SECTION 5. NONPOINT SOURCE NUTRIENT INPUTS

Contents

Figures

Tables

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5.1 Overview of the Nonpoint Source Nutrient Inputs

In the Phase 5.3 Model, the three key nonpoint source nutrient inputs are atmospheric deposition, manure inputs, and fertilizer inputs. Point sources and septic systems, which also contribute nutrient loads, are covered in Section 7. The trends in those key inputs over the 2-decade simulation period vary (Figure 5-1 and 5-2). Point source and atmospheric deposition loads are estimated on an annual basis.

Fertilizer and manure loads are estimated at 5-year intervals over the 1985–2005 Phase 5.3 simulation period in *Estimates Of County-Level Nitrogen and Phosphorus Data for Use in Modeling Pollutant Reduction: Documentation for Scenario Builder Version 2.2* (USEPA 2010). Scenario Builder Version 2.2 is a Phase 5.3 auxiliary tool designed for rapid scenario development so users can understand the impacts of best management practices and land use change, as well as develop more effective nutrient and sediment management strategies.

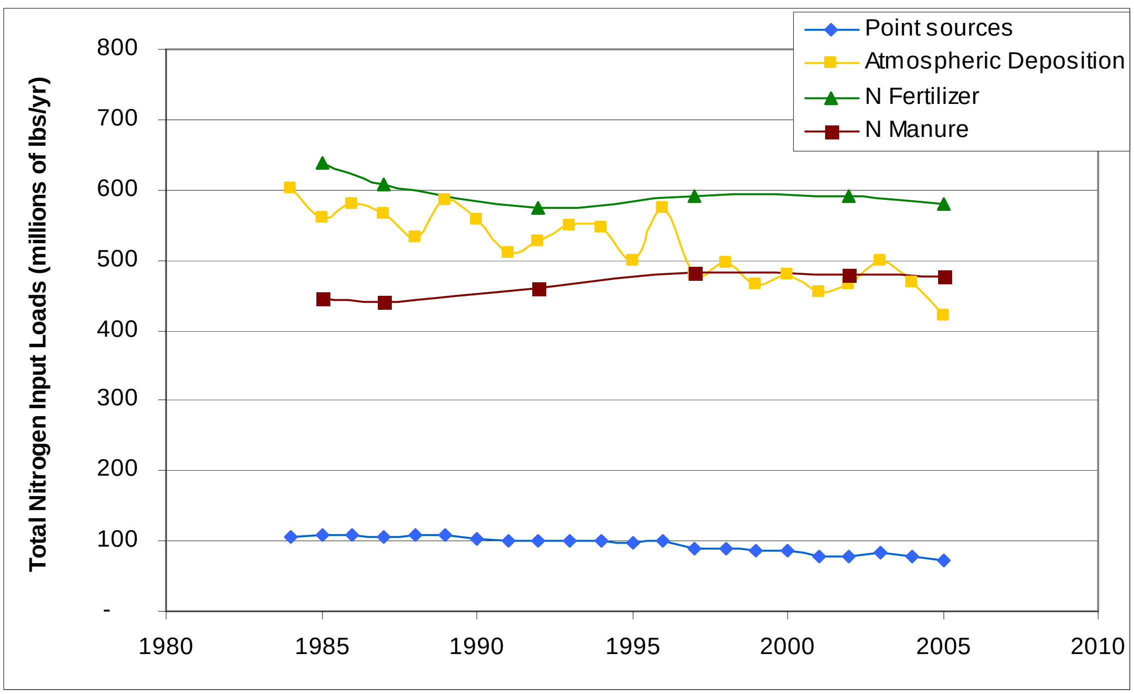


Figure 5-1. Time series of atmospheric, fertilizer, manure, and point source total nitrogen input loads to the Chesapeake Bay Watershed Model (Phase 5.3 calibration).

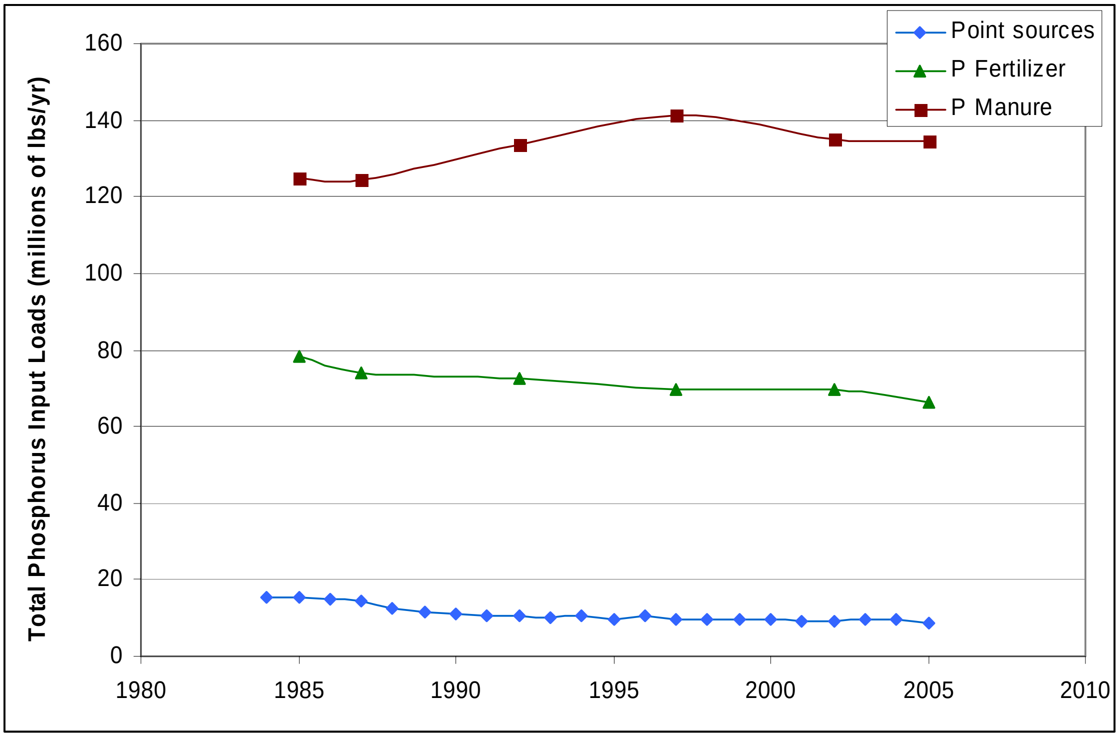


Figure. 5-2. Time series of fertilizer, manure, and point source total phosphorus input loads to the entire domain of the Chesapeake Bay Watershed Model (Phase 5.3 calibration).

Over the 1985 to 2005 Phase 5.3 simulation period, the Chesapeake watershed average atmospheric deposition loads of nitrogen have been declining, particularly for oxidized nitrogen.

Manure inputs are relatively constant over the simulation period, although shifts have occurred in the types of manure, with cattle decreasing in the northern portions of the watershed and poultry increasing in some coastal plain and Piedmont areas, such as the Eastern Shore and the Shenandoah Valley over the 20-year period. Overall in the Phase 5.3 Model, fertilizer inputs have been variable but trending downward over the 1985 to 2005 simulation period.

Another major input of nitrogen comes from crops that are nitrogen-fixing legumes such as soybeans and timothy hay. Annually, those legume crops add about an additional 71.2 million pounds of year of nitrogen to the watershed (legume nitrogen loads not shown in Figure 5-1).

Estimated point source inputs over the Phase 5.3 Model domain also have a downward trend, particularly in the later years of the simulation period. The estimated relative nitrogen, phosphorus, and sediment percent loads by source delivered to the Chesapeake Bay in 2007 are shown in Figures 5-3, 5-4, and 5-5.

2007 Scenario - Total Nitrogen Delivered to the Bay (millions of pounds per year)

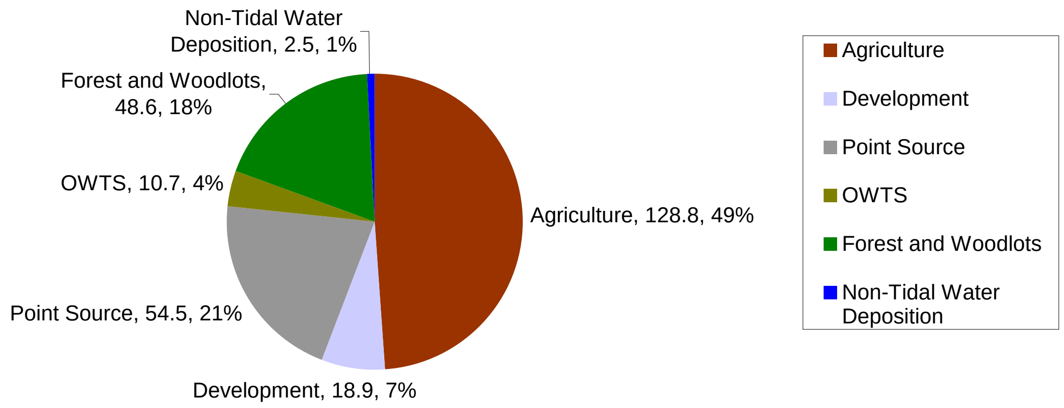


Figure 5-3. Estimated total nitrogen loads delivered to the Bay from major sources of the 2007 Scenario. The major source title is followed by millions of pounds nitrogen for the source and then by the percent of the total. The total nitrogen delivered to the Bay for the 2007 Scenario is 264 million pounds. (OWTS = on-site wastewater treatment systems or septic systems).

2007 Scenario - Total Phosphorus Delivered to the Bay (millions of pounds per year)

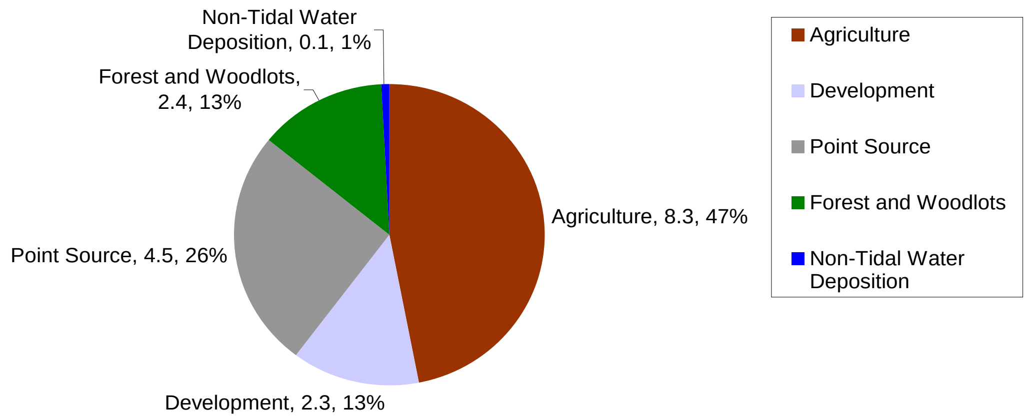


Figure 5-4. Estimated total phosphorus loads delivered to the Bay from major sources of the 2007 Scenario. The source title is followed by millions of pounds phosphorus and then by the percent of the total. Total phosphorus delivered to the Bay for the 2007 Scenario is 17.8 million pounds.

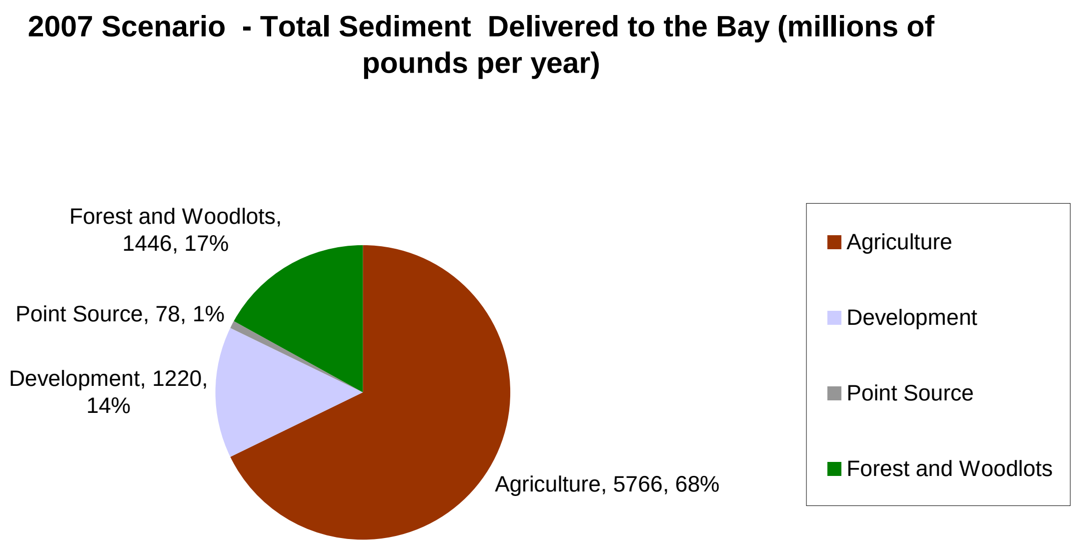


Figure 5-5. Estimated total suspended sediment loads delivered to the Bay from major sources of the 2007 Scenario. The source title is followed by millions of pounds sediment and then by the percent of the total. Total suspended sediment delivered to the Bay for the 2007 Scenario is 8,510 million pounds.

Tables 5-1 and 5-2 list the annual average calibration loads of nitrogen and phosphorus, respectively, for all the Phase 5.3 land uses in the Chesapeake watershed as total delivered loads to tidal waters.

Overall average annual nitrogen inputs to the Chesapeake watershed estimated in Phase 5.3 are about 1.6 billion pounds from the totals of fertilizers, manures, legumes, and atmospheric deposition. The average annual nitrogen loads delivered to the Bay in the calibration scenario are about 270 million pounds or only about 16 percent of the total inputs once the input load of about 100 million pounds of nitrogen from point sources is taken into account. Attenuation of the nitrogen input loads is due to plant uptake, denitrification, storage of organic nitrogen in soils, and other loss mechanisms.

Overall average annual phosphorus inputs to the Phase 5.3 watershed are about 214 million pounds from the total inputs of fertilizers, manures, and atmospheric deposition as well as about 10 million pounds from point source discharges. An estimated 18.7 million of pounds of phosphorus were delivered to the Bay in 2004 or about 9 percent of the input phosphorus. The primary loss mechanism for phosphorus is sorption and storage in soils and watershed storage in deposition zones such as reservoirs.

Tables 5-3 and 5-4 are the annual average input of nitrogen and phosphorus respectively to each overall average landuse acre. Forest, harvested forest, and impervious urban lands for example receive no manure of fertilizer inputs, only atmospheric deposition. On the other hand, high-till and low till with manure land uses receives nutrients from all sources including fertilizers, manures, legumes, and atmospheric deposition.

Table 5-1. Total annual average nitrogen calibration inputs for Phase 5.3 land uses in the Chesapeake watershed . Units in millions of pounds.

Land use	Fertilizer	Manure	Legume	Atmospheric Deposition
forest	0.0	0.0	0.0	356.8
harvested forest	0.0	0.0	0.0	3.6
low intensity pervious urban	75.9	0.0	0.0	23.9
high intensity pervious urban	11.1	0.0	0.0	3.7
construction	0.0	0.0	0.0	0.4
extractive	0.0	0.0	0.0	1.8
pasture	0.0	223.1	0.0	32.9
degraded riparian pasture	0.0	50.8	0.0	1.4
nursery	0.0	0.0	0.0	0.0
alfalfa	0.0	0.0	0.0	9.6
hay with nutrients	121.4	32.9	0.4	16.0
hay without nutrients	0.0	0.0	0.0	8.2
high-till without manure	32.0	0.0	7.5	3.4
high-till with manure	109.6	47.5	24.3	21.6
low-till with manure	96.2	35.7	23.3	20.2
nutrient management hay	17.0	7.1	0.1	2.8
nutrient management pasture	0.0	11.6	0.0	1.5
nutrient management alfalfa	0.0	0.0	0.0	1.8
nutrient management high-till without manure	5.8	0.0	1.9	0.7
nutrient management high-till with manure	23.5	9.0	5.8	5.1
nutrient management low-till	28.9	9.6	7.9	6.6
animal feeding operations	0.0	43.6	0.0	0.4
low intensity impervious urban	0.0	0.0	0.0	3.8
high intensity impervious urban	0.0	0.0	0.0	4.9
combined sewer system	0.0	0.0	0.0	2.7
water	0.0	0.0	0.0	5.6
TOTAL	**521.4**	**471.0**	**71.2**	**539.2**

Table 5-2. Total annual average phosphorus calibration inputs for Phase 5.3 land uses in the Chesapeake watershed.. Units in millions of pounds.

Land use	Fertilizer	Manure	Atmospheric Deposition
forest	0.0	0.0	17.1
harvested forest	0.0	0.0	0.2
low intensity pervious urban	2.3	0.0	1.0
high intensity pervious urban	0.3	0.0	0.2
construction	0.0	0.0	0.0
extractive	0.0	0.0	0.1
pasture	0.0	57.1	1.6
degraded riparian pasture	0.0	12.3	0.1
nursery	0.0	0.0	0.0
alfalfa	4.4	0.0	0.4
hay with nutrients	4.8	11.3	0.7
hay without nutrients	0.0	0.0	0.4
high-till without manure	6.0	0.0	0.2
high-till with manure	12.5	15.9	0.9
low-till with manure	13.2	12.9	0.9
nutrient management hay	0.6	2.5	0.1
nutrient management pasture	0.0	2.9	0.1
nutrient management alfalfa	0.7	0.0	0.1
nutrient management high-till without manure	1.2	0.0	0.0
nutrient management high-till with manure	3.0	3.2	0.2
nutrient management low-till	4.6	3.3	0.3
animal feeding operations	0.0	13.6	0.0
low intensity impervious urban	0.0	0.0	0.2
high intensity impervious urban	0.0	0.0	0.2
combined sewer system	0.0	0.0	0.1
water	0.0	0.0	0.3
TOTAL	**53.8**	**134.9**	**25.2**

Table 5-3. Annual average nitrogen calibration inputs for the Chesapeake watershed in the Phase 5.3 watershed model. Units in pounds per acre.

Land use	Fertilizer	Manure	Legume	Atmospheric Deposition
forest	0.00	0.00	0.00	12.81
harvested forest	0.00	0.00	0.00	12.81
low intensity pervious urban	45.50	0.00	0.00	14.31
high intensity pervious urban	45.59	0.00	0.00	14.98
construction	0.00	0.00	0.00	14.69
extractive	0.00	0.00	0.00	13.28
pasture	0.00	86.25	0.00	12.73
degraded riparian pasture	0.00	436.22	0.00	12.30
nursery	54.02	0.00	0.00	14.83
alfalfa	0.00	0.00	0.00	13.73
hay with nutrients	97.57	26.43	0.31	12.84
hay without nutrients	0.00	0.00	0.00	13.28
high-till without manure	130.62	0.00	30.69	13.95
high-till with manure	72.30	31.34	16.04	14.26
low-till with manure	69.10	25.67	16.74	14.52
nutrient management hay	85.24	35.47	0.42	13.88
nutrient management pasture	0.00	112.12	0.00	14.26
nutrient management alfalfa	0.00	0.00	0.00	14.96
nutrient management high-till without manure	120.70	0.00	39.00	15.03
nutrient management high-till with manure	70.05	26.99	17.33	15.18
nutrient management low-till	65.12	21.65	17.85	14.79
animal feeding operations	0.00	1590.22	0.00	13.87
low intensity impervious urban	0.00	0.00	0.00	14.27
high intensity impervious urban	0.00	0.00	0.00	15.02
combined sewer system	0.00	0.00	0.00	14.19

Table 5-4. Annual average phosphorus calibration inputs for the Chesapeake watershed in the Phase 5.3 watershed model. Units in pounds per acre.

Land use	Fertilizer	Manure	Atmospheric Deposition
forest	0.00	0.00	0.61
harvested forest	0.00	0.00	0.61
low intensity pervious urban	1.37	0.00	0.62
high intensity pervious urban	1.37	0.00	0.62
construction	0.00	0.00	0.62
extractive	0.00	0.00	0.63
pasture	0.00	22.06	0.60
degraded riparian pasture	0.00	105.43	0.59
nursery	31.40	0.00	0.62
alfalfa	6.36	0.00	0.60
hay with nutrients	3.82	9.10	0.60
hay without nutrients	0.00	0.00	0.61
high-till without manure	24.40	0.00	0.61
high-till with manure	8.23	10.46	0.62
low-till with manure	9.46	9.27	0.62
nutrient management hay	3.15	12.28	0.60
nutrient management pasture	0.00	27.99	0.61
nutrient management alfalfa	6.33	0.00	0.61
nutrient management high-till without manure	25.75	0.00	0.62
nutrient management high-till with manure	9.03	9.47	0.62
nutrient management low-till	10.49	7.51	0.62
animal feeding operations	0.00	497.07	0.61
low intensity impervious urban	0.00	0.00	0.62
high intensity impervious urban	0.00	0.00	0.62
combined sewer system	0.00	0.00	0.62

5.2 Atmospheric Deposition Inputs

Atmospheric loads of nitrogen are from chemical species of oxidized nitrogen, also called NO_x, and from reduced forms of nitrogen deposition, also called ammonia (NH_4^+). Oxidized forms of nitrogen deposition originate from conditions of high heat and pressure and are formed from eutrophicly inert diatomic atmospheric nitrogen. The principle sources of NO_x are industrially sized boilers, such as electric power plants (stationary sources), and the internal combustion engines in cars, trucks, locomotives, airplanes, and the like (mobile sources). Ammonia deposition originates from largely agricultural sources, predominately manures but also volatilization of ammonia from fertilizers. All nitrogen loads from oxidized and reduced nitrogen atmospheric deposition are estimated (using the CMAQ 36-km grid, see below for details) to be about 49 percent from sources in the watershed states and 51 percent from sources beyond the watershed.

Wet and dry deposition are two other types of deposition that are tracked in the Phase 5.3 Model and input daily. Wet deposition occurs during precipitation events and contributes to the loads only during days of rain or snow. Dry deposition occurs continuously and is input at a constant rate every day. Minor deposition sources also simulated as inputs in the Phase 5.3 Model include organic nitrogen, phosphorus, and inorganic phosphorus.

