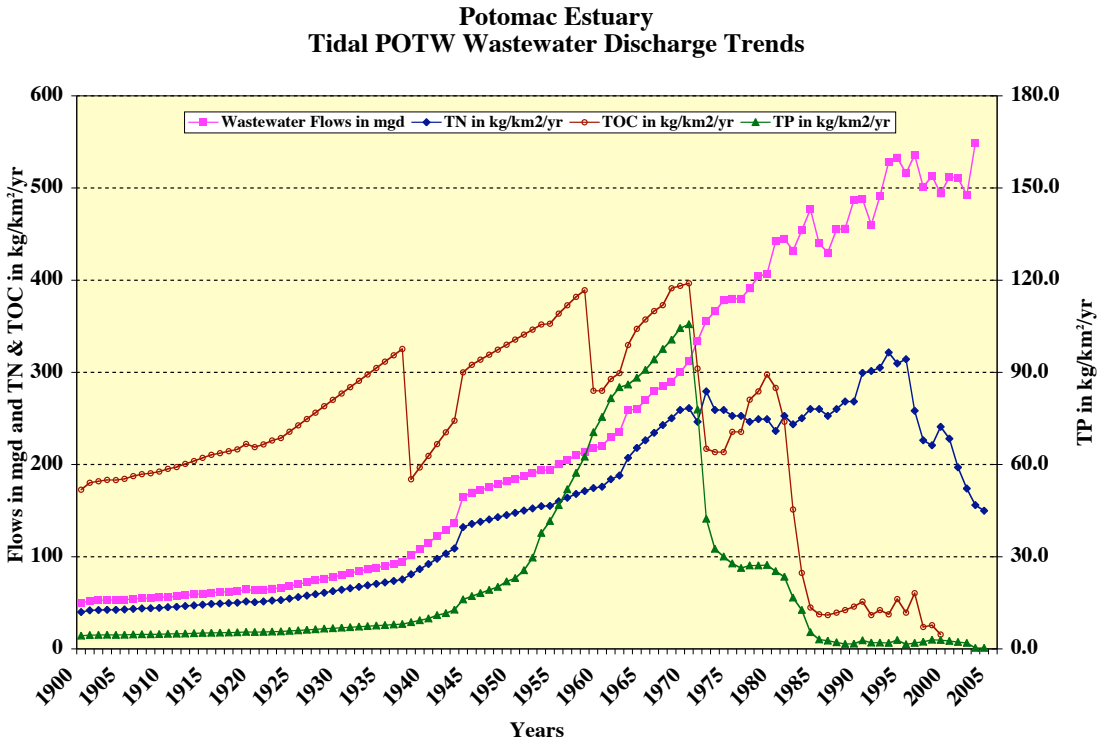
Chapter Five: Estuary Loadings from Wastewater Discharges Directly into Tidal Waters, Direct Air Deposition onto Tidal Waters, and Riverine Export

Average Annual Loading Trends from Wastewater Discharges Directly into Tidal Waters

In the early 1900s, about 50 mgd of mainly municipal wastewater effluents were discharged untreated into the Upper Estuary of the Potomac. The Blue Plains regional primary sewage treatment plant began operation in 1938. By the end of World War II, the wastewater flows had increased to about 150 mgd. Prior to the 1960s, there were no nutrient data on the quality of the wastewater discharges. Since 1980, monthly data characterizing the discharges has been compiled. In the late l990s, the wastewater flows had increased to over 500 mgd. Similar to the Upper Basin where data was missing, we estimated the contribution from wastewater discharges by using yearly population data, typical water use per capita, and typical effluent nutrient concentrations.

The TN loadings have increased from 30 kg/km^2/yr in the 1900s to over 300 kg/km^2/yr in the mid-1990s (see below).



Since the mid-1990s, TN from the POTWs has decreased to about 150 kg/km^2/yr, mainly due to denitrification at the Blue Plains Wastewater Treatment Plant, as presented above.

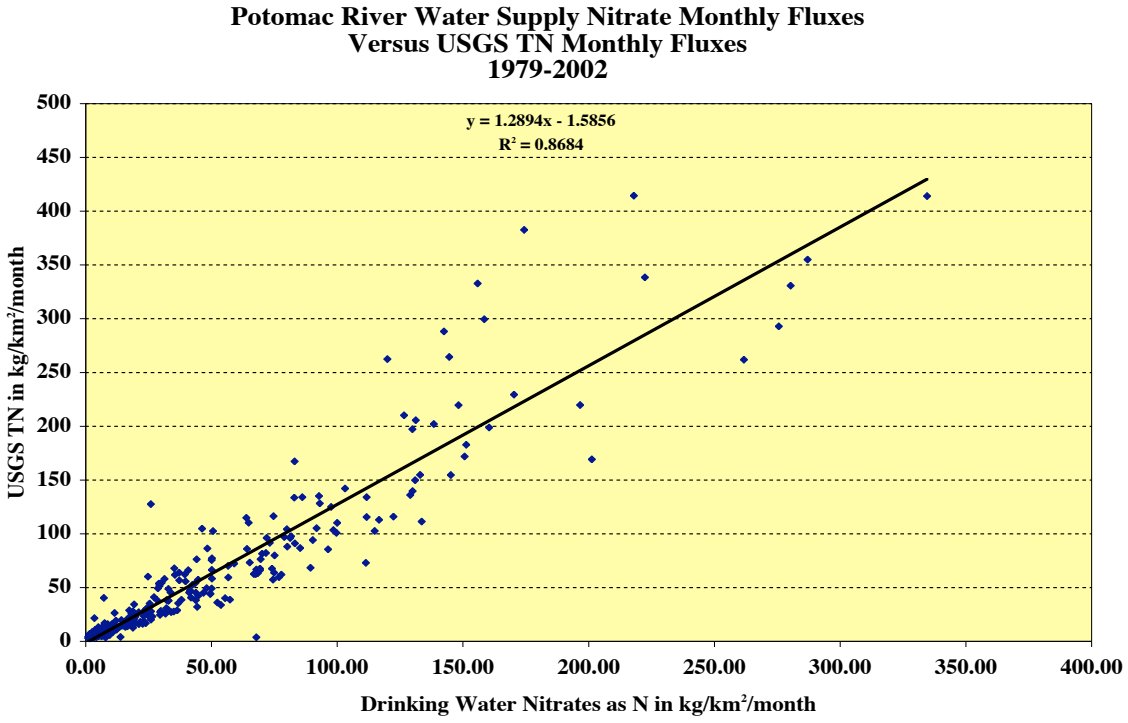
The TP loadings in the 1900s and 1920s were about 3 kg/km^2/yr, increased rapidly in the 1950s, and peaked in the1970s at 100 kg/km^2/yr (see above). The large decrease in the 1970s was due to the upgrading of the Blue Plains Wastewater Treatment Plant. Since 1985, the TP loadings were less than 2 kg/km^2/yr, mainly a result of TP removal by wastewater treatment facilities. Phosphate detergent bans by Maryland in 1985, the District of Columbia in 1986, and Virginia in 1987 also aided in decreasing TP loadings.

