Chapter Seven: Factors Affecting the Impact of Nutrient Enrichment on the Lower Estuary

As presented in Chapter Six, the water quality data for the upper stations of the tidal freshwater Potomac Estuary clearly suggest vast improvements in the health of this ecosystem. The dissolved oxygen levels have increased and the coliform bacteria have decreased by two orders of magnitude. The nutrient concentrations, especially TP, have decreased. The nuisance blue-green algal blooms have been reduced**. The cleanup of the Upper Estuary is a real success story** (1).

As also presented in the previous chapter, the bottom waters of the Lower Estuary, especially in the Ragged Point Station area, have become anoxic during the summer months since the 1910s. In this chapter, we present TN and TP concentration data from the headwaters of the Potomac River in Maryland, West Virginia, and Virginia to the Chesapeake Bay. Molar TP/TN ratios are also presented. We examine the effect of temperature and salinity on bottom water DO levels, Potomac River discharge flow rate impact on nutrient transport, and the POTW treatment reductions of phosphorus on nutrient enrichment of the Lower Estuary.

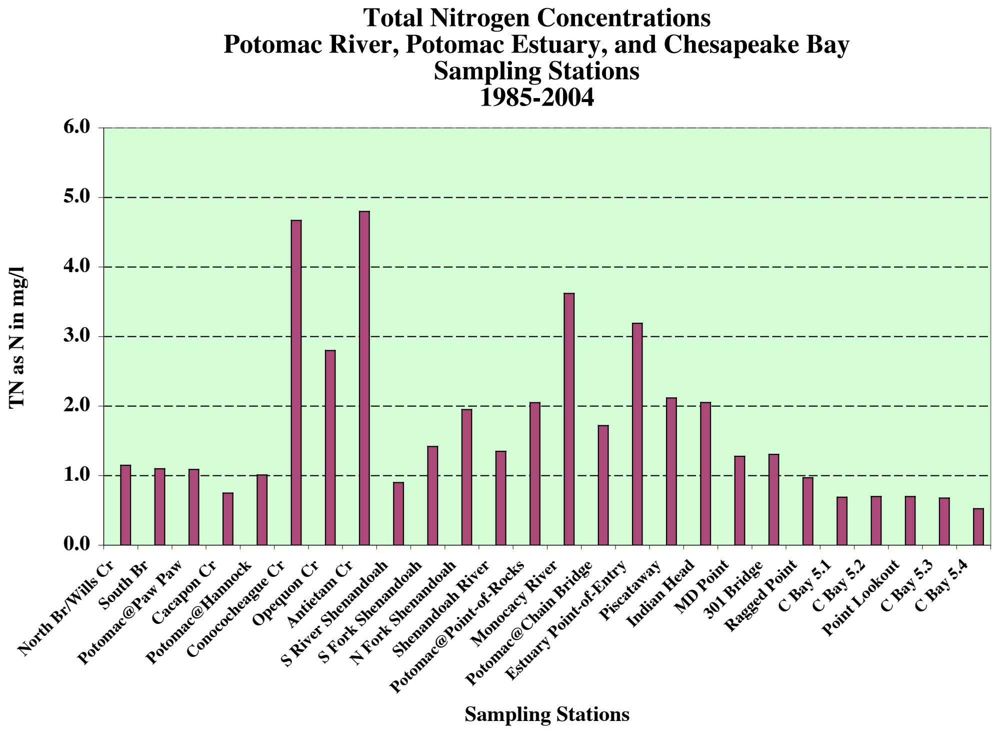
TN, TP, and Molar TN/TP Ratios of the Entire Potomac River Waterway and its Estuary

The average TN concentration data for 15 water quality sampling stations of the Upper Potomac River Basin for the 15-year period from 1985 to 2004 are presented in the figure below. The TN concentrations in these headwaters in Maryland, West Virginia, and Virginia were around 1.0 mg/l. The waters of the highly agricultural drainage area had TN concentrations over 3.0 mg/l. As the Potomac River flows downstream towards the Upper Estuary, it has a TN concentration of about +1.7 mg/l.

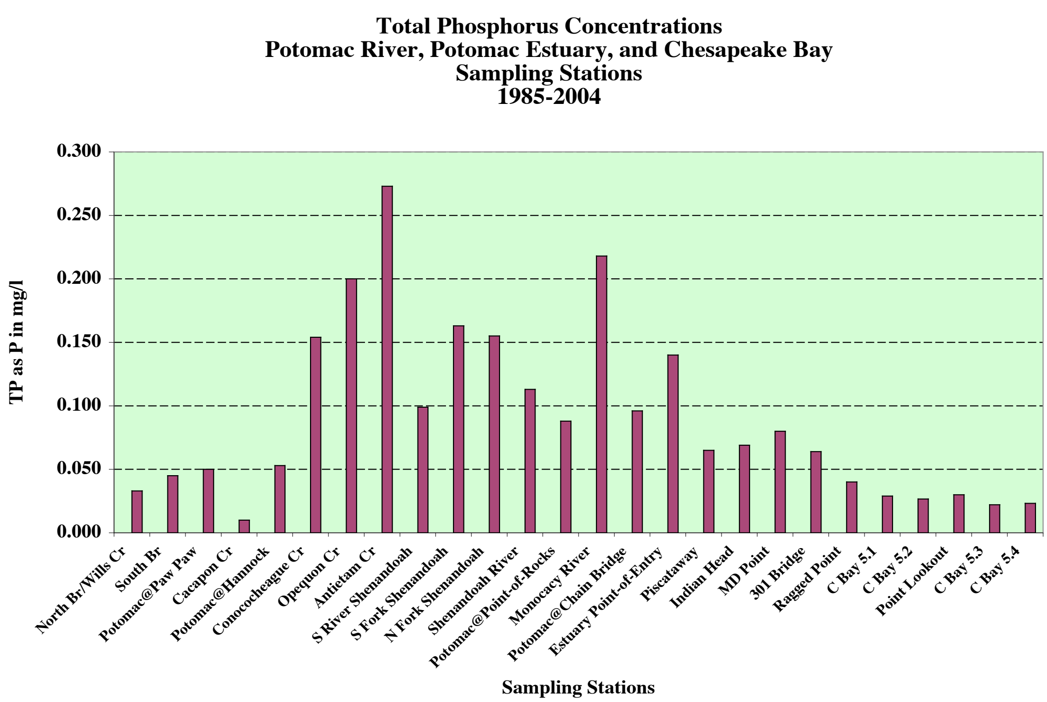
When the TN load from the tidal POTWs is added to the waters of the Potomac River from the Upper Basin, TN increased from +1.7 to over +3.0 mg/l, as reflected by the point-of-entry station calculation. In the two upper freshwater stations, Piscataway and Indian Head, the surface TN concentrations were about 2.0 mg/l.

