# 3 Section 3: Terrestrial Inputs

## 3.1 Introduction

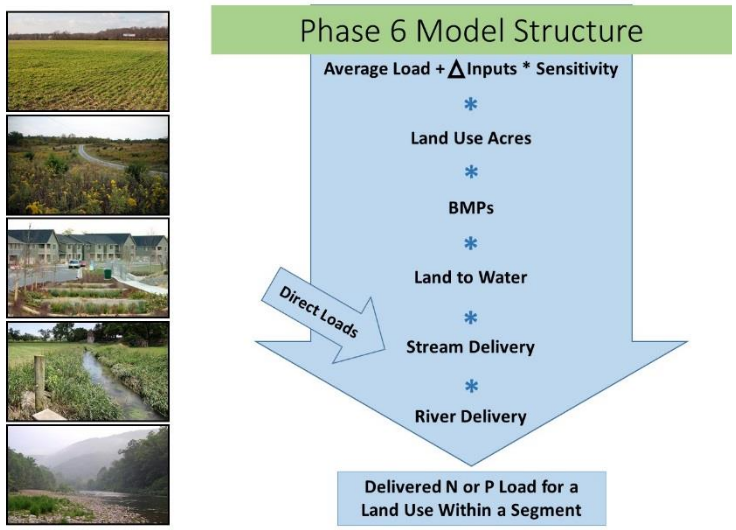


*Figure 3-1: Phase 6 Model structure*

Terrestrial inputs – atmospheric deposition, legume fixation, fertilizer, manure, biosolids, and residual soil nutrients - drive much of the spatial distribution of loads throughout the watershed. Referring to Figure 3-1 at right, terrestrial inputs are multiplied by a watershed load sensitivity to inputs, discussed in Section 4, to modify spatially averaged loads before further modification by downstream factors related to BMPs and the physical setting. Much of this section is similar to what would be referred to in the Phase 5 Watershed Model as Scenario Builder. In the Phase 6 Model, the separate parts of Scenario Builder, CAST, and the watershed model have been combined into one integrated tool. See Section 1 for a discussion of the model structure. Terrestrial inputs of nutrients are calculated for entire counties, including counties that are only partially within the Chesapeake Bay watershed. However, the nutrient and sediment loads to the Chesapeake Bay and its tributaries are only calculated from areas inside the watershed.

The Phase 6 model is generally run in a scenario mode where a scenario is defined by a specific set of inputs. The inputs for a scenario include land use, applications of nutrients to the land, management practices, point sources, and other inputs. Scenarios generally refer to a particular year and so would include the land use, applications, and other inputs that are estimated to represent that year. Scenarios of the future typically include projected land use and proposed management actions.

### 3.1.1 Comparison of Chesapeake Basin-Wide Loads

The major sources of nitrogen inputs into the watershed include legume fixation, manure/biosolids, commercial fertilizer, atmospheric deposition, point source discharges and septic runoff. The major sources of phosphorus into the watershed are commercial fertilizer, manure/biosolids, residual soil nutrients, point source discharges and rapid infiltration basins.

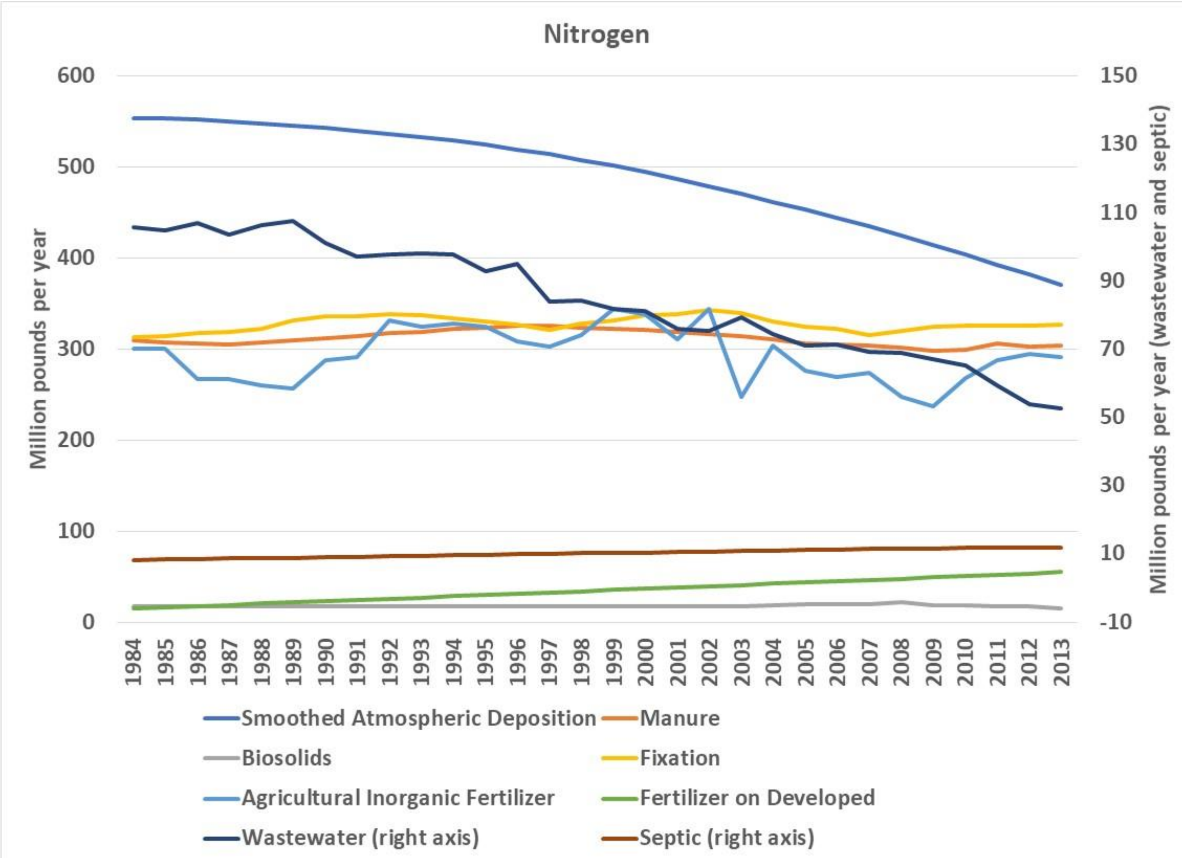



*Figure 3-2: Major nitrogen inputs to the Phase 6 Model. Note that wastewater and septic are plotted on the right-hand axis, which is enlarged by a factor of four reflecting the approximate difference of the delivery of nutrients deposited on land and discharged directly to waterways. The atmospheric deposition is the expected deposition over the 10-year period of hydrology 1991-2000 given emissions in the indicated year.*

Figure 3-2 and Table 3-1 show the nitrogen inputs over time. Atmospheric deposition and point source inputs have decreased substantially over time, agricultural inputs have remained fairly constant, and fertilizer on developed land has increased throughout the calibration period. Figure 3-3 and Table 3-2 show the phosphorus inputs over time. As with nitrogen, wastewater is down considerably during the period of simulation and manure is relatively constant. Phosphorus from agricultural inorganic fertilizers shows a sharp decline from the mid-1990s while fertilizer on developed increases throughout.

*Table 3-1: Nitrogen inputs to the Phase 6 Model*

| Year | Smoothed Atmospheric Deposition | Manure | Bio-solids | Fixation | Agricultural Inorganic Fertilizer | Fertilizer on Developed | Waste water | Septic |
|---|---|---|---|---|---|---|---|---|
| 1984 | 554.1 | 309.3 | 17.6 | 313.6 | 301.1 | 14.9 | 105.7 | 8.2 |
| 1985 | 554.1 | 307.5 | 17.6 | 314.7 | 300.6 | 16.3 | 104.9 | 8.3 |
| 1986 | 552.3 | 306.2 | 17.6 | 317.5 | 267.3 | 17.6 | 107.1 | 8.5 |
| 1987 | 550.3 | 305.1 | 17.6 | 319.1 | 266.8 | 19.0 | 103.7 | 8.6 |
| 1988 | 548.0 | 307.0 | 17.6 | 321.9 | 259.8 | 20.3 | 106.5 | 8.8 |
| 1989 | 545.6 | 309.2 | 17.6 | 331.1 | 257.3 | 21.7 | 107.6 | 8.9 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1990 | 542.9 | 311.9 | 17.6 | 335.7 | 288.3 | 23.1 | 101.1 | 9.0 |
| 1991 | 539.9 | 314.8 | 17.6 | 336.4 | 290.9 | 24.5 | 97.0 | 9.2 |
| 1992 | 536.6 | 317.4 | 17.6 | 338.7 | 331.5 | 25.8 | 97.8 | 9.3 |
| 1993 | 533.0 | 318.8 | 17.6 | 337.0 | 324.1 | 27.2 | 98.0 | 9.5 |
| 1994 | 529.0 | 322.1 | 17.6 | 334.5 | 327.8 | 28.6 | 97.8 | 9.6 |
| 1995 | 524.6 | 323.1 | 17.7 | 330.6 | 325.0 | 29.9 | 92.8 | 9.8 |
| 1996 | 519.6 | 325.4 | 17.7 | 327.3 | 309.0 | 31.3 | 95.0 | 9.9 |
| 1997 | 514.2 | 326.3 | 17.7 | 320.9 | 303.2 | 32.7 | 84.1 | 10.0 |
| 1998 | 508.2 | 323.8 | 17.7 | 327.7 | 315.8 | 34.0 | 84.2 | 10.2 |
| 1999 | 501.8 | 322.7 | 17.7 | 331.9 | 344.3 | 35.4 | 81.7 | 10.3 |
| 2000 | 494.8 | 321.2 | 17.7 | 336.8 | 338.8 | 36.8 | 81.2 | 10.5 |
| 2001 | 487.3 | 318.9 | 18.0 | 338.9 | 311.1 | 38.1 | 75.9 | 10.6 |
| 2002 | 479.1 | 316.6 | 17.9 | 342.7 | 343.9 | 39.5 | 75.5 | 10.7 |
| 2003 | 470.6 | 313.9 | 17.8 | 340.0 | 247.7 | 40.9 | 79.3 | 10.9 |
| 2004 | 462.0 | 310.5 | 18.3 | 330.6 | 304.1 | 42.3 | 74.6 | 11.0 |
| 2005 | 453.4 | 306.8 | 19.2 | 325.0 | 276.6 | 43.7 | 71.0 | 11.1 |
| 2006 | 444.4 | 305.6 | 19.2 | 321.9 | 269.8 | 45.0 | 71.4 | 11.3 |
| 2007 | 435.1 | 303.6 | 19.2 | 315.0 | 273.8 | 46.4 | 69.1 | 11.4 |
| 2008 | 425.2 | 301.7 | 21.9 | 320.6 | 247.2 | 47.9 | 69.0 | 11.5 |
| 2009 | 414.9 | 298.7 | 19.1 | 325.2 | 237.6 | 49.3 | 67.1 | 11.6 |
| 2010 | 404.1 | 299.3 | 18.8 | 326.3 | 267.9 | 50.8 | 65.3 | 11.8 |
| 2011 | 392.7 | 306.0 | 18.0 | 325.5 | 288.1 | 52.2 | 59.5 | 11.8 |
| 2012 | 381.9 | 302.5 | 17.6 | 326.4 | 295.2 | 53.6 | 53.9 | 11.8 |
| 2013 | 371.1 | 304.5 | 15.4 | 326.8 | 290.8 | 55.1 | 52.6 | 11.8 |

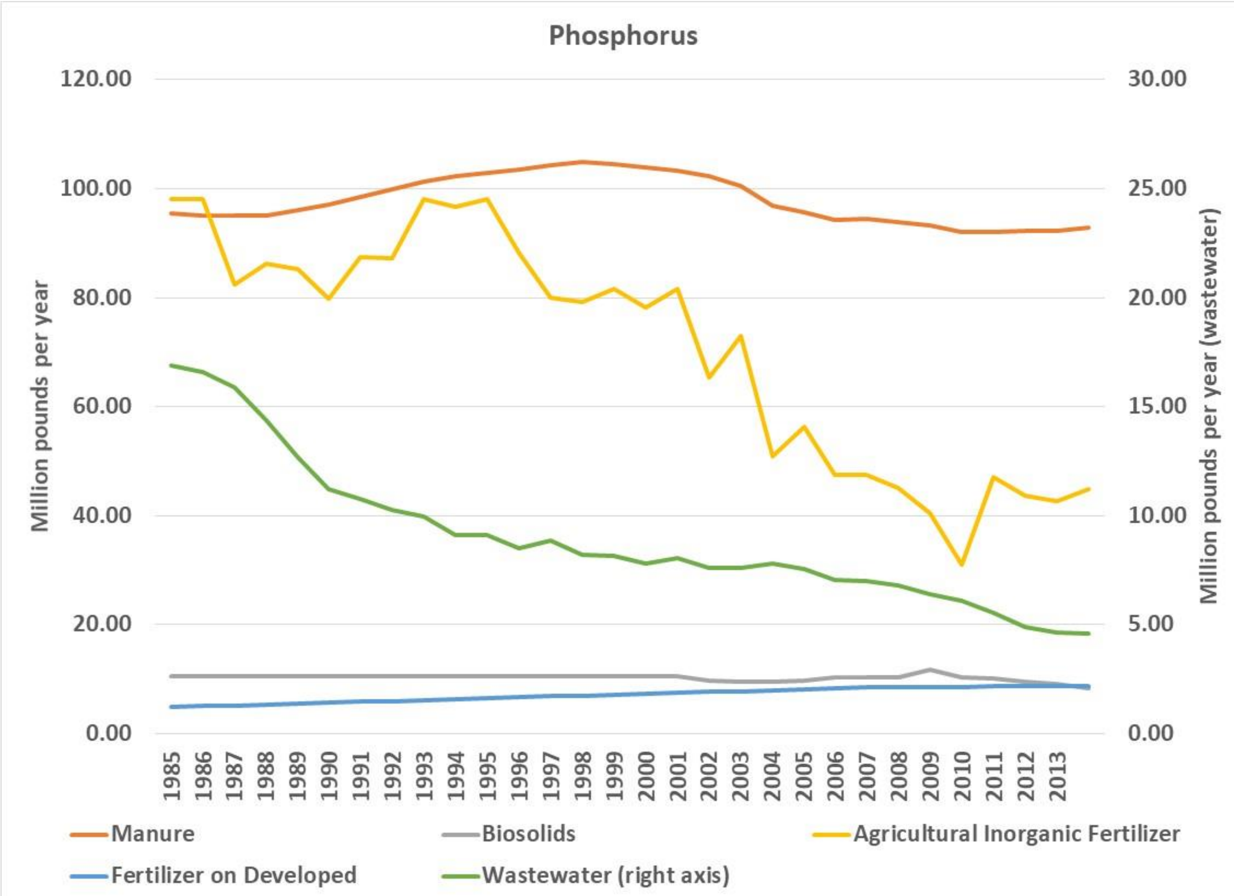



*Figure 3-3: Major phosphorus inputs to the Phase 6 Model. Note that wastewater and septic are plotted on the right-hand axis, which is enlarged by a factor of four reflecting the approximate difference of the delivery of nutrients deposited on land and discharged directly to waterways.*

*Table 3-2: Phosphorus inputs to the Phase 6 Model in million pounds per year. Note there is a small septic contribution less than 4000 pounds annually*

| Year | Manure | Biosolids | Agricultural Inorganic Fertilizer | Fertilizer on Developed | Wastewater (right axis) |
|---|---|---|---|---|---|
| **1984** | 95.37 | 10.56 | 98.07 | 4.88 | 16.86 |
| **1985** | 95.12 | 10.57 | 98.06 | 5.05 | 16.59 |
| **1986** | 95.00 | 10.57 | 82.39 | 5.21 | 15.86 |
| **1987** | 94.99 | 10.57 | 86.15 | 5.37 | 14.37 |
| **1988** | 96.01 | 10.57 | 85.31 | 5.53 | 12.69 |
| **1989** | 97.16 | 10.58 | 79.79 | 5.70 | 11.21 |
| **1990** | 98.48 | 10.58 | 87.41 | 5.86 | 10.77 |
| **1991** | 99.89 | 10.58 | 87.32 | 6.03 | 10.25 |
| **1992** | 101.18 | 10.58 | 98.14 | 6.20 | 9.95 |
| **1993** | 102.20 | 10.58 | 96.67 | 6.36 | 9.11 |
| **1994** | 102.97 | 10.58 | 98.03 | 6.52 | 9.13 |

| | | | | | |
|---|---|---|---|---|---|
| **1995** | 103.43 | 10.58 | 88.33 | 6.68 | 8.53 |
| **1996** | 104.37 | 10.59 | 80.01 | 6.84 | 8.86 |
| **1997** | 104.85 | 10.59 | 79.25 | 7.01 | 8.20 |
| **1998** | 104.48 | 10.59 | 81.54 | 7.17 | 8.18 |
| **1999** | 103.90 | 10.59 | 78.24 | 7.33 | 7.81 |
| **2000** | 103.34 | 10.60 | 81.71 | 7.50 | 8.04 |
| **2001** | 102.25 | 9.66 | 65.43 | 7.66 | 7.62 |
| **2002** | 100.39 | 9.60 | 72.95 | 7.83 | 7.59 |
| **2003** | 96.94 | 9.54 | 50.89 | 7.99 | 7.80 |
| **2004** | 95.58 | 9.80 | 56.29 | 8.16 | 7.58 |
| **2005** | 94.19 | 10.29 | 47.44 | 8.33 | 7.08 |
| **2006** | 94.45 | 10.28 | 47.49 | 8.49 | 6.99 |
| **2007** | 93.78 | 10.30 | 45.00 | 8.53 | 6.81 |
| **2008** | 93.29 | 11.76 | 40.54 | 8.57 | 6.41 |
| **2009** | 92.11 | 10.28 | 30.97 | 8.61 | 6.11 |
| **2010** | 91.97 | 10.16 | 47.02 | 8.66 | 5.53 |
| **2011** | 92.18 | 9.64 | 43.59 | 8.70 | 4.89 |
| **2012** | 92.35 | 9.24 | 42.61 | 8.74 | 4.66 |
| **2013** | 92.84 | 8.25 | 44.93 | 8.79 | 4.59 |

### 3.1.2 Calculating Nutrient Inputs to Agricultural Lands

The Phase 6 Model separates nutrient inputs to agricultural lands into the following categories:

- Manure collected (with losses) within the barnyard
- Manure deposited on pasture
- Manure deposited within riparian areas of pasture
- Organic sources (manure, biosolids, and spray irrigation) available for application to crops
- Inorganic fertilizer available for application to crops

Figure 3-4 shows a general, conceptual model of the fate of organic and inorganic nutrients through the modeling systems from source to application to runoff using the categories above. The detailed methods for estimating each category are described in the sections below.

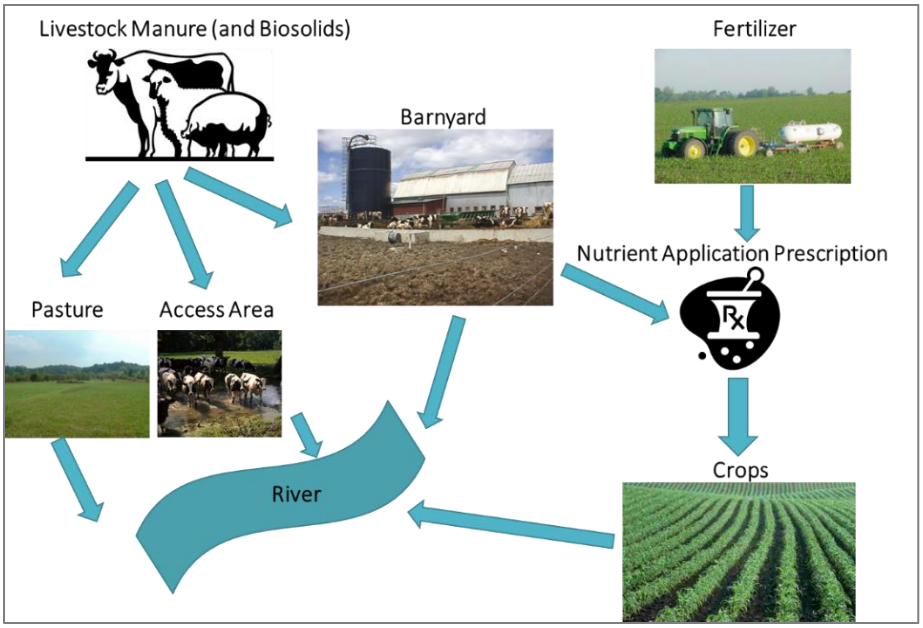



*Figure 3-4 Conceptual diagram of nutrient fate through agricultural lands*

### 3.1.3 Growth Regions for Crops

Much of the crop data used by the Phase 6 Model can vary at a "growth region" level. For example, the planting and harvesting dates for a crop dictate when applications can be made and uptake occurs, and those dates vary by growth region. There are twelve growth regions in the Chesapeake Bay Watershed.

Each state is necessarily its own region, since there are separate crop management and nutrient guidelines for each state. Where the agronomy guide from each state divides the state into different growing regions, those regions are used as well. Where the guides did not make a distinction, the 1990 USDA Hardiness Zone delineations were used to guide further state divisions. The more recent 2003 hardiness zones were not used since it is considered unlikely that farmers changed planting dates. The USDA Hardiness Zone boundaries are set where there is a 10° Fahrenheit difference in the average annual temperature. The lines were established by comparing multiple maps and determining which counties fell into which regions. Boundary lines were shifted to match county lines. Specifically:

- In New York, the portion of the state that lies in the watershed is primarily the central part, which the Cornell Ag Guide considers one region.
- In Pennsylvania, the Agronomy Guide divides the state into separate growing regions for each crop; however, the lines of the regions

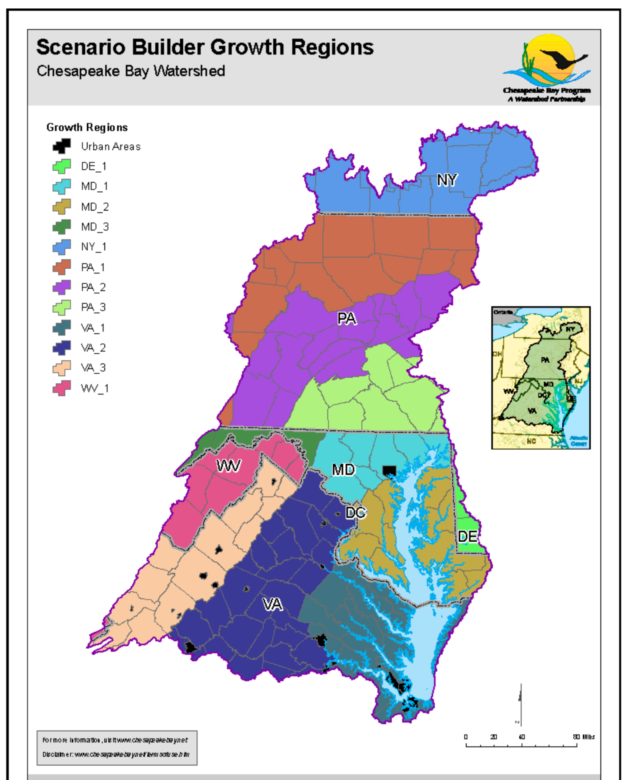



*Figure 3-5 Phase 6 growth regions*

are very similar to each other and to the lines of USDA Hardiness Zones. Therefore, it was determined that Pennsylvania would be divided into three regions that follow the boundaries given in the Agronomy Guide: Zone 1, Zone 2, and Zone 3.

- In West Virginia, the portion of the state that lies in the watershed was in a single USDA Zone, therefore, WV has one region.
- Maryland's Nutrient Management Manual does not divide the state; however, there are two USDA Zones. Therefore, MD was divided into USDA Zone 6 and USDA Zone 7. Concern arose that this left an Eastern Shore county in the same zone as a Western Maryland county and were thus subject to the same conditions. To address this concern, a third zone, "Western MD" was added that includes Garrett, Allegheny, and Washington counties.
- Delaware also falls into one USDA Zone, and was therefore left undivided.
- Virginia's Agricultural Guide divides the state into three sections that roughly follow geologic provinces: Eastern, Piedmont, and West of Blue Ridge.

The resulting growth regions are provided in Figure 3-5.

## 3.2 Manure Nutrient Inputs

The Phase 6 Model estimates monthly manure nutrient applications to each crop in a land use. These monthly crop applications are then aggregated across all crops within a land use to provide a single, weighted average monthly application for that land use. Table 3-3 provides an example of how the model combines monthly manure applications on two grain crops to determine a single monthly, average application on the land use, Grain with Manure.

*Table 3-3: Hypothetical nutrient application on grain with manure in April*

| Crop | Month | Lbs of Manure N/Acre | Acres | Total Lbs of Manure N Applied |
|---|---|---|---|---|
| Corn for Grain | April | 30 | 1,000 | 30,000 |
| Sorghum for Grain | April | 10 | 500 | 5,000 |
| Total | April | **23.33*** | 1,500 | 35,000 |

*23.33 Lbs of N/Acre = ((30 Lbs of N/Acre X 1,000 Acres) + (10 Lbs of N/Acre X 500 Acres))/ (1,000 Acres + 500 Acres)

The Phase 6 Model performs a number of calculations to determine the fate of manure after excretion and before estimating final manure applications to crops. The model must first estimate the amount of manure nutrients available in each county considering any losses that may occur prior to application. It must then consider the amount of manure each crop needs according to recommendations provided by partner states, and finally must distribute the manure to each crop based upon an algorithm which prioritizes applications to higher commodity crops first. Figure 3-6 provides an overview of these various processes simulated by Phase 6 Model. The Phase 6 Model begins with the assumption that manure generated within a county is available for deposition on pasture or application to crops only within that county. Manure only crosses county lines if jurisdictions[1] report that manure transport occurs. Transport of manure out of one county to another county simply changes the county of final application,

[1] Within the Chesapeake Bay Program Partnership, the word 'jurisdictions' is always taken to mean the six states in the Chesapeake Bay Watershed (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia) plus the District of Columbia.

while transport of manure out of the watershed removes the manure entirely from the simulation. Each of these steps will be described in detail in this section.

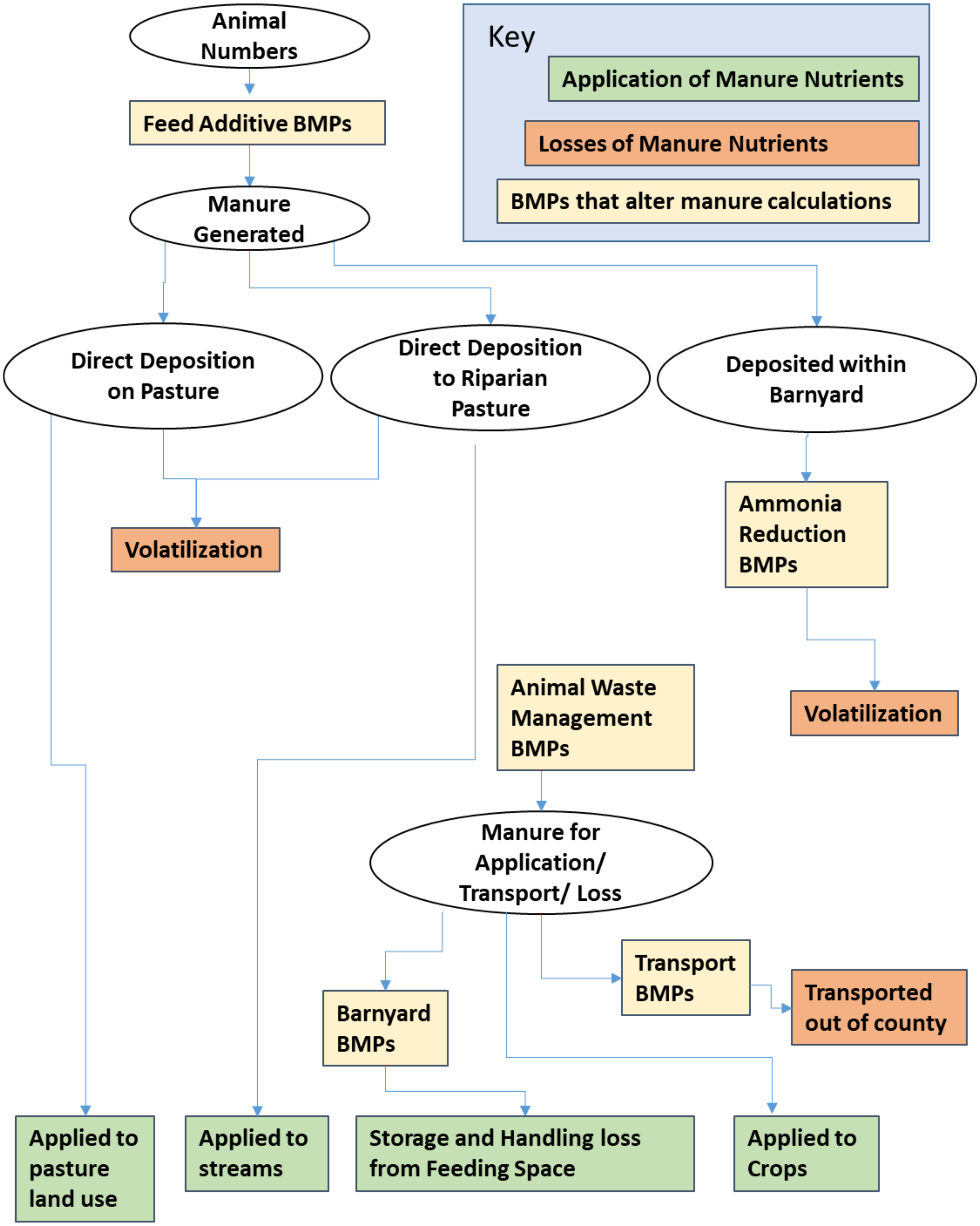



*Figure 3-6: Manure application processes*

*Arrows indicate direction that nutrients can "travel." Stacked arrows indicate that a BMP can reverse the nutrient "loss," adding nutrients back into the stream. For example, Barnyard BMPs for manure storage can decrease Storage and Handling Loss making more manure available for transport and application.*

Figure 3-6 applies individually for each county. Manure generated is calculated from animal numbers and can be modified by feed additive BMPs. The total manure generated is split into manure deposited in a barnyard, deposited on pasture, and deposited in a riparian area of pasture. Non-volatilized manure applied to pasture is directly applied to pasture land use. Non-volatilized manure in riparian areas is directly applied to streams after other losses are considered. Manure deposited in a barnyard may reach streams through storage and handling loss applied to the feeding space land uses. Manure nutrients from the barnyard that are left after storage and handling loss, transport, and volatilization are assumed to be applied to crops in the county. Note that barnyard BMPs restrict the feeding space loss, but increase the amount applied to crops. Similarly, ammonia volatilization reduction BMPs increase the amount applied to crops. Certain BMPs that reduce ammonia volatilization can receive credit for deposition reductions according to procedures described in Section 4.

### 3.2.1 Manure Generation

Nutrients in manure from all animal types are calculated based on the estimated population for an average day in a given year, the daily rate of manure production, and the typical nutrient content of the manure. The estimated population may be estimated from inventory or production statistics, depending on the animal type. Equation 3-1 provides an example calculation for estimating manure-nitrogen generated by beef cattle.