5.2.1 Atmospheric Deposition Input Trends

Between 1985 and 2005, the simulation period of the Phase 5.3 Watershed Model, wet atmospheric deposition loads of nitrate have tended to decrease overall in the Chesapeake watershed and in the Phase 5.3 domain generally. Over that 20-year period wet deposition nitrate loads decreased by about 30 percent (Figure 5-6); however, there is considerable variability across the Phase 5.3 domain with the greatest reductions occurring in the northern and western portions. In Figure 5-6 the average annual concentration of nitrate, ammonia, and dissolved inorganic nitrogen (DIN) is used as an adjustment to smooth out the high and low rainfall years, which bring different amounts of deposition load to the watershed primarily because of the volume of precipitation. Use of wet deposition nitrate, ammonia, and DIN concentrations provides a reasonable estimate of the overall trend in atmospheric deposition.

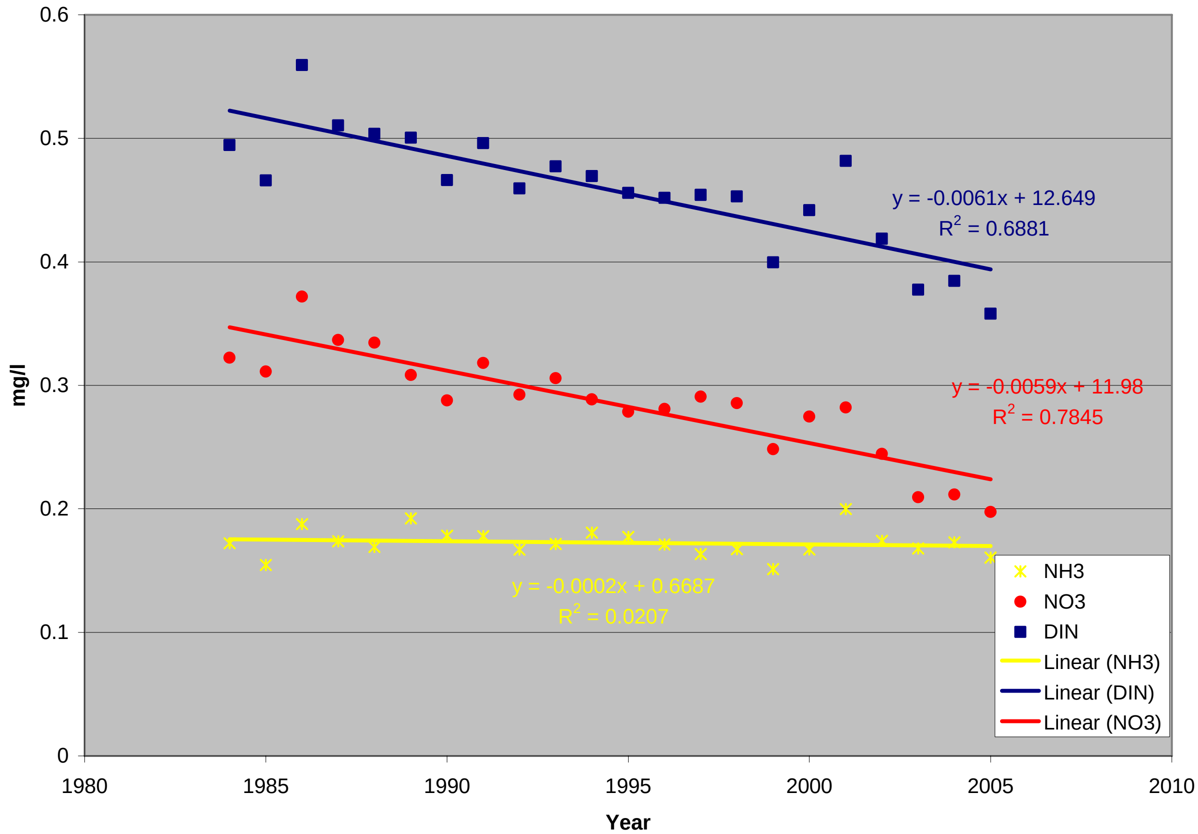


Figure 5-6. Trend of estimated average nitrate and ammonia deposition concentrations to the Phase 5.3 domain.

Much of the reduction has been due to point source air emission reductions, particularly from Electric Generating Units (EGUs) as shown in Figure 5-7. Further, more rapid declines are expected between 2008 to 2010 as the Clean Air Transport Rule (previously the Clean Air Interstate Rule) controls on power plant emissions and the air quality standards for ozone and particulate matter come into enforcement deadlines by 2010 (Figure 5-7). Further reductions are expected with the reduced ozone air quality standard expected in July 2011. Reductions from mobile sources are another large contributor to the downward trend. Reductions from mobile sources will continue past the year 2020 as large off-road diesel and marine diesel fleets are replaced.

Table 5-5 shows the estimated portion of deposited NO_x loads on the Chesapeake watershed from four sectors including EGUs, mobile sources, industry, and all other sources. From 1990 to 2020, considerable reductions have been made in the power sector. In addition, both on-road and off-road mobile sources have ongoing fleet turnover and replacement, which is putting cleaner spark and diesel engines in service, and that is expected to continue beyond 2030. Note that some sources like mobile sources seem to increasing in percentage relative to other sources like EGUs.

Both sources are actually decreasing, and the total deposition load in 2020 is less than 1990, 1990; however, EGU emission reductions are relatively more than mobile reductions.

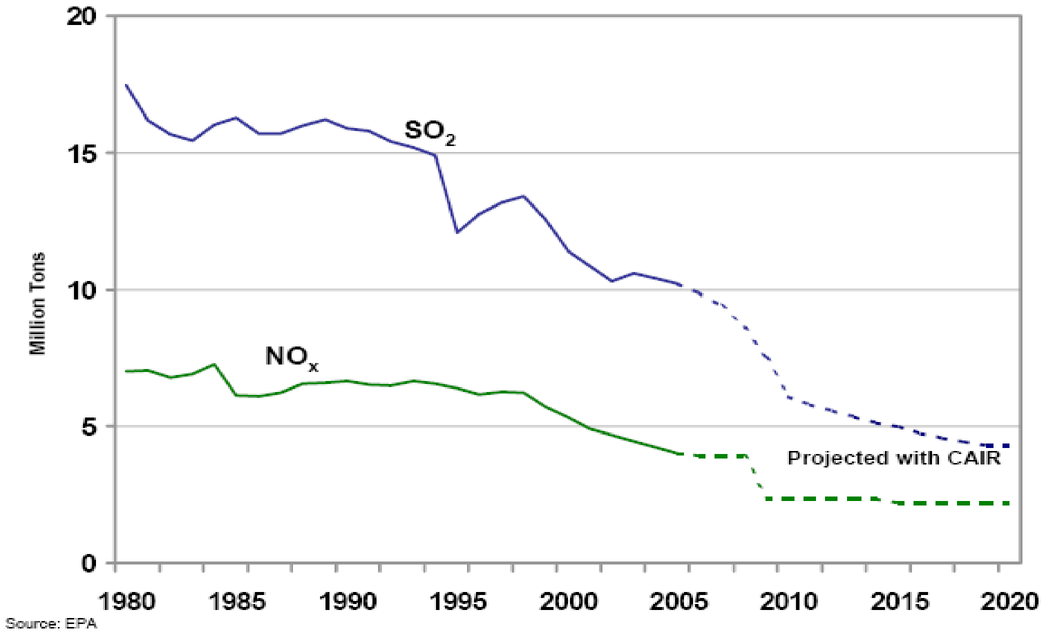


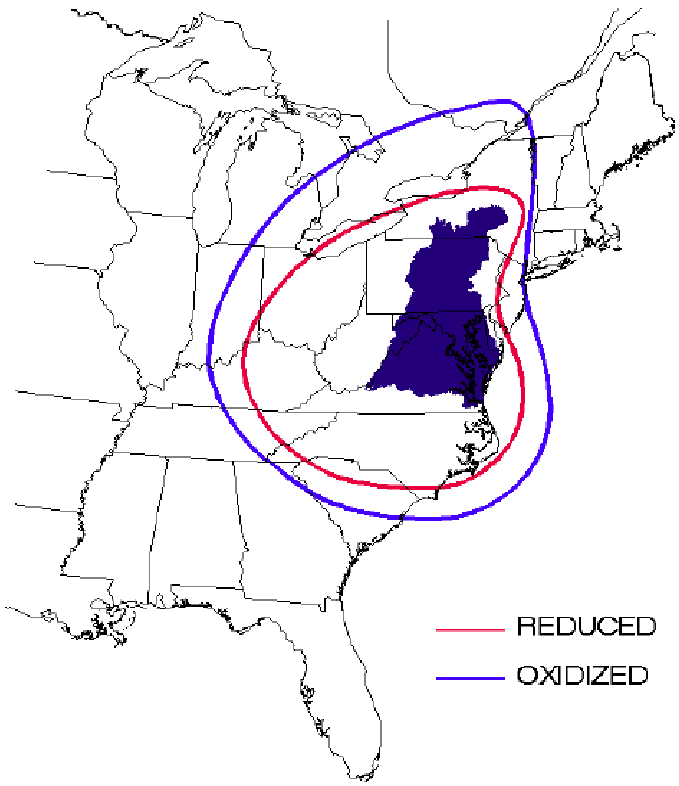
Figure 5-7. Estimated nationwide emissions of NO_x and SO_2 from EGUs since 1980 and estimated emissions to 2020.

Average ammonia loads over the Phase 5.3 domain have followed the trend in overall manure loads in the watershed and have remained steady over the 1985 to 2000 simulation period (Figure 5-6: NH_3 – yellow line, x symbol). Ammonia deposition is relatively site-specific and strongly influenced by local emissions. Local and regional trends in manure, such as the rise of poultry animal units in the Eastern Shore and Shenandoah and dairy's diminishment in the northern portions of the watershed in the late 1980s, affect regional ammonia deposition in the Phase 5.3 domain.

Table 5-5. Estimated portion of deposited NO_x loads on the Chesapeake watershed from four sectors including EGUs, mobile sources, industry, and all other sources in 1990 and 2020

Watershed		
	1990	2020 Preliminary
Power Plants (EGU's)	40%	17%
Mobile Sources (on-road)	30%	32%
Industry	8%	20%
Other (off-road-construction; residential & commercial)	21%	31%

The Bay's NO_x airshed—the area where emission sources that contribute the most airborne nitrates to the Bay originate—is about 570,000 square miles, or seven times the size of the Bay's watershed (Dennis 1997; Paerl et al. 2002). Close to 50 percent of the nitrate deposition to the Bay is from air emission sources in Bay watershed states. Another 25 percent of the atmospheric deposition load to the Chesapeake watershed is from the remaining area in the airshed, and the remaining 25 percent of deposition is from the area outside the airshed. The ammonia airshed is similar to the NO_x airshed but slightly smaller (Figure 5-8).



Source: U.S. EPA ORD/NERL

Figure 5-8. The oxidized nitrogen airshed (blue line) is the principle area of NO_x emissions that contribute nitrogen deposition to the Chesapeake Bay and its watershed. The reduced nitrogen airshed (red line) of ammonia deposition is slightly smaller.

5.2.2 CBP Airshed Model

The Chesapeake Bay Program Airshed Model is a combination of a regression model of wet deposition (Grimm and Lynch 2007), and a continental-scale air quality model of North America called the Community Multiscale Air Quality Model (CMAQ) for estimates of dry deposition (Dennis et al. 2007; Hameedi et al. 2007). The CBP Airshed Model is represented in Figure 5-9.

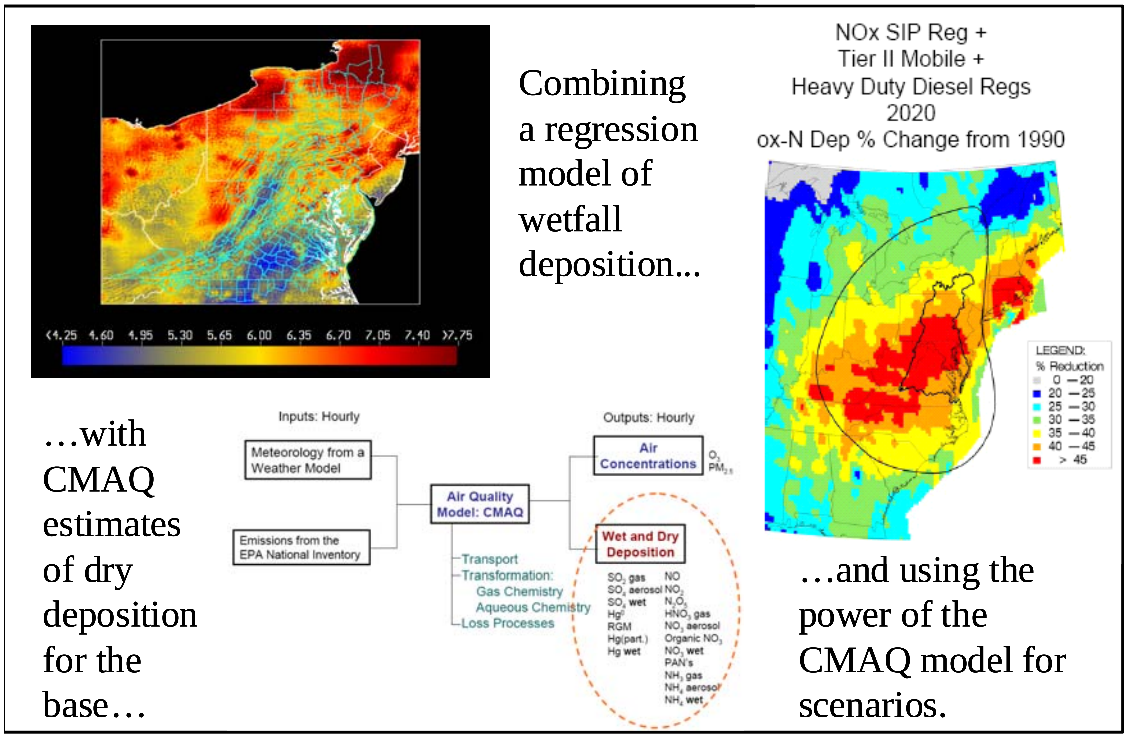


Figure 5-9. The CBP Airshed Model combining a regression model of wet deposition and the CMAQ Model of dry deposition.

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; Grimm and Lynch, 2000, 2005; Lynch and Grimm 2003).). The amount and timing of the wet atmospheric deposition input in the Phase 5.3 Model is hourly, and is related to the timing and amount of hourly rainfall in the Phase 5.3 precipitation input data. The dry deposition estimates are monthly constants that are input daily and are based on CMAQ (Dennis et al. 2007; Hameedi et al. 2007).

5.2.3 Wet Deposition Regression Model

Wet deposition is simulated using a regression model developed by Grimm and Lynch (2000, 2005; Lynch and Grimm 2003). The regression model provides hourly wet deposition loads to each land-segment based on each land-segment's rainfall. The regression model uses 29 National Atmospheric Deposition Program (NADP) monitoring stations and 6 AirMoN[a] stations to form a regression of wetfall deposition in the entire Phase 5.3 Model Domain over the entire simulation period (Figure 5-10).

a. AIRMoN joined NADP in 1992 and has seven sites. Samples are collected daily within 24 hours of the start of precipitation, often providing data for all or part of a single storm. Single-storm data facilitate studies of atmospheric processes and developing and testing computer simulations of those processes. Making data available for these studies is a principal AIRMoN goal: http://nadp.sws.uiuc.edu/airmon/

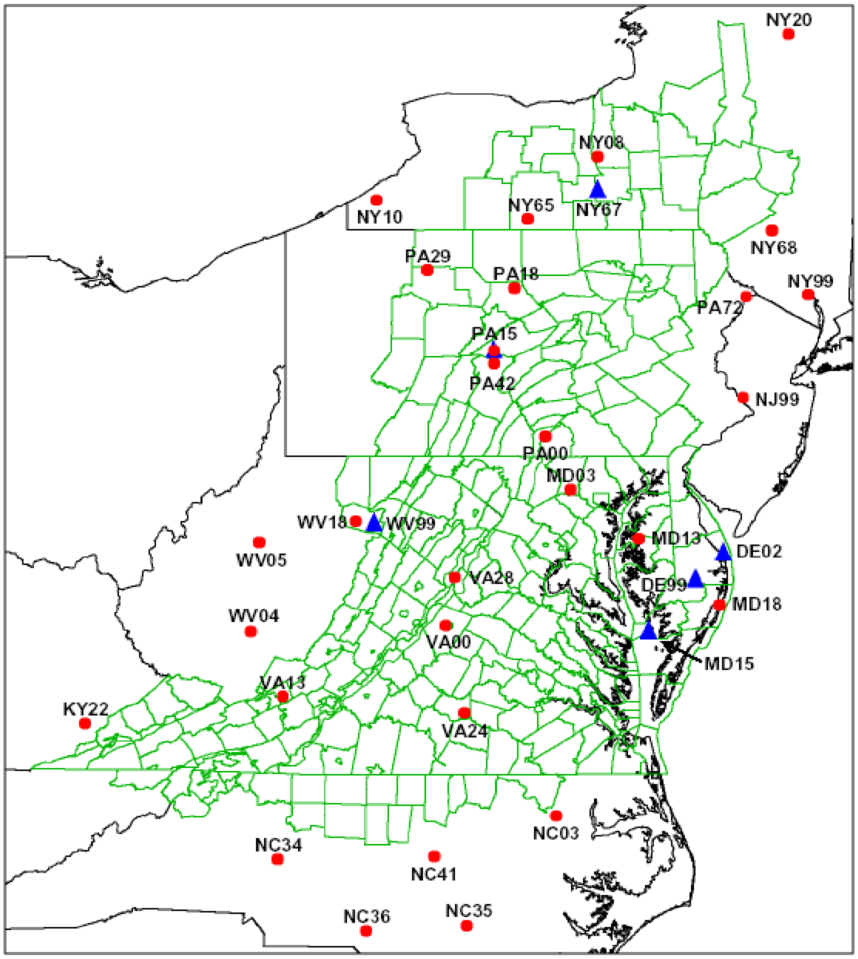


Figure 5-10. Atmospheric deposition monitoring stations used in the airshed regression model.

To improve the accuracy of the regression estimates over previous regression analyses (Linker 2000) 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.

This version of the regression model included nine additional National Atmospheric Deposition Program/National Trends Network (NADP/NTN) sites in the regression estimates (DE99, MD07, MD08, MD15, MD99, PA47, VA10, VA27, VA98, and VA99) that were placed in operation in and around the Chesapeake Bay watershed since 2001. The sites provided a more complete representation of agricultural influences than the station set used in the earlier analyses.

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 Phase 5.3 domain. An improved accounting of livestock production activities was achieved by combining county- and watershed unit-specific livestock production statistics with high-resolution (30 meters) 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 high-resolution NLCD to identify likely cropland areas. Last, localized estimates NH_3 and NO_x emissions for the Phase 5.3 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.

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

$$\mathbf{Log10(c) = b_o + b_1 log10(ppt) + 3b_{2s} season + b_3 v_3 + \ldots + b_n v_n + e}$$

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
$v_3 \,.\,.\, V_n$ = 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.
- Local emission levels of ammonia and nitrous oxides from EPA National Emission Trends (NET)
  - County emission totals 1985-2005
  - County containing each NADP/NTN monitoring site and for the nearest 3 counties

$b_3 \,.\,.\, b_n$ = coefficients corresponding to $v_3 \,.\,.\, V_n$

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 29 NADP/NTN sites and 6 AirMon 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. (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 either (1) the spatial and temporal distribution of emissions of ammonium and nitrate precursors from sources within or upwind of the Phase 5.3 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 also important in determining wet deposition flux, so the interactions between storm trajectories and emission sources were also 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 emitted, 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).

5.2.4 Dry Deposition—Community Multiscale Air Quality Model (CMAQ)

The CMAQ Model is a fully developed air simulation of the North American continent (Dennis et al. 2007; Hameedi et al. 2007). CMAQ simulates deposition to the Chesapeake watershed (indirect deposition) and tidal Bay (direct deposition) for every hour of every day for the representative year. A variety of input files are needed that contain information pertaining to the modeling domain, which is the entire North American continent. They include hourly emissions estimates and meteorological data in every grid cell as well as a set of pollutant concentrations to initialize the model and to specify concentrations along the modeling domain boundaries. The initial and boundary concentrations were obtained from output of a global chemistry model.

The CMAQ Model simulation period is for one year, 2002, with the 2002 year characterized as an average deposition year. The 2002 CMAQ simulation year was used to provide the monthly dry deposition estimate for all years of the 1985 to 2005 Phase 5.3 simulation. Phase 5.3 dry deposition input estimates are derived from the Community Multiscale Air Quality Model as monthly average inputs expressed as a daily load (USEPA 1999).

An adjustment for the 20-year trend in atmospheric deposition loads was applied by using the trend developed in the wet deposition regression model and assuming the dry deposition trend to be the same as the wet in the separate nitrate and ammonia estimates.

Figure 5-11 shows the 12-km grid used to provide better resolution of Phase 5.3 atmospheric deposition loads. 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).

