DELAWARE ESTUARY

MONITORING REPORT

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of the Delaware Estuary Program

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DELAWARE
ESTUARY PROGRAM

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1.O EXECUTIVE SUMMARY

The Delaware Estuary has shown large improvement in many aspects of water quality in the past and improvements in some parameters continue. From the late 1960s through 1990, large increases in dissolved oxygen content are demonstrable. Since that time, oxygen concentrations, which are often close to atmospheric saturation, remain stable. Today, along the mainstem of the Estuary minimum oxygen levels are at 3.5 to 4.0 mg/l at all DRBC Boat Run Stations. The minimum required dissolved oxygen standard within the upper Estuary from the area of the Pennsylvania - Delaware border to the mouth of Pennypack Creek over a 24 hour period is 3.5 mg/l. Fecal coliform bacteria levels over the period 1989-1997 showed a significant decline. The recent levels for both Fecal coliform and Enterococcus suggest levels of these bacteria in the area from the Pennsylvania - Delaware boundary line to Fieldsboro, New Jersey to be lower than Federal Fishable /Swimmable Criteria. Ammonium nitrogen showed a large decline in the past, with much of the decline coinciding with increased nitrate nitrogen. The total inorganic nitrogen (ammonium and nitrate) concentration is slightly lower today than in the late 1960s. Total phosphorus declined dramatically in the early 1970s. Concentrations of both nitrogen and phosphorus remain stable today and, although concentrations are high, there is no indication of problems from these nutrients.

A number of fisheries have shown a resurgence in recent years. In addition, a greater number fish species have been noted in the tidal Delaware River. Increases have been noted in the abundance of American shad, weakfish, striped bass, Atlantic croaker, Atlantic silversides, bay anchovy, black drum, hogchoker, northern kingfish and striped anchovy. Survey data suggest an increase in blue crab abundance as well. American eel landings for both adult and juvenile fish have been steadily increasing in recent years. The current commercial landing data for adult eel is spotty. Efforts are being made in the State of New Jersey to collect better information for this species. A number of data sets suggest a decline in the population level of horseshoe crabs in the Estuary. A fishery management plan is being prepared by the Atlantic States Marine Fisheries Commission to provide management recommendations for this species. Atlantic sturgeon numbers continue to show a decline. The 1996 population estimates place the levels for this species at 430 fish.

There is still progress to be made in restoring the important resource that is the Delaware Estuary. For example: There are fish consumption advisories for striped bass, white perch and catfish in all three states due to Polychlorinated Biphenyls (PCBs) and chlorinated pesticides. Aquatic sediments collected from the upper reaches of the Estuary continue to contain elevated levels of PCBs, Polycyclic Aromatic Hydrocarbons (PAHs), chlorinated pesticides and selected metals. These contaminants appear to be bio-available to organisms.

Other activities of the Monitoring Implementation Team regarding Delaware Estuary Program coordination, mapping and the development of a sortable data base of ongoing monitoring efforts the Estuary are discussed.

2.0 OVERVIEW

The National Estuary Program requires a monitoring plan in the Comprehensive Conservation and Management Plan (CCMP) of each estuary program. The plan is needed to assess the effectiveness of management action plans in meeting goals identified in the plan. Monitoring can identify environmental problems that require additional management action. For example, the toxic pollutant management strategy is built around the identification of events at an early stage so corrective action can be initiated. Historically, ambient water quality monitoring in the Delaware Estuary has served as an indicator of regulatory compliance toward managing urban and industrial pollution inputs to the system. The goal of the regulatory compliance has been attainment of the federal Clean Water Act's target of "fishable - swimmable" waters. Some living resources monitoring has been conducted to manage commercial and recreational fisheries.

A comprehensive monitoring program to assess the condition of natural resources in the Delaware Estuary (herein after referred to as The Plan) is extremely valuable to document a degrading condition. Appropriate monitoring provides a way to accurately assess potential damages and to develop corrective programs and plans. The availability of good monitoring information makes these efforts less costly in terms of time and funds to the agencies involved. It also supports quicker resolutions of problems and restoration actions.

Initially, the Delaware Estuary Program provided necessary characterization of the extent of knowledge of this resource. Four characterization reports [Najarian Associates, Philadelphia Academy of Natural Sciences (1991), Frithsen et.al., (1991), Sullivan et.al., (1991) and Sutton et. al., (1996)] prepared a characterization of the physical, biological, ecological and land use trends in the Estuary. These reports, prepared for the Scientific and Technical Advisory Committee of the Estuary Program helped to establish the status of the Estuary at the beginning of the CCMP implementation. Other Estuary Program supported activities have provided additional definition regarding such topics as living resources (Dove and Nyman, eds.,1995) and contaminant inputs (Reidel and Sanders, 1993). Based upon ongoing work by several agencies, the CCMP presented several aspects regarding the health of the Estuary. These include: non-compliance with primary contact recreation in sections of the upper Estuary and heavy usage of surface and groundwater. The latter can affect industrial and domestic use and the maintenance of habitat and living resources. The CCMP also identified concerns regarding: elevated levels of toxic substances in the sediments, water column and biota dependent on the Estuary, degraded benthic communities North of the Chesapeake and Delaware Canal to Trenton and habitat fragmentation and alteration. These efforts have helped the Delaware Estuary Program to establish a series of objectives to guide the development of management activities.

Taken together, these program objectives are designed to address the overall objective of the Clean Water Act to "restore and maintain the chemical, physical and biological integrity of the nation's waters." With the above in mind, the cooperative monitoring plan for the Delaware Estuary includes four specific goals:

- To obtain information on variables that may influence the condition of the Delaware Estuary, and to assess environmental indications of achievement of the management goals set by local, State and Federal authorities.

- To measure, with known confidence, the current status and trends in indicators of the condition of the Delaware Estuary (and surrounding watershed) on a system-wide basis.

- To estimate, with known confidence, the extent of the environmentally critical landscapes of the Delaware Estuary system.

- To evaluate and revise, periodically, the action plans to address dynamic developments in the Delaware Estuary.

The cooperative monitoring plan for the Delaware Estuary has four subject areas for which different monitoring strategies apply:

1. water quality
2. toxics
3. living resources
4. habitat/land cover/land use.

The monitoring plan developed by the Monitoring Committee of the Delaware Estuary Program is intended to be a cooperative and coordinated effort of the three surrounding States, the Federal government, the private sector, citizens groups and academia.

One key element within the cooperative monitoring plan was the establishment of the role of Monitoring Coordinator and the establishment of the Office of Monitoring and Mapping. This office was initiated in June 1997. Initial efforts have included enhancement of cooperation, assembling a sortable data base of ongoing monitoring efforts, assistance with ongoing programs, and facilitating data compilation. This first annual report represents an ongoing commitment by researchers, regulators and the private sector to enhance the multi-jurisdictional management of the Estuary. This report contains some data synthesis and trends, a feature which will be included in future reports.

3.0 **STATUS REPORT**

3.1 **Water Quality**

3.1.1 **Long Term Trends**

The Delaware Estuary includes a heavily urbanized tidal river, tidal tributaries and a broad saline bay that is surrounded by extensive salt marshes. The tidal freshwater portion was once considered one of the most polluted in the USA. From the early part of this century until the 1970s, very high biochemical oxygen demand rendered the Philadelphia /Camden region nearly anoxic for several months of the year. Control of industrial effluents and upgrades in municipal sewage treatment plants, completed by the late 1980s resulted in one of the most successful estuarine water quality improvements in the world. However, water quality problems continue to exist.

Like most urbanized estuaries, the Delaware has seen a long-term increase in nutrient loading (Ketchum, 1969; Jaworski, 1981). Figure 3-1 shows chloride and nitrate data for the Marcus Hook station. This figure shows a four-fold increase in nitrate concentration for the Delaware River near Philadelphia from 1913 to the 1980s. Some of the input for Figure 3-1 for the period 1911 - 1988 is based on sparse data of unsure quality. Since 1967, more extensive monitoring records are available for transects going down the majority of the length of the Delaware Estuary navigation channel (DRBC Boat Run Program). In the period from 1900 to 1950, the human population in the drainage basin increased significantly, but has been relatively constant since then. The observed increase in nutrient loading mirrors that of the human population for the first 50 years of the record period, but the increase in chloride only for the latter 40 years of the period (Sharp,1997).

