Chapter Three: Sources of Landscape Loading Inputs to the Upper Basin

The first inventory of the point sources of pollution in the Upper Basin was published in 1898 by the USGS (1). The following sources of pollution were identified:

Source	Number
Coal mines	28
Flour/grist mills	88
Saw mills	23
Machine shops	6
Tanning shops	12
Pulp mills	3
Towns and villages	35

In the report, towns and villages with an aggregate population of about 75,000 inhabitants were listed as the principal causes of pollution.

The US PHS compiled the first complete inventory of water uses and wastewater loadings in the Potomac River Basin in 1958. This compilation was expanded as part of the United States President's Water Quality Sub-Task Force Study and as part of the Chesapeake Bay-Susquehanna River Basins Project by FWPCA. The report, issued in December 1968, indicated that there were about 384 known wastewater discharges in the Potomac River Basin.

The first comprehensive analysis of the nutrient concentrations and loadings from domestic wastewater, industrial discharges, and land runoff was conducted and published by FWPCA in August 1969 (2). The FWPCA report also describes the first major nutrient survey, conducted in 1966.

An assessment of nonpoint pollution in the Potomac River Basin was published by ICPRB (3) in June 1975. The focus of the report was on acid mine drainage, sediment pollution, bacterial pollution, and nutrients. A watershed nitrogen and phosphorus mass balance of the Upper Potomac River Basin was published in 1992 (4).

In 2002, the international SCOPE Project on Nitrogen Transport and Transformation (4) included the Upper Potomac Basin as part of a nitrogen mass balance for 16 major watersheds of the Northeast USA.

The sources of nitrogen to the Upper Potomac Basin were:

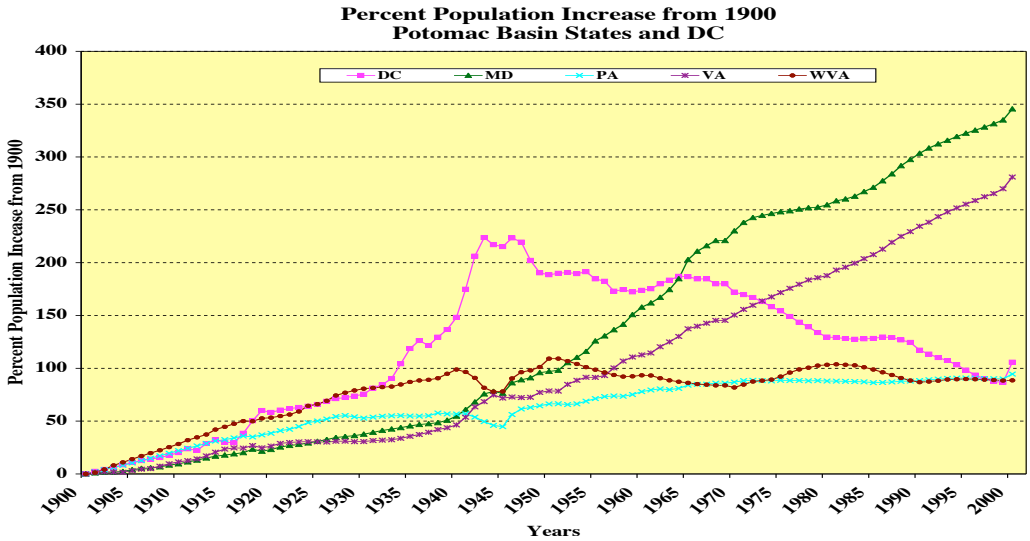
Source	**kg N/km^2/year**
NO_y deposition	714
NH_x deposition	255
Org N deposition	174
Fertilizer use	1,024
Forest fixation	271
Agricultural fixation	1,173
Import in feed	2,085
Total	5,696

Of the 16 watersheds in the SCOPE study, the Upper Potomac River Basin had the highest unit area of input sources at 5,696 kg N/km^2/yr.

As part of the NAWQA Program and as part of the Chesapeake Bay Program, the USGS synthesized nutrient data and loadings for the Potomac River in 1995 (6) and 1996 (7), including point and nonpoint sources.

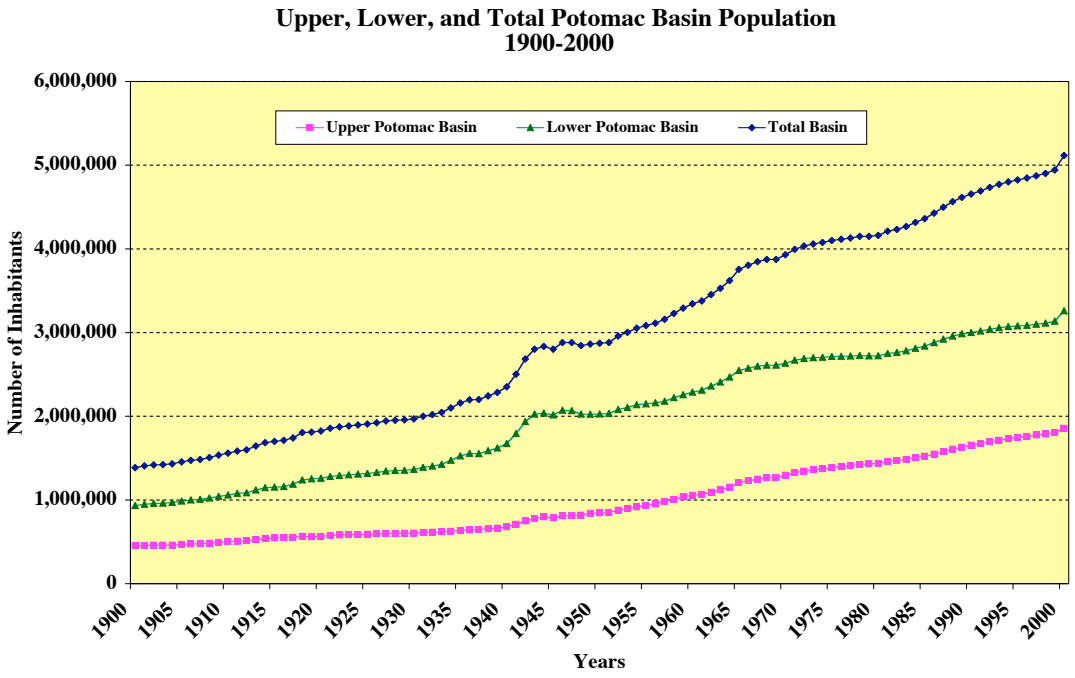
Population and Wastewater Trends

In the early 1900s, about 17% of the Upper Basin population of 452,000 lived in small towns and villages. The population of the District of Columbia was about 278,000. The percent of population increase since 1900 in the four states of the Potomac River Basin and the District of Columbia is presented below.



During World War II, the population of the District of Columbia increased over 200% from 1900 levels. The largest percent increases over the past century were for Maryland at 345% and for Virginia at 288%.

By the year 2000, Upper Basin population increased from about 500,000 in the 1900s to about 1,856,000 inhabitants, as shown below.



In the early 1900s, many of the small Upper Basin communities did not have sewers. Only a few of the sewered communities used septic tanks as a means of wastewater treatment. The domestic wastewater of many of the sewered communities flowed into nearby streams. By 1968, the sewered population had increased to 403,000, or 33% of the population of about 1,250,000. The 1969 FWPCA report estimated that about 2,230,000 pounds of phosphorus per year and 4,000,000 pounds of nitrogen per year were from domestic wastewater that discharged into the Upper Basin. For the year 1990, the USGS (6) estimated that about 59% of the domestic wastewater nitrogen and about 49% of the phosphorus came from sewage treatment discharges.

For the year 1986, Lugbill (8) compiled the first comprehensive nutrient source inventory of the Potomac River Basin. The reported loadings for the Upper Basin were as follows:

Source	**Nitrogen Pounds/yr**	**Phosphorus Pounds/yr**
Municipal	3,185,000	1,989,000
Industrial	3,303,000	985,000
Total	6,488,000	2,974,000

For 1990, the USGS (7) estimated the amount of nitrogen and phosphorus inputs from wastewater discharges. The estimated loadings are listed below.

Source	**Nitrogen Pounds/yr**	**Phosphorus Pounds/yr**
Municipal	5,620,000	792,000
Industrial	1,590,000	403,000
Septic Tanks	3,938,000	1,273,000
Total	6,090,000	2,468,000

The CBPO inventory has the following loadings from wastewater discharges, not including septic tanks (see below).