The BOD, or oxygen demanding matter (converted to TOC), in the untreated discharges was estimated to have been over 100 kg/km^2/yr in the 1900s (see above). The TOC loading increased to about 335 kg/km^2/yr in the late 1930s, after which many of the discharges began to receive primary treatment. Secondary treatment was provided in the early 1960s, with advanced treatment beginning in the late 1970s, further decreasing the TOC loading to less than 50 kg/km^2/yr.

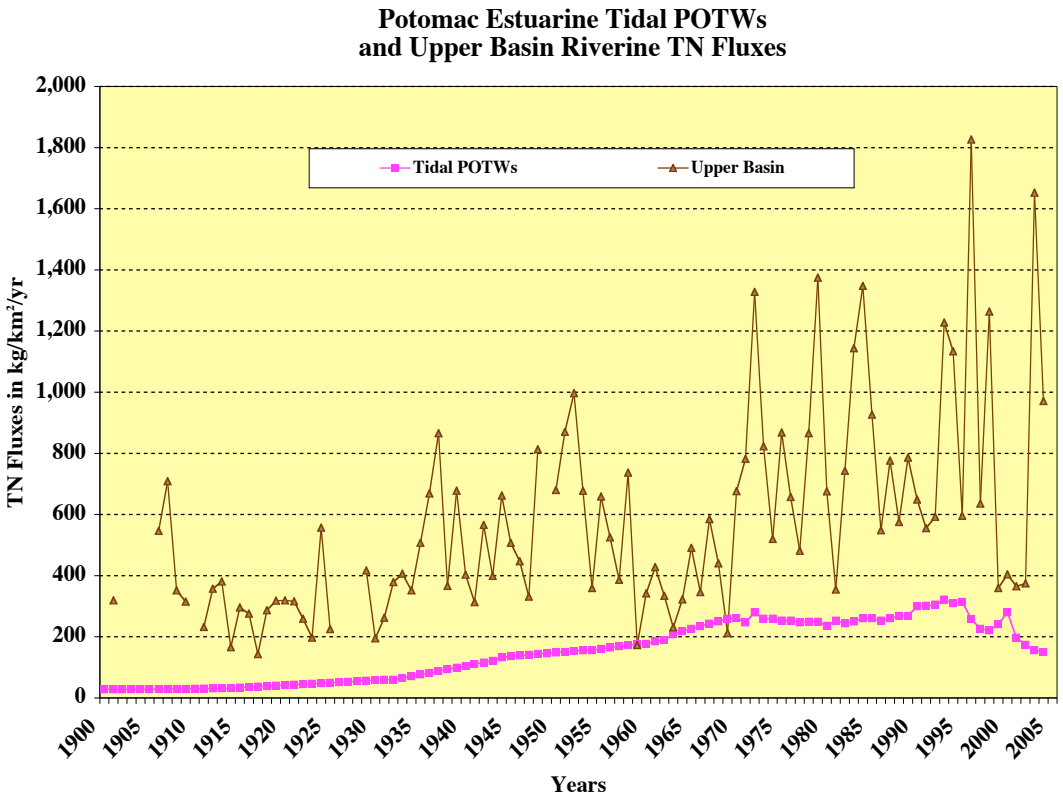
Upper Potomac Basin Average Annual Loading Trends

As we explained in Chapter Two, one of the longest monthly nitrate data records for the Upper Basin is from the analysis of untreated drinking water from 1905 to 2004. We also have USGS data from 1978 to 2004. There is a very significant relationship between the flux estimates for the common period of 1979 to 2002 (see below).

Using the linear relationship below, we estimated the TN fluxes for the 1905-1964 period from the drinking water data. Nutrient water quality monitoring began in 1965 by FWPCA (1) and was later transferred to EPA in 1970. These data were used to estimate the loadings from 1965 to 1978. USGS estimates were used from 1979 to the present.