As the estuarine waters flowed toward the Chesapeake Bay, TN surface concentration decreased to about 0.70 mg/l at the Point Lookout Station. The TN concentrations entering the Chesapeake Bay were similar to the stations in the Bay (CB 5.1, CB 5.5, CB 5.3, and CB 5.4).

The distribution pattern for the average TP concentration data for the 15 water quality sampling stations of the Upper Potomac River was similar to the TN data (see below). When the TP load from the tidal POTWs is added to the waters of the Potomac River, TP increased from 0.09 to over 0.14 mg/l, as reflected by the point-of-entry calculation. The TP concentrations entering the Chesapeake Bay were similar to the stations in the Bay.

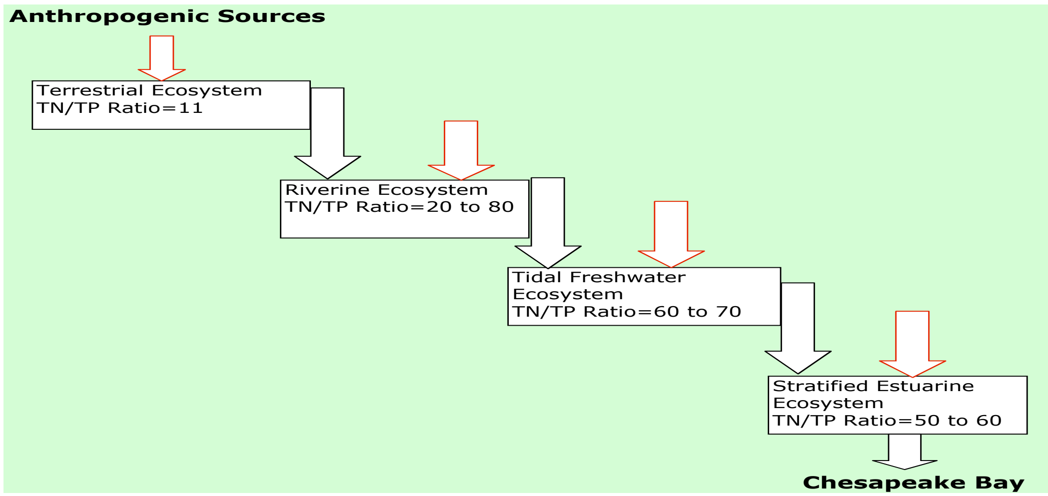


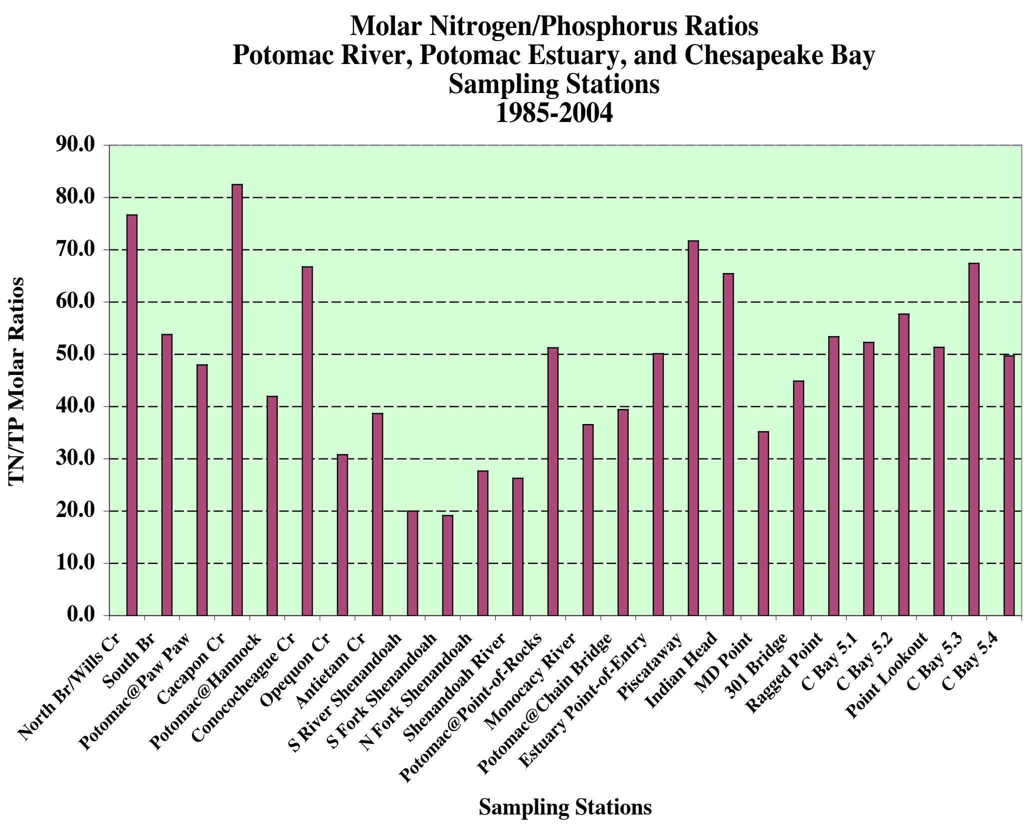
Total Nitrogen Concentrations
Potomac River, Potomac Estuary, and Chesapeake Bay
Sampling Stations
1985-2004
TN as N in mg/l
0.0
1.0
2.0
3.0
4.0
5.0
6.0
North Br/Wills Cr
South Br
Potomac@Paw Paw
Cacapon Cr
Potomac@Hannock
Conococheague Cr
Opequon Cr
Antietam Cr
S River Shenandoah
S Fork Shenandoah
N Fork Shenandoah
Shenandoah River
Potomac@Point-of-Rocks
Monocacy River
Potomac@Chain Bridge
Estuary Point-of-Entry
Piscataway
Indian Head
MD Point
301 Bridge
Ragged Point
C Bay 5.1
C Bay 5.2
Point Lookout
C Bay 5.3
C Bay 5.4
Sampling Stations



Total Phosphorus Concentrations
Potomac River, Potomac Estuary, and Chesapeake Bay
Sampling Stations
1985-2004
TP as P in mg/l
0.000
0.050
0.100
0.150
0.200
0.250
0.300
North Br/Wills Cr
South Br
Potomac@Paw Paw
Cacapon Cr
Potomac@Hannock
Conococheague Cr
Opequon Cr
Antietam Cr
S River Shenandoah
S Fork Shenandoah
N Fork Shenandoah
Shenandoah River
Potomac@Point-of-Rocks
Monocacy River
Potomac@Chain Bridge
Estuary Point-of-Entry
Piscataway
Indian Head
MD Point
301 Bridge
Ragged Point
C Bay 5.1
C Bay 5.2
Point Lookout
C Bay 5.3
C Bay 5.4
Sampling Stations

Movements of nutrients in the Potomac Waterways from their anthropogenic terrestrial sources through the four ecosystems, as well as molar TN/TP ratios, are shown below.