*Equation 3-1: Calculating Beef Manure Total Nitrogen Generated for a County*

*Lbs Manure Nitrogen from Beef cattle/Year*
*=*
*Beef animals*
*X*
*Lbs Dry Manure/animal/Year*
*X*
*Lbs of Total* Nitrogen/Lb Dry Manure*

**Total Nitrogen is broken down further into individual nitrogen species, as will be discussed later.*

*Example Total Nitrogen Calculation for 1,000 Beef Cattle:*

*157,614.3 Lbs N/Year*
*=*
*1,000 Beef*
*X*
*5,475 Lbs Dry Manure/beef/Year*
*X*

*0.028788 Lbs of N/Lb Dry Manure*

#### 3.2.1.1 Animal Populations

The first step in estimating manure available in a county is to estimate the number of animals in existence on an average day in each county for the scenario year. The Phase 6 Model uses animal inventories for cattle, dairy, sheep, goats, swine, pullets, and layers that are provided every five years by the USDA-National Agricultural Statistics Service (NASS)'s Census of Agriculture. Five-year census of agriculture sales numbers are used for hogs for slaughter and pullets. Populations for broilers and turkeys are provided every year in USDA-NASS's Poultry Production and Value surveys. Finally, populations for horses were provided by the states for the previous version of the modeling tools, and those populations were kept intact for the Phase 6 Model. These statewide populations were informed, in part, through state-sponsored horse censuses as the Census of Agriculture lacks information for pleasure horse farms and racehorse operations.

*Replacing Non-Disclosed Values*

The Census of Agriculture cannot release detailed sales or inventory data for an animal type if there are fewer than five operators raising that animal type within a county. When this occurs, the sales or inventory data are listed as non-disclosed. These non-disclosed values must be replaced with estimated sales or inventory values. This is done using the following steps:

Step 1: Subtract all county sales and inventory data reported from the total, statewide value. This difference becomes the number of animals that must be redistributed to counties with non-disclosed values.

Step 2: Determine the number of farms per animal type (e.g., Number of Farms with Hogs and Pigs Used for Breeding) in all counties with non-disclosed values and add farms up to create a statewide total of farms for non-disclosed counties.

Step 3: Determine the percent of statewide farms per animal type in each non-disclosed county.

Step 4: Multiply the non-disclosed animals found in step 1 by the percent found in step 3 to determine the final value for that animal type and county.

*Livestock and layers*

The values reported by the Census of Agriculture are meant to reflect inventories of all the farms in a county on December 31 of a census year. These values are used directly for livestock (beef, dairy, other cattle, sheep, goats and hogs for breeding.

*Hogs for slaughter and pullets*

Inventories do not accurately capture the total production for some animal types because many producers will cycle multiple flocks or groups of animals through their operation in a given year. For example, a farmer might have 1,000 hogs for slaughter on his or her farm on December 31, but those hogs may be the second group of hogs raised in that year. For those operations that do have multiple groups of animals cycled through during a year, the USDA-NRCS recommends considering both inventory and sales numbers to estimate total animals produced by using the following equation:

*Equation 3-2: Total Animals Produced in a Year*

Total Animals Produced in a Year = (Census of Agriculture Animal Inventory X 1/Production Cycles) + ((Census of Agriculture Animals Sold/Production Cycles) X (Production Cycles – 1/Production Cycles))

Most animals have a yearly production cycle of one, making the equation unnecessary. However, NRCS estimates that pullets and hogs for slaughter have 2.25 and 2 production cycles per year. The equation above is used to provide better estimates for those animal types. Equation 3-2 emphases inventory when production cycles are low and sales when production cycles are high.

#### *Turkey and Broiler Populations*

Statewide populations for broilers and turkeys are provided every year in USDA-NASS's Poultry Production and Value surveys. These statewide populations must be broken down into countywide populations for manure generation estimates. This is done by multiplying the annual, statewide value by the fraction of statewide animals reported in the most recent Census of Agriculture. For example, if the 2012 Census of Agriculture indicated that 80 percent of all broilers in Delaware were grown in Sussex County, then 80 percent of the statewide, annual populations reported in poultry production surveys past 2012 will be assigned to Sussex County.

### *3.2.1.2 Animal Size and Manure Generation*

Manure generation estimates published in literature studies are often tied to the size of animals studied. Unfortunately, there is very limited information available to determine how the sizes of most livestock species have changed throughout the watershed over time. For this reason, average manure generation values are used to estimate manure generation for all animal types other than broilers. The annual poultry production surveys do provide both statewide animal populations and pounds produced for broilers. These two values allow CAST to estimate the size of broilers by state on an annual basis. Manure generation and associated total nitrogen and phosphorus values by animal type are provided in Table 3-4.

*Table 3-4: Total nutrient manure characteristics for livestock*

| Animal Type | Manure Source | Lbs Dry Manure/Animal/Year | Lbs TN/Lb Dry Manure | LbsTP/Lb Dry Manure |
|---|---|---|---|---|
| Beef | Beef - Cow (confinement) from ASAE 2005 for manure values | 5,475.00 | 0.028788 | 0.006467 |
| Dairy | Lactating Cow, Dry Cow and Heifer from ASAE 2005 for manure values | 4,404.33 | 0.042221 | 0.006764 |
| Other Cattle | Estimated based upon weighted average combination of Beef and Dairy from Census of Agriculture; See Appendix D | 1,605.07 | 0.035504 | 0.006616 |
| Horses | Average of Horse- Sedentary and Horse - Intense Exercise from ASAE 2005 for manure values | 3,102.50 | 0.031672 | 0.005941 |
| Hogs for Breeding | Swine Characterization Report; See Appendix E | 220.62 | .294653 | Varies |
| Hogs for Slaughter | Swine Characterization Report; See Appendix E | 97.09 | 0.106841 | Varies |
| Sheep and Lambs | ASAE 2003 for manure values | 240.9 | 0.038182 | 0.007909 |
| Goats | ASAE 2003 for manure values | 680.91 | 0.034615 | 0.008462 |
| Pullets | PLS Report; See Appendix A | 12.95 | Varies | Varies |

| | | | | |
|---|---|---|---|---|
| Layers | PLS Report; See Appendix A | 17.89 | Varies | Varies |
| Broilers | PLS Report; See Appendix A | Varies | Varies | Varies |
| Turkeys | Turkey Characterization Report; See Appendix F | 7.62 | Varies | Varies |

#### 3.2.1.3 Feed Additive BMPs

A county's initial estimated manure generation can be reduced by the dairy precision feeding BMP. This BMP reduces total nitrogen from dairy by 24 percent and total phosphorus from dairy by 25 percent. Additionally, states can report changes to the nutrient concentrations. The Agriculture Workgroup agreed to replace the previously used swine phytase and poultry phytase BMPs with variable nutrient concentrations based upon the Poultry Litter Subcommittee report (Appendix A), Swine Characterization Study (Appendix E), and Turkey Characterization Study (Appendix F). Additionally, states can provide summary laboratory results describing changes in nutrient concentrations for these animal types in future years. Changes in nutrient concentrations will be considered by the Agriculture Workgroup prior to being incorporated into CAST for future years.

### 3.2.2 Separating Manure into Areas of Deposition

The total manure generated after feed additive BMPs are applied is split equally into twelve portions to represent monthly manure generation. This split is made to give jurisdictions the opportunity to distinguish the amount of time an animal spends in each of the following areas each month: pasture; riparian pasture access area; and barnyard. For example, an average dairy cow may spend 25 percent of its day on pasture and riparian pasture areas during the winter months when it is colder but spend 50 percent (or more) of its day there during warmer summer months. Each jurisdiction was asked to provide percentages for each animal type and month. The percentages could even vary by county or growth region to account for varying climates across a single state. An example of these percentages is included in Table 3-5.

*Table 3-5: Beef percent manure deposited by area in West Virginia growth region 1*

| Growth Region | Animal Type | Month | Barnyard Percent | Pasture Percent | Access Area Percent |
|---|---|---|---|---|---|
| WV_1 | beef | 1 | 6 | 91 | 3 |
| WV_1 | beef | 2 | 6 | 91 | 3 |
| WV_1 | beef | 3 | 0 | 96 | 4 |
| WV_1 | beef | 4 | 0 | 94 | 6 |
| WV_1 | beef | 5 | 0 | 94 | 6 |
| WV_1 | beef | 6 | 0 | 90 | 10 |
| WV_1 | beef | 7 | 0 | 90 | 10 |
| WV_1 | beef | 8 | 0 | 90 | 10 |
| WV_1 | beef | 9 | 0 | 94 | 6 |
| WV_1 | beef | 10 | 0 | 96 | 4 |
| WV_1 | beef | 11 | 0 | 96 | 4 |
| WV_1 | beef | 12 | 6 | 91 | 3 |

#### 3.2.2.1 Direct Deposition on Pasture

Table 3-5 indicates 91 percent of beef manure is assumed to be deposited on pasture in West Virginia in the month of January. This is manure that will be unavailable for manure transport or application to meet crop application goal. The manure is simply applied to the pasture land use and becomes one source of applications to that land use. Additionally, this manure is not applied toward the pasture's crop application goal. This means that regardless of the amount of direct deposition on pasture, it is always eligible to receive supplemental manure and/or inorganic fertilizer applications later in the scenario simulation.

*Equation 3-3: Example Direct Deposition to Pasture Total Nitrogen Monthly Calculation for 1,000 Beef Cattle*

*11,952.42 Lbs N/Month*
*=*
*1,000 Beef*
*X*
*5,475 Lbs Dry Manure/Beef/Year*
*X*
*0.028788 Lbs of N/Lb Dry Manure*
*÷*
*12 months/year*
*X*
*0.91 fraction in pasture*

#### *3.2.2.2 Direct Deposition to Riparian Pasture Areas*

Table 3-5 indicates 3 percent of beef manure is assumed to be deposited in riparian pasture areas in West Virginia in the month of January. This is also manure that will be unavailable for manure transport or application to meet crop application goal. The total amount deposited in riparian areas is calculated in sample calculation Equation 3-4.

*Equation 3-4: Example Direct Deposition to Riparian Pasture Total Nitrogen Monthly Calculation for 1,000 Beef Cattle*

*394.04 Lbs N/Month*
*=*
*1,000 Beef*
*X*
*5,475 Lbs Dry Manure/Beef/Year*
*X*
*0.028788 Lbs of N/Lb Dry Manure*
*÷*
*12 months/year*
*X*
*0.03 fraction in riparian area*

Only 80 percent of the total nitrogen and phosphorus assumed to be deposited in the riparian access area is estimated to reach streams. The estimates are based on the assumption that some deposition occurs outside of the stream itself and is subject to nutrient retention in the riparian area. The Agriculture Workgroup used an average assumption from a variety of Virginia bacterial TMDL models to estimate that 30 percent of manure deposited within the access area is deposited outside of the stream. Of that 30 percent, the Agriculture Workgroup assumed that 33 percent of N and 34 percent of P was delivered to streams based upon literature findings (Butler et al. 2008). Figure 3.7 shows how these assumptions combine to estimate total nitrogen delivered to streams from riparian access areas.

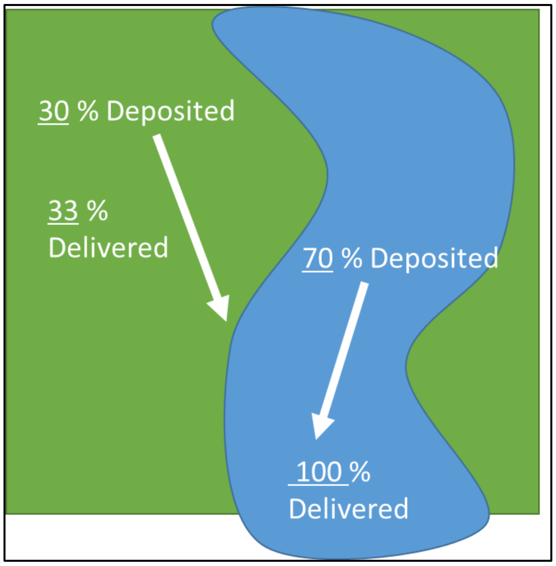



*Figure 3-7: Fraction of deposition and delivery of nitrogen in riparian areas.*

#### 3.2.2.3 Manure Deposition to Barnyard Areas

Table 3-5 indicates 6 percent of beef manure is assumed to be deposited in barnyard areas in West Virginia in the month of January. An example calculation is made in Equation 3-5. All manure deposited within the barnyard can be: 1) lost as part of incidental barnyard losses to the environment; 2) collected and transported to another county through manure transport; or 3) applied to crops within the county.

*Equation 3-5: Example manure deposition to barnyard total nitrogen monthly calculation for 1,000 beef cattle*

$$\text{788.07 Lbs N/Month} = \text{1,000 Beef} \times \text{5,475 Lbs Dry Manure/Beef/Year} \times \text{0.028788 Lbs of N/Lb Dry Manure} \div \text{12 months/year} \times \text{0.06 fraction in barnyard}$$

### 3.2.3 Volatilization in the Barnyard and Pasture

After manure is separated into the three deposition areas of pasture, riparian pasture, and barnyard, it is further subject to losses through a combination of volatilization, storage and handling loss, and manure transport, depending upon the area of deposition. This section will discuss each of these loss pathways and the BMPs which can reverse the losses.

#### 3.2.3.1 Volatilization Within the Barnyard

A portion of manure nitrogen collected within the barnyard is subject to volatilization. The amount of volatilization is based upon average values developed for the Integrated Farm System Model (Rotz 2013). The manure volatilized cannot be applied to crops or pasture in later simulation steps. Values for the fraction of manure nitrogen volatilized within the barnyard (and on crops following application) can be found in Table 3-6.

*Equation 3-6: Example barnyard total nitrogen post-volatilization monthly calculation for 1,000 beef cattle*

$$
\begin{gathered}
512.25 \text{ Lbs N/Month} \\
= \\
1{,}000 \text{ Beef} \\
X \\
5{,}475 \text{ Lbs Dry Manure/Beef/Year} \\
X \\
0.028788 \text{ Lbs of N/Lb Dry Manure} \\
\div \\
12 \text{ months/year} \\
X \\
0.06 \text{ fraction in barnyard} \\
X \\
(1-0.35) \text{ fraction not volatilized}
\end{gathered}
$$

*Table 3-6: Fraction of excreted manure lost to volatilization*

| Animal Type | Fraction Excreted N Lost in Barnyard* | Fraction Excreted N Lost in Field** | Fraction Excreted N Lost from Excretion to Field |
|---|---|---|---|
| **Beef** | 0.35 | 0.04 | 0.39 |
| **Other Cattle** | 0.35 | 0.04 | 0.39 |
| **Dairy** | 0.27 | 0.18 | 0.45 |
| **Hogs for Slaughter** | 0.30 | 0.27 | 0.57 |
| **Hogs for Breeding** | 0.30 | 0.27 | 0.57 |
| **Broiler** | 0.40 | 0.06 | 0.46 |
| **Layers** | 0.40 | 0.06 | 0.46 |
| **Pullets** | 0.40 | 0.06 | 0.46 |
| **Horses** | 0.35 | 0.04 | 0.39 |
| **Goats** | 0.35 | 0.06 | 0.41 |
| **Sheep** | 0.35 | 0.06 | 0.41 |

**Average calculated from Rotz 2003 values.*

*** Calculated from UMD (2009) values for fraction of ammonium-nitrogen conserved after application with no incorporation. Values adjusted based upon fraction of ammonium-nitrogen estimated within manure following application.*

*Ammonia Emission Reduction BMPs*

Biofilters for poultry houses, lagoon covers for swine and cattle operations, and poultry litter amendments are all BMPs which can reduce ammonia emissions within the barnyard. CAST simulates this reduction of ammonia volatilization in two ways. First, the ammonia "conserved" within the barnyard is available for application to crops, increasing the amount of plant-available nitrogen applied to the landscape outside of the barnyard. Second, CAST calculates a reduction in the load delivered to tidal waters from the atmospheric deposition of ammonia. For more information, see Section 6.6.1 on animal BMP exceptions, and Section 4.7 on the sensitivity of ammonia emissions.

*Manure Treatment Technologies*

Manure Treatment Technologies are a suite of practices that alter the amount of nutrients within manure, including everything from manure composting to high-temperature pyrolysis. These practices can increase the amount of nitrogen lost to the atmosphere. The calculation of the amount of atmospheric deposition and how it is credited is discussed in detail in Section 4.

#### 3.2.3.2 Volatilization on Pasture and Riparian Pasture

A portion of manure nitrogen applied to pasture and riparian pasture is subject to volatilization. The percent of manure nitrogen volatilized in these locations is assumed to be equal to the percent of nitrogen that would be volatilized within the barnyard plus the percent of nitrogen that would be volatilized from crop fields. For example, 35 percent of beef manure nitrogen (as excreted) is assumed to be lost within the barnyard, and an additional 4 percent of manure nitrogen (as excreted) is assumed to be lost from crop fields with no incorporation. Thus, a total of 39 percent of beef manure nitrogen (as excreted) is assumed to be lost due to volatilization within pasture and riparian pasture areas. Table 3-6 includes similar factors for all animal types.

*Equation 3-7: Example direct deposition to pasture total nitrogen post-volatilization monthly calculation for 1,000 Beef Cattle*

*7,290.98 Lbs N/Month*
*=*
*1,000 Beef*
*X*
*5,475 Lbs Dry Manure/Beef/Year*
*X*
*0.028788 Lbs of N/Lb Dry Manure*
*÷*
*12 months/year*
*X*
*0.91 fraction in pasture*
*X*
*(1-0.39) fraction not volatilized*

*Equation 3-8:* Example direct deposition to riparian pasture access area total nitrogen post-volatilization monthly calculation for 1,000 beef cattle

*240.36 Lbs N/Month*
*=*
*1,000 Beef*
*X*
*5,475 Lbs Dry Manure/Beef/Year*
*X*

*0.028788 Lbs of N/Lb Dry Manure*
*÷*
*12 months/year*
*X*
*0.03 fraction in riparian area*
*X*
*(1-0.39)*

### 3.2.4 Storage and Handling Loss

Barnyard manure remaining after accounting for volatilization of ammonia and ammonia reduction BMPs is subject to storage and handling loss. Storage and handling loss is the portion of manure deposited within the barnyard that is considered unrecoverable due to incidental losses to the environment immediately adjacent to the barnyard. These incidental losses become the nutrient load for the permitted feeding space and non-permitted feeding space land uses after watershed processing losses are considered. All remaining manure is considered recoverable and available for manure transport and application to crops. Recoverability can be increased on animal operations with adequate manure storage known as Animal Waste Management System practices (AWMS). The AWMS expert panel report provided values for the amount of manure recoverable with and without qualifying practices that are included in Table 3-7.

*Table 3-7: Recoverability of Manure with and Without AWMS (Hawkins, et al. 2016)*

| Animals | % Recoverable without AWMS | % Recoverable with AWMS |
|---|---|---|
| Beef | 60 | 99 |
| Dairy | 75 | 95 |
| Other Cattle | 60 | 99 |
| Hogs for Slaughter | 90 | 99 |
| Hogs for Breeding | 90 | 99 |
| Broilers | 90 | 99 |
| Layers | 90 | 99 |
| Turkeys | 90 | 99 |
| Pullets | 90 | 99 |
| Sheep | 95 | 98 |
| Horses | 95 | 98 |
| Goats | 95 | 98 |

*Equation 3-9: Example total nitrogen post-storage and handling loss with AWMS monthly calculation for 1,000 beef cattle*

*507.13 Lbs N/Month =*
*1,000 Beef*
*X*
*5,475 Lbs Dry Manure/Beef/Year*
*X*
*0.028788 Lbs of N/Lb Dry Manure*
*÷*
*12 months/year*
*X*

*0.06 fraction in barnyard*
*X*
*(1-0.35) fraction not volatilized*
*X*
*(0.99) fraction recoverable*

All example calculations described above were done based upon monthly manure production. The manure nutrients and tons can now be aggregated up to annual values for each county and animal type for manure transport calculations. Table 3-8 shows how the steps are applied to manure nutrients generated each month to arrive at an annual total.

*Table 3-8: Monthly nitrogen deposition and fate within the barnyard*

| Month | Lbs N Deposited in Barnyard | Lbs N Post-Volatilization | Lbs N Post-Storage and Handling Loss (Assumes AWMS) |
|---|---|---|---|
| January | 788.07 | 512.25 | 507.12 |
| February | 788.07 | 512.25 | 507.12 |
| March | - | - | - |
| April | - | - | - |
| May | - | - | - |
| June | - | - | - |
| July | - | - | - |
| August | - | - | - |
| September | - | - | - |
| October | - | - | - |
| November | - | - | - |
| December | 788.07 | 512.25 | 507.12 |
| **Total** | **2,364.21** | **1,536.74** | **1,521.37** |

*Assumes 6 percent deposition in January, February and December, and 0 percent deposition in other months.*

### 3.2.5 Manure Transport

All manure which is recoverable after AWMS BMPs are accounted for is made available for manure transport. States may submit tons of manure by animal type which are transported across county lines or even out of the watershed entirely. Because nutrient concentrations are calculated on a dry-weight basis, CAST must estimate the moisture content of manure to properly estimate nutrients transported. Table 3-9 lists the assumed moisture content of each type of manure for Phase 6. Sources for each animal type are the same as shown in Table 3-4. Alternatively, states can report the total number of dry tons transported if that information is available.

*Table 3-9: Moisture fraction of animal manure*

| Animal Type | Moisture Fraction |
|---|---|
| beef | 0.8800 |
| dairy | 0.8600 |
| other cattle | 0.8700 |
| horses | 0.8500 |
| hogs and pigs for breeding | 0.9000 |
| hogs for slaughter | 0.9000 |
| sheep and lambs | 0.7200 |

| | |
|---|---|
| goats | 0.6700 |
| pullets | 0.7406 |
| turkeys | 0.7400 |
| layers | 0.7421 |
| broilers | 0.2865 |

Following this step, CAST has the total pounds of dry manure applied to crops. The example equation 3-10 below describes the calculation.

*Equation 3-10: Example calculation of transport loss*

*3.45 lbs N lost to transport*
*=*
*1000 lbs wet manure transported*
*X*
*(1 – 0.88) lbs dry per lb wet manure*
*X*
*0.028788 Lbs of N/Lb Dry Manure*

## 3.2.6 Plant-Available Nutrients

Prior to determining applications to crops, CAST must convert total nitrogen and total phosphorus to plant-available nitrogen and phosphorus. For manure nitrogen, this means further decreasing the amount of nitrogen available through assumptions of in-field volatilization and mineralization of current and previous year manure applications.

### *3.2.6.1 In-Field Volatilization*

Table 3-6 includes estimates of the percent of manure generated that can be volatilized within the field. The original total nitrogen concentrations in Table 3-4 in generated manure are multiplied by this percentage in order to calculate an amount of nitrogen that is volatilized within the field. Equation 3-11 also provides an example of how post-volatilized nitrogen is calculated.

*Equation 3-11: Example total annual nitrogen available to crops following in-field volatilization for 1,000 cattle*

*40 Lbs N lost to in-field volatilization*
*=*
*1000 (Lbs N Post-Manure Transport)*
*X*
*0.04 (fraction lost to volatilization)*

### *3.2.6.2 Mineralization of Organic Nitrogen*

Mineralization of organic nutrients in manure transforms previously unavailable nutrients into a form that can be used for plant uptake. This process occurs continually within the soil for years after application of manure. The Phase 6 Model does not directly account for previous years' nutrient applications when calculating current or future year applications to crops. For this reason, CAST adjusts the amount of mineralized nutrient available from the current year's manure application to take into account previous applications.

Nutrient management plans currently estimate multiple years' worth of mineralization on a field when assessing how much additional manure or fertilizer is needed to grow a crop. However, this estimate of previous applications has changed over time. For example, nutrient management planners may have conservatively assumed no previous application in the 1980s, but three or even more years of previous applications in the 2000s. For this reason, the partnership elected to vary the mineralization rate by decade, using a three-year rate starting in 2000, a single-year rate through 1990, and interpolating between the two values for any year in the 1990s. These mineralization values are published in Table 3-10.

Mineralization fractions are applied only to the organic portion of nitrogen. Organic nitrogen is equivalent to the non-ammoniacal nitrogen in manure. Table 3-11 contains organic nitrogen (non-ammoniacal) values and associated mineralized nitrogen values in excreted manure.

*Table 3-10: Mineralization fraction of organic nitrogen*

| Animal Type | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 | 2013 |
|---|---|---|---|---|---|---|---|
| hogs and pigs for breeding** | 0.3 | 0.3 | 0.4375 | 0.575 | 0.575 | 0.575 | 0.575 |
| beef** | 0.3 | 0.3 | 0.415 | 0.53 | 0.53 | 0.53 | 0.53 |
| dairy** | 0.3 | 0.3 | 0.415 | 0.53 | 0.53 | 0.53 | 0.53 |
| hogs for slaughter** | 0.3 | 0.3 | 0.4375 | 0.575 | 0.575 | 0.575 | 0.575 |
| horses* | 0.2 | 0.2 | 0.275 | 0.35 | 0.35 | 0.35 | 0.35 |
| other cattle** | 0.3 | 0.3 | 0.415 | 0.53 | 0.53 | 0.53 | 0.53 |
| sheep and lambs* | 0.3 | 0.3 | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 |
| goats* | 0.3 | 0.3 | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 |
| broilers** | 0.55 | 0.55 | 0.65 | 0.75 | 0.75 | 0.75 | 0.75 |
| pullets** | 0.55 | 0.55 | 0.65 | 0.75 | 0.75 | 0.75 | 0.75 |
| turkeys** | 0.55 | 0.55 | 0.65 | 0.75 | 0.75 | 0.75 | 0.75 |
| layers** | 0.55 | 0.55 | 0.65 | 0.75 | 0.75 | 0.75 | 0.75 |

* Source for values is Mid Atlantic Water Program, 2013.
**Source for values is University of Maryland Cooperative Extension, 2011.
Red values are interpolated between 1990 and 2000.

*Table 3-11: Example mineralized n in excreted manure for Delaware in 2013*

| Animal | Excreted Non-Ammoniacal N | Mineralized Fraction | Excreted Mineralized N | Excreted Non-Mineralized N |
|---|---|---|---|---|
| Beef | 0.017215 | 0.53 | 0.009124 | 0.008091 |
| Dairy | 0.017876 | 0.53 | 0.009474 | 0.008402 |
| Other Cattle | 0.021231 | 0.53 | 0.011253 | 0.009979 |
| Hogs and Pigs for Slaughter | 0.027672 | 0.575 | 0.015911 | 0.011761 |
| Hogs and Pigs for Breeding | 0.076315 | 0.575 | 0.043881 | 0.032434 |
| Broilers | 0.034036 | 0.75 | 0.025527 | 0.008509 |
| Layers | 0.028779 | 0.75 | 0.021584 | 0.007195 |
| Turkeys | 0.042009 | 0.75 | 0.031507 | 0.010502 |
| Pullets | 0.025152 | 0.75 | 0.018864 | 0.006288 |
| Sheep and Lambs | 0.021344 | 0.5 | 0.010672 | 0.010672 |
| Horses | 0.018734 | 0.35 | 0.006557 | 0.012177 |
| Goats | 0.019350 | 0.5 | 0.009675 | 0.009675 |

*Mineralization fractions vary by year.*

Non-mineralized nitrogen is removed from the amount of nitrogen available to fulfill crop application goals. This is the final step in the process to determine manure nitrogen nutrients available to fulfill crop application goals.

#### 3.2.6.3 Phosphate and Mineralized Phosphorus

Phosphate and mineralized phosphorus are considered to be available to meet crop application goals. Together, these two constituents make up 100 percent of the phosphorus in manure. Thus, 100 percent of phosphorus that is applied is considered available to meet crop application goals. Table 3-12 lists the phosphate and mineralized phosphorus concentrations per pound of dry manure.

*Table 3-12: Phosphate and mineralized phosphorus concentrations*

| Animal | Phosphate | Mineralized Phosphorus |
|---|---|---|
| Beef | 0.002156 | 0.004311 |
| Dairy | 0.006547 | 0.000217 |
| Other Cattle | 0.002205 | 0.004411 |
| Hogs and Pigs for Slaughter | 0.014615 | 0.007307 |
| Hogs and Pigs for Breeding | 0.024426 | 0.012213 |
| Broilers | 0.004748 | 0.011078 |
| Layers | 0.005572 | 0.013001 |
| Turkeys | 0.004856 | 0.011331 |
| Pullets | 0.005817 | 0.013573 |
| Sheep and Lambs | 0.003955 | 0.003955 |
| Horses | 0.001485 | 0.004456 |
| Goats | 0.002821 | 0.005641 |

*Total phosphorus for poultry species can vary by year, but fraction phosphate is assumed to remain the same.*

### 3.2.7 Biosolids, Septage, and Spray Irrigation

Jurisdictions provided pounds of nutrients from wastewater treatment plant, biosolids, septage, and spray irrigation that were applied to cropland within specific counties and in specific years. Where data were unavailable, the Chesapeake Bay Program estimated nutrients available for application based upon reported values from other years. Septage and spray irrigation are handled in the same was as biosolids in application calculations. The remainder of Section 3 will refer to biosolids only with the understanding that this includes septage and spray irrigation. Biosolids and manure are collectively referred to as organic fertilizer.

## 3.3 Establishing Crop Application Goals

Nutrients from manure and inorganic fertilizer are applied in an effort to meet crop application goals. Jurisdictions consulted nutrient management planners to define average application goals for various crops by growth regions. These goals were not meant to reflect actual applications, but rather the expected application per acre or yield unit for any producer with a nutrient management plan. When combined with acres of nutrient management and yields, these goals inform the relative magnitude of manure or inorganic nutrients each crop should receive. Jurisdictions provided the following:

- Total N and P application goals per acre or yield unit (varied by decade as nutrient management guidelines changed)

    - Example: 0.92 lbs of N/bushel of corn for grain yield
- Fraction of total application goal which should be met by applications in each month
    - Example: 0.4 of yearly total N on corn for grain should be applied in April
- Indication of which applications are eligible to be met by manure nutrients in each month
    - Example: April applications are eligible to be met by manure nutrients

Information provided by jurisdictions can be found in Appendix G.

### 3.3.1 Adjusting Application Goals Based upon Acres of Nutrient Management

States provide acres covered under qualifying nutrient management plans. The Nutrient Management Expert Panel recommended that each acre under a qualified nutrient management plan receive an application goal equal to that provided by the states. However, the panel also recommended that every acre that does not have a qualifying plan will receive a higher application goal. This higher goal is calculated by multiplying the state-supplied application goal by a coefficient provided in Table 3-13. For example, an acre of corn that could receive manure with a qualifying nutrient management plan would have an application goal equal to 0.92 lbs of N/bushel as prescribed by the state-submitted application goal. However, an acre of corn that could receive manure without a qualifying nutrient management plan would have an application goal of about 1.2 lbs of N/bushel.

*Table 3-13: Non-nutrient management application goal multipliers*

| Land Use | Non-Nutrient Management Nitrogen Multiplier | Non-Nutrient Management P Multiplier |
|---|---|---|
| Full Season Soybeans | 1.2 | 1.5 |
| Grain w/ Manure | 1.3 | 3 |
| Grain w/o Manure | 1.2 | 1.5 |
| Legume Hay | 1.2 | 1 |
| Silage w/ Manure | 1.4 | 3 |
| Silage w/o Manure | 1.2 | 1.5 |
| Small Grains and Grains | 1.2 | 1.5 |
| Small Grains and Soybeans | 1.2 | 1.5 |
| Specialty Crop High | 1.3 | 2 |
| Specialty Crop Low | 1.2 | 2 |
| Other Agronomic Crops | 1.1 | 1.5 |
| Other Hay | 1 | 1 |
| Pasture | 1 | 1 |

### 3.3.2 Adjusting Application Goals Based upon Yields

Nutrient management plan writers across the watershed base application goals on historic crop yield information. If crop yields have increased in recent years, nutrient management planners will adjust the applications upward to match these increases. Likewise, the Phase 6 Model adjusts yields for major crops up and down according to yearly crop yield data provided by NASS.

