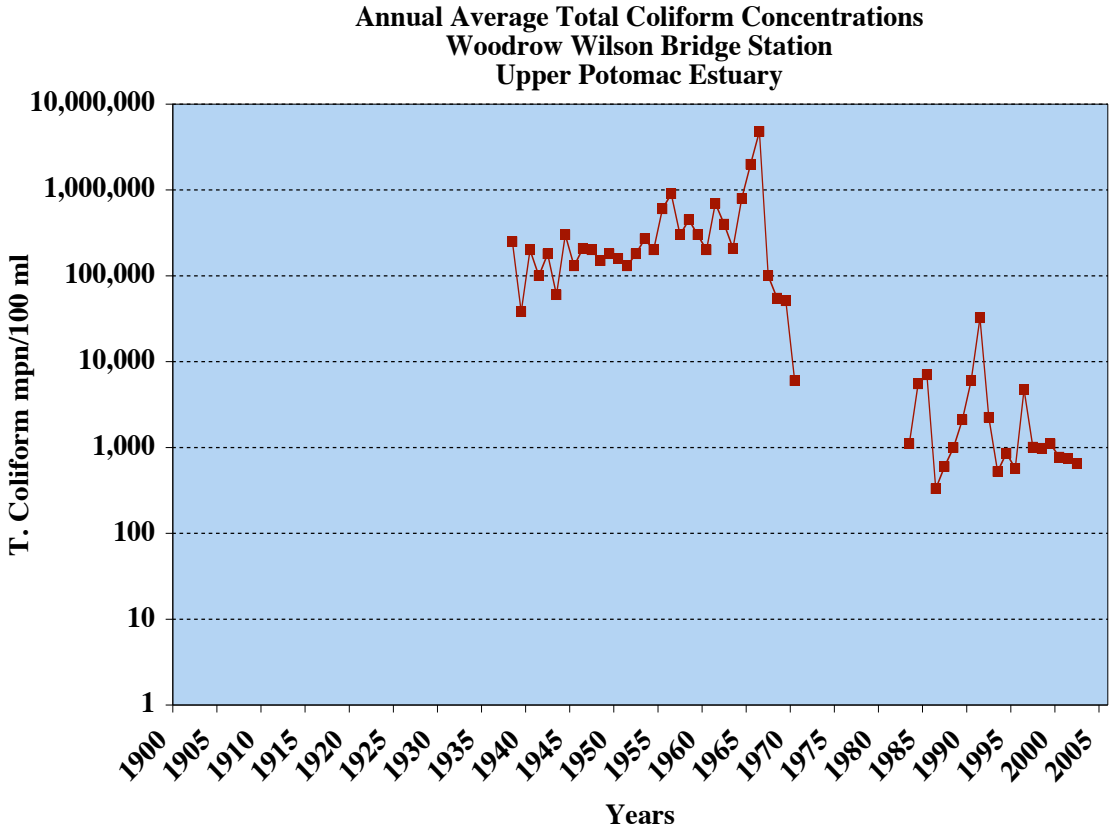
Bacterial and Dissolved Oxygen (DO) Concentrations in the Upper Estuary

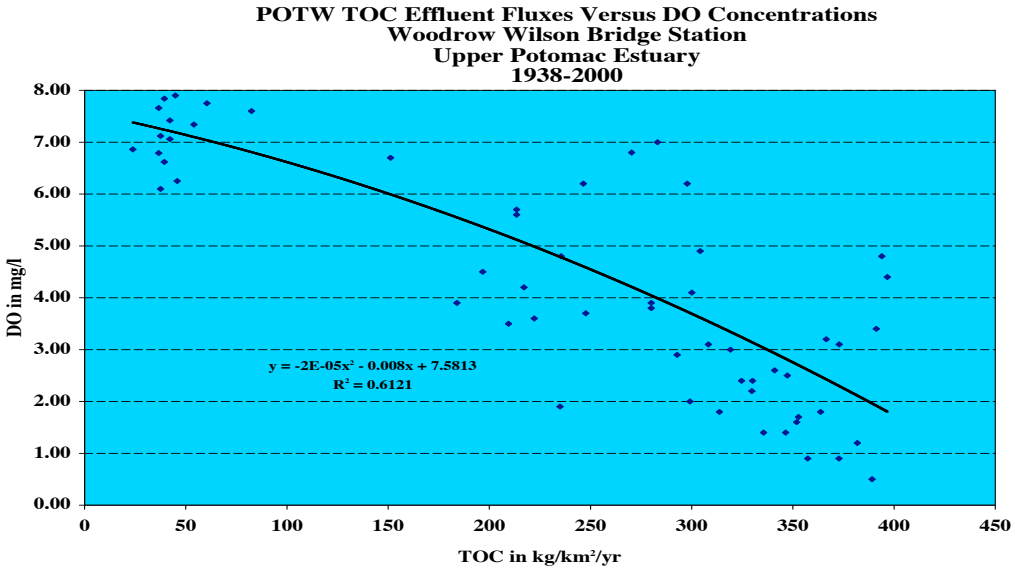
The Upper Estuary water quality, including DO and bacterial concentrations, has been monitored (usually on a monthly basis for about 10 stations) since the 1940s by the District of Colombia. For this analysis, we present the District of Columbia data for the Woodrow Wilson Bridge Station. This station is downstream from the Blue Plains Wastewater Treatment Plant outfall.

The annual average total coliform levels at the Woodrow Wilson Bridge Station in the 1940s and 1950s were about 60,000 to 200,000 mpn/100 ml (see below).

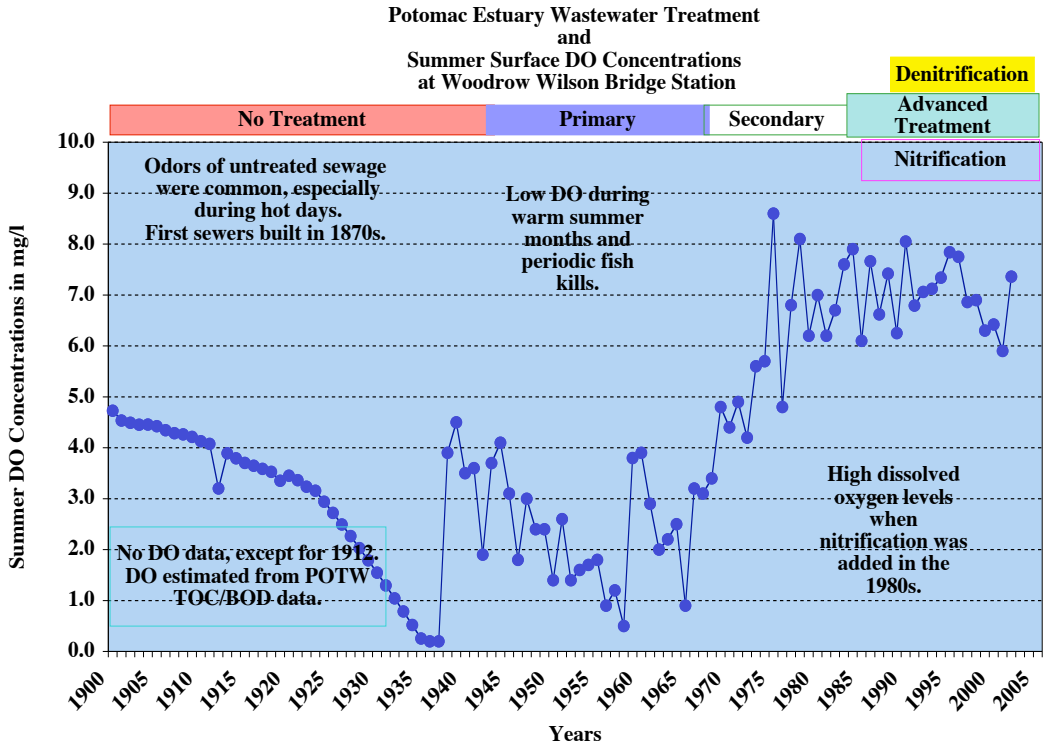


In the 1960s, the Woodrow Wilson Bridge Station total coliform levels increased to a maximum of 6,000,000 mpn/100 ml. As a result of improved wastewater treatment, including chlorination and the reduction of untreated wastewater bypassing, the total

coliform levels decreased to 1,000 to 10,000 mpn/100 ml in the 1970s, 1980s, and 1990s. In the early 2000s, the coliform levels were less than 1,000 mpn/100 ml.
Because monthly water quality monitoring did not begin until the early 1940s, we used a statistical relationship of TOC versus DO from the 1938-2000 period to estimate the summer DO at Woodrow Wilson Bridge Station for the period 1900 to 1938.



At the turn of the 20th century, the average summer surface DO at Woodrow Wilson Bridge was about 4 mg/l (see below).



As untreated wastewater volumes increased from 50 mgd in the 1900s to over 100 mgd in the 1930s, using the statistical relationship above, we estimated that DO decreased to less than 1 mg/l in the late 1930s.

