

Chapter Eight: Nutrient Dynamics, Depletion, and Replenishment

The nutrient and oxygen dynamics of the Chesapeake Bay have been well described in a book entitled *Oxygen Dynamics in the Chesapeake Bay* (1), in a study of hypoxia in the Chesapeake Bay, 1950-2001 (2), and in a recent analysis of historical trends and ecological interactions of eutrophication in the Chesapeake Bay (3). While the focus of many studies has been on the stem of the Chesapeake Bay, there has not been enough attention given to the nutrient dynamics of the Potomac Estuary. A nutrient management study for the Potomac Estuary was completed in 1972 (4), resulting in a phosphorus control program to reduce the hyper-eutrophic water conditions of the Upper Estuary.

For this analysis, we present the nutrient and oxygen dynamics of the Upper Estuary using the Indian Head Station as a control because it has the longest consistent data set and is river-flow neutral, as described in Chapter Six. The Upper Estuary, from its beginning above the District of Columbia to the Indian Head Station, is a freshwater tidal river. The nutrient dynamics are mainly influenced by the Upper Basin river flow, tidal POTW discharges, and inputs from the Upper Basin.

At the Indian Head Station, which is mainly fresh water and therefore has very little salinity, we present the surface temperatures, surface DO concentrations, and light penetration for the 1990-2004 time frame.

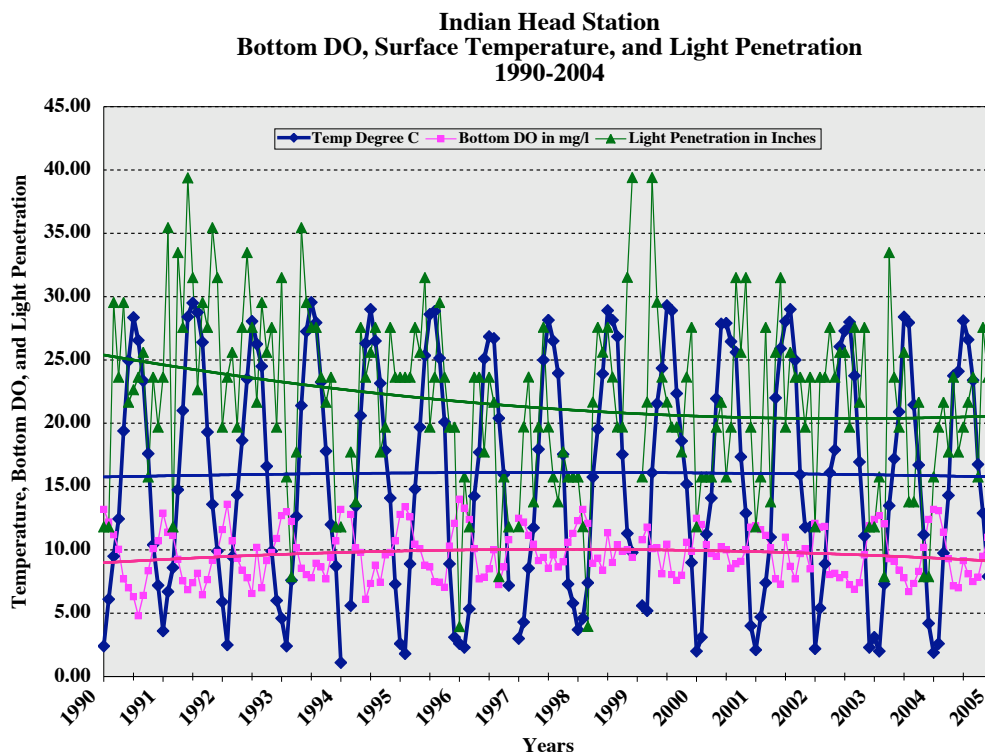
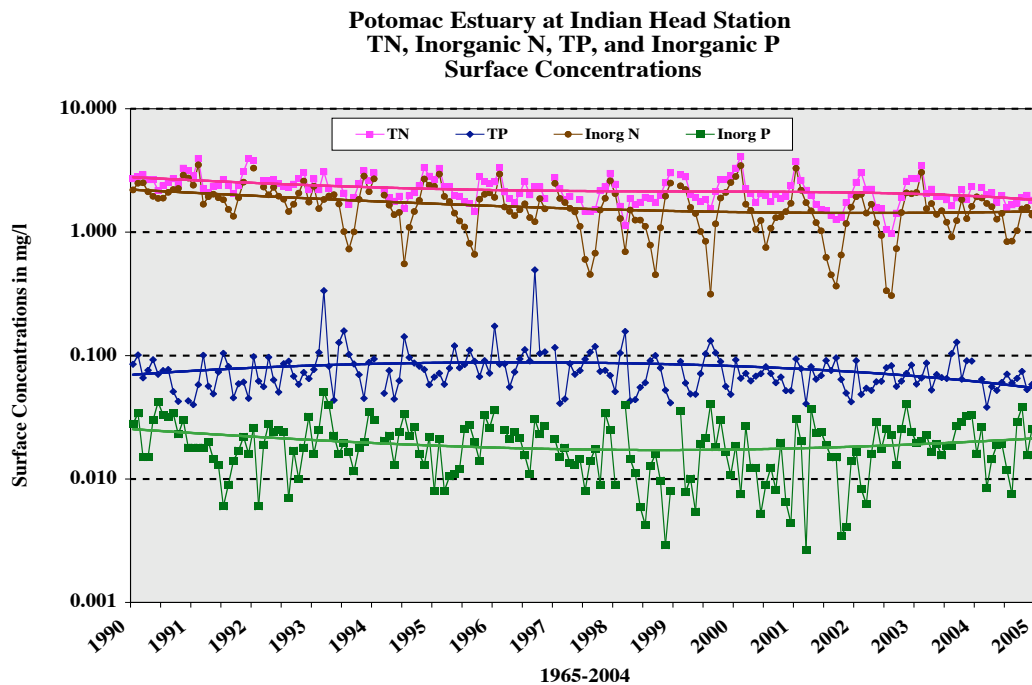
For the Lower Estuary, we describe the depletion and replenishment of the surface TP, TN, DIN, ITP (Inorganic TP), and silica pools in relation to the bottom water DO using Ragged Point Station data for the years 1996 through 2004.

We further describe how, using 301 Bridge Station data, the depletion of the DIN pool in the Lower Potomac Estuary affects the DO depletion of the bottom waters. Similar to Chapter Six, we selected the 301 Bridge Station because it is mainly impacted by the Potomac inputs and not, to a large degree, by tidal diffusion from the Chesapeake Bay. Finally, we describe how the DIN pool is replenished at the 301 Bridge Station, mainly from large spring runoff pulses.