Year	**Nitrogen Pounds/yr**	**Phosphorus Pounds/yr**
1985*	4,200,000	1,300,000
1999	5,002,000	724.000
2000	5,331,000	987,000
2001	4,400,000	987,000
2002	4,805,000	1,053,000

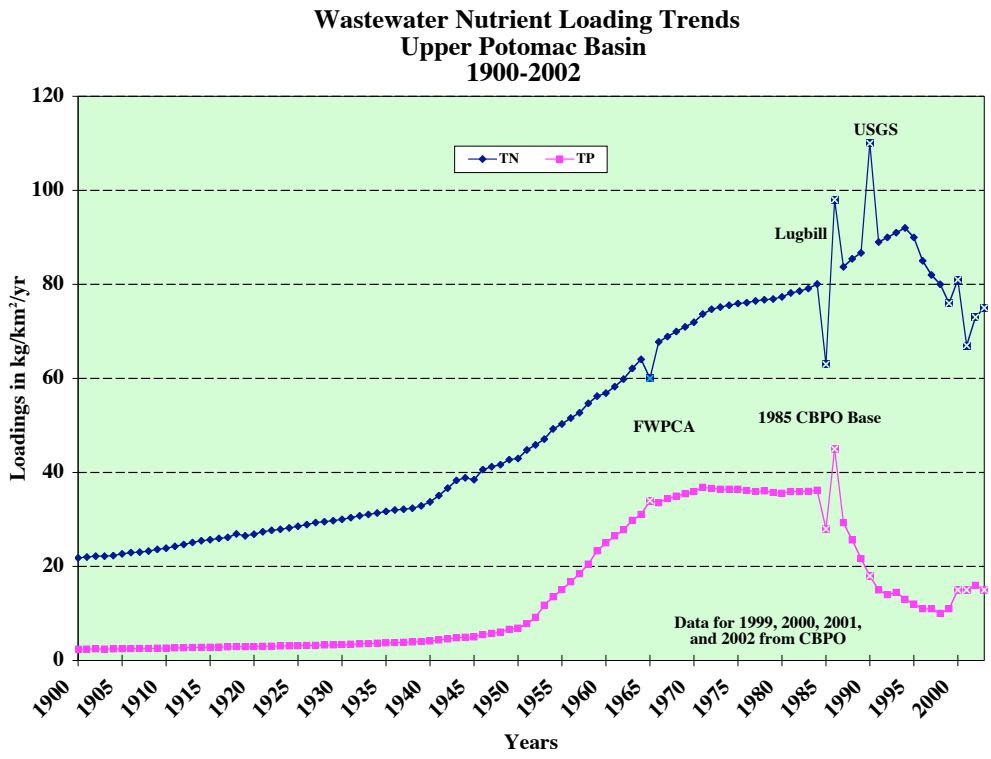
* CBPO base year

The Lugbill, USGS, and CBPO wastewater loading estimates are in good agreement.

For the years where there were no inventory data, we estimated the contribution of nutrients from the data above and from wastewater discharges by using yearly population, typical water use per capita, and typical nutrient concentrations, as presented below.

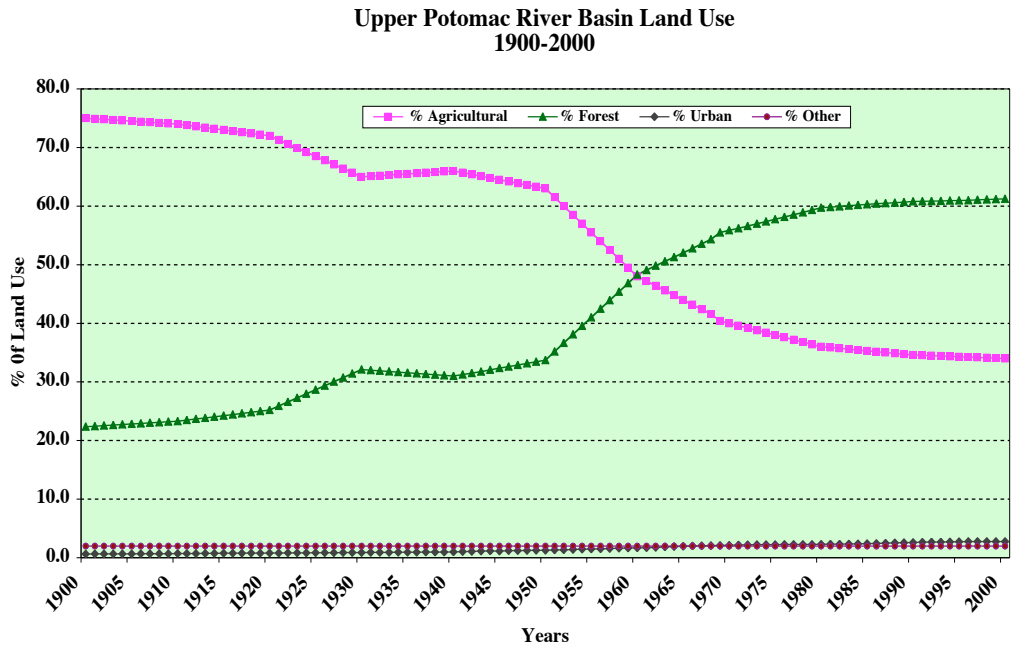
As can seen in the figure below, the FWPCA, USGS, Lugbill, and CBPO base estimates fall along our calculated curves. More recent TN and TP loadings for 1999 through 2002 have been compiled by the CBPO. The CBPO loading estimates suggest that the TP loadings have leveled off, while the TN loadings have decreased. The CBPO loadings better reflect estimates of loadings from the Upper Basin POTWs.

The increases in TN follow the increases in population. For TP, the large increase was due to the addition of phosphorus to soaps and detergents after World War II. When phosphorus was removed from soaps and detergents, there was a large decrease in TP.



Land Use Trends

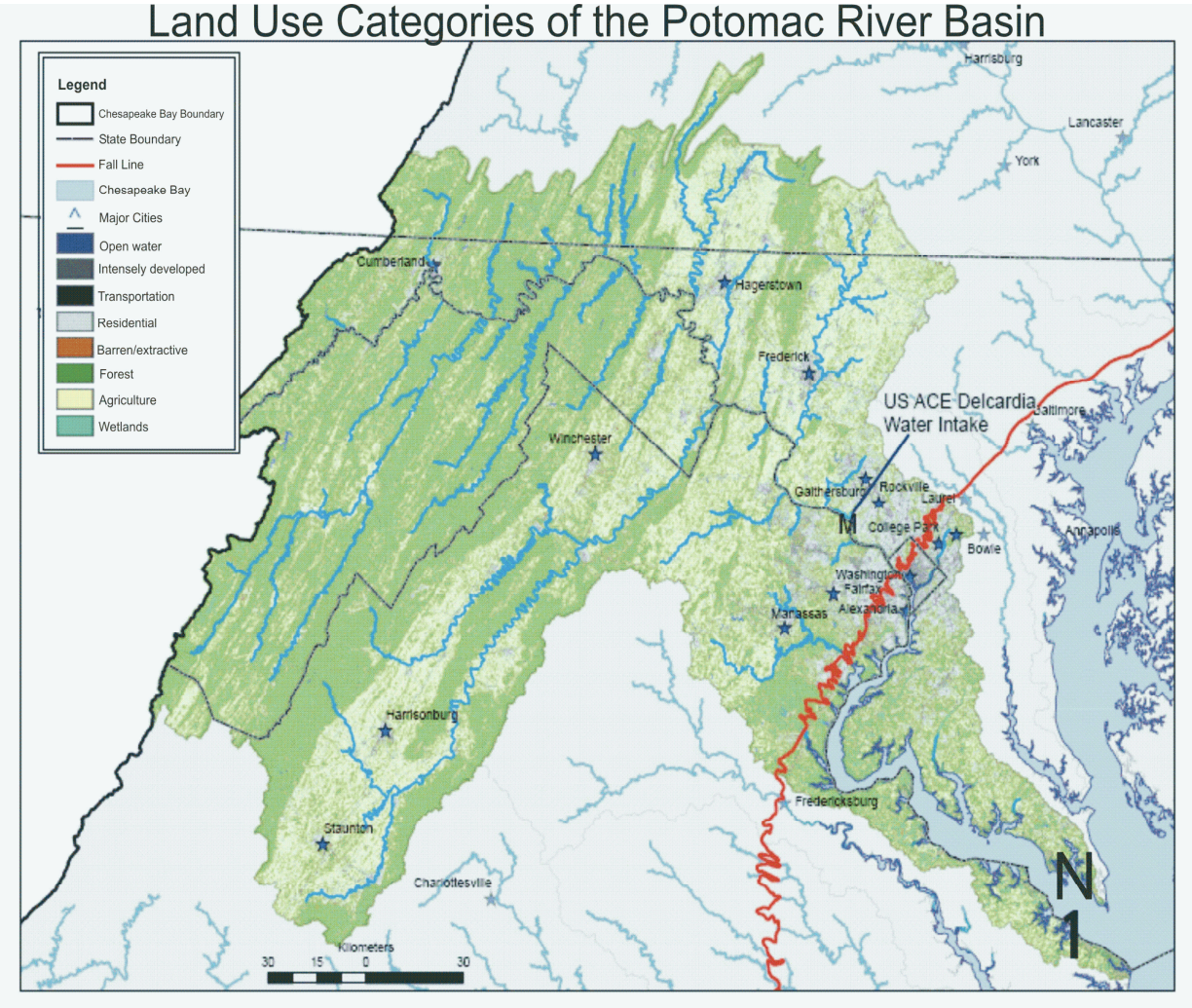
In the early 1900s, the Upper Basin was rural with the economy based on agriculture, wood products, and coal mining. In the early 1900s, about 75% of the Upper Basin land was used for agriculture while 22% was in forest (see below).



By the 1990s, agricultural use had decreased to 35% and forestland had increased to 61%. The major changes in land use occurred in the period from 1950 to 1975.

In Chapter One, we presented the land use category estimates based on SCOPE and USGS data. Presented below is a map specially developed for this treatise by the CBPO. The CBPO has eight land use categories, instead of the four presented in Chapter One.