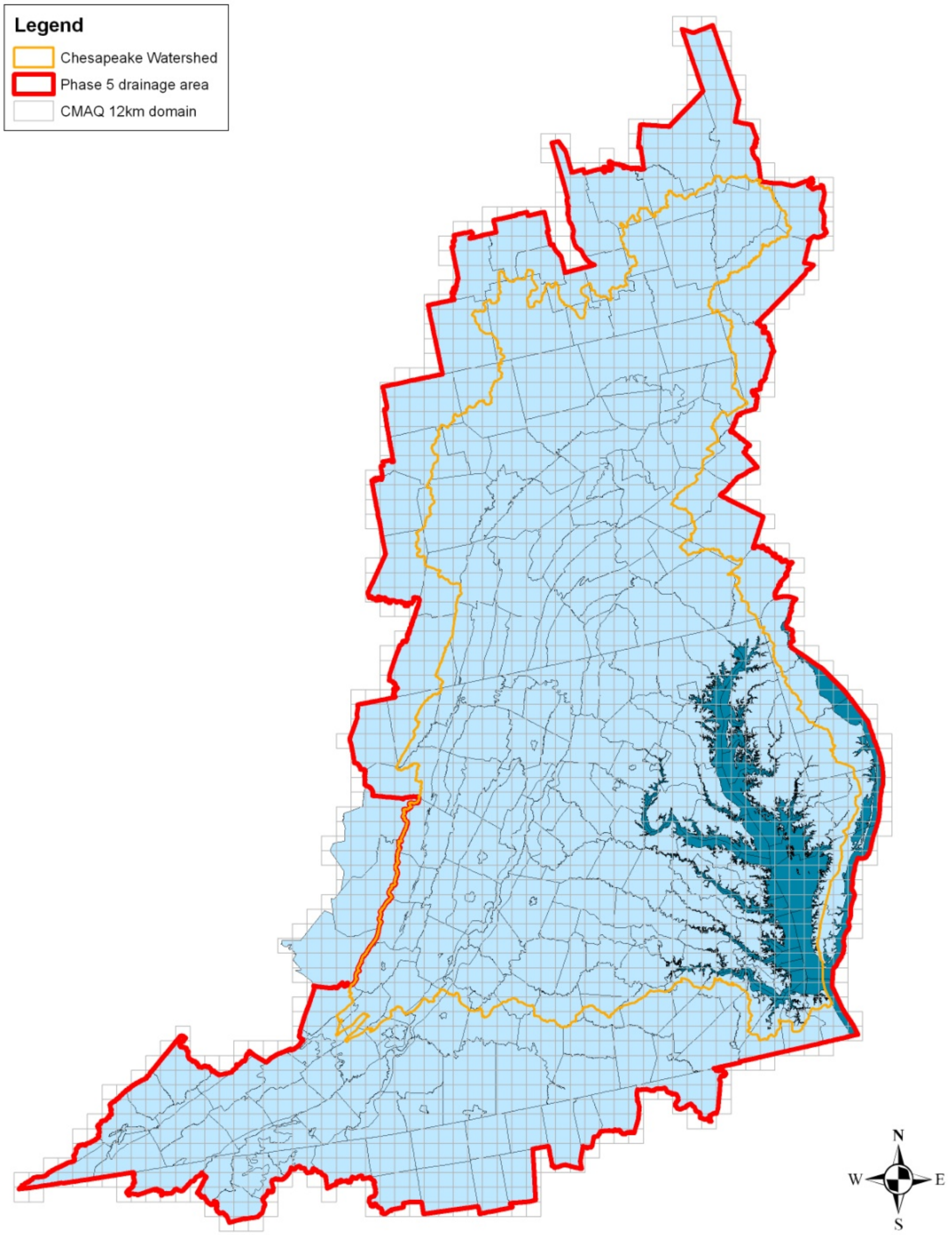


Figure 5-11. The CMAQ 12-km grid over the Phase 5.3 domain.

5.2.5 Organic Nitrogen Deposition

The Phase 5.3 Model accounts for estimated loads of atmospheric organic nitrogen to the *open water* land use only, on the assumption 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 is represented as wet fall only, i.e., dissolved organic nitrogen (DON). The magnitude of dry fall organic nitrogen is unknown.

5.2.5.1 Dryfall Organic Nitrogen Deposition

The dryfall organic nitrogen is likely to be sorbed onto large and small particles or even to be particles themselves, like pollen. The dryfall organic carbon species can be involved in long-range transport, as the pollens and organic nitrates found on the dust coming over from Africa, but the CBP does not have a good estimate of the fraction of the dry deposition the particles compose.

Also, the latest CMAQ simulations with updated chemical mechanisms do include peroxyacyl nitrates **(**PAN, $CH_3COOONO_2$) and an organic nitrate group (NTR). The NTR represents several organic nitrates that are produced from ozone photochemistry. Both of those species are relatively small in magnitude, and both are biologically labile and is easily available to the biology. Therefore, the dryfall PAN and NTR are lumped into the oxidized nitrogen atmospheric deposition dryfall inputs.

5.2.5.2 Wetfall Organic Nitrogen Deposition

In the 1992 Phase 2 version of the Watershed Model, organic nitrogen was assumed to be about 670 µg/l (as N) on the basis of data summarized by Smullen et al. (1982). The data showed considerable seasonal variability. The organic nitrogen load was constant in all watershed model segments. An equivalent annual load was used in the tributary model with application of the seasonal variability suggested by Smullen et al.

Organic nitrogen measurements from Bermuda are calculated at about 100 micrograms per liter (µg/l) (as N) (Knap et al. 1986) (Knap et al. 1986). 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 between 90 µg/l to 120 µg/l (Scudlark and Church 1993). A recent study reports an annual volume weighted average DON concentration in the mid-Atlantic coastal areas to be about 130 µg/l (as N) (Scudlark et al. 1996). 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. (1996). 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 in a land-segment, but assuming 40 inches of precipitation, the load would be on the order of 0.4 lb/ac-yr.

5.2.6 Total Atmospheric Deposition Inputs of Nitrogen from Wet and Dry Deposition

The annual average rate of total nitrogen atmospheric deposition to the Phase 5.3 calibration land-segments is shown in Figure 5-12. Table 5-6 is an excerpt of a table listing the entire atmospheric deposition inputs that can be found in the Phase 5.3 Model Data Library: http://ches.communitymodeling.org/models/CBPhase5/datalibrary/model-input.php.

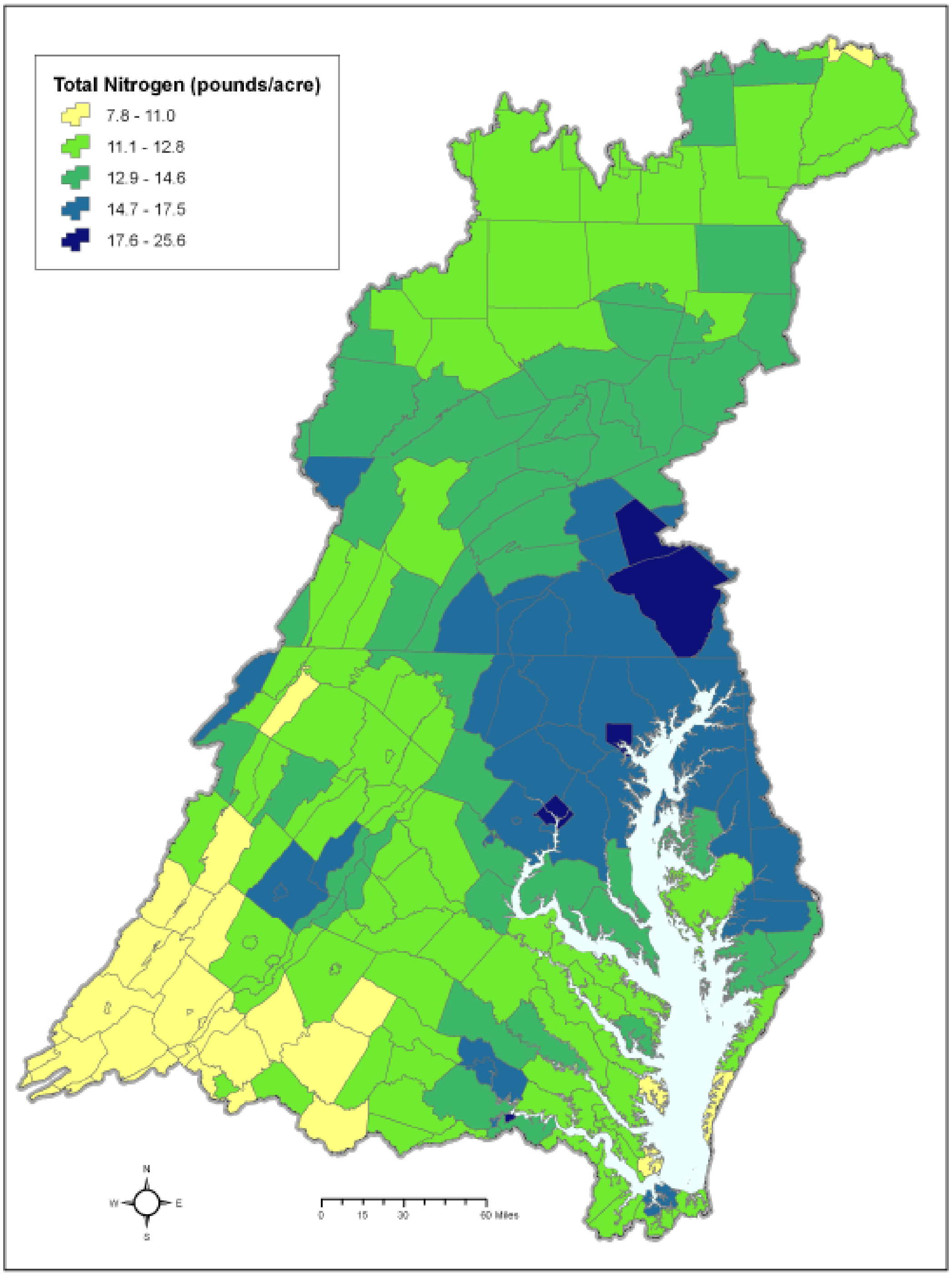


Figure 5-12. Annual average total nitrogen atmospheric deposition to the Phase 5.3 Calibration Scenario (1984-2005). Units in pounds/acre-year.

Table 5-6. Annual average atmospheric deposition of reduced DIN, oxidized DIN and total DIN on land-segments in the entire Phase 5.3 Model domain. The full table is available from the Phase 5.3 Model Data Library: http://ches.communitymodeling.org/models/CBPhase5/datalibrary/model-input.php.

Land-Segment	NH4	NO3	Total DIN
A10001	2.50	3.21	**5.71**
A10003	1.68	2.87	**4.55**
A10005	5.62	4.55	**10.16**
A11001	0.24	0.44	**0.68**
A24001	0.41	1.37	**1.78**
A24003	1.02	2.99	**4.01**
A24005	2.02	4.42	**6.44**
A24009	0.40	1.29	**1.69**
A24011	1.60	1.64	**3.25**
C51071	0.17	0.53	**0.69**
C51165	0.45	0.28	**0.72**
TOTAL	**264.07**	**556.59**	**820.66**

5.2.7 Organic and Inorganic Phosphorus Deposition

The Phase 5.3 Model accounts for estimated loads of atmospheric organic and inorganic phosphorus to the *open water* land use on the assumption that, like organic nitrogen, the load 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. Following Smullen et al. (1982), loads of wet deposition organic and inorganic phosphorus are from constant concentrations of 47 µg/l and 16 µg/l, respectively, applied to the volume of precipitation at any simulated hour. 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 bare ground of spring 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.

5.2.8 CMAQ Airshed Scenarios

The CMAQ Model also provides estimates of nitrogen deposition resulting from changes in emissions from utility, mobile, and industrial sources due to management actions or growth. For the CMAQ Model, the base deposition year is 2002 and scenarios include the management actions required by the Clean Air Act in 2010, 2020, and 2030. The future year scenarios reflect emissions reductions from national control programs for both stationary and mobile sources, including the following:

- Clean Air Interstate Rule
- Tier-2 Vehicle Rule
- Nonroad Engine Rule
- Heavy-Duty Diesel Engine Rule
- Locomotive/Marine Engine Rule

Although the Clean Air Interstate Rule (CAIR) has been remanded to EPA, it will remain in place pending a rulemaking to replace it. It unclear how the replacement rule (Transport Rule) will compare to the remanded rule. However, EPA anticipates that NO_x emissions reductions close to those originally projected will occur.

To develop a Watershed Model scenario using one of the CMAQ Model air scenarios below, a monthly factor is determined by CMAQ by comparing the CMAQ atmospheric deposition loads in the scenario year to the CMAQ 2002 Base year. The CMAQ scenario factor is then used to adjust the base atmospheric deposition conditions of both wet and dry deposition in Phase 5.3 over the simulation period of the scenario.

5.2.8.1 CMAQ 2010 Scenario

The 2010 Scenario represents emission reductions because of regulations implemented through the Clean Air Act authority to meet National Ambient Air Quality standards for criteria pollutants in 2010. That includes National/Regional and available State Implementation Plans (SIPs) for NO_x reductions. Other components of the 2010 Scenario include Tier 1 vehicle emission standards reaching high penetration in the vehicle fleet for on-road, light-duty mobile sources along with Tier 2 vehicle emission standards, which were fully phased in by the 2006 model year and will in 2010 begin to show an impact. For EGUs, the 2010 controls assume that the NO_x SIP call, NO_x Budget Trading Program, and the CAIR program that regulates the ozone season NO_x are all in place and that the CAIR program is designed for annual NO_x reductions to match the ozone season reductions under the 2010 CAIR first phase conditions.

5.2.8.2 CMAQ 2020 Scenario

The 2020 Scenario has all components of the 2010 Scenario and includes the Clean Air Mercury Rule (CAMR), the Best Available Retrofit Technology (BART) used for reducing regional haze and the off-road diesel and heavy-duty diesel regulations. The 2020 Scenario represents emission reductions due to regulations implemented through the Clean Air Act authority to meet National Ambient Air Quality standards for criteria pollutants in 2020. Those include the following:

- On-Road mobile sources: For on-road light duty mobile sources, this includes Tier 2 vehicle emissions standards and the Gasoline Sulfur Program that affects SUVs, pickups, and vans, which are now subject to same national emission standards as cars.
- On-Road Heavy Duty Diesel Rule – Tier 4: New emission standards on diesel engines starting with the 2010 model year for NO_x, plus some diesel engine retrofits.
- Clean Air Non-Road Diesel Rule: Off-road diesel engine vehicle rule, commercial marine diesels, and locomotive diesels (phased in by 2014) require controls on new engines.
- Off-road large spark ignition engine rules affect recreational vehicles (marine and land based).
- EGUs: CAIR second phase in place (in coordination with earlier NO_x SIP call); Regional Haze Rule and guidelines for BART for reducing regional haze; CAMR all in place.
- Non-EGUs: Solid Waste Rules (Hospital/Medical Waste Incinerator Regulations).

5.2.8.3 CMAQ 2020 Maximum Feasible Scenario

The 2020 Maximum Feasible Scenario includes additional aggressive EGU, industry, and mobile source controls. Emissions projections were developed that represented incremental improvements and control options (beyond 2020 CAIR) that might be available to states to meet a more stringent ozone standard. The more stringent standard is due to a reconsideration of the

National Ambient Air Quality standards for ozone that were promulgated in 2008 along with a review of the secondary National Ambient Air Quality standards for oxides of nitrogen and sulfur. The new 2010 ozone standard will be announced at the close of July 2011 and is expected to be between 0.070 parts per million (ppm) and 0.060 ppm. The 2020 Maximum Feasible Scenario was designed to meet a 0.070 ppm ozone standard, which is less than the 0.075 ppm ozone standard in place since 2008.

Incremental control measures for five sectors were developed:

- EGUs: lower ozone season nested emission caps in Ozone Transport Commission states; targeting use of maximum controls for coal fired power plants in or near nonattainment areas.
- Non-EGU point sources: new supplemental controls, such as low NO_x burners, plus increased control measure efficiencies on planned controls and step up of controls to maximum efficiency measures, e.g., replacing SNCRs (Selective Non-Catalytic Reduction) with SCRs (Selective Catalytic Reduction) control technology.
- Area (nonpoint area) sources: switching to natural gas and low sulfur fuel.
- On-Road mobile sources: increased penetration of diesel retrofits and continuous. inspection and maintenance using remote onboard diagnostic systems.
- Non-Road mobile sources: increased penetration of diesel retrofits and engine rebuilds.
- Reduced NO_x emissions from marine vessels in coastal shipping lanes.

The 2020 Maximum Feasible Scenario also includes a reduction of ammonia deposition of 15 percent because of estimated ammonia emission programs in the Bay Program states. Estimates of up to about 30 percent ammonia emission reductions from manures can be achieved through rapid incorporation of manures in to soils at the time of application, biofilters on poultry houses, and other management practices (Mark Dubin 2009, personal communication). From a state and sector analysis of NO_x emissions and deposition, an estimated 50 percent of emissions from Bay states becomes deposition to the Chesapeake watershed, along with a further 50 percent of the ammonia deposition load coming from outside the watershed. Assuming only 50 percent of the emissions is from watershed sources, a 30 percent reduction of emissions results in an estimated 15 percent decrease in wet and dry ammonia deposition for the Maximum Feasible Scenario from ammonia emission control management practices in the Bay Program states.

5.2.8.4 CMAQ 2030 Scenario

The 2030 scenario is in some areas a further decrease in emissions beyond the 2020 Maximum Feasible Scenario due to continuing fleet replacement of heavy diesels, off-road diesels, and of mobile sources of all types. The emission decreases are offset by continued growth in the Chesapeake region. The emissions projections assume continued stringent controls are in place, such as the following:

- Tier 2 vehicle emissions standards fully penetrated in the fleet.
- Heavy Duty Diesel vehicle fleet fully replaced with newer heavy-duty vehicles that comply with new standards.
- On-Road mobile sources: Increased penetration of diesel retrofits maintained.
- Non-Road mobile sources capped at 2020 Maximum Feasible Scenario levels.
- EGUs and Non-EGUs emissions capped at 2020 Maximum Feasible Scenario levels.

- Area sources emissions capped at 2020 Maximum Feasible Scenario levels, assuming energy efficiency and control efficiencies keep up with growth.
- Further reductions in NO_x emissions from marine vessels in coastal shipping lanes.

5.2.8.5 Indirect Atmospheric Deposition Loads to the Watershed

Nitrogen loads deposited to the Chesapeake watershed by state and by nitrogen species of wet and dry deposition for key scenarios are tabulated in Table 5-7. Table 5-7 lists the loads delivered to the Bay from the key scenarios, in millions of pounds, using the Phase 5.2 - August 2009 Version of the Watershed Model.

All the scenarios in Table 5-7 use 2002 as their base year. The point sources, human and animal populations, and septic system loads and so on, are at the same 2002 levels in all the scenarios, only the atmospheric deposition changes. The 1985 CMAQ Scenario uses the trend of atmospheric deposition described in Figure 5-6, and the same trend was used for the 2002 atmospheric deposition in the 2002 Scenario. The scenarios of 2010, 2020, 2020 Maximum Feasible, and 2030 used estimated atmospheric deposition loads from CMAQ.

Table 5-7 shows the estimated total nitrogen delivered loads to the Bay by the 9 major basins of the Chesapeake under different key CMAQ atmospheric deposition scenarios. All of the CMAQ atmospheric deposition scenarios were applied to a 2002 Base condition of land use, BMPs, and point source discharges in order to show the relative effect of changing atmospheric deposition loads only in the watershed.

Table 5-8. Atmospheric deposition loads of nitrogen to the Chesapeake watershed for key scenarios by state units in millions of pounds as N (Phase 5.2 - August 2009 Version). This table does not include the 15 percent decrease in wet and dry ammonia deposition for the Maximum Feasible Scenario due to ammonia emission control management practices in the Bay Program states described in 5.2.8.3.

	STATE							Chesapeake
Total Nitrogen	**DE**	**DC**	**MD**	**NY**	**PA**	**WV**	**VA**	**Watershed**
1985 Scenario	7.8	0.8	97.4	53.7	221.7	30.6	179.8	591.8
1985-2000 Calibration	7.1	0.7	84.0	46.0	192.2	26.2	159.3	515.4
2002 Scenario	6.5	0.6	73.0	39.5	167.3	22.5	142.3	451.6
2010 Scenario	6.3	0.5	59.6	30.6	133.3	17.2	112.8	360.2
2020 Scenario	6.6	0.4	54.6	26.2	117.6	15.3	99.9	320.6
2020 Maximum Feasible	6.5	0.4	51.9	24.8	111.2	14.5	95.0	304.3
2030 Scenario	7.4	0.4	56.9	26.1	121.4	15.4	100.0	327.6
Dry NOx Deposition								
1985 Scenario	3.1	0.5	51.0	23.1	102.1	15.7	97.5	293.0
1985-2000 Calibration	2.6	0.4	42.2	19.2	84.9	13.1	83.2	245.4
2002 Scenario	2.2	0.3	35.2	16.2	71.3	10.9	71.8	207.8
2010 Scenario	1.6	0.2	23.1	10.8	46.2	6.7	46.7	135.4
2020 Scenario	1.3	0.1	16.6	7.9	32.5	4.8	33.3	96.5
2020 Maximum Feasible	1.1	0.1	14.3	6.9	28.2	4.2	29.6	84.5
2030 Scenario	1.0	0.1	13.7	6.7	27.0	4.1	28.9	81.6
Dry NH_3 Deposition								
1985 Scenario	2.1	0.1	12.2	5.0	25.3	2.9	18.2	65.8
1985-2000 Calibration	2.2	0.1	12.1	4.7	25.3	2.8	18.5	65.7
2002 Scenario	2.3	0.1	12.1	4.5	25.4	2.8	18.7	65.7
2010 Scenario	3.0	0.1	15.8	5.3	32.0	3.7	24.8	84.7
2020 Scenario	3.7	0.1	18.7	5.6	36.5	4.4	29.2	98.3
2020 Maximum Feasible	3.9	0.1	19.4	5.8	37.2	4.5	29.8	100.7
2030 Scenario	4.8	0.1	23.9	6.6	45.5	5.2	34.0	120.3
Wet NOx Deposition								
1985 Scenario	1.6	0.1	22.2	17.0	63.4	8.1	42.0	154.4
1985-2000 Calibration	1.3	0.1	17.9	13.9	51.7	6.6	35.4	126.9
2002 Scenario	1.1	0.1	14.1	11.0	40.9	5.2	29.4	101.8
2010 Scenario	0.7	0.1	9.4	7.3	26.7	3.4	19.6	67.2
2020 Scenario	0.6	0.0	7.2	5.3	19.3	2.5	14.7	49.6
2020 Maximum Feasible	0.5	0.0	6.4	4.7	16.9	2.2	13.3	44.1
2030 Scenario	0.5	0.0	6.2	4.6	16.7	2.2	13.0	43.3
Wet NH_3 Deposition								
1985 Scenario	0.9	0.1	12.0	8.7	30.9	3.9	22.0	78.6
1985-2000 Calibration	1.0	0.1	11.8	8.2	30.3	3.7	22.3	77.4
2002 Scenario	1.0	0.1	11.7	7.8	29.7	3.6	22.5	76.4
2010 Scenario	1.0	0.1	11.3	7.3	28.3	3.5	21.7	73.0
2020 Scenario	1.0	0.1	12.0	7.4	29.2	3.6	22.7	76.1
2020 Maximum Feasible	1.0	0.1	11.8	7.4	28.9	3.6	22.4	75.1
2030 Scenario	1.1	0.1	13.0	8.1	32.2	3.9	24.1	82.4

Table 5-9. Total nitrogen delivered to the Bay under different key CMAQ atmospheric deposition scenarios which are all applied to a 2002 Base condition of land use, BMPs, and point source discharges in order to show the relative effect of changing atmospheric deposition loads only in the watershed. (Units in millions of pounds as N; Phase 5.2 - August 2009 Version). This table does not include the 15 percent decrease in wet and dry ammonia deposition for the Maximum Feasible Scenario due to ammonia emission control management practices in the Bay Program states described in 5.2.8.3.