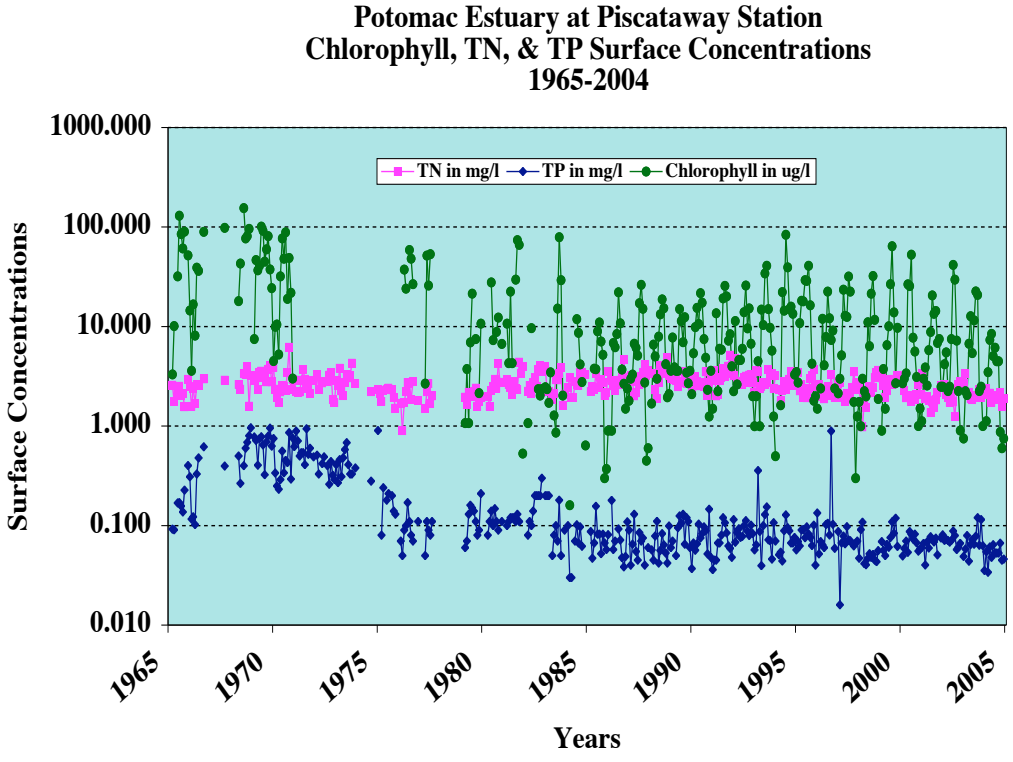
In the early 1940s, the surface DO concentrations during the summer months at the Woodrow Wilson Bridge Station increased to about 4.0 mg/l, due to the fact that the bulk of the wastewater effluents were receiving primary treatment. As the volume of wastewater increased during and after World War II, DO levels decreased to less than1.0 mg/l by the late 1950s.

In the early 1960s, most of the wastewater treatment facilities were providing secondary treatment and the DO at the Woodrow Wilson Bridge Station improved to about 4 mg/l. However, as the volume of wastewater increased during the 1960s, the DO at the Woodrow Wilson Bridge Station decreased again to about 1 mg/l.

As the wastewater facilities were further upgraded to advanced treatment beginning in the early 1970s, the DO at the Woodrow Wilson Bridge Station improved to about 5 mg/l (1). In the late 1970s, most of the wastewater facilities added nitrification units, resulting in a DO improvement of 6.0 to 8.0 mg/l in the 1980s and 1990s.

Upper Estuary at the Piscataway, Indian Head, and Maryland Point Stations

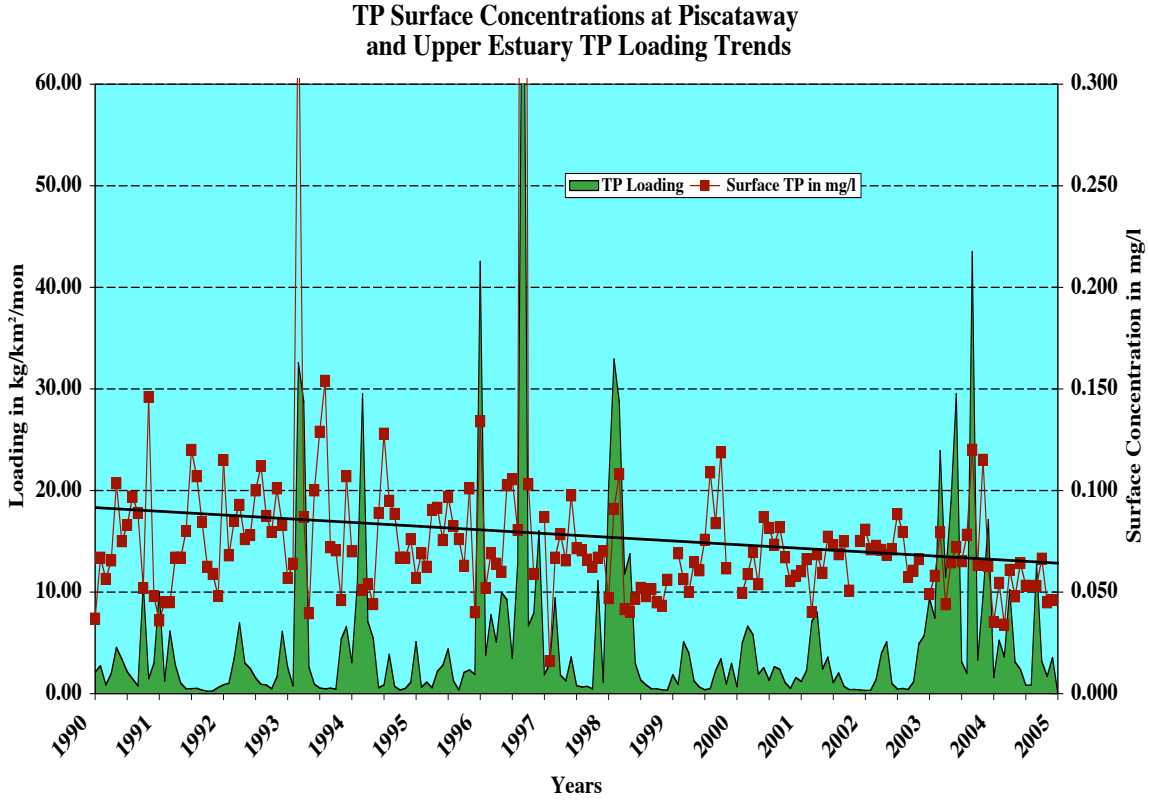
The concentrations of TP, TN, and chlorophyll at the Piscataway Station from 1965 through 2004 are presented below.



The TN concentrations at the Piscataway Station are impacted by the river flow from the Upper Basin. During wet years, such as early 1998, the POTW effluents were diluted more by the higher flows from the Upper Basin, resulting in lower nitrogen levels at the Piscataway Station.

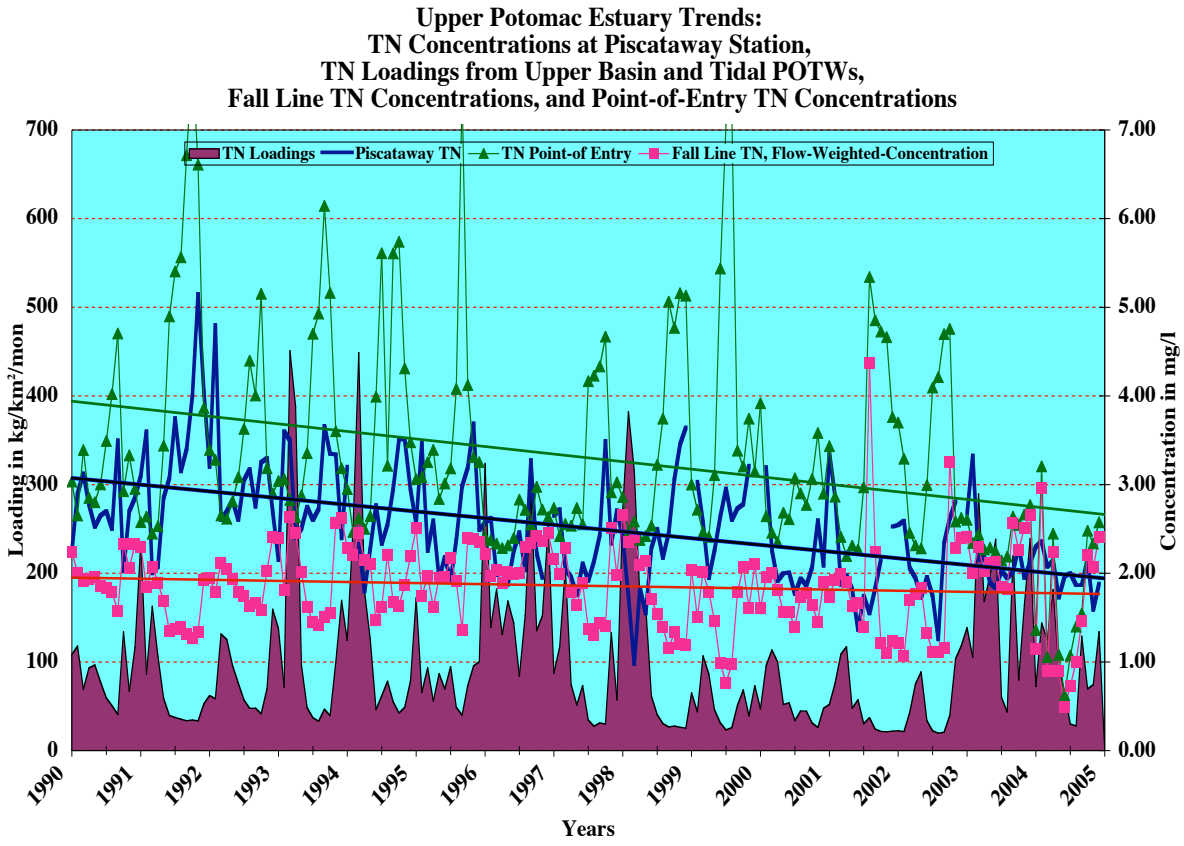
In the period from 1965 to 1975, the POTWs discharging into the Upper Estuary were providing secondary treatment. The TP concentrations during low summer river flows often were about 0.7 mg/l. During high river flows, the TP levels were diluted and dropped below 0.3 mg/l. Since 1975, after the implementation of phosphorus removal, the TP levels have usually been less than 0.1 mg/l. **As the phosphorus levels decreased, chlorophyll also decreased**.