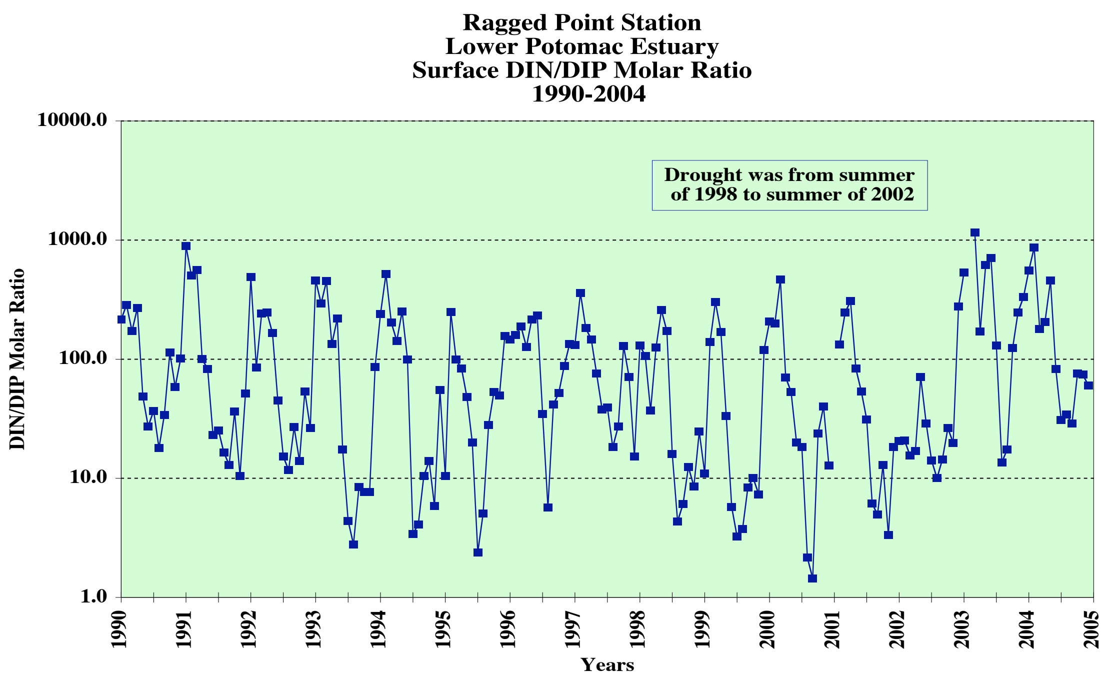


The average molar TP/TN ratio for the anthropogenic sources of terrestrial nutrients to the Upper Potomac Basin was 11 for the 15-year period, as shown above. Because only 8% of the landscape loading inputs of TP are exported by riverine flow, while about 20% of the landscape loading inputs of TN are exported, the riverine molar TN/TP ratios increased from 11 to 20 to 80 for the 15 riverine stations.

The TN/TP ratios for the two freshwater tidal stations were 60 to 70. For the Lower Estuary and Chesapeake Bay stations, the average TN/TP ratios were about 50 to 60. This suggests that, on average, phosphorus was limiting phytoplankton primary production in the Lower Estuary.

A recent review of evolving views over the past three decades on nitrogen as the limiting nutrient for coastal ecosystems was published by Howarth and Marino (2). While the review suggests that nitrogen is probably the major cause of coastal eutrophication, there are some coastal ecosystems that are phosphorus limited.

Kemp, *et al,* recently reviewed historical trends and ecological interactions in the eutrophication of the Chesapeake Bay (3). The section of the review on nutrient limitation suggests that light limitation is common in the Upper Bay during the winter months. Phosphorous limitation primarily occurs in the spring months of April and May and for brief periods in late fall. Nitrogen limitation occurs in summer when the DIN surface pool is depleted.



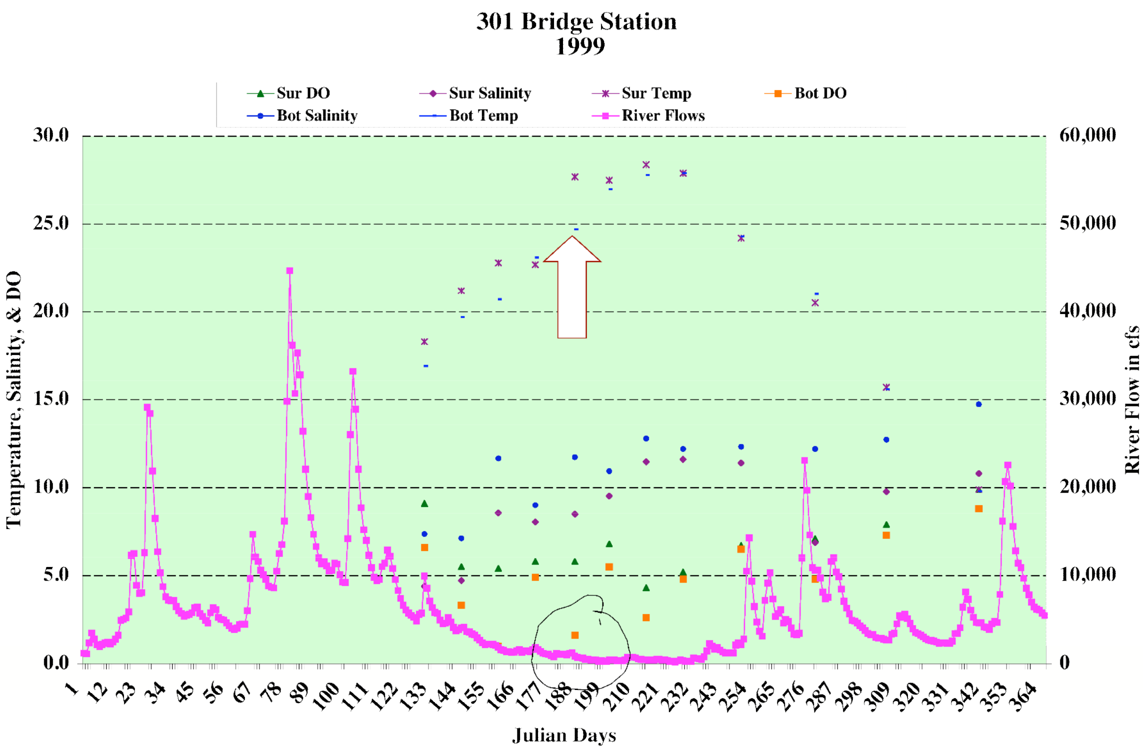
The DIN/DIP ratios for the Ragged Point Station are very similar to those reported by Kemp (3) for the Chesapeake Bay near its confluence with the Potomac Estuary, as shown above. The molar ratios were 100 in late fall, winter, and spring, and often fell below 10 in the late summer months. At a molar ratio of 10, the Lower Estuary is nitrogen limited.