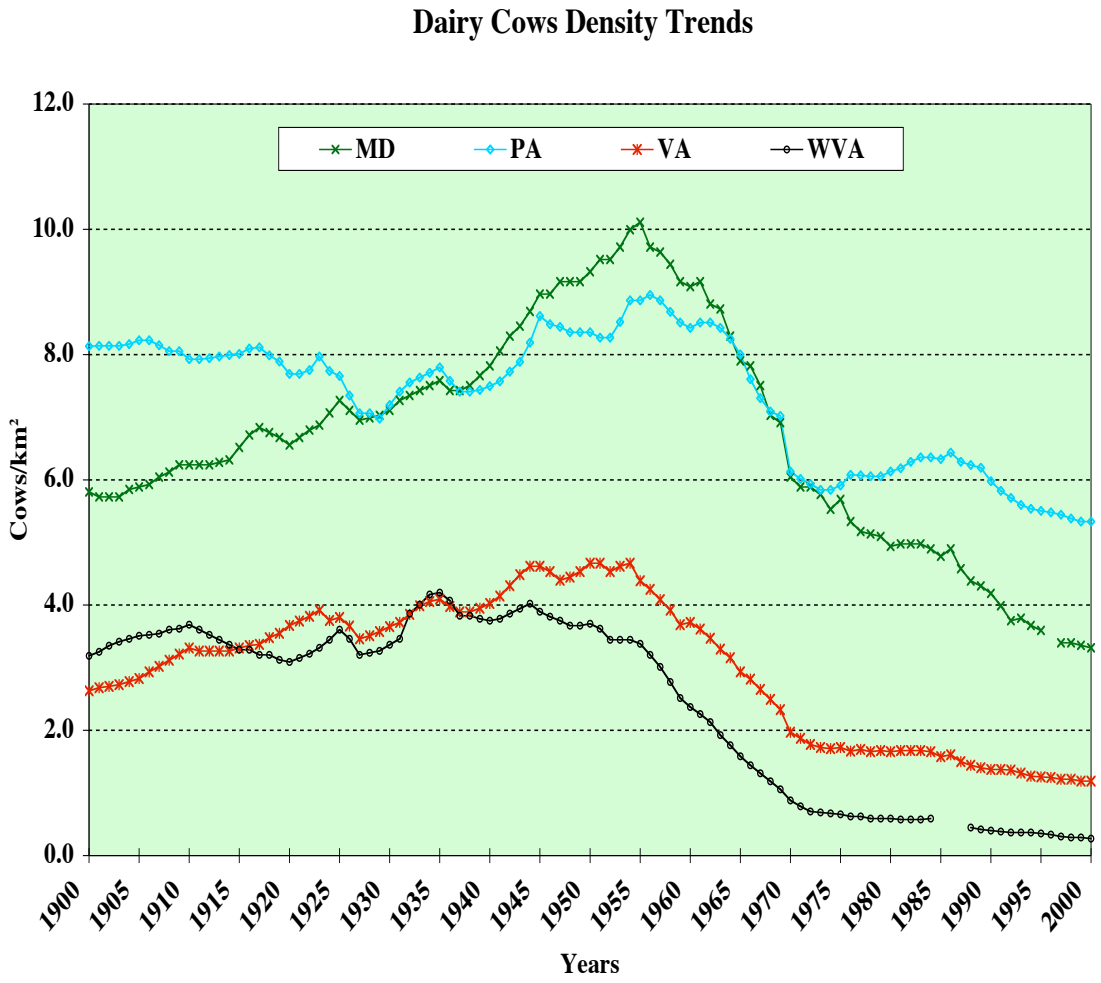
As can be seen in the map below, the headwaters of the Potomac River Basin are forestlands, except for the South Fork of the Shenandoah. The agricultural lands are mainly in the sub-basins above Washington, DC and in the Shenandoah River watershed.



Source: CBPO

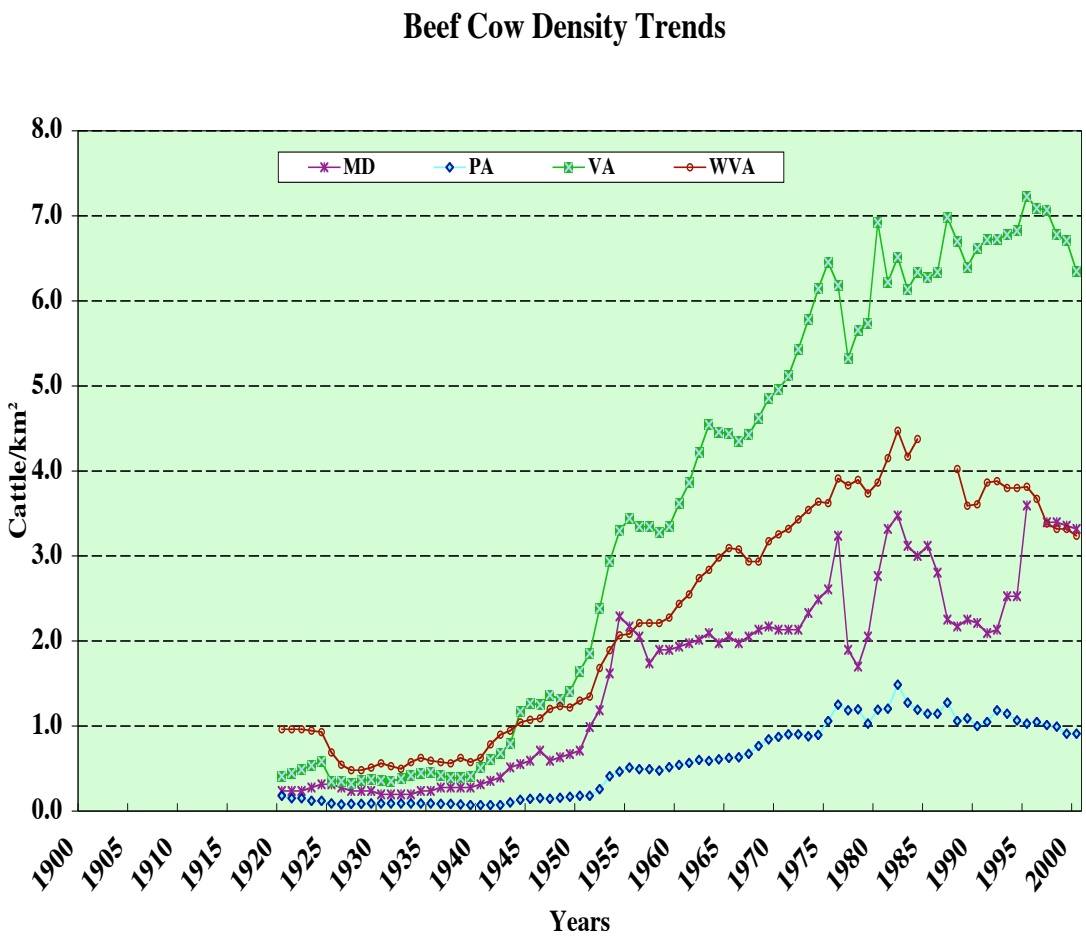
Animal Production Trends

There were also major changes in animal and crop production during the past century. The dairy cattle density for Pennsylvania and Maryland in the early 1900s was about 8 and 6 cows/km^2 and increased to 10 and over 8 respectively in the 1950s (see below).



The dairy cow densities in Virginia and West Virginia increased to about 4 cows/km^2 in the 1950s, as presented above. For the states of Maryland, Virginia, and West Virginia, the densities decreased dramatically to the lowest levels in the 1990s. While the dairy cattle densities in the 1990s were low compared to the early 1900s, annual milk production increased from about 5,000 pounds/year/cow (8) in the early 1900s to about 15,000 to 18,000 pounds/year/cow (9) in the 1990s. One dairy cow excretes 166.5, 29.5, and 80.5 kgs of nitrogen, phosphorus, and potassium per year respectively.