We examined the nutrient and oxygen dynamics at the Ragged Point Station for the 1996-2004 time frame, including a detailed look at DIN and Organic Nitrogen (ON) and both ITP and Organic Phosphorus (OP). We also present surface water and bottom water DO comparisons at the Ragged Point Station.

Upper Estuary at the Indian Head Station

The Indian Head Station monthly surface TN, DIN, TP, and ITP concentrations from 1990 through 2004 are presented below. Also presented below are the Indian Head Station monthly surface temperatures, light penetration, and bottom water DO from 1990 through 2004.



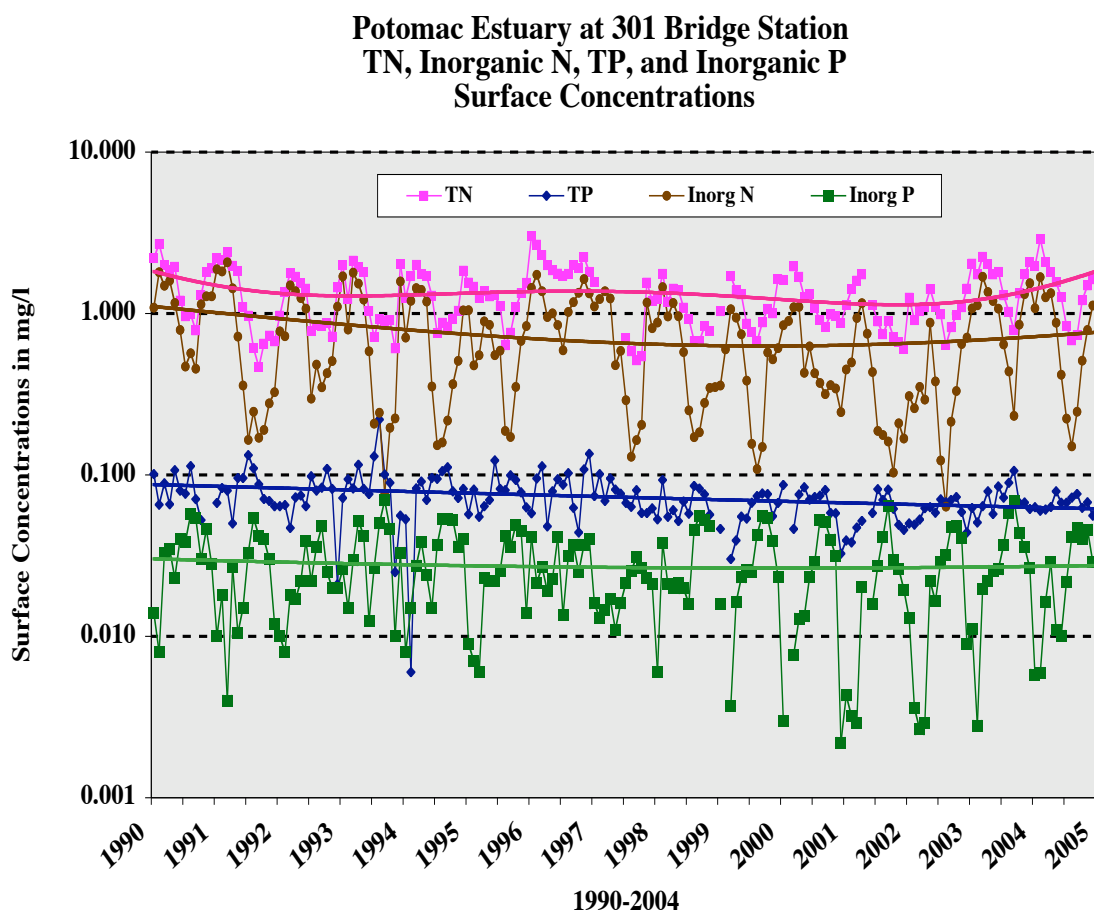
In general, the monthly surface TN and DIN concentrations were cyclic in nature. The highest concentrations occurred in the late winter-spring months and the lowest concentrations were in the late-summer months.

The monthly surface TP and ITP concentrations are also cyclic in nature (see above). However, the highest TP and ITP levels were in the summer months, while the lowest were in the winter-early spring months.

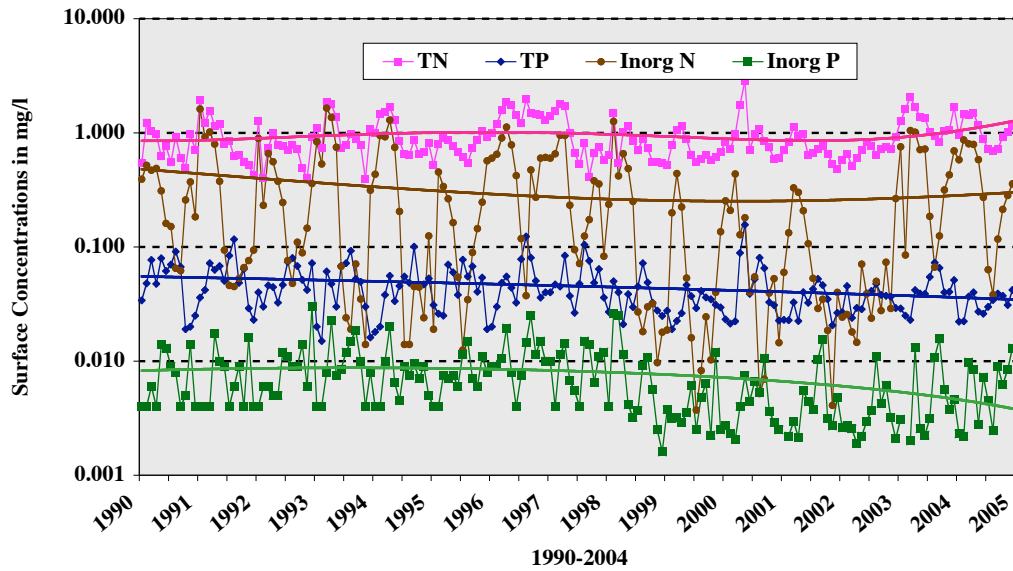
The surface temperatures, which also have a well-defined annual cycle, were fairly uniform over the 15-year period from 1990 to 2004. The lowest temperatures were usually in January and the highest in August. The bottom water DO also had a well-defined annual cycle and the annual average concentrations were fairly constant over the 15-year period. Light penetration was usually higher in the winter months and lower in the spring months. Light penetration overall has decreased by 5 inches over the past 15 years.