Factors Affecting Bottom DO in the Lower Estuary

An analysis of how both temperature and salinity stratification can significantly reduce bottom water DO levels was made for the 301 Bridge Station for 34 of the 51 sampling years in the period 1950 to 2001. The 301 Bridge Station was selected because it is mainly impacted by the loadings to the Potomac Estuary and not by low DO bottom waters entering the Lower Estuary from the Chesapeake Bay.

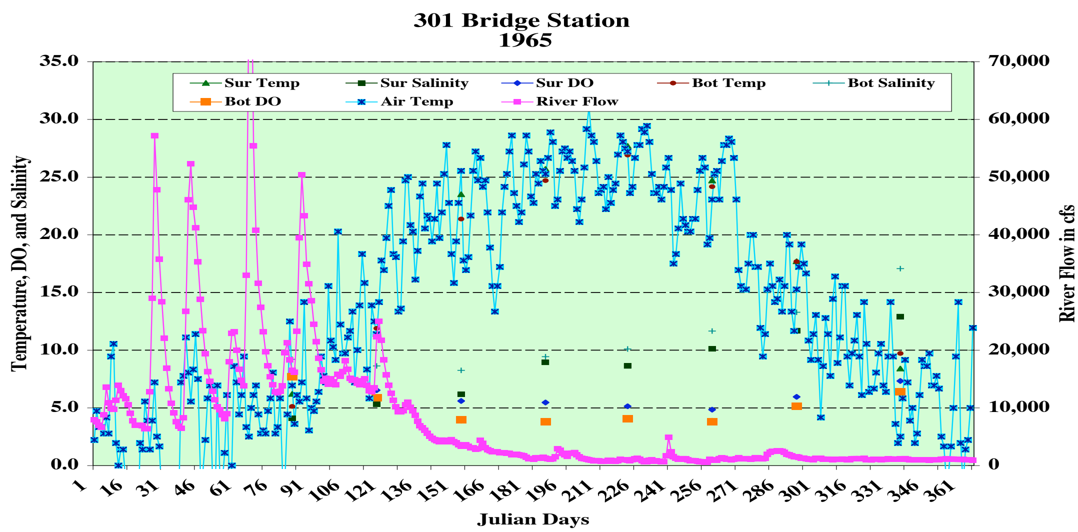
For each of the 34 years, surface and bottom temperature, DO, and salinity data for each sampling cruise (usually one a month) were plotted for each individual year. In addition, daily river flow of the Potomac River at Little Falls was added to the 34 plots to determine the influence of stream flow on bottom DO. Daily air temperatures were later added to determine their influence on changes of surface temperatures and on bottom DO.

An example of the yearly plot for 1999 (a low-flow year) with daily Potomac River flows is presented below.

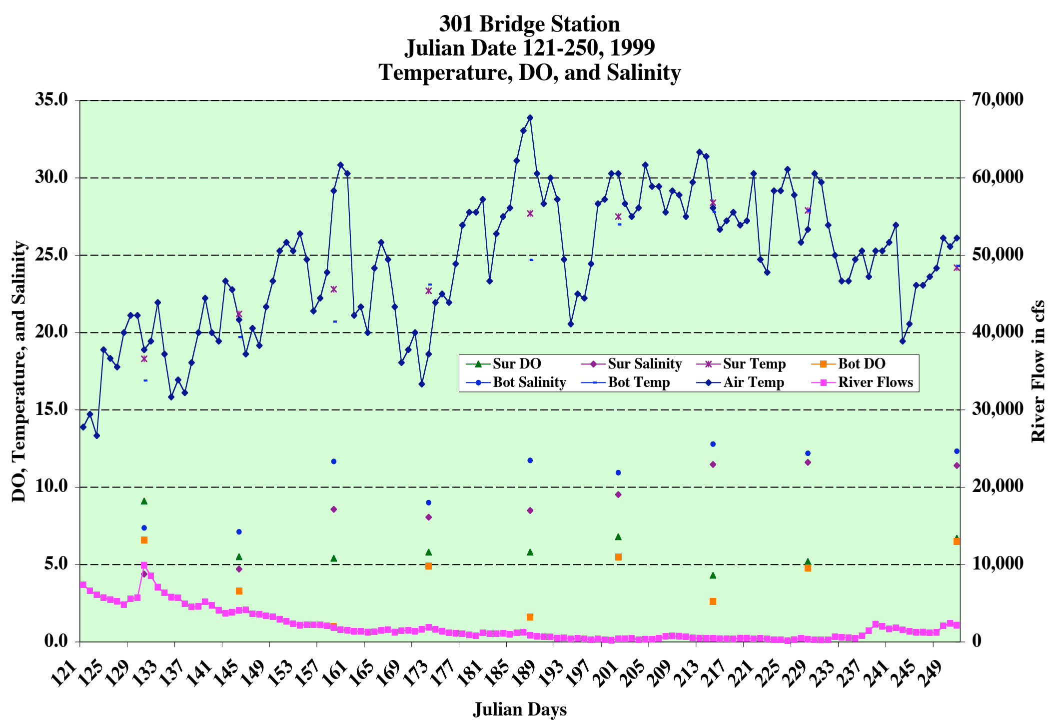


When we examined the 34 plots, we observed that the impact of sharp increases in surface temperature during the summer months was usually followed by a decrease in DO in bottom waters. This occurred on the Julian date 187 cruise presented above, when the surface temperature increased by about 3°F and the bottom DO decreased to a concentration of 0.50 mg/l.

The earliest year with a complete yearly sampling was 1965 (see below for 301 Bridge Station). Because there were only eight cruises in 1965, no major increases in surface temperatures were detected and the bottom DO during the summer months was stable at about +4.0 mg/l.



To demonstrate how temperature increases and decreases can impact the bottom DO, the data for Julian date 121 (5/1/99) to Julian date 250 (9/8/99) are presented below.