Figure 3-2 shows Duncan's Multiple Range Test for dissolved oxygen for all stations in the Delaware River Boat Run conducted by Delaware Department of Natural Resources and Environmental Control (DNREC) for the Delaware River Basin Commission (DRBC). That figure presents, for each year, a single average value. Using a least square method, each mean is evaluated to other years. Those years that are not significantly different ($\prec$ = 95%) are grouped together. Statistically non-significant groupings suggest that data from all stations over the period 1977-1986 had lower average oxygen levels than the period 1988-1994 (refer to Appendix C). Trend data over the 1994 - 1995 period show minimum dissolved oxygen values in the mainstem of the Delaware River to be generally above 5 to 6 mg/l in the lower and middle Estuary (Ship John Light (River Mile 36) to Marcus Hook (River Mile 78). Further North in the Philadelphia area (River Mile 84 - 111) minimum dissolved oxygen levels were typically above 3.5 mg/l , which is the DRBC criteria within a 24-hour period (See Figure 3-3 and Appendix C). Annual average values are approaching 7 - 8 mg/l.

Figure 3-4 shows nitrate for the 1967 - 1997 period. In Figure 3-5, ammonium nitrogen for the 1967 - 1993 period shows a dramatic decline. Values are reported in micromoles N per liter (100 **µ**MN/l = 1.4 mg/l). Some of the ammonium decline (3.9 µM N/l/yr.) can be accounted for by the nitrate increase (1.4 µM N/l), although there is also a slight overall decline in total inorganic nitrogen. Combining these data sets, one can see a large increase in nitrate during the population increase and then a relatively level nitrate concentration for several decades but a large change in nitrogen speciation. As presented in Sharp (1997) the shift in nitrogen speciation can be evaluated stoichiometrically with the increase in oxygen content of the water. In fact, although the concept was developed for subsurface oceanic waters (Redfield et.al., 1963), Redfield stoichiometry can be applied to coastal (Sharp and Church, 1981) and estuarine (Culberson, 1988) waters. In doing this, the ammonium oxidation to nitrate over the quarter century period accounts for about 40% of the oxygen decrease. Figure 3-6 shows a similar trend for total phosphorus; unfortunately, the data set does not consistently contain dissolved phosphate data. The presumed cause of this very large decrease has reportedly been attributed to the detergent phosphate ban of the early 1970s (Jaworski 1997). Sharp (1997) noted that in all probability, the total phosphorus reduction involves changes in partitioning between dissolved and soluble phases for the phosphorus and changes in solubility of phosphate (Lebo, 1991; Lebo and Sharp, 1992), as well as decreases of phosphorus inputs. The relation of total inorganic nitrogen decrease (2.5 µM N/l per year) to total phosphorus decrease (1.2 µM P/l) could account for only about 10% of the phosphorus change. Thus, much of the decline in phosphorus concentration appears to be actual removal from the water column.

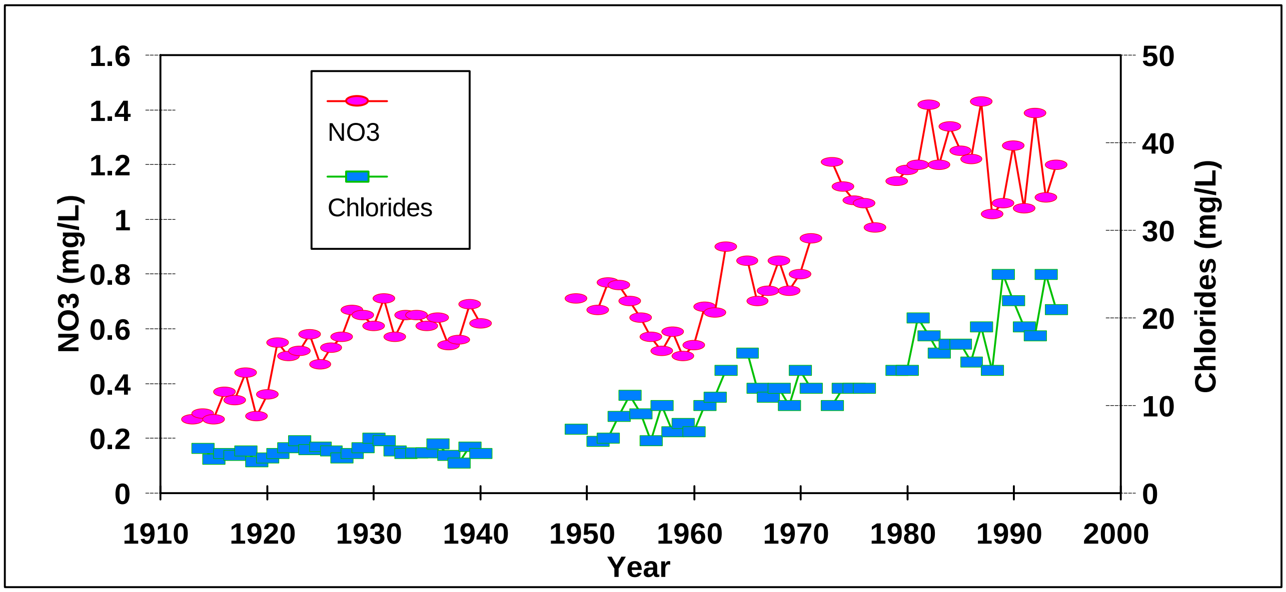
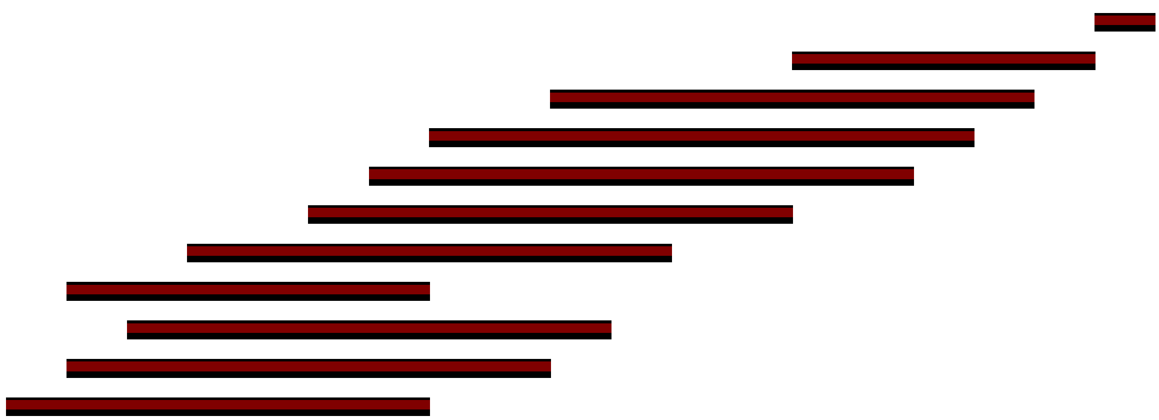


FIGURE 3-1 LONG TERM NITRATE AND CHLORIDE DATA FOR THE MARCUS HOOK STATION (FROM SHARP, et. al., (1997) BASED UPON DATA FROM N. A. JAWORSKI).

FIGURE 3-2 DUNCANS MULTIPLE RANGE TEST - DISSOLVED OXYGEN OVER THE PERIOD 1977 - 1995 FOR ALL DRBC BOAT RUN STATIONS.

