WATERSHED MODEL PHASE 4.3
CALIBRATION RULES

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INTRODUCTION

The Chesapeake Bay Watershed Model (WSM) has been in continuous operation at the Chesapeake Bay Program since 1982, and has had many upgrades and refinements since that time. The WSM described in this paper is application Phase 4.3, based on the Hydrologic Simulation Program - Fortran (HSPF) Version 11 (Bicknell, et al.,1996). HSPF is a widely used public domain model supported by the EPA, USGS, and Corps of Engineers.

The WSM calculates nutrient and sediment loads delivered to the Chesapeake Bay from all areas of the watershed (Donigian et al., 1994; Linker et al., 1996; Linker, 1996; Thomann et al., 1994). Land uses of cropland, pasture, urban areas, and forests are simulated on an hourly time step tracing the fate and transport of input nutrient loads from atmospheric deposition, fertilizers, animal manures, and point sources. The ultimate fate of input nutrients is simulated, so that they are either incorporated into crop or forest plant material, incorporated into soil, or discharged to river and Bay. Nitrogen fates include volatilization into the atmosphere and denitrification. Sediment is simulated as eroded material washed off land surfaces and transported to the tidal Bay. Scenarios are run for ten years (1985 to1994) on a one hour time step, and results are aggregated into daily loads and flows for input to the Chesapeake Bay Estuary Model Package (CBEMP) or in ten year average loads for comparison among scenarios.

To simulate the delivery of nutrients and sediment to the Bay, the watershed is divided into 89 major model segments based on hydrologic units, each with an average area of 187,000 hectares (Figure 1). Model segment boundaries are adjusted so that model segment outlets are close to monitoring stations. Observed water quality and discharge data are obtained from Federal and state agencies, universities, and other organizations that collect information at multiple and single land use sites (Langland et al. 1995). At the interface between the WSM and CBEMP models, model segments are further divided into 259 subsegments to deliver flow, nutrient, and sediment loads to appropriate areas of the tidal waters.

Nutrient and sediment loads from the following nonpoint sources are simulated: conventional-tilled cropland, conservation-tilled cropland, cropland in hay, pasture, pervious urban land, impervious urban land, forest, animal waste areas, and atmospheric deposition directly to water surfaces. Sediment is simulated from all pervious land surfaces using an empirically-based module (SEDMNT) which represents sediment detachment and export as a function of the runoff intensity. HPSF11 allows two types of nutrient export simulation from pervious land, AGCHEM and PQUAL. The AGCHEM group of subroutines simulate nutrient cycling and export mechanistically, using storages of nutrients in the soil and plant mass and parameters to govern movement between the storages. The PQUAL group of subroutines uses an empirically-based approach, with potency factors for surface runoff and monthly specified concentrations in the subsurface. Nitrogen cycling is simulated in forest using recent research of forest dynamics included in the AGCHEM subroutines for HSPF 11 (Hunsaker, 1994). Forest phosphorus is simulated using PQUAL. Crops are simulated using a yield-based nutrient uptake AGCHEM algorithm for both nitrogen and phosphorus. This method allows for the direct simulation of nutrient management practices. Pasture and pervious urban use AGCHEM for nitrogen simulation and PQUAL for phosphorus. Nutrient export from animal waste areas are simulated as a concentration applied to the calculated runoff. Impervious urban exports depend on nutrient storage that is incremented by a daily accumulation factor equal to the atmospheric deposition. This storage is then washed off as a function of the rainfall intensity

HSPF is a lumped-parameter model and each land use is simulated as an average for the entire segment. For example, conventional-tilled cropland is simulated as an average crop rotation of corn, soybeans, and small grains in a segment with an average model segment input of fertilizer and manure loads, and with average slope, soil conditions, and so on.

A consistent land use data base is compiled for the entire Chesapeake basin using a LANSAT derived GIS land cover as a base (U.S. EPA, 1994; Hopkins et al., 2000) . Detailed information on agricultural lands is obtained from the U.S. Census Bureau series, Census of Agriculture for 1982, 1987, and 1992 (Volume 1, Geographic Area Series) published for each state. Tillage information on a county level is obtained for the conventional and conservation cropland distribution from the Conservation Technology Information Center (CTIC) (Palace et al., 1998). State agricultural engineers provide fertilizer and manure application rates and timing of applications as well as information on crop rotations, and the timing of field operations. Soil characteristics for nutrient interaction are obtained from the Soils-5 data base (USDA, 1984). The USGS Land Use and Land Cover System (USGS LU/LC, Level II) is used to differentiate the urban land into five urban subcategories: residential, commercial, industrial, transportation, and institutional. Each urban subcategory is associated with a level of imperviousness. Other sources used to generate the land use data base are Soil Interpretations Records (SCS-SOI-5 data file) (1984), National Resources Inventory (NRI)(1984), Forest Statistics for New York, (1980), Forest Statistics for Pennsylvania, (1980), Forest Resources of West Virginia, (1978), and Virginia's Timber, (1978). Information on land slope and soil fines is provided by the NRI data base. Information on hydrologic characteristics of soils, such a percolation and reserve capacity, was obtained primarily from the Soil Interpretation Records. Delivery of sediment from each land use is calibrated to the NRI estimates of annual edge of field sediment loads calculated by the USLE (Universal Soil Loss Equation).

Precipitation is the primary forcing function in the WSM; simulated flow and nonpoint source loads primarily depend on the hourly input of precipitation. For the 12 years of hourly time-series input data, 147 precipitation stations are used, of which 88 are hourly records and 59 are daily records of rainfall. Typically, about six stations are used to develop the precipitation record for a model segment using the Thiessen polygon method for spatial distribution. The average daily precipitation rates are formed from all hourly and daily rainfall gages associated with a model segment. Then the total average daily precipitation rate is converted to an hourly record by choosing, for each day, the hourly gage closest in volume with the day's total average volume (Wang, et al., 1997).