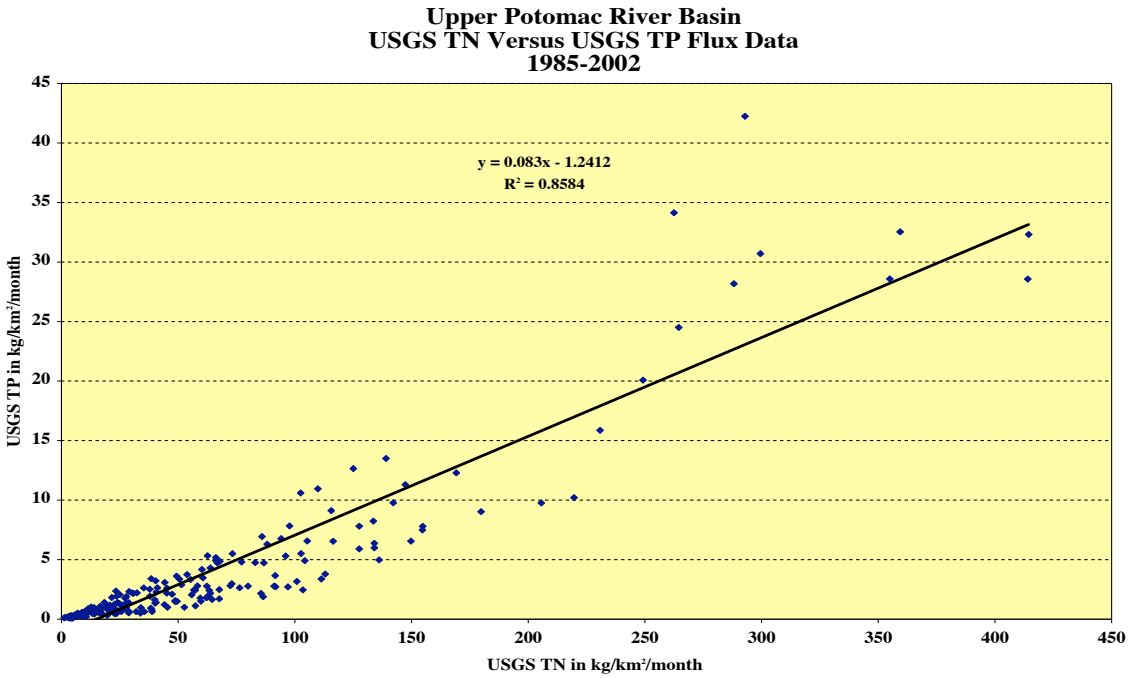


Annual TN loadings from the Upper Basin have increased from about 350 kg/km^2/yr in the late 1900-1910s to about 840 kg/km^2/yr in the 1995-2000 period, with a peak load of over 1,800 kg/km^2/yr in 1996 (see below).

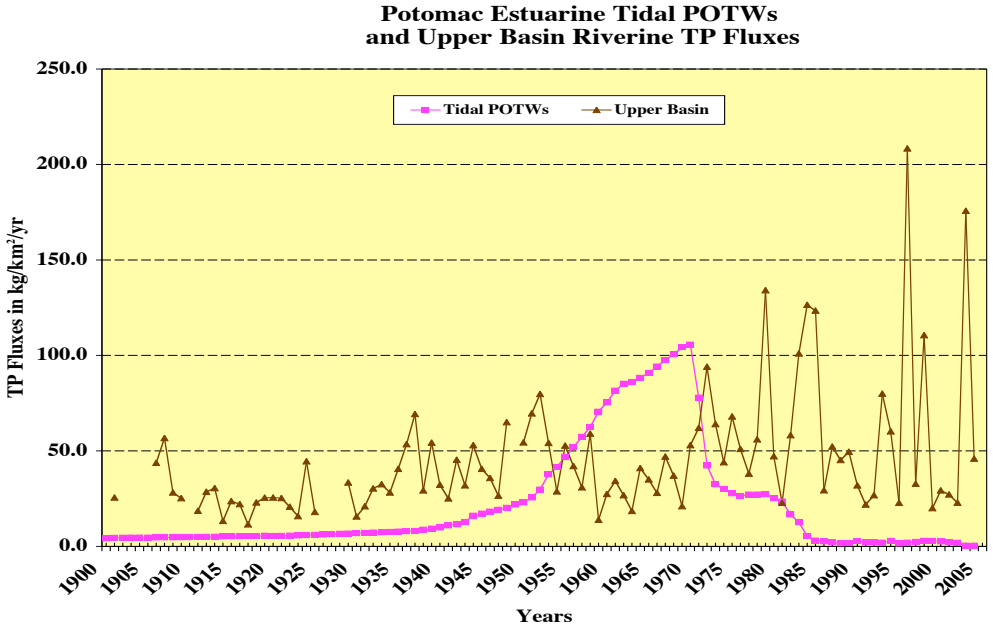


For the past 100 years, the Upper Basin TN contribution has been two to three times that from the direct POTW discharges, except in periods of low river discharge, such as in the 1960s, in 1999, and in the early 2000s, where the Upper Basin and the POTW average annual loadings were about 400 and 200 kg/km^2/yr respectively.

Similarly, we used the statistical relationship (see below) to extend the USGS TP Upper Basin data back to 1905. We limited the relationship to the months from 1985 to 2002 when the phosphate detergent bans began to be implemented. We realize that the relationship may not have been linear in the early part of the 1900s. Nevertheless, we used it to get an estimate of what the loading might have been. Wastewater effluent TP concentrations would be similar to those in the first part of the 1900s.

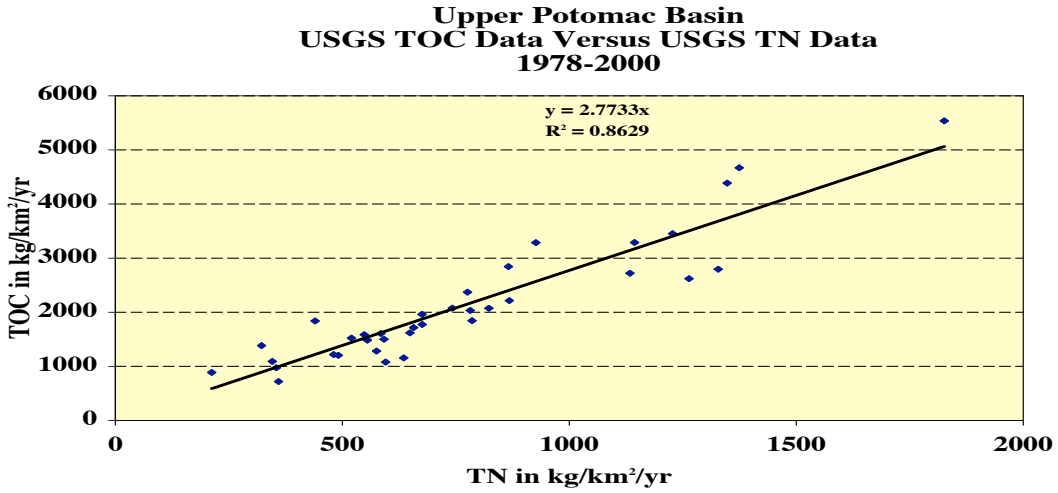


The estimated TP loadings from the Upper Basin have increased from about 25 kg/km^2/yr in the late 1900-1910s to about 45 kg/km^2/yr in the 1995-2000 period, with a peak load of over 200 kg/km^2/yr in 1996 and a large load over 150 kg/km^2/yr in 2003 (see below).