Mean O_2 (mg/l)	6.3	6.5	6.6	6.7	6.8	6.9	6.9	7.0	7.1	7.1	7.3	7.4	7.4	7.45	7.5	7.55	7.64	7.8	8.0	9.4
N of Analyses	354	323	262	249	268	317	337	350	359	389	355	303	393	323	88	323	92	36	291	67
YEAR	85	84	83	79	96	82	78	77	81	86	95	88	87	91	89	90	92	93	94	80



BARS DENOTE NON-SIGNIFICANCE AT ALPHA = 0.05, df = 5227

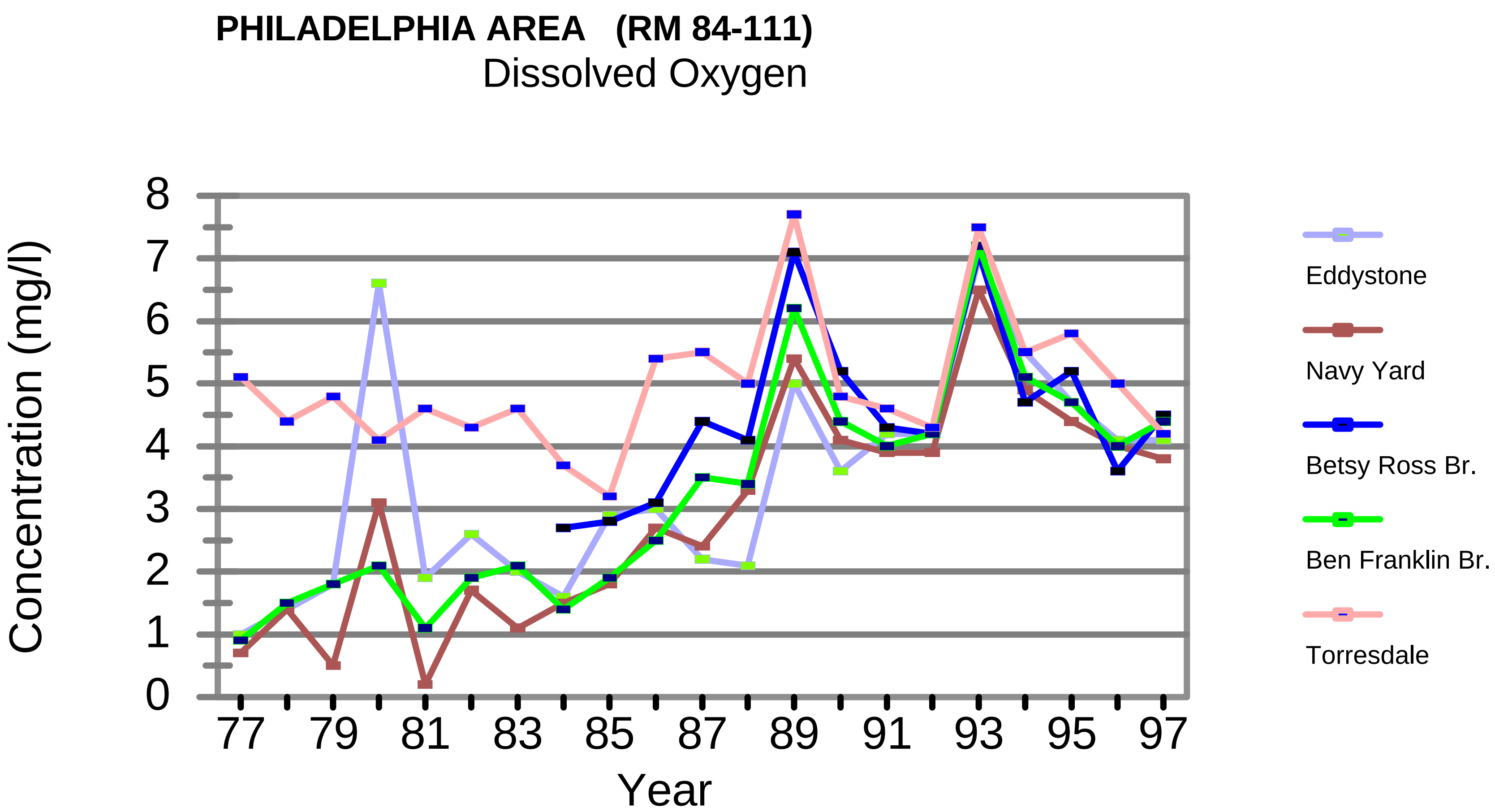


FIGURE 3-3 DISSOLVED OXYGEN MINIMUM VALUES FROM 5 BOAT RUN STATIONS IN THE PHILADELPHIA / CAMDEN AREA OVER THE PERIOD 1977 to 1997.

FIGURE 3-4 NITRATE-NITROGEN TREND 1967-1997 FROM THE MARCUS HOOK STATION - MONTHLY AVERAGES FROM SAMPLING PERIOD MARCH - NOVEMBER. SQUARES ARE 4-YEAR RUNNING AVERAGES CENTERED AROUND JULY OF EACH YEAR, BASED UPON DRBC BOAT RUN DATA (SHARP et. al., 1997).

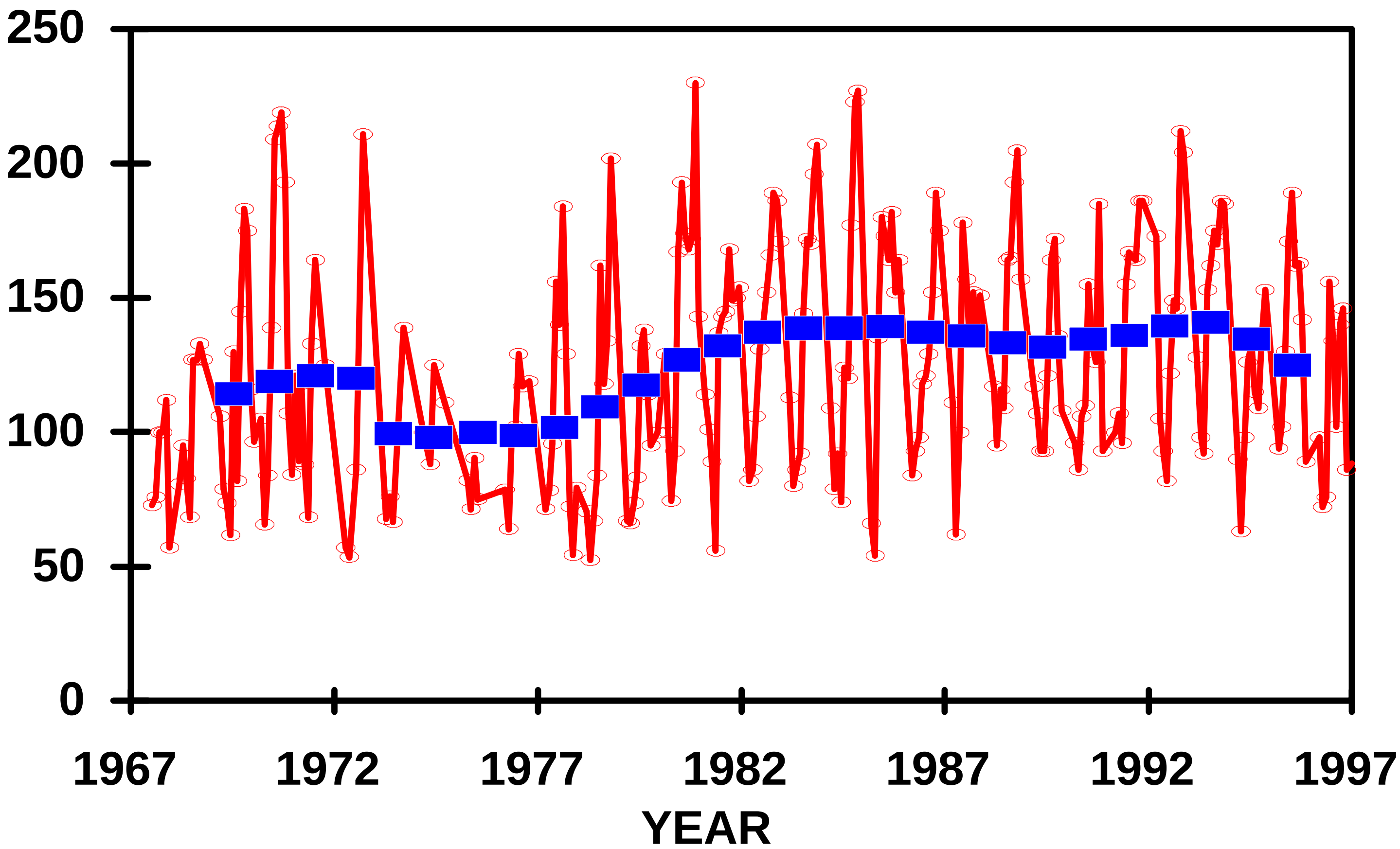


FIGURE 3-5 AMMONIUM-NITROGEN TREND – MARCUS HOOK STATION FROM THE PERIOD 1967-1997. MONTHLY AVERAGES FROM SAMPLING PERIOD MARCH - NOVEMBER. SQUARES ARE 4-YEAR RUNNING AVERAGES CENTERED AROUND JULY OF EACH YEAR BASED UPON DRBC BOAT RUN DATA, (SHARP, et. al., 1997)