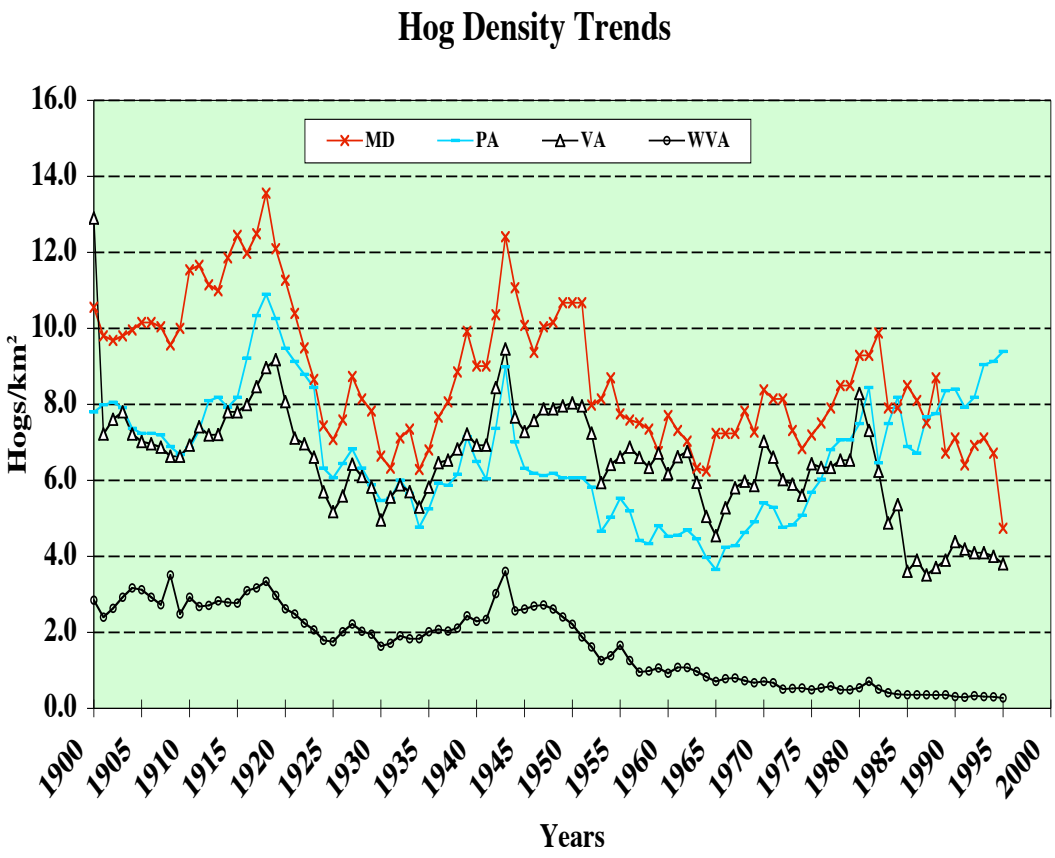
While dairy cow densities have decreased during the past century, beef cow densities have increased, especially since the 1950s (see below).



The largest beef cow density increase has been in Virginia, where in the 1990s the density was about 6.5 beef cows/km^2, with Maryland and Pennsylvania about 3.5 beef cows/km^2. When one drives through the Shenandoah Valley of the Upper Potomac River Basin, large herds of beef cattle can be seen grazing in the pasture at all times of the year.

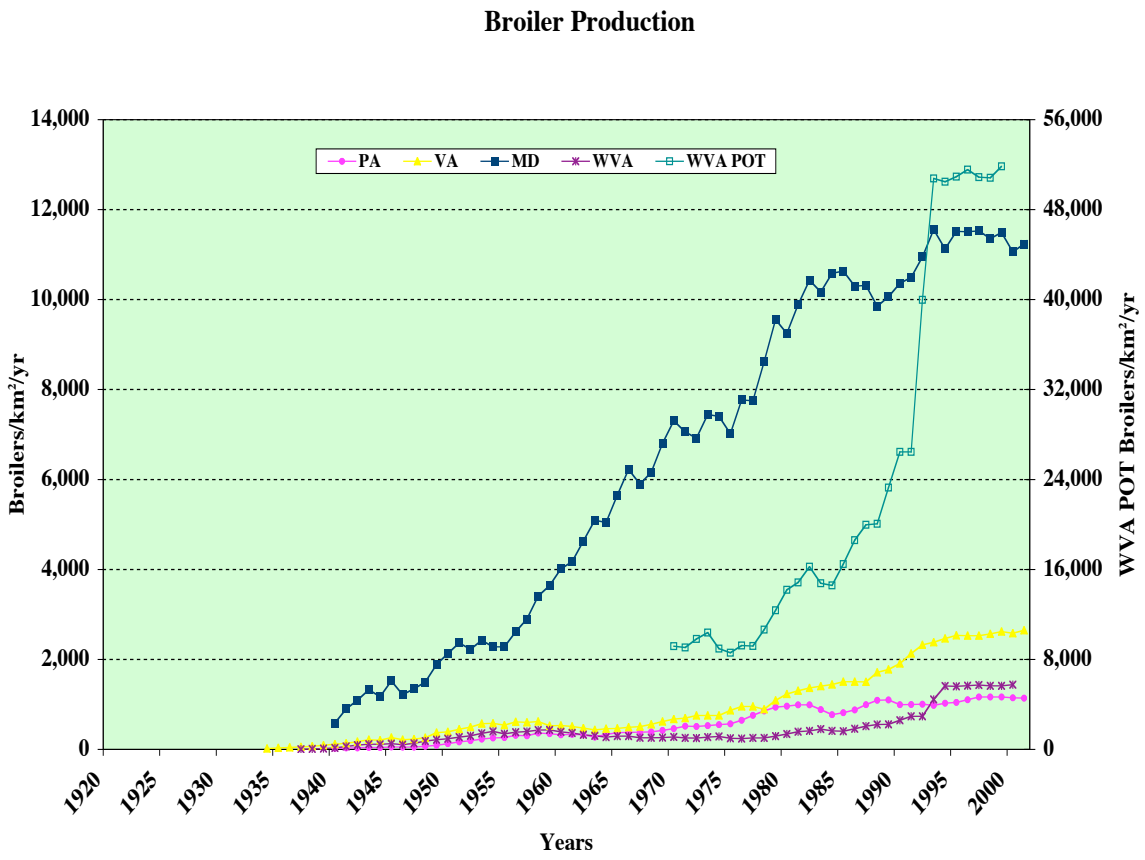
The switch from dairy to beef production had a major impact on animal nutrient needs and animal waste production in terms of annual kg manure/animal/year. Dairy cows require over twice the annual nutrient intake of beef cows and excrete nearly twice as much nitrogen and approximately three times as much phosphorus and potassium. One beef steer excretes 59.6, 10.5, and 26.8 kgs of nitrogen, phosphorus, and potassium per year respectively.

Hog production in Maryland, Virginia, and West Virginia has declined for the past century, except for an upturn during World War II (see below).



Pennsylvania hog production has remained fairly constant over the past 100 years, with the lowest density during the Depression in the 1920s and 1930s and again in the late 1960s. Maryland and Virginia hog production trends were similar to Pennsylvania. However, during the past 30 years in Pennsylvania, hog production has increased to a density of over 8 hogs per square kilometer, while hog production decreased in both Maryland and Virginia. One hog excretes 5.8, 0.9, and 1.9 kgs of nitrogen, phosphorus, and potassium respectively, per life cycle.

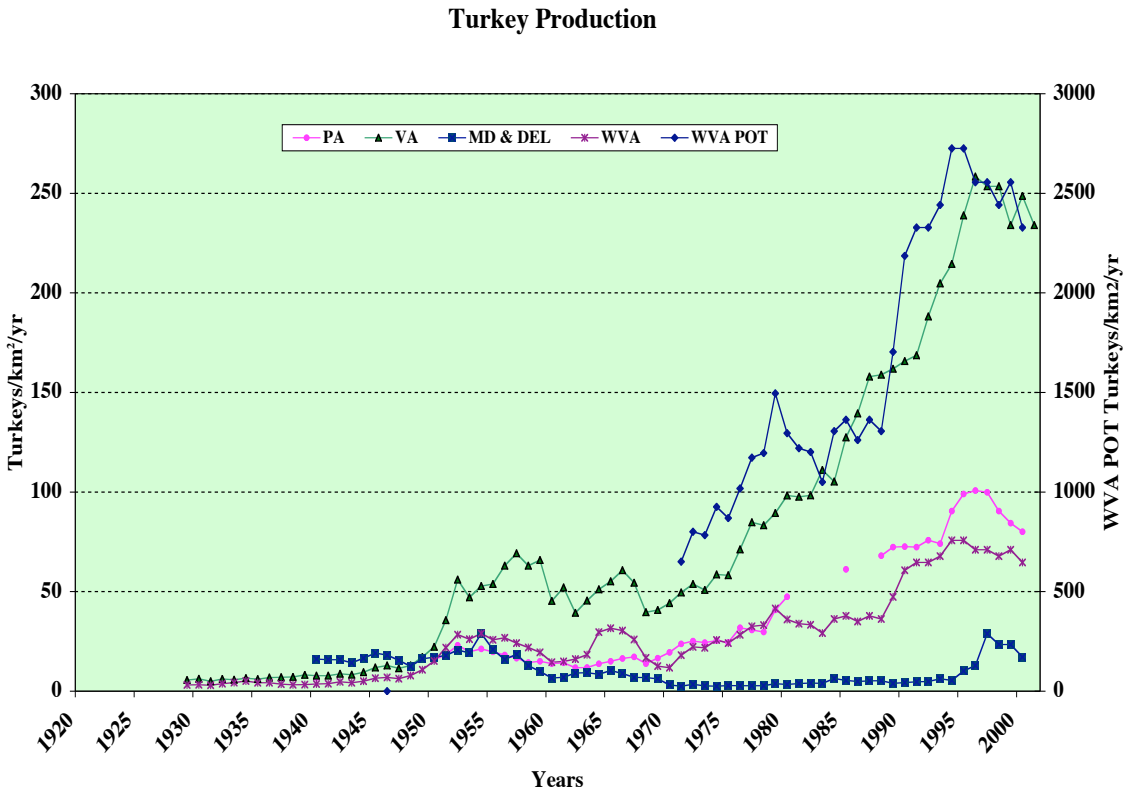
Poultry production statistical data are limited to about the past 60 years. For the entire state of Maryland, broiler production has increased dramatically, as presented below.



About 78% of Maryland broiler production, as presented above, is located in its Eastern Shore counties and not in the Potomac River Basin.