Basins	CMAQ Atmo. Deposition 1985 Scenario	CMAQ Atmo. Deposition 2002 Scenario	CMAQ Atmo. Deposition 2010 Scenario	CMAQ Atmo. Deposition 2020 Scenario	CMAQ Atmo. Deposition 2020 Maximum Feasible Scenario	CMAQ Atmo. Deposition 2030 Scenario
Susquehanna	160.4	148.1	141.4	138.7	137.6	139.3
West Shore	15.7	15.3	15.07	15.0	14.9	15.0
Potomac	77.0	72.2	69.4	68.3	67.9	68.6
Patuxent	4.8	4.5	4.4	4.3	4.3	4.3
Rappahannock	11.0	9.8	10.0	9.8	9.8	9.8
James	37.9	36.7	35.6	35.2	35.	35.1
York	9.3	8.9	8.6	8.4	8.4	8.4
East Shore MD-DE	31.6	29.8	29.2	29.2	29.1	29.7
East Shore VA	3.0	2.9	2.8	2.8	2.8	2.8
Total	**350.7**	**328.1**	**316.5**	**311.7**	**309.7**	**313.0**

Figure 5-13 and Figure 5-14 show cumulative distribution functions of the Phase 5.3 atmospheric deposition input for the key scenarios. In the plots, the inputs to all the land-segments are shown for different scenarios ranging from the high load scenario of 1985 to the low load E3 Scenario. Nitrogen atmospheric deposition to the watershed ranges from 4 to 27 pound per acre per year over all land-segments and scenarios with the lowest cumulative distribution for the E3 Scenario and the highest for the 1895 Scenario. The atmospheric deposition loads for the Tributary Strategy Scenario are the same as the input loads used in the 2010 TMDL Allocation Target Scenario which are not shown in Figure 5-13 and Figure 5-14.

Phosphorus atmospheric deposition ranges from 0.4 to 0.8 pound per acre per year and is constant for all scenarios. As described previously, 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. Because those concentrations are constant, the load changes to the different land-segments are caused by only the amount of precipitation in the land-segments. Phosphorus atmospheric deposition loads are only to water surfaces as previously described.

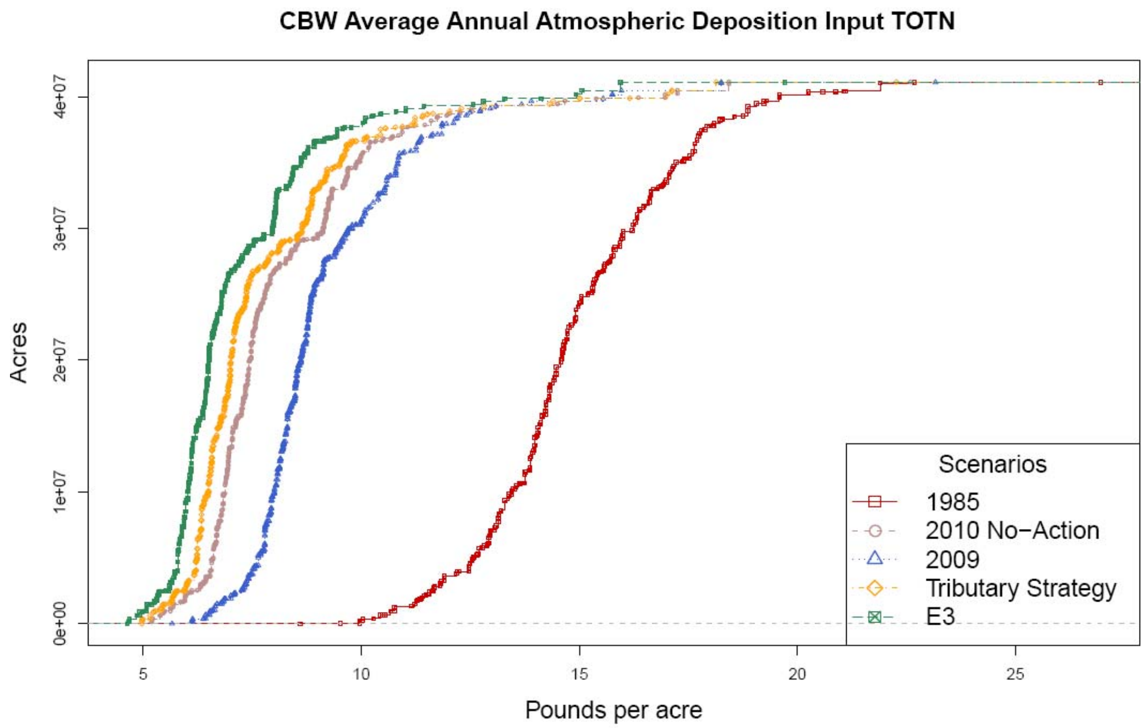


Figure 5-13. Annual total nitrogen atmospheric deposition input for the key scenarios.

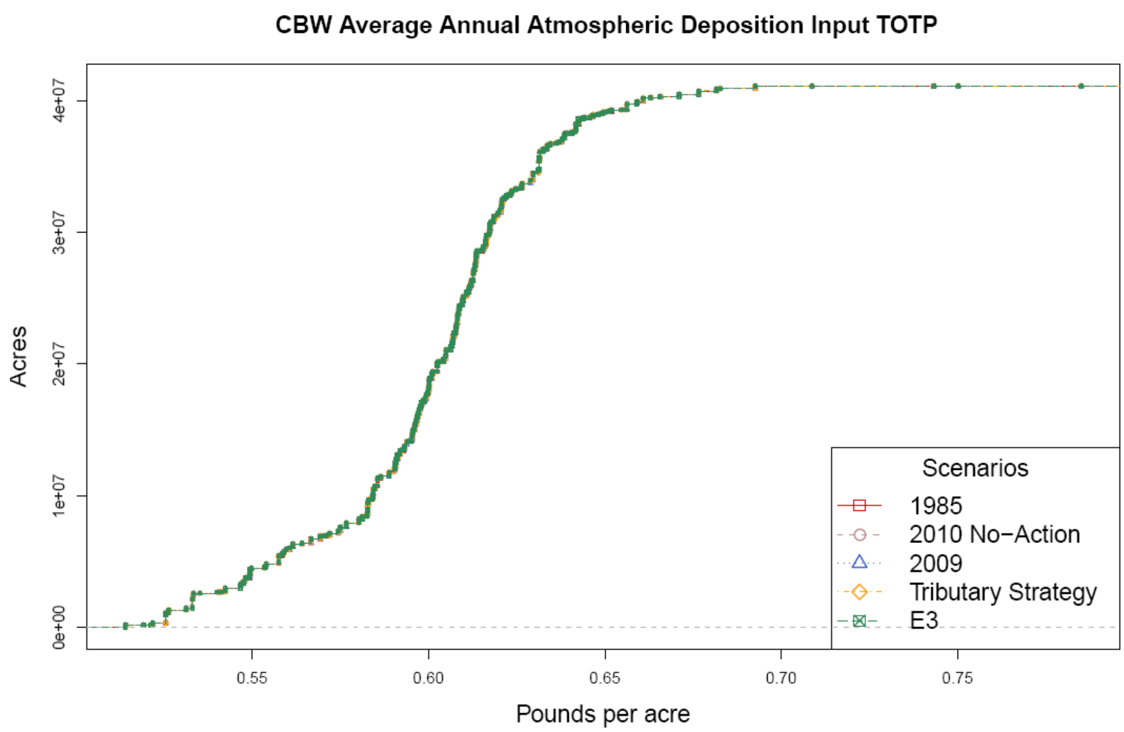


Figure 5-14. Annual total phosphorus atmospheric deposition for the key scenarios.

5.2.9 Direct Atmospheric Deposition of Nitrogen to the Tidal Chesapeake Bay

The regression and CMAQ models provide estimates of direct deposition to the tidal waters of the Chesapeake. Table 5-9 lists the estimates of direct deposition to the tidal Bay for the Base and for key scenarios.

Table 5-9 shows a relative increase in estimated reduced nitrogen deposition over time and an absolute increase in the dry deposition of reduced nitrogen. A key factor in the relative increase in the estimated reduced nitrogen deposition over time is the downward pressure on oxidized nitrogen emissions and the lack of controls on ammonia emissions. It is notable that changes in atmospheric chemistry of SO_X and NO_x in the seven key scenarios also affect ammonia dry deposition. In the scenarios with decreased SO_X and NO_x emissions, the dry deposition of ammonia increases, even though the total nitrogen deposition is decreasing. Figure 5-15 illustrates how decreased SO_X and NO_x emissions affect an increase of NH_3 dry deposition.

How the ratio of ammonia, or reduced atmospheric nitrogen deposition, to total nitrogen deposition is changing can be seen in Table 5-9. For the 1985 Scenario, the percent of total DIN direct deposition to tidal waters that was ammonia was 21 percent. For the 2010 and 2030 Scenarios, the fraction of ammonia deposition to the tidal Chesapeake was estimated to increase to 38 percent for the 2010 Scenario and 55 percent for the 2030 Scenario because of reductions in NO_x emissions. The respective estimated ammonia indirect depositions on the watershed for the same scenarios are 24 percent, 44 percent, and 64 percent.

Table 5-10. Direct atmospheric deposition loads of nitrogen to the tidal Chesapeake Bay for key scenarios. Units in millions of pounds as nitrogen. This table includes two entries for the Maximum Feasible Scenario. One includes the 15 percent decrease in wet and dry ammonia estimated to be due to E3 BMPs on ammonia emissions from agriculture manures as described in more detail in Section 12.

SCENARIO	Wet NOx Deposition	Dry NOx Deposition	Wet NH3 Deposition	Dry NH3 Deposition	Total Inorganic Nitrogen Deposition	Wet Organic Nitrogen Deposition	Total Nitrogen Deposition	Wet PO4 Deposition	Wet Organic Phosphoru Deposition	Total Phosphorus Deposition
1985 Scenario	6.57	13.15	3.34	1.97	25.03	1.05	26.08	0.33	0.98	1.31
2002 Scenario	4.81	10.04	3.57	2.12	20.54	1.05	21.59	0.33	0.98	1.31
2010 Scenario	3.27	6.85	3.49	2.76	16.37	1.05	17.42	0.33	0.98	1.31
2020 Scenario	2.56	5.11	3.72	3.24	14.63	1.05	15.68	0.33	0.98	1.31
2020 Maximum Feasible Scenario	2.30	4.48	3.64	3.41	13.83	1.05	14.88	0.33	0.98	1.31
2020 Max Fes w/ 15% NH4 Drop	2.30	4.48	3.09	2.90	12.77	1.05	13.82	0.33	0.98	1.31
2030 Scenario	2.22	4.30	3.96	4.08	14.56	1.05	15.61	0.33	0.98	1.31

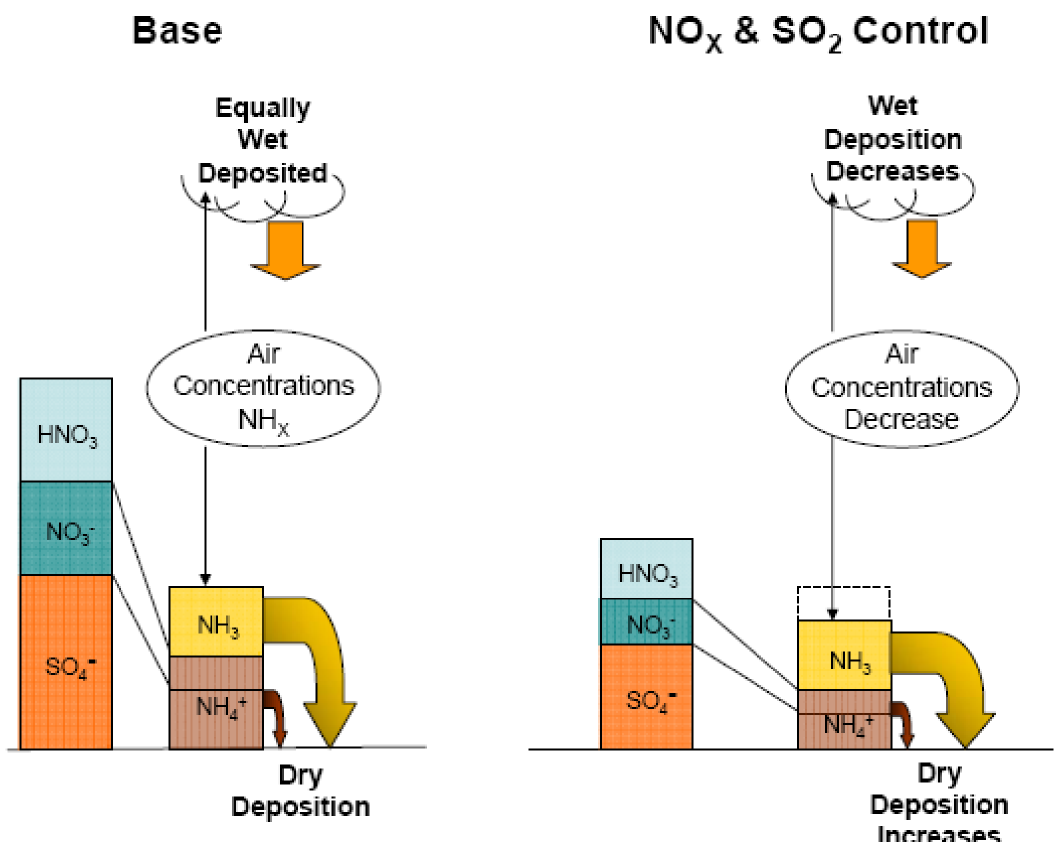


Figure 5-15. Decreased SOX and NO_x emissions cause increased NH_3 dry deposition.

5.2.10 Atmospheric Deposition of Nitrogen to the Coastal Ocean

The CMAQ Model allows CBP to estimate how atmospheric deposition loads to the coastal ocean off the Chesapeake contribute to the coastal ocean nutrient budgets independently made by others (Fennel et al. 2006; Howarth et al. 1995; Howarth 1998).

The estimated distribution of 2001 atmospheric deposition loads to North America and adjacent coastal ocean is shown in Figure 5-16. Howarth (1998) estimated that that atmospheric deposition loads are roughly equivalent to watershed loads in the northeast United States, which includes all watersheds from Maine to Virginia draining to the Atlantic, Howarth estimates that the watershed inputs of nitrogen to the Northeast coastal waters to be 0.27 teragrams (10^{12} grams). Inputs from direct atmospheric deposition to coastal waters are 0.21 teragrams, and inputs from deep ocean upwelling are 1.54 teragrams for a total input to the coastal ocean of 2.02 teragrams.

That has implications for the fixed ocean boundary condition used in the Water Quality Sediment Transport Model (WQSTM). To determine CMAQ estimates of atmospheric deposition to the coastal ocean region effecting nitrogen loads through the Chesapeake Bay's ocean boundary, an area was delineated as shown in Figure 5-17 that corresponded to the proximate region of the coastal ocean that is exchanging waters with the Chesapeake. That boundary is adjacent to the shore, and is inside, or west of, the Gulf Stream. 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 mouth.

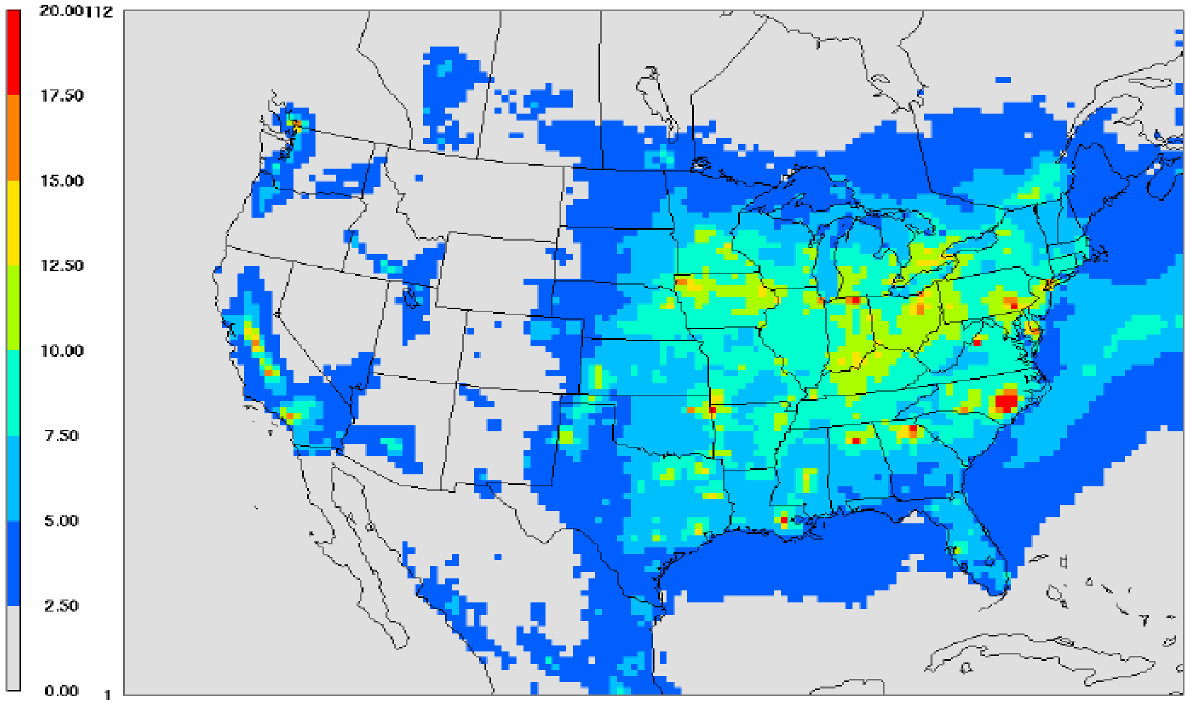


Figure 5-16. Estimated 2001 annual total deposition of nitrogen (kg-N/ha) to North America and adjacent coastal ocean (CMAQ Air Quality Model – 36 km x 36 km). Atmospheric deposition loads are approximately equal to watershed loads in the northeast United States (Howarth 1998).

Atmospheric deposition total nitrogen loads to the coastal ocean are estimated to be about 6.63 kg/ha Base Case 2002 Scenario (Table 5-10). That correlates to 43.8 million kilograms of total nitrogen deposition to a region of the ocean that can exchange waters with the Chesapeake (Table 5-11). In the case of the 2020 Maximum Feasible Scenario the nitrogen deposition to the same region is estimated to be 29.4 million pounds, a reduction of 32 percent. If EPA extrapolates that same reduction to the coastal ocean, the direct atmospheric inputs to the coastal ocean would decrease to 0.14 teragrams. Assuming the watershed loads discharged to the ocean and the and 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. Table 5-12 lists the estimated reductions of the ocean boundary for the five key CMAQ scenarios

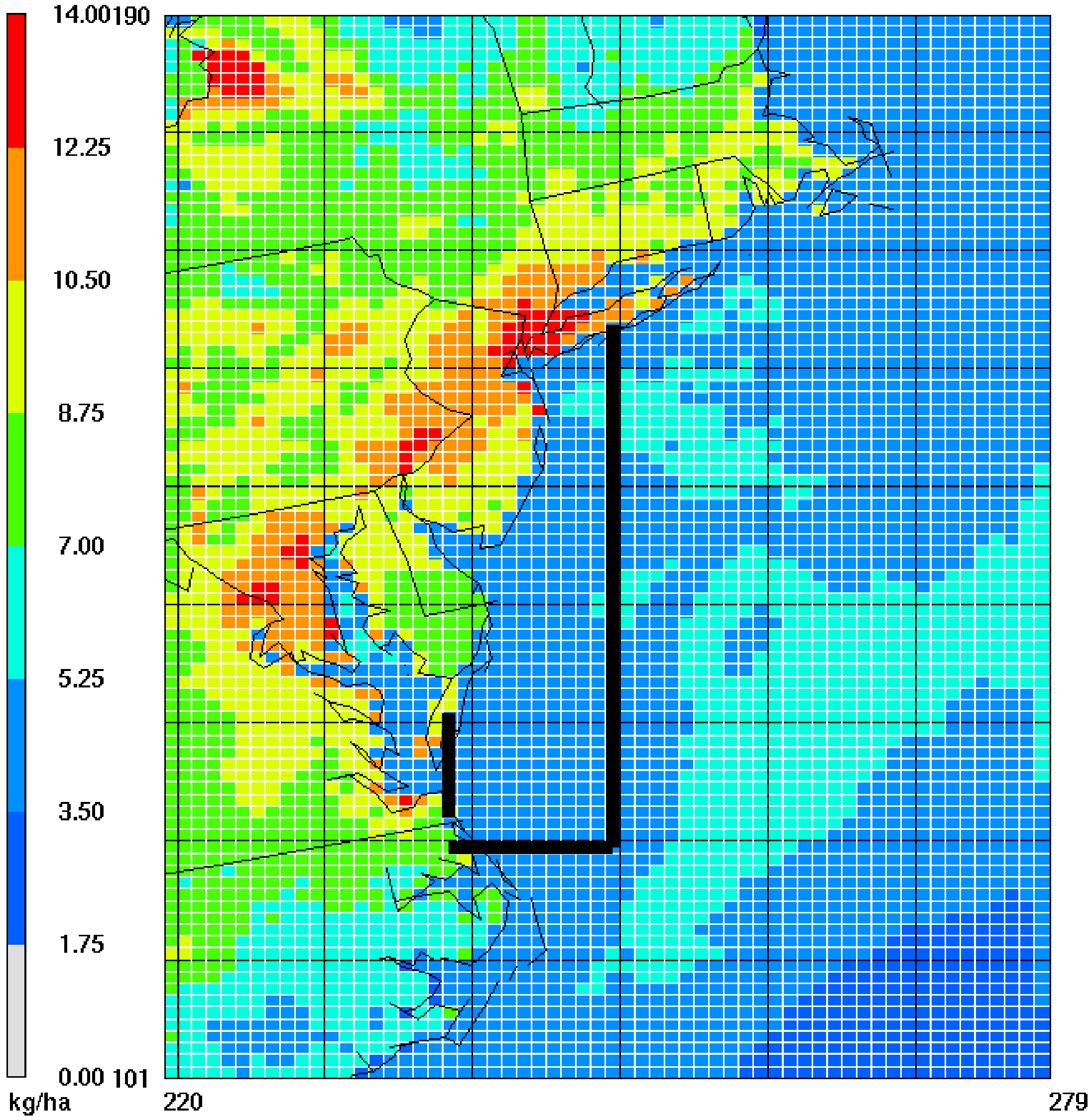


Figure 5-17. Boundaries of the coastal ocean region used to adjust the ocean boundary conditions in the WQSTM.