Monthly Nutrient Concentrations at 301 Bridge, Ragged Point, and Point Lookout Stations

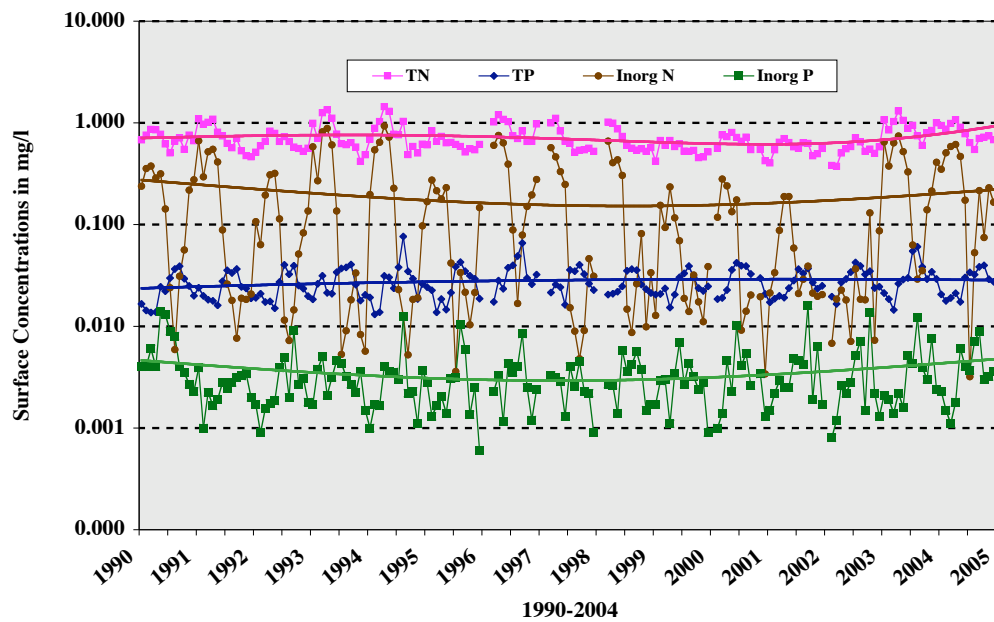
Also presented below are the monthly surface TN, DIN, TP, and ITP concentrations for the three stations.



Potomac Estuary at Ragged Point Station
TN, Inorganic N, TP, and Inorganic P
Surface Concentrations



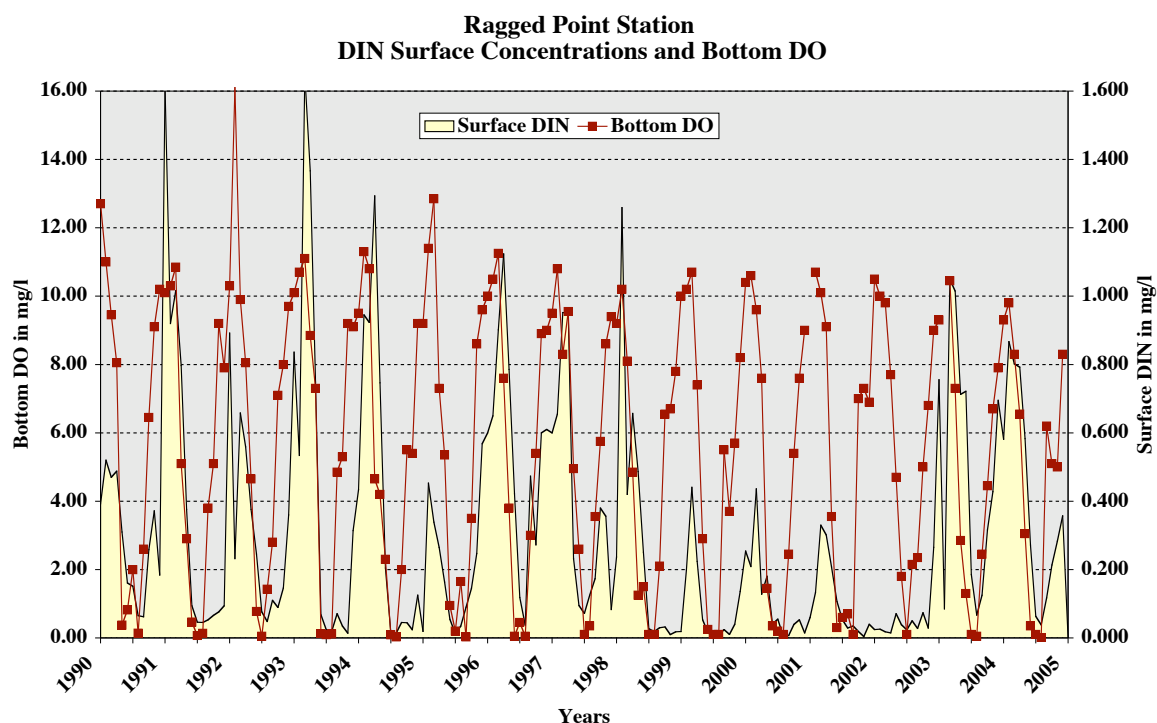
Potomac Estuary at Point Lookout Station
TN, Inorganic N, TP, and Inorganic P
Surface Concentrations



The monthly surface TN, DIN, TP, and ITP concentrations for all of the three stations above were cyclic in nature and similar to annual cycles for the Indian Head Station. The highest TN and DIN concentrations were in the late winter-spring months, with the lowest concentrations in the late summer months. The monthly surface TP and ITP concentrations are also cyclic in nature. Similar to the Indian Head Station, the highest TP and ITP concentrations were in the summer months and the lowest were in the winter-early spring months.

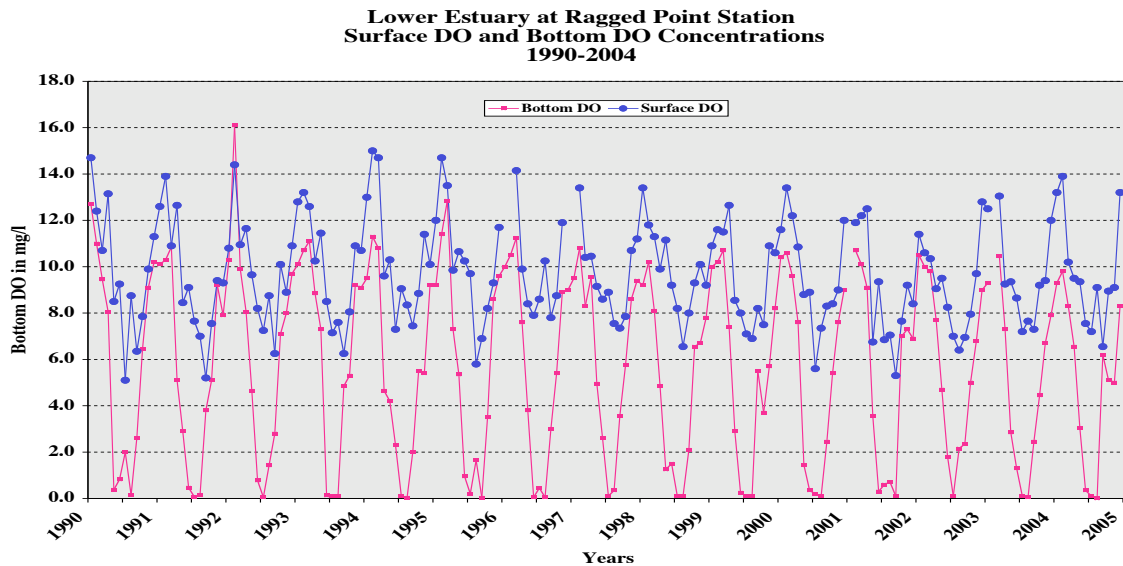
Nitrogen and Dissolved Oxygen Depletion and Replenishment at the Ragged Point Station