Yields are calculated for each major crop in each county for each year. The step-by-step yield calculation procedure can be found in Appendix C.

Yield data are often sparse or variable for the majority of crops simulated by Phase 6 Model, so states provided application goals for these crops on a per acre basis. Application goal yield units by crops are supplied in Table 3-14.

*Table 3-14: Crop application goal yield units*

| Crop Name | Application Goal Yield Unit |
|---|---|
| Alfalfa Hay Harvested Area | dry tons |
| Alfalfa seed Harvested Area | acres |
| Aquatic plants Area | acres |
| Asparagus Harvested Area | acres |
| Barley for grain Harvested Area | bushels |
| Bedding/garden plants Area | acres |
| Beets Harvested Area | acres |
| Berries- all Harvested Area | acres |
| Birdsfoot trefoil seed Harvested Area | acres |
| Broccoli Harvested Area | acres |
| Bromegrass seed Harvested Area | acres |
| Brussels Sprouts Harvested Area | acres |
| Buckwheat Harvested Area | bushels |
| Bulbs, corms, rhizomes, and tubers – dry Harvested Area | acres |
| Canola Harvested Area | acres |
| Cantaloupe Harvested Area | acres |
| Carrots Harvested Area | acres |
| Cauliflower Harvested Area | acres |
| Celery Harvested Area | acres |
| Chinese Cabbage Harvested Area | acres |
| Collards Harvested Area | acres |
| Corn for Grain Harvested Area | bushels |
| Corn for silage or greenchop Harvested Area | tons |
| Cotton Harvested Area | acres |
| Cropland idle or used for cover crops or soil improvement but not harvested and not pastured or grazed Area | acres |
| Cropland in cultivated summer fallow Area | acres |
| Cropland on which all crops failed or were abandoned Area | acres |
| Cropland used only for pasture or grazing Area | acres |
| Cucumbers and Pickles Harvested Area | acres |
| Cut Christmas Trees Production Area | acres |
| Cut flowers and cut florist greens Area | acres |
| Dry edible beans, excluding limas Harvested Area | acres |
| Dry Onions Harvested Area | acres |
| Eggplant Harvested Area | acres |
| Emmer and spelt Harvested Area | acres |
| Escarole and Endive Harvested Area | acres |
| Fescue Seed Harvested Area | acres |

| | |
|---|---|
| Foliage plants Area | acres |
| Garlic Harvested Area | acres |
| Green Lima Beans Harvested Area | acres |
| Green Onions Harvested Area | acres |
| Greenhouse vegetables Area | acres |
| Haylage or greenchop from alfalfa or alfalfa mixtures Harvested Area | acres |
| Head Cabbage Harvested Area | acres |
| Herbs, Fresh Cut Harvested Area | acres |
| Honeydew Melons Harvested Area | acres |
| Kale Harvested Area | acres |
| Land in Orchards Area | acres |
| Lettuce, All Harvested Area | acres |
| Mushrooms Area | acres |
| Mustard Greens Harvested Area | acres |
| Nursery stock Area | acres |
| Oats for grain Harvested Area | bushels |
| Okra Area | acres |
| Orchardgrass seed Harvested Area | acres |
| Other field and grass seed crops Harvested Area | acres |
| Other haylage, grass silage, and greenchop Harvested Area | acres |
| Other managed hay Harvested Area | acres |
| Other nursery and greenhouse crops Area | acres |
| Parsley Harvested Area | acres |
| Pastureland and rangeland other than cropland and woodland pastured Area | acres |
| Peanuts for nuts Harvested Area | acres |
| Peas, Chinese (sugar and Snow) Harvested Area | acres |
| Peas, Green (excluding southern) Harvested Area | acres |
| Peas, Green Southern (cowpeas) – Black-eyed, Crowder, etc. Harvested Area | acres |
| Peppers, Bell Harvested Area | acres |
| Peppers, Chile (all peppers – excluding bell) Harvested Area | acres |
| Popcorn Harvested Area | acres |
| Potatoes Harvested Area | acres |
| Potted flowering plants Area | acres |
| Pumpkins Harvested Area | acres |
| Radishes Harvested Area | acres |
| Red clover seed Harvested Area | acres |
| Rhubarb Harvested Area | acres |
| Rye for grain Harvested Area | bushels |
| Ryegrass seed Harvested Area | acres |
| short-rotation woody crops Harvest Area | acres |
| Small grain hay Harvested Area | acres |
| Snap Beans Harvested Area | acres |
| Sod harvested Area | acres |
| Sorghum for Grain Harvested Area | bushels |
| Sorghum for silage or greenchop Area | tons |
| Soybeans for beans Harvested Area | bushels |

| | |
|---|---|
| Spinach Harvested Area | acres |
| Squash Harvested Area | acres |
| Sunflower seed, non-oil varieties Harvested Area | acres |
| Sunflower seed, oil varieties Harvested Area | acres |
| Sweet Corn Harvested Area | acres |
| Sweet potatoes Harvested Area | acres |
| Timothy seed Harvested Area | acres |
| tobacco Harvested Area | acres |
| Tomatoes Harvested Area | acres |
| Triticale Harvested Area | acres |
| Turnip Greens Harvested Area | acres |
| Turnips Harvested Area | acres |
| Vegetable & flower seeds Area | acres |
| Vegetables, Mixed Area | acres |
| Vetch seed Harvested Area | acres |
| Watermelons Harvested Area | acres |
| Wheat for Grain Harvested Area | bushels |
| Wild hay Harvested Area | acres |

### 3.3.3 Calculating Application Goals for Crops in a County

The example calculations included below show how nutrient management and yield information can adjust application goals for a hypothetical county.

*Equation 3-12: Example application goal for county*

Step 1. Calculate the acres of crop.

Example:

- 1,000 acres of Corn for Grain
- 1,000 acres of Pasture

Step 2. Separate acres into nutrient management (NM) acres and non-nutrient management

Example: 50 percent nutrient management on Corn for Grain and 0 percent on Pasture

- 1,000 acres of Corn for Grain X 0.5 = 500 acres of Corn for Grain with NM plan
- 1,000 acres of Corn for Grain X 0.5 = 500 acres of Corn for Grain without NM plan
- 1,000 acres of Pasture X 1 = 1,000 acres of Pasture without NM plan.

Step 3. Multiply acres by yield goal to determine application goal yield for each crop.

Example:

- 500 acres of Corn for Grain with NM X 100 bushels/acre = 50,000 bushels
- 500 acres of Corn for Grain without NM plan X 100 bushels/acre = 50,000 bushels
- 1,000 acres of Pasture without NM plan X 1 acre/acre = 1,000 acres. (Remember that applications on pasture and many other crops are not based upon changes in yields.)

Step 4. Multiply application goal yield for each crop by the state-supplied application goal per yield unit AND the non-nutrient management plan multiplier.

Example:

- 500 acres of Corn for Grain with NM X 100 bushels/acre X 0.92 Lbs N/Bushel X 1 = 46,000 Lbs N
- 500 acres of Corn for Grain without NM X 100 bushels/acre X 0.92 Lbs N/Bushel X 1.3 = 59,800 Lbs N
- 1,000 acres of Pasture without NM X 1 acre/acre X 15 Lbs N/Acre X 1 = 15,000 Lbs N

This information is then further broken into application goals for each month of the year. Monthly application goals are also designated as either organic-eligible, meaning that they can be fulfilled with either organic or inorganic applications, or inorganic-only, meaning that applications of biosolids and manure cannot be used to meet the application goals. Inorganic-only applications may be specified for crops that are typically never grown with organic fertilizer or for specific inorganic applications, such as starter fertilizer, on crops that are generally grown with organic fertilizer. Once application goals are established for all crops in all months, applications of available biosolids, manure, and fertilizer can be made. All relevant data, including application goals by crop and month can be downloaded from the CAST site under 'source data'.

## 3.4 Distributing Manure and Biosolids Applications to Crops

CAST handles manure and biosolids distribution to crops according to the same logic, but with slightly different specifications. Biosolids applications are handled first and then manure applications follow. A fundamental assumption of the Phase 6 Model is that all manure and biosolids estimated to be available to crops in a county must be applied. This means that in counties with high animal populations and little manure transport data, manure and biosolids could be applied above and beyond the organic-eligible goals specified for each crop by the jurisdictions. Likewise, applications could be far lower than the organic-eligible goal in counties with very few animals and low biosolid application. The Phase 6 Model attempts to simulate all potential cases such as these with a single set of application curves which prioritizes application to higher-commodity crops such as vegetables and corn before applications occur on crops such as pasture, hay and other legumes. The prioritization curves for manure are shown in Figure 3-8. Rather than creating over a hundred individual curves for all types of crops, the crops were lumped into land use groups. Table 3-15 lists the land uses included in each land use group. The inflection points and slopes for each curve are also included in Table 3-16. The prioritization curves for biosolids are shown in Figure 3-9, with land use groupings in Table 3-15 and specifications in Table 3-16.

Figure 3-8 provides a relationship between percent of the crop application goal between different types of agricultural land uses within a given county. The horizontal axis is the percent of crop application goal for grains and specialty crops. The vertical axis is the percent of crop application goal for all land uses. For example, suppose that a county with a manure and biosolids deficit relative to the total crop need has just enough manure to supply 50% of the application goal for grain and specialty crops. The grain and specialty line would specify that they get 50% of their application goal while all other land use groups would receive no manure as they would be at 0% on the vertical axis. As more manure became available, the application to grain and specialty would continue to climb, but applications would also begin, first on non-legume hay and pasture and then legumes. As a county increases the amount of manure relative to the application goal, legumes, pasture, and hay climb faster than grain and specialty such that grain and specialty would only receive 120% of their application goals when there was enough manure all crops and pasture to receive 120% of their application goals. Application percentages higher than 120% climb faster for pasture and non-legume hays than for grain and specialty and slower for legumes. A similar relationship was developed for biosolids

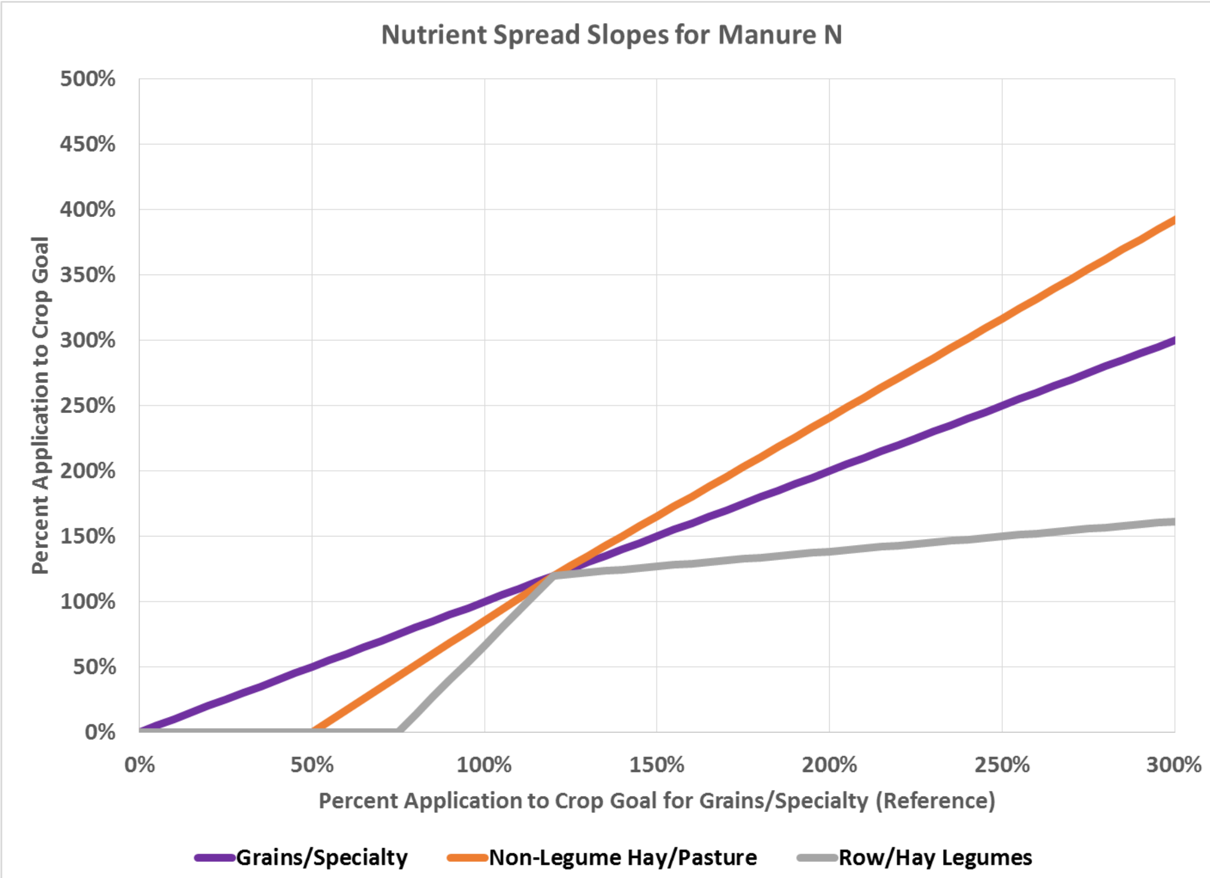



*Figure 3-8: Manure nitrogen application curves by crop group*

*Table 3-15: Land use groups for manure application curves*

| Curve | Land Use |
|---|---|
| Grains/Specialty | Grain with Manure |
| Grains/Specialty | Silage with Manure |
| Grains/Specialty | Small Grains and Grains |
| Grains/Specialty | Other Agronomic Crops |
| Grains/Specialty | Specialty Crop High |
| Grains/Specialty | Specialty Crop Low |
| Grains/Specialty | Small Grains and Soybeans |
| Row/Hay Legumes | Full Season Soybeans |
| Row/Hay Legumes | Legume hay |
| Non-Legume Hay/Pasture | Pasture |
| Non-Legume Hay/Pasture | Other Hay |

*Table 3-16: Manure curve inflection points*

| Grains/Specialty | Non-Legume Hay/Pasture | | | Row/Hay Legumes | | |
|---|---|---|---|---|---|---|
| % of goal | % of goal | slope | intercept | % of goal | slope | intercept |
| 0% | 0% | 0 | 0 | 0% | 0 | 0 |
| 50% | 0% | 1.71 | -0.86 | | | |
| 75% | | | | 0% | 2.67 | -2.00 |
| 120% | 120% | 1.51 | -0.62 | 120% | 0.23 | 0.92 |
| 500% | 695% | | | 208% | | |

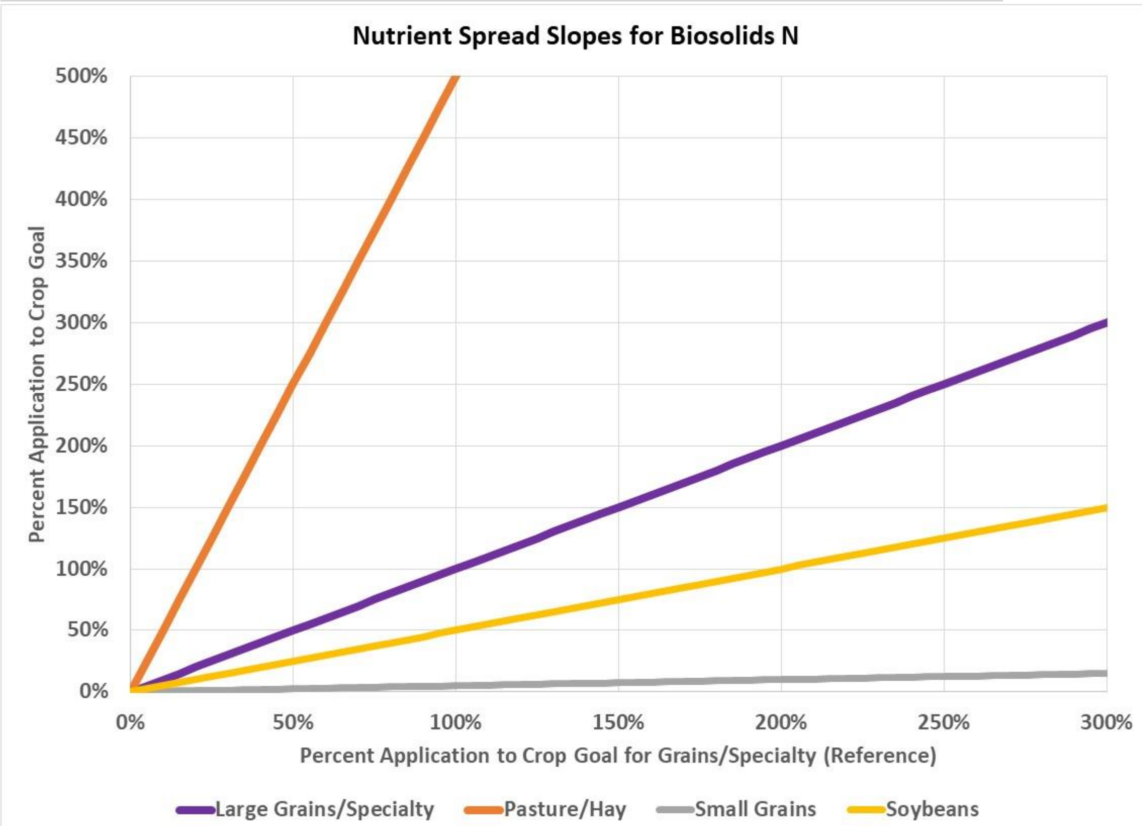



*Figure 3-9: Biosolids application curves by crop group*

*Table 3-17: Land use groups for biosolids applications*

| Curve | Land Use |
|---|---|
| Large Grains/Specialty | Grain with Manure |
| Large Grains/Specialty | Silage with Manure |
| Small Grains | Small Grains and Grains |
| Large Grains/Specialty | Other Agronomic Crops |

| | |
|---|---|
| Large Grains/Specialty | Specialty Crop High |
| Large Grains/Specialty | Specialty Crop Low |
| Small Grains | Small Grains and Soybeans |
| Soybeans | Full Season Soybeans |
| Pasture/Hay | Legume hay |
| Pasture/Hay | Pasture |
| Pasture/Hay | Other Hay |

Table *3-18*: Biosolid curve inflection points

| Large Grains | Pasture/Hay | | | Soybeans | | | Small Grains | | |
|---|---|---|---|---|---|---|---|---|---|
| % of goal | % of goal | slope | intercept | % of goal | slope | intercept | % of goal | slope | intercept |
| 0% | 0% | 5.00 | 0 | 0% | 0.50 | 0 | 0 | 0.05 | 0 |
| 100% | 500% | 5.00 | 0 | 50% | 0.50 | 0 | 0 | 0.05 | 0 |
| 500% | 2500% | | | 250% | | | | | |

As Figure 3-8 indicates, the Phase 6 Model prioritizes applications to specialty grain crops first. For example, if the manure nitrogen available in a county only equals 40 percent of the manure-eligible application goals of all specialty crops and grain crops, then no other crops within the county will receive manure. However, applications to other crop groups begin as more manure nitrogen becomes available in the county. The last crops which will receive manure are leguminous crops including hays and soybeans. Additionally, if there are excessive amounts of manure within a county, applications are increased on pasture to simulate disposal of the manure.

As noted above, biosolid applications occur first in the Phase 6 model. The nutrient spread slope for manure in Figure 3-8 then apply to the total of manure and biosolid applications. That is, if an organic-eligible application event for a crop in a given month is 10 pounds and 2 pounds of biosolids are applied, then the 200% application level for that application event would be 20 pounds total, consisting of 18 pounds of manure and 2 pounds of biosolids.

The Agriculture Workgroup agreed not to apply phosphorus manure and biosolids nutrients separately from nitrogen nutrients. Thus, manure and biosolids are applied to fulfill nitrogen application goals and phosphorus is applied in direct proportion to the nitrogen-to-phosphorus ratio of the manure and biosolids. For example, if the countywide manure and biosolids N:P is 3:1, then one pound of phosphorus will be applied for every three pounds of nitrogen.

Nitrogen and phosphorus applications from manure and biosolids count towards a crop's nitrogen and phosphorus application goals, meaning that less inorganic fertilizer is assumed to be needed in counties with large animal populations.

## 3.5 Inorganic Fertilizer Nutrients

Crops in the Phase 6 Model can receive both organic nutrients in the form of manure and biosolids and inorganic fertilizer nutrients to meet nutrient application goals prescribed by states. The Agricultural Modeling Subcommittee determined that no reliable data source exists which provides countywide inorganic fertilizer use adequate for the Phase 6 Model. However, both the International Plant Nutrition Institute's Nutrient Use Geographic Information System (NuGIS) and USGS's SPARROW modeling tool provide estimates of countywide inorganic fertilizer use which are based upon fertilizer sales data provided by the Association of American Plant Food Control Officials (AAPFCO). After reviewing both methods, the Agricultural Modeling Subcommittee developed a unique fertilizer use estimation procedure which also relies upon AAPFCO fertilizer sales data.

### 3.5.1 Determining Fertilizer Available in County

AAPFCO provides the following fertilizer sales information per year:

- County of fertilizer sale
- Tons of fertilizer sold
- Designated use of fertilizer (farm, non-farm or unknown)
- Concentration of nutrients within fertilizer sold (translated into total nitrogen and total phosphorus)

AAPFCO data cannot be directly used to estimate fertilizer use in a county because the data only reflects the county in which fertilizer was sold. Fertilizer sales may occur around transportation and commerce hubs, such as large cities, rather than in the rural counties where the fertilizer is actually used. Additionally, fertilizers may cross state lines after sale, making it difficult to ascertain the amount of fertilizer used within a state, much less within a county, based solely upon AAPFCO sales data. Finally, the reliability of fertilizer sales data reporting by states to AAPFCO varies over time. For example, a state might report that all fertilizer sold within a county in 1990 was of "unknown" use, but then in 1991, the same state may report that 75 percent of the fertilizer sold in the county was for use on farms. All of these issues inherent with fertilizer sales data had to be addressed in order to estimate fertilizer use in each county. The steps the Phase 6 Model takes to estimate fertilizer use in each county are addressed briefly below, and more extensively in the following sections.

Step 1. Smooth variability of fertilizer sales across space by summing yearly sales to a regional scale across all six states, including areas inside and outside of the watershed.

Step 2. Smooth variability of fertilizer sales across time by calculating a three-year rolling average fraction of total sales across the region which were designated for farm use.

Step 3. Use dollars spent on fertilizer and soil conditions (found in the Census of Agriculture) to estimate total watershed-wide fertilizer use. Assume that the fraction of the total dollars spent in the six-state region that is spent within watershed counties is equal to the fraction of total fertilizer sales in the six-state region that is applied within watershed counties.

Step 4. Distribute the resulting watershed-wide fertilizer sales to individual counties proportional to each county's fraction of the total watershed-wide inorganic crop application goal. The inorganic crop application goal is equal to the total crop application goal described in Section 3.3 reduced by the manure applications described in Section 3.4.

#### *3.5.1.1 Aggregating Fertilizer Sales to Regional Scale*

Pounds of total nitrogen and total phosphorus can be ascertained by multiplying the tons of fertilizer sold by the nutrient concentrations provided by AAPFCO. The Phase 6 Model then aggregates these data for each state within the watershed (including sales for counties both inside and outside the watershed), separating the data by year. Table 3-19 and Table 3-20 include the raw sales by state before individual outliers were removed. Note that 1997 values were not considered in the procedure.

*Table 3-19: Raw pounds of nitrogen fertilizer sales by state (AAPFCO)*

| Year | DE | MD | NY | PA | VA | WV | Regional Total |
|---|---|---|---|---|---|---|---|
| 1985 | 41,444,716 | 112,134,802 | 194,419,516 | 137,383,012 | 198,029,479 | 25,706,650 | 709,118,175 |
| 1986 | 33,886,303 | 98,676,291 | 176,896,480 | 114,762,370 | 159,025,624 | 19,524,450 | 602,771,517 |
| 1987 | 33,031,398 | 102,397,091 | 169,926,980 | 149,322,463 | 156,071,808 | 20,238,127 | 630,987,866 |
| 1988 | 31,476,339 | 104,444,571 | 152,104,777 | 147,323,135 | 156,178,750 | 25,603,647 | 617,131,218 |
| 1989 | 34,780,074 | 97,694,132 | 153,555,044 | 141,677,814 | 158,354,005 | 26,934,890 | 612,995,958 |
| 1990* | - | - | 184,307,431 | 148,045,008 | 181,559,182 | 27,650,998 | 541,562,619 |
| 1991 | 42,792,192 | 118,076,477 | 157,731,977 | 145,455,746 | 197,739,464 | 34,781,014 | 696,576,869 |
| 1992 | 44,239,436 | 150,348,101 | 189,766,607 | 141,831,862 | 234,866,164 | 35,559,100 | 796,611,270 |
| 1993 | 39,591,974 | 126,050,961 | 185,798,322 | 192,792,795 | 216,268,364 | 19,360,917 | 779,863,333 |
| 1994 | 39,444,256 | 119,734,506 | 232,598,340 | 206,060,959 | 202,800,760 | 17,929,914 | 818,568,734 |
| 1995 | 41,269,782 | 146,345,257 | 199,864,693 | 184,511,703 | 194,813,200 | 16,177,250 | 782,981,885 |
| 1996 | 44,355,021 | 142,008,878 | 131,854,972 | 203,830,918 | 206,576,580 | 14,123,004 | 742,749,372 |
| 1997** | - | - | - | - | - | - | - |
| 1998 | 37,995,676 | 126,472,170 | 167,433,714 | 208,483,600 | 205,323,088 | 21,920,063 | 767,628,313 |
| 1999 | 44,086,204 | 110,470,922 | 191,928,900 | 201,617,740 | 243,550,980 | 42,550,316 | 834,205,062 |
| 2000 | 42,125,399 | 207,615,434 | 146,052,721 | 215,322,704 | 229,704,509 | 16,473,409 | 857,294,175 |
| 2001 | 37,294,300 | 135,127,059 | 168,607,460 | 171,917,882 | 192,760,703 | 17,548,599 | 723,256,001 |
| 2002 | 42,983,855 | 134,446,805 | 157,329,402 | 235,805,657 | 214,884,861 | 21,465,524 | 806,916,105 |
| 2003 | 33,874,050 | 91,326,561 | 153,679,136 | 137,760,896 | 189,600,236 | 11,523,040 | 617,763,919 |
| 2004 | 30,520,293 | 162,186,060 | 194,538,736 | 169,306,844 | 192,236,091 | 31,395,060 | 780,183,083 |
| 2005 | 34,764,568 | 148,233,088 | 165,429,881 | 171,648,508 | 168,134,916 | 75,708,134 | 763,919,094 |
| 2006 | 33,250,192 | 100,058,576 | 181,111,309 | 181,855,345 | 174,102,984 | 49,242,074 | 719,620,479 |
| 2007 | 39,110,557 | 110,147,192 | 160,592,593 | 211,107,399 | 185,524,912 | 47,357,757 | 753,840,410 |
| 2008 | 44,816,762 | 118,139,285 | 158,996,237 | 186,619,695 | 178,002,531 | 4,823,692 | 691,398,202 |
| 2009 | 40,678,401 | 83,783,873 | 126,071,437 | 228,865,028 | 157,298,984 | 4,296,655 | 640,994,378 |
| 2010 | 47,486,702 | 58,677,608 | 155,424,698 | 197,247,992 | 183,423,406 | 20,078,088 | 662,338,494 |
| 2011 | 44,498,304 | 87,966,135 | 155,983,311 | 190,998,888 | 189,528,340 | 12,740,116 | 681,715,094 |
| 2012 | 39,981,186 | 88,395,490 | 155,980,123 | 200,303,240 | 199,187,416 | 12,844,511 | 696,691,966 |

*DE and MD did not report data to AAPFCO for 1990.
**There was an error in the database for 1997 and these values were not used.

*Table 3-20: Raw pounds of phosphorus fertilizer sales by state (AAPFCO)*

| Year | DE | MD | NY | PA | VA | WV | Regional Total |
|---|---|---|---|---|---|---|---|
| 1985 | 7,069,736 | 32,950,758 | 68,216,215 | 47,707,004 | 58,609,224 | 11,957,072 | 226,510,009 |
| 1986 | 5,897,622 | 28,995,852 | 57,296,981 | 41,374,002 | 47,929,478 | 8,802,712 | 190,296,645 |
| 1987 | 5,476,568 | 31,765,834 | 57,937,747 | 48,008,933 | 46,521,178 | 9,215,834 | 198,926,095 |
| 1988 | 5,061,966 | 32,401,013 | 52,718,445 | 47,814,758 | 48,537,439 | 11,112,868 | 197,646,490 |
| 1989 | 5,523,451 | 21,082,105 | 53,190,870 | 45,967,711 | 48,017,702 | 11,370,286 | 185,152,126 |
| 1990 | - | - | 59,571,213 | 46,037,826 | 54,826,821 | 10,501,988 | 170,937,849 |
| 1991 | 6,521,385 | 31,047,969 | 46,988,025 | 45,247,129 | 62,848,614 | 15,133,319 | 207,786,442 |
| 1992 | 6,846,196 | 31,427,583 | 63,311,491 | 48,197,079 | 68,899,268 | 15,757,547 | 234,439,164 |
| 1993 | 5,908,438 | 25,968,779 | 54,105,787 | 63,754,872 | 66,363,025 | 9,103,265 | 225,204,166 |
| 1994 | 6,055,140 | 30,571,355 | 66,952,424 | 57,991,768 | 58,477,417 | 8,369,270 | 228,417,374 |
| 1995 | 6,064,768 | 28,813,141 | 56,832,799 | 54,708,789 | 57,494,443 | 6,134,409 | 210,048,349 |
| 1996 | 6,275,361 | 29,242,751 | 39,514,128 | 48,084,661 | 57,424,904 | 5,244,452 | 185,786,257 |
| 1997 | - | - | - | - | - | - | - |
| 1998 | 6,303,762 | 26,029,207 | 41,510,475 | 49,748,803 | 54,981,481 | 8,143,765 | 186,717,494 |
| 1999 | 8,129,565 | 20,505,625 | 43,439,636 | 42,756,364 | 59,371,671 | 5,685,632 | 179,888,492 |
| 2000 | 5,590,524 | 36,468,933 | 33,760,226 | 52,003,600 | 56,012,334 | 5,559,659 | 189,395,277 |
| 2001 | 4,016,265 | 22,731,154 | 36,928,989 | 36,957,910 | 49,327,699 | 4,718,908 | 154,680,925 |
| 2002 | 4,322,658 | 23,263,636 | 38,086,319 | 47,049,633 | 56,136,182 | 4,105,197 | 172,963,623 |
| 2003 | 3,625,522 | 13,461,916 | 27,871,941 | 27,638,699 | 47,754,272 | 2,801,179 | 123,153,528 |
| 2004 | 2,637,297 | 18,008,809 | 34,512,982 | 32,255,176 | 47,505,609 | 3,114,747 | 138,034,621 |
| 2005 | 3,419,193 | 14,471,777 | 28,513,442 | 29,416,153 | 41,689,415 | 1,211,056 | 118,721,036 |
| 2006 | 2,973,035 | 10,957,490 | 28,553,534 | 32,475,310 | 41,385,402 | 3,293,772 | 119,638,543 |
| 2007 | 3,285,836 | 16,955,275 | 28,117,138 | 29,836,744 | 38,839,676 | 3,299,850 | 120,334,519 |
| 2008 | 3,146,493 | 13,120,873 | 26,950,222 | 33,728,602 | 30,850,095 | 1,419,004 | 109,215,289 |
| 2009 | 2,753,862 | 7,932,270 | 18,351,523 | 26,412,126 | 25,261,371 | 815,403 | 81,526,555 |
| 2010 | 7,799,517 | 10,144,980 | 27,330,975 | 25,566,084 | 30,058,216 | 11,493,959 | 112,393,731 |
| 2011 | 3,141,824 | 18,137,832 | 24,707,413 | 24,643,970 | 27,870,449 | 3,968,745 | 102,470,234 |
| 2012 | 2,643,346 | 17,214,105 | 24,704,230 | 26,257,731 | 28,822,909 | 3,080,058 | 102,722,380 |

*DE and MD did not report data to AAPFCO for 1990.
**There was an error in the database for 1997 and these values were not used.