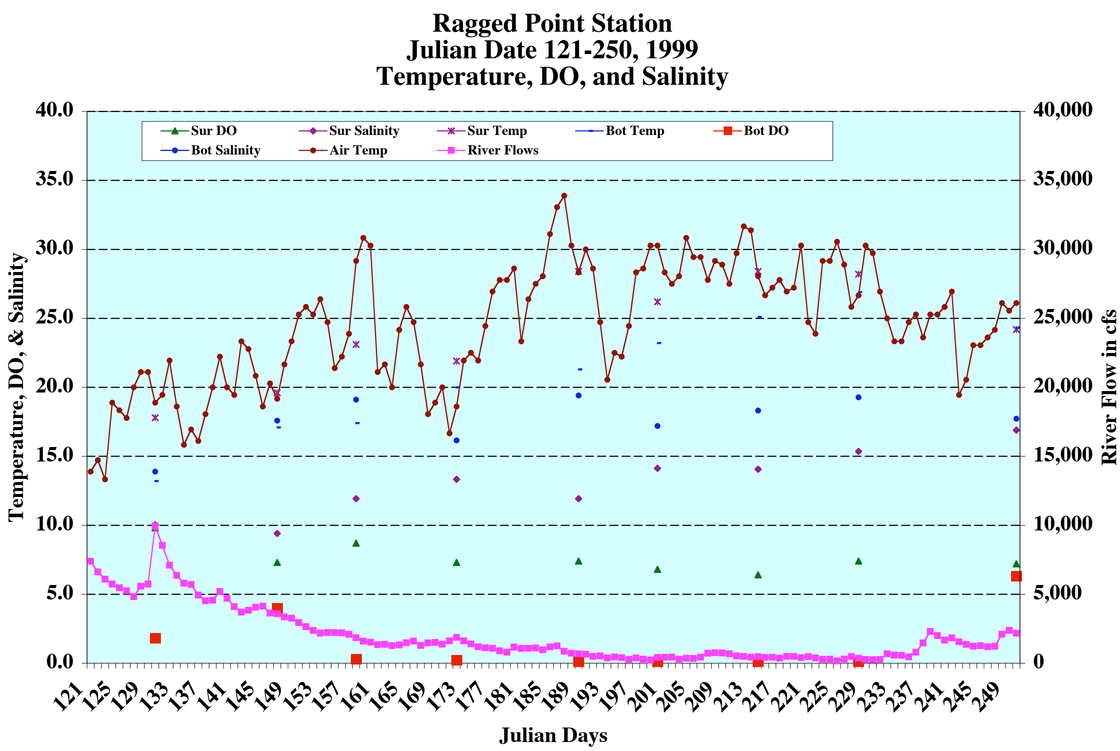


From Julian date 130 to Julian date 157, the air temperature increased from 20ºC to over 30ºC, resulting in an increase in the surface water temperature. During short periods of increasing temperatures, surface temperature often increases faster than bottom temperature, causing thermal stratification resulting in bottom DO of less than 2.0 mg/l, as occurred on Julian date 160. These fluctuations occurred even under long periods of steady state, low-flow river discharge conditions, such as occurred in 1999.

From Julian date 157 to Julian date 172, the air temperature dropped from 30ºC to less than 20ºC. The Estuary mixed, as indicated by similar top and bottom salinities, on Julian 172, while bottom DO increased to 5 mg/l.

From Julian date 172 to Julian date 187, the air temperature increased from 20ºC to over 30ºC, resulting in a higher surface than bottom temperature. The bottom DO dropped, again to 2 mg/l. By Julian date 200, the bottom and surface temperatures were again equal and the Estuary mixed, while the bottom DO was back to 5 mg/l.

For the same Julian dates, the same data for the Ragged Point Station are presented below.



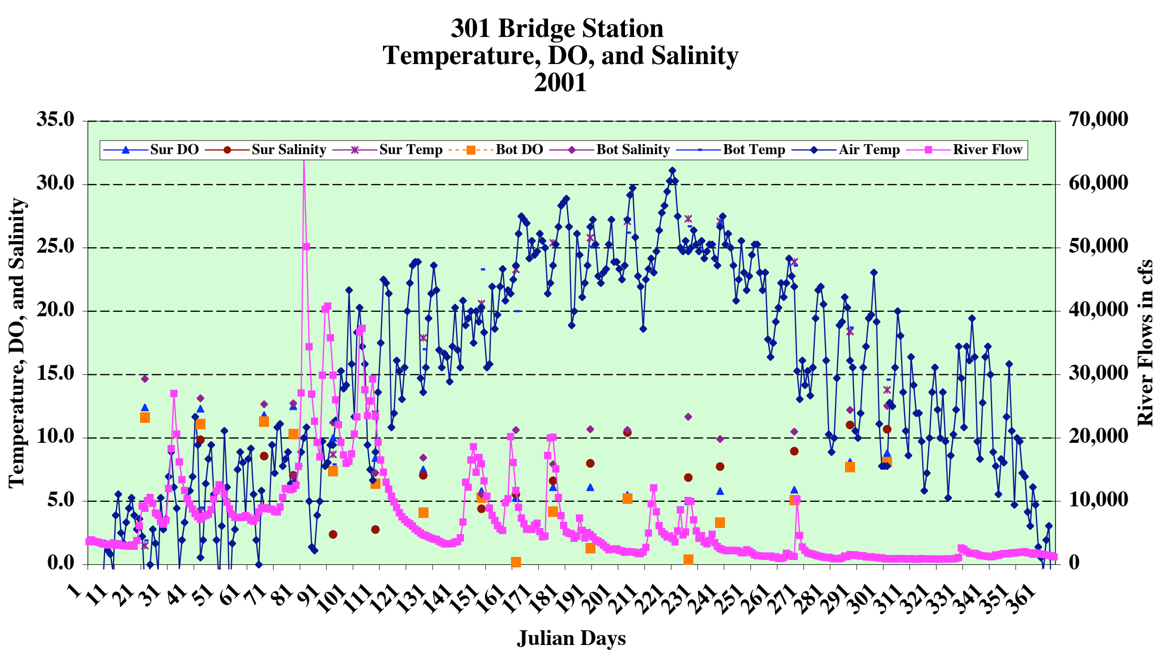
For most of the summer cruises, the bottom water DO was less than 0.3 mg/l at the Ragged Point Station (see above). There were significant differences between the surface and bottom salinities and temperatures.

Presented below is a comparison of the differences in the bottom and surface densities and the bottom DO concentrations for the 301 Bridge and Ragged Point stations.