TP concentrations and the sum of TP loadings from the Upper Basin and from direct POTW discharges for the period 1990 to 2004 are presented below.



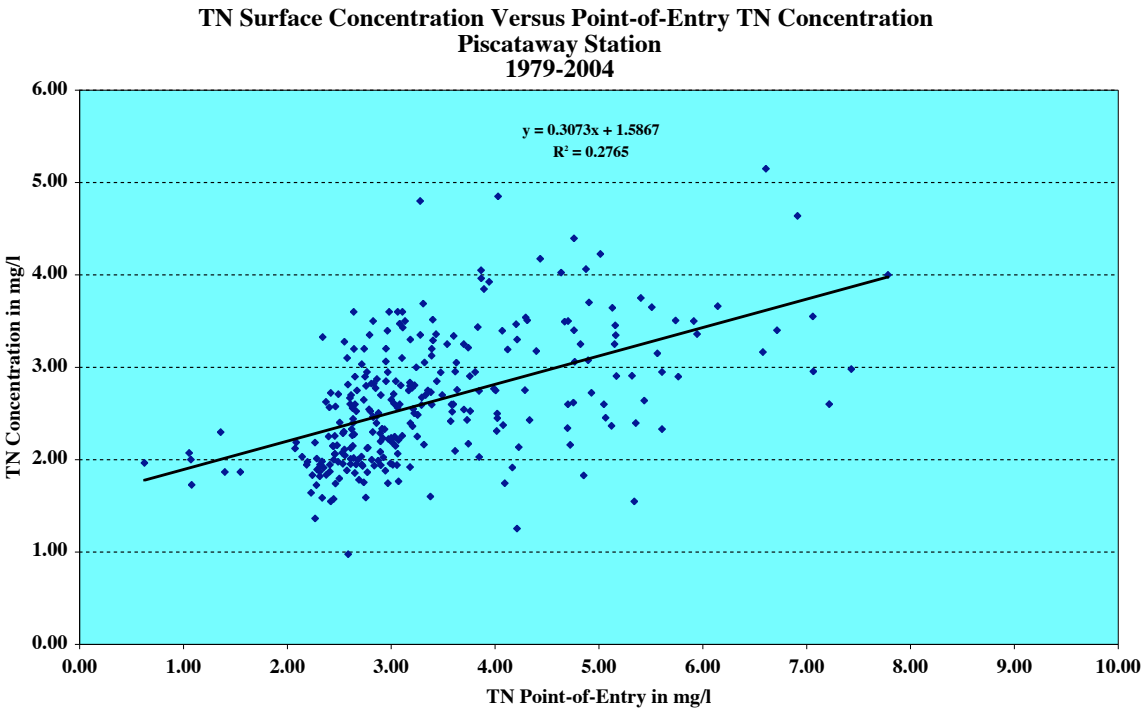
For the 15-year period from 1990 to 2004, the major increases in TP were from high-loading fluxes, such as in early 1993,1996, early1998, 2003, and 2004. The large TP increase in both concentration and load in 1996 was due to the impact of a hurricane.

The Piscataway TN surface concentrations, TN loadings from the Upper Basin and tidal POTW discharges, fall line TN concentrations, and point-of-entry concentrations for the period 1990 through 2004 are presented below.



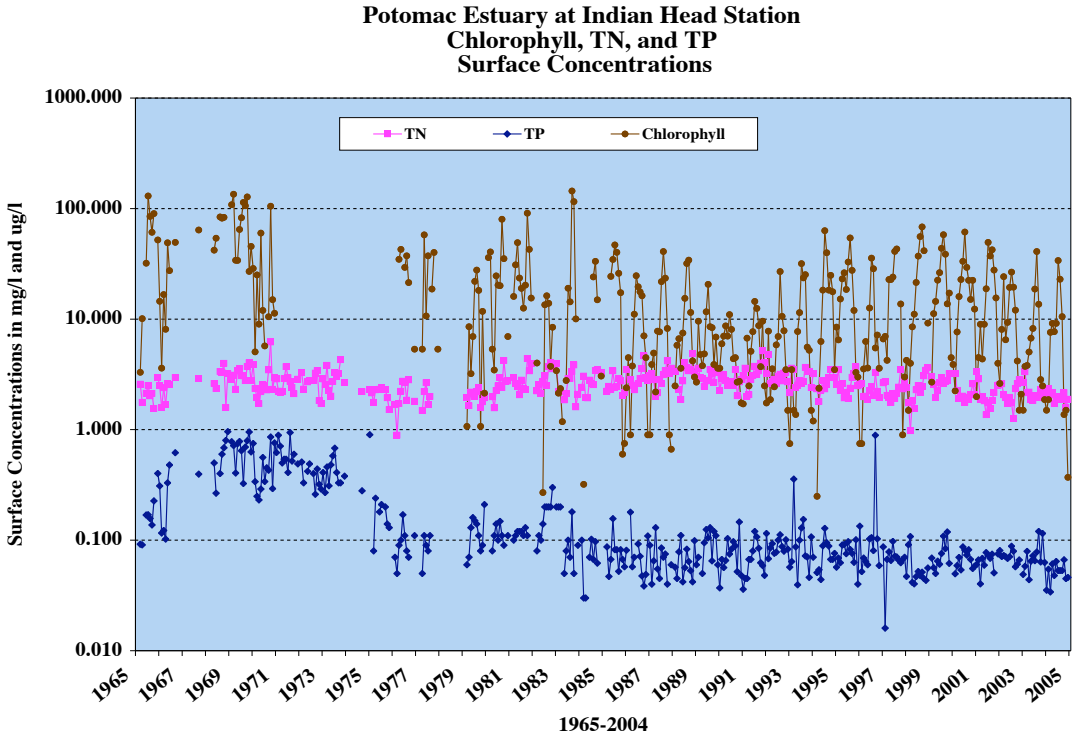
For the 15-year period from 1990 to 2005, the Piscataway Station TN surface concentrations decreased by about 1.0 mg/l, while the point-of-entry TN concentrations decreased by 1.3 mg/l. In 2003 and 2004, there were large pulses of TN from the Upper Basin. The annual average TN concentrations at the fall line of the Potomac River above the District of Columbia were unchanged, about 2.0 mg/l. The decreases in both TN surface and point-of-entry concentrations were due primarily to the addition of denitrification processes at the POTWs.