Estimated atmospheric deposition loads to the coastal waters are listed in Table 5.10 for key scenarios. The loads to the coastal ocean in kilograms per hectare for the CMAQ Base 2002 Scenario are shown in Figure 5.18.

Table 5-11. Atmospheric deposition loads of nitrogen to the coastal water area shown Figure 5.17 for key scenarios. Units in kg per hectare.

Scenario	Dry Deposition	Wet Deposition	Total Deposition
Base 2002 Scenario	3.32	3.31	6.63
2010 Scenario	2.59	2.68	5.27
2020 Scenario	2.26	2.49	4.75
2020 Maximum Feasible	2.10	2.35	4.45
2030 Scenario	2.13	2.40	4.53

Table 5-12. Total atmospheric deposition loads of nitrogen to coastal waters for key scenarios. Units in millions of kg.

Scenario	Dry Deposition	Wet Deposition	Total Deposition
Base 2002 Scenario	21.90	21.89	43.80
2010 Scenario	17.12	17.71	34.82
2020 Scenario	14.94	16.45	31.39
2020 Maximum Feasible	13.87	15.50	29.37
2030 Scenario	14.06	15.88	29.95

Table 5-13. Adjustment of the ocean boundary load for all nitrogen species for key CMAQ scenario deposition to coastal waters adjacent to the Chesapeake.

Scenario	% Reduction of Ocean Boundary
Base 2002 Scenario	0%
2010 Scenario	2.1%
2020 Scenario	2.9%
2020 Maximum Feasible	3.5%
2030 Scenario	3.3%

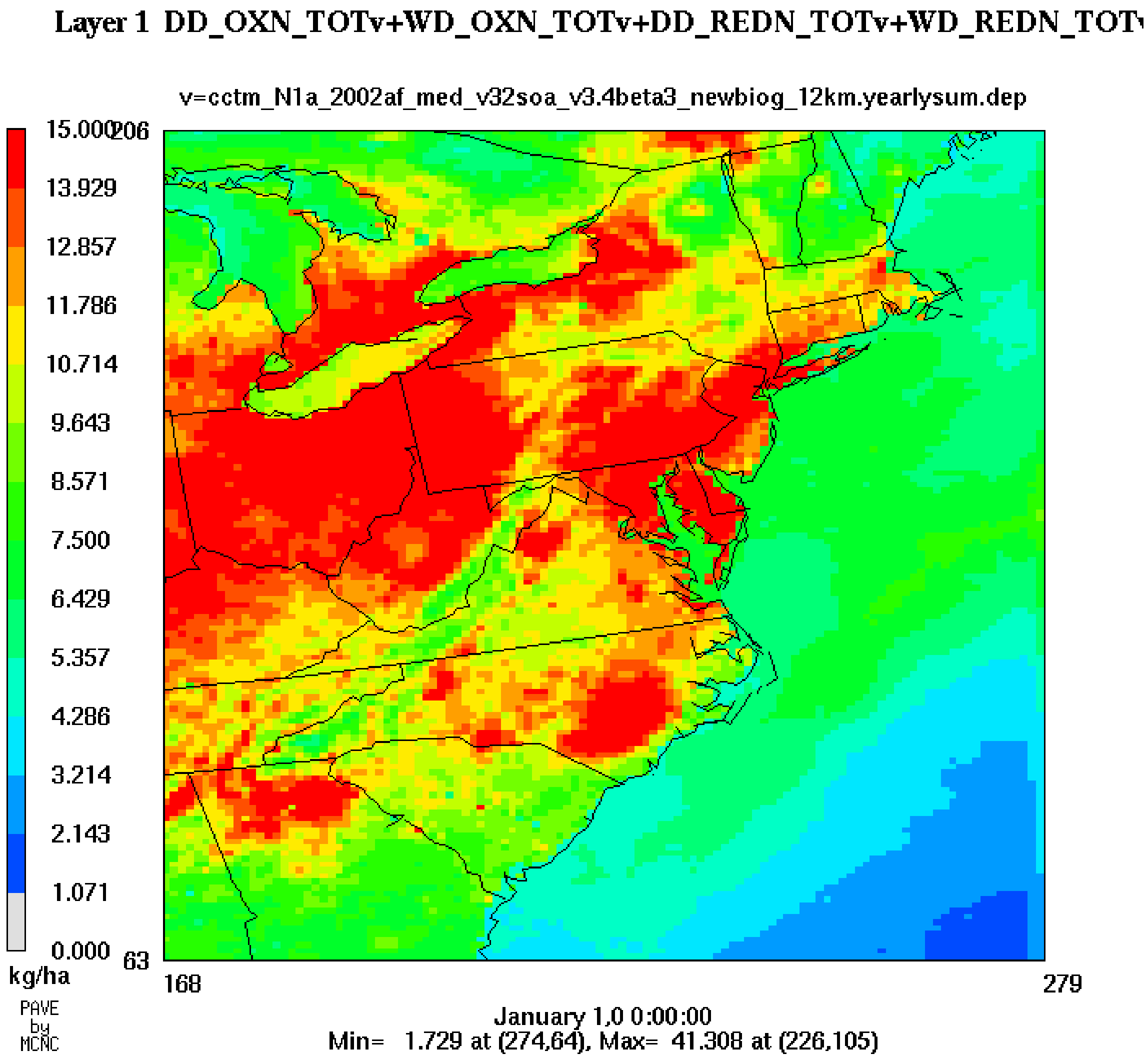


Figure 5-18. Deposition to the coastal ocean region in kg/ha for the Base 2002 Scenario.

5.3 Inputs from Scenario Builder

Scenario Builder Version 2.2 is a tool designed to develop scenarios so users can understand the impacts of best management practices and land use change, as well as develop more effective nitrogen and phosphorus management strategies (USEPA 2010). Scenario Builder provides the inputs to the Chesapeake Bay Program's Watershed Model – Hydrological Simulation Program in Fortran (HSPF), which was recently updated to Phase 5.3. The data used to calculate the inputs to the Watershed Model – HSPF Phase 5.3 are finer scale and take additional factors into consideration, such as mineralization from organic fertilizer, crop types, and double-cropping (USEPA 2010).

The U.S. Department of Agriculture National Agricultural Statistics Service (NASS) produces an agricultural census twice each decade in years ending with a 2 or 7. The NASS Agricultural Census is conducted on a county scale and includes data on animal populations, farms, agricultural land areas, and crop yields. Scenario Builder uses the censuses of agriculture as a main input data source.

Scenario Builder Version 2.2 is a process-based model designed to follow the nutrient generation process from the animal through storage and application. While the calculations are performed at the county scale, the processes follow what happens at a farm scale. For example, manure from various animal types is kept separate throughout the production, volatilization, storage, and application to crops' sequence. That was deliberate design feature and allows for considerations of changes in animal types, and the types of manures applied to crops.

Crop growth parameters are also considered in nutrient applications. Scenario Builder calculates nitrogen fixation by legumes; amount of bare soil based on residue and leaf cover, and nutrient uptake by plants; and is designed to estimate these parameters independent of each other. The types of data and parameters used in Scenario Builder are listed in Figure 5-19.

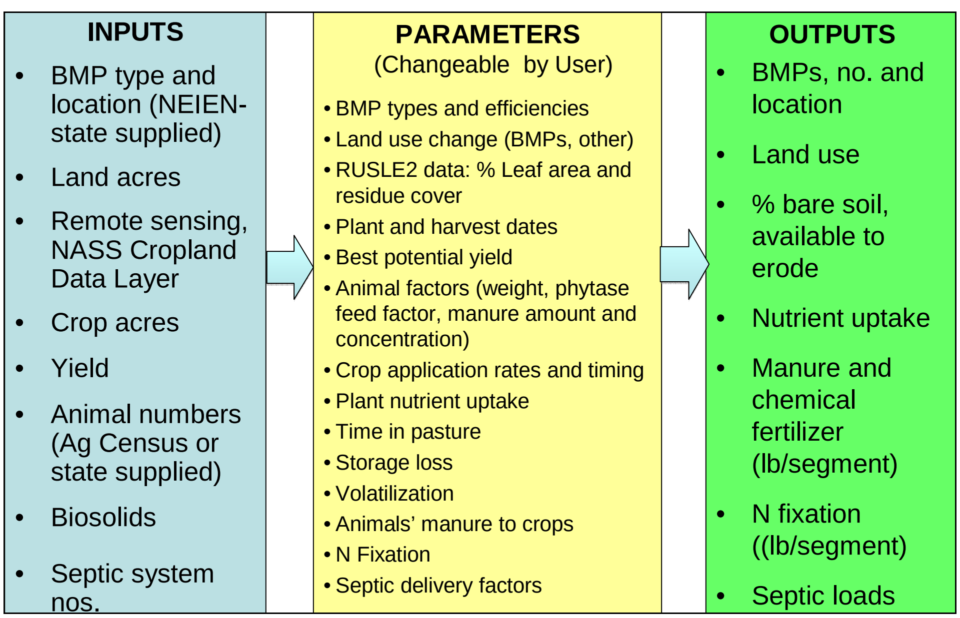


Figure 5-19. Model data relationships in Scenario Builder 2.2.

Scenario Builder Version 2.2 produces tabular reports of loading to land by land use and segment for manure and chemical Fertilizer (lbs/acre), land use, BMP reduction, plant uptake, N fixation, bare soil % (erodible portion), septic N delivery, and scenario parameters specified by user. For more details and to review the Scenario Builder documentation, visit http://www.chesapeakebay.net/watershedimplementationplantools.aspx or http://archive.chesapeakebay.net/pubs/SB_Documentation_Final_V22_9_16_2010.pdf.

5.3.1 Uptake Inputs

According to Alley and Vanlauwe (2009), the total nitrogen uptake is a function of the total crop biomass (top growth and roots) and it is calculated using:

$$Uptake(lbs/acre) = CropYield(YieldUnit/acre) \times CropNutrientContent(lbs/YieldUnit)$$

The fraction of the annual uptake mass is calculated on a monthly basis for each of the 12 growing regions using the recommended plant date. That does not account for the range of varieties used throughout the watershed. The curve information was informed by normalizing empirical data from peer-reviewed research to a fraction of the total uptake per month. The normalized data were averaged for each crop type where measurements were available. Uptake fraction per month was generalized to all the crop types modeled in Scenario Builder from the peer-reviewed research data on corn, soybeans, and winter wheat.

Improved methodology is being used for informing the curves. The timing of uptake should be based on the average temperature. Thus, heat units and the number of days warm enough to support crop growth, or growing degree days, were used to establish plant growth stages. The growing degree days are calculated as

(Temperature Minimum + Temperature Maximum) / 2 – crop basal unit

The basal unit for corn is generally accepted as 50 degrees F. There are established basal units for most crops that are modeled in Scenario Builder. Because development is faster when temperatures are warmer, and slower when temperatures are cooler, the use of growing degree days more closely informs the timing of nutrient uptake. Moreover, maturity dates for crops change by variety. In the Scenario Builder, CBP does not have various varieties of crops. The heat units serve to approximate the uptake for crops even without varietal differences being specified. Data using those methods are being prepared for a subsequent version of the Phase 5 Watershed Model.

Figure 5-20, Figure 5-21, Figure 5-22, and Figure 5-23 show area-weighted empirical cumulative distribution functions (ECDF) of the Phase 5.3 crop uptake input for the key scenarios. The graphs display the distribution of the nitrogen and phosphorus uptake per year for each land use versus the total acreage associated to those land uses for the key scenarios.

For example, the plot of high till without manure (hom) in Figure 5-20 is a representation of a common cropland type that would typically grow vegetables for human consumption. Note that the uptake is typically between 75 to 200 pounds per acre in all the Phase 5.3 land segments and that is determined largely by the crop yield as estimated in the Agricultural Census for the different counties in the watershed. More acres are in high till without manure (hom) in the 1985 scenario than in the 2009 scenario, which in turn has more acres than the Tributary Strategy Scenario. (Those scenarios are explained in detail in Section 12.) That is because more acres are appearing in the similar but more managed land use of nutrient management high till without manure (nho) which can be seen several panels down. In nutrient management high till without manure (nho) the E3 Scenario, the scenario with the highest level of management has the highest acres of nho. In both hom and nho the model uptake rates, determined by the Ag Census productivity estimates, remain the same and are between 75 and 200 pounds per acre as one would expect under nutrient management conditions that reduce excess nutrient inputs but maintain crop productivity.

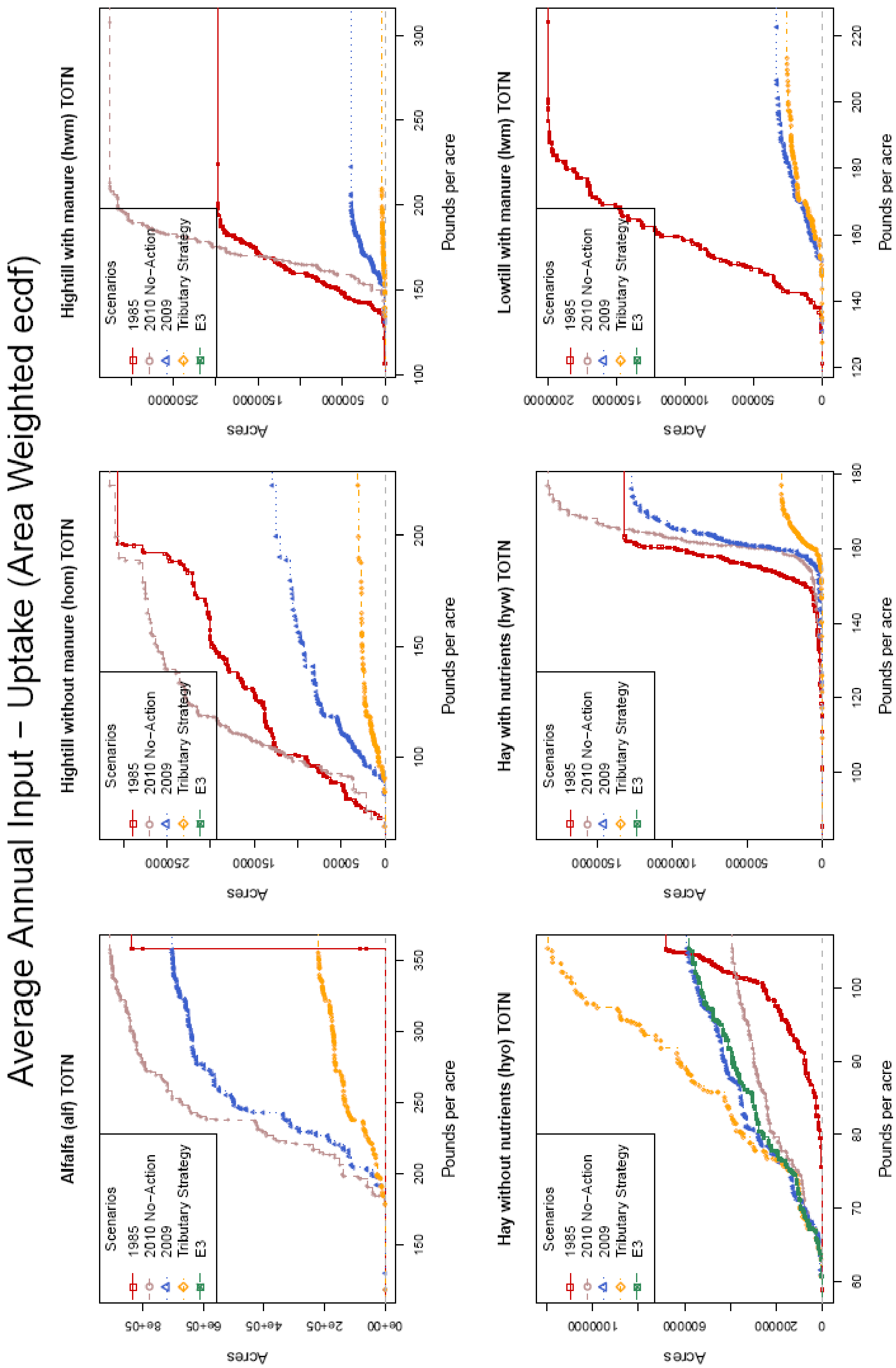


Figure 5-20, Area-weighted ECDF of annual total nitrogen uptake input for the Phase 5.3 key scenarios.

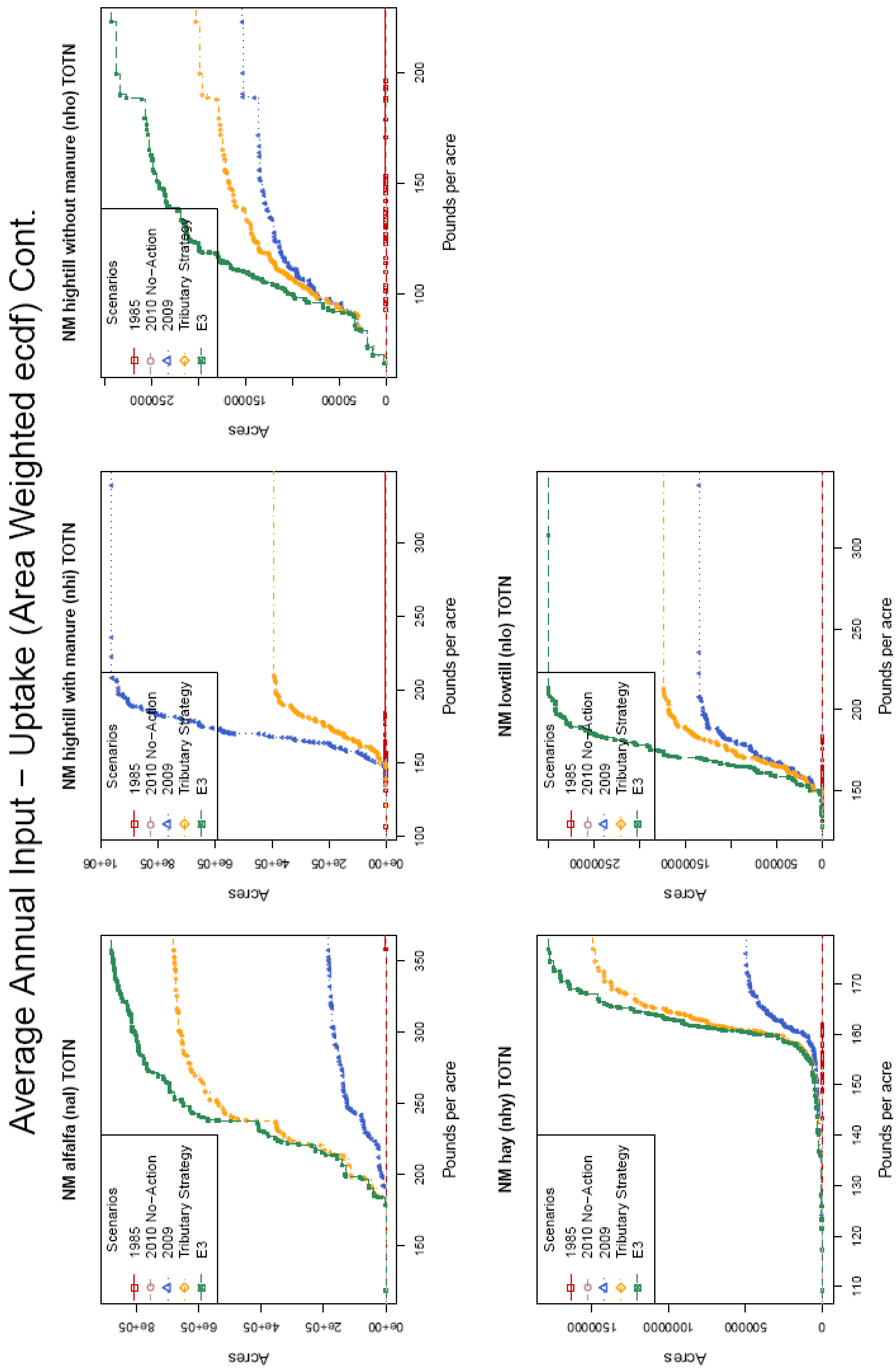


Figure 5-21. Area-weighted ECDF of annual total nitrogen uptake input for Phase 5.3 key scenarios.