Broiler production in the West Virginia Potomac Headwaters counties has increased dramatically since the late 1980s (see WVA POT above). In the late 1990s, West Virginia Headwaters production was over 50,000 broilers/km^2, as compared to Rockingham County, Virginia, which had a production of 5,600 broilers/km^2. Most of West Virginia broiler production is in the Potomac Headwaters. One hundred broilers excrete 7.1, 1.1, and 1.96 kgs of nitrogen, phosphorus, and potassium respectively, per life cycle.

Turkey production has increased significantly in Virginia and in the Potomac Headwaters in West Virginia, as shown below.



Since the 1970s, Virginia turkey production has increased from 50 birds to over 250 birds/km^2/yr, as presented above. Rockingham County, Virginia, which is in the Shenandoah sub-basin, has a turkey production of 2,200 turkeys/km^2/yr.

For the Headwater counties of West Virginia, turkey production has increased from 600 to over 2,300 turkeys/km^2 (see WVA POT above). One hundred turkeys excrete 39.5, 8.8, and 12.8 kgs of nitrogen, phosphorus, and potassium respectively, per life cycle.

A significant amount of poultry production is concentrated in the Upper Basin. Broiler and turkey production in the Upper Basin in 1992 is presented below.

Poultry	**Birds/km^2/yr**
Broilers	6,135
Turkeys	620

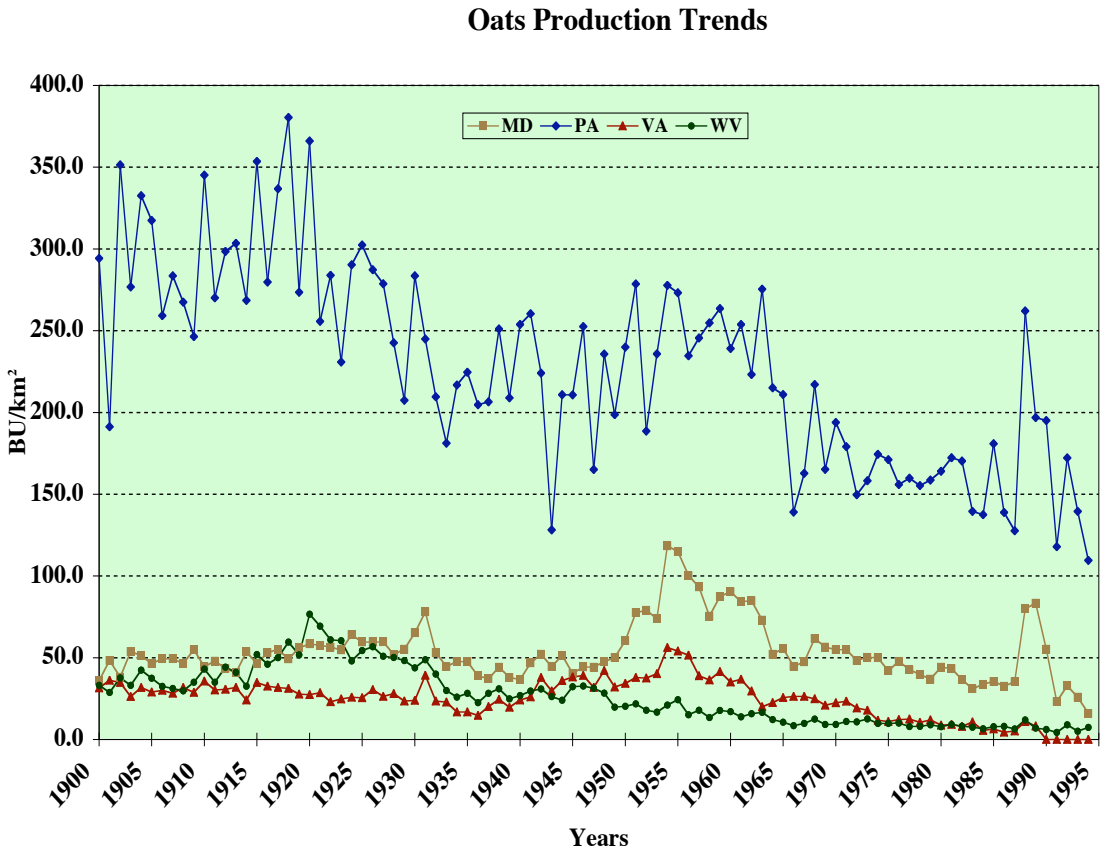
The number of horses and ponies in the four states has decreased by 70% to over 80% since 1935, as shown below.

Horses & Ponies
Animals/km^2

	MD	PA	VA	WVA
1935	3.52	2.46	1.74	1.60
1997	0.89	0.56	0.49	0.27
% Decrease	74.7	77.2	71.8	83.2

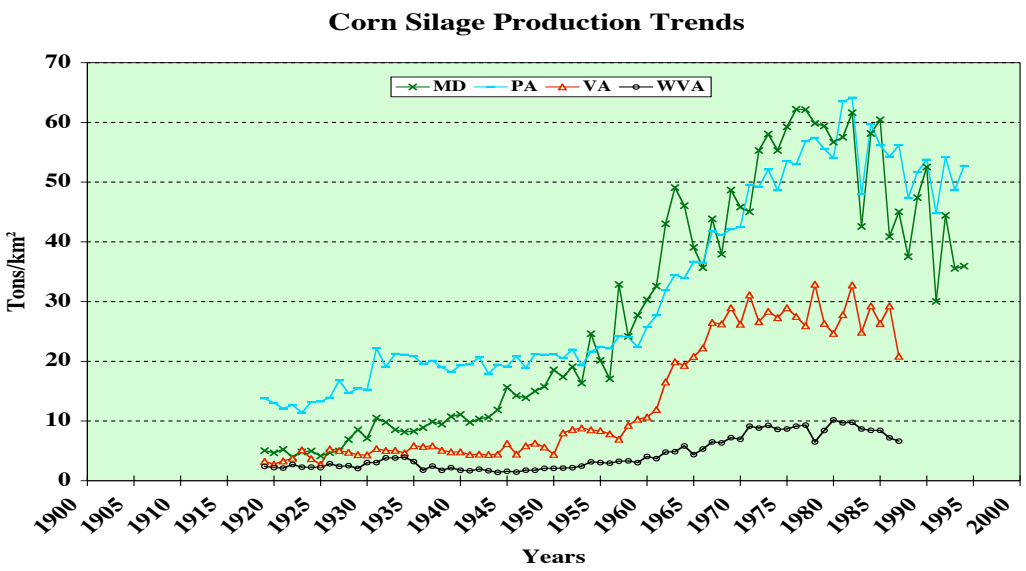
Crop Production Trends

The major agricultural crops supporting the change in animal feed needs have also changed over the past 100 years. Grain crops, such as oats, have decreased dramatically since the early 1900s, as shown below.

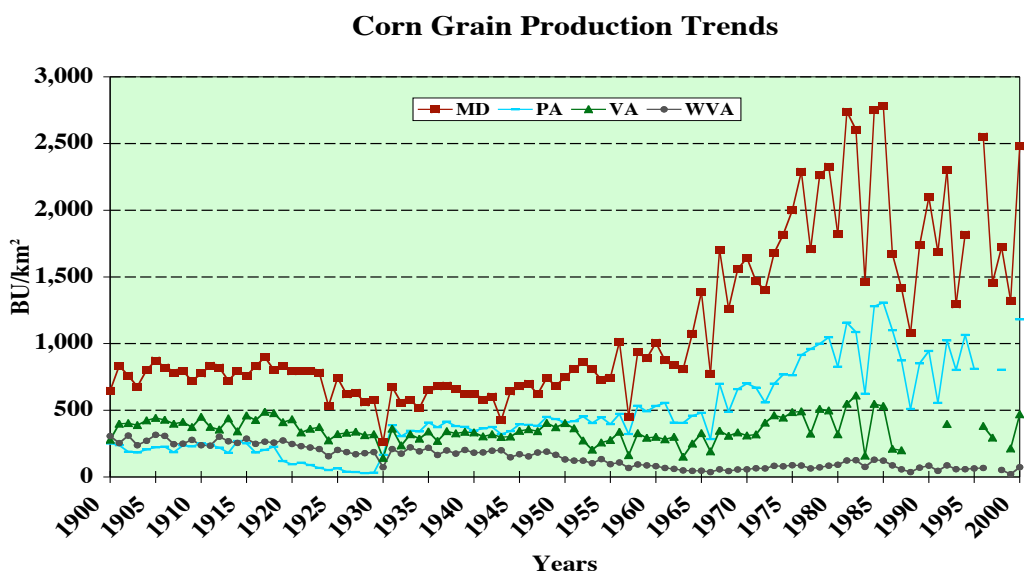


At the start of the 20th century, a large portion of oats production was for horse feed. As presented in the table above, the population of horses has declined substantially in the past 50 years, thus reducing the demand for oats.

To support increased milk production per dairy cow, corn silage production has increased, as shown below.



To support dairy, beef cattle, hog, and poultry production, corn grain production has also increased, as shown below.