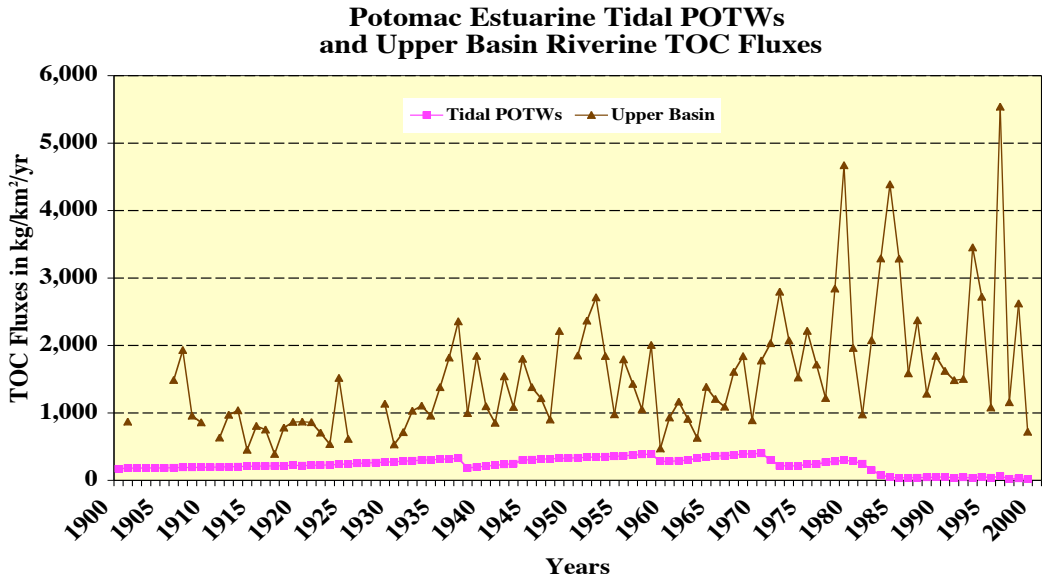


For the past 100 years, the Upper Basin TP contribution has been up to 10 times that of the direct tidal POTW discharges, except from the 1950s to the early 1970 period where TP loadings from direct tidal POTW discharges were about three times that of the Upper Basin (see above). The large increase in TP in the 1950-1970 time frame was mainly due to phosphate detergents.

We extended the USGS TOC data set from 1978 to 2000 using the TOC/TN relationship, as presented below.



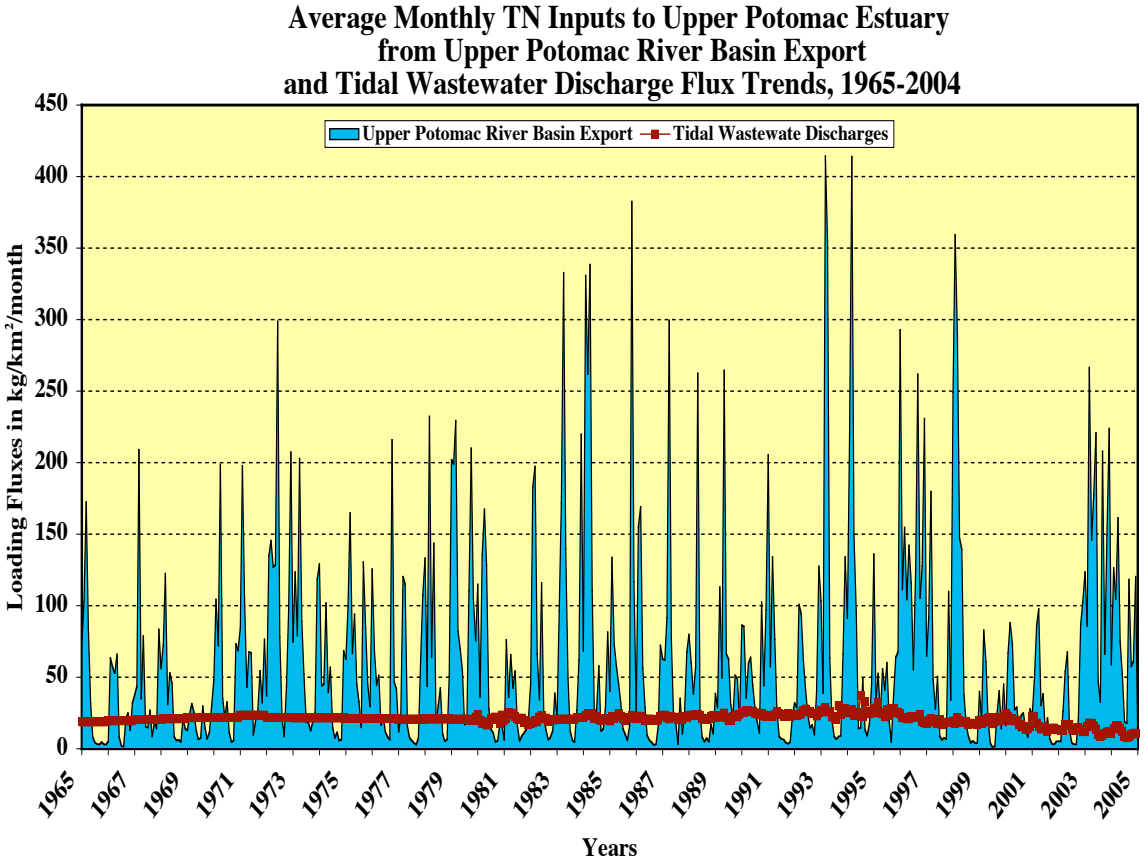
The estimates of TOC loadings from the Upper Basin have increased from about 865 kg/km^2/yr in the late 1900-1910s to about 2,320 kg/km^2/yr in the 1995-2000 period (see below).



The Upper Basin TN, TP, and TOC riverine exports have increased since the 1950s. Since 1970, there have been eight years when there were very large pulses of TOC exported from the Upper Basin into the Potomac Estuary.