The depletion of the surface DIN pool begins in February and by June the pool is completely assimilated by the plankton, as shown below. Organic matter produced by the phytoplankton sinks to the bottom water where it decomposes, consuming oxygen in the process.



As the surface DIN pool was depleted, approaching 0 mg/l, the bottom water DO was depleted and became anoxic, with concentrations less than 1.0 mg/l in each of the 15 years. In fact, the bottom waters of the Lower Estuary have gone anoxic since 1950 when monitoring began. These anoxic or low redox conditions result in elevated fluxes of ammonium and phosphate being released from the sediments to the overlying waters (2).

Surface and bottom DO concentrations at the Ragged Point Station were highest in January, as presented below.



By April, the DO depletion of the bottom waters is well on its way, paralleling the depletion of the DIN surface pool, as shown in the two graphs above. The surface DO was highest during the months of January and February, about 2 to 4 mg/l greater than the bottom water DO. In 2002, the bottom waters went anoxic for only the month of June, probably due to low nutrient inputs during the fourth year of the late 1998-2002 drought.

While the surface DIN pool in the summer months approaches 0.0 mg/l, the TN surface pool had about 0.5 mg/l of total nitrogen, which was mainly in the organic form. There appears to be sufficient DIN in the spring surface pool for the plankton to produce enough oxygen-consuming organic matter to drive the DO in the bottom waters anoxic.

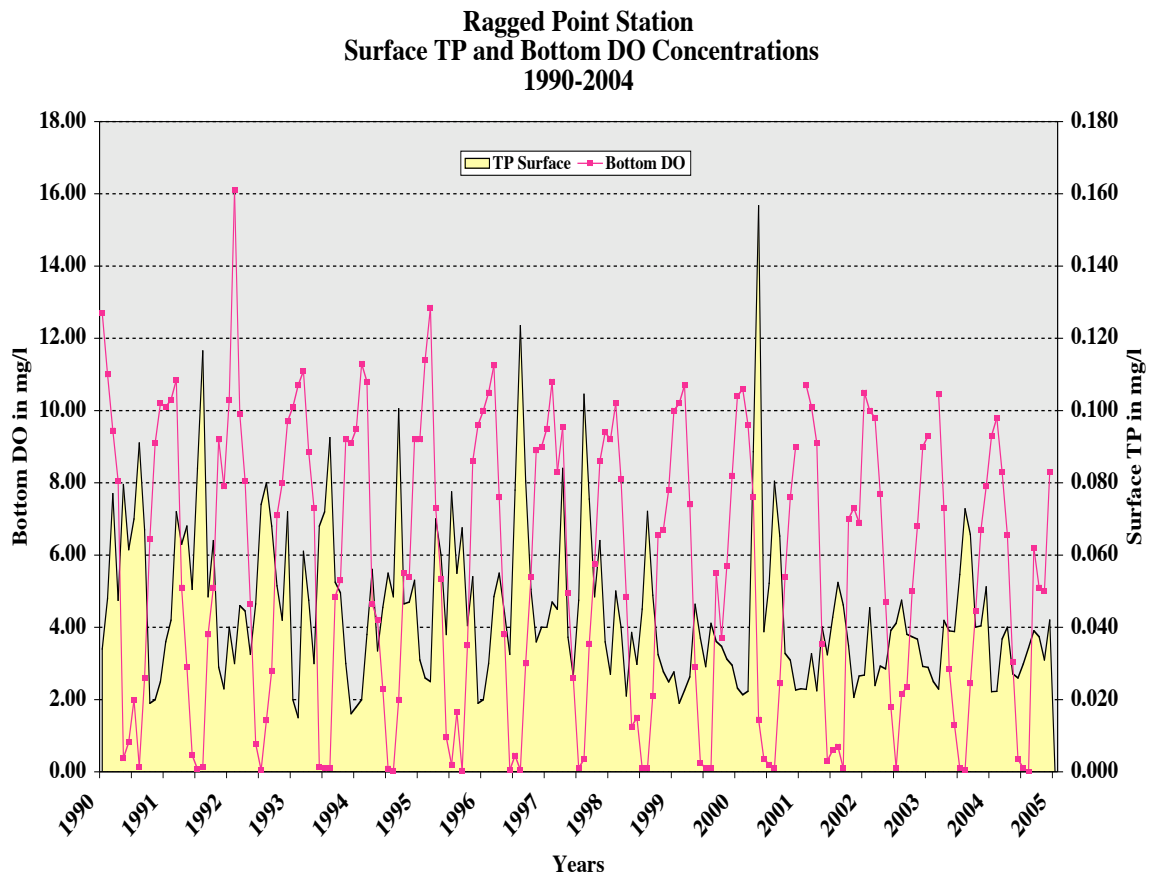
There also appears to be sufficient surface DIN, which diffuses from the anoxic bottom waters during the summer months, to supply the nitrogen needs of the plankton in the surface pool. The DIN surface pool produces ample plankton, which produce enough oxygen-consuming organic matter to keep the DO in the bottom waters anoxic. As presented in Chapter Seven, the molar DIN/Inorganic P ratios in the surface waters were often less than 10, suggesting that the Lower Estuary is a nitrogen limited system in the summer months.

For the dry springs of 1990, 1992, 1995, and 1999 to 2002, the spring DIN pool was half the concentration of a typical river-flow year, during which the spring concentration was about 1 mg/l. Nevertheless, the DO in the bottom waters went anoxic. In 2002, the surface DIN was not replenished from the Upper Basin. However, the bottom DO still went anoxic for only the month of June. **This suggests that even if the spring DIN pool concentrations were reduced by over 50%, there will still be enough nitrogen recycled to the surface DIN pool to cause the bottom waters of the Lower Estuary to go anoxic during the early summer months.**

In September, the surface water cools faster than the bottom water. When the surface and bottom water are the same temperature, the Lower Estuary de-stratifies. The Lower Estuary mixes, water temperatures decrease, and bottom water DO levels increase. Depending on Upper Basin river flow conditions, the surface DIN pool is then replenished in the fall or winter months. This aspect will be covered in more detail for the 301 Bridge Station later in this chapter.