These statewide sales data can vary drastically from one year to the next, and it is not known if the variability is real or caused by a lack of reporting or other human error. The Phase 6 Model reduces some of the variability by replacing any yearly statewide N and P sales totals that fall outside of two standard deviations from the median for the state over all years for which data were recorded. Outliers are replaced by taking the average of the two years of available sales data closest in time to the outlier year. Table 3-21 and Table 3-22 include the revised fertilizer sales data by state following this step.

*Table 3-21: Revised pounds of nitrogen fertilizer sales by state*

| Year | DE | MD | NY | PA | VA | WV | Regional Total |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1985 | 41,444,716 | 112,134,802 | 194,419,516 | 137,383,012 | 198,029,479 | 25,706,650 | 709,118,175 |
| 1986 | 33,886,303 | 98,676,291 | 176,896,480 | 143,352,737 | 159,025,624 | 19,524,450 | 631,361,884 |
| 1987 | 33,031,398 | 102,397,091 | 169,926,980 | 149,322,463 | 156,071,808 | 20,238,127 | 630,987,866 |
| 1988 | 31,476,339 | 104,444,571 | 152,104,777 | 147,323,135 | 156,178,750 | 25,603,647 | 617,131,218 |
| 1989 | 34,780,074 | 97,694,132 | 153,555,044 | 141,677,814 | 158,354,005 | 26,934,890 | 612,995,958 |
| 1990 | 38,786,133 | 107,885,304 | 184,307,431 | 148,045,008 | 181,559,182 | 27,650,998 | 688,234,056 |
| 1991 | 42,792,192 | 118,076,477 | 157,731,977 | 145,455,746 | 197,739,464 | 34,781,014 | 696,576,869 |
| 1992 | 44,239,436 | 150,348,101 | 189,766,607 | 141,831,862 | 234,866,164 | 35,559,100 | 796,611,270 |
| 1993 | 39,591,974 | 126,050,961 | 185,798,322 | 192,792,795 | 216,268,364 | 19,360,917 | 779,863,333 |
| 1994 | 39,444,256 | 119,734,506 | 192,831,507 | 206,060,959 | 202,800,760 | 17,929,914 | 778,801,902 |
| 1995 | 41,269,782 | 146,345,257 | 199,864,693 | 184,511,703 | 194,813,200 | 16,177,250 | 782,981,885 |
| 1996 | 44,355,021 | 142,008,878 | 131,854,972 | 203,830,918 | 206,576,580 | 14,123,004 | 742,749,372 |
| 1997 | 41,175,348 | 134,240,524 | 149,644,343 | 206,157,259 | 205,949,834 | 18,021,534 | 755,188,842 |
| 1998 | 37,995,676 | 126,472,170 | 167,433,714 | 208,483,600 | 205,323,088 | 21,920,063 | 767,628,313 |
| 1999 | 44,086,204 | 110,470,922 | 191,928,900 | 201,617,740 | 217,513,798 | 42,550,316 | 808,167,880 |
| 2000 | 42,125,399 | 122,798,990 | 146,052,721 | 215,322,704 | 229,704,509 | 16,473,409 | 772,477,731 |
| 2001 | 37,294,300 | 135,127,059 | 168,607,460 | 171,917,882 | 192,760,703 | 17,548,599 | 723,256,001 |
| 2002 | 42,983,855 | 134,446,805 | 157,329,402 | 235,805,657 | 214,884,861 | 21,465,524 | 806,916,105 |
| 2003 | 33,874,050 | 91,326,561 | 153,679,136 | 137,760,896 | 189,600,236 | 11,523,040 | 617,763,919 |
| 2004 | 30,520,293 | 162,186,060 | 194,538,736 | 169,306,844 | 192,236,091 | 31,395,060 | 780,183,083 |
| 2005 | 34,764,568 | 148,233,088 | 165,429,881 | 171,648,508 | 168,134,916 | 40,318,567 | 728,529,526 |
| 2006 | 33,250,192 | 100,058,576 | 181,111,309 | 181,855,345 | 174,102,984 | 49,242,074 | 719,620,479 |
| 2007 | 39,110,557 | 110,147,192 | 160,592,593 | 211,107,399 | 185,524,912 | 47,357,757 | 753,840,410 |
| 2008 | 44,816,762 | 118,139,285 | 158,996,237 | 186,619,695 | 178,002,531 | 4,823,692 | 691,398,202 |
| 2009 | 40,678,401 | 83,783,873 | 126,071,437 | 228,865,028 | 157,298,984 | 4,296,655 | 640,994,378 |
| 2010 | 47,486,702 | 58,677,608 | 155,424,698 | 197,247,992 | 183,423,406 | 20,078,088 | 662,338,494 |
| 2011 | 44,498,304 | 87,966,135 | 155,983,311 | 190,998,888 | 189,528,340 | 12,740,116 | 681,715,094 |
| 2012 | 39,981,186 | 88,395,490 | 155,980,123 | 200,303,240 | 199,187,416 | 12,844,511 | 696,691,966 |

Yellow cells indicate values that were replaced during the outlier removal and replacement procedure.

*Table 3-22: Revised pounds of phosphorus fertilizer sales by state*

| Year | DE | MD | NY | PA | VA | WV | Regional Total |
|---|---|---|---|---|---|---|---|
| 1985 | 7,069,736 | 32,950,758 | 68,216,215 | 47,707,004 | 58,609,224 | 11,957,072 | 226,510,009 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1986 | 5,897,622 | 28,995,852 | 57,296,981 | 41,374,002 | 47,929,478 | 8,802,712 | 190,296,645 |
| 1987 | 5,476,568 | 31,765,834 | 57,937,747 | 48,008,933 | 46,521,178 | 9,215,834 | 198,926,095 |
| 1988 | 5,061,966 | 32,401,013 | 52,718,445 | 47,814,758 | 48,537,439 | 11,112,868 | 197,646,490 |
| 1989 | 5,523,451 | 21,082,105 | 53,190,870 | 45,967,711 | 48,017,702 | 11,370,286 | 185,152,126 |
| 1990 | 6,022,418 | 26,065,037 | 59,571,213 | 46,037,826 | 54,826,821 | 10,501,988 | 203,025,304 |
| 1991 | 6,521,385 | 31,047,969 | 46,988,025 | 45,247,129 | 62,848,614 | 10,501,988 | 203,155,110 |
| 1992 | 6,846,196 | 31,427,583 | 63,311,491 | 48,197,079 | 68,899,268 | 9,802,626 | 228,484,243 |
| 1993 | 5,908,438 | 25,968,779 | 54,105,787 | 63,754,872 | 66,363,025 | 9,103,265 | 225,204,166 |
| 1994 | 6,055,140 | 30,571,355 | 66,952,424 | 57,991,768 | 58,477,417 | 8,369,270 | 228,417,374 |
| 1995 | 6,064,768 | 28,813,141 | 56,832,799 | 54,708,789 | 57,494,443 | 6,134,409 | 210,048,349 |
| 1996 | 6,275,361 | 29,242,751 | 39,514,128 | 48,084,661 | 57,424,904 | 5,244,452 | 185,786,257 |
| 1997 | 6,289,562 | 27,635,979 | 40,512,301 | 48,916,732 | 56,203,193 | 6,694,109 | 186,251,876 |
| 1998 | 6,303,762 | 26,029,207 | 41,510,475 | 49,748,803 | 54,981,481 | 8,143,765 | 186,717,494 |
| 1999 | 8,129,565 | 20,505,625 | 43,439,636 | 42,756,364 | 59,371,671 | 5,685,632 | 179,888,492 |
| 2000 | 5,590,524 | 36,468,933 | 33,760,226 | 52,003,600 | 56,012,334 | 5,559,659 | 189,395,277 |
| 2001 | 4,016,265 | 22,731,154 | 36,928,989 | 36,957,910 | 49,327,699 | 4,718,908 | 154,680,925 |
| 2002 | 4,322,658 | 23,263,636 | 38,086,319 | 47,049,633 | 56,136,182 | 4,105,197 | 172,963,623 |
| 2003 | 3,625,522 | 13,461,916 | 27,871,941 | 27,638,699 | 47,754,272 | 2,801,179 | 123,153,528 |
| 2004 | 2,637,297 | 18,008,809 | 34,512,982 | 32,255,176 | 47,505,609 | 3,114,747 | 138,034,621 |
| 2005 | 3,419,193 | 14,471,777 | 28,513,442 | 29,416,153 | 41,689,415 | 1,211,056 | 118,721,036 |
| 2006 | 2,973,035 | 10,957,490 | 28,553,534 | 32,475,310 | 41,385,402 | 3,293,772 | 119,638,543 |
| 2007 | 3,285,836 | 16,955,275 | 28,117,138 | 29,836,744 | 38,839,676 | 3,299,850 | 120,334,519 |
| 2008 | 3,146,493 | 13,120,873 | 26,950,222 | 33,728,602 | 30,850,095 | 1,419,004 | 109,215,289 |
| 2009 | 2,753,862 | 7,932,270 | 18,351,523 | 26,412,126 | 25,261,371 | 815,403 | 81,526,555 |
| 2010 | 7,799,517 | 10,144,980 | 27,330,975 | 25,566,084 | 30,058,216 | 11,493,959 | 112,393,731 |
| 2011 | 3,141,824 | 18,137,832 | 24,707,413 | 24,643,970 | 27,870,449 | 3,968,745 | 102,470,234 |
| 2012 | 2,643,346 | 17,214,105 | 24,704,230 | 26,257,731 | 28,822,909 | 3,080,058 | 102,722,380 |

Yellow cells indicate values that were replaced during the outlier removal and replacement procedure.

The results are then aggregated across all states to estimate total regional sales of fertilizer for each year, which are shown in the final columns of Table 3-21 and Table 3-22. The results are aggregated in this way to remove variability that may exist in a single state's fertilizer sales data and to remove any assumptions that fertilizer sales within a county, or even a state, reflect fertilizer use in that county or state.

Finally, regional fertilizer sales, which are not separated by designated use at this point, are then broken back out by designated use. Again, variability exists within the reporting of designated use, so the Phase 6 Model uses the initial designated uses only to calculate a three-year rolling average fraction of fertilizer sales for farm use. This three-year rolling average begins in 1993 using 1991 through 1993 farm use sales because data prior to 1991 was often designated by states as "unknown use." The three-year rolling average fractions are included in Table 3-23. These rolling averages are then applied to the previously calculated regional sales numbers to estimate regional fertilizer sales for farm use each year. The resulting values are included in Table 3-24.

*Table 3-23: Regional rolling average fraction of farm fertilizer sales*

| Year | Annual Fraction for N | Rolling Average Fraction for N | Annual Fraction for P | Rolling Average Fraction for P |
|---|---|---|---|---|
| 1985 | 0.000000 | 0.871537 | 0.000000 | 0.901213 |
| 1986 | 0.280182 | 0.871537 | 0.301093 | 0.901213 |
| 1987 | 0.437241 | 0.871537 | 0.425402 | 0.901213 |
| 1988 | 0.849291 | 0.871537 | 0.880281 | 0.901213 |
| 1989 | 0.865909 | 0.871537 | 0.893873 | 0.901213 |
| 1990 | 0.719825 | 0.871537 | 0.796829 | 0.901213 |
| 1991 | 0.900965 | 0.871537 | 0.927798 | 0.901213 |
| 1992 | 0.874691 | 0.871537 | 0.935436 | 0.901213 |
| 1993 | 0.838954 | 0.871537 | 0.840405 | 0.901213 |
| 1994 | 0.933644 | 0.882430 | 0.925574 | 0.900471 |
| 1995 | 0.839021 | 0.870540 | 0.880662 | 0.882214 |
| 1996 | 0.847761 | 0.873475 | 0.904753 | 0.903663 |
| 1997 | NULL | 0.843391 | NULL | 0.892707 |
| 1998 | 0.863840 | 0.855801 | 0.914484 | 0.909618 |
| 1999 | 0.895126 | 0.879483 | 0.906692 | 0.910588 |
| 2000 | 0.937799 | 0.898922 | 0.873298 | 0.898158 |
| 2001 | 0.796009 | 0.876312 | 0.850070 | 0.876687 |
| 2002 | 0.848041 | 0.860616 | 0.882786 | 0.868718 |
| 2003 | 0.794728 | 0.812926 | 0.828444 | 0.853767 |
| 2004 | 0.738918 | 0.793896 | 0.829786 | 0.847006 |
| 2005 | 0.793964 | 0.775870 | 0.843939 | 0.834057 |
| 2006 | 0.762974 | 0.765285 | 0.836313 | 0.836680 |
| 2007 | 0.670699 | 0.742546 | 0.699998 | 0.793417 |
| 2008 | 0.752353 | 0.728675 | 0.810832 | 0.782381 |
| 2009 | 0.840673 | 0.754575 | 0.893735 | 0.801522 |
| 2010 | 0.880733 | 0.824586 | 0.932942 | 0.879170 |
| 2011 | 0.870651 | 0.864019 | 0.862052 | 0.896243 |
| 2012 | 0.847669 | 0.866351 | 0.827531 | 0.874175 |

*Table 3-24: Final estimated pounds regional fertilizer sales for farm use*

| Year | Final Regional Farm N | Final Regional Farm P |
|---|---|---|
| 1985 | 618,022,483 | 204,133,724 |
| 1986 | 550,255,025 | 171,497,776 |
| 1987 | 549,929,054 | 179,274,747 |
| 1988 | 537,852,478 | 178,121,550 |
| 1989 | 534,248,448 | 166,861,470 |
| 1990 | 599,821,208 | 182,969,006 |
| 1991 | 607,092,275 | 183,085,990 |
| 1992 | 694,275,922 | 205,912,929 |
| 1993 | 679,679,481 | 202,956,881 |
| 1994 | 687,237,913 | 205,683,286 |
| 1995 | 681,616,681 | 185,307,491 |
| 1996 | 648,773,210 | 167,888,130 |
| 1997 | 636,919,424 | 166,268,434 |
| 1998 | 656,936,953 | 169,841,622 |
| 1999 | 710,770,017 | 163,804,253 |
| 2000 | 694,397,158 | 170,106,871 |
| 2001 | 633,797,554 | 135,606,686 |
| 2002 | 694,445,284 | 150,256,636 |
| 2003 | 502,196,245 | 105,144,393 |
| 2004 | 619,383,842 | 116,916,117 |
| 2005 | 565,244,123 | 99,020,077 |
| 2006 | 550,715,019 | 100,099,138 |
| 2007 | 559,760,850 | 95,475,455 |
| 2008 | 503,804,695 | 85,448,000 |
| 2009 | 483,678,191 | 65,345,319 |
| 2010 | 546,155,129 | 98,813,162 |
| 2011 | 589,014,829 | 91,838,211 |
| 2012 | 603,579,944 | 89,797,313 |

#### 3.5.1.2 Estimating Fertilizer Use within Chesapeake Bay Watershed

The Phase 6 Model turns to the Census of Agriculture to help estimate the amount of fertilizer applied within the watershed out of the entire six-state regional sales. The Census of Agriculture provides "dollars spent on fertilizer and soil conditioners" for each county in 1997, 2002, 2007, and 2012. Dollars spent between reported years were interpolated, and 1985 through 1997 dollars spent were assumed to remain constant at 1997 values, while all years past 2012 were assumed to remain constant at 2012 values.

The Phase 6 Model then sums all dollars spent by counties within the watershed for each year and compares that value to the total dollars spent by counties across all six states. The resulting fraction becomes the fraction of regional fertilizer sales which were applied within the watershed for each year. These fractions are included in Table 3-25 with the resulting watershed-wide fertilizer application estimates included in Table 3-26.

*Table 3-25: Fraction of dollars spent on fertilizer and soil conditioners within watershed (Census of Agriculture)*

| Year | Fraction |
|---|---|
| 1997* | 0.664045 |
| 1998 | 0.668436 |
| 1999 | 0.672787 |
| 2000 | 0.677097 |
| 2001 | 0.681367 |
| 2002 | 0.685598 |
| 2003 | 0.683257 |
| 2004 | 0.681377 |
| 2005 | 0.679834 |
| 2006 | 0.678545 |
| 2007 | 0.677452 |
| 2008 | 0.679627 |
| 2009 | 0.681447 |
| 2010 | 0.682993 |
| 2011 | 0.684323 |
| 2012 | 0.685478 |

*No values were reported prior to 1997, so 1985 through 1996 are assumed to be equal to 1997.

*Table 3-26: Final watershed-wide pounds of fertilizer use for farms*

| Year | Watershed N Farm Use | Watershed P Farm Use |
|---|---|---|
| 1985 | 410,394,928 | 135,554,041 |
| 1986 | 365,394,266 | 113,882,293 |
| 1987 | 365,177,806 | 119,046,554 |
| 1988 | 357,158,412 | 118,280,779 |
| 1989 | 354,765,173 | 110,803,575 |
| 1990 | 398,308,457 | 121,499,710 |
| 1991 | 403,136,774 | 121,577,392 |
| 1992 | 461,030,666 | 136,735,514 |
| 1993 | 451,337,968 | 134,772,564 |
| 1994 | 456,357,109 | 136,583,020 |
| 1995 | 452,624,356 | 123,052,569 |
| 1996 | 430,814,804 | 111,485,324 |

| | | |
|---|---|---|
| 1997 | 422,943,353 | 110,409,773 |
| 1998 | 439,120,517 | 113,528,308 |
| 1999 | 478,196,516 | 110,205,300 |
| 2000 | 470,173,959 | 115,178,786 |
| 2001 | 431,848,742 | 92,397,922 |
| 2002 | 476,110,510 | 103,015,695 |
| 2003 | 343,128,981 | 71,840,618 |
| 2004 | 422,033,670 | 79,663,909 |
| 2005 | 384,272,024 | 67,317,189 |
| 2006 | 373,684,830 | 67,921,753 |
| 2007 | 379,211,085 | 64,680,034 |
| 2008 | 342,399,088 | 58,072,736 |
| 2009 | 329,601,074 | 44,529,374 |
| 2010 | 373,020,262 | 67,488,722 |
| 2011 | 403,076,302 | 62,846,986 |
| 2012 | 413,741,002 | 61,554,117 |

#### *3.5.1.3 Estimating Fertilizer Use by County*

The watershed-wide fertilizer sales values are then distributed down to the county scale to estimate countywide fertilizer use (not sales). This is done by calculating each county's remaining relative inorganic crop application goal following manure applications. The watershed-wide sales value is then multiplied by each county's fraction of remaining of crop application goal. An Example of this calculation is provided below.

Step 1. Determine county's remaining, inorganic crop application goal.

Example:

- Original Crop Application Goal =1,000,000 lbs N
- Organic Nutrients Applied = 500,000 lbs N
- County's Remaining Inorganic Crop Application Goal = 500,000 lbs N = 1,000,000 lbs N – 500,000 lbs N

Step 2. Determine county's relative fraction of remaining application goal.

Example:

- County's Remaining Inorganic Crop Application Goal = 500,000 lbs N
- Watershed's Remaining Inorganic Crop Application Goal = 100,000,000 lbs N
- Relative Fraction of Remaining Inorganic Crop Application Goal = 0.005 = 500,000 lbs N / 100,000,000 lbs N

Step 3. Multiply watershed-wide fertilizer sales by relative fraction of remaining inorganic crop application goal to calculate fertilizer available in a county.

Example:

- Relative Fraction of Remaining Inorganic Crop Application Goal = 0.005
- Watershed-wide fertilizer sales = 400,000,000 lbs N
- Fertilizer available in county = 2,000,000 lbs N = 400,000,000 lbs N X 0.005

#### 3.5.1.4 Estimating Future Fertilizer Use by County

The Phase 6 Model has projections of crop application goals and manure generation for future years but does not have estimates of fertilizer sales or use in future years. Fertilizer use varies across years based upon many economic factors including, but not limited to: cost of oil; cost of fertilizer; price of crop returns; crop yields; and equipment available for application. Because the Phase 6 Model does not have access to all of the economic variables at play, it estimates future fertilizer use based upon past fertilizer use.

Fertilizer use for any given crop in any given county in any future year for which fertilizer sales are not available is assumed to be the same fraction of the application goal in 2012, the last year for which these data were available. For example, if total applications to corn met 95 percent of a county's total corn application goal in 2012, then total applications in 2013 must also meet 95 percent of a county's total corn application goal. If manure applications exceed the 2012 fraction of the crop application goal, the manure applications are not reduced.

Implementation of the nutrient management BMP will affect the fraction of crop application goal in future years consistent with Table 3-13 in Section 3.3.1. For example, if soy had received 120 percent of the application goal in 2012, each additional acre under nutrient management in 2013 would receive 100 percent of the application goal, calculated by dividing 120 by the soy nutrient management multiplier of 1.2.

### 3.5.2 Nutrient Concentrations Within Fertilizer

The AAPFCO data were not used directly to determine concentrations of nutrient species but were analyzed to confirm current assumptions. The current Phase 5.3.2 Watershed Model assumed that for every pound of nitrogen fertilizer used, 0.75 pounds was ammonia nitrogen and 0.25 pounds was nitrate nitrogen. An analysis of AAPFCO data indicated that 77 percent of nitrogen fertilizer sold in 2012 across the Mid-Atlantic was in the form of ammonia nitrogen, with the remaining 23 percent being nitrate nitrogen. This confirmed current assumptions. Both the ammonia and nitrate portions are assumed to be plant available. Similarly, 100 percent of each pound of phosphorus fertilizer is assumed to be in the phosphate form and plant available. These values do not vary between urban and agricultural fertilizer applications.

### 3.5.3 Prioritizing Inorganic Applications to Crops

Just as with manure, the Phase 6 Model assumes that all inorganic fertilizer available in a county is applied within the county. Also, just as with manure applications, inorganic fertilizer applications are made to higher-value commodity crops before hay and pasture. Unique application curves were developed for inorganic fertilizer nitrogen and phosphorus applications (Figure 3-10 and Figure 3-11). Again, the application curves were developed for land use groups within which many crops are included. These land use groups are described in Table 3-27 for inorganic nitrogen and Table 3-28 for inorganic phosphorus. As can be seen, land use groups for inorganic nitrogen applications match the land use groups for manure nitrogen, while the phosphorus land use groups were changed so that all leguminous row crops received a similar application of phosphorus as non-leguminous row crops. Thus, legumes do not receive priority in the application process for nitrogen but do for phosphorus. Table 3-29 and Table 3-30 contain the inflection points and slopes for each land use group curve.

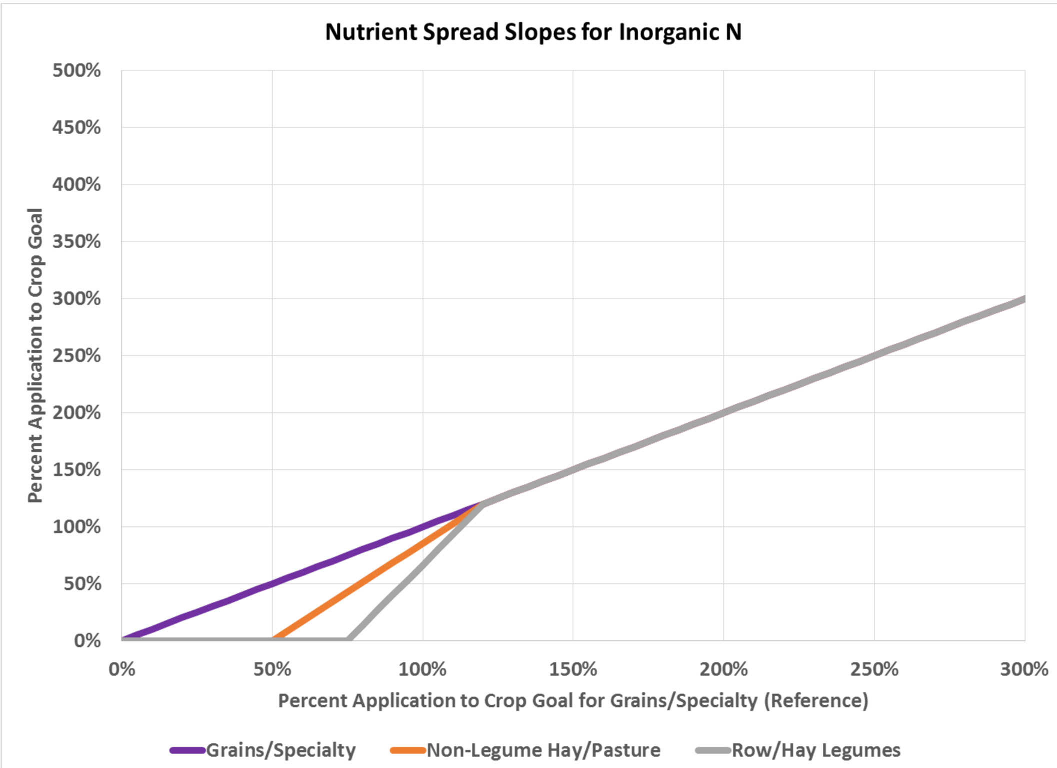



*Figure 3-10: Inorganic Nitrogen Application Curves by Crop Group*

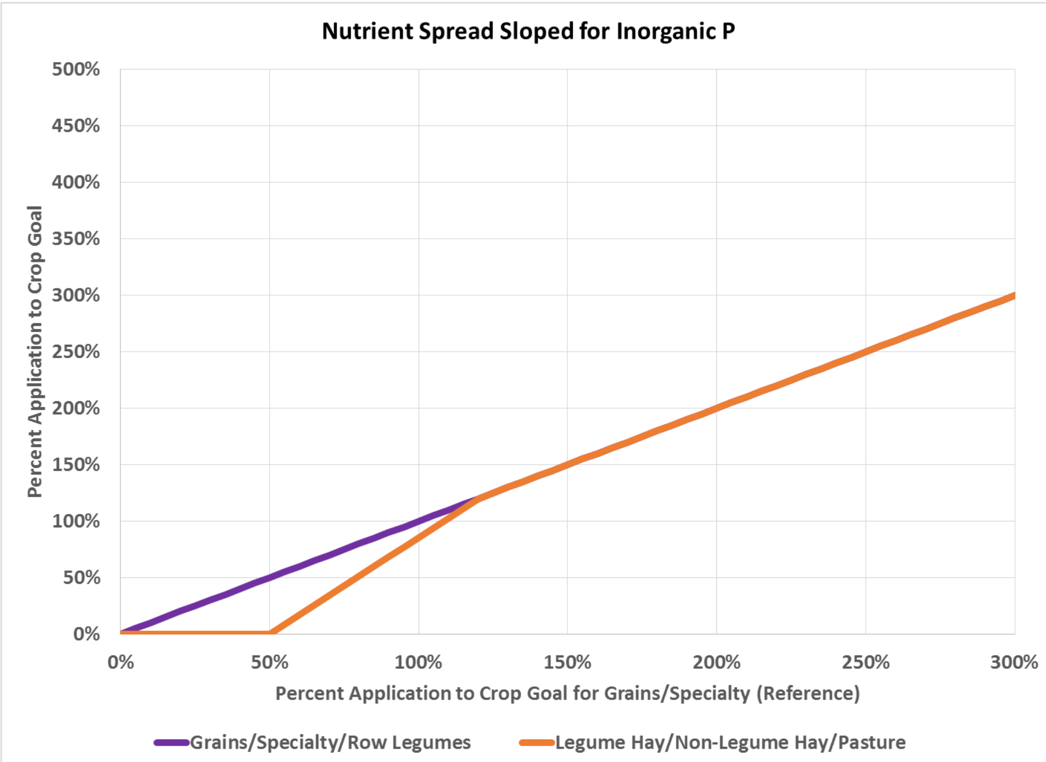



*Figure 3-11: Inorganic phosphorus application curves by crop group*

*Table 3-27: Land use groups for inorganic nitrogen application curves*

| Land Use Curve Group | Land Use |
|---|---|
| Grains/Specialty | Grain with Manure |
| Grains/Specialty | Silage with Manure |
| Grains/Specialty | Small Grains and Grains |
| Grains/Specialty | Other Agronomic Crops |
| Grains/Specialty | Specialty Crop High |
| Grains/Specialty | Specialty Crop Low |
| Grains/Specialty | Small Grains and Soybeans |
| Row/Hay Legumes | Full Season Soybeans |
| Row/Hay Legumes | Legume hay |
| Non-Legume Hay/Pasture | Pasture |
| Non-Legume Hay/Pasture | Other Hay |

*Table 3-28: Land use groups for inorganic phosphorus application curves*

| Land Use Curve Group | Land Use |
|---|---|
| Grains/Specialty/Row Legumes | Grain with Manure |
| Grains/Specialty/Row Legumes | Silage with Manure |
| Grains/Specialty/Row Legumes | Small Grains and Grains |
| Grains/Specialty/Row Legumes | Small Grains and Soybeans |
| Grains/Specialty/Row Legumes | Full Season Soybeans |
| Legume Hay/Non-Legume Hay/Pasture | Legume hay |

| | |
|---|---|
| Grains/Specialty/Row Legumes | Other Agronomic Crops |
| Grains/Specialty/Row Legumes | Specialty Crop High |
| Grains/Specialty/Row Legumes | Specialty Crop Low |
| Legume Hay/Non-Legume Hay/Pasture | Other Hay |
| Legume Hay/Non-Legume Hay/Pasture | Pasture |

*Table 3-29: Inorganic N curve inflection points*

| Grains/Specialty | Non-Legume Hay/Pasture | | | Row/Hay Legumes | | |
|---|---|---|---|---|---|---|
| % of goal | % of goal | slope | intercept | % of goal | slope | intercept |
| 0% | 0% | 0 | 0 | 0% | 0 | 0 |
| 50% | 0% | 1.71 | -0.86 | | | |
| 75% | | | | 0% | 2.67 | -2.00 |
| 120% | 120% | 1.00 | 0 | 120% | 1.00 | 0 |
| 500% | 500% | | | 500% | | |

*Table 3-30: Inorganic P curve inflection points*

| Grains/Specialty/Row Legumes | Legume Hay/Non-Legume Hay/Pasture | | |
|---|---|---|---|
| % of goal | % of goal | slope | intercept |
| 0% | 0% | 0 | 0 |
| 50% | 0% | 1.71 | -0.86 |
| 120% | 120% | 1.00 | 0 |
| 500% | 500% | | |

## 3.5.4 Urban Fertilizer Applications

Turfgrass fertilizer application rates vary through time and among states in the Phase 6 Model according to a process approved by the Bay Program's Urban Stormwater Workgroup. Total estimated fertilizer applied in entire counties that are wholly or partially within the Chesapeake Bay Watershed in a given state is divided by the acres of turfgrass in those same counties. Fertilizer estimates are based on data from the USGS National Water-Quality Assessment (NAWQA) program. Turfgrass acres are the acres of turfgrass calculated prior to the application of land use change BMPs as described in Section 5. Estimates of state-wide fertilizer application rates are made for each year from 1985-2013 and held constant thereafter.