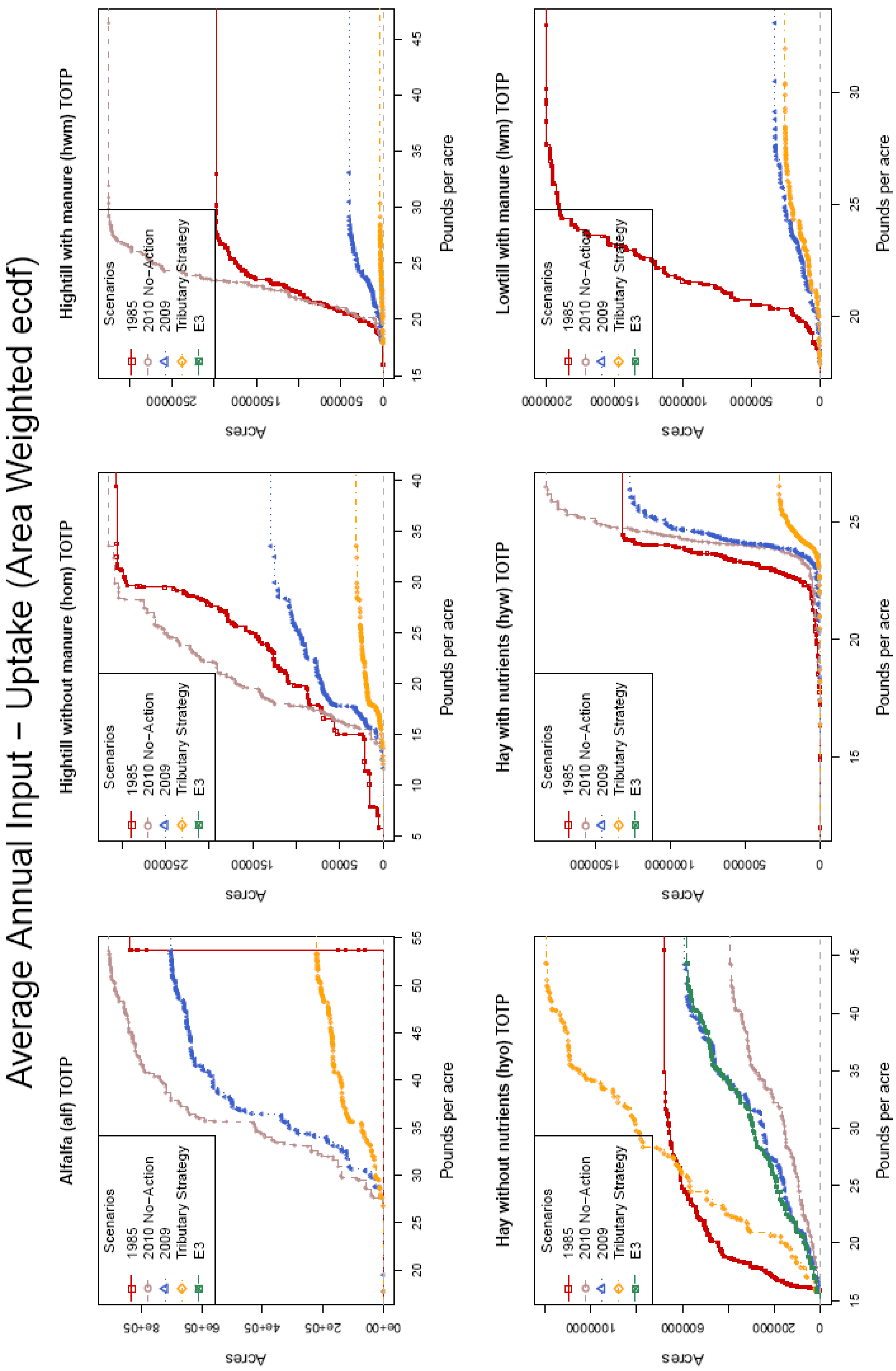


Figure 5-22. Area-weighted ECDF of annual total phosphorus uptake input for Phase 5.3 key scenarios.

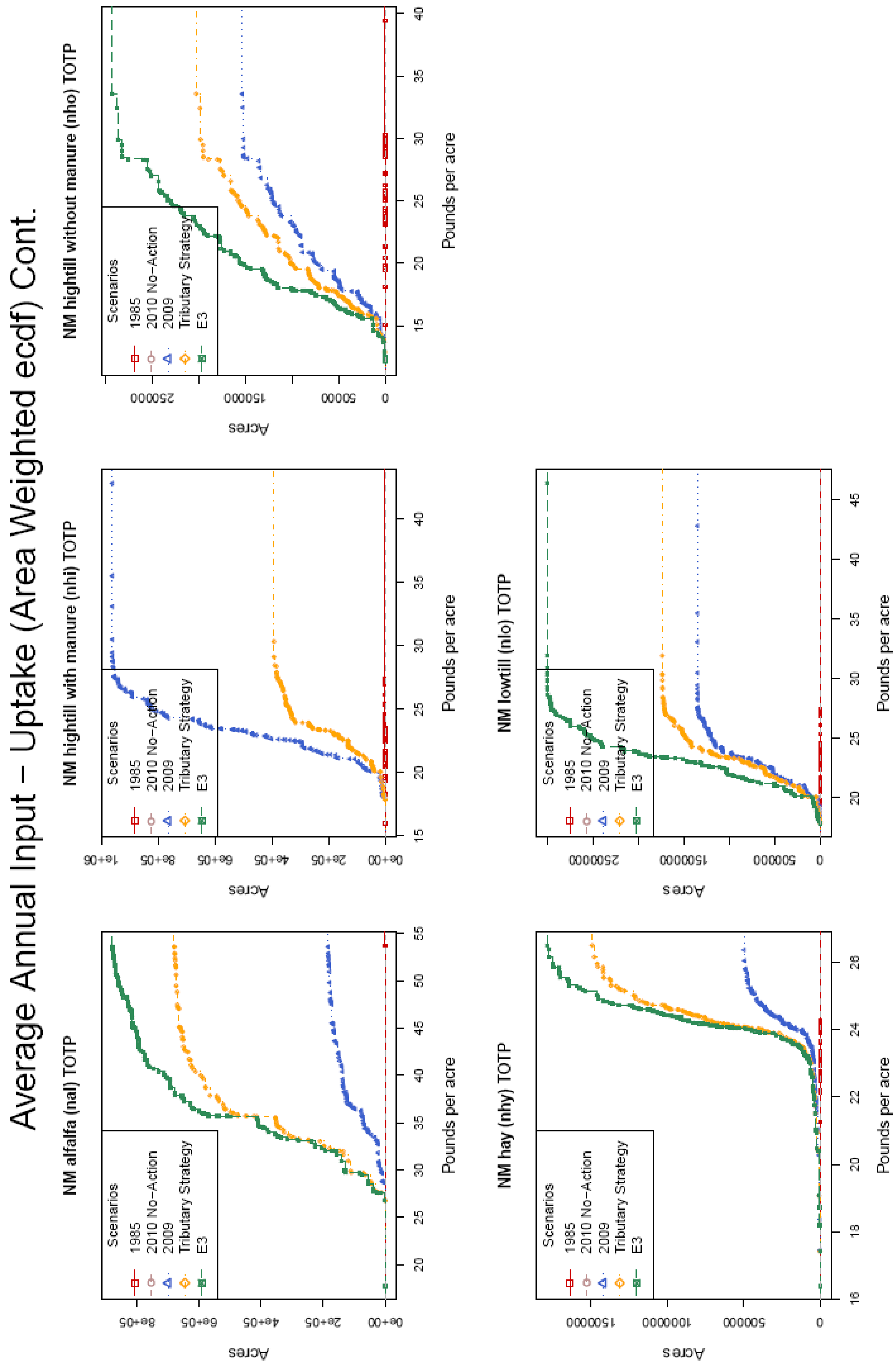


Figure 5-23. Area-weighted ECDF of annual total phosphorus uptake input for the Phase 5.3 key scenarios.

5.3.2 Fertilizer Inputs

In the Scenario Builder, fertilizer sales data were consulted for comparison purposes only. The fertilizer sales data are prepared by the Association of American Plant Food Control Officials on the basis of fertilizer consumption information submitted by state fertilizer control offices. The consumption data include total fertilizer sales or shipments for farm and non-farm use. Liming materials, peat, potting soils, soil amendments, soil additives, and soil conditioners are excluded. Materials used for manufacturing or blending reported fertilizer grades or for use in other fertilizers are excluded to avoid duplicate reporting.

The fertilizer sales data were not used directly because of complications with consistency of reported data throughout the modeled time-period and region. In addition, several major ports are in the Chesapeake Bay watershed. Fertilizer can be sold at the port and transferred to another region for resale, which could result in double counting the sales.

Fertilizer application rates are determined by the composite crop uptake, and monthly application rates are specified in the land use inputs that represent starter, side-dress, and other fertilizer applications for the composite crop represented. Monthly nutrient application data for fertilizer, legumes, and manure by species (organic nitrogen and phosphorous, nitrate, ammonia, and phosphate), land use, and land segment in pounds per acre can be downloaded from ftp://ftp.chesapeakebay.net/Modeling/phase5/data/model_inputs/nps_nutrients.zip.

It is assumed in the simulation that farmers apply inorganic fertilizer in a way that avoids harming crops. Nutrient over-application could cause lodging in grains or other harmful effects on plants. That is least likely to occur on hay and pasture crops so applications greater than plant need can occur where excess manure is produced. Where manure has not met the application rate, inorganic fertilizer is applied to meet the state-recommended application rate. A further assumption is that farmers apply fertilizer in an economically rational manner and aim toward agronomically efficient application rates. In effect that means that fertilizer is never over or under applied in the Phase 5.3 Model when manure is not in excess for the crop. That means that only in land-segments where manure is in excess of the crop need for the entire land-segment is nutrient management an effective BMP. Those decision rules are being modified in next phase, Phase 5.3.2 Watershed Model to ensure that nutrient management is more generally effective throughout the watershed.

Fertilizer and manure applications depend on agronomic practices, and inputs are largely centered around the time of crop planting. Fertilizer loads are estimated annually for the 1985–2005 simulation period by a mass balance on the scale of the entire Phase 5.3 domain. The trend on fertilizer inputs to the Chesapeake watershed is relatively flat over the Phase 5.3 domain (Figure 5-1 and Figure 5-2).

The watershed model fertilizer input contains ammonia (NH_3), nitrate (NO_3), and phosphate (PO_4). The nitrogen component of inorganic fertilizer is composed of ammonia, nitrate, or both. Ammonia is about 75 percent of the total nitrogen applied as fertilizer. All the phosphorus is found in the form of PO_4. Table 5-13 lists the types of fertilizers applied in the Chesapeake watershed over the 1993–1995 period.

For some fertilizers, such as urea and anhydrous ammonia, nitrogen is lost to the atmosphere by volatilization. Nitrogen loss by volatilization from urea and ammonia are reduced by incorporation into the soil, or by injection into soil in the case of ammonia. Little or no ammonia loss occurs from surface applications of acidic fertilizers such as ammonium nitrate or ammonium sulfate unless the soil pH is very high. Ammonia volatilization increases with increasing soil pH, decreasing moisture content and higher temperatures.

Looking at the overall fertilizers sales by fertilizer type in the Chesapeake watershed (Table 5-13), the amount of urea and anhydrous ammonia (including blended fertilizer *identified by grade*) is about 30 percent of total fertilizer nitrogen. In the simulation of developed and agricultural lands, CBP simulates ammonia volatilization from fertilizers and manures as a user-specified, temperature-corrected rate. The calculated ammonia volatilization from fertilizer is shown in Figure 5-24.

Note that the land uses with high manure and fertilizer inputs such as high till with manure (hwm) have high volatilization rates of up to about 20 pounds of nitrogen volatilized per acre-year. Conversely, alfalfa with no negligible inputs of manures and fertilizer has low volatilization rates of no more than a few pounds per acre. Some land uses like hay with manure which sees high loading rates of manure as a disposal method highest volatilization rates, which approach 80 pounds nitrogen per year and in one case is estimated to exceed 120 pounds of nitrogen volatilized per year.

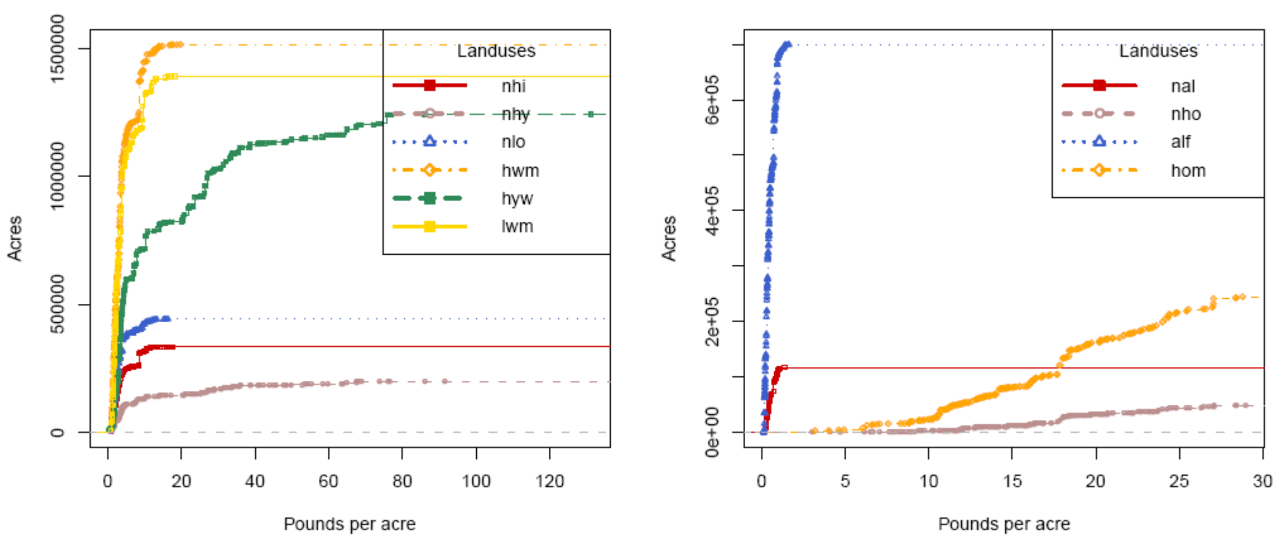


Figure 5-24. Phase 5.3 volatilization of nitrogen from key agricultural land uses. Units in pounds per acre.

Table 5-14 . Types of fertilizers applied in the Chesapeake watershed.

fertyear	fertcode	Fertname	type_pct
1993	0	IDENTIFIED BY GRADE	30.4%
1993	66	UREA	19.6%
1993	59	NITROGEN SOLUTION 30%	18.1%

1993	203	DIAMMONIUM PHOSPHATE	5.6%
1993	60	NITROGEN SOLUTION 32%	5.6%
1993	10	AMMONIUM NITRATE	3.7%
1993	2	ANHYDROUS AMMONIA	3.1%
1993	56	NITROGEN SOLUTION <28%	2.6%
1993	24	AMMONIUM SULFATE	2.2%
1993	58	NITROGEN SOLUTION 28%	2.1%
1993	209	MONOAMMONIUM PHOSPHATE	1.7%
1993	97	NITROGEN PRODUCT - CODE UNKNOWN	1.3%
1993	16	AMMONIUM NITRATE-SULFATE	0.9%
1993	20	AMMONIUM POLYSULFIDE	0.7%
1993	249	LIQUID AMMONIUM POLYPHOSPHATE	0.6%
1994	0	IDENTIFIED BY GRADE	29.8%
1994	66	UREA	18.9%
1994	59	NITROGEN SOLUTION 30%	18.2%
1994	203	DIAMMONIUM PHOSPHATE	5.7%
1994	2	ANHYDROUS AMMONIA	4.6%
1994	60	NITROGEN SOLUTION 32%	3.7%
1994	56	NITROGEN SOLUTION <28%	3.5%
1994	10	AMMONIUM NITRATE	3.2%
1994	24	AMMONIUM SULFATE	2.8%
1994	97	NITROGEN PRODUCT - CODE UNKNOWN	2.0%
1994	209	MONOAMMONIUM PHOSPHATE	1.8%
1994	58	NITROGEN SOLUTION 28%	1.5%
1994	16	AMMONIUM NITRATE-SULFATE	1.3%
1994	249	LIQUID AMMONIUM POLYPHOSPHATE	0.9%
1995	0	IDENTIFIED BY GRADE	32.6%
1995	59	NITROGEN SOLUTION 30%	19.5%
1995	66	UREA	13.3%
1995	2	ANHYDROUS AMMONIA	7.5%
1995	60	NITROGEN SOLUTION 32%	6.1%
1995	203	DIAMMONIUM PHOSPHATE	3.3%
1995	24	AMMONIUM SULFATE	3.0%
1995	10	AMMONIUM NITRATE	2.5%
1995	56	NITROGEN SOLUTION <28%	2.5%
1995	58	NITROGEN SOLUTION 28%	1.9%
1995	97	NITROGEN PRODUCT - CODE UNKNOWN	1.8%
1995	209	MONOAMMONIUM PHOSPHATE	1.7%
1995	68	UREA-FORMALDEHYDE	1.5%
1995	249	LIQUID AMMONIUM POLYPHOSPHATE	0.8%

5.3.2.1 Fertilizer Inputs to Agricultural Lands

Using the agricultural census, the nutrient management target yield for each state is calculated differently:

> *Delaware*: average of the highest four of seven yields from the Agricultural Census. If less than seven Censuses are available, use as manure are available as long as there are greater than four.
>
> *Maryland*: average the highest 60 percent of the available Agricultural Censuses.
>
> *New York, Pennsylvania, District of Columbia, West Virginia, Tennessee, and North Carolina*: average the highest three of five yields from the Agricultural Censuses.

In contrast, the non-nutrient management target yield is the highest Agricultural Census yield instead of any recent average.

The non-nutrient management yield cannot be greater than the upper limit (quantile p = 0.95) of the Census to prevent exceedingly high yield goals that appear to be statistical outliers. The average application yield ratio (YR = nutrient management yield / upper limit yield) is 0.78. The rates are calculated as below by combining the application rate and uptake calculations:

Non-nutrient management application rate (lb/ac) = upper limit yield (bu/ac) * uptake (lb/bu)

Nutrient Management application rate (lb/ac) = nutrient management yield (bu/ac) * uptake (lb/bu)

Figure 5-25, Figure 5-26, Figure 5-27, and Figure 5-28 show area-weighted empirical cumulative distribution function (ECDF) of the watershed model Phase 5.3 fertilizer input for the key scenarios. The graphs display the distribution of the nitrogen and phosphorus fertilizer applied per year to the nutrient management (NM) and non-nutrient management land uses versus the total acreage associated to those land uses for the key scenarios.

Inorganic fertilizer is applied to agricultural lands where manure has not already met the application rate recommended from the states. Model decision rules for fertilizer are that it's never under- or over-applied. Chemical fertilizer is assumed to be mixed to specification as needed by all crops. For example, if the crop nitrogen need was met through manure, chemical fertilizer containing only phosphorus would be applied to fully satisfy crop need. That is a universal representation in the Phase 5.3 Model of a more precise use of chemical fertilizers than what is actually applied in the Chesapeake Bay watershed.

The essential approach is to satisfy the entire crop need for nutrients. The model decision rules are designed to first satisfy that need with manures. In the simulation, if all crop nutrient need is not satisfied with manure, fertilizer is added. In all cases, the crop need of nitrogen is first attempted to be satisfied with manures. That means that in land segments with an excess of manure and where manures would satisfy all the crop need, phosphorus would be over-applied because the ratio of nitrogen to phosphorus (N/P) in manures is lower than crop need. The exception is the extreme management scenario titled E3 and discussed in Section 12. For the E3 Scenario, manures are applied to fully satisfy the crop need of phosphorus, and then fertilizer nitrogen is applied to fully satisfy crop need. In that case over application of phosphorus is avoided.