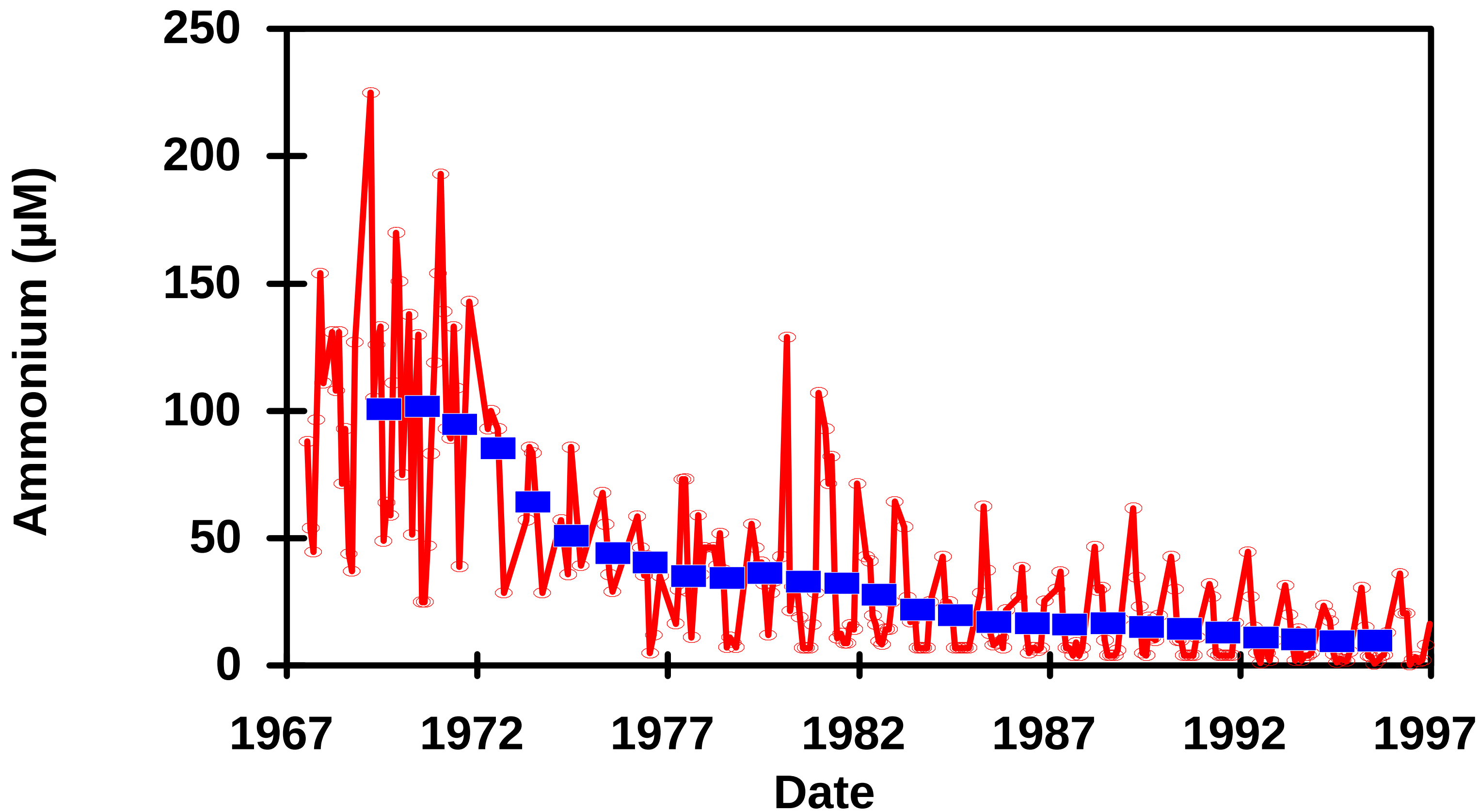
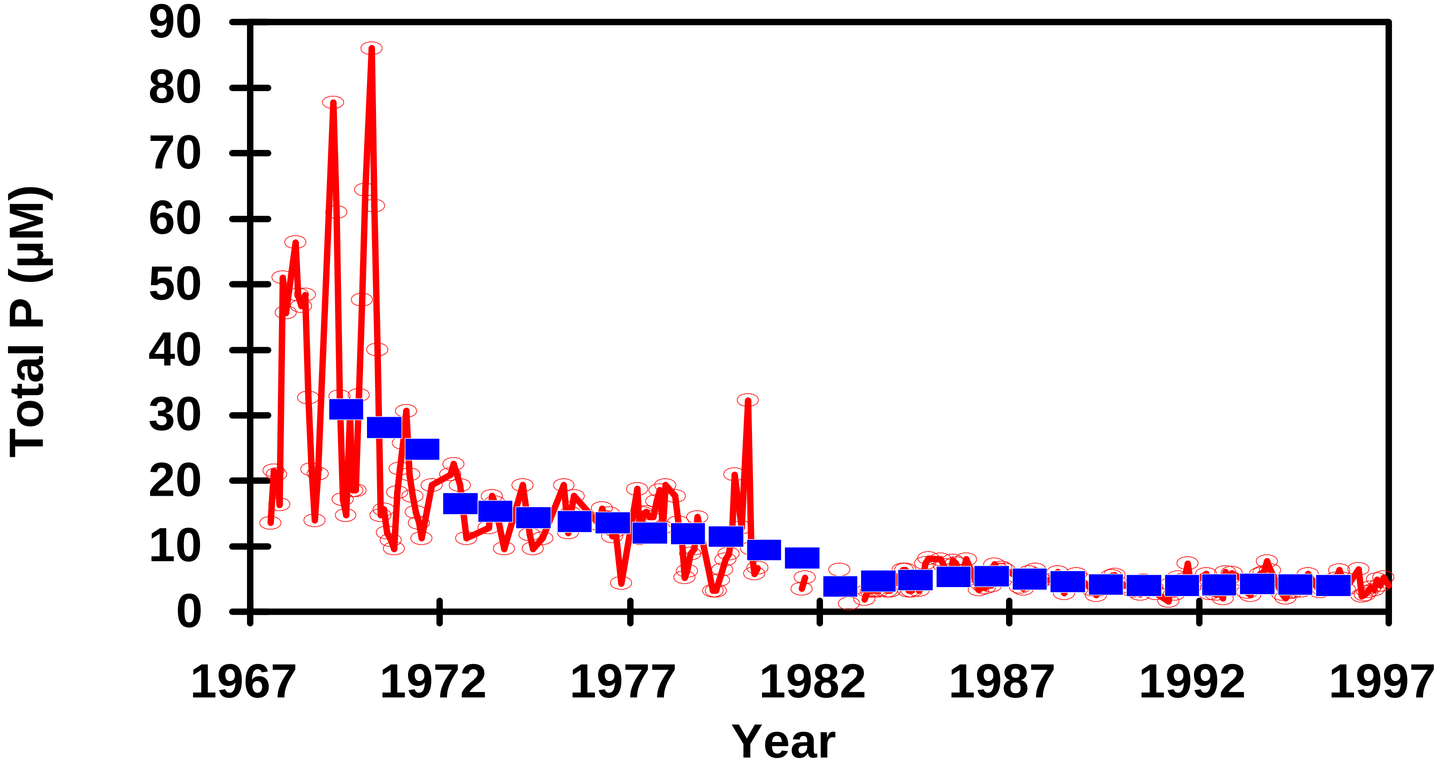


FIGURE 3-6 TOTAL PHOSPHOROUS TREND FROM THE MARCUS HOOK STATION MARCUS HOOK STATION FROM THE PERIOD 1967-1997. MONTHLY AVERAGES FROM SAMPLING PERIOD MARCH - NOVEMBER. SQUARES ARE 4-YEAR RUNNING AVERAGES CENTERED AROUND JULY OF EACH YEAR BASED UPON DRBC BOAT RUN DATA, (SHARP et. al., 1997)



3.1.2 Nutrient/Algal Productivity Relationship

Despite higher dissolved oxygen concentrations in the Delaware River today and some sporadic declines in nutrients, overall nutrient concentrations remain high. However, these high nutrient concentrations do not appear to pose a serious eutrophication problem (Sharp, 1994). Figure 3-7 shows nitrate and ammonium nitrogen concentrations along the length of the Estuary. There are considerable seasonal patterns of the nitrogen species with seasonally varying rates of nitrification (Cifuentes et. al., 1988; 1989), nitrogen transport to the lower Estuary (Cifuentes et. al., 1990), and of phytoplankton use of nitrogen (Pennock, 1987). The values in Figure 3-7 are annual averages and they indicate a major input of nitrogen in the urban region of the Estuary from sewage effluents. Also, a large phosphorus input isin the same location (Sharp, 1994;1997).