### *3.5.4.1 Non-Farm Fertilizer Nutrient Mass*

The CBP uses non-farm fertilizer application data by county assembled by the USGS for use in the National Water-Quality Assessment (NAWQA). The methods for determining fertilizer nutrient inputs for the NAWQA program and the county-level data are detailed in (Gronberg and Spahr 2012). The CBP assessed fertilizer sales and use data from state agencies as an alternate, however it was found that the submitted by individual states were considerably more variable than the NAWQA methods and data and therefore the Urban Stormwater Workgroup decided to use the NAWQA data.

The origin of the fertilizer mass data is primarily county-level commercial fertilizer sales for the conterminous United States for 1987 through 2006. There are divisions in the source data for farm fertilizer versus non-farm – and sales are in terms of masses of nitrogen and phosphorus. Specifically, the estimates of nutrient masses are calculated from fertilizer sales data from the Association of American Plant Food Control Officials (AAPFCO), the Census of Agriculture fertilizer expenditures, and U.S. Census Bureau county populations. The use of fertilizer expenditures data lessens the volatility through time of the sales data. USGS uses the AAPFCO data and developed methods to fill in missing information, such as when a county didn't report sales, or the sales data were not split between farm and non-farm.

The USGS report notes that "with a few exceptions, non-farm nitrogen estimates were found to be reasonable when compared to the amounts that would result if the lawn application rates recommended by state and university agricultural agencies were used. Also, states with higher non-farm-to-total fertilizer ratios for nitrogen and phosphorus tended to have higher urban land-use percentages."

Trends in the data sets, rather than the original data, were used to reduce volatility through time. The long-term trend, determined through ordinary least-squares regression, is used for all years from 1985 through 2006. Double exponential smoothing was applied to the 1985-2006 data with an alpha value of 0.9 and a beta value of 0.1 to determine a value for 2016. Values for the years 2007-2015 were determined by linear interpolation. Results are shown in Figure 3-12.

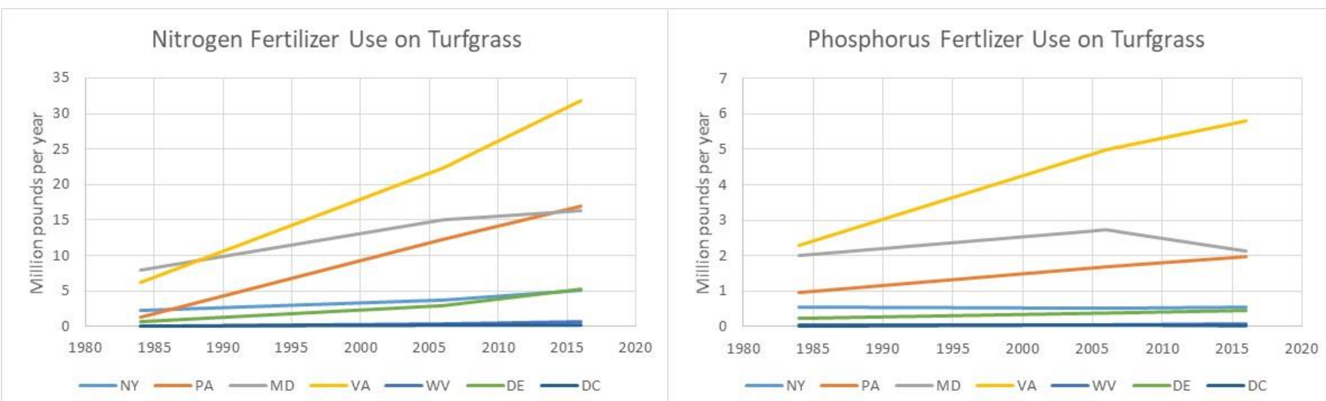



*Figure 3-12: Nitrogen and phosphorus fertilizer applied to turfgrass in counties partially or completely within the Chesapeake Bay Watershed*

### *3.5.4.2 Turfgrass acres*

The methods for calculating turfgrass acres are described in Section 5. For counties that straddle the border of the watershed, turfgrass acres are compiled for whole counties since fertilizer use data is also county-wide. Acres of turfgrass have been established for each year going back to 1985, which is the beginning year for the Phase 6 calibration. Turfgrass acres are calculated prior to the implementation of land-use change BMPs.

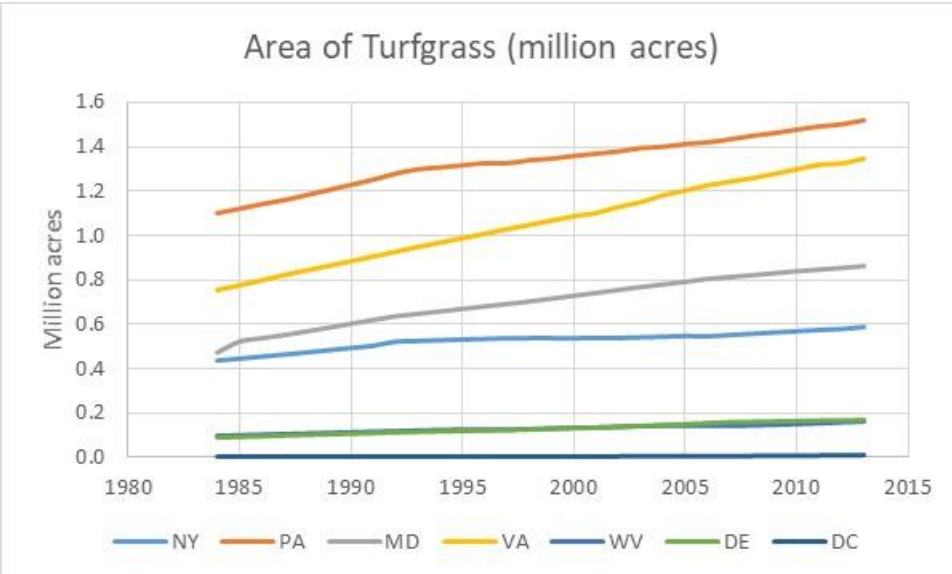
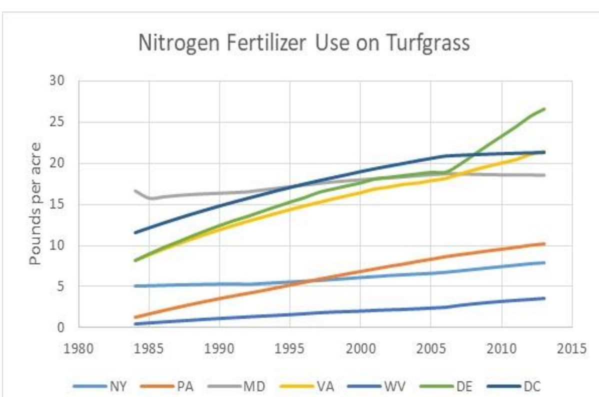



*Figure 3-13: Turfgrass acres in counties partially or completely within the Chesapeake Bay Watershed*

### *3.5.4.3 Calculating turfgrass application rates*

Both the mass of fertilizer nutrient use and acres of turfgrass are summed to the scale of each state's counties that are at least partially within in the Chesapeake Bay watershed. That is, for both counties that are completely within the Chesapeake Bay watershed and counties that are only partially within the watershed, the entire mass of non-farm fertilizer and the entire extent of turfgrass acreage is used. For each state, the application rate is the state-wide fertilizer nutrient mass divided by the state-wide turfgrass acres. Figure 3-14 shows the trends in fertilizer use on turfgrass in the Chesapeake Bay Watershed. The trends are for an increasing application of nitrogen fertilizer to turfgrass for all states. Phosphorus application trends are mixed with some decreasing trends, particularly in recent data. There are no data for fertilizer use for the District of Columbia in the NAWQA dataset. The application rates were calculated as the average of MD and VA application rates for each year and then multiplied by the acres of turfgrass to arrive at the total fertilizer applied in DC by year in Figure 3-12. The final land use was delivered after the values calculated in Figure 3-13 and so the average application rate for DC shown in Figure 3-14 is no longer the average of MD and VA.



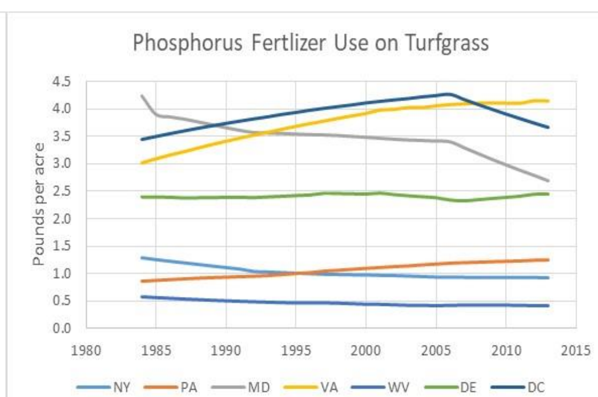




*Figure 3-14: Nitrogen and phosphorus fertilizer application rates to turfgrass by state.*

## 3.6 Legume Fixation

Leguminous plants, such as soybeans, develop bacterial nodules on their roots which transform atmospheric nitrogen gas into ammonia nitrogen. This adds a source of plant-available nitrogen to the soil and is an important load in the overall nutrient balance within a watershed. This fixation is intended to include the portion fixed in the roots and taken up into the plant, and the total amount of fixation can vary by growth region.

Nitrogen fixation varies depending upon the amounts of nitrogen available from the soil and applied to the crop. The higher the amount of nitrogen available from these two sources, the lower nitrogen fixation will be. The relationship between percent fixation and available nitrogen is explained in Figure 3-22. (Meisinger and Randall, 1991) The Agriculture Workgroup agreed to estimate nitrogen available from soils at 45 lbs/acre. Using the equation in Figure 3-15, the Phase 6 Model can assume leguminous plants will fix 77 percent of their entire uptake from the atmosphere if no additional pounds of nitrogen are applied to the land. When additional pounds are applied, the fraction of uptake from nitrogen fixation amount will decrease. Table 3-31 shows the pounds of nitrogen fixed per yield unit for each crop that fixes nitrogen. The equation in Figure 3-15 is used to estimate the fraction of the total inputs from fixation. This is then multiplied by yield per acre and the pounds of removal per yield unit to determine the amount of fixed nitrogen taken up by plants. Finally, the fixed nitrogen taken up by plants is multiplied by 1.5 to determine the total amount of fixation.

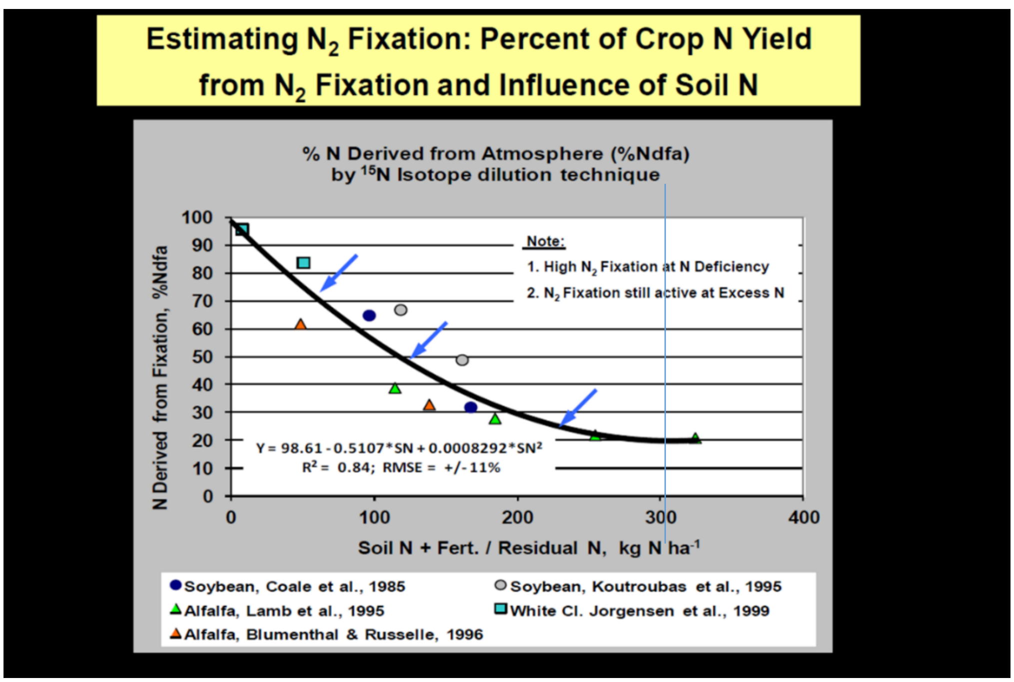



*Figure 3-15: Nitrogen fixation as a percent of crop yield*

*Table 3-31: Estimated total nitrogen pounds fixed by leguminous crops per yield unit*

| Crop Name | N Fixed Per Yield Unit | Yield Unit |
|---|---|---|
| alfalfa hay | 75.59 | dry tons |
| alfalfa seed | 151.18 | acres |

| | | |
|---|---|---|
| birdsfoot trefoil seed | 128.2 | acres |
| cropland used only for pasture or grazing | 30.24 | acres |
| dry edible beans excluding limas | 72 | acres |
| green lima beans | 91.2 | acres |
| haylage or greenchop from alfalfa or alfalfa mixtures | 151.18 | acres |
| other haylage; grass silage and greenchop | 175.73 | acres |
| pastureland and rangeland other than cropland and woodland pastured | 30.24 | acres |
| peanuts for nuts | 210 | acres |
| peas - chinese (sugar and snow) | 72 | acres |
| peas - green (excluding southern) | 72 | acres |
| peas - green southern (cowpeas) | 72 | acres |
| red clover seed | 134.08 | acres |
| snap beans | 24 | acres |
| soybeans for beans | 5.31 | bushels |
| vetch seed | 123.54 | acres |

## 3.7 Nutrient Uptake and Removal

The Phase 6 Model estimates pounds of crop removal or crop uptake for all crops. Crop removal is defined as the amount of nutrient removed through harvest, while uptake includes nutrients in the non-harvested portions of the plant as well, such as stalks and roots. The Agriculture Workgroup elected to replace existing crop uptake information for the following crops with crop removal values from Meisinger and Randall, 1991:

- Alfalfa Hay
- Cropland used only for Pasture or Grazing
- Green Lima Beans
- Haylage or greenchop from alfalfa or alfalfa mixtures
- Pastureland and rangeland other than cropland and woodland
- Snap Beans
- Soybeans for Beans
- Corn for Grain
- Cropland Idle
- Cropland in Cultivated Summer Fallow
- Cropland on which all Crops Failed

Crop uptake for all other crops remains consistent with the Phase 5.3.2 Model inputs (Chesapeake Bay Program 2013a). If the Phase 6 Model simulated a complete mass balance, then it would be essential to be consistent across all crops choosing either uptake or removal. However, the Phase 6 Model is simply using the change in these values over time and between different areas of the watershed to estimate loads (see Figure 3-1). Uptake and removal values for each crop are provided in Table 3-32. These values are per application goal unit. This means that the value will vary temporally and spatially for all major crops with yield information.

*Table 3-32: Uptake or removal per application goal unit*

| Crop | Nitrogen uptake per yield unit | Phosphorus uptake per yield unit | Application Yield Unit | Estimated from (U)ptake or (R)emoval |
|---|---|---|---|---|
| Alfalfa Hay Harvested Area | 75.5903 | 7.0825 | dry tons | R |
| Alfalfa seed Harvested Area | 151.1806 | 14.165 | acres | U |
| Aquatic plants Area | 91.2 | 22.704 | acres | U |
| Asparagus Harvested Area | 60 | 26.4 | acres | U |
| Barley for grain Harvested Area | 1.3407 | 0.2665 | bushels | U |
| Bedding/garden plants Area | 104.4 | 23.22 | acres | U |
| Beets Harvested Area | 96 | 23.22 | acres | U |
| Berries- all Harvested Area | 96 | 25.8 | acres | U |
| Birdsfoot trefoil seed Harvested Area | 128.1981 | 9.7284 | acres | U |
| Broccoli Harvested Area | 192 | 23.22 | acres | U |
| Bromegrass seed Harvested Area | 124.9707 | 9.2356 | acres | U |
| Brussels Sprouts Harvested Area | 150 | 23.22 | acres | U |
| Buckwheat Harvested Area | 1.2251 | 0.2279 | bushels | U |
| Bulbs, corms, rhizomes, and tubers – dry Harvested Area | 104.4 | 41.28 | acres | U |
| Canola Harvested Area | 102 | 15.6 | acres | U |
| Cantaloupe Harvested Area | 96 | 23.22 | acres | U |
| Carrots Harvested Area | 84 | 23.22 | acres | U |
| Cauliflower Harvested Area | 156 | 38.7 | acres | U |
| Celery Harvested Area | 174 | 33.54 | acres | U |
| Chinese Cabbage Harvested Area | 108 | 23.22 | acres | U |
| Collards Harvested Area | 96 | 23.22 | acres | U |
| Corn for Grain Harvested Area | 1.1894 | 0.2271 | bushels | R |
| Corn for silage or greenchop Harvested Area | 11.6252 | 3.3966 | tons | U |
| Cotton Harvested Area | 74.4 | 36 | acres | U |
| Cropland idle or used for cover crops or soil improvement but not harvested and not pastured or grazed Area | 0 | 0 | acres | R |
| Cropland in cultivated summer fallow Area | 0 | 0 | acres | R |

| | | | | |
|---|---|---|---|---|
| Cropland on which all crops failed or were abandoned Area | 0 | 0 | acres | R |
| Cropland used only for pasture or grazing Area | 140.5805 | 22.2666 | acres | R |
| Cucumbers and Pickles Harvested Area | 156 | 15.48 | acres | U |
| Cut Christmas Trees Production Area | 90 | 16.512 | acres | U |
| Cut flowers and cut florist greens Area | 91.2 | 41.28 | acres | U |
| Dry edible beans, excluding limas Harvested Area | 72 | 10.32 | acres | U |
| Dry Onions Harvested Area | 104.4 | 11.352 | acres | U |
| Eggplant Harvested Area | 164.4 | 51.6 | acres | U |
| Emmer and spelt Harvested Area | 78 | 27.6 | acres | U |
| Escarole and Endive Harvested Area | 134.4 | 51.6 | acres | U |
| Fescue Seed Harvested Area | 140.5805 | 22.2666 | acres | U |
| Foliage plants Area | 91.2 | 11.352 | acres | U |
| Garlic Harvested Area | 91.2 | 11.352 | acres | U |
| Green Lima Beans Harvested Area | 91.2 | 23.22 | acres | R |
| Green Onions Harvested Area | 91.2 | 11.352 | acres | U |
| Greenhouse vegetables Area | 105.6 | 11.352 | acres | U |
| Haylage or greenchop from alfalfa or alfalfa mixtures Harvested Area | 151.1806 | 14.165 | acres | R |
| Head Cabbage Harvested Area | 91.2 | 11.352 | acres | U |
| Herbs, Fresh Cut Harvested Area | 91.2 | 10.32 | acres | U |
| Honeydew Melons Harvested Area | 91.2 | 11.352 | acres | U |
| Kale Harvested Area | 78 | 25.8 | acres | U |
| Land in Orchards Area | 78 | 18.06 | acres | U |
| Lettuce, All Harvested Area | 134.4 | 20.64 | acres | U |
| Mushrooms Area | 0 | 0 | acres | U |
| Mustard Greens Harvested Area | 78 | 10.32 | acres | U |
| Nursery stock Area | 91.2 | 10.32 | acres | U |
| Oats for grain Harvested Area | 0.8975 | 0.1637 | bushels | U |
| Okra Area | 164.4 | 25.8 | acres | U |
| Orchardgrass seed Harvested Area | 124.9707 | 9.2356 | acres | U |
| Other field and grass seed crops Harvested Area | 124.9707 | 9.2356 | acres | U |
| Other haylage, grass silage, and greenchop Harvested Area | 175.7256 | 27.8333 | acres | R |

| | | | | |
|---|---|---|---|---|
| Other managed hay Harvested Area | 175.7256 | 27.8333 | acres | U |
| Other nursery and greenhouse crops Area | 91.2 | 15.48 | acres | U |
| Parsley Harvested Area | 192 | 20.64 | acres | U |
| Pastureland and rangeland other than cropland and woodland pastured Area | 140.5805 | 22.2666 | acres | R |
| Peanuts for nuts Harvested Area | 210 | 14.4 | acres | U |
| Peas, Chinese (sugar and Snow) Harvested Area | 72 | 18.06 | acres | U |
| Peas, Green (excluding southern) Harvested Area | 72 | 18.06 | acres | U |
| Peas, Green Southern (cowpeas) – Black-eyed, Crowder, etc. Harvested Area | 72 | 18.06 | acres | U |
| Peppers, Bell Harvested Area | 138 | 20.64 | acres | U |
| Peppers, Chile (all peppers – excluding bell) Harvested Area | 138 | 20.64 | acres | U |
| Popcorn Harvested Area | 62.1119 | 9.9536 | acres | U |
| Potatoes Harvested Area | 316.8 | 48.675 | acres | U |
| Potted flowering plants Area | 91.2 | 15.48 | acres | U |
| Pumpkins Harvested Area | 74.4 | 11.352 | acres | U |
| Radishes Harvested Area | 60 | 11.352 | acres | U |
| Red clover seed Harvested Area | 134.0767 | 13.482 | acres | U |
| Rhubarb Harvested Area | 91.2 | 22.704 | acres | U |
| Rye for grain Harvested Area | 1.5835 | 0.2809 | bushels | U |
| Ryegrass seed Harvested Area | 87.8741 | 13.2806 | acres | U |
| short-rotation woody crops Harvest Area | 91.2 | 15.48 | acres | U |
| Small grain hay Harvested Area | 42 | 8.4 | acres | U |
| Snap Beans Harvested Area | 24 | 20.4 | acres | R |
| Sod harvested Area | 153.6 | 26.4 | acres | U |
| Sorghum for Grain Harvested Area | 1.3932 | 0.2483 | bushels | U |
| Sorghum for silage or greenchop Area | 129.3336 | 26.838 | tons | U |
| Soybeans for beans Harvested Area | 5.3128 | 0.5442 | bushels | R |
| Spinach Harvested Area | 180 | 22.704 | acres | U |
| Squash Harvested Area | 90 | 22.704 | acres | U |
| Sunflower seed, non-oil varieties Harvested Area | 48 | 18 | acres | U |

| | | | | |
|---|---|---|---|---|
| Sunflower seed, oil varieties Harvested Area | 96 | 18 | acres | U |
| Sweet Corn Harvested Area | 315.09 | 60.225 | acres | U |
| Sweet potatoes Harvested Area | 74.4 | 11.352 | acres | U |
| Timothy seed Harvested Area | 115.3106 | 21.3955 | acres | U |
| tobacco Harvested Area | 180 | 36 | acres | U |
| Tomatoes Harvested Area | 96 | 22.704 | acres | U |
| Triticale Harvested Area | 84 | 32.4 | acres | U |
| Turfgrass | 10.335 | 1.065 | acres | U |
| Turnip Greens Harvested Area | 78 | 11.352 | acres | U |
| Turnips Harvested Area | 74.4 | 11.352 | acres | U |
| Vegetable & flower seeds Area | 91.2 | 18 | acres | U |
| Vegetables, Mixed Area | 96 | 10.8 | acres | U |
| Vetch seed Harvested Area | 123.5361 | 13.7093 | acres | U |
| Watermelons Harvested Area | 120 | 11.352 | acres | U |
| Wheat for Grain Harvested Area | 1.9299 | 0.3359 | bushels | U |
| Wild hay Harvested Area | 18.4315 | 2.9194 | acres | U |

## 3.8 Crop Soil Cover Fractions and Detached Sediment

The Phase 6 Model estimates both the amount of detached sediment due to plowing, and the fraction of soil cover provided by canopy or crop residue for each crop during each month throughout a year. Detached sediment and crop cover information is used to inform the temporal release of sediment as described in Section 10. Crop cover information is also used to estimate the sediment erosion rates as described in Section 2.

Crop cover and detached sediment information was gathered using the USDA's Revised Universal Soil Loss Equation 2 model (RUSLE2). Based upon a recommendation from the Scientific and Technical Advisory Committee, the Agriculture Workgroup worked with Dave Lightle, a RUSLE2 technical expert, to design a set of scenarios that reflected common management of major crops across the watershed. Additional runs were made to gather information for non-major crops such as vegetables. Together, these scenarios were used to summarize results for all crops in the Phase 6 Model. Table 3-33 indicates the RUSLE2 crop scenario used for each of the crops simulated. Crop scenarios were run for each of the USDA's Crop Management Zones (CMZs) within the watershed. While pasture scenarios were run for each of the forage zones within the watershed. Figures 3-12 and 3-13 depict CMZs and forage zones.

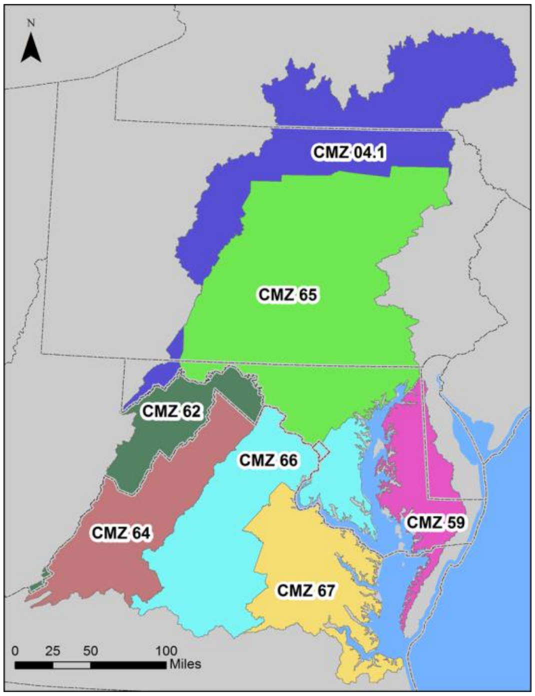



*Figure 3-16: State CMZs*

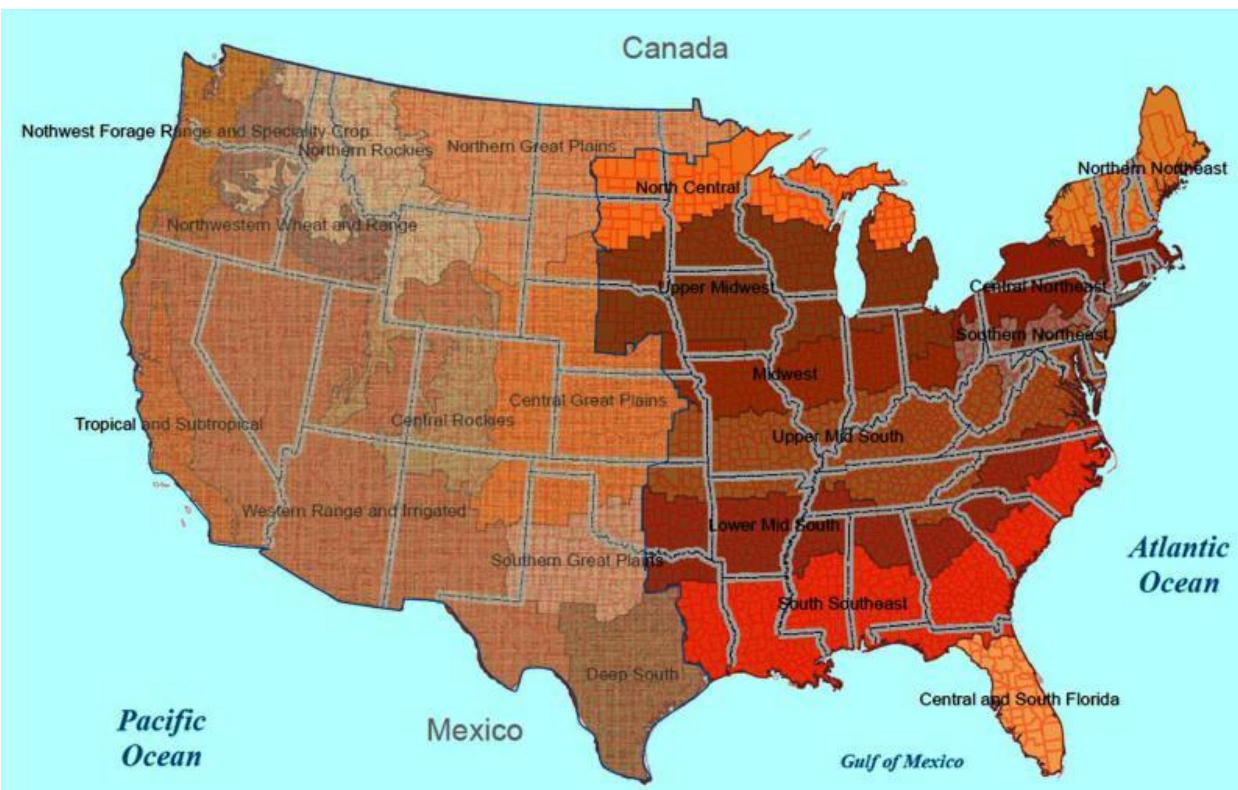



*Figure 3-17: Forage zones*

*Table 3-33: RUSLE2 crop scenario for each Phase 6 crop*

| Crop Name | Double Cropped | RUSLE2 Crop Scenario |
|---|---|---|
| Alfalfa Hay Harvested Area | Y | Alfalfa Hay Harvested Area |
| Alfalfa Hay Harvested Area | N | Alfalfa Hay Harvested Area |
| Alfalfa seed Harvested Area | N | Alfalfa Hay Harvested Area |
| Haylage or greenchop from alfalfa or alfalfa mixtures Harvested Area | N | Alfalfa Hay Harvested Area |
| Canola Harvested Area | N | Corn for Grain |
| Corn for Grain Harvested Area | N | Corn for Grain |
| Popcorn Harvested Area | N | Corn for Grain |
| Sorghum for Grain Harvested Area | N | Corn for Grain |
| Sunflower seed, non-oil varieties Harvested Area | N | Corn for Grain |
| Sunflower seed, oil varieties Harvested Area | N | Corn for Grain |
| Sweet Corn Harvested Area | N | Corn for Grain |
| Corn for silage or greenchop Harvested Area | N | Corn for Silage |
| Sorghum for silage or greenchop Area | N | Corn for Silage |
| Barley for grain Harvested Area | Y | Double Crop |
| Corn for silage or greenchop Harvested Area | Y | Double Crop |
| Rye for grain Harvested Area | Y | Double Crop |
| Sorghum for Grain Harvested Area | Y | Double Crop |
| Soybeans for beans Harvested Area | Y | Double Crop |
| Triticale Harvested Area | Y | Double Crop |
| Wheat for Grain Harvested Area | Y | Double Crop |
| Other haylage, grass silage, and greenchop Harvested Area | Y | Other managed hay Harvested Area |
| Small grain hay Harvested Area | Y | Other managed hay Harvested Area |
| Other haylage, grass silage, and greenchop Harvested Area | N | Other managed hay Harvested Area |
| Other managed hay Harvested Area | N | Other managed hay Harvested Area |
| Small grain hay Harvested Area | N | Other managed hay Harvested Area |
| Wild hay Harvested Area | N | Other managed hay Harvested Area |
| Asparagus Harvested Area | N | Other Veg |
| Bedding/garden plants Area | N | Other Veg |
| Beets Harvested Area | N | Other Veg |
| Berries- all Harvested Area | N | Other Veg |
| Broccoli Harvested Area | N | Other Veg |
| Brussels Sprouts Harvested Area | N | Other Veg |