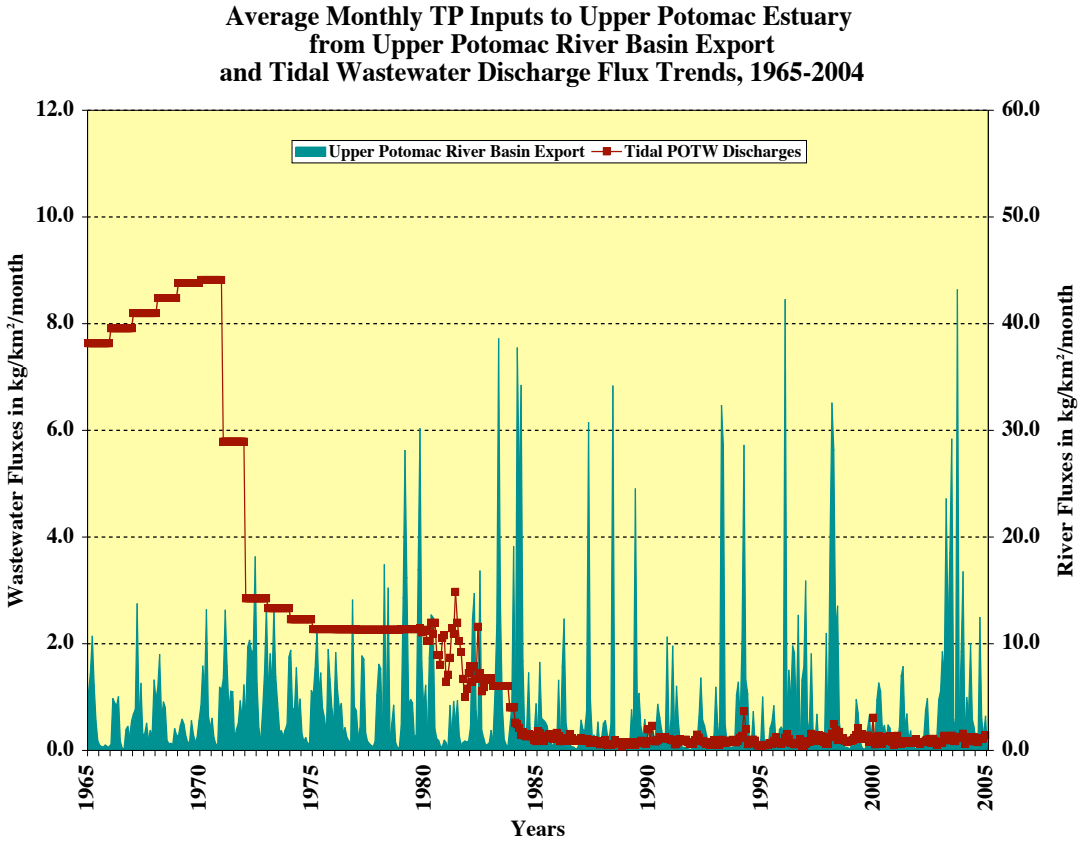
Monthly Variability of TN and TP Loadings for the 1965-2004 Period

A comparison of monthly TN inputs from the Upper Basin and direct tidal POTW discharges was made for the 1965-2004 period, as shown below. The direct tidal POTW discharge fluxes were based on the area of the entire Potomac River Basin (37,995 square kilometers).



The average monthly TN loading flux from the Upper Basin ranged from 1 to over 400 kg/km^2/month, with an average loading from the direct tidal POTWs of about 22 kg/km^2/month. In the early 2000s, the average monthly POTW loading had decreased to about 12 kg/km^2/month, responding to nitrogen removal at the tidal POTWs.

A comparison of monthly TP inputs from the Upper Basin and direct tidal POTW wastewater discharges was made and is shown below.



Since 1980, the average monthly TP loading flux from the Upper Basin was about 5.4 kg/km^2/month, with monthly highs of over 60 kg/km^2/month. The average loading from the direct tidal POTWs was about 0.2 kg/km^2/month.

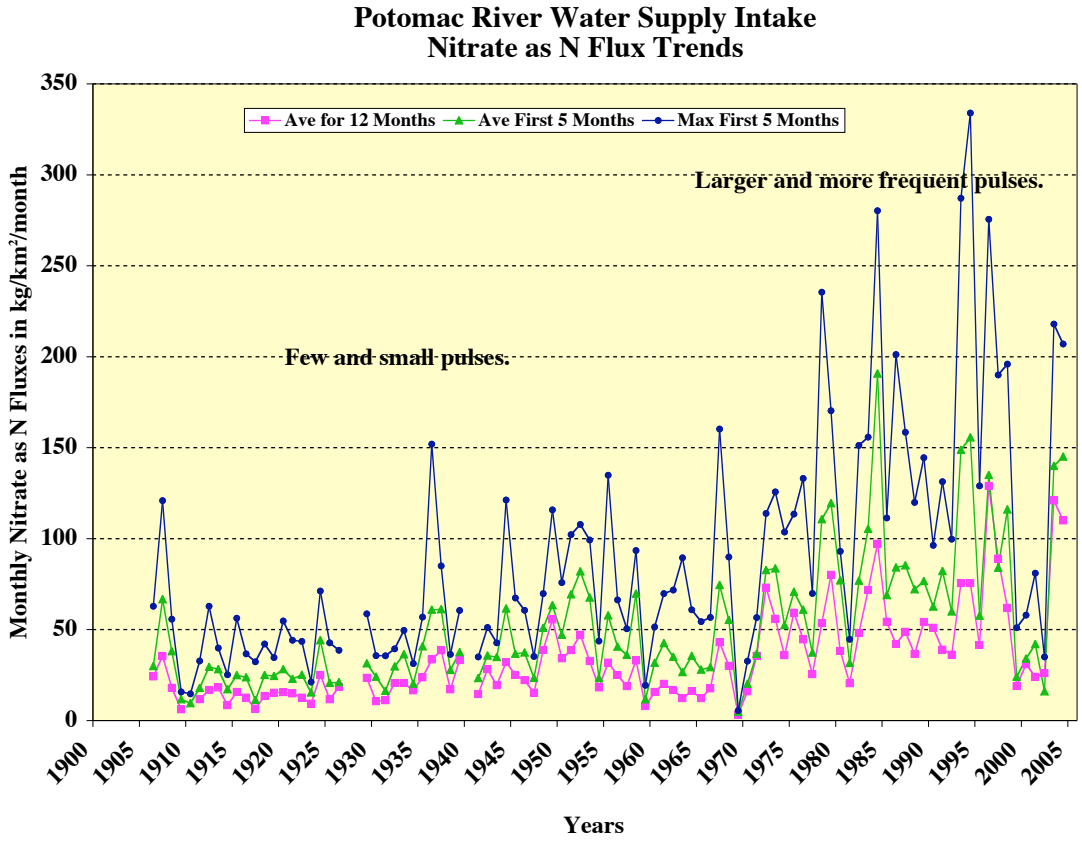
For the 35-year period from 1965 to 2002, there were 29 large monthly loading pulses of TN loadings of over 200 kg/km^2/month from the Upper Basin. From 1965 to 2004, there were 37 large monthly loading pulses of TP loadings of over 10.0 kg/km^2/month from the Upper Basin.

