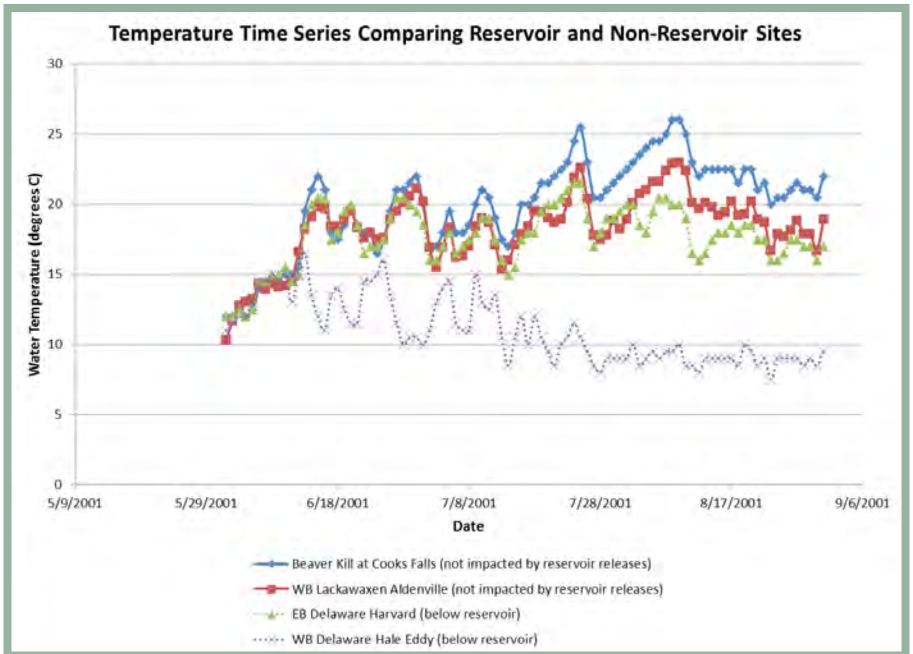

Fig. 3.78. Comparison of Temperature Time Series at Reservoir and Non Reservoir Affected Sites

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).

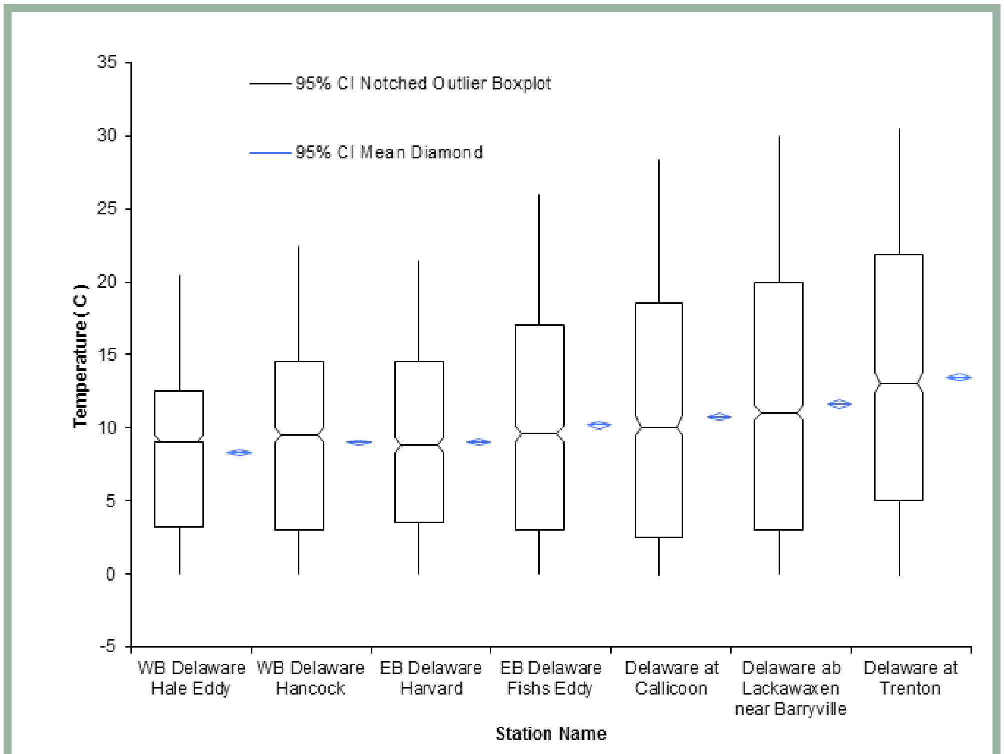

Fig. 3.79. Box and Whisker Plot of Temperature Data Longitudinally along the main stem Delaware River

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.