Phosphorus and Dissolved Oxygen Depletion and Replenishment at the Ragged Point Station

During the summer months when the bottom waters go anoxic, the Ragged Point Station surface TP pools were the largest, as shown below.



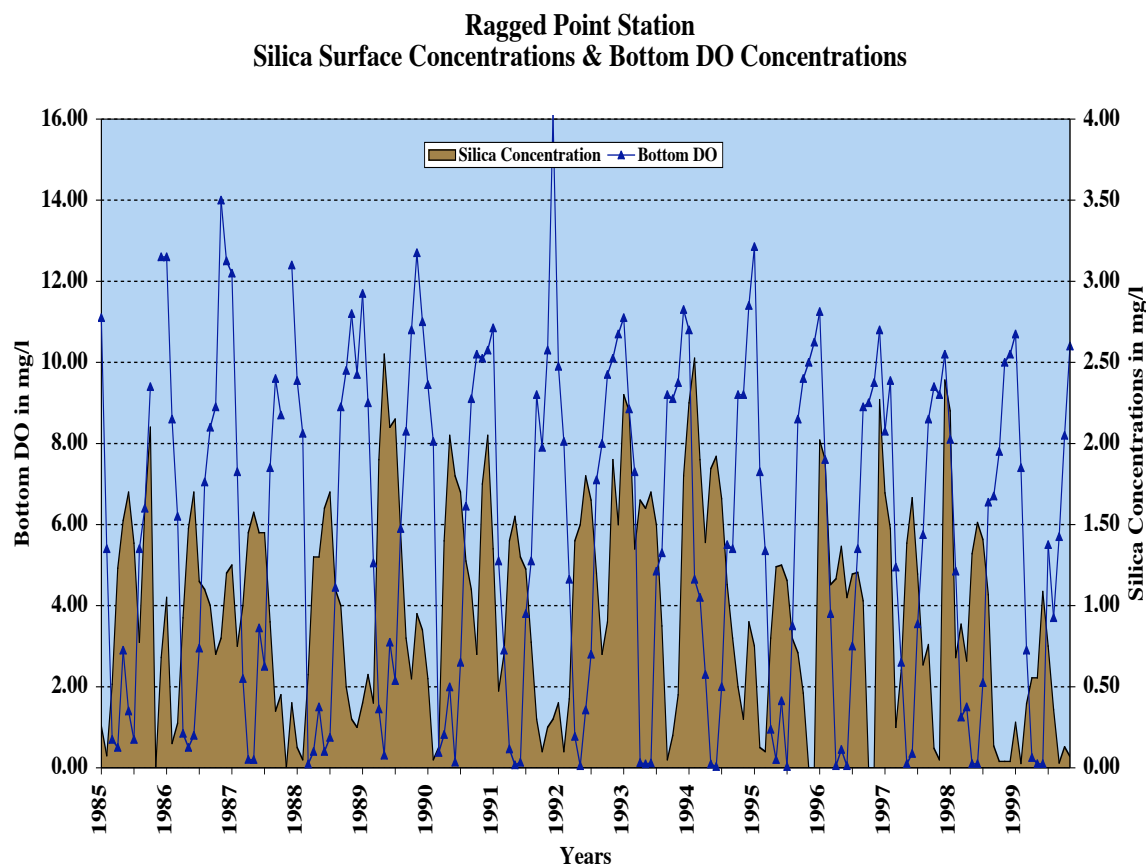
In the beginning of a typical year, the TP concentrations range from 0.02 to 0.04 mg/l. The spring runoff increases the TP levels to about 0.04 to 0.05 mg/l. The spring-early summer plankton bloom generally reduces the TP to about 0.02 to 0.04 mg/l.

When the bottom waters do go anoxic, the surface TP in July and August often doubles in concentration to 0.08 to 0.10 mg/l. Most of this increase in the surface TP pool is from the diffusion of phosphorus from the anoxic bottom waters and from the sediments. As the Lower Estuary mixes in September, the TP levels decrease to about 0.04 mg/l. This depletion-replenishment process suggests that more than 50% of the surface TP, which is mostly in the organic form, recycles and resettles to the sediment.

The surface TP pool has two annual peaks: a spring peak, replenished by Upper Basin spring runoff, and an even larger summer peak, replenished by the diffusion of phosphorus from the anoxic bottom waters and from the sediments. The DIN surface pool has usually only one annual peak, the spring peak, replenished by Upper Basin spring runoff.

Silica and Dissolved Oxygen Depletion and Replenishment at the Ragged Point Station

In a typical year, surface silica concentrations have two distinct annual peaks: the winter-spring peak from riverine export, and the summer peak, during the anoxic period. The replenishment of the surface silica during the second peak is from low DO bottom waters and sediments, as shown below.