1999 Julian Date of Cruise	301 Bridge Density Difference mg/l	301 Bridge Bottom DO mg/l	Ragged Point Density Difference mg/l	Ragged Point Bottom DO mg/l
130	2.538	6.6	3.761	1.8
144	2.201	3.3	6.750	4.0
158	2.847	1.0	6.779	0.3
172	0.614	4.9	2.596	0.2
187	3.268	1.6	7.556	0.1
200	1.204	5.5	3.244	0.1
214	1.160	2.6	4.526	0.1
228	0.302	4.8	3.319	0.1
250	0.663	6.5	0.209	6.3

For the months of June, July, and August, the density differences at the Ragged Point Station were about two times the differences at the 301 Bridge Station (see above). The mixing that occurred on the 172 Julian date cruise at the 301 Bridge Station did not occur at the Ragged Point Station; in fact, no mixing occurred until the cruise of Julian date 250.

High river flows for short periods in the summer can impact the bottom DO, as shown below for the 301 Bridge Station for the year 2001.

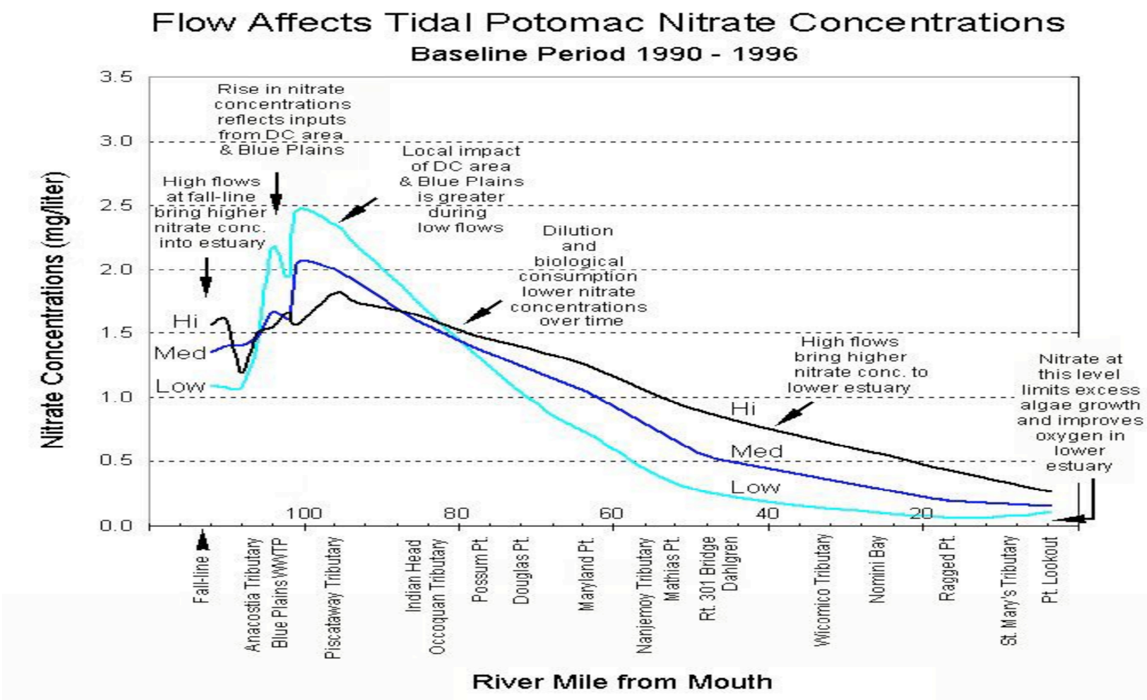


In 2001, there were three large runoff periods in which the river flow was about twice the annual average of about 11,000 cfs. The 149 Julian date cruise data indicated the Estuary was well mixed and the bottom DO was 5 mg/l. The first rainstorm occurred about Julian date 151.

The second storm, which peaked on Julian date 162, resulted in both thermal and salinity stratification and the bottom DO dropped to less than 1 mg/l. The third storm, which peaked on Julian date 176, caused the Estuary to be well mixed and the bottom DO increased back to 5 mg/l.

How River Flow Impacts Nutrient Transport from the Upper to the Lower Estuary

To demonstrate how river flows affect tidal nutrient concentrations, we selected nitrate profiles for high-, medium-, and low-flow conditions, as presented below.

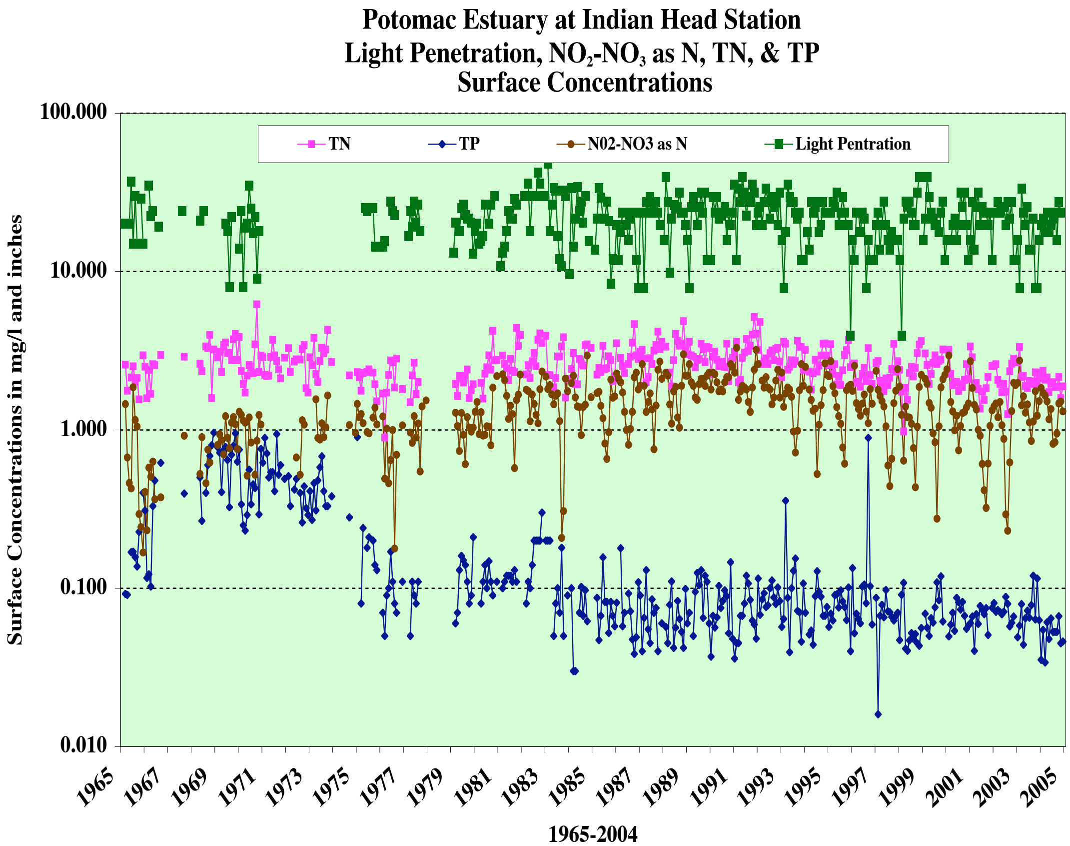


Source: ICPRB

In the Upper Estuary, river waters from the Upper Basin dilute the nitrogen from the POTW wastewater discharges and reduce the estuarine nitrate levels. During high river flows, dilution is the largest and higher concentrations of nitrogen are transported to the Lower Estuary. During low river flows, there is less dilution and fewer nitrates are transported to the Lower Estuary.