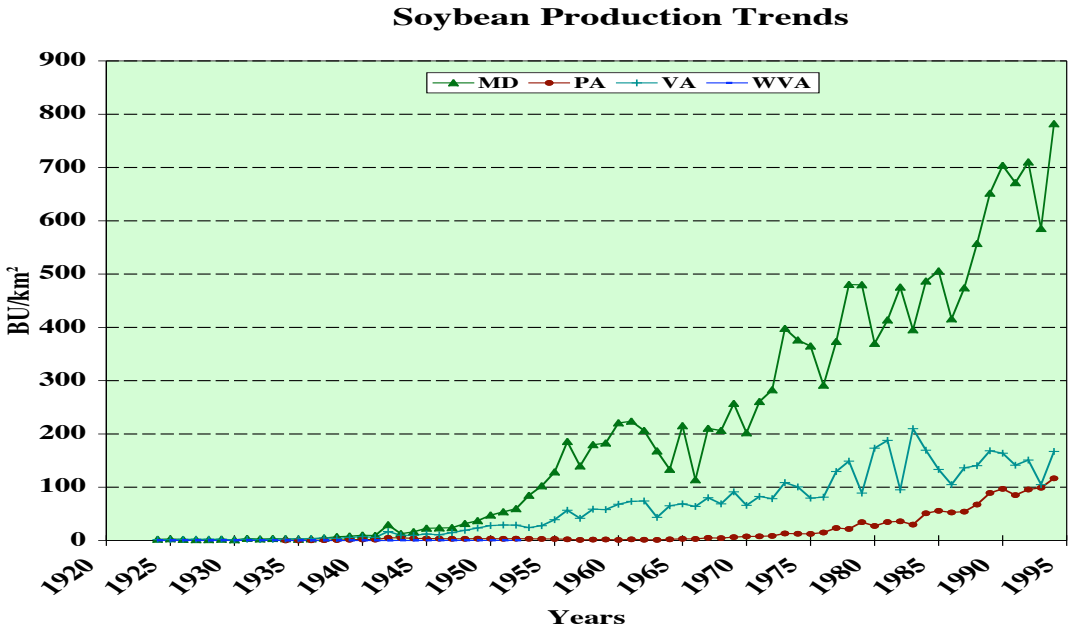
Hay production in the four states has been fairly stable over the past 40 years, as presented below.

Hay, Alfalfa, and other Tame, Small Grain, and Wild Grass
Dry tons/km^2/yr

Year	MD	PA	VA	WVA
1959	29.85	35.17	15.80	13.14
1964	23.55	30.20	12.03	11.09
1969	20.04	28.64	12.47	10.08
1974	21.38	30.86	13.68	10.46
1978	23.19	37.73	14.97	11.47
1982	21.09	36.44	16.72	10.73
1987	23.46	38.57	17.87	10.80
1992	21.55	35.25	21.26	12.08
1997	17.80	33.87	22.34	14.20
2000	20.85	38.16	31.59	18.51
Alfalfa				
2000	6.28	17.36	4.68	2.56

Virginia hay production has doubled since the late 1950s. In Pennsylvania, about half of the hay produced in 2000 was alfalfa. Alfalfa hay is one of the main sources of animal nitrogen feed for dairy cattle.

Since the 1950s, there has been a significant increase in soybean production, especially in the Maryland Eastern Shore, as shown below.



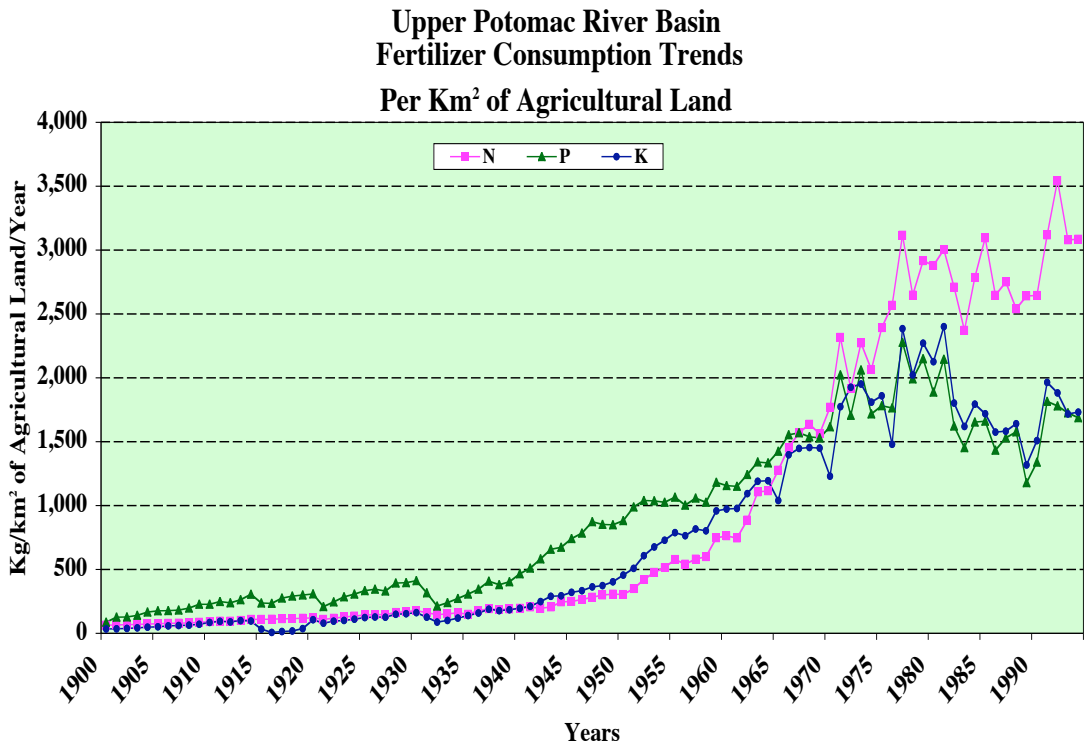
Pennsylvania and Virginia produce about 100 BU/km^2/yr of soybeans, while there is very little production in West Virginia.

The major crops supporting animal production needs were corn grain, corn silage, alfalfa hay, and soybeans. Of the 3,822 kg/km^2/yr of nitrogen needed in animal production (for eggs, milk, and meat), about 2,085 kg/km2/yr, or 54%, was obtained from imported animal feed (5) for the 1990-1993 period.

For 1990, the USGS estimated that animal manure contributes about 1,270 kg/km^2/yr of nitrogen and 322 kg/km^2/yr of phosphorus to the Upper Potomac Basin. In the SCOPE nitrogen balance study (5), crop production for animal feed needs was 1,737 kg/km^2/yr. Crop production plus the animal feed import of 2,085 kg /km^2/yr produces about 3,820 kg/km^2/yr of nitrogen inputs to the Upper Basin before any loss to volatilization. The SCOPE estimate of volatilization from animal waste was about 1,460 kg N/km^2/yr, resulting in an animal waste input of about 2,360 kg/km^2/yr.

Fertilizer Use Trends

For the Upper Potomac Basin, the USGS estimated that commercial fertilizer inputs for 1990 were 1,010 kg/km^2/yr of nitrogen and 310 kg/km^2/yr of phosphorus (7). The SCOPE study had a nitrogen fertilizer input of 1,024 kg/km^2/yr (5). The historical commercial nitrogen, phosphorus, and potassium fertilizer use for the Upper Basin is presented below.



The rate of nitrogen, phosphorus, and potassium fertilizer use began to significantly increase in the 1940s and continued to increase until the late 1970s. This increase was in response to the need for increased corn and corn silage production for dairy, poultry, and hog production.

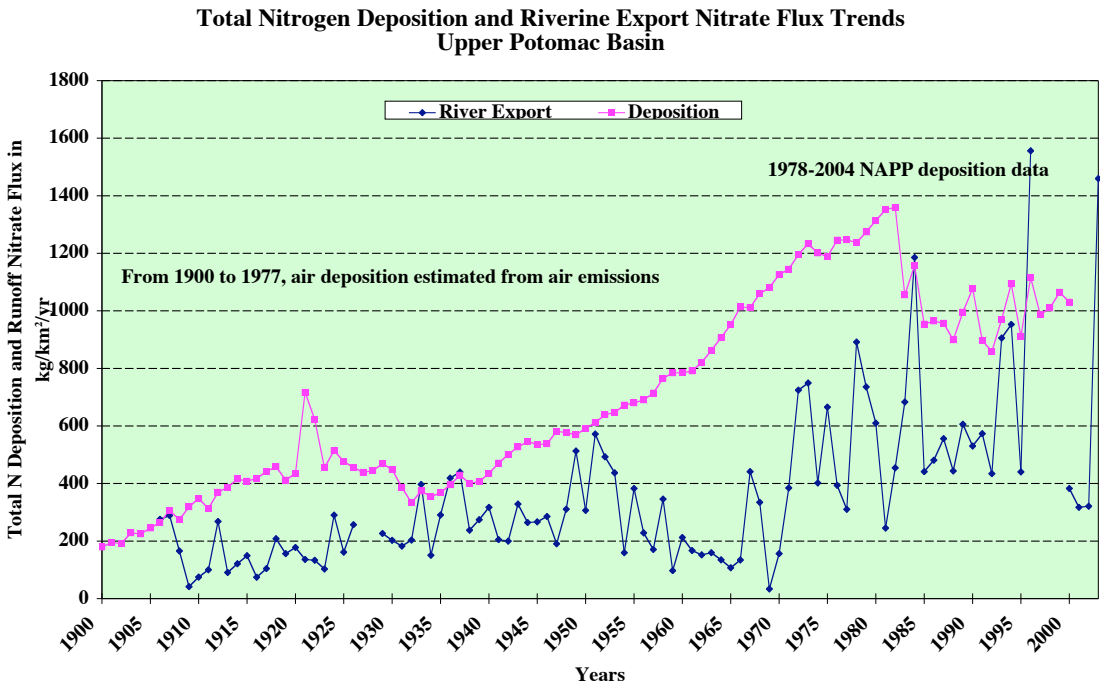
Since the early 1980s, the rate of nitrogen fertilizer use either leveled off or decreased, while the rate of phosphorus and potassium fertilizer use decreased significantly since the mid-1980s.