In spite of the upper Estuary high nutrient concentrations, the major algal primary production occurs in the lower Estuary distant from the urban inputs and high nutrient concentrations. Figure 3-8 shows the primary algal production measured as mmol carbon/m^2/day for four seasons along the length of the estuary. Samples are not routinely collected for algal speciation. Superimposed on this figure is the suspended sediment concentration (Setson). There is very low primary production in the tidal river region except in the uppermost portion (upstream of 170 km (105.6 mi)) in the summer. A spring bloom of moderately high production with very high chlorophyll occurs in the lower Estuary followed by high production with low chlorophyll in the summer (Pennock and Sharp, 1986; 1994). The nutrient maximum region of the Estuary is about 80 - 150 km (49.7 - 93.2 mi.). The primary production in this region is not high. Low light levels caused by the turbidity maximum limits primary productivity in the 80 - 100 km (49.7 mi. - 62.14 mi.) zone. The 120 - 150 km (74.5 mi. - 93.2 mi.) region has sufficient light and high nutrients; the low primary production here is somewhat puzzling and possibly due to cumulative effect of toxic substances and wastewater treatment plant disinfection and chlorination (Sharp, 1994; Sanders and Riedel, 1992). The overall effect is that of extremely high nutrient inputs in the urban region with little stimulation of algal production, followed by dilution of the nutrients, that supports moderately high production only in the lower estuary. The lower estuary is well mixed throughout the summer and fall, so that the primary production appears to be fairly well consumed and does not contribute to signs of eutrophication (Sharp et. al., 1986; 1994; 1994). Based upon the above information, nutrient and oxygen levels appear to be stable despite very high nutrient levels. Chlorophyll-a concentration and productivity in a tidal river are not high despite high nutrients. Clearly, monitoring for nutrients, light, chlorophyll-a and productivity should continue as they are important indicators of the health and productivity of the estuary.

FIGURE 3-7 NITRATE (□) AND AMMONIUM NITROGEN (○) CONCENTRATIONS ALONG THE LENGTH OF THE ESTUARY BASED UPON MONTHLY WEIGHTED ANNUAL AVERAGE VALUES DURING 1987 - 1988 (FROM SHARP et. al., 1994).

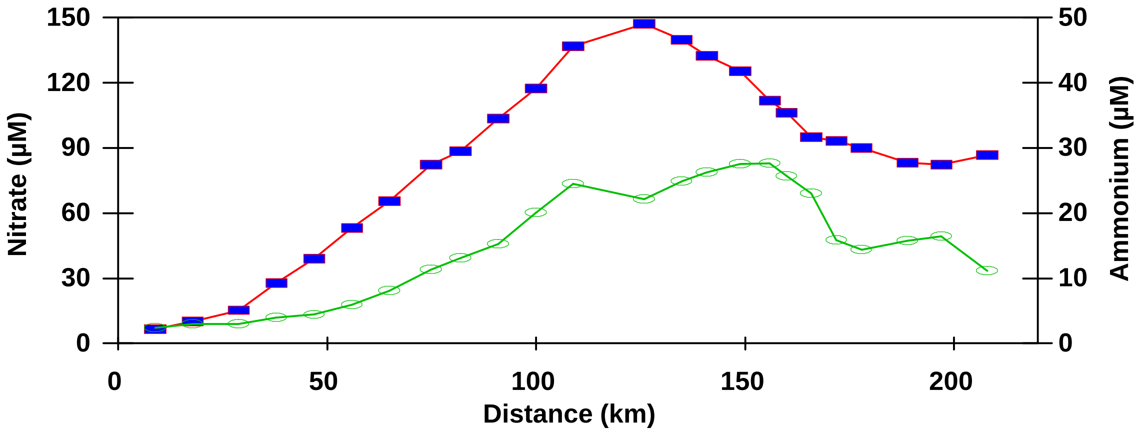
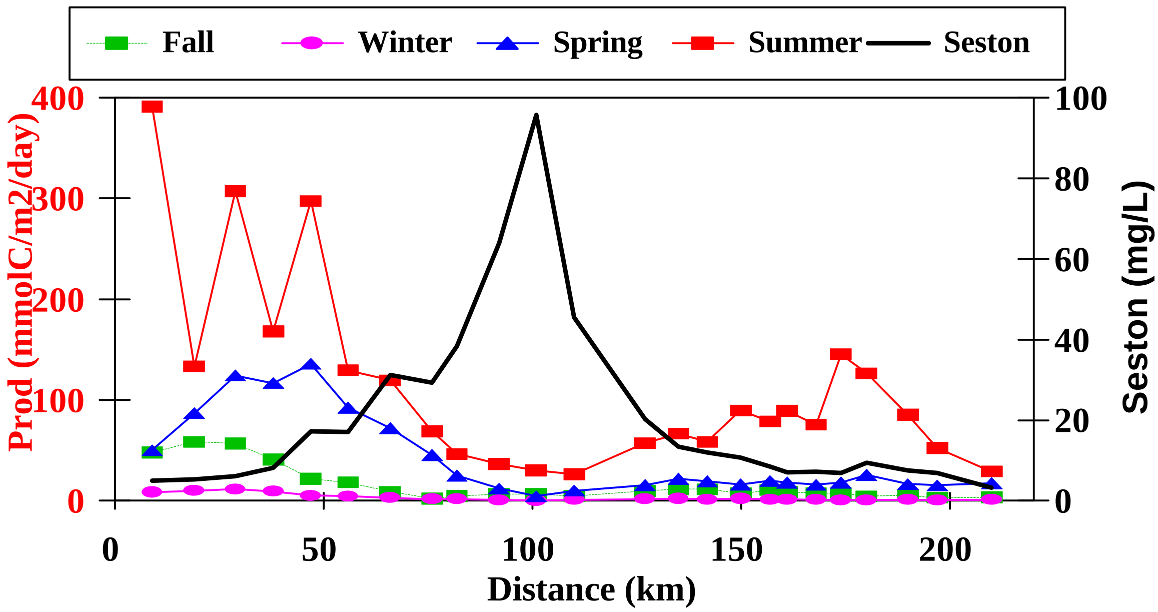


FIGURE 3-8 PRIMARY ALGAL PRODUCTION BY SEASON -DELAWARE ESTUARY (FROM SHARP et. al., 1994)