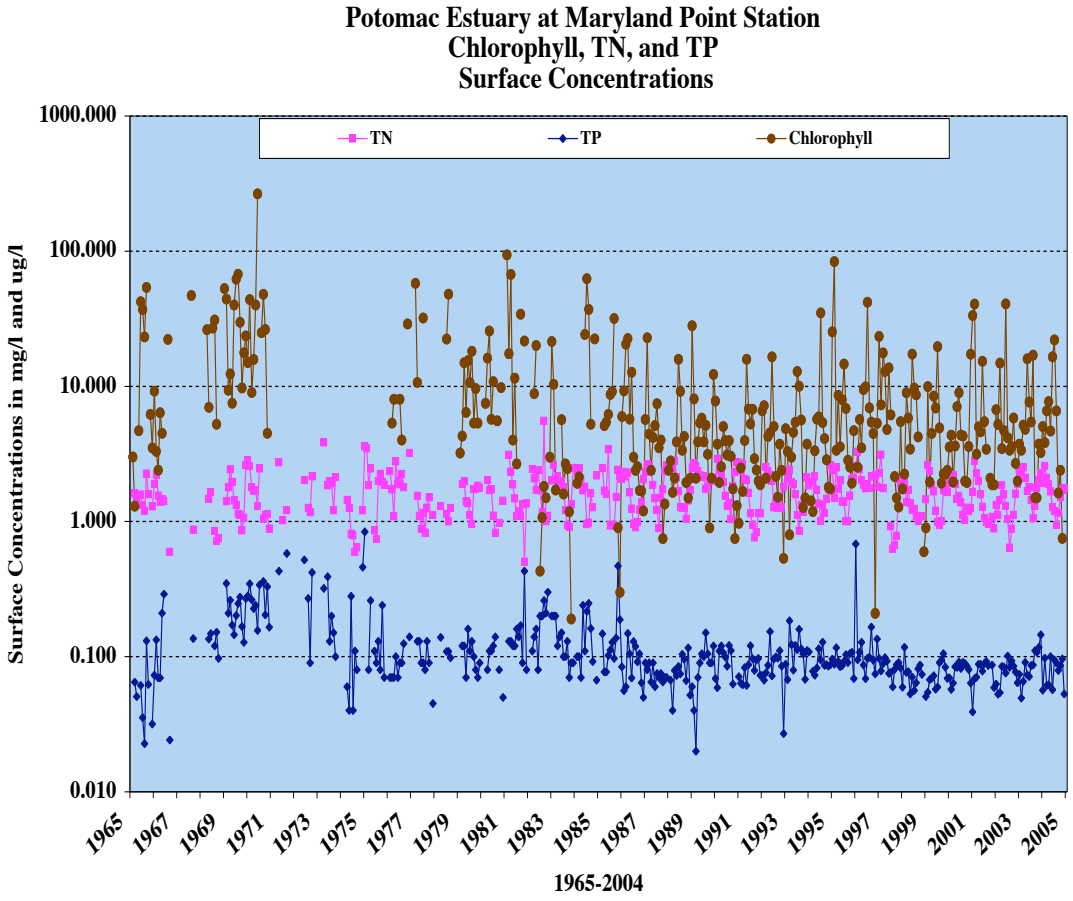
There appears to be a linear relationship, although not a strong correlation, between point-of-entry TN concentrations and observed TN levels at the Piscataway Station, as shown below.



With a slope of 0.3, the relationship above suggests that for a delta of 1.0 mg/l point-of-entry TN concentration, the observed TN surface concentration delta at the Piscataway Station would be 0.3 mg/l

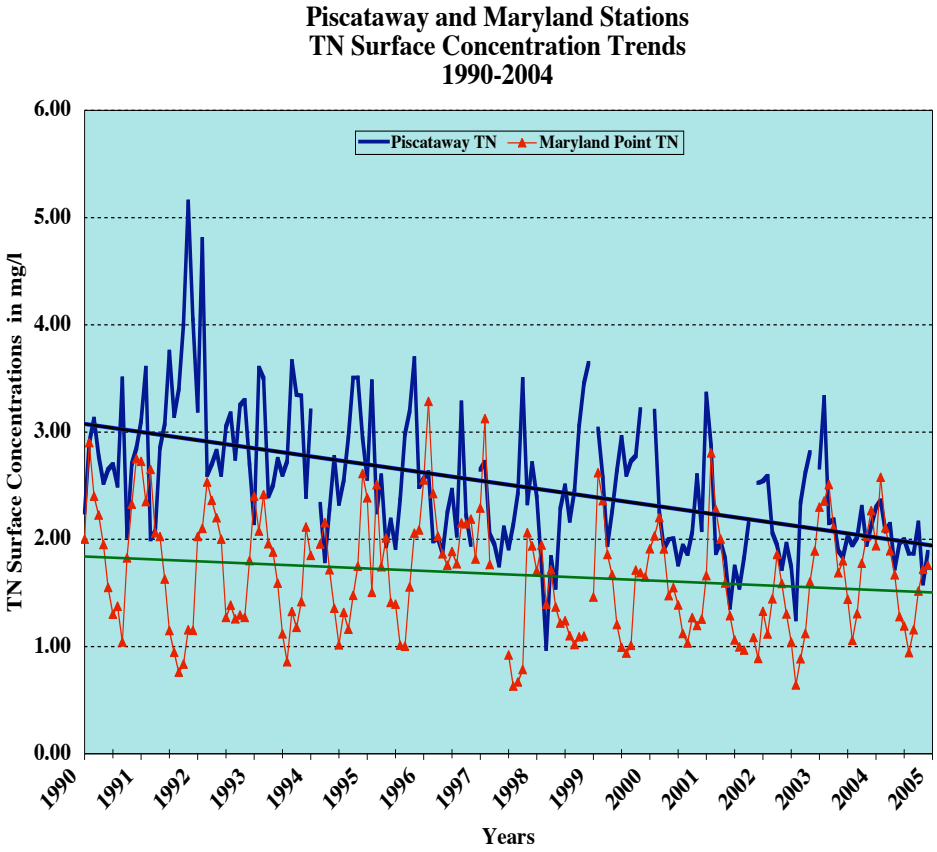
The concentrations of TP, TN, and chlorophyll at the Indian Head and Maryland Point stations from 1965 to 2004 are presented below.





Both at the Indian Head and Maryland Point stations, there were significant reductions in TP surface concentrations over the 1965-2004 time frame, while TN concentrations were unchanged (see above). There were significant reductions in chlorophyll surface concentrations at both Indian Head and Maryland Point stations, as presented in the charts above.

While there was no significant reduction in TN surface concentrations at the two stations over the 1965-2004 period, there was some reduction of TN levels for the 1990-2004 period for Maryland Point Station (about 0.2 mg/l), as shown below. However, the reduction was not as large as for the Piscataway Station, which was 1.0 mg/l. These reductions were due primarily to the addition of the denitrification process at the POTWs, as described in Chapter Five and earlier in this chapter.



Nutrient Concentration and Impact of Nutrient Enrichment Trend Analysis

For the nutrient trend analysis, we present spring and summer data for eight five-year periods from 1965 through 2004 for the six current water quality monitoring stations along the length of the entire Estuary, as well as the Fall Line monitoring station. In the nutrient trend analysis, we focused on TN, Dissolved Inorganic Nitrogen (DIN), and TP. For the impact of nutrient enrichment trend analysis, we focused on spring and summer data for the bottom and surface DO, light penetration as measured by secchi disk, and surface chlorophyll for the six stations along the length of the Estuary.

Total Phosphorus

Of the eight five-year periods beginning in 1965, the TP surface spring and summer concentrations for the six stations decreased for the first 10 years (1965-1974), the years 1985 through1999, and the last five years (2000 through 2004), as presented below. Data for the 1980 through 1984 five-year period were not used because the start-up of the nitrification unit at Blue Plains caused major pH and alkalinity problems resulting in phosphorus being released from the sediments (2). For the percent change in concentrations, we used the 1965-1974 period and the recent period, 2000 through 2004. We defined the three spring months as March, April, and May and the summer months as June, July, and August.

Spring TP in mg/l at the Surface

Station	1965-79	1985-99	2000-04	% Change 1965-2004
Piscataway	0.245	0.077	0.120	-68.7
Indian Head	0.191	0.079	0.060	-58.8
MD Point	0.165	0.093	0.080	-43.6
301 Bridge	0.106	0.072	0.060	-32.0
Ragged Point	0.085	0.049	0.040	-42.8
Point Lookout	0.056	0.020	0.020	-63.4

Summer TP in mg/l at the Surface

Station	1965-79	1985-99	2000-04	% Change 1965-2004
Piscataway	0.432	0.090	0.074	-79.3
Indian Head	0.269	0.096	0.073	-64.5
MD Point	0.169	0.095	0.084	-43.5
301 Bridge	0.116	0.097	0.060	-16.7
Ragged Point	0.088	0.068	0.038	-22.7
Point Lookout	0.053	0.035	0.034	-32.9

These reductions were the result of phosphorus removal at the POTWs discharging directly into the tidal waters and the implementation of the phosphate detergent bans, as presented above. The total input of TP from the Upper Basin and POTWs discharging into tidal waters is summarized below.

Years	Inputs of TP kg/km^2/yr	Point-of-Entry mg/l
1965-69	158.4	0.606
1970-74	132.1	0.302
1975-79	104.0	0.240
1980-84	91.6	0.235
1985-89	62.8	0.277
1990-94	47.0	0.171
1995-99	86.3	0.170
2000-04	61.6	0.150

There was a 22% decrease of TP at the Fall Line during the summer months and a 26% decrease during the spring months. When the TP data for the 2000-2004 period is compared to the 1984-1999 period, there was a downward trend, especially during the summer season, reflecting the lower inputs.

A comparison of surface TP concentrations in mg/l between the summer and spring months of 1985 to 1999 (see chart on previous page) is presented below.

Station	Spring	Summer	% Change
Fall Line	0.105	0.101	-03.8
Piscataway	0.077	0.090	+25.9
Indian Head	0.079	0.096	+21.5
MD Point	0.093	0.095	+02.1
301 Bridge	0.072	0.097	+34.7
Ragged Point	0.049	0.068	+38.7
Point Lookout	0.020	0.035	+75.0

While there was a small decrease in TP at the Fall Line, there was a slight increase in TP concentration for the upper three stations. For the lower three stations, the summer levels of TP were much higher than the spring concentrations. This suggests that during low DO levels in the bottom waters, TP was being released from the sediments.