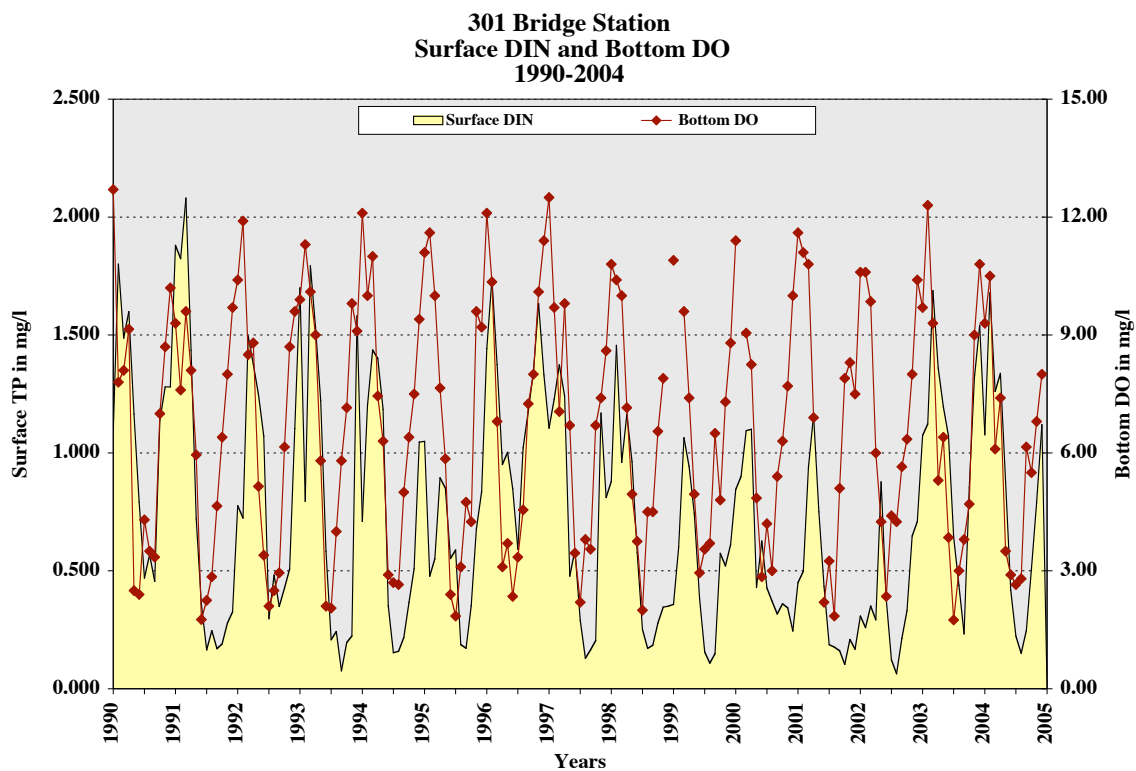


As with DIN pool dynamics, there were large increases in silica concentrations due to high river spring flows. These spring increases were followed by rapid depletion of silica by the plankton.

When the bottom waters do go anoxic, surface silica levels in July and August have doubled in concentration, often to 2.0 mg/l. The source of most of this increase is from the sediments. As the Lower Estuary mixes in September and the bottom DO level increases, the silica levels decrease rapidly to concentrations often less than 0.2 mg/l by the end of the calendar year. This suggests that, like TP, most of the silica recycles and resettles to the sediment.

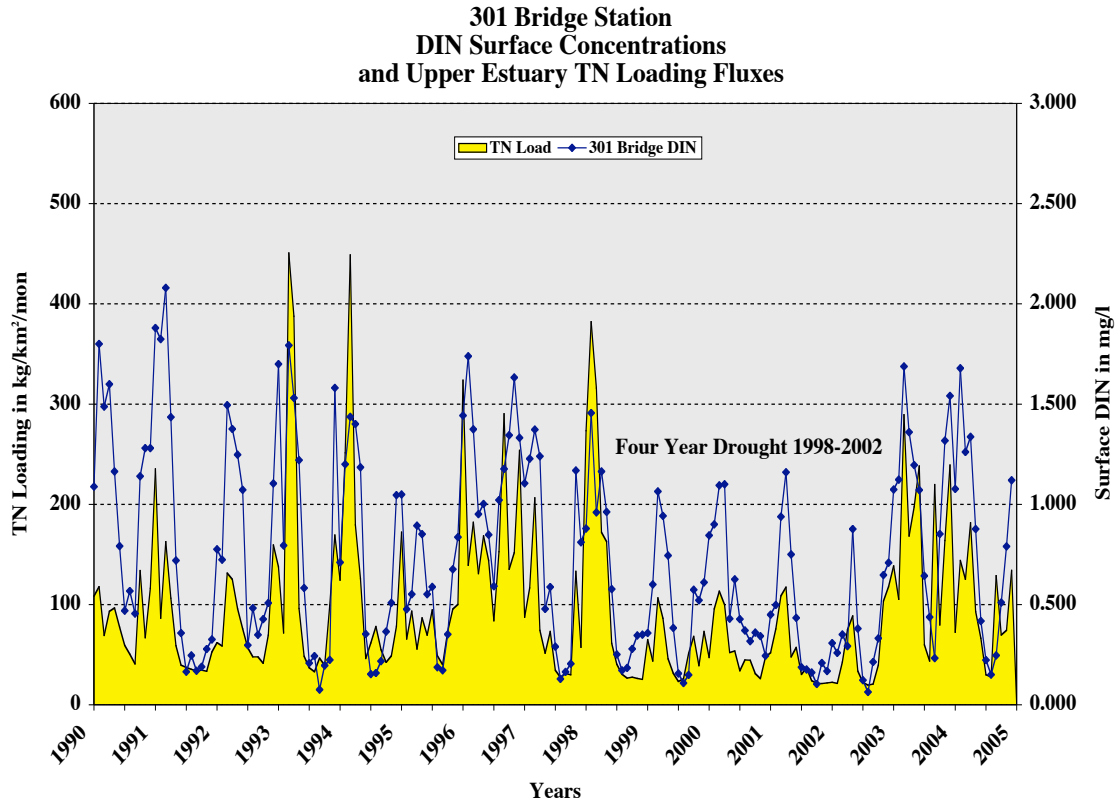
Nutrient Dynamics at the 301 Bridge Station

For the 301 Bridge Station, the assimilation of the surface DIN pool and the depletion of the bottom water DO were similar to Ragged Point, as shown below.



At the 301 Bridge Station, the surface DIN pools were depleted to about 0.2 mg/l by mid-summer and bottom water DOs were usually about +2.0 mg/l (see above). Even in a wet year, such as 1996, there was depletion of the surface DIN pool to 0.6 mg/l and bottom water DO to about 3.0 mg/l. In the low flow years of 1998 through 2002, the DIN pools were not fully replenished as they were in 2003 and 2004.

For a typical river-flow year for the 301 Bridge Station, the depletion of the DIN surface pool parallels that of TN loading reduction, as shown below.