| | | |
|---|---|---|
| Cantaloupe Harvested Area | N | Other Veg |
| Cauliflower Harvested Area | N | Other Veg |
| Celery Harvested Area | N | Other Veg |
| Chinese Cabbage Harvested Area | N | Other Veg |
| Collards Harvested Area | N | Other Veg |
| Cucumbers and Pickles Harvested Area | N | Other Veg |
| Cut Christmas Trees Production Area | N | Other Veg |
| Cut flowers and cut florist greens Area | N | Other Veg |
| Eggplant Harvested Area | N | Other Veg |
| Escarole and Endive Harvested Area | N | Other Veg |
| Garlic Harvested Area | N | Other Veg |
| Green Lima Beans Harvested Area | N | Other Veg |
| Green Onions Harvested Area | N | Other Veg |
| Head Cabbage Harvested Area | N | Other Veg |
| Herbs, Fresh Cut Harvested Area | N | Other Veg |
| Honeydew Melons Harvested Area | N | Other Veg |
| Kale Harvested Area | N | Other Veg |
| Land in Orchards Area | N | Other Veg |
| Lettuce, All Harvested Area | N | Other Veg |
| Mustard Greens Harvested Area | N | Other Veg |
| Nursery stock Area | N | Other Veg |
| Okra Area | N | Other Veg |
| Parsley Harvested Area | N | Other Veg |
| Peas, Chinese (sugar and Snow) Harvested Area | N | Other Veg |
| Peas, Green (excluding southern) Harvested Area | N | Other Veg |
| Peas, Green Southern (cowpeas) – Black-eyed, Crowder, etc. Harvested Area | N | Other Veg |
| Peppers, Bell Harvested Area | N | Other Veg |
| Peppers, Chile (all peppers – excluding bell) Harvested Area | N | Other Veg |
| Potted flowering plants Area | N | Other Veg |
| Pumpkins Harvested Area | N | Other Veg |
| Radishes Harvested Area | N | Other Veg |
| Rhubarb Harvested Area | N | Other Veg |
| short-rotation woody crops Harvest Area | N | Other Veg |
| Snap Beans Harvested Area | N | Other Veg |
| Sod harvested Area | N | Other Veg |
| Spinach Harvested Area | N | Other Veg |
| Squash Harvested Area | N | Other Veg |
| Tomatoes Harvested Area | N | Other Veg |
| Turnip Greens Harvested Area | N | Other Veg |
| Turnips Harvested Area | N | Other Veg |
| Vegetable & flower seeds Area | N | Other Veg |

| | | |
|---|---|---|
| Vegetables, Mixed Area | N | Other Veg |
| Watermelons Harvested Area | N | Other Veg |
| Cropland used only for pasture or grazing Area | N | Pasture |
| Pastureland and rangeland other than cropland and woodland pastured Area | N | Pasture |
| Bulbs, corms, rhizomes, and tubers – dry Harvested Area | N | Root Veg |
| Carrots Harvested Area | N | Root Veg |
| Dry Onions Harvested Area | N | Root Veg |
| Peanuts for nuts Harvested Area | N | Root Veg |
| Potatoes Harvested Area | N | Root Veg |
| Sweet potatoes Harvested Area | N | Root Veg |
| Cotton Harvested Area | N | Soybean |
| Dry edible beans, excluding limas Harvested Area | N | soybean |
| Soybeans for beans Harvested Area | N | Soybean |
| tobacco Harvested Area | N | Soybean |
| Barley for grain Harvested Area | N | Wheat for Grain |
| Birdsfoot trefoil seed Harvested Area | N | Wheat for Grain |
| Bromegrass seed Harvested Area | N | Wheat for Grain |
| Buckwheat Harvested Area | N | Wheat for Grain |
| Emmer and spelt Harvested Area | N | Wheat for Grain |
| Fescue Seed Harvested Area | N | Wheat for Grain |
| Oats for grain Harvested Area | N | Wheat for Grain |
| Orchardgrass seed Harvested Area | N | Wheat for Grain |
| Other field and grass seed crops Harvested Area | N | Wheat for Grain |
| Red clover seed Harvested Area | N | Wheat for Grain |
| Rye for grain Harvested Area | N | Wheat for Grain |
| Ryegrass seed Harvested Area | N | Wheat for Grain |
| Timothy seed Harvested Area | N | Wheat for Grain |
| Triticale Harvested Area | N | Wheat for Grain |
| Vetch seed Harvested Area | N | Wheat for Grain |
| Wheat for Grain Harvested Area | N | Wheat for Grain |

### 3.8.1 Crop Cover Fractions

Crop cover fraction is defined as the greater of crop canopy cover or crop residue cover in any given month. RUSLE2 provides daily values for canopy and residue cover which were then converted into average monthly values for each crop. The average monthly results for a single CMZ (NY 4.1) are provided in Table 3-34. Values for other CMZs are available on the CAST source data page.

*Table 3-34: Monthly cover fraction by crops in NY 4.1*

| Month | Alfalfa | Other Managed Hay | Pasture | Corn for Grain | Corn for Silage | Wheat for Grain | Soybeans | Double Crops | Root Veg | Other Veg |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.4600 | 0.6500 | 0.3319 | 0.7000 | 0.2600 | 0.3800 | 0.7100 | 0.3800 | 0.0390 | 0.0892 |
| 2 | 0.4600 | 0.6500 | 0.4243 | 0.7000 | 0.2600 | 0.3800 | 0.7100 | 0.3800 | 0.0383 | 0.0900 |
| 3 | 0.4626 | 0.6510 | 0.5016 | 0.7000 | 0.2600 | 0.3990 | 0.6990 | 0.3990 | 0.0240 | 0.0942 |
| 4 | 0.4800 | 0.6707 | 0.7230 | 0.2353 | 0.0832 | 0.7143 | 0.6607 | 0.7143 | 0.1083 | 0.0711 |
| 5 | 0.5619 | 0.8994 | 1.0000 | 0.1197 | 0.0971 | 1.0000 | 0.2044 | 1.0000 | 0.4000 | 0.1516 |
| 6 | 0.6353 | 0.8877 | 1.0000 | 0.4887 | 0.4733 | 0.9667 | 0.4787 | 0.9667 | 0.6667 | 0.6583 |
| 7 | 0.6271 | 0.8765 | 1.0000 | 0.9339 | 0.9048 | 0.2526 | 0.9913 | 0.1726 | 0.7226 | 0.8500 |
| 8 | 0.5790 | 1.0000 | 0.9719 | 0.9800 | 0.9500 | 0.2616 | 1.0000 | 0.7129 | 0.5861 | 0.8500 |
| 9 | 0.7410 | 0.8740 | 0.7673 | 0.9160 | 0.2680 | 0.2767 | 0.9480 | 0.9067 | 0.0770 | 0.8500 |
| 10 | 0.4739 | 0.9939 | 0.7648 | 0.7068 | 0.2600 | 0.0832 | 0.7829 | 0.0832 | 0.0522 | 0.8500 |
| 11 | 0.4600 | 0.8543 | 0.5790 | 0.7000 | 0.2600 | 0.3433 | 0.7307 | 0.3433 | 0.0421 | 0.0843 |
| 12 | 0.4600 | 0.6500 | 0.3410 | 0.7000 | 0.2600 | 0.3800 | 0.7119 | 0.3800 | 0.0392 | 0.0883 |

### 3.8.1 Detached Sediment

The USDA's RUSLE2 was used to estimate pounds of detached sediment by comparing a scenario with plowing and one with no plowing other than planting. The difference between the two scenarios represented the pounds of sediment that could be detached due to regular plowing activities or heavy grazing. The scenarios were designed using existing Phase 6 Model crop data for planting and harvesting dates. BMPs such as conservation tillage and prescribed grazing were intentionally left out of these scenarios to allow these BMPs to be credited with reductions in sediment (and nutrient) losses for future scenarios. The summed monthly results for a single CMZ (NY 4.1) are included in Table 3-35. Data for other CMZs are available on the CAST source data page.

*Table 3-35: Monthly pounds of detached sediment by crop in NY 4.1*

| Month | Alfalfa | Other Managed Hay | Pasture | Corn for Grain | Corn for Silage | Wheat for Grain | Soybeans | Double Crops | Root Veg | Other Veg |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.89 | 0.24 | 0.02 | 6.10 | 19.00 | 27.00 | 10.40 | 29.00 | - | 245.16 |
| 2 | 1.10 | 0.29 | 0.02 | 7.30 | 23.00 | 32.00 | 12.10 | 35.20 | - | 328.57 |
| 3 | 14.20 | 3.70 | 0.18 | 93.40 | 300.00 | 390.00 | 163.10 | 428.00 | 709.68 | 3,612.90 |
| 4 | 15.00 | 2.90 | 0.17 | 793.00 | 1,290.00 | 160.00 | 193.00 | 200.00 | 2,000.00 | 8,400.00 |
| 5 | 13.00 | 2.90 | 0.32 | 884.00 | 1,070.00 | 60.00 | 1,848.00 | 109.00 | 1,935.48 | 12,709.68 |
| 6 | 30.00 | 8.30 | 2.65 | 2,870.00 | 3,110.00 | 200.00 | 5,770.00 | 390.00 | 4,666.67 | 14,000.00 |
| 7 | 15.00 | 4.60 | 2.50 | 650.00 | 500.00 | 350.00 | 660.00 | 1,770.00 | 1,290.32 | 2,000.00 |
| 8 | 14.00 | 4.20 | 1.80 | 560.00 | 430.00 | 330.00 | 560.00 | 580.00 | 645.16 | 1,419.36 |
| 9 | 30.00 | 8.40 | 2.03 | 1,100.00 | 1,230.00 | 480.00 | 724.00 | 420.00 | 1,333.33 | 2,600.00 |
| 10 | 11.00 | 2.30 | 0.38 | 105.00 | 370.00 | 890.00 | 160.00 | 887.00 | - | 645.16 |
| 11 | 13.00 | 2.60 | 0.40 | 114.00 | 380.00 | 590.00 | 189.00 | 619.00 | 666.67 | 5,333.33 |
| 12 | 11.50 | 2.45 | 0.34 | 91.70 | 298.00 | 405.00 | 154.10 | 438.10 | 64.52 | 3,838.71 |

## 3.9 Soil Phosphorus Storage

Section 4 on sensitivities identifies soil phosphorus as the most important indicator of phosphorus load from agricultural land. The Phase 6 CBWM requires an estimate of the average soil P in each county and land use for every year 1985-2014 for the calibration and predicted future storage concentrations. A complete annual history is unavailable from the available data on soil P. In addition, the data could also suffer from significant sampling bias. The process-based model Annual Phosphorus Loss Estimator (APLE), described in Section 4, predicts soil P based on the balance of inputs and outputs and can be used to construct the history and estimate future soil P. There is also the knowledge that it is impossible for the soil P, averaged over a county and land use, to change by a large amount in any given year. The available data, the process-based model APLE, and expert opinion on uncertainty and the physical system were combined in a Bayesian analysis to estimate soil phosphorus concentrations, with uncertainty for each land use in each land segment.

### 3.9.1 Available Soil P Data

The Phase 6 Model requires an estimate of soil phosphorus storage for each land segment (approximately county scale) and agricultural land use. The soil test data are point data with uncertainty associated with location and with sampling density. For use in the Bayesian analysis used to estimate the soil phosphorus for each land use in each land segment, the soil tests from all sources (Table 3-36) were aggregated into a single collection of distributions through a four-step process.

- All data were converted to the chosen concentration unit, Mehlich 3.
- All data collected were labeled with agricultural land use assignments where available.
- Land segment location assignments were made for all data points, creating a discretization that could be used in modeling at the necessary spatial scale.
- Definition of distribution shape and uncertainty

Although aggregating data with this method provides a set that can be used in conjunction with soil P concentration model results and the general overall modeling structure, the process requires additional labels that were not included in the original metadata and inherently carry uncertainty. To address this issue, uncertainty was defined on two levels: 1) by source, where data from the different providers were considered to have different uncertainties from the previously described processes, and 2) at the land segment land use combination level, where uncertainty was added through scaling the uncertainty of individual data points based on their distance from the central tendency of the discretized set. Thus, the final aggregated product was not simply a collection of point measurements, but a collection of normal distributions centered about each measurement with a standard deviation defined by the two-tier estimation of uncertainty described above. The resulting collection represents not only a large number of soil tests converted to common unit and labeling schemes covering a large spatial and temporal range, but a guide for interpreting these data based on an estimate of their uncertainty defined through distributions.

*Table 3-36: Soil test data sources*

| SOURCE | YEARS | LOCATION | UNITS | TYPE |
|---|---|---|---|---|
| AgriAnalysis* | 2003 – 2014 | DE,MD,NY,PA,VA,WV | Phosphorus lbs/ac | by county & zip code |
| Penn State University** | 2001 – 2014 | PA | Mehlich 3 soil P (ppm) | by county and by crop |
| Virginia Tech** | 2012 | VA | Mehlich 3 soil P (ppm) | by county and by crop |
| University of Maryland 1* | 1954 – 2002 | MD | Percent of samples in Mehlich 3 range | by county |
| University of Maryland 2 | 1992 | DE,MD,NY,PA,VA,WV | Mehlich 3 soil P (ppm) | by county |
| University of Delaware | 1992 – 2015 | DE | P-FIV, Equal to 0.5 X Mehlich 3 lbs/ac | by county |

*Required conversion to Mehlich 3

** source includes land use metadata

#### 3.9.1.1 Mehlich 3 Conversions

Separate conversion methods were used in the process of creating unit consistency across soil test sources to report in Mehlich 3. Mehlich 3 is a test method for measuring soil nutrient levels and is cited as a standard metric for quantifying P concentrations in agricultural soils (Donohue, 1992). Sources that needed conversion were the AgriAnalysis, University of Maryland 1, Virginia Tech, and the University of Delaware. Units of pounds (lbs) per acre (ac) were reported by AgriAnalysis and were converted to Mehlich 3 ppm using an equation approved by the state of Virginia (Virginia Soil and Water Conservation Board, 2014):

*Equation 3-13*

$$\boldsymbol{C_{m3}} = \frac{1}{2} * \boldsymbol{M_{m3}}$$

where $\boldsymbol{C_{m3}}$ is the Mehlich 3 P concentration in the soil (ppm) and $\boldsymbol{M_{m3}}$ is the Mehlich 3 mass of P (lbs) per unit area, (ac) of soil. Although reported in Mehlich 3 by the source, Virginia Tech's data contained documentation indicating the original values were collected in Mehlich I and converted to Mehlich 3 using one of two equations Equation 3-14, depending on the value of Mehlich I being converted (Commonwealth of Virginia, 2005).

*Equation 3-14*

$$\boldsymbol{C_{m3}} = \begin{cases} \frac{(C_{m1}+3.26)}{0.458} & \boldsymbol{C_{m1}} < 90.63 \\ \frac{(C_{m1}+103.5)}{0.945} & \boldsymbol{C_{m1}} \geq 90.63 \end{cases}$$

Equation 3-14 was used to convert $\boldsymbol{C_{m1}}$ , Mehlich I soil concentration (ppm) to $\boldsymbol{C_{m3}}$ , Mehlich 3 soil concentration (ppm). Data from University of Maryland 1 were also converted from the original reporting units to Mehlich 3. These data were reported as percent of samples in three Mehlich 3 ranges, low, 0-25 ppm, medium 26-50 ppm, optimum, 51-100 ppm, and three separate excessive ranges, 101-150, 151-250, and greater than 250 ppm. Additionally, the data spanned a change in convention in the source, and samples summarized form years earlier than 1998 were only categorized by high, medium, and low qualitative labels without listed ranges. The low, medium, and first excessive range from the newer data in this set were used to define the values of the older test summaries. A weighted average (Equation 3-15) using the percent of samples and the center value of the defined ranges to assign a single value estimate for each summary of observations:

*Equation 3-15*

$$\boldsymbol{C_{m3}} = (\boldsymbol{P_1})\boldsymbol{C_{r1}} + (\boldsymbol{P_2})\boldsymbol{C_{r2}} + \dots (\boldsymbol{P_x})\boldsymbol{C_{rx}}$$

where $\boldsymbol{C_{m3}}$ is soil concentration (ppm), P represents reported percentage of soil tests that fell within their corresponding Mehlich 3 range with midpoint $\boldsymbol{C_r}$ (ppm) as defined above, and x is the total number of ranges in the reporting convention, equal to 6 for reports from 1998 to 2002, and 3 for data from 1997 and older. Summing all P's for a single calculation always equals 100 percent. Data in the University of Delaware set were reported in P-FIV, a fertility index value equal two times the Mehlich 3 P measurement in lbs per acre. Thus, the data were converted to Mehlich 3 ppm with Equation 3-16 and Equation 3-17:

*Equation 3-16*

$$\boldsymbol{M_{m3} = 2\ PFIV}$$

*Equation 3-17*

$$\boldsymbol{C_{m3} = *\ \frac{1}{2} M_{m3}}$$

where $\boldsymbol{C_{m3}}$ is the Mehich 3 soil P concentration (ppm), $\boldsymbol{M_{m3}}$ is the Mehlich 3 mass in lbs per ac, and $\boldsymbol{PFIV}$ is the soil test report value in University of Delaware P fertility index value units.

#### *3.9.1.2 Land Use Categorization*

A method was designed to make use of the two data sources which provided crop type with reported test data, Penn State University and Virginia Tech for land use categorizations. Crop types included harvested grains, soybeans, vegetables, and grasses. In order to assign land use categories, crop types were grouped into land uses labels. This was completed by translating the Phase 6 Model crop type to land use definitions based on similar crop types (Figure 3-18). For example, in the Phase 6 Model definitions, crop type "Alfalfa Harvested Area" is defined as land use "legume hay," in the soil P test sets, this relationship was used to label crop types from the Penn State and Virginia Tech sources "Planting Alfalfa" and "Alfalfa, Alf-Grass – Estab" as land use "legume hay." The resulting categorizations are shown in Table 3-37 and Table 3-38.

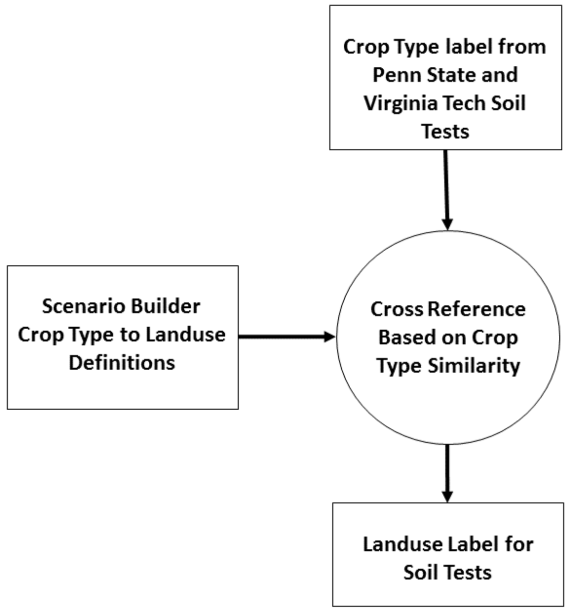



*Figure 3-18: Illustration of decision process used to categorize crop types into land uses.*

*Table 3-37: Crop type to land use classifications for Virginia Tech data resulting from the cross-referencing process*

| LAND USE | CROP NAME |
|---|---|
| Full Season Soy | SM GR - SOY DOUBLE CROP ROTA |
| Full Season Soy | SOYBEANS |
| Full Season Soy | SOYBEANS |
| Grain With Manure | CORN (GRAIN), CONVENTIONAL T |
| Grain With Manure | CORN (GRAIN), NO TILL |
| Grain With Manure | GRAIN SORGHUM |
| Grain With Manure | IRRIGATED CORN |
| Legume Hay | ALFALFA, ALFALFA – GRASS |
| Legume Hay | ALFALFA, ALFALFA-GRASS |
| Legume Hay | ALFALFA, ALF-GRASS – ESTAB |
| Legume Hay | RED CLOVER-GRASS HAY |
| Legume Hay | RED/LADINO CLOVER-GRASS HAY |
| Other Agronomic Crop | BEANS, SNAP |
| Other Agronomic Crop | CORN-PEANUT ROTATION |
| Other Agronomic Crop | COTTON |

| | |
|---|---|
| Other Agronomic Crop | PEANUTS |
| Other Agronomic Crop | SOD PRODUCTION - BERMUDA, ZO |
| Other Agronomic Crop | SOD PRODUCTION - BLUEGRASS, |
| Other Agronomic Crop | SWEET CORN - FRESH MARKET |
| Other Agronomic Crop | SWEET CORN - FRESH MARKET |
| Other Agronomic Crop | SWEET CORN – PROCESSING |
| Other Agronomic Crop | TOBACCO, BURLEY |
| Other Agronomic Crop | TOBACCO, DARK-FIRED |
| Other Agronomic Crop | TOBACCO, FLUE-CURED |
| Other Agronomic Crop | TOBACCO, SUN-CURED |
| Other Hay | FAIRWAYS - BLUEGRASS, FESCUE |
| Other Hay | ORCHARDGRASS/FESCUE-CLOVER E |
| Other Hay | ORCHARDGRASS/FESCUE-CLOVER P |
| Other Hay | STOCKPILED TALL FESCUE |
| Pasture | BERMUDAGRASS – PASTURE |
| Pasture | HAY AND PASTURE MIXTURES |
| Pasture | NATIVE OR UNIMPROVED PASTURE |
| Pasture | TALL GRASS-CLOVER PASTURE |
| Silage With Manure | BARLEY SILAGE - CORN SILAGE |
| Silage With Manure | CORN (SILAGE), CONVENTIONAL |
| Silage With Manure | CORN (SILAGE), NO TILL |
| Silage With Manure | SORGHUM (SILAGE) |
| Small Grains and Grains | WHEAT |
| Small Grains and Grains | BARLEY |
| Small Grains and Grains | CANOLA |
| Small Grains and Grains | OATS |
| Small Grains and Grains | OATS |
| Small Grains and Grains | RYE (GRAIN OR SILAGE ONLY) |
| Specialty Crop High | ONIONS, SCALLIONS |
| Specialty Crop High | BROCCOLI, CAULIFLOWER |
| Specialty Crop High | BRUSSELS SPROUTS, COLLARDS |
| Specialty Crop High | CABBAGE |
| Specialty Crop High | CUCUMBERS |
| Specialty Crop High | FOLIAGE PLANTS |
| Specialty Crop High | MUSKMELONS |
| Specialty Crop High | ONIONS, BULBS |

| | |
|---|---|
| Specialty Crop High | PEAS |
| Specialty Crop High | PEPPERS |
| Specialty Crop High | POTATOES, SWEET |
| Specialty Crop High | POTATOES, WHITE |
| Specialty Crop High | POTATOES, WHITE |
| Specialty Crop High | POTTED HOUSE PLANTS |
| Specialty Crop High | PUMPKINS |
| Specialty Crop High | PUMPKINS |
| Specialty Crop High | SPINACH |
| Specialty Crop High | SQUASH |
| Specialty Crop High | TOMATOES - FRESH MARKET, BAR |
| Specialty Crop High | TOMATOES - PROCESSING, MULTI |
| Specialty Crop High | TOMATOES - PROCESSING, SINGL |
| Specialty Crop High | WATERMELONS |
| Specialty Crop Low | ASPARAGUS - NEW HYBRIDS |
| Specialty Crop Low | ASPARAGUS - NONHYBRID STRAIN |
| Specialty Crop Low | BEANS, LIMA |
| Specialty Crop Low | BLACKBERRIES |
| Specialty Crop Low | BLACKBERRIES, RASPBERRIES |
| Specialty Crop Low | BLUEBERRIES |
| Specialty Crop Low | BLUEBERRIES |
| Specialty Crop Low | CHRISTMAS TREES-BLUE SPRUCE, |
| Specialty Crop Low | CHRISTMAS TREES-FRASER FIR, |
| Specialty Crop Low | CHRISTMAS TREES-NURSERY |
| Specialty Crop Low | CHRISTMAS TREES-PINES |
| Specialty Crop Low | GOOSEBERRIES |
| Specialty Crop Low | RASPBERRIES |
| Specialty Crop Low | STRAWBERRIES |
| Specialty Crop Low | STRAWBERRIES |

*Table 3-38: Crop type to land use classifications for Penn State data resulting from the cross-referencing process*

| LAND USE | CROP NAME |
|---|---|
| Grain With Manure | Corn for Grain |
| Grain With Manure | Corn for Grain (no-till) |
| Grain With Manure | Sorghum for Grain |

| | |
|---|---|
| Legume Hay | Planting Alfalfa-Grass |
| Legume Hay | Planting Red Clover-Grass |
| Legume Hay | Planting Alfalfa |
| Legume Hay | Established Alfalfa |
| Legume Hay | Planting Red Clover |
| Legume Hay | Planting Trefoil |
| Legume Hay | Planting Red Clover (No-till) |
| Legume Hay | Planting Alfalfa (No Till) |
| Legume Hay | Established  Trefoil-grass |
| Legume Hay | Established  Red Clover |
| Legume Hay | Established Alfalfa Grass |
| Legume Hay | Established  Red Clover-Grass |
| Legume Hay | Planting Trefoil-Grass |
| Legume Hay | Planting Trefoil (No-till) |
| Legume Hay | Planting Crownvetch |
| Legume Hay | Planting Alfalfa-Trefoil |
| Legume Hay | Established  Trefoil |
| Legume Hay | Established  Crownvetch |
| Legume Hay | Planting Crownvetch (no-till) |
| Other Agronomic Crops | Sweet Corn (Fresh Market) |
| Other Agronomic Crops | Tobacco |
| Other Agronomic Crops | Sweet Corn - Processing |
| Other Agronomic Crops | Sod Production-To Plant |
| Other Agronomic Crops | Beans (Other Dry Types) |
| Other Agronomic Crops | Kidney Beans |
| Other Hay | Planting Timothy |
| Other Hay | Planting Orchardgrass |
| Other Hay | Established Timothy |
| Other Hay | Established Bromegrass |
| Other Hay | Established Orchardgrass |
| Other Hay | Established Tall Fescue |
| Other Hay | Planting Bromegrass |
| Other Hay | Planting Tall Fescue |
| Pasture | Established Pasture (without legume) |
| Pasture | Renovating Pasture (with legume) |
| Pasture | Established Pasture (with legume) |

| | |
|---|---|
| Pasture | Planting Pasture (without legume) |
| Pasture | Planting Pasture (with legume) |
| Specialty Crop High | MIXED VEGETABLES CROPS |
| Specialty Crop High | Watermelon |
| Specialty Crop High | Pumpkin |
| Specialty Crop High | Fresh Market Tomato |
| Specialty Crop High | Potatoes-Unspecified Use |
| Specialty Crop High | Muskmelon (Cantaloupe) |
| Specialty Crop High | Popcorn |
| Specialty Crop High | Garlic |
| Specialty Crop High | Stored Tablestock Potatoes |
| Specialty Crop High | Home Potato Patch |
| Specialty Crop High | Early Tablestock Potatoes |
| Specialty Crop High | Broccoli |
| Specialty Crop High | Hot Peppers (Fresh Market) |
| Specialty Crop High | Spinach |
| Specialty Crop High | Processing Tomato (Transplants) |
| Specialty Crop High | Sweet-Fresh Market Peppers |
| Specialty Crop High | Beets |
| Specialty Crop High | Rhubarb-To Plant |
| Specialty Crop High | Turnip Roots |
| Specialty Crop High | Rhubarb-Maintain |
| Specialty Crop High | Turnip Greens |
| Specialty Crop High | Sweet Potato |
| Specialty Crop High | Cucumbers (Slicers) |
| Specialty Crop High | Cauliflower |
| Specialty Crop High | Brussels Sprouts |
| Specialty Crop High | Cucumbers (Picklers) |
| Specialty Crop High | Carrot |
| Specialty Crop High | Squash, Winter-Processing |
| Specialty Crop High | Cabbage (Kraut) |
| Specialty Crop High | Radish |
| Specialty Crop High | Stored Chip Potatoes |
| Specialty Crop High | Eggplant |
| Specialty Crop High | Experimental (500 CWT/A) Potatoes |
| Specialty Crop High | Processing Tomato (Direct Seeded) |

| | |
|---|---|
| Specialty Crop High | Mustard Greens |
| Specialty Crop High | Head Lettuce |
| Specialty Crop High | Kale |
| Specialty Crop High | Celery |
| Specialty Crop High | Sweet Processing Peppers |
| Specialty Crop High | Unstored Chip Potatoes |
| Specialty Crop High | Collards |
| Specialty Crop High | Hot Peppers (Processing) |
| Specialty Crop High | Chinese Cabbage |
| Specialty Crop Low | Blueberries |
| Specialty Crop Low | Strawberries-To Plant |
| Specialty Crop Low | Asparagus (To Plant) |
| Specialty Crop Low | Strawberries-Maintain |
| Specialty Crop Low | Snap Beans |
| Specialty Crop Low | Asparagus (Maintain) |
| Specialty Crop Low | Sunflowers |
| Specialty Crop Low | Peas |
| Specialty Crop Low | Lima Beans |
| Small Grains and Grains | Planting Red Clover in Wheat |
| Small Grains and Grains | Wheat |
| Small Grains and Grains | Rye |
| Small Grains and Grains | Oats |
| Small Grains and Grains | Planting Alfalfa in Oats |
| Small Grains and Grains | Planting Red Clover in Oats |
| Small Grains and Grains | Winter Barley |
| Small Grains and Grains | Planting Alfalfa in Wheat |
| Small Grains and Grains | Spring Barley |
| Small Grains and Grains | Buckwheat |
| Small Grains and Grains | Planting Trefoil in Oats |
| Small Grains and Grains | Canola |
| Small Grains and Grains | Planting Trefoil in Wheat |
| Small Grains and Grains | Barley/Soybean Double Crop |
| Full Season Soy | Soybeans |
| Silage With Manure | Corn for Silage |
| Silage With Manure | Corn for Silage (No-till) |

Categorized in this way, data could be compared across land use and source. However, since using this method required some subjective rules, statistical tests were completed to assess the efficacy of the labels. The Penn State University source included data in the state of Pennsylvania (PA), and the Virginia Tech source contained data for the state of Virginia (VA). A test was design to leverage this source difference as a means to assess the land use categorization process. Under the supposition that P concentration data labeled with land use categories reflecting reality would display significant differences between data from single land use categories compared with unlabeled data, the concentration data were tested for significant differences. Distributions were non-normal and contained different numbers of samples, thus the Mann-Whitney U test was chosen to assess the differences between the data sets (Mann and Whitney, 1947). In concept, the Mann-Whitney U test is similar to the t-test but is non-parametric and appropriate to use when the data do not meet the required normality assumptions (McKnight and Najab, 2010). Test 3-1 was performed for the 10 land uses present in the PA and VA data sets after the labeling process, and the hypotheses were formulated as follows:

*Null Hypothesis 3-1 – Data sharing a common land use label have the same distribution as unlabeled data*

*Alternate Hypothesis 3-1 – Data sharing a common land use label do not have the same distribution as unlabeled data*

Test 3-1 was performed separately for all land uses in both PA and VA, always comparing to the overall set as if the data did not have any land use labels. Results from these tests are shown in columns 2 and 3 of Table 3-39. An additional test was performed to assess the difference between the distributions of labeled land use sets between PA and VA locations. Performing this test provided evidence for whether or not data that share the same land use label but come from different states are from the same distribution or not. Test 2 was used to check for the presence of factors affecting the data that would make inter-state applicability of the results unadvisable. Test 3-2 was performed for the 10 land uses present in the PA and VA data sets after the labeling process, and the hypotheses for test 3-2 were formulated as follows:

*Null Hypothesis 3-2 – Data from VA and PA Data sharing a common land use label have the same distribution*

*Alternate Hypothesis 3-2 – Data from VA and PA sharing a common land use label do not have the same distribution.*

The p-values for test 3-1 and test 3-2 are summarized in Table 3-39. At a 0.05 significance level, test 3-1 provided evidence to reject null hypothesis 3-1 for all but the full season soy land use, and test 3-2 was unable to provide evidence to reject null hypothesis 3-2 in all but the silage with manure and specialty crops high land uses. Overall, outcomes supporting the discriminatory ability to prove differences of distributions caused by location of common land use labels across PA and VA were observed in 84 percent of the tests. Generally rejecting null hypothesis 3-1 provides evidence that the land use labels are indeed discretizing the data in one way that would be expected if the labels were true, and a general inability to reject null hypothesis 3-2 provides no evidence against the assumption that central tendencies of distributions with common land use labels do not differ between PA and VA. In summary, test 3-1 provided a means to assess the both the discriminatory behavior of the land use labels, and the spatial applicability of the central tendency of the concentration values for each land use category. Additionally, the mean of each land use category for both PA and VA are shown in Figure 3-19.