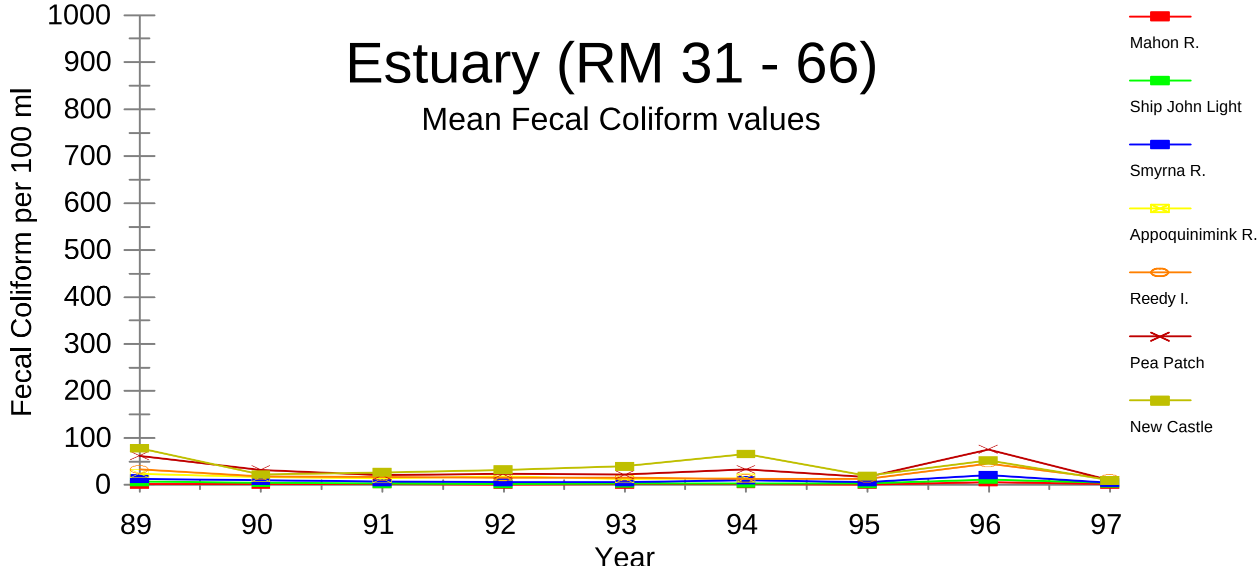
3.1.3 Bacteria Levels

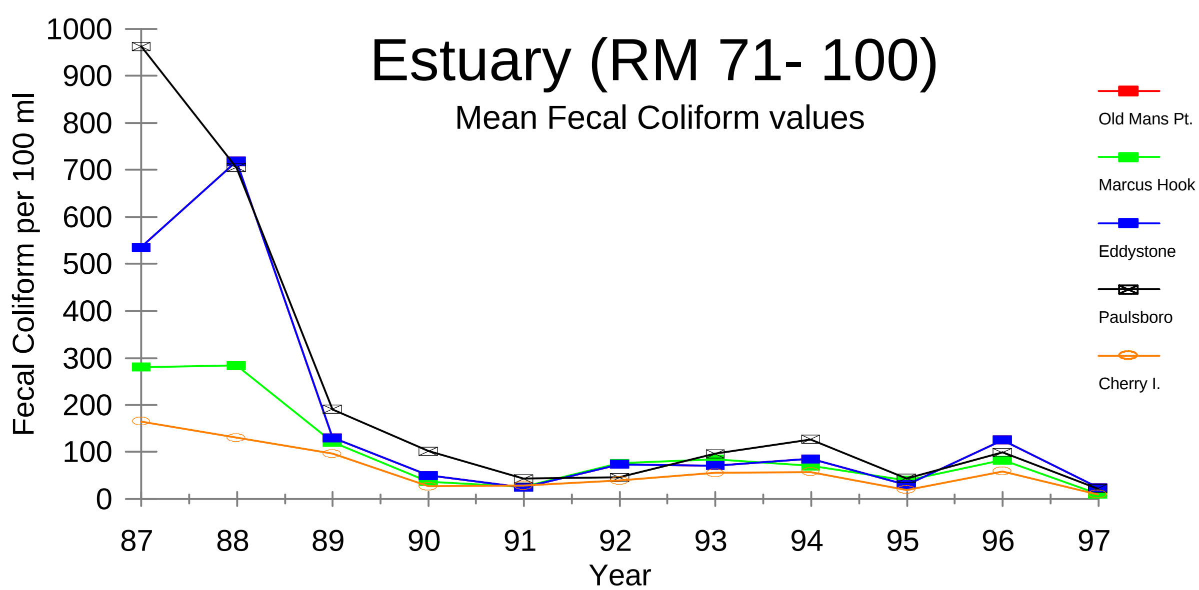
Bacteria samples collected during the DRBC Boat Run Program are presented in Figure 3-9. From 1989 to 1997 (excluding the months of December to February, inclusive), levels of fecal coliform drastically dropped at almost all stations. Most notably for River Miles 71-100 which revealed a drop from an average of approximately 1000 fecal coliforms/100 ml in 1989 at Paulsboro to less than 50 fecal coliforms/100 ml, at that same station, in 1997. It should be noted that no disinfection of sewage effluent was conducted from Trenton to the Delaware State line from fall 1987 to spring 1988, as part of a seasonal disinfection study conducted and approved by the DRBC (DRBC 1990). Full disinfection occurred prior to fall 1987 and after spring 1988. It is anticipated that the eventual merging of data sets from NJDEP, PADEP and other DNREC data to the Boat Run data set will further define fecal coliform trends. In the near future, merging of the fecal coliform Boat Run data sets prior to 1989, which utilized different methodology, will be merged with post- 1989 data for use by the Monitoring Implementation Team members.

Log mean fecal coliform values were calculated for Boat Run data for the period 1987 - 1997. The data are presented on Figures 3-10 a & b. Data for the period 1989 to 1997 show mean levels would be consistently below the Federal fecal coliform criteria of 200/100 ml for primary contact recreation and well below the DRBC fecal coliform standard, which is a maximum geometric average of 770 cells/100 ml for secondary contact recreation (Zone 3) and portions of Zone 4 above RM 81.8.

Levels of enterococcus bacteria were also evaluated for the DRBC Boat Run data for the period 1987 - 1997. In the areas of Zone 3 and Zone 4, the mean level of enterococcus was considerably below both the DRBC standard (for secondary contact recreation) of 88 cells per 100 mL (geometric average) and the Federal requirement of 33 cells/100 mL (geometric average) for primary contact recreation in saline waters (See Figure 3-11 a & b). The lower mean levels for both enterococcus and fecal coliform bacteria clearly suggest that the DRBC should adopt a standard which is commensurate with the attainment of primary contact goals in Zones 3 and 4. Clearly, we need to continue bacteriological monitoring to track these parameters.