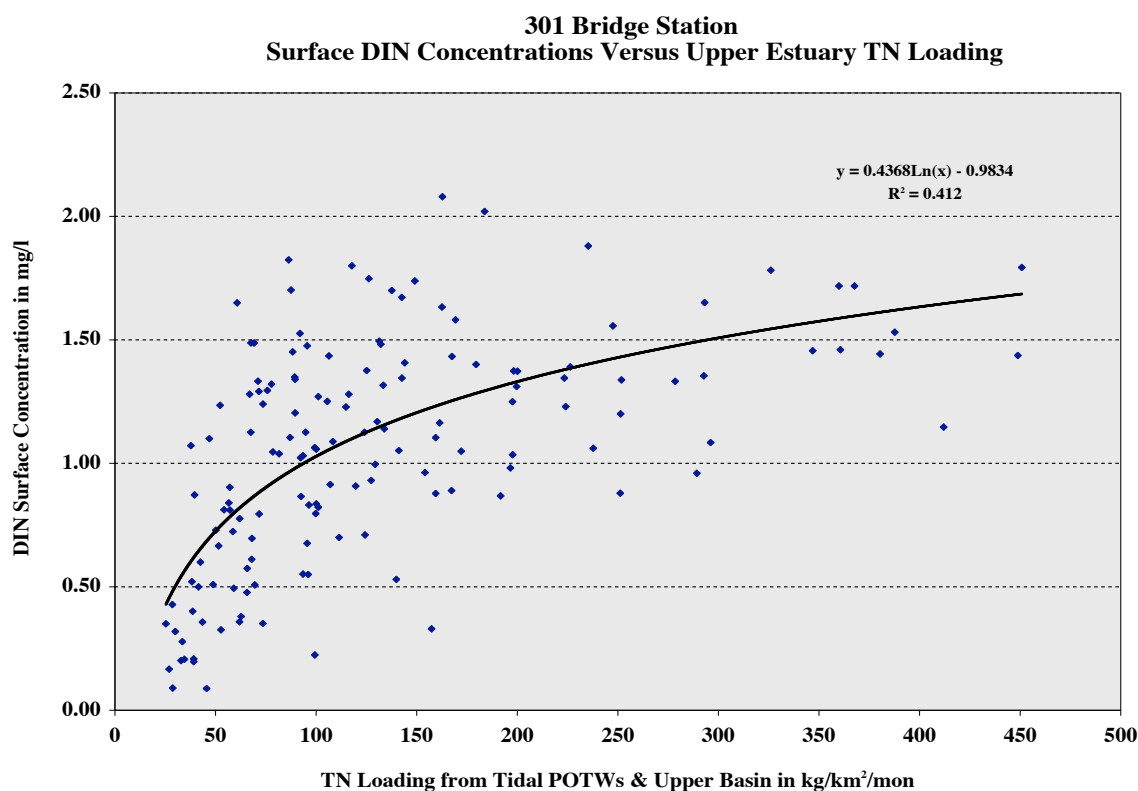
As the DIN pools were depleted by the spring-early summer plankton blooms, the TN loadings also decreased. Usually, the lowest TN loading occurred in the summer months when the loadings from the Upper Basin were the lowest.

While the depletion of the DIN pool and the reduction of the TN loading flux processes occurred at the same time, the two processes are independent. The algal blooms deplete the surface DIN pools from a concentration of 1.0-1.5 mg/l to often less than 0.2 mg/l by July. The spring monthly TN loading fluxes, ranging from 100 to over 300 kg/km²/month, decrease to around 50 kg/km²/month in the summer months.

The replenishment of the surface DIN pool is a function of the increased loadings from the Upper Basin in the fall and winter months and of the de-stratification and mixing of the Lower Estuary. As can be seen in the plot above, the surface DIN pool increased to about 1 mg/l in 1999 through 2002, even though the TN loadings were dramatically lower, with maximum TN loads of about 100 kg/km²/month. This suggests that over half of the replenished DIN pool is from recycled nitrogen, when the bottom nutrient-rich pools are mixed with the surface depleted pools.

The DO concentration of the bottom water begins to increase in August. By the end of the calendar year, it reaches a maximum. The replenishment of the surface DIN pool usually lags behind the bottom DO replenishment but coincides with the increase in TN loadings and the mixing of the Lower Estuary.

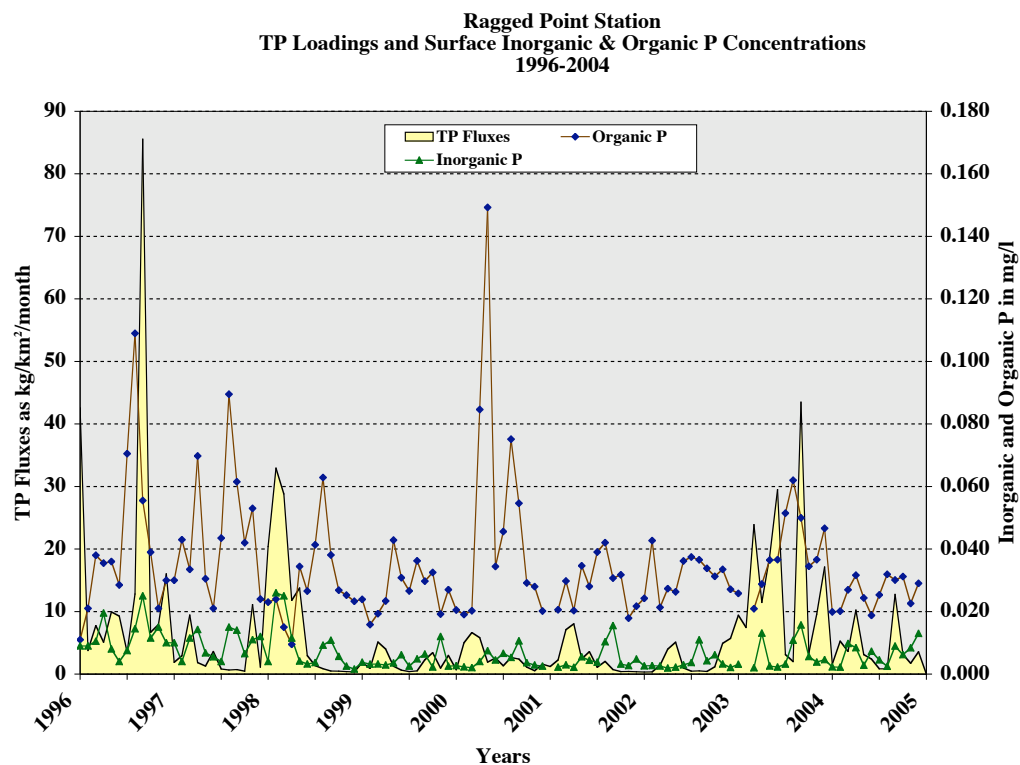
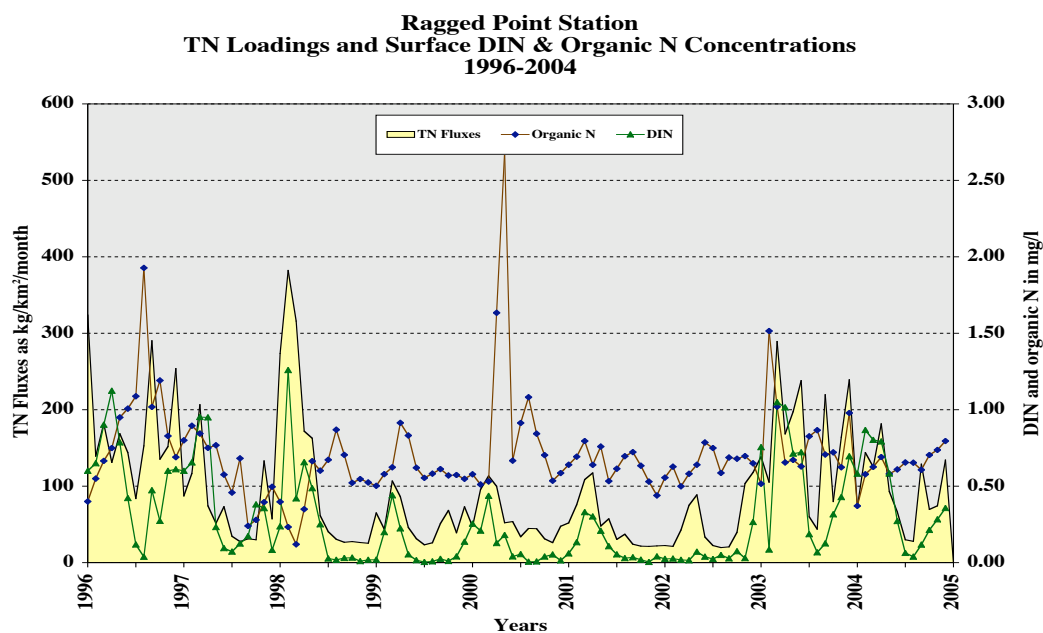
The surface DIN concentration at the 301 Bridge Station correlates with the Upper Estuary TN loadings, as shown below.