*Table 3-39: P-values for Test 1 and Test 2. Values shaded in gray were used to reject the null hypotheses at a significance level of 0.05.*

| Land use | Test 3-1 PA | Test 3-1 VA | Test 3-2 |
|---|---|---|---|
| Grain With Manure | 1.51E-11 | 5.25E-01 | 0.8197 |
| Legume Hay | 5.38E-144 | 1.28E-02 | 0.4303 |
| Other Agronomic Crops | 7.97E-65 | 8.25E-06 | 0.9946 |
| Other Hay | 1.32E-113 | 7.50E-03 | 0.3011 |
| Pasture | 3.51E-214 | 1.17E-04 | 0.5941 |
| Specialty Crop High | 5.10E-11 | 6.88E-21 | 0.0216 |
| Specialty Crop Low | 1.88E-160 | 2.89E-12 | 0.2399 |
| Small Grains and Grains | 1.21E-62 | 7.15E-01 | 0.1312 |
| Full Season Soy | 1.27E-01 | 2.01E-01 | 0.1535 |
| Silage With Manure | 1.78E-10 | 1.59E-02 | 0.0348 |

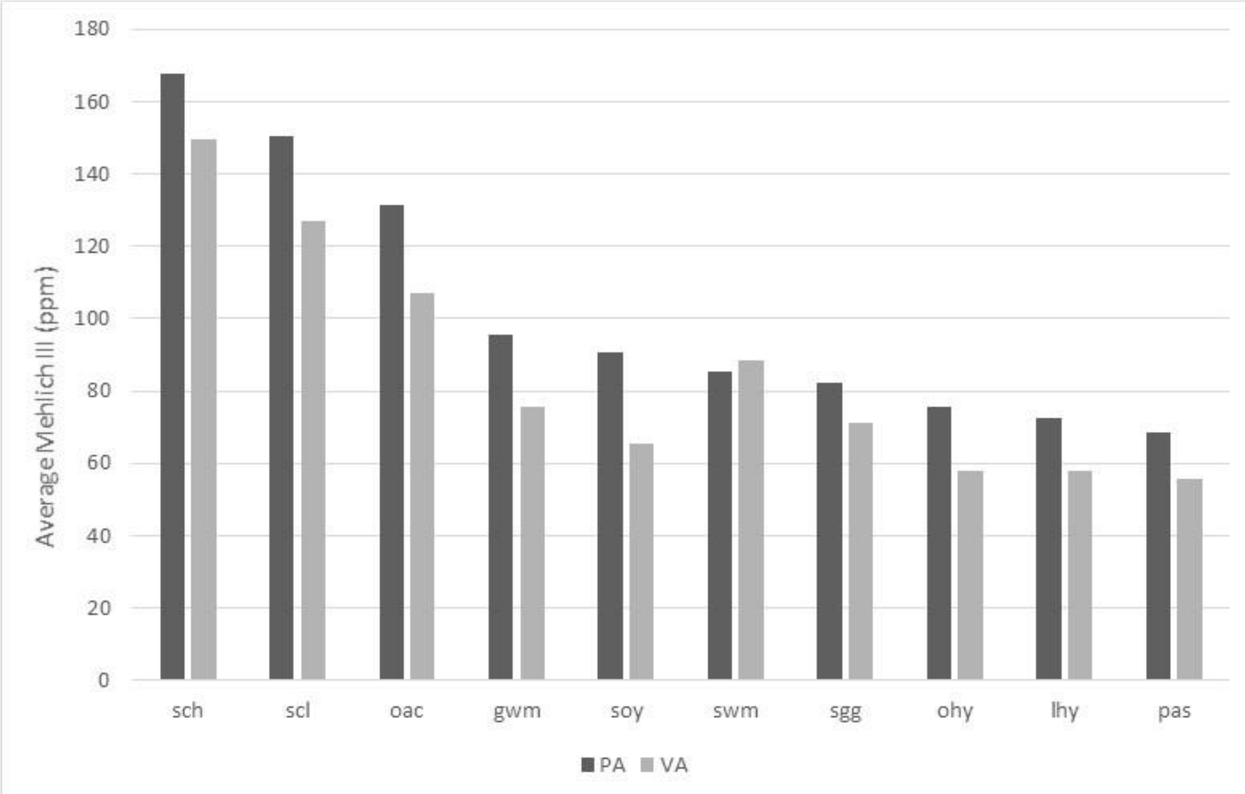



*Figure 3-19: Average Mehlich 3 ppm for Pennsylvanian (PA) and Virginia (VA) data sets. Most of the data have similar results, with the highest similarity between the data sets on the swm, land use*

Following the results of test 3-1, an assumption was made concerning the behavior of distributions with land use labels and those without. Given that data from common land use labels is generally significantly different from those without, a ratio can be calculated which can be used to shift the mean of an unlabeled data set to a value that would describe the central tendency of a set with a common land use label. Assumption 3-1 was used to scale the remainder of the unlabeled soil P concentrations into land use categorizations.

*Assumption 3-1 – A comparison of central tendencies can be used to describe the relationship between soil P concentrations with and without land use labels for the Chesapeake Bay*

Following assumption 3-1, mean ratios were calculated for each land use-labeled data set compared to the full set from both Penn State and Virginia Tech (Table 3-40). These ratios were used to obtain land use-labeled estimates from all other remaining soil P concentration data sources by applying assumption 3-1. All data were multiplied by each corresponding mean ratio as a scaling factor, obtaining soil P concentrations with land use labels. Although test 3-1 provided evidence for almost all land uses to be treated separately across space, considering differences across time, manifesting in this case as crop rotations, suggests that Assumption 3-1 be applied only to crops which generally are managed differently longer term compared to the others. Thus, commonly rotated row crops were lumped into the same category and left unscaled. The results from Test 3-1 are still used to apply this process across the watershed. The resulting data treatment was to calculate mean ratios for Specialty Crop High, Specialty Crop Low, Other Agronomic Crops, Other Hay, Legume Hay, and Pasture. Soil test data were scaled to these labels, and all other land uses were represented by unscaled data.

*Table 3-40: Ratios calculated from the mean of all P concentration data points from Penn State and independent source 1 compared with data labeled with each land use.*

| Land use | Mean Ratio |
|---|---|
| Specialty Crop High | 1.803 |
| Specialty Crop Low | 1.615 |
| Other Agronomic Crops | 1.404 |
| Other Hay | 0.812 |
| Legume Hay | 0.779 |
| Pasture | 0.735 |

#### *3.9.1.3 Spatial Discretization*

All data were reported at the county level excluding the AgriAnalysis data, which reported data by zip code. AgriAnalysis data zip codes did not refer to the zip code in which the soil sample was taken, but the reporting zip code, which is the operating consultant's physical address. The county that the data were assigned to was assumed to be the corresponding county to the reported zip code (US Census, 2010), plus the two nearest counties via county centroid distance. This effectively assumes any consultant had a 3-county reporting area, and that there exists no further information to assign the measurements to a particular county. These soil P measurements appear in each possible county with an uncertainty due to spatial location applied, which is explained in detail below. After county labels were applied to all data to county level spatially, each data source was combined into a single table. One single value for each land use, county, and year combination was calculated from the combined data set. Where multiple values for a given land use in a given county in a given year existed, these values were aggregated through averaging. The resulting average value could include data from multiple sources, or multiple measurements from the same source, or both. In the case of single data points already existing in a unique year, county, and land use, the data available were listed alone. Thus, each combination of land use and county can have a mix of averages across sources and/or various data from single sources depending on overlap. This method aggregates soil tests from all sources into a single data set representing annual county average Mehlich 3 P concentrations for the 10 labeled land uses.

#### 3.9.1.4 Uncertainty Definition and Distributions

The Agricultural Modeling Subcommittee (AMS) assigned uncertainties by considering the reporting structures, goals of the data collection, and if or how the results were converted to Mehlich 3 values. These uncertainties were based on the relative extensiveness of preprocessing data from each source were subject to and qualitative assessments including assumptions on certainties between data from different states. Where the mean value was calculated from multiple sources, the maximum uncertainty level from the sources was used. Data points were then assumed (assumption 3-2) to be the central tendencies of normal distributions containing the true state of the average soil P concentration from their corresponding land segment, land use, and year. From these general guidelines (Table 3-41), standard deviations were subjectively chosen by the members of the AMS through an iterative process with the goal of representing reasonable variations following the guidelines discussed above for each distribution (Table 3-42). Furthermore, an assumption was made defining a distribution containing the true state of P concentration for each land segment, land use, and year combination that contains the true state of the average P concentration in that time and space (Assumption 3-2). A large range with uniform distribution was chosen to represent an unknown, but reasonable state.

*Table 3-41: Uncertainty guidelines for source*

| SOURCE | TIME RANGE | STATE | RELATIVE UNCERTAINTY |
|---|---|---|---|
| AgriAnalysis | 2003 - 2014 | DE,MD,NY,PA,VA,WV | Medium |
| Penn State University | 2001 - 2014 | PA | Medium low |
| Virginia Tech | 2012 | VA | Medium High |
| University of Maryland 1 | 1954 - 2002 | MD | High |
| University of Maryland 2 | 1992 | DE,MD,NY,PA,VA,WV | Medium to High |
| University of Delaware | 1992 - 2015 | DE | Medium |

*Table 3-42: Standard Deviations Assigned to by Source and State*

| SOURCE | STATE | STANDARD DEVIATION |
|---|---|---|
| AgriAnalysis | DE | 25 |
| AgriAnalysis | MD | 25 |
| AgriAnalysis | NY | 25 |
| AgriAnalysis | PA | 25 |

| | | |
|---|---|---|
| AgriAnalysis | VA | 25 |
| AgriAnalysis | WV | 25 |
| Penn State University | PA | 15 |
| Virginia Tech | VA | 30 |
| University of Maryland 1 | MD | 50 |
| University of Maryland 2 | DE | 25 |
| University of Maryland 2 | MD | 40 |
| University of Maryland 2 | NY | 50 |
| University of Maryland 2 | PA | 15 |
| University of Maryland 2 | VA | 50 |
| University of Maryland 2 | WV | 20 |
| University of Delaware | DE | 20 |

*Assumption 3-2 – The true state of annual P concentration for a particular land segment land use combination exists within a normal distribution centered about the soil test data point that exists for that year.*

*Assumption 3-3 – The true state of annual P concentration for a particular land segment land use combination exists within a uniform distribution bounded by 0 and 400 when no soil test data point exists for that year.*

From the uncertainty based on source, each mean value representing a unique combination of county, year, and land use received an uncertainty scaling factor based on the central tendency of the final discretization it was contained within. Thus, for every land segment land use combination, source-based uncertainties were scaled with Equation 3-18 to attenuate the influence of outliers.

*Equation 3-18*

$$\boldsymbol{\sigma_{scaled1}} = \boldsymbol{\sigma_{unscaled}} \left(\frac{\mathbf{1.01}}{\mathbf{1}}\right)^{\boldsymbol{abs(mean(S)-s_1)}}$$

Equation 3-18 is used to calculate the final, annual scaled standard deviation ($\boldsymbol{\sigma_{scaled1}}$) which is unique for each year, from the original standard deviation from the source-based uncertainties ($\boldsymbol{\sigma_{unscaled}}$) which is constant across time for a given source, the set including all annual soil test values for a single land use land segment combination after the complete aggregation process ($\boldsymbol{S}$), and the single soil test value corresponding to the final unique annual scaled standard deviation. In this way, uncertainties were adjusted based on the distributions of the individual land segment land use combination soil test sets resulting from the aggregation process. The scaling factor, $\left(\frac{\mathbf{1.01}}{\mathbf{1}}\right)$ and equation shape were chosen empirically based on sensible reductions of the influence of outliers in the opinion of the AMS.

Using the process described above and assumptions 2 and 3, a collection of distributions containing the true state of soil P concentrations over the entire time series for every land segment and land use combination for the Chesapeake Bay was defined. Although this collection contains some uninformative distributions where there was missing data, it describes the probabilities of the values in a useful manner. When coupled with a quantification of the probability of inter-annual change in state of the soil P concentrations, a new estimate can be produced that presents a reasonable combination of the strengths of model estimates and this aggregate data set attenuated by the defined uncertainties. Figures 1 and 2 summarize the aggregation process converting a group of soil P tests from different sources into a single set of distributions.

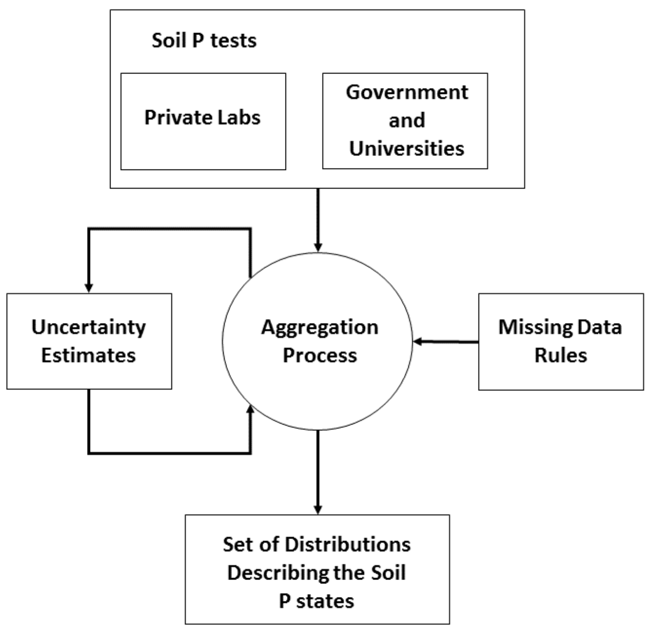



*Figure 3-20: Summary of the aggregation process and conversion of soil test data sets into a complete set of distributions.*

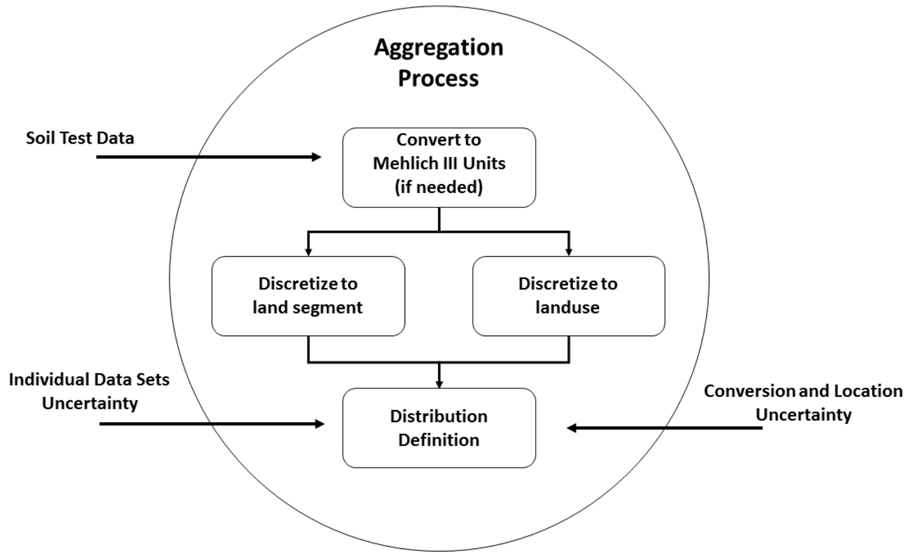



*Figure 3-21: Detail of the aggregation process used to define the distributions from soil test data. Two categories of soil test data are used to define the distribution of each random variable. Thus, the aggregation process combines data, assumptions, and expert knowledge to create the product usable in the Bayesian analysis.*

### 3.9.2 Combined Use of Bayesian Model to Reconstruct History

There are two sets of data used to describe the state of soil phosphorus history for every land segment / land use combination over the annual temporal range 1984 through 2014. One set is composed of a combination of soil tests from multiple sources. Although this data set is the most spatially and temporally complete collection of phosphorus soil sets yet compiled by the CBP, the data have various levels of confidence due to different sources varying in methods, goals, and reporting guidelines. Additionally, privacy of land owners is a major concern while conducting these tests, and therefore none of the data have absolute location information, but have county level labels from the reporting location, which may encompass multiple counties of actual test data. The data set is sparse as well, missing many values for early years; those years that do exist often show unlikely large inter-annual variabilities. For these reasons, the data can be thought of as lower quality than data collected for a scientific study. Thus, rather than simply accounting for noise in these soil tests and using them as observations, this method attempts to quantify their efficacy as guides to inform our initial assumptions about soil phosphorus history in each land use and land segment combination. The main assumption governing the use of the soil test data in this is that these data give an overall picture of the central tendency of the soil phosphorus levels but are not reliable for defining the inter-annual time series describing the change in soil phosphorus levels over time.

The second set of data describing soil phosphorus history are simulated values from a mass-balance-based model, the Annual Phosphorus Loss Estimator (APLE). The simulated data set is governed by assumptions made about the physical processes dictating soil storage in agricultural fields. This model requires inputs for soil characteristics, hydrologic and meteorologic information, and variables describing agricultural actions each year across all counties and agricultural land uses in the Chesapeake Bay watershed. These compiled inputs represent the most descriptive and complete set of data summarizing phosphorus-sensitive agricultural operations available to the CBP. The data set has no missing values and provides reasonable inter-annual changes for soil phosphorus concentrations.

The APLE model requires calibration to provide meaningful estimates; the calibration was a simple process of choosing the optimum starting concentration for APLE given all the soil test data for each land use / land segment combination. The calibration process had mixed success with annual estimates often exceeding expected values. Although the inter-annual changes of the APLE data set were reasonable, the absolute values were not always inside expected boundaries. Rather than turning to more complex calibration methods, revisiting assumptions, or retroactively adjusting input data, this study attempts to address the short-comings in both data sets by leveraging the well performing traits of each through a hierarchal Bayesian formulation of the time series with the goal of estimating the true state of soil phosphorus concentrations.

Through collective study and the distillation of multiple expert opinions the use of both data sets is governed by the following assumptions for each land use / land segment combination. The following assumptions were made about the data sets and used a guide in the formulation of the Bayesian model.

*Assumption 3-4 - The soil test data set provides an overall guide for absolute values of annual soil phosphorus concentrations but does not provide meaningful information about the inter-annual variability of the data.*

*Assumption 3-5 - The APLE data set provides a guide for assessing the inter-annual movements of the state of soil phosphorus concentrations but does not provide meaningful information about the absolute value of an individual annual soil phosphorus concentration.*

Following the assumptions above, the soil test data were chosen to inform prior distributions for years where these data existed, and the APLE data set was used as a change model to update the current state of the model through time. Each soil test data point was assumed to be the mean of a normal distribution of possible values for that year. Additionally, uncertainties in both these processes were defined through expert consultation, literature values, and knowledge concerning the details of each data set. When no data existed for a year, the prior distribution was assumed to be uniform between two possible values. For each land segment / land use combination the initial values were formulated as described below in Equation 3-19.

*Equation 3-19*

$$m_t \sim \begin{cases} normal(s_t\,, e_1) & s_t \in S \\ uniform(a, b) & s_t \notin S \end{cases}$$

Where: $m_t$ is the final estimate of Mehlich 3 level in the soil, $s_t$ is the average soil test value at year t, $S$ is the full set of available annual soil test data points for a particular land segment land use subset, $e_1$ is the estimated standard deviation, quantifying the uncertainty in soil test data, $a$ is the lower limit of possible Mehlich 3 phosphorus concentrations when no soil tests was available, and $b$ is the upper bound under the same condition. These bounds were chosen as 0 and 400, defining a range of possible Mehlich 3 values informed by extreme values found in the literature to avoid over-confident estimations. The second component of the model defines the inter-annual change in state of the soil phosphorus concentrations by adding the change defined by the APLE data set to the current state and adding a term to account for the uncertainty in the inter-annual variability defined by APLE. This value was chosen based on expert opinion in the AMS and estimation of uncertainties in the inputs required to produce APLE estimates. This term was used in the absence of parameterized APLE inputs and was designed estimate the resulting possible outcomes in the estimated annual changes due to the inputs, providing a means to quantify uncertainty.

*Equation 3-20*

$$\Delta APLE_t = APLE_t - APLE_{t-1}$$

*Equation 3-21*

$$m_t \sim normal(m_{t-1} + \Delta APLE_t, e_2)$$

In Equation 3-20 and Equation 3-21 $m_t$ is the estimate of the Mehlich 3 level in the soil at year t through updating the previous year's state ($m_{t-1}$) by the estimated change in concentration at year t ($\Delta APLE_t$), $APLE_t$ is the soil Mehlich 3 estimate from the APLE data set at year t, $APLE_{t-1}$ is the soil Mehlich 3 estimate from the APLE data set on the previous year, and $e_2$ is the estimated standard deviation of the normal distribution, representing the error in $\Delta APLE_t$ estimates. The process is simplified in Figure 3-22.

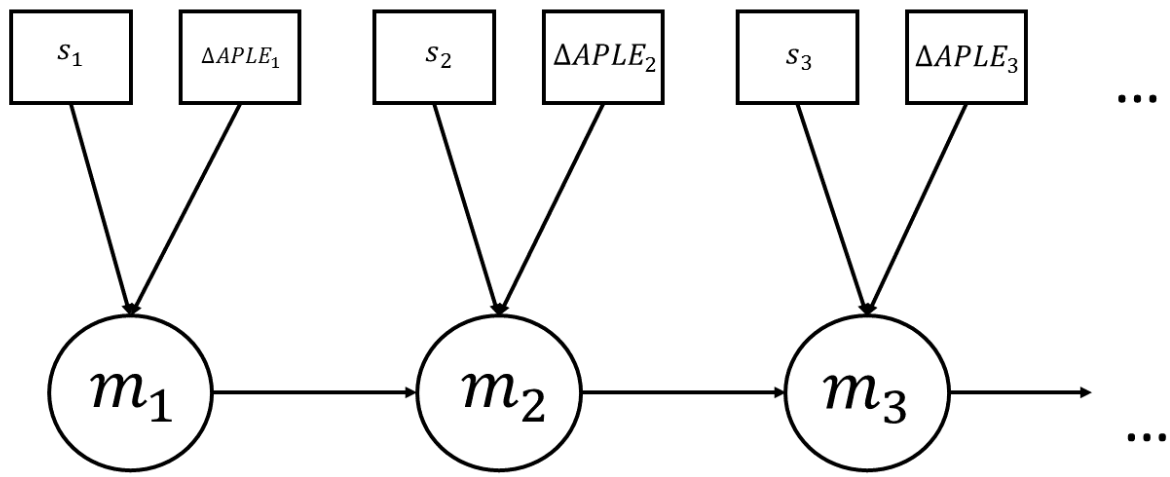



*Figure 3-22: Diagram of the update of estimated soil phosphorus concentration states. Each new state contains information from the soil test data set, the APLE data set, and the previous estimated state.*

### 3.9.3 Soil Phosphorus in Scenarios

Sections 3.9.1 and 3.9.2 described the data and methods to produce the estimated history of soil phosphorus to be used in the calibration of the Phase 6 Watershed Model. When running scenarios, the CBP Watershed Model is estimating the loads over the long term with management held constant. In this case, constant management is not taken to mean constant soil P, but rather a constant application of fertilizer and manure. For a given scenario, the balance of inputs, uptake, and other losses may lead to an annual increase or an annual decrease in soil phosphorus levels.

Soil P levels for scenarios are estimated by simulating the effect on soil P of holding management constant for a period of 25 years. The beginning point for the 25-year simulation is either the base year for the scenario or the most recent year for which an estimate is available. For example, a 1990 scenario would start with the estimated soil P in 1990 and then simulate the effects of 1990s management for 25 years. A 2025 scenario would use soil P for the latest available year (2014) and simulate soil P after 25 years of projected 2025 management. This process and the 25-year simulation period were decisions of the Water Quality Goal Implementation Team on August 28, 2017.

#### *3.9.3.1 Analysis of APLE sensitivity to inputs*

These projections were needed individually for unique land segments and land uses, given a particular annual management condition which will be repeated into the future. This was done by creating linear sensitives for major inputs as defined by the APLE model in combination with an empirical non-linear recursive equation which estimated the year-to-year sag that is observed in soil P draw down or buildup under constant management conditions. This process required several assumptions to complete, the major assumptions are described below.

Assumption 1: All future projections retain the latest years management as the yearly input for the duration of the projection

Assumption 2: Sensitivities calculated from the APLE model are shared by all land segments (for example, a pound of manure contributes the same concentration increase in one county and any other county)

Assumption 3: Non-linear components of draw down and buildup can be modeled empirically with a recursive function

Assumption 4: Each land segment contains a soil P “momentum”, which can be represented as an intercept in a linear equation.

Assumption 5: All input variables independently effect the concentration of soil P in a given area

The resulting function was a dampened iterative implementation of the following linear equation

*Equation 3-22: Annual soil phosphorus change*

$$(\textbf{Future Annual Change M3}) = \sum_{n=1}^{i} \left(\textbf{Variable}_i * \frac{\textbf{Annual Change M3}}{\textbf{Unit Variable}}_i\right)$$

Thus, the process to create soil P projection equations was completed in three major steps:

1. Global soil P sensitives to APLE were calculated using a simple method to test APLE inputs
2. A non-linear recursive equation framework was defined to assist with estimating draw down and build up
3. The intercept of the previously defined function was found through a meta-heuristic search process and fitness evaluation of estimates compared to historical estimates described in previous sections.

Global soil P sensitivities were estimated by Sobol sampling the multivariate ranges of the following variables and values.

*Table 3-43: Sample ranges of APLE input variables used in sensitivity analysis for future soil P estimates*

| Input | Minimum | Maximum |
|---|---|---|
| Uptake | 0 | 10 |
| % Incorporation | 10 | 90 |
| % Mixing | 0 | 9 |
| Depth of Incorporation | 0 | 10 |

| | | |
|---|---|---|
| Liquid Manure TP | 0 | 10 |
| Solid Manure TP | 0 | 10 |
| Fertilizer TP | 0 | 10 |
| Biosolids TP | 0 | 10 |
| Direct Manure | 0 | 10 |
| Total Manure | 0 | 10 |
| Start Concentration | 50 | 500 |
| Number of Years Applied | 2 | 30 |

Automatic scripts were written to create input files for APLE post sampling. From there, the Chesapeake Bay fortran version of APLE was run using those inputs, and the resulting soil P concentration was saved along with the value of each input under the sensitivity test. The automated process simply accepted a Sobol generated set of inputs, created files from those inputs, ran APLE on them, and gather the APLE output in Mehlich 3 concentration units.  The post processing then included gathering all input cases and resulting concentrations separately by input and performing a linear regression with Mehlich 3 concentration as the target variable and the tested input as the independent variable. The result was a linear equation containing a slope which defined the average change in Mehlich 3 per unit of each dependent variable. Initial results from this process were characterized relatively, providing a view into the how APLE treats inputs, and how they affect soil P. Years applied was left off the list, as it was only included to test the average annual nature of the effects which were found to be relatively constant in near-term projections. An example of two competing input samples and their resulting regression is shown in Figure 3-23. The figures have been zoomed in to show detail. The Sobol sampling process created dense and complete coverage of the area shown, and the linear effect is quite small per unit of each input variable. This is characteristic of all variables and is in agreement with the common understanding that annual average soil P changes slowly but measurably with changing inputs.