The three nitrate concentration profiles intersect around the Indian Head Station. This intersection suggests that the nutrient concentrations at the Indian Head Station are not sensitive to river discharge rates. This further suggests that the Indian Head Station is river flow neutral and therefore an ideal station to show water quality trends.

The nutrient trends, including light penetration, for the Potomac Estuary at the Indian Head Station therefore represent a river-flow neutral assessment of how nutrients varied during the 1965-2004 time frame (see below).



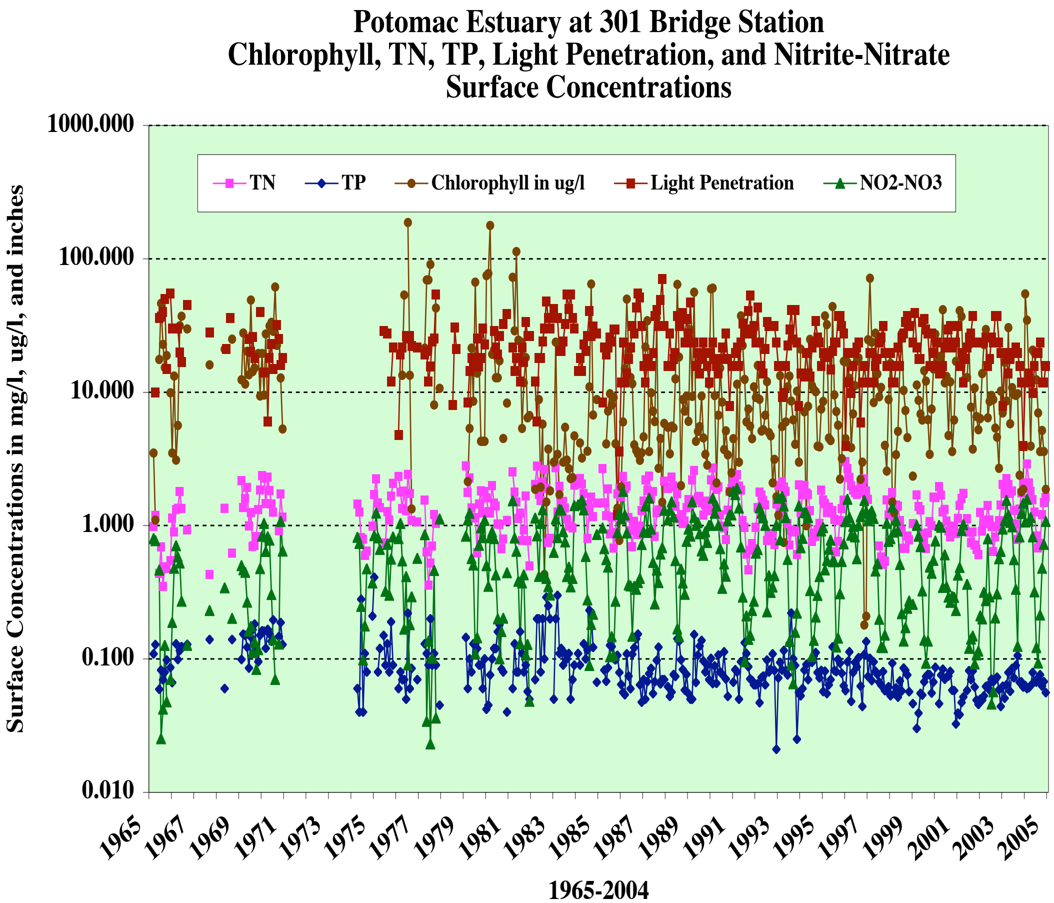
Light penetration at the Indian Head Station varied from month to month, with an average of about 22 inches. There appears to be no upward or downward trend for the 1965-2004 time frame.

The TN concentration trend line appears to be parabolic, with the highest concentration in the 1980s. The NO_2-NO_3 concentration trend line is similar to the TN trend line, with one exception: the period from 1965 to the early 1980s. During this period, nitrogen from the POTWs was mainly in the un-oxidized form: ammonia and organic nitrogen. When nitrification was added to the POTW treatment processes in the 1980s, the TN and NO_2-NO_3 trend lines became parallel. The highest NO_2-NO_3 concentrations usually occur in the spring months with the lowest in July and August.

The large decrease in the TP trend line—a factor of 10—reflects the addition of phosphorus removal at the POTWs in the 1970s. There appears to be a TP downward trend in the past 20 years.

__Impact of Phosphorous Reduction by the POTW Wastewater Treatment Plants on the Nutrient Enrichment of the Lower Estuary__