For years of fall and winter low riverine flow conditions, such as in 1991, 1992, 1999, 2000, 2001, and 2002, the loadings remain low for the entire year. However, the DIN pools were replenished, in part, by recycled bottom water nitrogen. In the relationship above, recycled nitrogen is not included in the TN load. Thus, that is why there is a lot of scatter in the relationship.

The importance of inputs, transformations, and transport of nutrients in the Chesapeake Bay, including the Potomac Estuary, has been well documented (5). These depletion-replenishment mechanisms, inputs, transformations, and transport processes are vital to the workings of the Chesapeake Bay Eutrophication Model (6). A recent study of hypoxia in the Chesapeake Bay from 1950 to 2001 (7) suggests that a 40% reduction of TN loadings from current levels will be required to eliminate or reduce anoxia in the main stem.

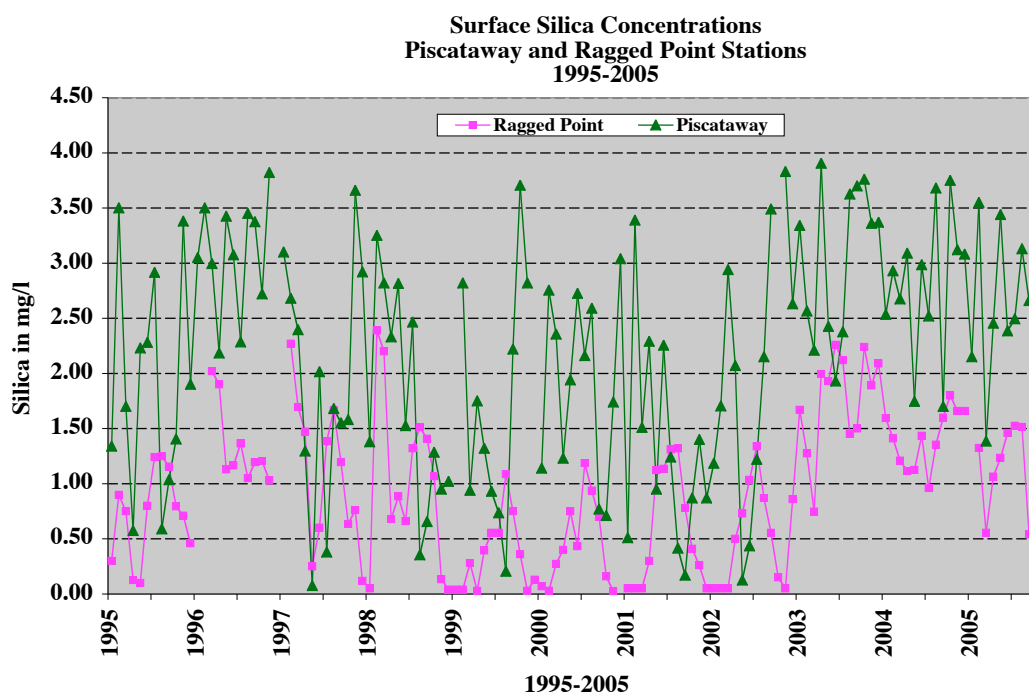
DIN, Organic Nitrogen, Inorganic Phosphorus, Organic Phosphorus (OP), and Silica Concentrations at the Ragged Point Station



As can be seen in the two graphs presented above, most of the phosphorus and most of the nitrogen were in the organic form for the Lower Estuary at the Ragged Point Station. The surface concentrations of organic phosphorus usually ranged from 0.02 to 0.04 mg/l, while the inorganic phosphorus concentrations were usually less than 0.01 mg/l. The surface concentrations of organic nitrogen usually ranged from 0.50 to 1.00 mg/l, while the inorganic nitrogen concentrations were often less than 0.08 mg/l in the summers.

The replenishment of the spring surface DIN pool was usually preceded by a large increase in TN loading flux. During the drought conditions of 1998 to the summer of 2002, the increase in surface inorganic phosphorus occurred in the late summers.

The surface silica concentrations for the Ragged Point and Piscataway stations for the period 1995 through 2005 are presented below. As can be seen in the graph, the major decreases in the Ragged Point Station surface silica concentrations were during the winter months of the drought years of late 1998 through 2002. During a typical river flow year, 1998, there was a large spring silica pulse followed by surface silica pool depletion by the plankton. There was also a large summer increase of surface silica concentration when the bottom waters went anoxic.



What is surprising is that the lowest silica concentrations at Ragged Point Station occurred during the winter months of the low river flow years of 1998 through 2002 (see above). The silica levels at the Piscataway Station were also lower than during the low river flow period 1998 through 2002, as shown above. Likewise, the silica riverine concentrations from the Upper Basin were often the lowest during the months of November to February, especially during low river flows. See scatter plots in Chapter Two for similar observations.

Understanding silica dynamics is scientifically challenging.

References for Chapter Eight

1. Kemp, W, M., *et al*, (2005), Eutrophication of Chesapeake Bay: Historical trends and ecological interactions, *Marine Ecology Progress Series*, Vol. 303.1-29.
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3. Boynton, W.R. and W. M. Kemp, (2000), Influence of River Flow and Nutrient Loads on Selected Ecosystem Processes, A Synthesis of Chesapeake Bay Data, *Estuarine Science*, Edited by J.E. Hobbie, Island Press, Washington, DC, pp 269-298.
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6. Cerco, C.F., (2000), Chesapeake Bay Eutrophication Model, *Estuarine Science*, Edited by J.E. Hobbie, Island Press, Washington, DC, pp 363-404.
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