No similar historical data on urban or suburban fertilizer use have been found.

Air Deposition Trends

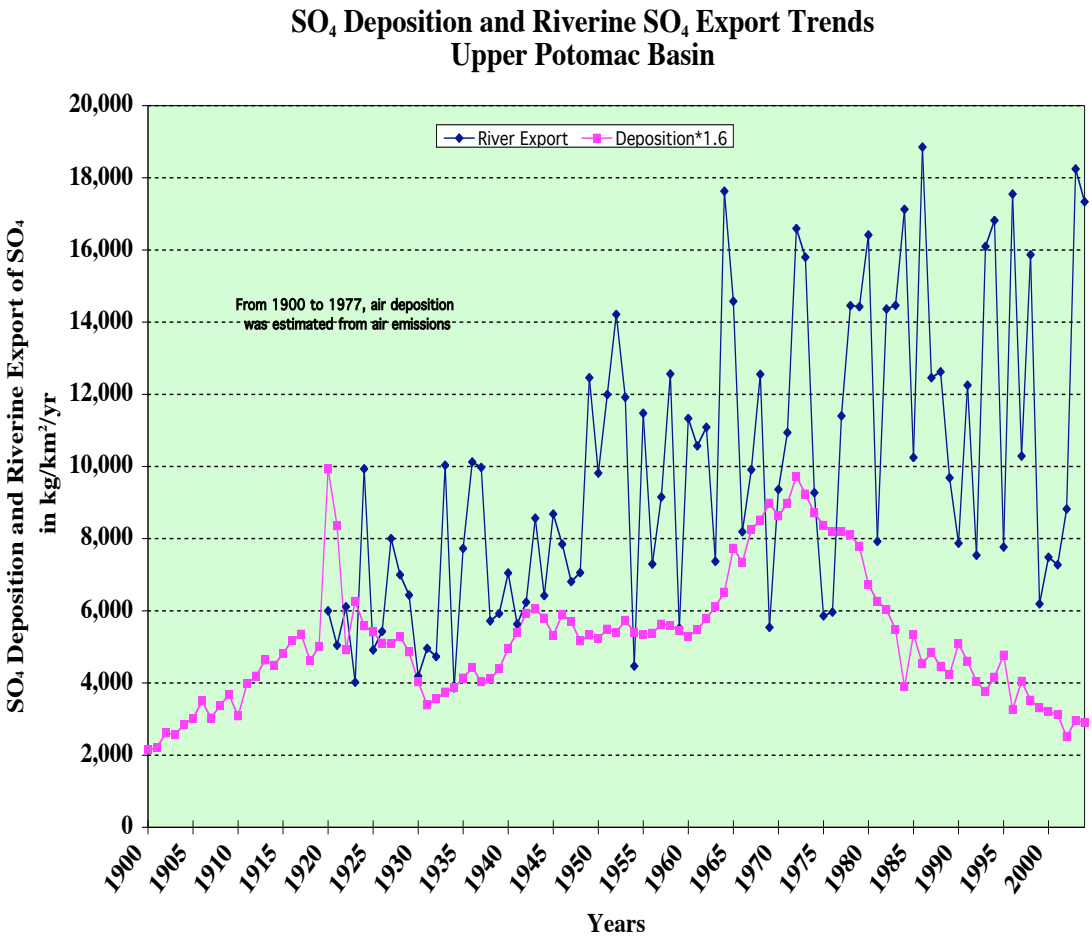
The USGS estimated that in 1970 the atmospheric deposition of nitrogen in the Upper Basin was about 1,160 kg/km^2/yr (7). The SCOPE study had a nitrogen input from atmospheric deposition of total inorganic nitrogen (wet and dry) of 969 kg/km^2/yr (5).

Because the National Acid Precipitation Program (NAPP) did not start until the late 1970s, atmospheric deposition rates prior to the measurement program were estimated from NO_x emission rate data (11). The atmospheric deposition rate was estimated to have been about 200 kg/km^2/yr in the early 1900s, increasing to a maximum of about 1,400 kg/km^2/yr in the late 1970s. From 1995 to 2004, the atmospheric deposition rate was about 970 kg/km^2/yr (see below).



Riverine nitrate export flux (in blue as presented above) has increased from about 200 kgN/km^2/yr in the 1900s, to over 800 kgN/km^2/yr in the early 2000s.

Similar to nitrogen deposition estimate methodology, we estimated the SO_4 deposition rates for the years prior to the NAPP, as presented below. We assumed that total deposition (wet and dry) was 1.6 times the measured wet deposition.

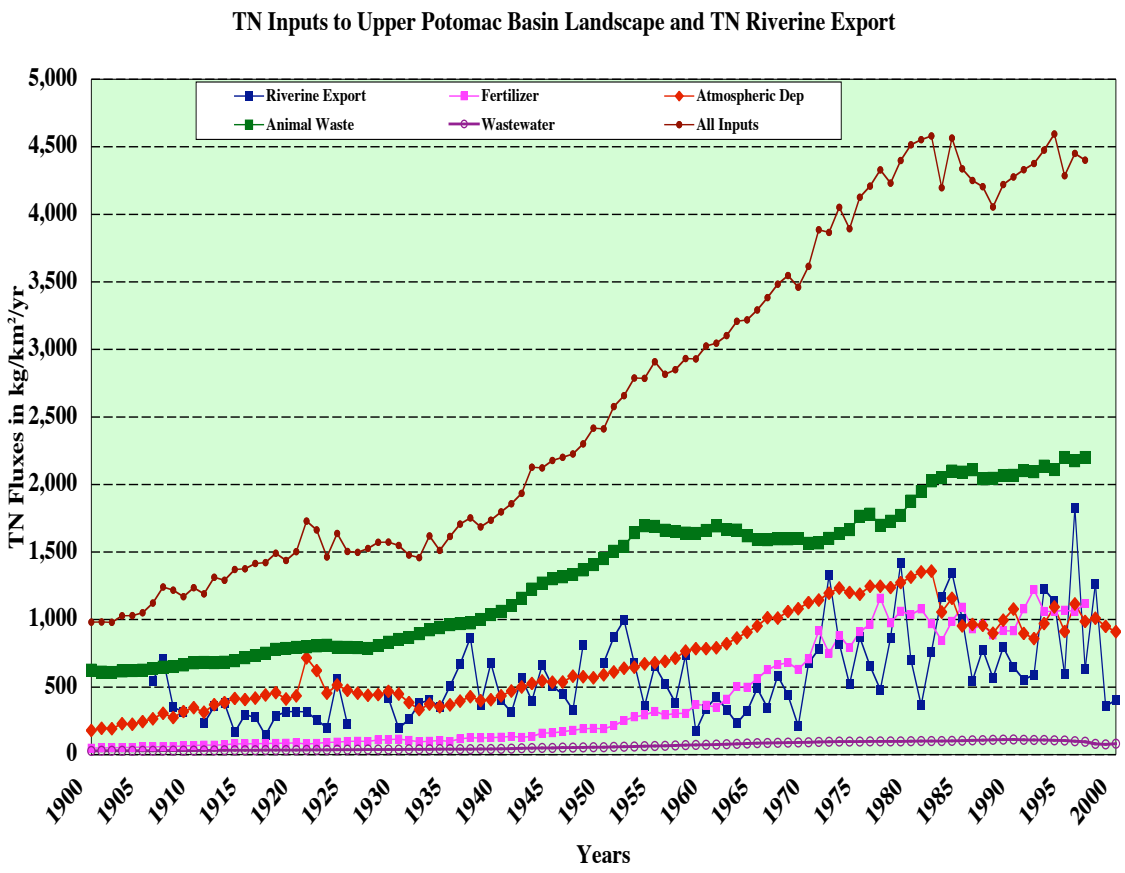


The sulphate deposition rates peaked in the early 1970s, as presented above. Since then, the deposition rate has continued to decrease as a result of similar decreases in air emissions. During this same period, the riverine sulphate export flux has decreased from highs of +15,000 kg/km^2/yr since 1970 to lows of less than 10,000 kg/km^2/yr in the early 2000s, except during the high stream flow year of 2003.