Total Nitrogen

There were no large significant changes in spring total nitrogen concentrations for the six stations, as shown below.

Spring TN in mg/l at the Surface

Station	1965-79	1985-99	2000-04	% Change 1965-2004
Piscataway	2.443	2.261	1.99	-18.55
Indian Head	2.104	2.198	2.00	-4.95
MD Point	1.876	2.033	1.85	-1.37
301 Bridge	1.545	1.714	1.60	3.57
Ragged Point	1.101	1.217	1.29	17.17
Point Lookout	0.654	0.939	0.79	20.85

There was about a 21% increase in TN at the Point Lookout Station and an 18% decrease at the Piscataway Station, as presented above. As can be seen below, there were also no large significant changes in summer surface TN concentrations.

Summer TN in mg/l at the Surface

Station	1965-79	1985-99	2000-04	% Change 1965-2004
Piscataway	2.802	2.589	1.970	-29.69
Indian Head	2.226	2.035	1.860	-16.43
MD Point	1.369	1.273	1.347	-1.58
301 Bridge	0.873	0.984	1.099	25.91
Ragged Point	0.662	0.794	0.758	14.49
Point Lookout	0.719	0.660	0.631	-12.29

During the summer months, the TN concentrations at the Piscataway Station decreased about 29% while the Indian Head Station decreased about 16%. This decrease was mainly due to the reduction of nitrogen coming from the POTWs. During the summer months, the decrease in TN at the Piscataway Station was about 0.9 mg/l.

When one discounts the low river flows during 1965 through 1969 and late 1998 through 2002 (Chapter Five), the TN input loadings or the TN point-of-entry concentrations have not significantly changed over the past 40 years (see below). TN inputs and point-of-entry concentrations are summarized below.

Years	Inputs of TN kg/km^2/year	Point-of-Entry mg/l
1965-69	723.25	3.07
1970-74	1143.97	2.66
1975-79	1126.59	2.83
1980-84	1315.95	3.25
1985-89	1187.96	3.82
1990-94	1331.39	3.52
1995-99	1357.30	3.57
2000-04	900.00	2.80

When the TN data for the 2000-2004 period are compared to the1985-1999 period, as presented earlier in this section, large downward trends were observed at the Piscataway and Indian Head stations.

Dissolved Inorganic Nitrogen (DIN)

Similar to TN concentrations for the six stations, the DIN surface concentrations have some modest increases and decreases for the spring season, as shown below.

Spring DIN in mg/l

Station	1965-79	1985-99	2000-04	% Change 1965-2004
Piscataway	1.76	1.61	1.52	-14.03
Indian Head	1.32	1.53	1.47	11.11
MD Point	1.24	1.34	1.28	2.73
301 Bridge	0.71	0.97	0.82	14.37
Ragged Point	0.30	0.53	0.41	34.87
Point Lookout	0.34	0.39	0.29	-15.70

For the summer season, there were increases in DIN at all stations except the Piscataway Station. At the Maryland Point and 301 Bridge stations, the increases were especially large (see below). For the Piscataway Station, the average DIN concentrations for the 40-year period for both the spring and summer months were the same at about1.6 mg/l.

Summer DIN in mg/l

Station	1965-79	1985-99	2000-04	% Change 1965-2004
Piscataway	1.657	1.659	1.460	-11.89
Indian Head	1.141	0.956	1.161	1.75
MD Point	0.553	0.663	0.745	34.72
301 Bridge	0.254	0.405	0.441	73.62
Ragged Point	0.112	0.072	0.117	4.46
Point Lookout	0.065	0.071	0.070	7.69

There were significant lower summer DIN concentrations than spring levels for the five lower estuarine stations for the 1985-1999 period, as shown below.

Station	Spring	Summer	% Change
Fall Line	1.413	1.060	-25.0
Piscataway	1.618	1.659	+02.5
Indian Head	1.535	0.956	-37.7
MD Point	1.344	0.663	-50.6
301 Bridge	0.970	0.405	-58.2
Ragged Point	0.533	0.072	-86.5
Point Lookout	0.395	0.071	-82.0

During the summer months, the plankton in the lower portion of the Estuary consumed most of the surface DIN from the spring inputs. When the spring DIN data for the 2000-2004 period are compared to the 1985-1999 period, there were downward trends for all stations. For the summer season, there were no large differences in the 1985-1999 and 2000-2004 time frames.

Chlorophyll

Surface chlorophyll concentrations for the upper three stations significantly decreased during the spring season. However, there was a major increase in chlorophyll levels at the Ragged Point Station, as shown below.

Spring Chlorophyll in ug/l

Station	1965-79	1985-99	2000-04	% Change 1965-2004
Piscataway	19.259	7.027	6.26	-67.50
Indian Head	30.178	8.036	9.92	-67.13
MD Point	16.594	7.693	7.46	-55.04
301 Bridge	20.773	11.853	20.25	-2.52
Ragged Point	17.003	16.025	33.56	97.38
Point Lookout	10.356	14.425	11.42	10.27

There were major spring algal blooms in the Potomac Estuary at the 301 Bridge and Ragged Point stations during the 2000-2004 period and in 2006 (2). There were no major trends in the upper three stations, for the 1985-1999 and 2000-2004 periods (see above).

In the spring of 2000, there were chlorophyll concentrations of over 200 ug/l at Ragged Point. There were major decreases in surface chlorophyll concentrations in the summer season for all stations for the 40-year period, as presented below.

Summer Chlorophyll in ug/l

Station	1965-79	1985-99	2000-04	% Change 1965-2004
Piscataway	59.56	20.58	14.59	-75.50
Indian Head	34.83	27.11	26.04	-25.25
MD Point	65.62	9.067	10.76	-83.60
301 Bridge	44.36	13.00	10.69	-75.90
Ragged Point	16.62	14.71	13.09	-21.28
Point Lookout	12.53	10.83	10.98	-12.42

Summer chlorophyll levels for the 2000-2004 period were very similar to the 1985-1999 period, as presented above. It appears that the reduction of chlorophyll in the Upper Estuary parallels the reduction in phosphorus in the Upper Estuary, as presented earlier in this chapter.

Light Penetration (Secchi Disk) in Inches

The spring light penetration analysis indicates that there were no major changes in light penetration from 1985 through 2004, as presented below.

Spring Light Penetration in Inches

Station	1965-79	1985-99	2000-04	% Change 1965-2004
Piscataway	19.03	24.00	25.2	32.43
Indian Head	20.43	22.36	21.4	4.76
MD Point	17.52	16.72	16.4	-6.37
301 Bridge	31.05	22.48	20.11	-35.24
Ragged Point	54.60	44.14	50.79	-6.98
Point Lookout	110.67	72.57	61.42	-44.50

There was some improvement in light penetration at the upper two stations, especially at the Piscataway Station, as presented above. There was a general reduction in light penetration in the Lower Estuary.

Summer Light Penetration (Secchi Disk) in Inches

Station	1965-79	1985-99	2000-04	% Change 1965-2004
Piscataway	17.31	25.02	25.10	44.98
Indian Head	23.94	24.14	21.60	-9.78
MD Point	23.96	26.03	21.50	-10.26
301 Bridge	29.14	31.88	29.65	1.75
Ragged Point	58.00	48.95	52.23	-9.95
Point Lookout	76.50	65.78	54.92	-28.21

There were also improvements in the summer months at the Piscataway Station (see above) that can be attributed to a dramatic decrease in suspended matter in the effluents of the POTWs as a result of advanced wastewater treatment. There were no large changes in light penetration for the Indian Head and Maryland Point stations. For the two lower stations, there was a reduction in light penetration for both summer and spring conditions. The spring and summer light penetration for the 1985-1999 time frame was very similar to the 2000-2004 time frame.

Bottom Dissolved Oxygen

For the same time frame as for chlorophyll and light penetration, the bottom DO analysis is presented below.

Spring Bottom DO in mg/l

Station	1965-79	1985-99	2000-04	mg/l of Change 1965-2004
Piscataway	7.90	9.90	9.91	2.01
Indian Head	8.28	9.90	9.27	0.99
MD Point	8.20	9.06	7.15	-1.05
301 Bridge	7.89	7.36	6.68	-1.21
Ragged Point	7.08	7.16	6.39	-0.69
Point Lookout	9.19	7.76	7.15	-2.04

While there was about a 2 mg/l **increase** in spring bottom DO at the Piscataway Station, there was about a 2 mg/l **decrease** at the Point Lookout Station (see above).

The bottom water DO concentrations for the upper three stations had a significant improvement for both the 1985 through 1999 and 2000 through 2004 summer conditions, as presented below.