FIGURE 3-9 FECAL COLIFORM DATA COLLECTED DURING THE BOAT RUN PROGRAM OVER THE 1989 - 1997 PERIOD





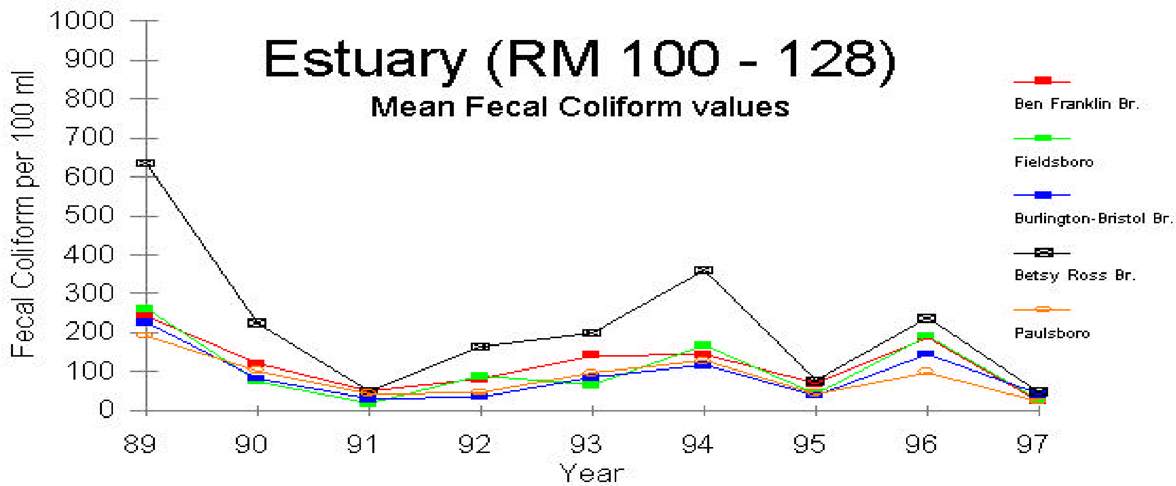


FIGURE 3-10a - FECAL COLIFORM - BOAT RUN 1987 - 1997 - ZONE 3

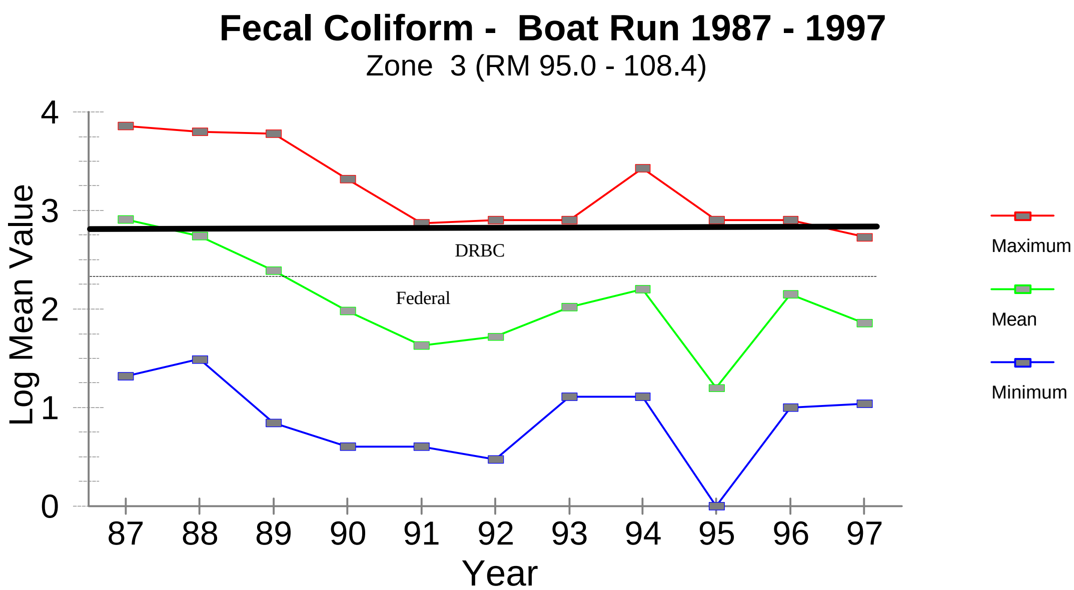


FIGURE 3-10b - FECAL COLIFORM - BOAT RUN 1987 - 1997 - ZONE 4

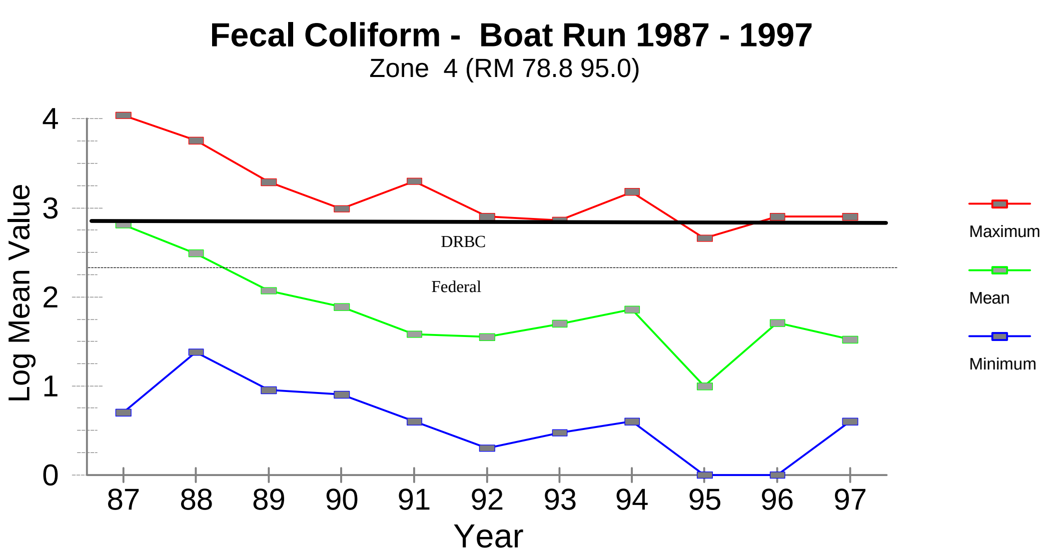


FIGURE 3-11a - ENTEROCOCCUS BACTERIA - BOAT RUN 1987 - 1997 - ZONE 3

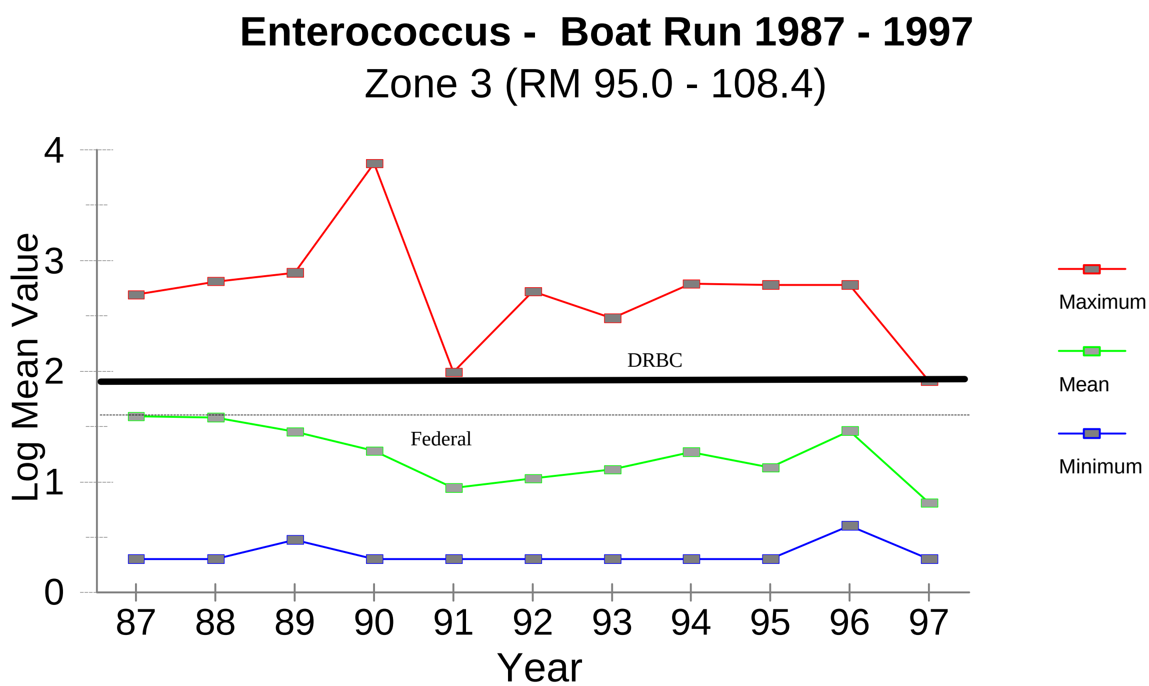
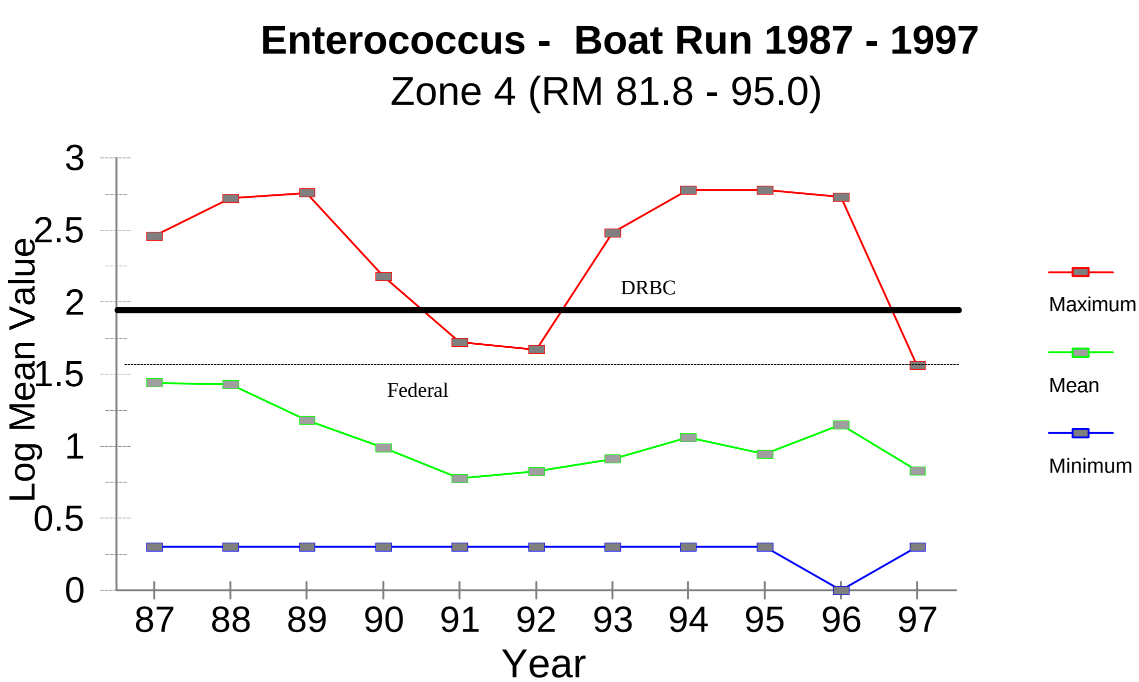