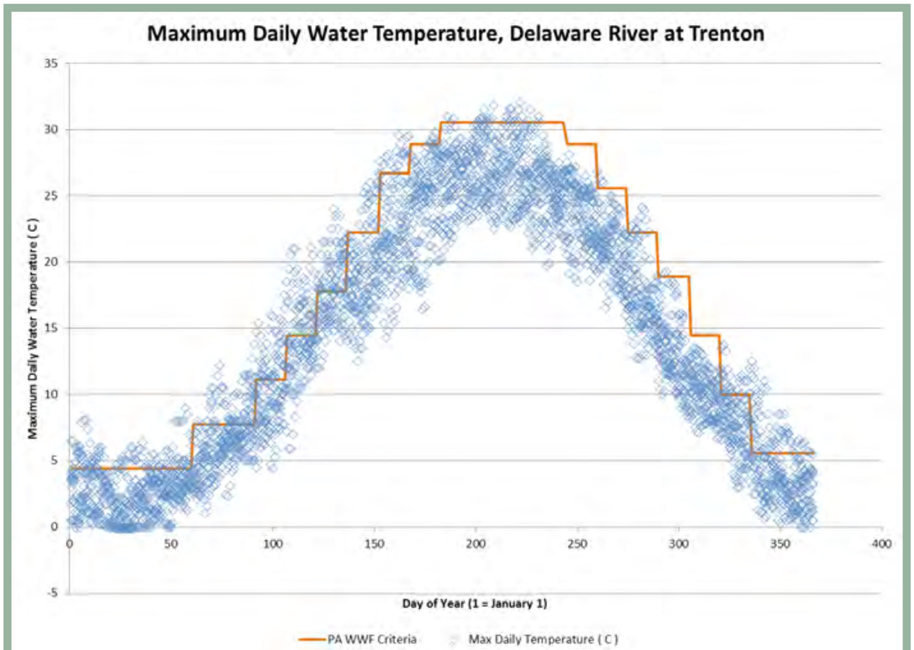

Fig. 3.80. Comparison of maximum daily water temperature by day of year at the Trenton monitor compared to PA warm water fishery temperature criteria

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.

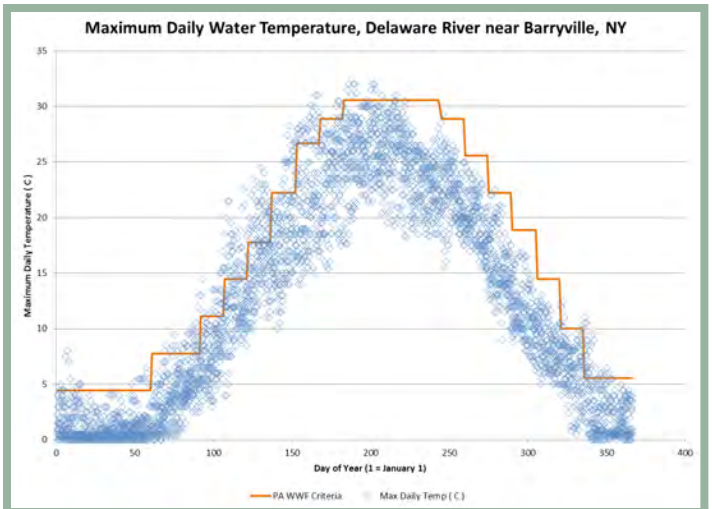

Fig. 3.81. Comparison of maximum daily water temperature by day of year at the Trenton monitor compared to PA warm water fishery temperature criteria

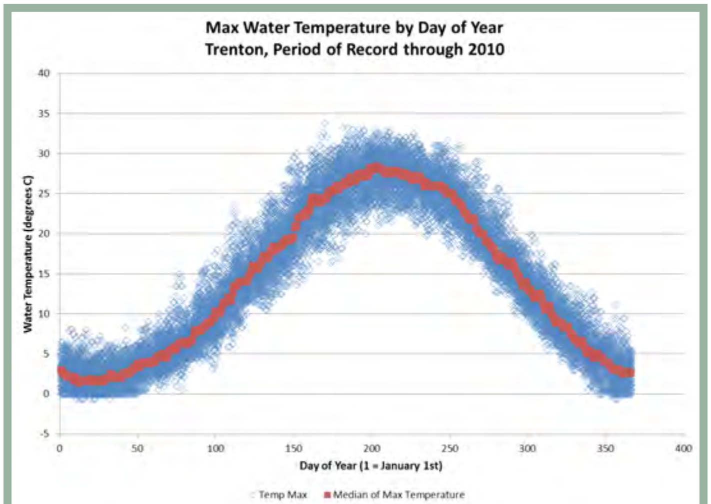

Fig. 3.82. Water Temperature and Median by Day of Year at Trenton

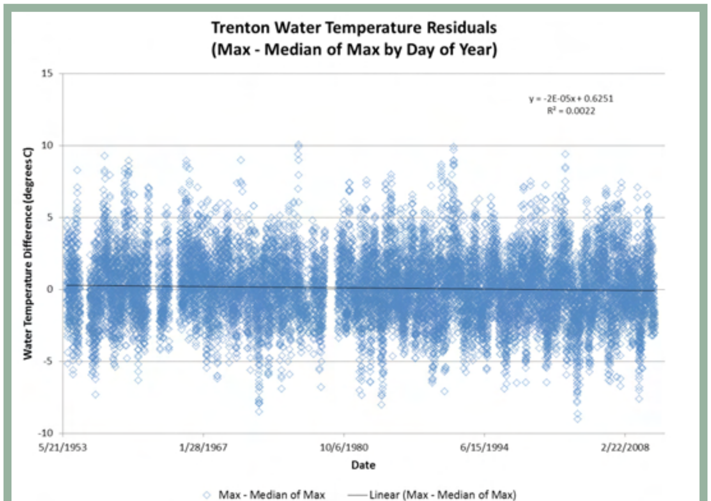

Fig. 3.83. Water Temperature Residual Time Series at Trenton

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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