During low river flow months, the TN loadings from the Upper Basin were often below 5.0 kg/km^2/month, while loadings from direct tidal POTW discharges were over 20.0 kg/km^2/month. Since the 1980s, during low river flow months, the TP loadings from the Upper Basin were often below 0.1 kg/km^2/month, while loadings from direct tidal POTW discharges were less than 0.2 kg/km^2/month.

Nitrate Export Flux Trends from Upper Basin

The monitoring of the raw drinking water supply of the Potomac River above Washington, DC provides a unique opportunity to examine how the spring pulses have changed for the period 1905 to 2004. For the period 1900 to 1950 (see Chapter One), there were four years in which the average annual river flow was greater than 15,000 cfs. From 1950 to 2004, there were 12 years in which the average annual flow was greater than 15,000 cfs. When one examines the mean monthly flows for the two periods, there were 20 months in which the river flows were greater than 30,000 cfs in the 1900-1950 period. From 1950 to 2004 (a 54-year period), there were 45 years in which there was a mean monthly flow greater than 30,000 cfs. In Chapter Four, we showed that the percent of landscape loading inputs that are exported by the river in a given year is a linear function of the annual river flow.

With the annual and monthly river flows on an increase since the 1950s, we anticipated that the spring nitrate pulses have also increased. The average annual NO_3 exported from the Upper Basin has more than doubled for the period 1905 to 2004, increasing from a mean monthly load of about 20 kg/km^2/month to over 50 kg/km^2/month (see below).



As a result of the greater number of high flow months and increased loading of nitrogen to the landscape (see above), the **spring pulses** for the first five months of the calendar year **have increased in intensity and frequency**. Prior to the 1950s, there were only five years in which the maximum monthly loadings from the Upper Basin were over 100 kg/km^2/month for the first five months of the calendar year. From 1950 to 2004, there were 28 years in which the maximum monthly loadings from the Upper Basin were over 100 kg/km^2/month for the first five months of the calendar year. Twenty-six years had a maximum monthly load of less than 100 kg/km^2/month.

Total Estuary Nutrient Input Fluxes from the Upper Basin and Direct Tidal POTW Discharges

For the seven five-year periods beginning in 1965, the total nutrient input fluxes into the Potomac Estuary from the Upper Basin and from direct tidal POTW discharges are presented below.

Total Potomac Estuary Nutrient Input Fluxes
From Upper Basin and Estuarine Wastewater POTWs

Years	TN kg/km^2/yr	TOC kg/km^2/yr	TP kg/km^2/yr	Silica kg/km^2/yr
1965-69	723	1,629	158	1,099
1970-74	1,144	2,322	132	2,558
1975-79	1,127	2,607	104	1,690
1980-84	1,316	2,850	92	1,312
1985-89	1,188	2,183	63	1,126
1990-94	1,331	2,232	47	1,476
1995-99	1,357	2,321	86	2,523
2000-04	944	*NA	61	*NA

*Not Available

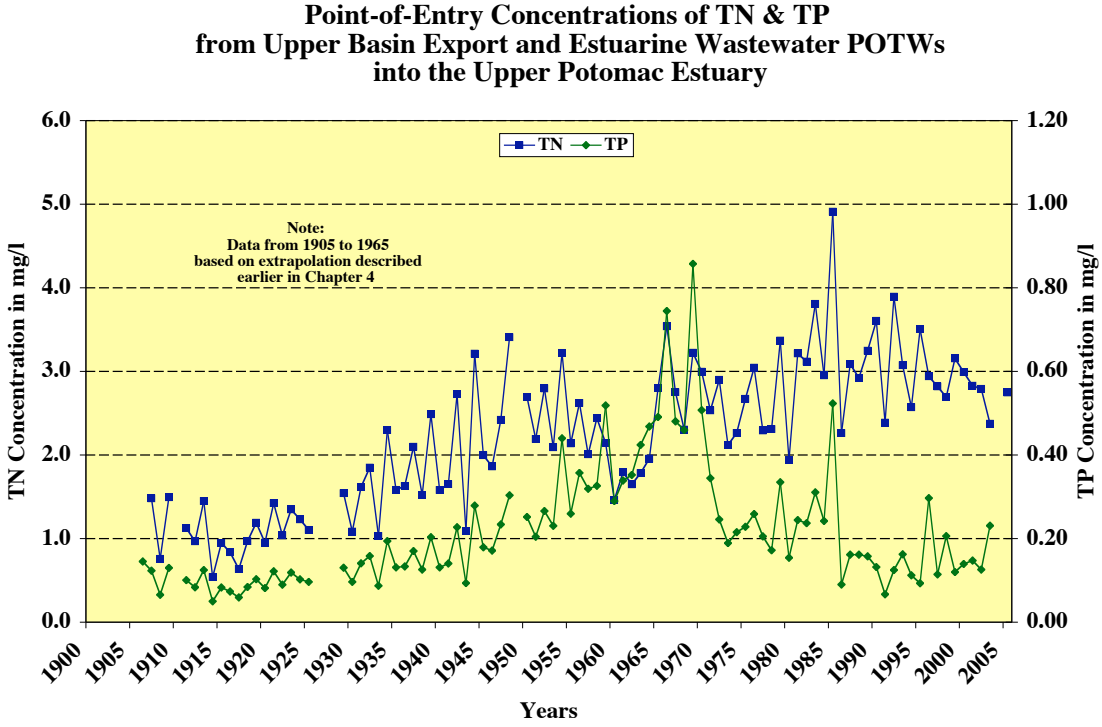
The TN input fluxes have increased from 730 kg/km^2/yr in the 1965-69 period to over 1,300 kg/km^2/yr in the early 1980s. During the past two decades, the TN input fluxes have remained fairly level with a rate around 1,300 kg/km^2/yr. For the three low-flow years beginning in the summer of 1998 to 2002, the annual TN fluxes were 500 to 600 kg/km^2/yr. The high-flow years of 2003 and 2004 had TN fluxes of 1,800 and 1,100 kg/km^2/yr respectively.