FIGURE 3-11b - ENTEROCOCCUS BACTERIA - BOAT RUN 1987 - 1997 - ZONE 4



3.2 Toxic Pollutants

Concerns about toxic pollutants in the Delaware Estuary rose in the mid-1980s as dissolved oxygen levels improved, fish populations rebounded, and regulatory efforts focused on controlling toxic pollutants. In 1989, fish consumption advisories were issued by New Jersey and Pennsylvania, based upon studies performed by the DRBC, and in 1996 additional advisories were issued in Delaware as well. The DRBC initiated the Estuary Toxics Management Program in 1989 to identify, address, and control toxic pollutants impacting the estuary. Several categories of pollutants affecting the Estuary are briefly discussed below:

3.2.1 Volatile Organic Compounds

Based upon a preliminary review of the Boat Run Data for volatile organic compounds in water for the period March 1997 through early June 1977, and compared to DRBC water quality criteria, all 32 parameters tested were found to be below the limits of detection (detection limit: 1 - 2 µg/l) at most sampling locations. One sample collected at the Burlington Bristol Bridge Station did contain 1.3 μg/l of 1,1,-Dichloroethene (sample collected on April 22, 1997).

3.2.2 Polynuclear Aromatic Hydrocarbons (PAH)

Arthur D. Little, Inc. (1994) performed an extensive study on sediments in the Estuary for the USEPA and DRBC. Potential PAH inputs were noted from several different petrogenic sources (e.g. oil refineries). Furthermore, a consistent background of pyrogenic, high-molecular-weight PAHs was found in sediments throughout the estuary.

PAHS concentrations, which correlated strongly with toxicity across the 16 stations surveyed, exceeded sediment effects levels at 10 stations, with the highest concentrations measured at stations between River Miles 80 - 115. PAHs were detected in many of the samples collected in the upper estuary. Compounds with the highest concentrations included benzopyrene, benzo(b)fluoranthene, fluoranthene, phenanthrene and pyrene. Total PAH concentrations were highest between the Tacony-Palmyra Bridge (RM 107.0) and at RM 92.9 near the mouth of the Schuylkill River.

Arthur D. Little, Inc. (1994) further suggested that a full complement of alkylated PAHs, in addition to those on the priority pollutant list should be collected and analyzed to document relative inputs of background non point sources of pyrogenic PAHs and localized point sources of petroleum.

3.2.3 Pesticide/PCBs

PCBs and chlorinated pesticides are classes of pollutants of concern, and several synoptic studies and ongoing monitoring programs have been conducted to document the spatial distribution and temporal patterns of selected pollutants (Arthur D. Little, Inc., 1994); (DRBC, 1994). PCBs, DDT and its metabolites (DDE and DDD) have not declined to acceptable risk levels in the tissues of white perch and catfish. A recent study of PCB concentrations in 10 tributaries and point source discharges conducted by the DRBC and Delaware DNREC found the highest concentrations in municipal discharges and in tributaries following wet weather events (DRBC 1998). These point source locations are presented on Figure 3-12.

Sediment sampling conducted by the U. S. Army Corps of Engineers in 1996 found elevated levels of PCBs in surface and subsurface sediments collected in the channel above New Castle, Delaware. These concentrations were significantly less than those observed in samples collected from shoal areas in 1993 (Arthur D. Little, Inc., 1994). Evidently, PCBs accumulate in shallow depositional areas when compared to samples collected in deeper navigational channels.

From the Arthur D. Little, Inc. (1994) study, PCBs were found to be far more widespread in sediments throughout the estuary than previously reported. PCB concentrations exceeded sediment effects levels (ER-L) at 13 of 16 stations sampled, with the highest concentrations measured at stations within River Miles 80 - 115. Concentrations of DDT and its DDE and DDD metabolites exceeded sediment effects levels (ER-L) at 15 of 16 stations, with the highest concentrations measured at stations within River Miles 80 - 115. Concentrations of dieldrin, another chlorinated pesticide, exceeded sediment effects levels at 44% of the stations sampled, with the highest concentrations measured at stations within River Miles 80 - 115.

DRBC (1994) found DDT and its metabolites at elevated levels, dieldrin, and many of the PAHs in sediments collected from the tidal river. PCB Arochlors were not detected in any of the samples. However, the laboratory reported that individual PCB cogeners may have been present. The highest concentrations of most pollutants occurred in the upper portion of the estuary between river miles 93 and 107. The lowest concentrations were generally observed in the lower portion of the tidal river. No significant lateral differences in pollutant concentrations were detected at the sampling locations.

Sediment-bound PCBs, DDT-related pesticides, and to a lesser extent PAHs were found to be accumulated by benthic organisms. Through food-chain transfer, the bio-accumulation of these toxic contaminants may result in adverse impacts to organisms that bio-magnify these contaminants and may pose potential health risk to humans who consume fish from the Estuary. A. D. Little, Inc. (1994) suggested that all future chemical analyses should require cogener-specific quantification of PCBs to ensure quantification in the absence of identifiable Aroclor patterns.

3.2.4 Metals

Chromium, copper, lead, mercury, and zinc levels reported in the DRBC (1994) study all exceeded sediment effects levels at stations within River Miles 80 - 115. As reported by the DRBC (1994), the heavy metals with the highest concentrations included chromium, copper, lead and zinc. Data on loadings from point sources and the results of a study on the Raritan River basin suggested that copper,

FIGURE 3-12 - MAJOR POINT SOURCE SAMPLING LOCATIONS FOR PCBs IN A PORTION OF THE TIDAL DELAWARE RIVER (RM 60-133). (DRBC 1998)

lead, and zinc levels are predominately anthropogenic in origin, while chromium has significant natural sources (McLaughlin et. al., 1988). Metals were detected in all of the estuary sediment samples (Table 3-1). The results of one-way analysis of variance tests of these parameters indicated that significant differences existed between the sampling locations for cadmium, lead and zinc. The highest concentrations of these three metals occurred between river miles (RM) 97.5 and 107, with the lowest concentrations occurring at locations in the lower estuary. The results of non-parametric tests for those metals whose distributions were not normally distributed (arsenic, chromium, copper and nickel) indicated significant differences between sampling locations for copper only (DRBC 1994). The highest concentrations of copper also occurred between river miles (RM) 97.5 and 107.

Results of statistical analyses of metals data normalized to the percent fine-grained particles in the sample indicated that site-related differences existed for cadmium, copper, lead, silver and zinc were normally distributed (DRBC 1994). In general, normalized concentrations of all four metals were highest in the upper estuary between RM 101.0 (North of the Ben Franklin Bridge) and RM 125.0 (Roebling). Elevated concentrations were also observed at RM 88.5 (Paulsboro) for cadmium and zinc.

DRBC (1994) noted several possible sources for the observed concentrations of these metals: natural sources, point source discharges from industrial and municipal facilities located on the mainstem or tributaries, non-point sources such as storm water runoff, and atmospheric inputs. Several of these municipal point source sampling locations are presented in Figure 3-12 . Natural sources of these metals are unlikely to account for the observed distribution in the estuary. The highest concentrations are not located near the major freshwater inputs to the estuary, the Delaware and Schuylkill Rivers. Data on loadings of these metals from point sources indicate that these five metals also rank among the highest in terms of both inorganic and organic pollutants discharged to the estuary (See Table 3-2).