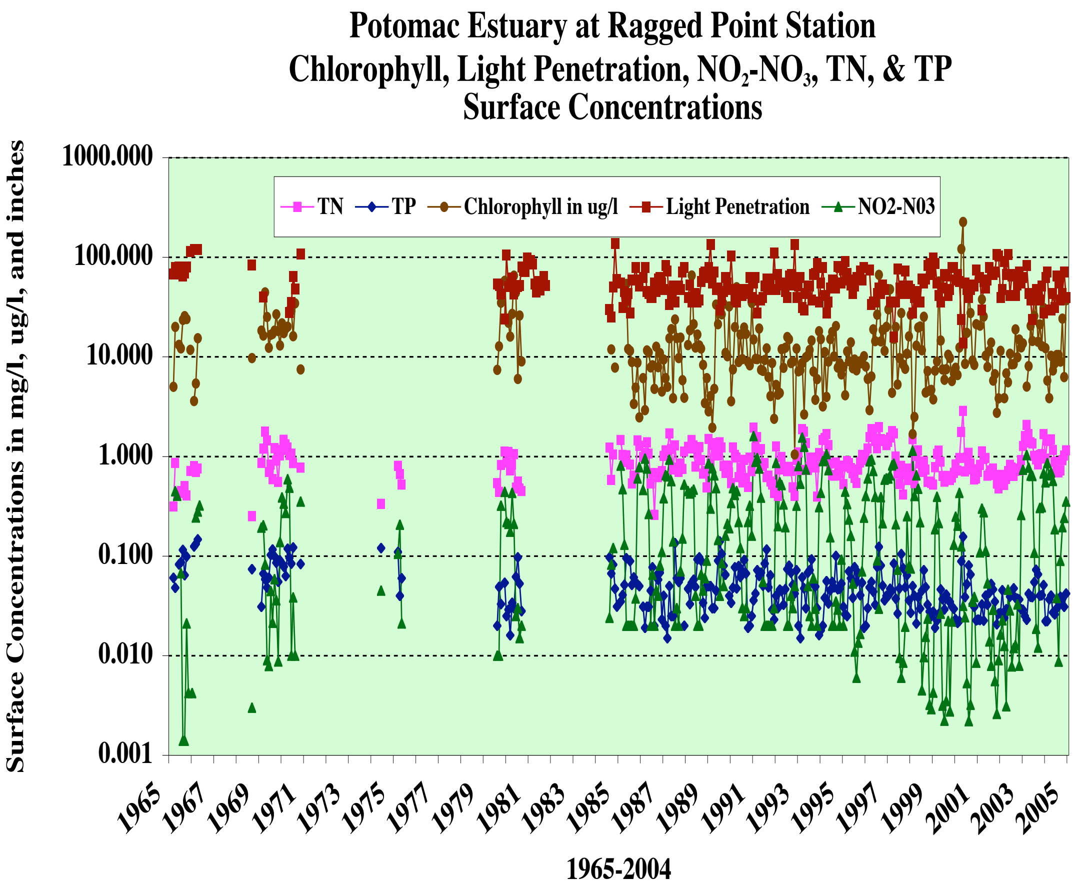
The chlorophyll, light penetration, NO_2-NO_3, TN, and TP water quality monitoring for the 301 Bridge and Ragged Point stations for the 1965-2004 time frame are presented below.



The major downward trend was for TP at the 301 Bridge Station, reflecting the factor of 10 reduction observed at the Indian Head Station presented earlier in this chapter. There was also a downward trend for chlorophyll at the 301 Bridge Station for the 1965-2004 time frame.

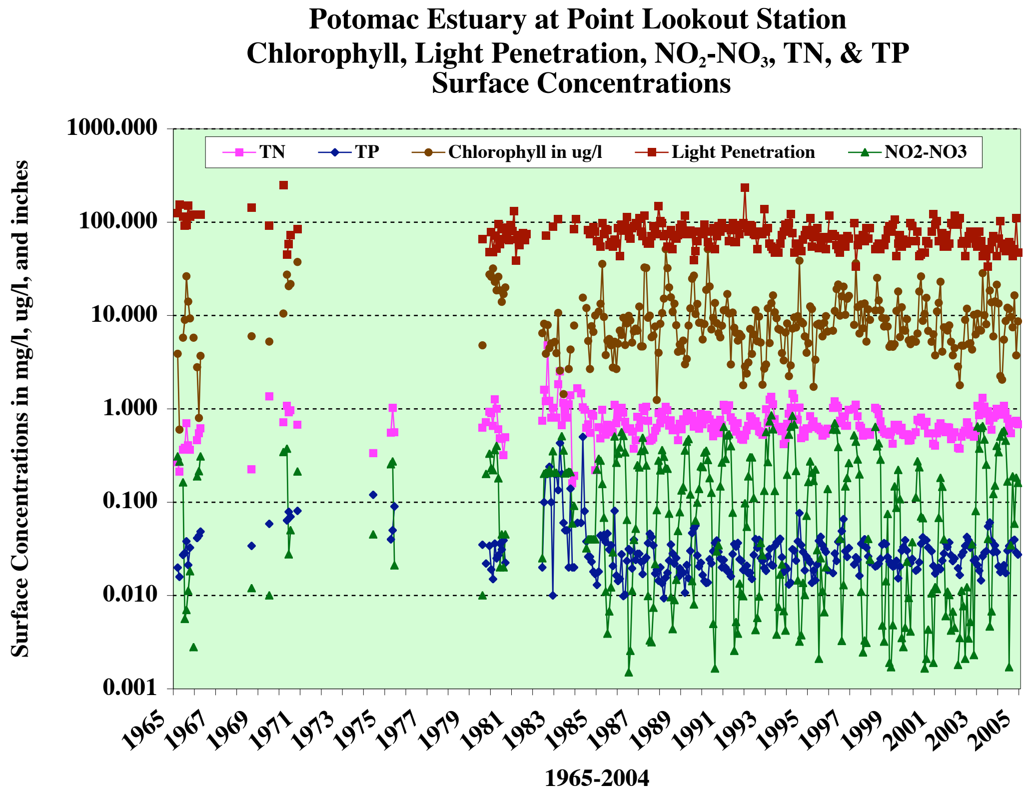
Likewise, the major downward trend was for TP at the Ragged Point Station (see below), also reflecting the factor of 10 reduction observed at the Indian Head Station presented earlier in this chapter.

There were also slight downward trends for light penetration and surface chlorophyll concentrations at the Ragged Point Station. There also appears to be a slight increase in surface TN concentration at this station.



During the Upper Basin low-flow years from the middle of 1998 to the summer of 2002, the NO_2-NO_3 surface concentrations were often below 0.01 mg/l during the late summer months. These low concentrations were also observed during the low flows of the summer of 1965.

There was also a downward trend for TP at the Point Lookout Station during the 1965-2004 time frame. However, there appears to be a slight increase in TP surface concentrations since the late 1980s, as presented below.



At all three stations, there were downward trends in surface chlorophyll concentrations paralleling the downward trend in TP concentrations. What is unexplainable is the downward trend in light penetration at all three stations. One would expect light penetration to increase in response to a decrease in chlorophyll levels. **The source of this reduction in light penetration needs to be investigated.** The light penetration for the Indian Head Station, which is river-flow neutral, was fairly constant over the 1965-2004 time frame.

During the summer months, the NO_2-NO_3 surface concentrations often fell below 0.01 mg/l. These low NO_2-NO_3 surface concentrations suggest that nitrogen may be the limiting nutrient during the summer months, as discussed earlier in this chapter.

References for Chapter Seven

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. Howarth, R.W. and R. Marino, (2006), Nitrogen as the limiting nutrient for Eutrophication in coastal ecosystems: Evolving views over three decades, *Limnol. Oceanogr*., 51 (1, part 2), 364-376.

3. Kemp, W. M., *et al*, (2005), Eutrophication of Chesapeake Bay: Historical trends and ecological interactions, *Marine Ecology Progress Series*, Vol. 303.1-29.