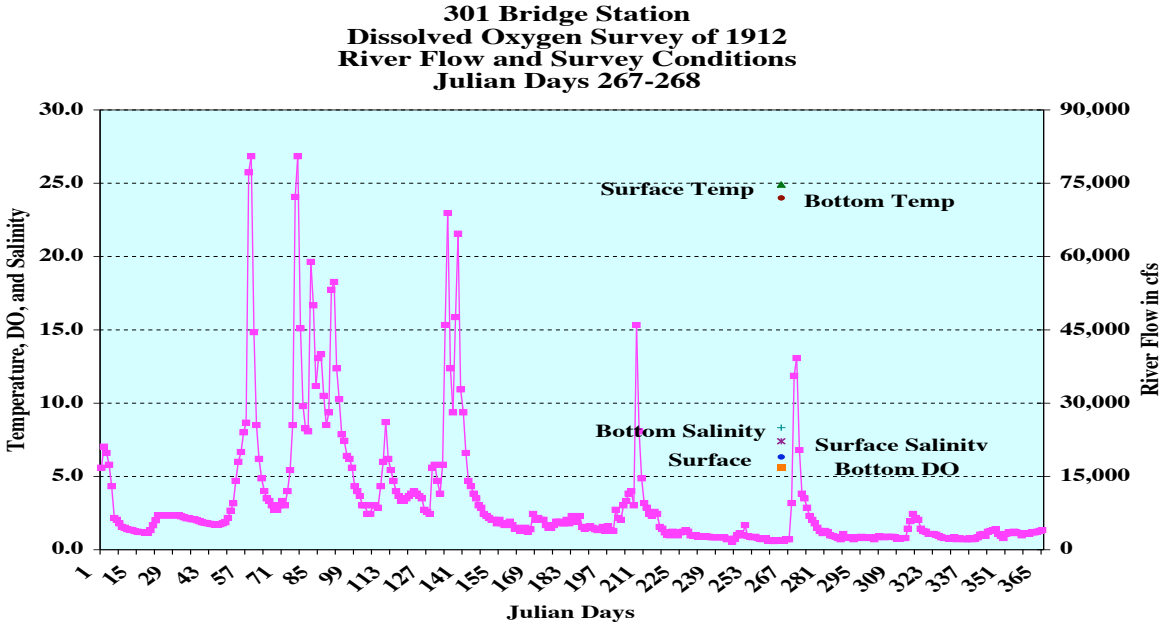
Summer Bottom DO in mg/l

				mg/l of Change
Station	**1965-79**	**1985-99**	**2000-04**	**1965-2004**
Piscataway	4.30	6.41	6.41	2.11
Indian Head	4.93	6.77	6.82	1.89
MD Point	5.08	5.67	5.78	0.70
301 Bridge	3.97	2.93	3.29	-0.68
Ragged Point	0.64	0.94	1.14	0.50
Point Lookout	1.45	1.15	1.47	0.02

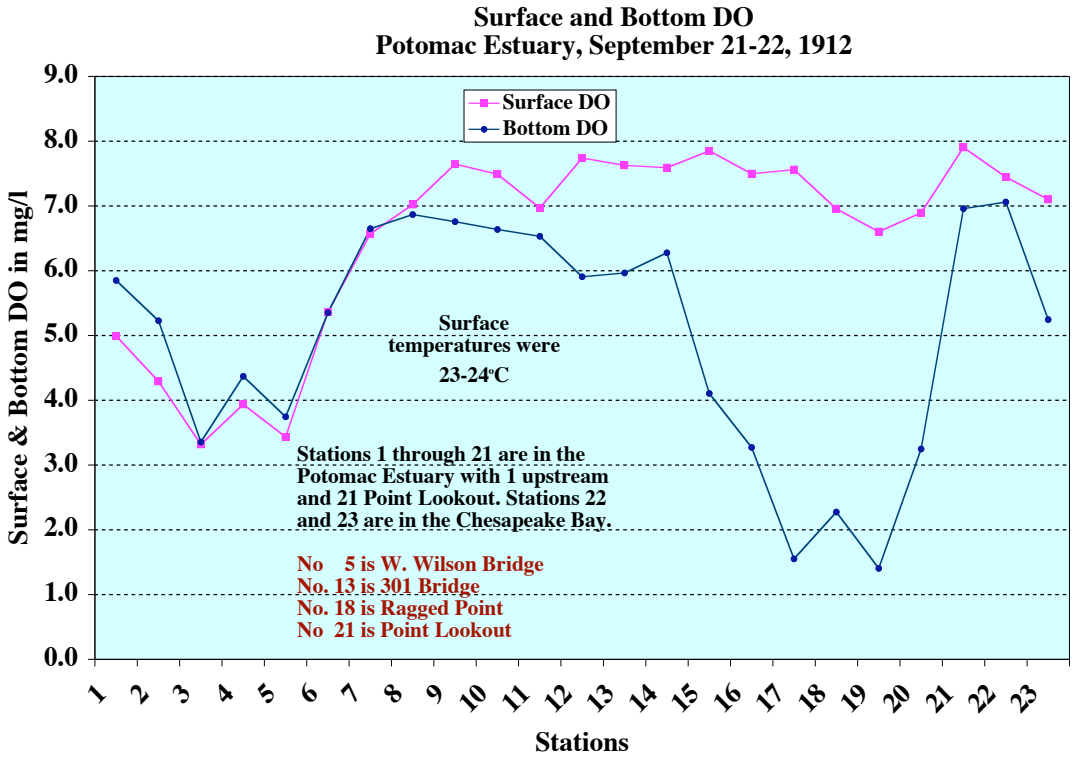
Before secondary wastewater was initiated in 1965, the bottom DO at Piscataway was often less than 2.0 mg/l. **The summer bottom DO levels for the lower three stations suggests that the bottom DO conditions have not improved over the past 40 years.**

The 1912-13 Dissolved Oxygen Surveys of the Potomac Estuary

There were six water quality surveys of the Potomac Estuary during 1912 and 1913 (3). The most useful survey was the cruise on September 21-22, 1912 (Julian Date 267-268), as presented below.



Although the survey was in the later part of September, there were 40 days of low stream flows prior to the survey. The data for all 21 stations along the Potomac Estuary are presented below. Station 1 was the farthest upstream, near the current Chain Bridge. Station 5 was near Woodrow Wilson Bridge. Stations 22 and 23 were in the Chesapeake Bay.



There were two areas of low DO bottom waters—in Washington, DC and in the Ragged Point area (see above). The Biological Oxygen Demand (BOD) of the untreated wastewater discharged into the Upper Estuary caused the depletion of DO in the Washington, DC area, which is a well-mixed, tidal freshwater ecosystem. The organic matter produced in the Lower Estuary by the spring phytoplankton blooms sinks into deep, stratified bottom water. The organic matter then decomposes in the oxygen-consuming process causing the depletion of bottom-water oxygen in the Lower Estuary below the current Ragged Point Station.

In the 1910s, there were fish and shellfish mortalities reported in the Lower Estuary near the Chesapeake Bay (3). Fish kills are still occurring. As recently as June 2006, a large fish kill occurred in the Lower Potomac Estuary (4).

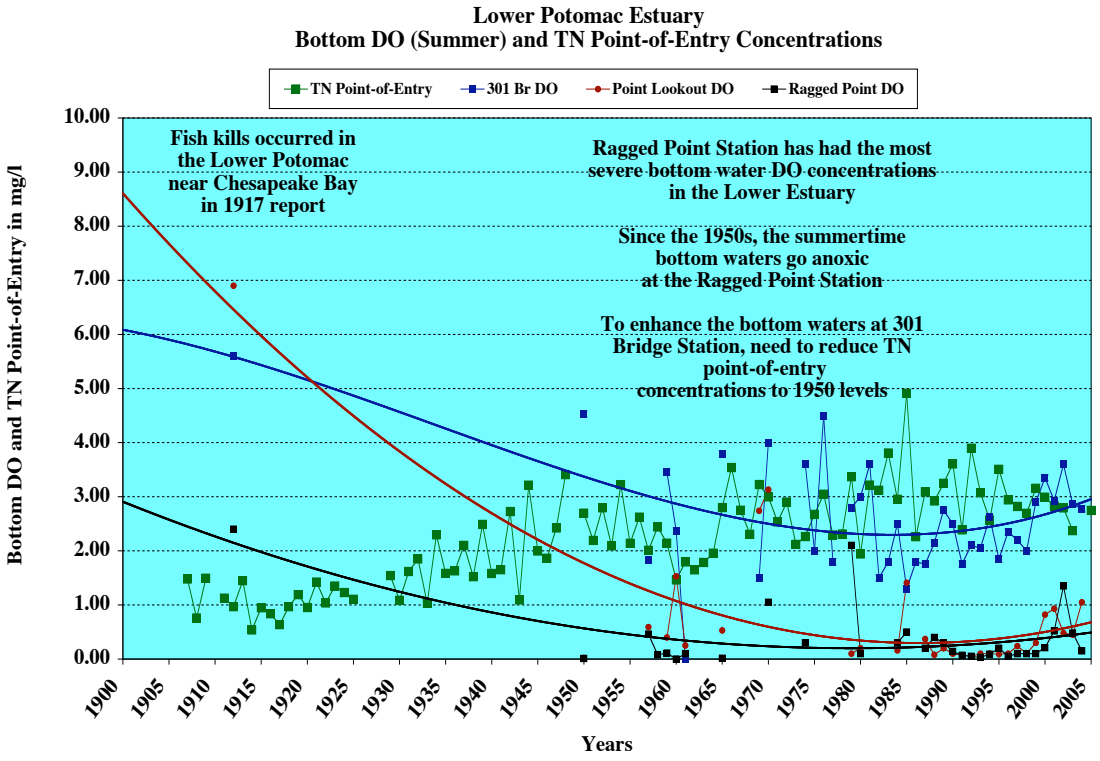
What is surprising is that the one station near the Chesapeake Bay (No. 21) and the two in the Chesapeake Bay (No. 22 and 23) had bottom DOs of over 5.0 mg/l. This suggests that the current low DOs of the bottom waters of the Lower Estuary may be caused mainly by nutrient inputs to the Upper Potomac Estuary and, to a lesser extent, by inputs from the Chesapeake Bay.