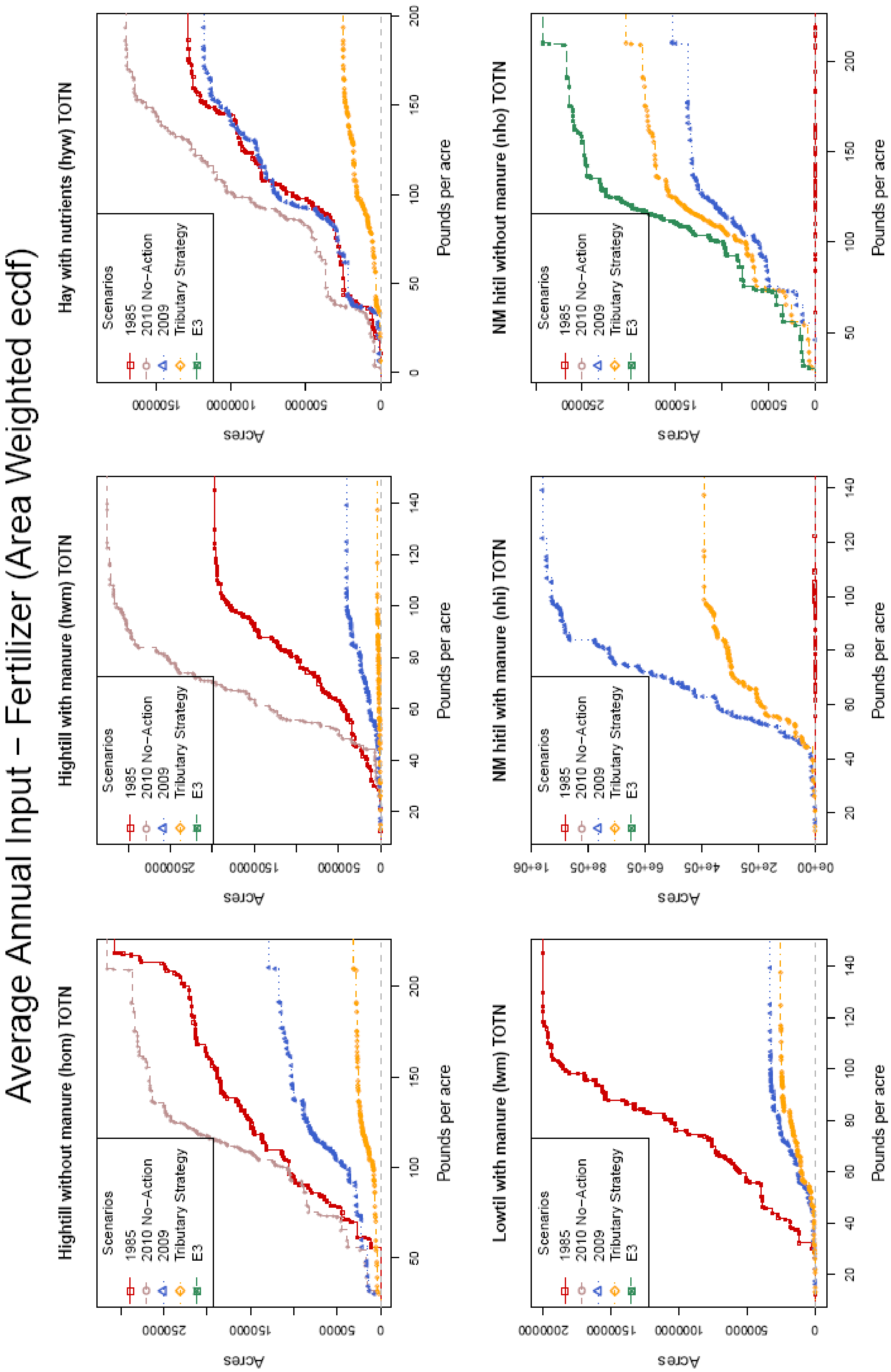


Figure 5-25. Area-weighted ECDF of annual total nitrogen inorganic fertilizer application rate input for Phase 5.3 key scenarios

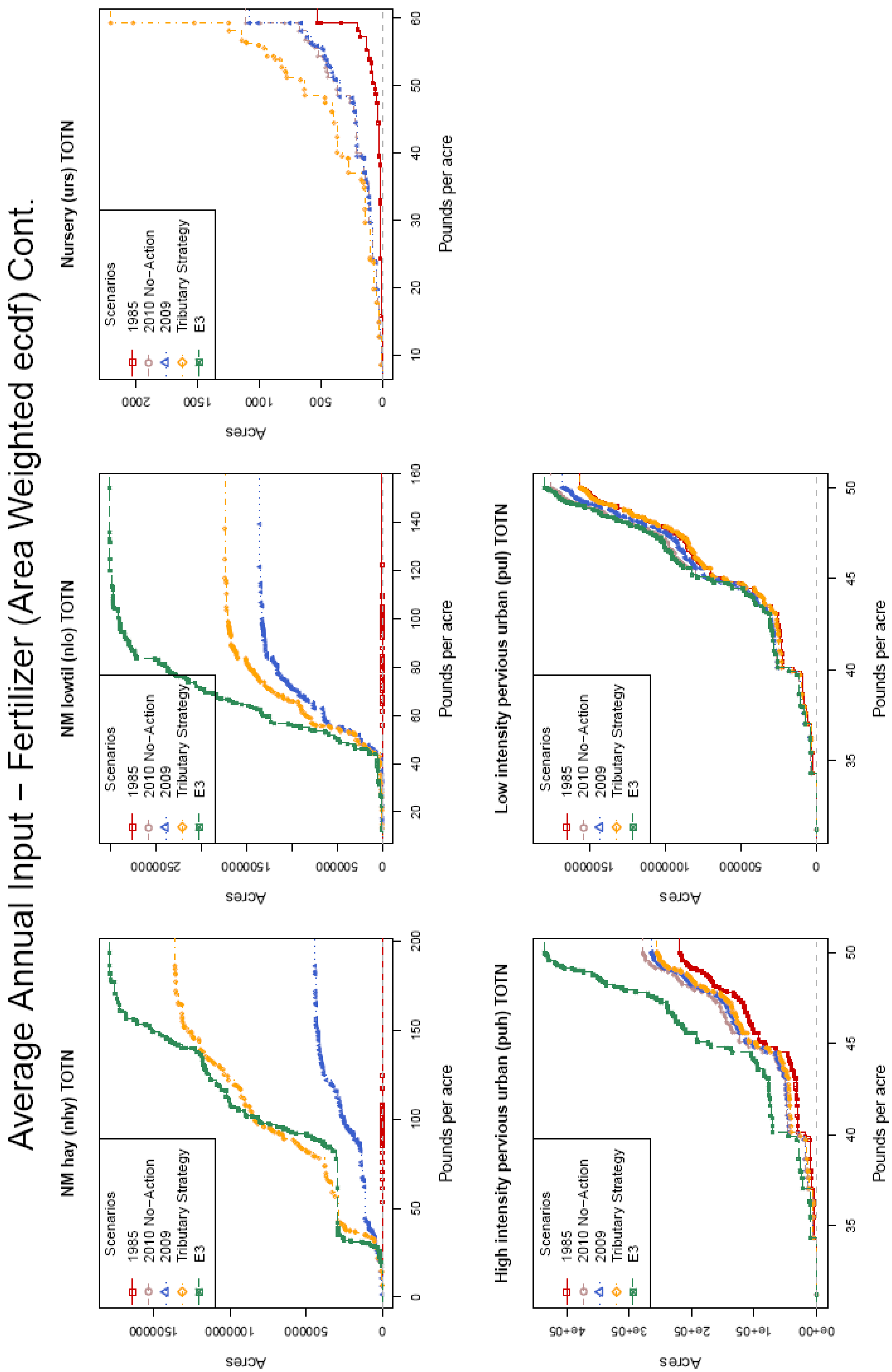


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Figure 5-26. Area-weighted ECDF of annual total nitrogen inorganic fertilizer application rate input for Phase 5.3 key scenarios.

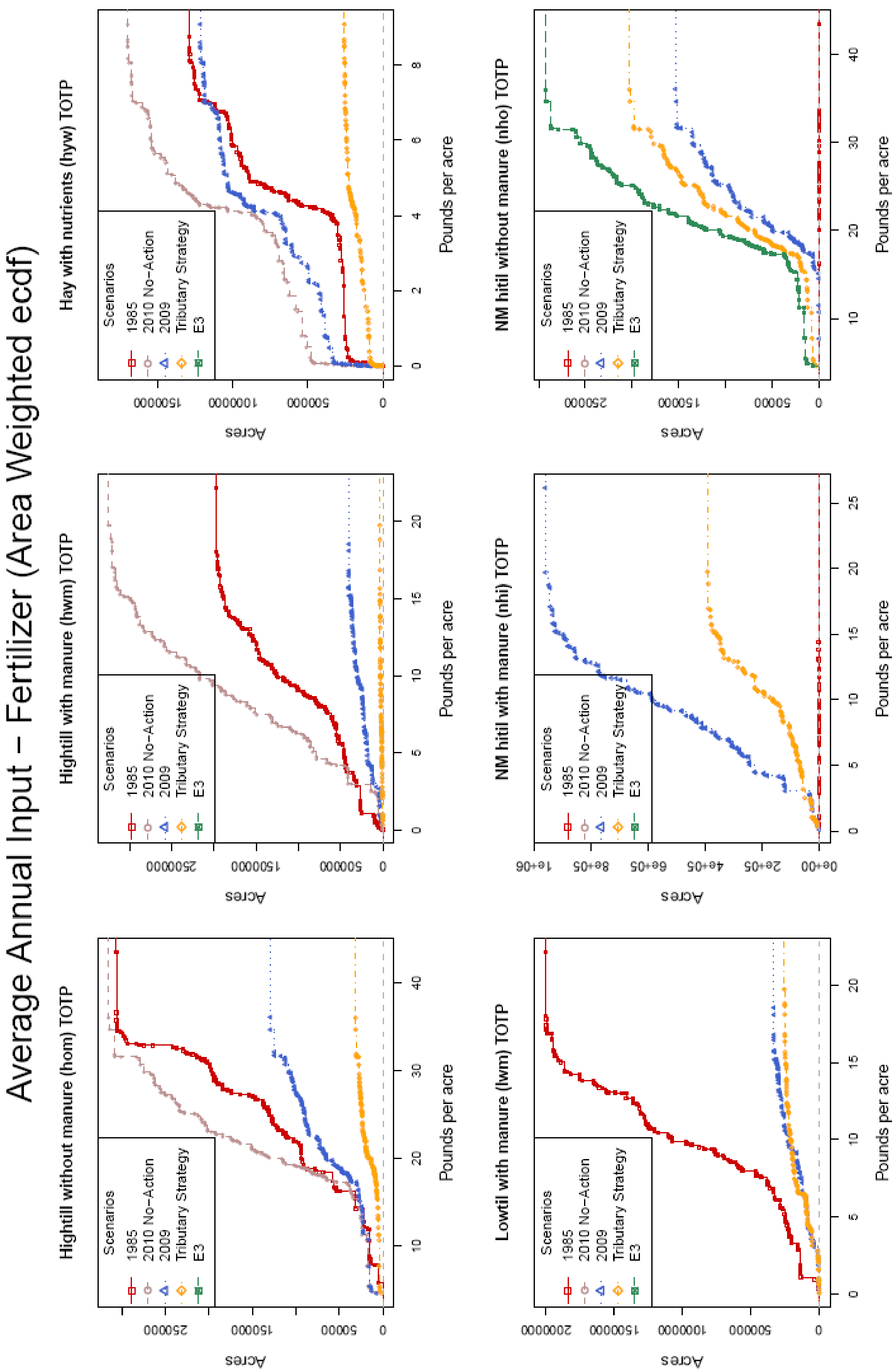


Figure 5-27. Area-weighted ECDF of annual total phosphorus inorganic fertilizer application rate input for Phase 5.3 key scenarios

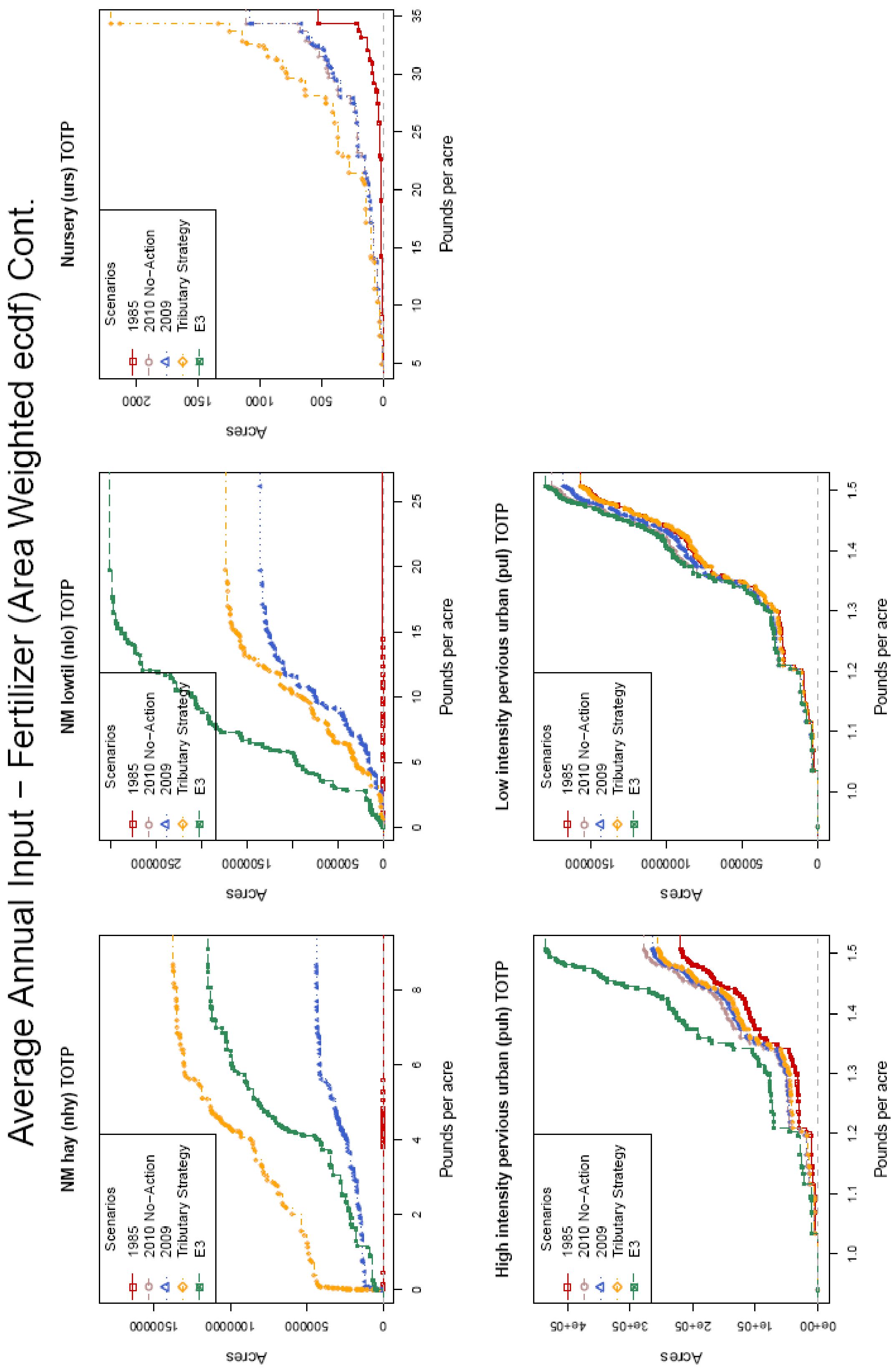


Figure 5-28. Area-weighted ECDF of annual total phosphorus inorganic fertilizer application rate input for Phase 5.3 key scenarios.

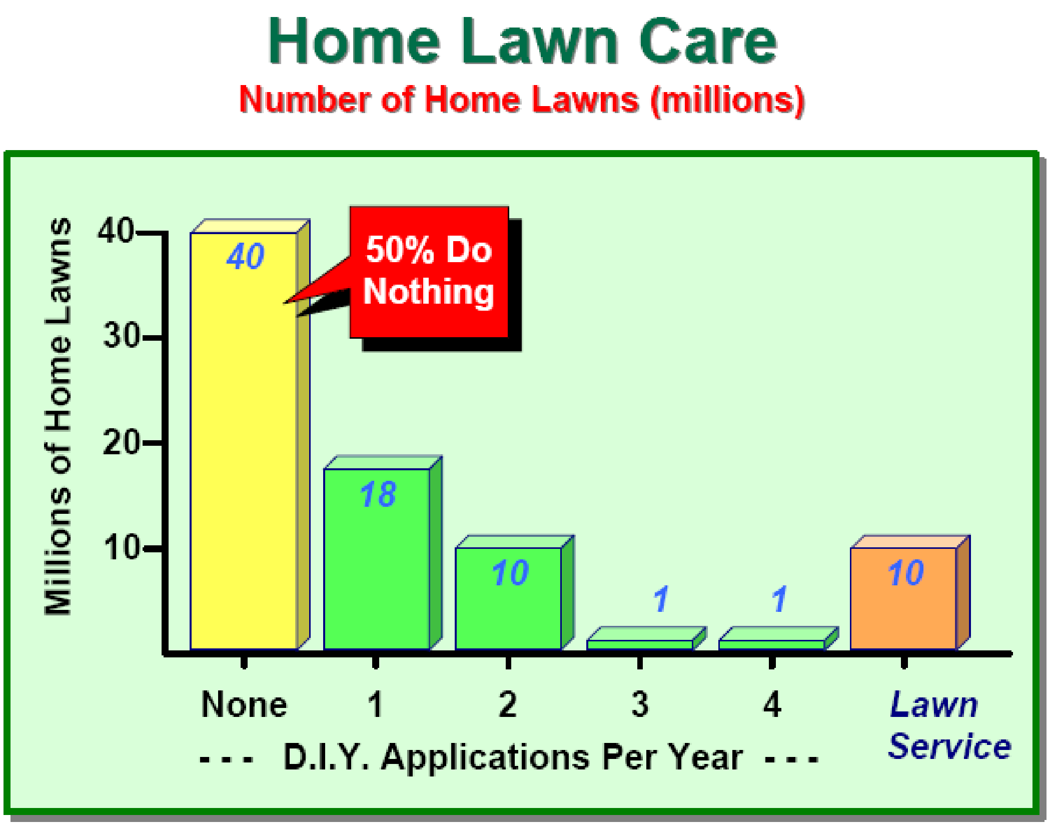
5.3.2.2 Fertilizer Inputs to Developed Lands

For developed land, inorganic fertilizer is applied only to the urban lawns or turf grass areas that are in low-intensity pervious urban and high-intensity pervious urban land uses. Fertilizer consumption data by county submitted by state fertilizer control offices, total non-farm use fertilizer sales, and turf grass acres were used to estimate nitrogen and phosphorus application rates for urban lawns. For the Chesapeake Bay watershed counties as a whole, the urban lawns fertilizer application rate is calculated using

$$TurfApplicationRate(lbs/acre) = \frac{NonFarmFertilizer}{TurfGrassAcres}$$

Approximately 50 lbs/acre of nitrogen and 1.5 lbs/acre of phosphorus are applied annually to urban lawns in the Chesapeake Bay watershed. Lower applications are from the combination of turf grass and pervious pavement acres.

In the Phase 5.3 simulation, nitrogen application rates to pervious urban acres ranges from 30 to 50 pound per acre per year and phosphorus application rates to pervious urban acres ranges from 0.9 to 1.5 pound per acre per year. Figures 5-26 and 5-28 show area-weighted ECDF of the inorganic fertilizer rates applied to developed lands for the key scenarios. The graphs display the distribution of the nitrogen and phosphorus fertilizer application rates applied to the low-intensity pervious and high-intensity pervious urban land uses versus the total acreage associated to those land uses for the key scenarios. Figure 5-29 shows the relative proportions of applications of fertilizer on developed lands from none applied (50 percent), to *do it yourself* (DIY) applications, to professional services.



Source: presentation to the Implementation Committee April 20, 2006.
http://www.chesapeakebay.net/pubs/calendar/IC_04-20-06_Presentation_3_6658.pdf

Figure 5-29. Estimated applications of do-it-yourself fertilizer applied to lawns.

5.3.3 Animal Manure Inputs

The NASS Agricultural Census animal inventory data is used in lieu of animal sales data (USEPA 2010). The inventory information from the Agricultural Census is the number of animals on the farm at the end of the year. Using the animal inventory data assumes no seasonal fluctuations in herd size and continuous replacement. This steady state assumption tends to underestimate animal numbers. Sales data deliver a greater number of animals in some cases than inventory. To be conservative, the Chesapeake Bay Program is using the inventory data. The number of farms for each animal type is also taken from the Censuses. The number of farms informs the acres assigned for the Animal Feeding Operation land use category.

Organic fertilizer sources include animal manure and biosolids. In organic fertilizer, nitrogen and phosphorus are linked, because a farmer does not chemically separate the various forms. The total mass of manure per day per animal unit is split into total nitrogen and total phosphorus for each animal species. Total nitrogen is further broken into NH_3, organic nitrogen, and mineralized nitrogen.

As described in Scenario Builder (USEPA 2010), manure is applied to pasture according to the amount of animals in a county and the amount of time that animal type spends in the pasture (Figure 5-31 and Figure 5-33). The amount of time that the animal does not spent in pasture (confinement) defines the amount of manure that is stored, all that animal type's manure will be applied to cropland (Figure 5-30, Figure 5-31, Figure 5-32, and Figure 5-33).

Manure can also volatilize and be lost during storage. The amount of the manure that is lost to runoff during storage and in manure collection is accounted for as loads from Animal Feeding Operations (USEPA 2010) (Figure 5-30 and Figure 5-32).

$$Total\_mass = AnimalUnit \times ManureperAU \times day\sin amonth \times Concentration$$

Total_mass is the total pounds of nutrient of manure per day per animal unit, *AnimalUnit* is the number of animals per one animal unit (animal unit=1000 lbs), *Manure per AU* is the amount of manure per animal unit per day (lbs of manure), and *Concentration* is the amount of nutrient per pound of manure (lbs of nutrient/lbs of manure).

Figure 5-30, Figure 5-31, Figure 5-32, and Figure 5-33 show area weighted empirical cumulative distribution functions (ECDFs) of the Phase 5.3 manure annual input for the key scenarios. The graphs display the distribution of the nitrogen and phosphorus organic fertilizer applied to cropland and pasture land uses and the distribution of the manure lost in animal feeding operations versus the total acreage associated to those land uses for the key scenarios.