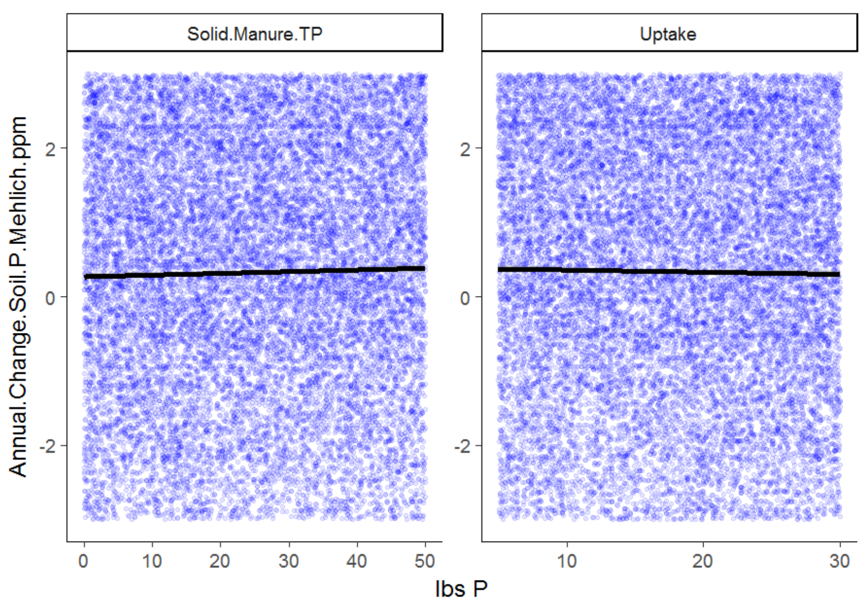



*Figure 3-23: Detail of sensitivity regressions on two competing input variables*

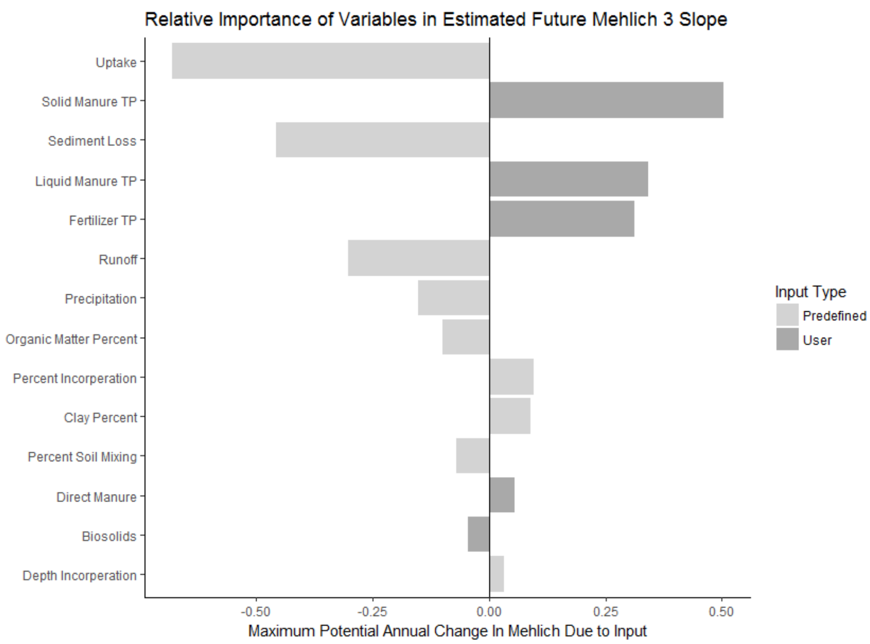



*Figure 3-24: Relative Effects of APLE inputs on soil P*

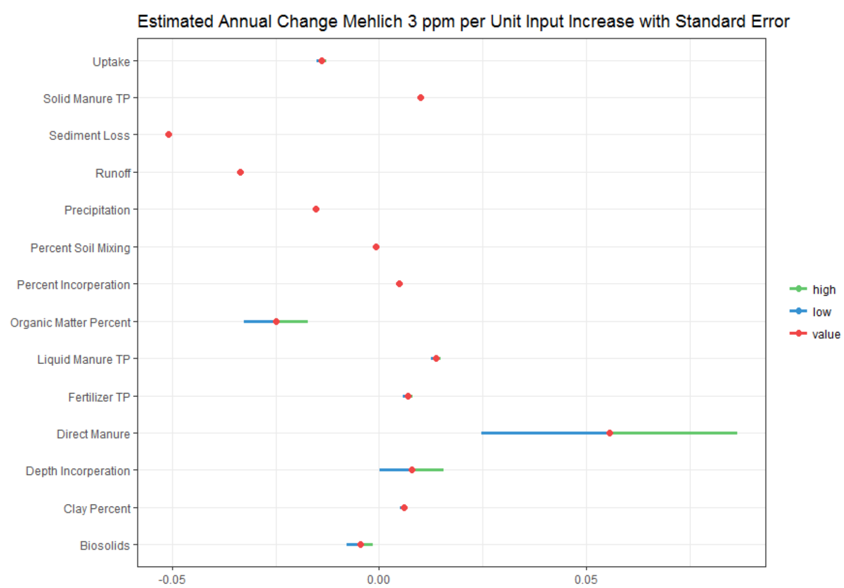



*Figure 3-25: resulting sensitivities from independent linear regressions of each sampling profile for all input variables*

The resulting slopes from all input variables were calculated as described above and shown in Figure 3-24. Along with the slope, the standard error was extracted to assist in estimating the uncertainty of the slopes, which define the annual change in Mehlich 3 per unit of each input variable. Organic matter, depth incorporated, and direct manure all have relatively high influence and uncertainty. However, none of the standard error bounds include zero, meaning the direction of all input effects is well known. Additionally, many of the input sensitivities have very low uncertainty when considering the standard error of the slopes.

#### 3.9.3.2 Prediction of Soil Phosphorus for Scenarios

The above analysis is used to estimate the parameters for a statistical emulation of the Bayesian soil model. For any given scenario Equation 3-23 is evaluated iteratively for 25 years to estimate the soil phosphorus that would result from a consistent management of inputs over a 25-year period.

*Equation 3-23: Iterative equation to estimate soil P in scenarios*

$$M_{i+1} = M_i + \left( \sum_{n=1}^{Nfactors} (Factor * Coefficient) \right) * (1 - 0.95 * \log_{75} i)$$

Where:
M = Soil phosphorus Mehlich 3 (ppm)
i = year
Nfactors = number of factors listed in Table 3-44

*Table 3-44: Coefficients for estimation of soil P in scenarios*

| Factor | unit | Coefficient |
|---|---|---|
| **Solid Manure** | pound/acre/year TP | 0.151 |
| **Liquid Manure** | pound/acre/year TP | 0.154 |
| **Fertilizer** | pound/acre/year TP | 0.0559 |
| **Biosolids** | pound/acre/year TP | 0.00463 |
| **Uptake** | pound/acre/year TP | -0.159 |
| **Sediment Loss** | ton/acre/year | -0.208 |
| **Runoff** | inches/year | -0.0355 |
| **Percent Incorporation** | percent | 0.0479 |
| **Percent Mixing** | percent | -0.0508 |
| **Depth of Incorporation** | inches | 0.183 |
| **Precipitation** | inches/year | -0.00152 |
| **Clay percent** | percent | Clay > 15: 0.160<br>Else: 0.000 |
| **Organic Matter** | percent | Clay >15: -0.549<br>Else: 0.000 |
| **Local Adjustment** | ppm Mechlich 3 | Varies |

Year 1 is the estimated historical soil P for the scenario year for scenarios based on 2014 and prior years. Year 1 is 2014 for scenarios based on 2014 and future years.

## 3.10 Water Extractable Phosphorus

### 3.10.1 Manure

Water extractable phosphorus (WEP), expressed as a percentage of total P, is a source of P loss in runoff. In Phase 6 WEP in used in P loss sensitivities in reference to manure applications. The Agricultural Modeling Subcommittee (AMS) determined through a review of literature that water extractable phosphorus could be predicted by animal type. Table 3-45 contains the fraction of manure phosphorus that is considered WEP for different animal types.

*Table 3-45: WEP for different animal types*

| Animal Name | Fraction WEP In Manure |
|---|---|
| pullets | 0.19 |
| turkeys | 0.34 |
| hogs and pigs for breeding | 0.37 |
| beef | 0.43 |
| broilers | 0.2 |
| dairy | 0.6 |
| hogs for slaughter | 0.37 |
| horses | 0.515 |
| layers | 0.19 |
| other cattle | 0.515 |
| biosolids/spray irrigation | 0.025 |
| fertilizer | 0.85 |
| sheep and lambs | 0.515 |
| goats | 0.515 |

### 3.10.2 Inorganic fertilizer

In Phase 6, a WEP of 85 percent is assumed for inorganic commercial fertilizer (Brandt et al. 2004). A second line of evidence for this assumption was found in the source equations driving APLE model estimates. The APLE Model contains separate equations for P runoff from manure sources and P runoff from inorganic fertilizer sources. The mathematical relationship between these two formulations based on the expected difference of the separate distribution factors for manure and fertilizer (distribution factors are important empirical parameters embedded in APLE designed to describe P runoff from various sources) can be solved for an estimated constant WEP of inorganic fertilizer (Figure 3-26). Based on this evidence, inorganic fertilizer was assigned a WEP of 85 percent.

$$PR_{manure} = WEP_{manure} * P_{manure} * \frac{Runoff}{Precipitation} * D_{manure}$$

$$PR_{fertilizer} = P_{fertilizer} * \frac{Runoff}{Precipitation} * D_{fertilizer}$$

$$\mathcal{E}(D_{fertilizer} - D_{manure}) = 0.175 \quad \epsilon \;\; \theta_{APLE\ hydro}$$

$$\mathcal{E}\ (PR_{fertilizer}) = P_{fertilizer} * \frac{Runoff}{Precipitation} * D_{manure} + \mathcal{E}(D_{fertilizer} - D_{manure})$$

$$\mathcal{E}\ (PR_{fertilizer}) = PR_{manure} * \mathcal{E}(D_{fertilizer} - D_{manure})$$

$$PR_{fertilizer} = P_{fertilizer} * \frac{Runoff}{Precipitation} * D_{manure} * \frac{1}{\mathcal{E}(D_{fertilizer} - D_{manure})}$$

$$\mathcal{E}\ (WEP_{fertilizer}) = \frac{1}{\mathcal{E}(D_{fertilizer} - D_{manure})} = \frac{1}{0.175} = 0.851$$

*Variable Definitions*

| | |
|---|---|
| $PR_{manure}$ | *P runoff from manure (lbs per acre)* |
| $PR_{fertilizer}$ | *P runoff from fertilizer (lbs per acre)* |
| $WEP_{manure}$ | *Water extractible P of manure (unitless)* |
| $WEP_{fertilizer}$ | *Water extractible P of fertilizer (unitless)* |
| $D_{fertilizer}$ | *Empirical distribution factor for fertilizer (unitless)* |
| $D_{manure}$ | *Empirical distribution factor for manure (unitless)* |
| $\frac{Runoff}{Precipitation}$ | *Fraction of water runoff over precipitation (inches / inches)* |
| $\theta_{APLE\ hydro}$ | *Set of hydrology parameters contained in APLE input files* |

*Figure 3-26: Evidence from APLE equations for an Inorganic Fertilizer WEP of 85 percent*

## 3.11 Atmospheric Deposition

### 3.11.1 Introduction

Quantification of the deposition loads to the Chesapeake Bay and its watershed began with assessments of key oxidized (NOx) and reduced ($NH_3$) loads in both wet and dry deposition (Tyler, 1988; Fisher et al. 1988; Hinga et al. 1991; Fisher and Oppenheimer, 1991). In addition to the inorganic nitrogen deposition loads, in the case of the open waters of the tidal Chesapeake and rivers and lakes of the watershed, organic nitrogen deposition also needs to be considered (Knap et al. 1986; Scudlark and Church, 1993; Neff et al. 2002). The inclusion of all nitrogen deposition species is particularly important in the mass balance models of the estuary (Cerco and Noel, 2013) in which all estimated nutrient input loads are included. Estimates of coastal ocean loads of nitrogen deposition (Howarth et al. 1995; Howarth, 1998; Pearl et al. 2002; Fennel et al. 2006) are considered in the modeling as well and were handled through adjustment of the ocean concentration boundary condition in the estuarine model (USEPA, 2010). As shown in Figure 3-2, atmospheric deposition loads are the largest input loads of nitrogen in the watershed. About half the atmospheric deposition loads of nitrogen originate from emission sources outside the Chesapeake watershed (USEPA, 2010a-05).

### 3.11.2 Methods

The Chesapeake Bay Program airshed model is a combination of a regression model of wet deposition (Grimm and Lynch, 2000; 2005; Grimm, 2016) and a continental-scale Community Multiscale Air Quality (CMAQ) Model application for estimates of dry deposition, with North America as the model domain (Dennis et al. 2007; Hameedi et al. 2007). The regression and deterministic airshed models that provide atmospheric deposition input estimates have gone through a series of refinements, with increasingly sophisticated models of both applied over time (Linker et al. 2000; 2013; Grimm and Lynch, 2000; 2005; Lynch and Grimm, 2003; Grimm, 2017). Wet atmospheric deposition is estimated hourly. The dry deposition estimates are supplied as monthly estimates based on CMAQ (Dennis et al. 2007; Hameedi et al. 2007) and equally disaggregated to daily time step. The Phase 6 model uses the information at various time scales. CAST uses annual averages for calculations described in Section 4 while the dynamic model using monthly time steps for the land simulation and hourly for the river simulation. The airshed model CMAQ tracks the changes in wet and dry nitrogen deposition load due to expected management actions.

#### *3.11.2.1 Regression Model of Wetfall Deposition*

Wet deposition is simulated using a regression model developed by Grimm and Lynch (2000, 2005; Lynch and Grimm, 2003) and extensively updated and refined by Grimm for the Phase 6 Model version as documented in Section 3 Appendix H (Grimm, 2017). The regression model provides hourly wet deposition loads to each land segment based on each land segment's rainfall, seasonality, proximity to sources, and other characteristics. The land segment grid for the regression model exactly follows the Phase 6 land segments. The latest version of the regression model uses data from 85 National Atmospheric Deposition Program / National Trend Network (NADP/NTN) and Pennsylvania Atmospheric Deposition Monitoring (PADM) network precipitation chemistry monitoring sites to produce local estimates of wetfall inorganic nitrogen deposition across the entire Chesapeake watershed and the Bay during the entire simulation period of 1985 to 2014 (Appendix H). The NADP/NTN and PADM are specifically designed to measure ammonium and nitrate wet deposition.

To improve the accuracy of the regression estimates over previous regression analyses (Linker et al. 2000: 2013) a number of improvements in the sampling and representation of spatial and temporal patterns of land use activities and intensities and of emission levels were made. Also, detailed meteorological data were assimilated into the regression model to identify contributing emission source areas and to estimate the impact of those contributions on daily deposition rates on a per-event basis.

Refinements also involved developing a more accurate and comprehensive representation of the spatial and temporal distribution and intensity of livestock production and other agricultural activities across the Chesapeake watershed model domain. An improved accounting of livestock production activities was achieved by combining county- and watershed unit-specific livestock production statistics with 30-meter land use data from the USGS's National Land Cover Database (NLCD). Estimates of local ammonia emissions from fertilizers and manure applications to croplands were also assimilated into the model using EPA inventories and NLCD land cover to quantify emissions from cropland areas likely to be fertilized, although there are significant uncertainties in the agricultural ammonia emission inventories. Last, localized estimates of $NH_3$ and $NO_x$ emissions for the Chesapeake watershed model domain and surrounding states were developed by combining facility- and county-specific emissions reports from EPA's National Emissions Inventory database with the NLCD classifications (Grimm and Lynch, 2005) and further upgraded in the 2017 version of the model as described in Appendix H.

For each day of precipitation, wetfall atmospheric deposition is estimated by the regression model, which has the general form:

$$\mathbf{Log10(c) = b_o + b_1 log10(ppt) + b_{2s} season + b_3 v_3 + \ldots + b_n v_n + e}$$

where

- $c$ = daily wet-fall ionic concentration (mg/l)
- $b_o$ = intercept
- ppt = daily precipitation volume (inches)
- $b_1$ = coefficient for precipitation term
- season = vector of 5 binary indicator variables encoding the 6 bi-monthly seasons
- $b_{2s}$ = vector of 5 coefficients for season terms
- $v_3 \ldots v_n$ = additional predictors selected through stepwise regression
    - National Land Cover Data (NLCD)
    - Within proximities of 0.8, 1.6, 3.2, 8.0, and 16.1 km of each NADP/NTN site: open water, forested, residential, industrial/transportation, croplands, and vegetated wetlands.
    - Annual emission levels of ammonia and nitrous oxides from EPA National Emission Trends (NET) for:
        - County containing each NADP/NTN monitoring site
        - Four counties nearest to each NADP/NTN monitoring site
    - Twelve-hour back-trajectory exposure of precipitating air-mass to ambient concentrations of transported ammonia and nitrous oxide emissions
- $b_3 \ldots b_n$ = coefficients corresponding to $v_3 \ldots V_n$
- $e$ = residual error

The daily precipitation nitrate and ammonium concentration models were developed using a linear least-squares regression approach and single-event precipitation chemistry data from the 85 NADP/NTN sites and PADM stations. The most significant variables in both models included precipitation volume, the number of days since the last event, seasonality, latitude, and the proportion of land within 8 km covered by forests or devoted to transportation and industry (Grimm and Lynch, 2005). Local and regional ammonia and nitrogen oxides emissions were not as well correlated as land cover. The abilities of those variables to predict wet deposition arise primarily from their relationship to (1) the spatial and temporal distribution of emissions of ammonium and nitrate precursors from sources within or upwind of the Chesapeake watershed model domain and (2) the chronology and characteristics of precipitation events. Modeled concentrations compared very well with event chemistry data collected at six

NADP/AirMoN sites in the Chesapeake watershed. Wet deposition estimates were also consistent with observed deposition at selected sites.

Volume, duration, and frequency of precipitation events have obvious roles in determining wet deposition rates. However, those parameters alone do not completely describe all the characteristics of a precipitation event. In particular, the intersection of a precipitation event and a volume of air with a particular history is estimated by the wet deposition model to have greater relevance to observations at a wet deposition monitor than local and regional emissions in determining wet deposition flux. For this reason, the interactions between storm trajectories and emission sources were incorporated into the model.

Using metrological data from the National Center for Environmental Prediction's North American Regional Reanalysis (NARR), variables were added to daily ammonium and nitrate wet deposition models that predict the rate at which emissions from area and point sources are dispersed and transported to specific deposition locations. Surface and upper-level vertical and horizontal air movement data from the NARR allowed estimates of the extent to which emissions were transported and mixed into surface and upper-level atmospheric layers; and, thereby, enabled construction of more realistic multi-level air mass trajectories with which to predict the movement of emissions from multiple source locations to deposition points of interest (Grimm and Lynch, 2000, 2005).

#### *3.11.2.2 CMAQ Model Community Multiscale Air Quality Model (CMAQ)*

The CMAQ Model that was applied for Phase 6 was a fully developed, one-atmosphere air simulation model of the North American continent. The CMAQ Model has more than 1,000 users worldwide and has been applied in many countries (Byun and Schere, 2006; Dennis et al. 2007; Hameedi et al. 2007). Byun and Schere (2006) review the governing equations and computational algorithms of the Community Multiscale Air Quality (CMAQ) modeling system, including the simulation approach for wet deposition. A description of the CMAQ dry deposition simulation can be found in Pleim and Ran (2011).

The CMAQ version used in this application was version 5.0.2 using MM5 model output with unidirectional ammonia simulation (Grell et al. 1994). The mesoscale model MM5 is a terrain-following sigma-coordinate model designed to simulate mesoscale atmospheric circulation. The CMAQ Model simulates deposition to the Chesapeake watershed (indirect deposition) and tidal Bay (direct deposition) for every hour of every day for a climatically representative year. To calculate nitrogen deposition budgets CMAQ needs to be a one-atmosphere model incorporating (1) photochemistry of nitrogen oxides (NOx) and volatile organic compounds (VOCs) to produce ozone and oxidized nitrogen products, (2) gas- and aqueous-phase oxidation of sulfur dioxide to create sulfuric acid, (3) particle thermodynamics and physics to treat ammonia neutralization of acids that partitions the atmospheric species of nitrogen between gases (which rapidly deposit) and particles (which slowly deposit), and (4) cloud, wet scavenging, and aqueous chemistry processes for wet deposition.

A variety of input files are needed that contain information pertaining to the modeling domain, which is the entire continental US, northern Mexico, and southern Canada. They include hourly emissions estimates and meteorological data in every grid cell, pollutant concentrations to initialize the model, and pollutant concentrations along the modeling domain boundaries. The CMAQ grid cells in this application are generally 36-km grid in size across the US but have a nested finer grid of 12-km in size across the eastern US covering the Chesapeake airshed and containing the watershed Figure 3-27. The initial and boundary concentrations were obtained from output of a global chemistry model, GEOS-Chem (Bey, et al. 2001).

A 12-km grid was used to provide better resolved atmospheric deposition loads to the watershed and Bay. The improved spatial resolution of direct deposition loads to tidal waters as well as the deposition loads to the watershed adjacent to tidal waters from metropolitan and mobile sources was an important improvement (STAC, 2007) and allowed better tracking of the deposition fate of these emissions.

The CMAQ Model simulation period is for the years 2002 to 2012. CMAQ Model dry deposition outputs were used to estimate the monthly dry deposition for all years of the 1985 to 2014 simulation period of the Chesapeake Bay watershed and tidal estuary models. This was done for each watershed model land segment by adjusting oxidized nitrogen dry deposition load for the years using a linear regression analysis of the annual CMAQ dry deposition and wet deposition of nitrate estimates as described in Section **Error! Reference source not found.**. Linear regression analysis did not yield good explanatory performance for the reduced nitrogen dry deposition, therefore pre-2002 estimates were held at the average annual level of 2002-2004, and CMAQ data were used for rest of the period. Estimated annual dry deposition input for the watershed model land segments were disaggregated into monthly time step based on the seasonality curves for the land segments derived from the CMAQ Model dry deposition outputs. Similar regression analyses were performed for the estuary as a whole. Further considerations were given to not use land deposition in the estimation of dry deposition for the Bay open water, as in general dry deposition on the land are higher than on the water. Given the 12-km resolution of CMAQ grid, this was particularly important for the accuracy of estimated dry depositions for the narrow tributaries. The resulting monthly dry deposition inputs were expressed as a daily load to watershed model land segments and estuarine model grid cells.

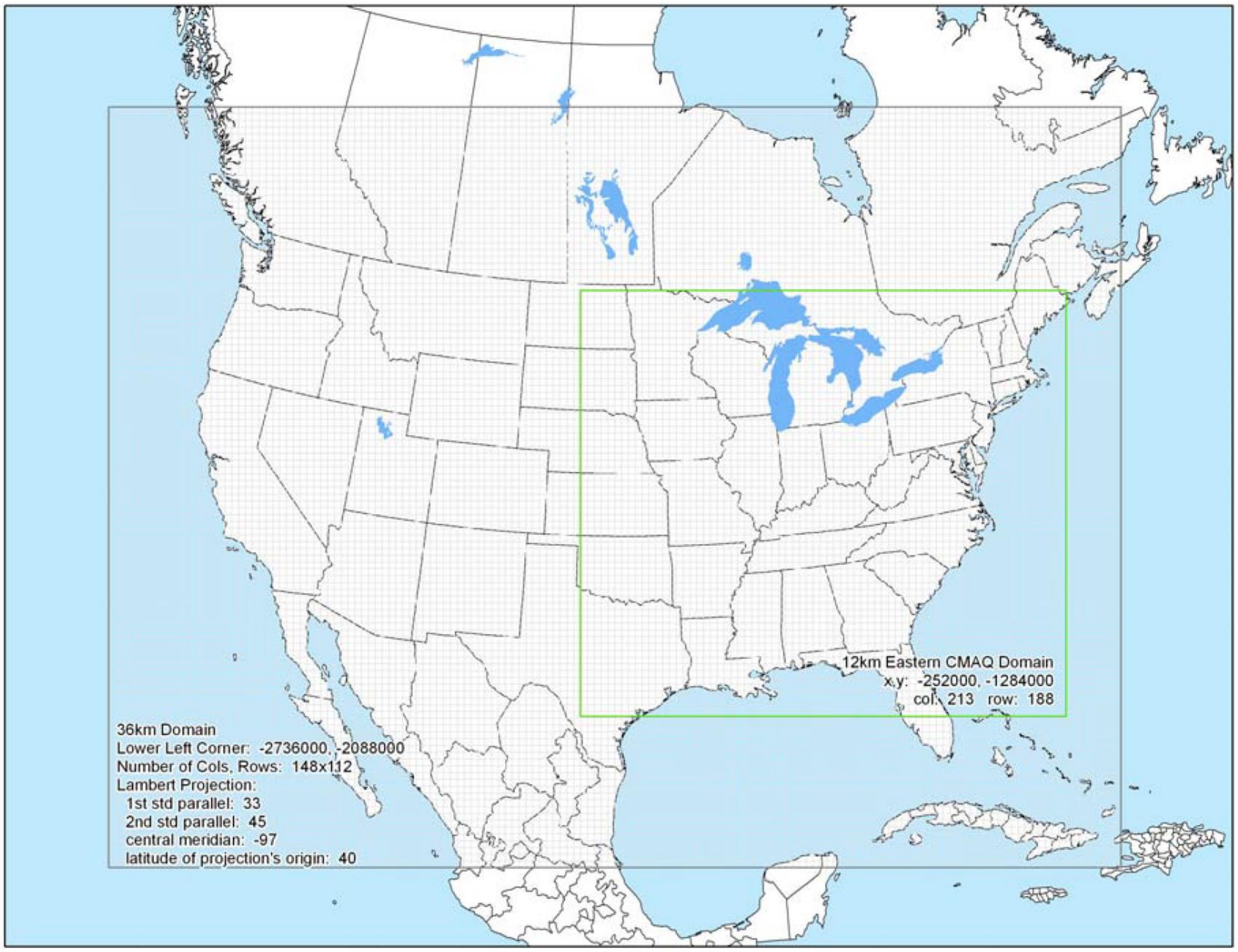



*Figure 3-27: CMAQ modeling domain and the grid cells (Figure 4-1 from Dimmick et al. 2002). The box shown in gray color is the 36-km national model domain, whereas the box shown in green color is the finer 12-km Eastern US.*

#### 3.11.2.3 Organic Nitrogen Deposition

Organic nitrogen loads are a complex and significant source of nitrogen atmospheric deposition to the Chesapeake (Scudlark et al. 1998; Cape et al. 2011). Estimated loads of atmospheric organic nitrogen are to surface waters of the watershed and Bay only, because it is assumed that all organic nitrogen is derived from aeolian processes, which result in no net change in organic nitrogen on terrestrial surfaces but do result in a net gain when deposited on water surfaces. Organic nitrogen atmospheric deposition loads are primarily represented as wet fall only, i.e., dissolved organic nitrogen (DON). The magnitude of dry fall organic nitrogen is less well characterized (Neff et al. 2002). Organic nitrogen deposition loads are considered to be uncontrollable loads, which are unaltered by any Chesapeake management practices except in the limited case of peroxyacyl nitrates (PAN, CH3COOONO2) and an organic nitrate group in the CMAQ simulation involved in products of NOx photochemistry as discussed below.

#### 3.11.2.3.1 Wetfall Organic Nitrogen Deposition

Organic nitrogen measurements from Bermuda (Knap et al. 1986) are calculated at about 100 µg/l (as N). Mopper and Zika (1987) reported an average DON concentration from the western Atlantic and Gulf of Mexico of about 100 µg/l (as N). That is consistent with the reported range from the North Sea and northeast Atlantic of 90 µg/l to 120 µg/l (Scudlark and Church, 1993). Scudlark et al. (1998) report an annual volume weighted average DON concentration in the mid-Atlantic coastal areas to be about 130 µg/l (as N). Measurements in that study are consistent with the interannual variation (maximum in spring) reported by Smullen et al. (1982). A later study identified methodological problems with some of the previous studies and suggests the wet deposition of organic nitrogen in the Chesapeake watershed would be closer to 50 µg/l on an annual average basis (Keene et al. 2002). That study also documents the highest concentrations of organic nitrogen in the spring.

The approach CBP has taken is to use 50 µg/l (as N) as representative of an average annual wet deposition concentration to the watershed and tidal waters with the seasonal loading pattern suggested by Smullen et al. (1982) and Scudlark et al. (1998). That applies an average concentration of 40 µg/l from July to March in rainfall and an average concentration of 80 µg/l from April to June. The load of organic nitrogen would depend on the precipitation, but assuming 100 centimeters of precipitation, the load would be on the order of 0.45 kg/ha-yr.

#### 3.11.2.3.2 Dryfall Organic Nitrogen Deposition

Other than measurements of peroxyacyl nitrates (PAN) there are few measurements of dry deposition of organic N (Neff et al. 2002). The CMAQ simulations used in the Chesapeake TMDL have updated chemical mechanisms that include peroxyacyl nitrates (PAN, CH3COOONO2) and an organic nitrate group (NTR) as products of NOx photochemistry. The NTR represents several organic nitrates (such as alkyl nitrate) that are produced from ozone photochemistry. Both of these deposition loads are relatively small in magnitude, and both are biologically labile and available. Therefore, the dryfall PAN and NTR are lumped into the oxidized nitrogen atmospheric deposition dryfall inputs (Dennis et al. 2007).

### *3.11.2.4 Organic and Inorganic Phosphorus Deposition*

Organic and inorganic phosphorus deposition loads are considered to be uncontrollable, and are unaltered by any Chesapeake management practices, but because they contribute to the overall Chesapeake phosphorus loads and eutrophication they are quantified as inputs to water surfaces. Estimated loads of atmospheric organic and inorganic phosphorus are accounted for as an input to surface waters of the watershed and tidal Bay on the assumption that, like organic nitrogen, the load is derived from aeolian processes, which result in no net change in organic phosphorus on terrestrial surfaces but do result in a net gain when deposited on water surfaces. Following Smullen et al. (1982), loads of wetfall deposited organic and inorganic phosphorus average annual loads are consistent with constant concentrations of 47 µg/l and 16 µg/l, respectively, applied to the volume of precipitation of every simulated hour, resulting in approximately 0.35 kg/ha and 0.11 kg/ha of organic and inorganic phosphorus load to the waterbodies.

Seasonally, those loads are treated in the same way as organic nitrogen, assuming that organic phosphorus will follow a pattern similar to organic nitrogen and that an aeolian source of inorganic phosphorus could well increase during the spring due to exposure and tillage of bare soil by agricultural practices. Accordingly, organic and inorganic phosphorus concentrations are set at 74 µg/l and 25 µg/l, respectively, from April to June, and at half those concentrations for the other nine months of the year. The values are selected such that the average annual loads are the same for the Chesapeake Bay watershed as the application of a constant concentration.

The airshed model is the combination of the regression model of wet deposition and CMAQ estimates of dry deposition. The three-decade 1985 to 2014 time series of daily wet deposition atmospheric deposition loads were developed by using the wet deposition regression model of daily inputs. The daily estimated wet deposition loads were input into the Phase 6 Dynamic Watershed Model as aliquots for each month of precipitation on land and each hour of precipitation on water. See Section 10 for more details.

Combining the daily time series of wet deposition from the regression model and the monthly time series of dry deposition from CMAQ provided the means to generate atmospheric deposition nutrient loads to the Chesapeake watershed and tidal Bay consistent with the long term trends, as well as the seasonal variation in loads due to dry deposition and event-scale variation in loads due to wet deposition.

### 3.11.3 Coastal Ocean Loads of Nitrogen Deposition

The CMAQ Model domain extending out into the Atlantic Ocean provides estimates of atmospheric deposition loads to the coastal ocean at the mouth of the Chesapeake Bay. Coastal ocean nutrient budgets have been made (Fennel et al. 2006; Howarth et al. 1995; Howarth, 1998). Howarth (1998) reported that atmospheric deposition loads are roughly equivalent to watershed loads in the northeast United States (Maine to Virginia) and estimated that the watershed inputs of nitrogen to the northeast coastal waters to be 0.27 teragrams. Inputs from direct atmospheric deposition to coastal waters were estimated to be 0.21 teragrams, and inputs from deep ocean upwelling estimated to be 1.54 teragrams, for a total input to the coastal ocean of 2.02 teragrams (Howarth 1998).

To determine CMAQ estimates of atmospheric deposition to the coastal ocean region that affects nitrogen loads to the Chesapeake through ocean/Bay exchange, boundaries were assigned to approximate the region of exchanged waters. The assigned boundary is about 150 km off the Atlantic shore and west of the Gulf Stream, and extends north to include all of the New Jersey shoreline and south to include all of Virginia's shoreline (USEPA, 2010c, appendix L). To account for the prevailing north to south current along the coast, the coastal ocean boundary includes more of the coastal waters north of the Chesapeake Bay mouth (USEPA, 2010c, appendix L).

Atmospheric deposition total nitrogen loads to the coastal ocean are estimated to be about 6.63 kg/ha in the CMAQ 2002 average year 2002. That correlates to 43.8 million kilograms of total nitrogen deposition to a region of the ocean estimated to exchange waters with the Chesapeake. In the case of the 2020 Maximum Feasible scenario, the nitrogen atmospheric deposition to the same region is estimated to be 29.4 million kilograms, a reduction of 32 percent. If that same reduction is extrapolated to the coastal ocean, the direct atmospheric inputs to the coastal ocean would decrease to 0.14 teragram. Assuming the watershed loads discharged to the ocean and the deep upwelling pelagic loads are constant, that would give a combined watershed, direct deposition, and uncontrollable deep upwelling load of 1.95 teragrams, a decrease of 3 percent relative to the estimated current ocean boundary condition. This approach was used to estimate the relative change in ocean boundary conditions for the 6 key CMAQ scenarios (USEPA, 2010c, appendix L).