Upper Basin Landscape Nutrient Loading Input Trends

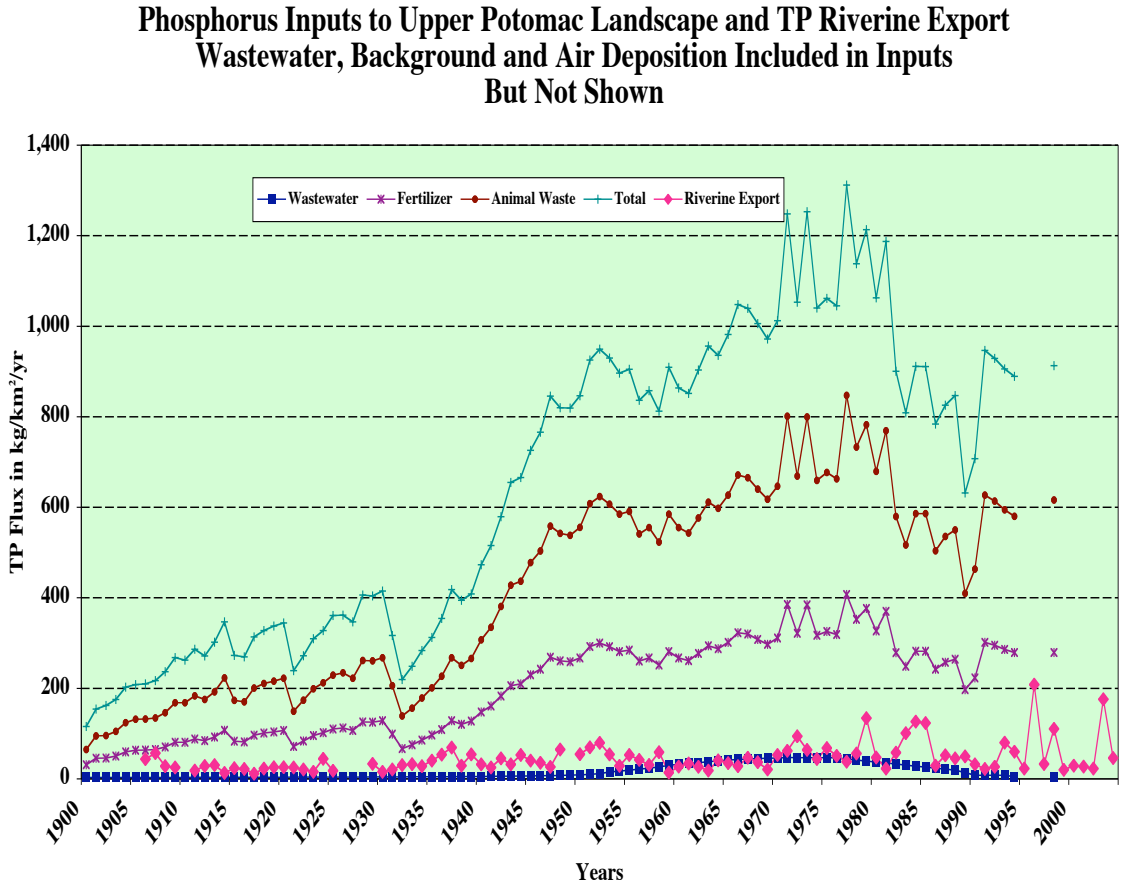
For the Upper Basin, we estimated the total landscape loading inputs for the past 100 years for nitrogen and phosphorus based on the methodology described earlier in this chapter.

For nitrogen, the total landscape inputs were about 1,000 kg/km^2/yr in the early 1900s, increasing to about 4,000 to 4,500 kg/km^2/yr in the 1980s and 1990s, as presented below.



As can readily be seen in the chart above, only about 18% to 20% of the major sources of nitrogen are exported out of the watershed by the Potomac River (see next chapter).

Only about 6% to 8% of the major sources of phosphorus are exported out of the watershed by the Potomac River, as presented below. See next chapter for further details.



Of the 4,000 to 4,500 kg/km^2/yr of TN inputs, over 2,000 kg/km^2/yr, or about 50%, was from animal waste. Fertilizer and air deposition TN inputs were the same, about 1,000 kg/km^2/yr.

The landscape loading inputs for phosphorus were about 100 kg/km^2/yr at the turn of the 20th century. The TP inputs increased to about 1,200 kg/k^2/yr in the 1970s and have since decreased to about 800 kg/km^2/yr in the 1990s.

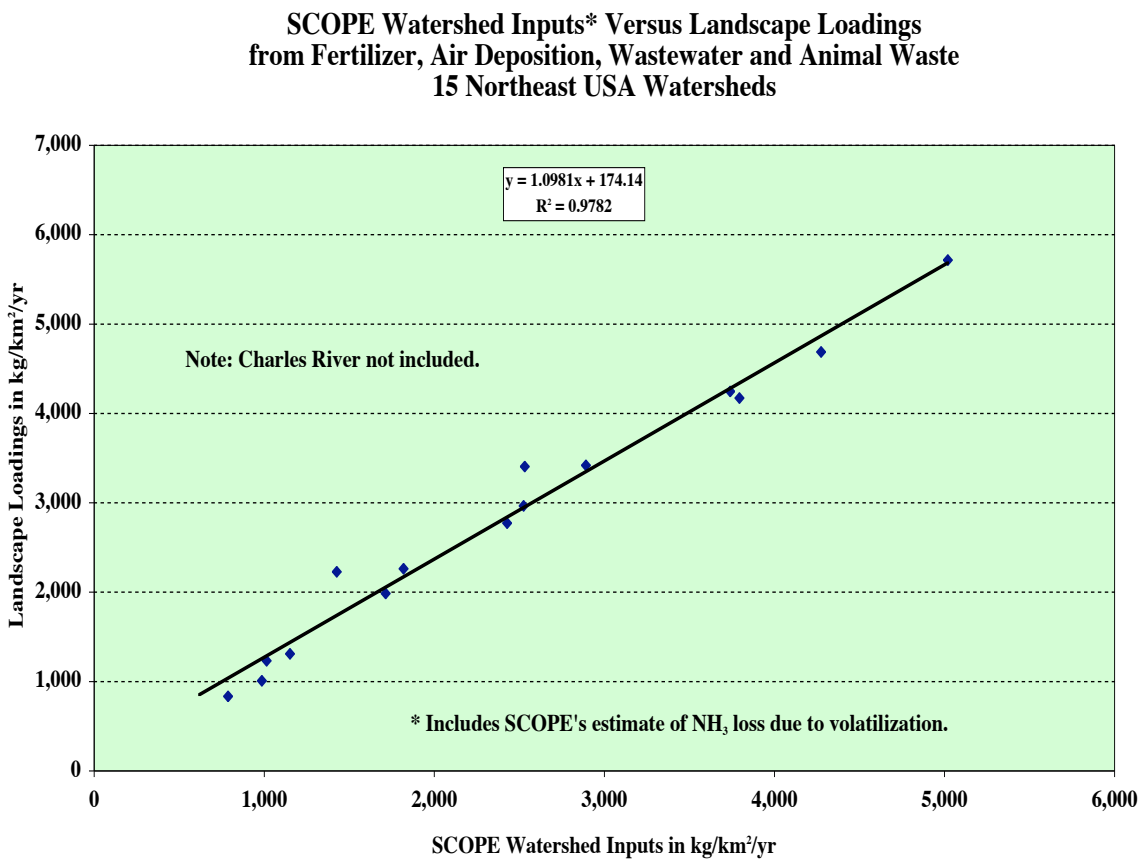
Of the 900 kg/km^2/yr of total TP inputs in the 1990s, about 600 kg/km^2/yr, or about 66%, were from animal waste. Fertilizer TP inputs were about 300 kg/km^2/yr.

Predicting Riverine Export Fluxes: Mass Balances Versus Landscape Loading Inputs

In the SCOPE study, a mass balance of nitrogen inputs and outputs was attempted (12). While the riverine export fluxes for the 16 watersheds of the Middle Atlantic and Northeast USA varied, about 22% of the inputs left the watersheds in riverine export and was a linear function of input loadings. The USGS (7) used a simpler approach, relating riverine export fluxes to landscape loadings from wastewater discharges, atmospheric deposition, fertilizer, and animal manure fluxes.

Another approach developed by the USGS (13) was a statistical model, SPARROW, which had five sources: 1) fertilizer use; 2) livestock waste; 3) wet deposition; 4) nonagricultural land; and 5) point sources.

Because the main objective in the USGS simpler approach is to predict riverine export fluxes in response to landscape loadings, we selected the USGS simpler method as the better method because the nitrogen landscape input sources are those used in nitrogen control. Moreover, the need to calculate food and feed import and export fluxes, as in the SCOPE approach, is eliminated.



As can be seen above, the SCOPE TN inputs and the landscape loading inputs are very similar for the 15 Northeast USA watersheds. Agricultural and forest nitrogen fixation fluxes are not needed because the two fixation fluxes are not a landscape input source.

The USGS model SPARROW is similar, but it includes nonagricultural land, which has air deposition as a major source. These two are possible duplications.

To be able to temporally and spatially investigate the relationship between landscape input loadings and riverine export fluxes (Chapter Four), the loading inputs and riverine export fluxes were developed for the Upper Basin, for the eight major sub-basins, and for 25 watersheds of the Middle Atlantic and Northeast USA for nitrogen, phosphorus, and potassium.

While the current interest is not on controlling potassium, the inclusion of K in this analysis enhances the relationships for nitrogen and phosphorus. Potassium is also a nutrient, but a conservative chemical and mainly in the dissolved inorganic form. Thus, potassium acts a tracer for nitrogen and phosphorus.

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