As a result of phosphorus removal in the direct tidal POTWs and the phosphate detergent bans, TP input fluxes have decreased from 158 kg/km^2/yr in the 1965-1969 period to an average of 66 kg/km^2/yr during the 1990s. Similar to TN, the TOC input fluxes have increased from 1,629 kg/km^2/yr in the 1965 to 1969 period to over 2,800 kg/km^2/yr in the early 1980s. During the past decades, the TOC input fluxes have remained fairly level with a rate around 2,270 kg/km^2/yr. The silica input fluxes varied, with an average rate of 1,680 kg/km^2/yr.

Point-of-Entry Concentrations of TN and TP for the Upper Potomac Estuary

One means of comparing or normalizing estuary nutrient loadings is to express the loadings in grams of a nutrient entering the estuary per square meter of estuary surface per year (gr/m^2/yr). Another means of comparison is the point-of-entry concentrations as computed for the estuaries of the Northeast USA (2). Summing the annual (or monthly) input fluxes from the riverine export from the Upper Basin and from the direct POTW loadings and dividing that sum by the annual (or monthly) river flow, we calculated the average annual (or monthly) point-of-entry concentration estimates. The point-of-entry concentration does not reflect any effect of tidal dispersion or diffusion.

The point-of-entry concentration comparison is especially applicable to long and narrow estuaries with the major tidal wastewater discharges located at the upper end of the estuary. The Potomac, Rappahannock, York, James, and Upper Chesapeake Bay are examples of these types of estuaries.



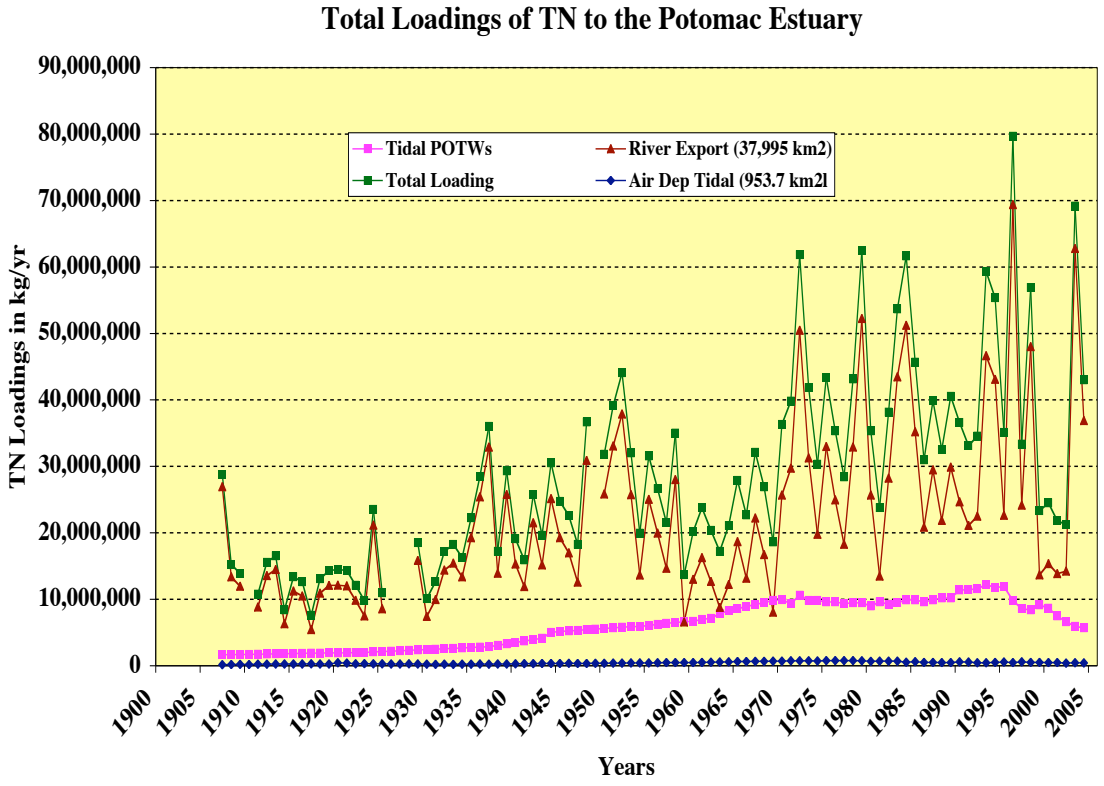
To aid in analysis of the impact of the combined inputs and annualized river flow, the point-of-entry TN and TP concentrations were estimated for the Upper Estuary (see above).

For the 1905-1920 period, the TN point-of-entry concentrations were about 1.0 mg/l, increasing to 2.0 mg/l in the 1950s, and increasing to 3.0 mg/l in the 1980s and 1990s. This analysis indicates that TN loadings to the Upper Estuary have increased by only 200% over the past century, which is less than suggested for most coastal waters (3).

For the 1905-1920 period, the TP point-of-entry concentrations were about 0.1 mg/l, increasing to 0.8 mg/l in the late 1960s, and then decreasing to 0.2 mg/l in the late1980s through the 1990s. This analysis indicates that TP loadings to the Upper Estuary have increased by only 100% over the past century, which is less than the expected three-fold increase reported for rivers flowing into the ocean (4).