Point-of-Entry TN and TP Concentrations and Bottom DO Relationships for the Lower Estuary

One of the key water quality management questions is*: Is there any relationship between point-of-entry TN and TP concentrations and low bottom water DO during the summer months at 301 Bridge, Ragged Point, and Point Lookout stations?*

As presented earlier in this chapter, the TP point-of-entry concentrations have been dramatically reduced from 0.606 mg/l in the 1960s to 0.150 mg/l (a 75% reduction) by the early 2000s. The surface TP concentrations were reduced from 30% to 60% at all stations. There was also a reduction in spring chlorophyll levels at all stations**. However, there was no major increase in bottom water DO concentrations in the Lower Estuary as a result of the 75% decrease in TP point-of-entry concentrations.**

We examined the TN point-of-entry concentrations and bottom water DO concentrations for the three lower estuary stations, as presented below.



During the past 50 years, the TN point-of-entry level has increased from a concentration of 2.0 mg/l to a concentration of 3.0 mg/l (a 50% increase). During the same time, summer bottom water DO at the 301 Bridge Station has decreased from a concentration of 4.0 mg/l to a concentration of 2.0 mg/l.

There was a decrease in the TN point-of-entry concentration in the early 2000s during low-flow conditions. There was also an increase in bottom water DO at all stations during the low-flow conditions of late1998 to 2002.

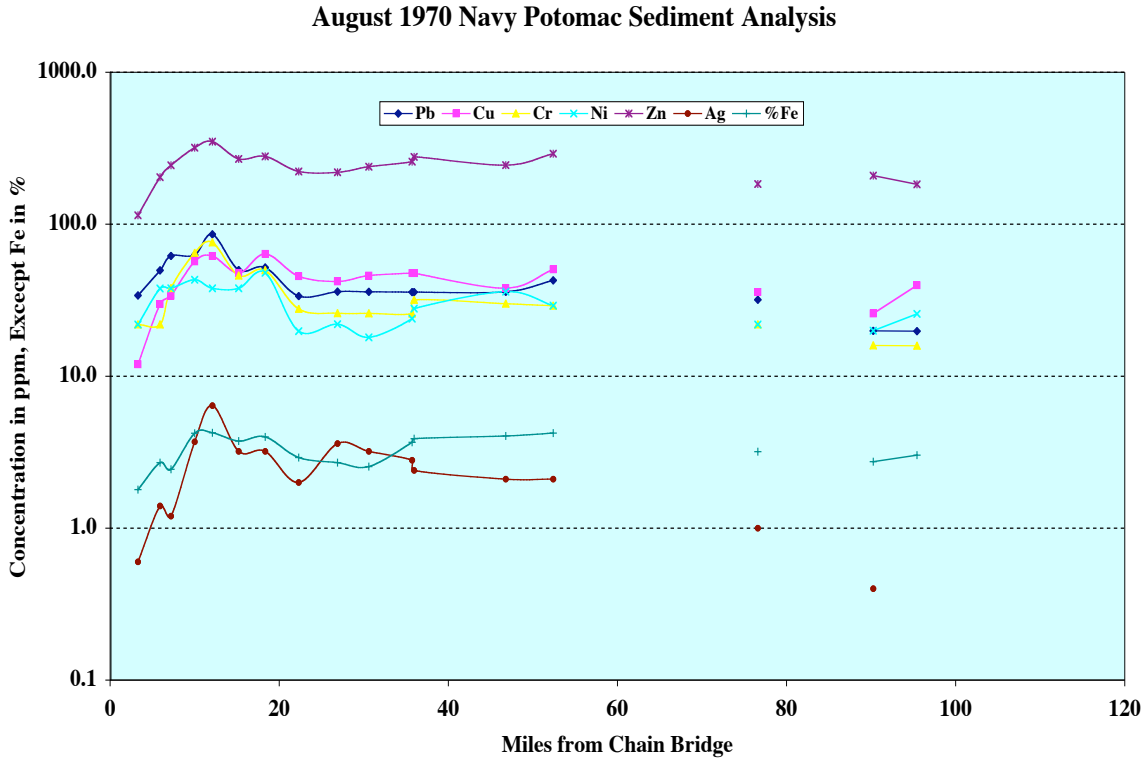
The increase in bottom water DO was the highest in the fourth year of the four-year drought. This suggests that nitrogen reduction to the point-of-entry levels in the 1950s and early 1960s should improve the bottom water DO levels from a concentration of 2.0 mg/l to a concentration of 3-4 mg/l at the 301 Bridge Station.

For most of the summer months sampled at the Ragged Point Station during the past, the bottom water DO levels were about 1 mg/l or less**. This suggests that nitrogen reduction to the point-of-entry levels in the 1950s and early 1960s may not improve the summer bottom DO levels at the Ragged Point Station.**

However, the 1912 data suggest that the bottom waters of Point Lookout **may improve** significantly when the Chesapeake Bay improves.

Sediment Quality

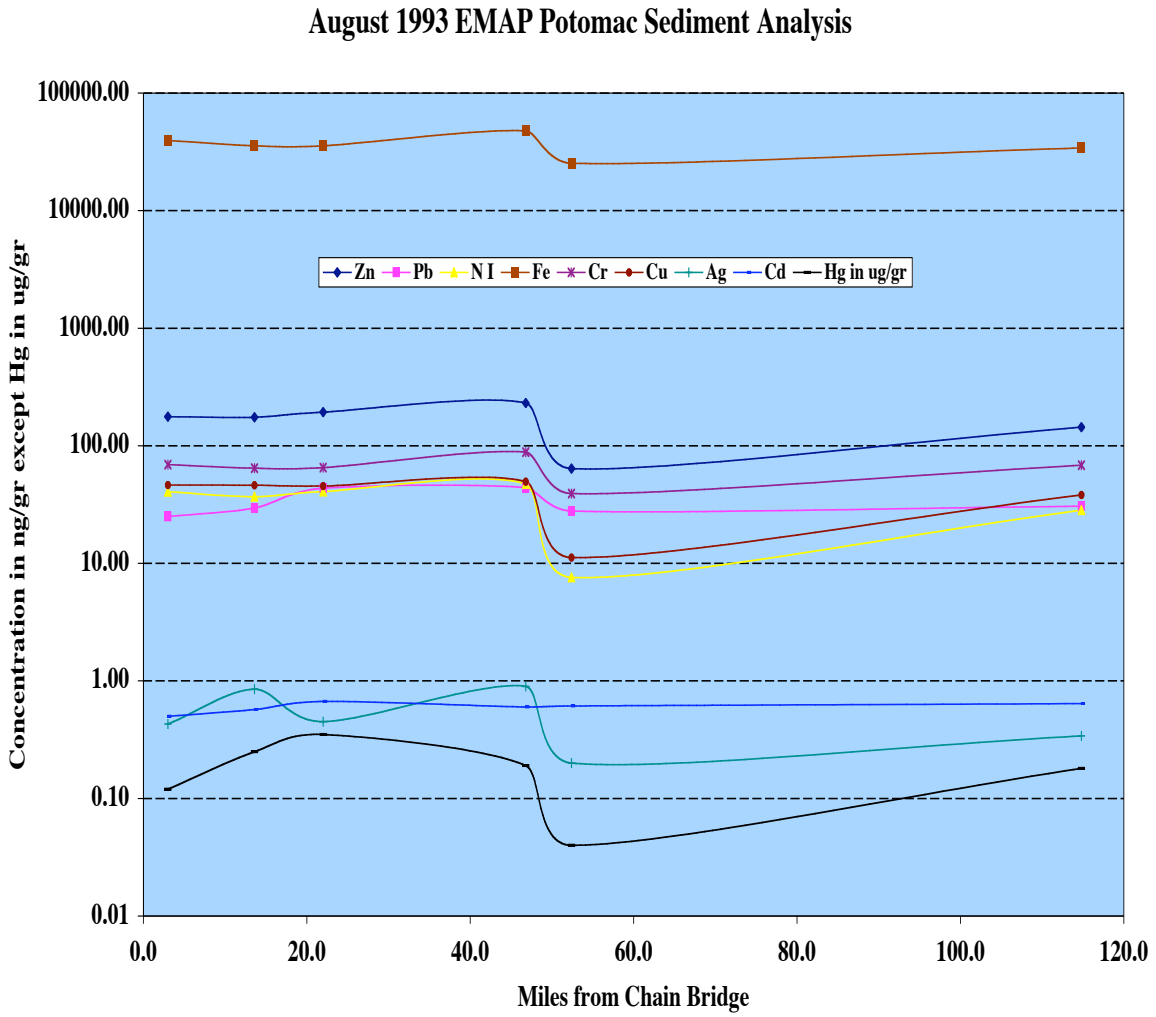
The first comprehensive sediment quality survey for metals in the Potomac Estuary was done in 1970 by the Navy (5), as presented below.