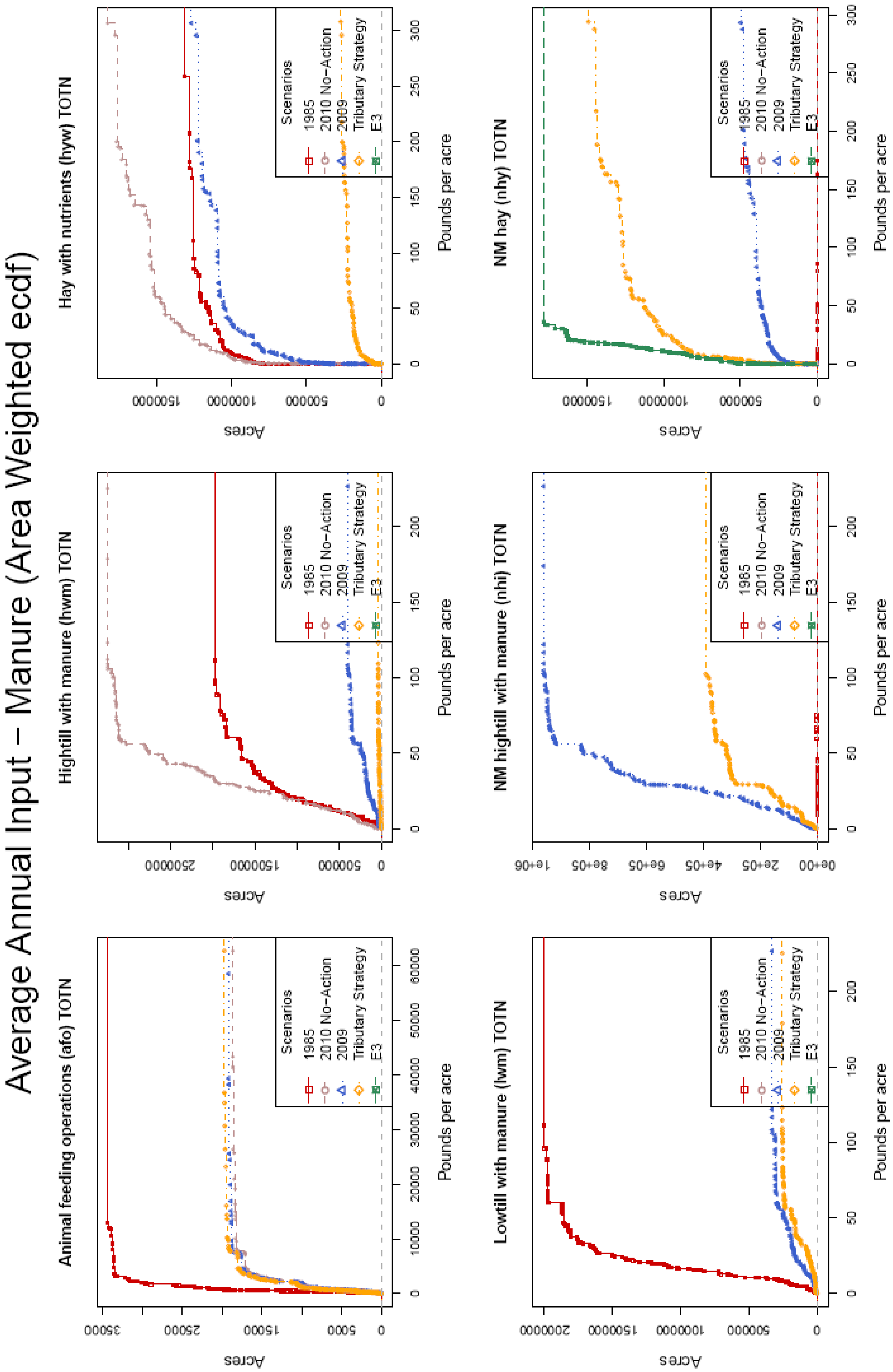


Figure 5-30. Area-weighted ECDF of annual total nitrogen manure input for Phase 5.3 key scenarios.

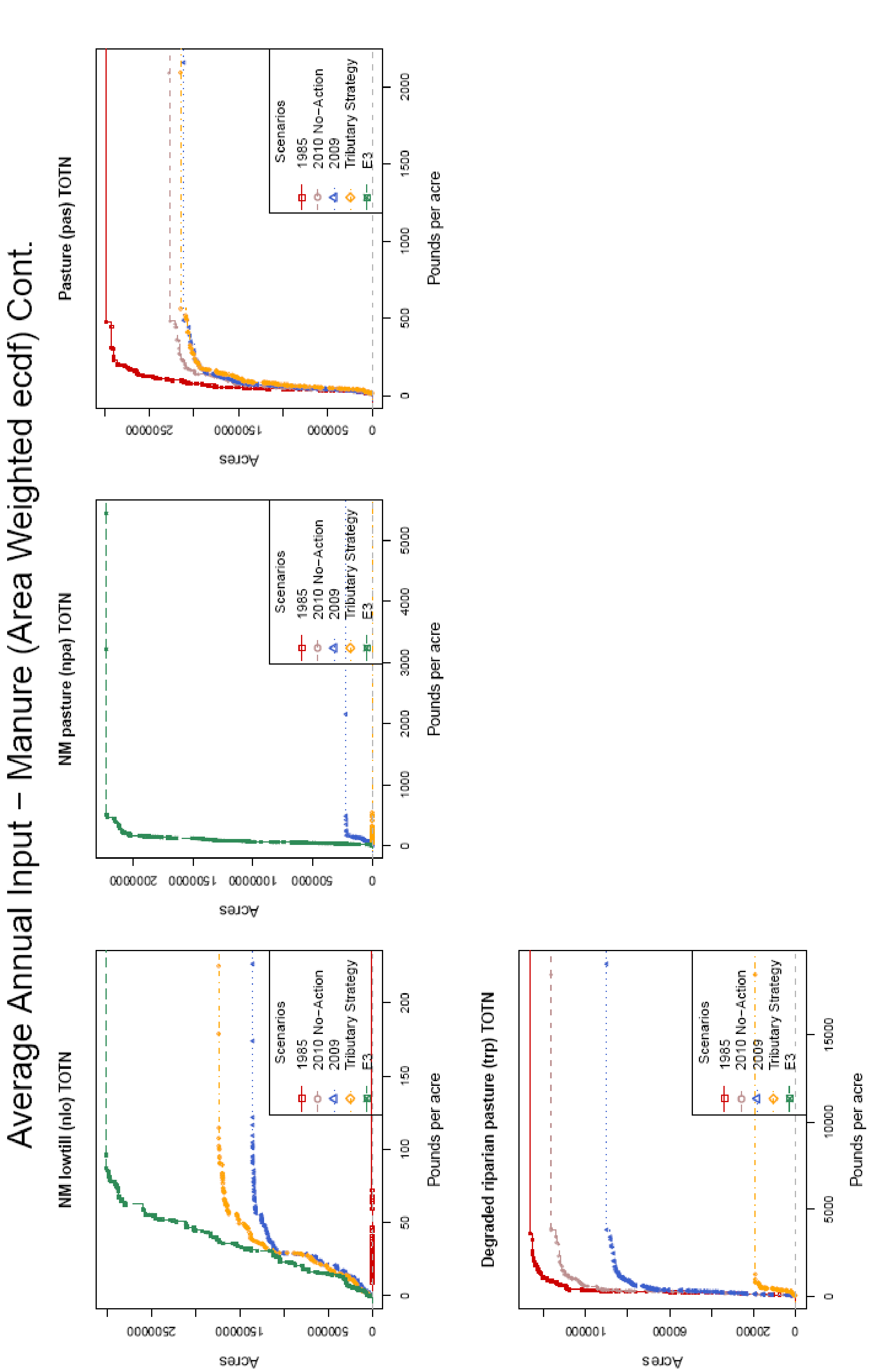


Figure 5-31. Area-weighted ECDF of annual total nitrogen manure input for Phase 5.3 key scenarios.

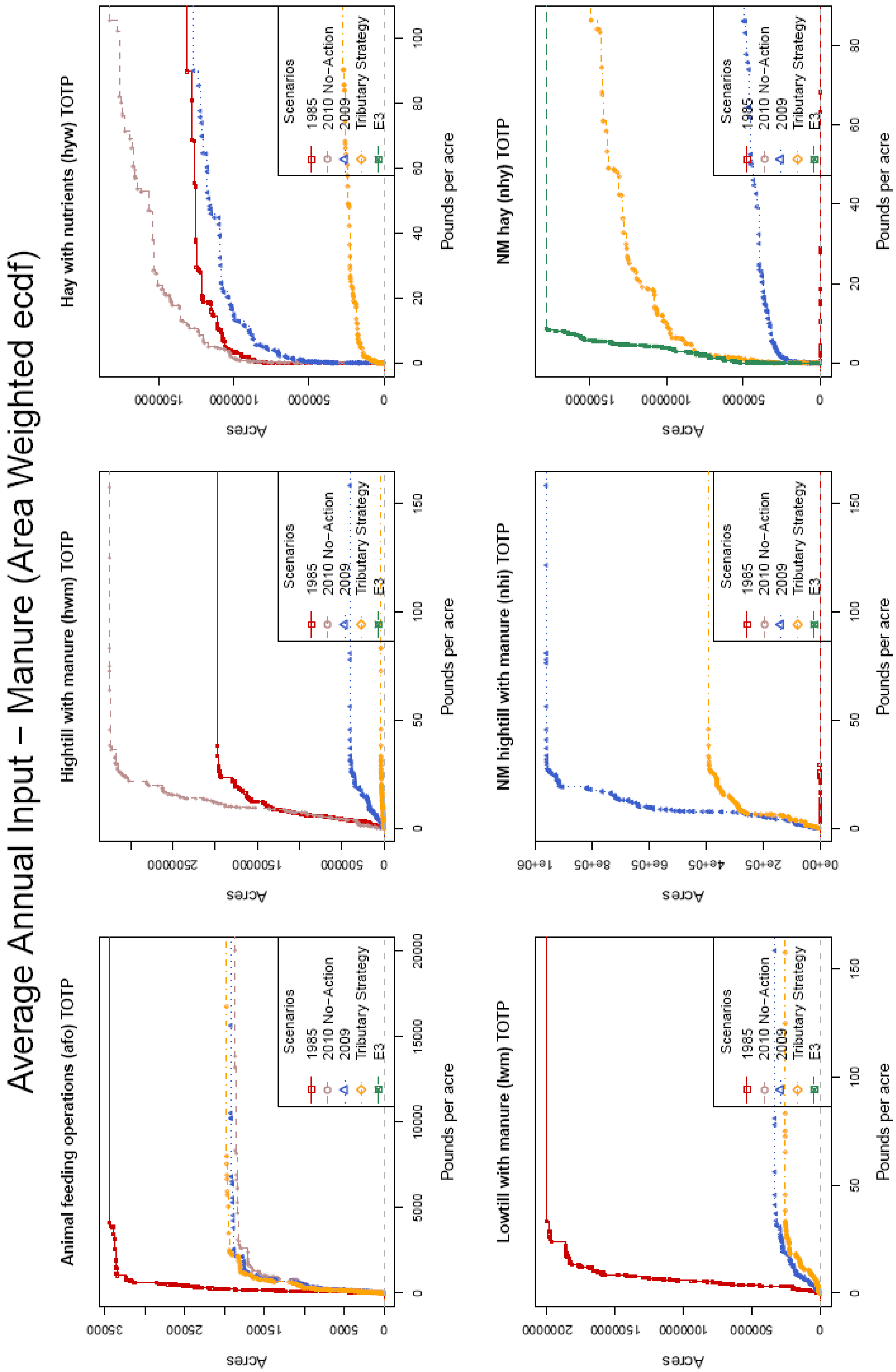


Figure 5-32. Area-weighted ECDF of annual total phosphorus manure input for Phase 5.3 key scenarios.

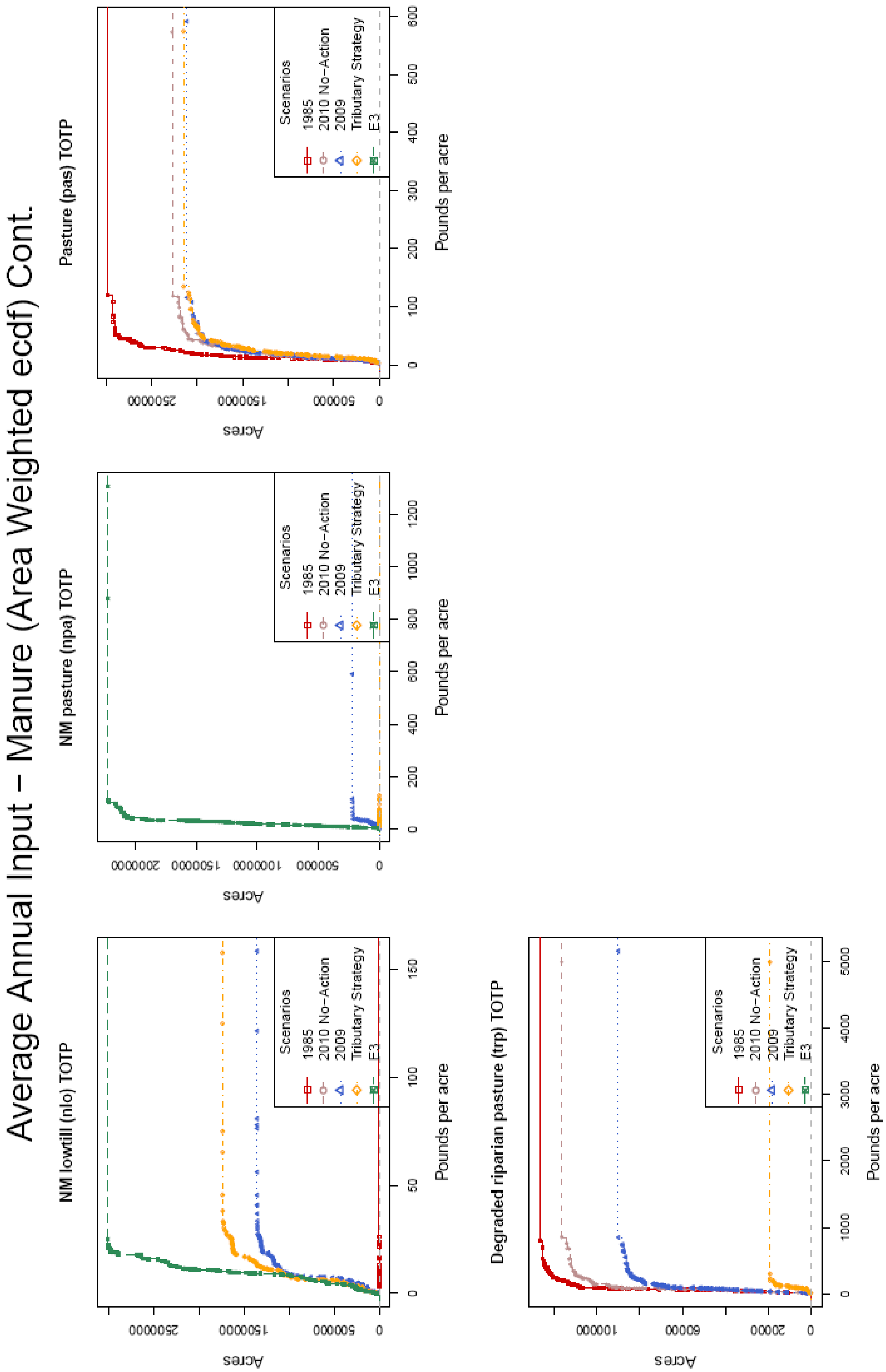


Figure 5-33. Area-weighted ECDF of annual total phosphorus manure input for Phase 5.3 key scenarios.

5.3.4 Legume Inputs

The Scenario Builder Version 2.2 calculates on a monthly time-step the amount of nitrogen that legumes fix (USEPA 2010). Nitrogen fixation includes the portion fixed in the roots and taken up into the plant. Legumes are a class of plants that generally grow pods. Legumes develop nodules on the roots that are a bacterial infection. The bacteria transform N_2 to NH_3, a process called nitrogen fixation. Thus, inert diatomic nitrogen from air is reduced and added to the plant-soil system. The Scenario Builder reports the pounds/acre of ammonia (NH_3) that is fixed by crop, county, month, and year.

The land uses where nitrogen fixation is simulated and a legume input is created are *hay with nutrients, high till with manure, low till with manure, and high till without manure* (Figure 5-34 and Figure 5-35). The nitrogen fixing crops in the mix of composite crops represented in these Phase 5.3 land uses are primarily timothy and other nitrogen fixing hays and grasses, and soybeans. The Agricultural Census categories that include legumes but are not exclusively legumes are not considered for legume fixation. The CBP assumes the area comprising legumes is insignificant. Nitrogen fixation amounts are not adjusted for temperature or rainfall in the Chesapeake Bay Program's Watershed Model. The exception is alfalfa. Nitrogen fixation for alfalfa is calculated by the Watershed Model so that rainfall and temperature data can parameterize fixation amounts.

Figure 5-34 and Figure 5-35 show area-weighted empirical cumulative distribution functions (ECDFs) of the watershed model Phase 5.3 legume input for the key scenarios. The graphs display the distribution of the amount of nitrogen that is fixed per year by cropland land uses versus the total acreage associated to those land uses for the key scenarios.

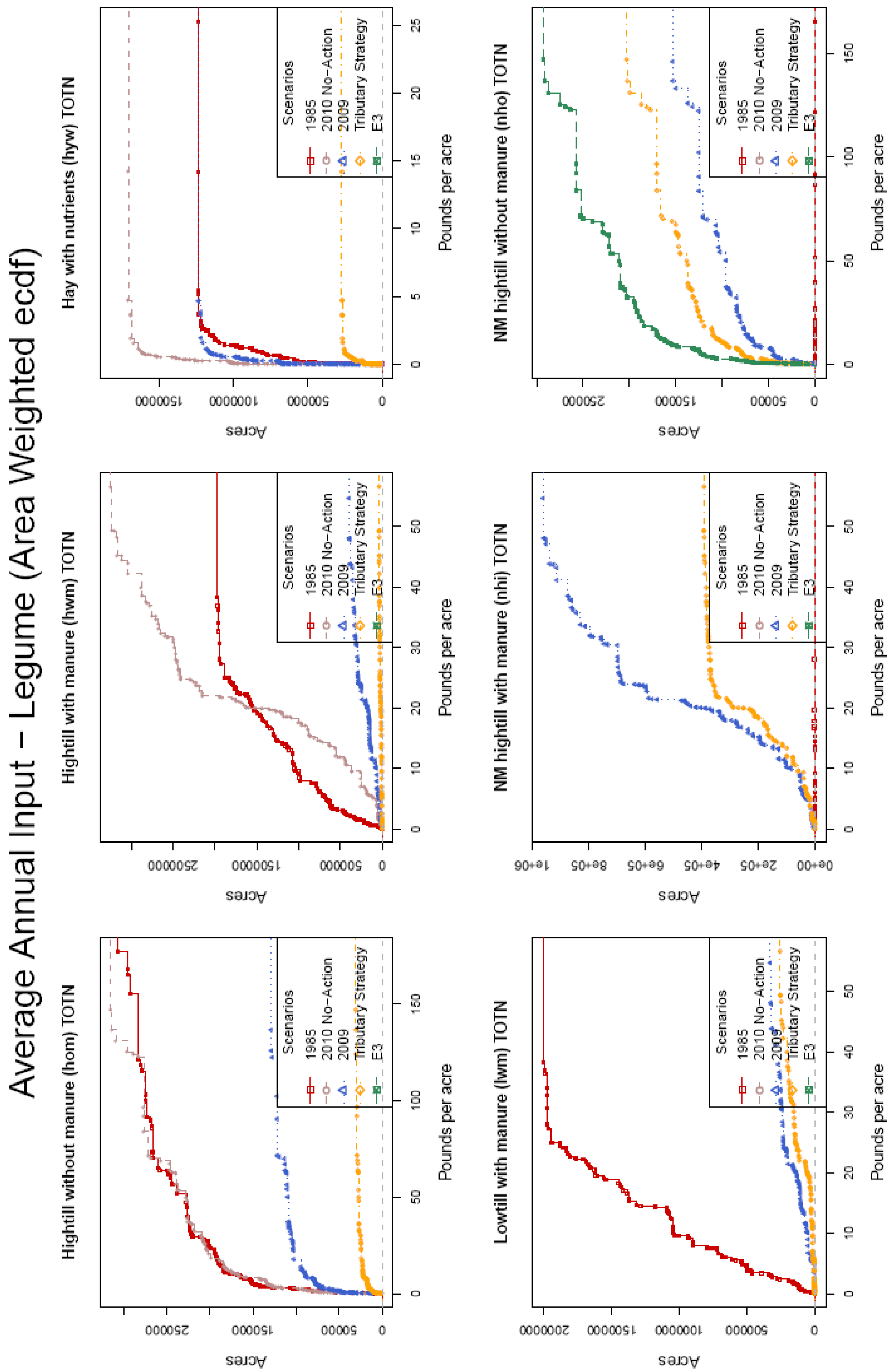


Figure 5-34. Area-weighted ECDF of annual total nitrogen legume input for Phase 5.3 key scenarios.

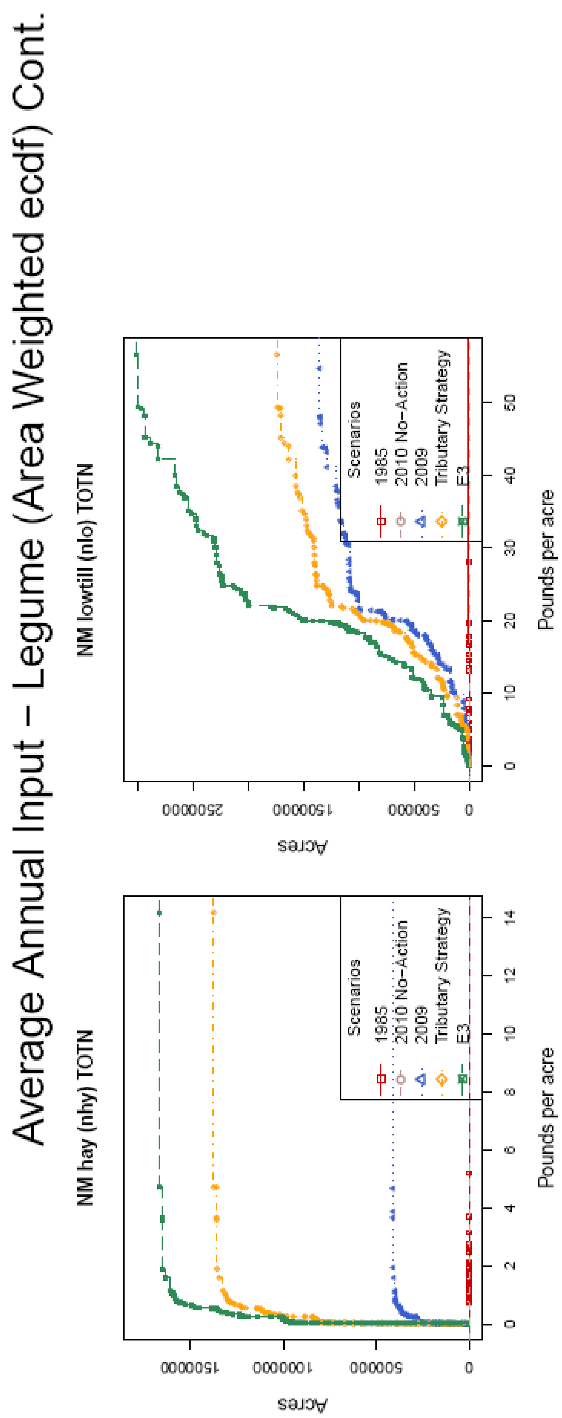


Figure 5-35. Area-weighted ECDF of annual total nitrogen legume input for Phase 5.3 key scenarios.

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