Total Loadings of TN and TP to the Entire Potomac Estuary

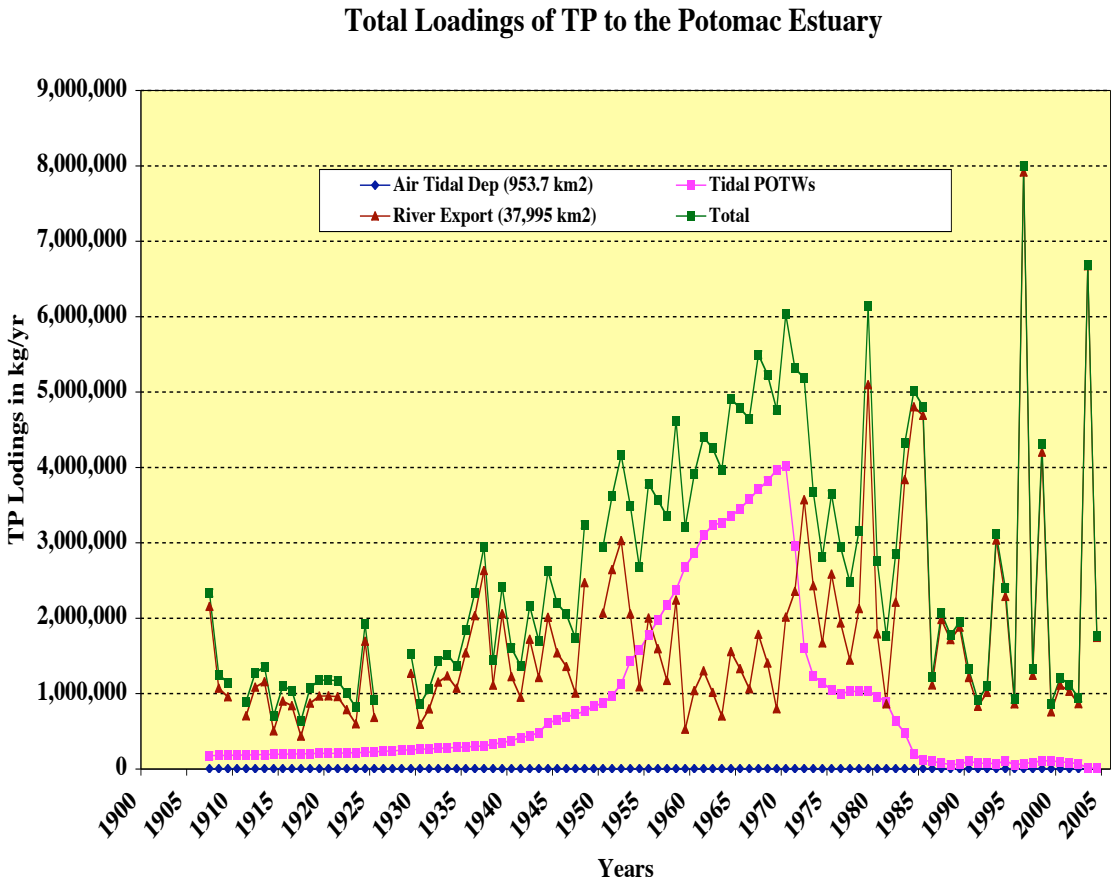
For the period from 1905 to 2004, estimates were made of TN and TP loadings to the entire Potomac Estuary. Estimates included inputs from direct air deposition on the tidal waters, from direct tidal POTW discharges, and from riverine export of the entire 37,995 km^2 drainage basin (see below). No long-term estimates of input to the Lower Estuary from the Chesapeake Bay were available.



The total TN loadings to the entire Potomac Estuary have increased from about 13,674,000 kg/yr in the late 1900-1910s to about 43,159,000 kg/yr from the 1980s to the summer of 1998 (see above). This is an increase of about 215%.

During the four low-flow years (1998-2002), the total TN loadings were 21,000,000 to 24,000,000 kg/yr, or only about 10% of the landscape loadings as described in Chapter Four. For the next two years (2003 and 2004), which were high-flow years, the TN loads were 69,000,000 and 43,000,000 kg/yr respectively. Riverine export was the major source of total TN loadings to the Upper Estuary.

The total TP loadings to the entire Potomac Estuary have increased from about 1,111,000 kg/yr in the late 1900-1910s to a high of about 6,000,000 kg/yr in the late 1960s. The TP loadings decreased to about 2,671,000 kg/yr for the 1980-2000 period (see below). This was an overall increase from the 1900s to early 2000s of 142%.



During the low-flow years of 1998 to 2002, total TP loading to the Potomac Estuary was about 1,000,000 kg/yr (see above). Only about 4% of the landscape input loadings of TP from the Upper Basin were exported to the Upper Estuary during these low-flow years.

As with TN loadings, riverine export was the major source of total TP loading. However, the large increase after World War II was due to phosphorus in soaps and detergents. The increase and decrease of phosphorus in soaps and detergents has been well documented by the USGS (5). The large decrease in TP load, beginning in the early 1970s, was due to phosphorus removal at the tidal POTWs.

References for Chapter Five

1. Jaworski, N. A., (1969), Nutrients in the Upper Potomac River Basin, U.S. Department of the Interior, Federal Water Pollution Control Administration, Middle Atlantic Region, Chesapeake Technical Support Laboratory, pp 40.

2. Roman, C.T., N. Jaworski, F.T. Short, S. Findlay, and R. S. Warren, (2000), Estuaries of the northeastern United States: habitat and land use signatures, *Estuaries* 23: 743-764.

3. Howarth, R.W., *et al*, (2002), Nitrogen Use in the United States from 1961-2000 and Potential Future Trends, *AMBIO*, Vol. XXXI, No. 4, pp 88-96.

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5. Litke, David W., (1999), Review of Phosphorus Control Measures in the United States and Their Effects on Water Quality, USGS, Water-Resources Investigations Report 99-4007, Denver, Colorado, pp 38.