All of the metals increased in concentration in the Upper Estuary near the POTW and storm sewer outfalls. The metal concentrations then decreased downstream for sampling stations toward the Chesapeake Bay.

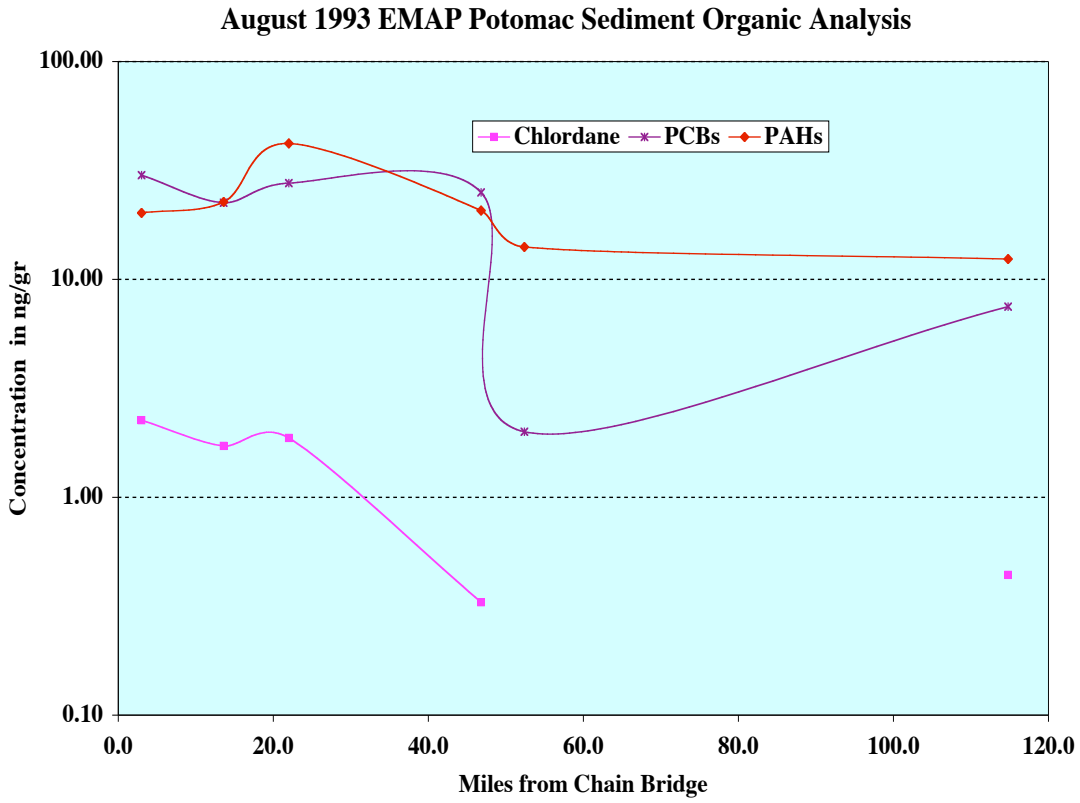
In 1991, a sediment quality survey was made of the Upper Potomac Estuary near the District of Columbia, Anacostia River, Tidal Basin, and Shipping Channel (6). In a comparison to other urban estuarine surveys, the metals were lower in the Potomac Estuary near the District of Columbia than in Baltimore Harbor or in the Schuylkill River portion of Delaware Bay (7).

In 1993, the US EPA Environmental Monitoring and Assessment Program (EMAP) (8) conducted an August survey of six randomly sampled stations, as presented below.



Except for Ag, which was much lower in the 1993 survey, the Navy and EMAP data show similar concentrations.

The chemical analysis of the August 1993 EMAP survey indicates elevated levels of organic chemicals near the District of Columbia (see below).



For the 1991 District of Columbia area survey, the Upper Potomac Estuary had high to moderately high levels of PCBs, PAHs, DDT, and chlordane when compared to other urban estuarine sediments (9).

Maryland Department of Natural Resources Trend Analyses: 1985-2005 Time Frame

The Maryland Department of Natural Resources performs trend analyses on water quality data that are collected on a monthly or bimonthly basis from monitoring stations along the main stem of the Potomac River. The most recent trends available are for the 1985-2005 time frame.

Trends are analyzed using the seasonal Kendall test, which is a non-parametric trend assessment technique (10). The percent change in the value over the trend assessment period is based on Sen's estimate of slope (11).

Total nitrogen concentrations dramatically decreased between 1985 and 2005 at and above the 301 Bridge Station in Morgantown, Maryland. Changes ranged from –43% at Piscataway to –17% at the 301 Bridge Station. No significant trends were detected in total nitrogen at either Ragged Point or Point Lookout stations.

No trends were detected in total phosphorus in the 1985-2005 time frame. This result is not surprising, because dramatic decreases in phosphorus occurred following upgrades in sewage treatment at Blue Plains in the mid-1970s, which is outside of the current trend assessment time frame.

Only one significant trend was detected in chlorophyll: a 45% increase at the Route 301 Bridge Station. The lack of decreasing trends in chlorophyll may be an indication that the waters of the tidal Potomac River are still nutrient rich and that phytoplankton growth is limited only by light availability.

Trends in dissolved oxygen are reported for the bottom layer during the summer season (June through September). Because low dissolved oxygen events do not occur in the surface layer or during the winter months in either the surface or bottom layers, none were reported. Unfortunately, no trends in summer bottom-layer dissolved oxygen were detected.

Decreasing trends, which indicate degrading water quality, were detected in secchi depth readings at the Maryland Point Station (-21%), 301 Bridge Station (-22%), and Point Lookout Station (-26%). Degrading secchi depth readings at the Maryland Point Station, which is in the turbidity maximum zone, and at Point Lookout Station are attributable to the resuspension and deposition of sediment, as there have not been significant changes in phytoplankton biomass. Decreased water clarity at the 301 Bridge Station appears to be, in part, a result of increased phytoplankton biomass based on the increasing trends that were detected in chlorophyll.

These results are alarming because they indicate continued degradation of water quality in the lower Potomac River despite efforts to make improvements through the implementation of best management practices. It appears that the only improvements in water quality in the 1985-2005 trend period were to total nitrogen in the Upper Estuary. These improving total nitrogen trends are likely attributable to improvements in wastewater treatment, but they may be fleeting as the population in Washington, DC and the surrounding area continues to soar.

It appears that much more effort is needed in reducing nonpoint sources of nutrients and sediments before improvements to water quality in the lower Potomac River will be observed.

References for Chapter Six

1. Jaworski, N.A, (1990), Retrospective Study of the Water Quality Issues of the Upper Potomac Estuary, *Aquatic Sciences*, Vol. 3/Issue 1, pp. 11-40.

2. Thomann, R.V., Jaworski. N.A., Nixon, S.W., Pearl, H.W., and Taft, J., (1985), The 1983 algal bloom in the Potomac Estuary, Report of Algal Bloom Expert Panel, Prepared for Potomac Strategy EPA Management Committee, March 14, 1985.

3. Sale J.W. & W.W. Skinner, (1917), Vertical Distribution of Dissolved Oxygen and the Precipitation by Salt Water in Certain Tidal Areas, Journal of the Franklin Institute, 184:837-848.

4. Potomac Basin Reporter, (2006), Region's Scientists Investigate Lower Potomac Fish Kill, Vol. 62, No. 3, ICPRB, Rockville, MD.

5. Houser, M.E., and M.I. Fauth, (1972), Potomac River Sediment Study, U.S. Navy, IHTE 355, Indian Head, MD, pp 31.

6. Velinsky, D.J., T.L. Wade, C. Schlekat and B.J. Presley, (1994), Tidal river sediments in the Washington, D.C. area. I. Distribution and sources of trace metals, *Estuaries* 17:305-320.

7. Wade, T.L., D.J. Velinsky, E. Reinharz and C.E. Schlekat, (1994), Tidal river sediments in the Washington, D.C. area. II. Distribution and sources of chlorinated and non-chlorinated aromatic hydrocarbons, *Estuaries* 17: 321-333.

8. US EPA, EMAP Web Site.

9. Schlekat, C.E., B.L. McGee, D.M. Boward, E. Reinharz, T.L. Wade and D.J. Velinsky, (1994), Tidal river sediments in the Washington, D.C. area. III. Biological effects associated with sediment contamination, *Estuaries* 17: 333-344.

10. Hirsch, R. M., J. R. Slack, and R. A. Smith, (1982). Techniques of trend analysis for monthly water quality data, *Water Resources Research* 18:107-121.

11. Sen, P. K., (1968). Estimates of the regression coefficient based on Kendall's tau, *Journal of the American Statistical Association* 67:1379-1389.