Temperature, solar radiation, wind speed, snow pack, and dewpoint temperature data are from 7 primary meteorological stations in the watershed. Three back-up meteorological stations are used in cases when data is missing from the primary stations (Wang, et al., 1997).

Each WSM river reach is simulated as completely mixed waters of a fifth to seventh order river with all simulated land uses considered to be in direct hydrologic connection. Of the 44 reaches simulated, the average length is 170 kilometers, the average drainage area is 1900 square kilometers, and the average time of travel is one day. Seven of the reaches are impounded by reservoirs. One of the reservoirs, Conowingo (model segment 140), is used for power generation and is simulated with specific spill and release rules.

For the Phase 4.3 WSM, the period of 1984 through 1995 is used as the calibration time period. Previously, for version 4.0, calibration was on the 1984 to 1992 period and verification was performed on the period 1993 through 1995 period, without adjustment of the earlier 1984 -1992 calibration. Agreement between the WSM simulation and observed 1984-1992 data of the calibration period was compared with the agreement between the WSM and observed data for the 1992-1995 verification period with the finding of no significant difference in model accuracy.

LAND USE CALIBRATION RULES

All simulated land uses receive nitrogen inputs from atmospheric deposition. Other inputs include fertilizer and manures to cropland and hay land, and manure inputs to pasture. The urban simulation includes inputs of fertilizer and is associated with loads from point sources, On Site Waste Disposal Systems (OSWDS), and combined sewer overflows (CSO). Figures 2 and 3 describe the Phase 4.2 calibration quartile range of atmospheric, fertilizer and manure loads used for the different land use simulations. Development of these input nitrogen loads is described below. The simulation of nitrogen is a complete mass balance for all land uses, but the phosphorus load simulation uses a more simplified application of loading factors for pasture, urban, and forest land uses.

Conventional Tillage and Conservation Tillage Cropland

The approach used for the calibration of cropland is to simulate in a consistent manner the growth and nutrient uptake of estimated crop types, taking into account drought, heat stress, growing season, and using estimated nutrient inputs. Nutrient inputs to conventional tillage and conservation tillage cropland are from fertilizers, manure, and atmospheric deposition. Fertilizers and manures are applied at specific times and usually correspond with tillage and harvest operations. Crop types and insight into crop rotations are determined by the record of the 1987 Agricultural Census which provides county level information. Rates of fertilizer and input for each crop type are estimated by personnel in the state agriculture departments and the county Natural Resource Conservation Service (NRCS) offices. Manure inputs are calculated by an overall mass balance of manure in each segment based on the estimated year to year changes in animals, the composition of manures for each animal type, and the predominant manure handling operations (Palace et al., 1998). Agriculture Census records are used from 1982, 1987, 1992, or 1997 with other annual values interpolated between the years of record. . Wet and dry atmospheric deposition loads are input as a daily time series.

In the cropland simulation, as application loads increase, all else being equal, the nutrient export of nitrogen and phosphorus increase. This is seen in Figures 4-7. Deviation from the regression line of nutrient application versus nutrient export may be due to differences in hydrology, crop yields, soil type, and the needs of an overall basin-wide calibration. In the case of a basin-wide calibration modification, all land uses are calibrated to incrementally increase or decease nutrient export as needed at the calibration station. In land uses simulated by AGCHEM, the adjustments are made to the rates of soil organic mineralization and grassland uptake. For land uses simulated with PQUAL adjustments are made to potency and concentration factors.

Cropland nutrient load export has the same distribution as the nutrient inputs. Both are a gamma distribution, skewed to the right, as shown in Figures 9-11. This is consistent with the observation that most crop total application loads are relatively consistent with crop need, but in some regions, particularly those estimated to have manure in excess to crop need, application rates are several times that of the median.

Simulated cropland loads are compared to several reports of annual data of cropland loads synthesized from literature reports or model results (Figure 12). Beaulac and Reckhow (1982) looked at reported literature on cropland nutrient export from across the U.S. The SPARROW data is obtained from a spatially referenced regression model of the entire U.S. which is based on key watershed attributes (Alexander, et al., 2000). SPARROW data is available only for nitrogen. The Sweeney and Chang data is collected from published papers of cropland loads, weighted more to the Chesapeake Basin. The Watershed model total nitrogen (TN) loads are in general agreement with the other reported data except that the nitrogen export is high relative to the Beaulac and Reckhow data. This may be because the annualized surface and subsurface loads of Watershed Model cropland nitrogen are difficult to compare with the literature cited by Beaulac and Reckhow which seems to have a preponderance of surface load data without subsurface loads. Subsurface loads from cropland account for about half of the TN loads. Since phosphorus loads are mostly surface loads from cropland, the Watershed Model cropland loads of total phosphorus (TP) are in good agreement with Beaulac and Reckhow (Figure 13). The range of observed annual TN and TP loads is usually greater than the model range of export loads, consistent with the average simulation approach of each HSPF land use.

The spatial distribution of cropland loads, split into conventional tillage (hitill) and conservation tillage (lowtill) practices is shown in figures 14-17. The ranges shown are for edge of stream per acre loads of total nitrogen and total phosphorus. The pattern shows some areas of high loads, such as the lower Susquehanna and Eastern Shore, which have both high per acre loads and a high proportion of land in crops. Other segments may show up as high loads on a per acre basis, but have little area in cropland, such as in the Appalachian Highlands and in the Ridge and Valley region of the watershed.

To get a sense of the fate of crop nutrients, these data are included from the Phase 4.2 calibration. For an average hectare of conventional or conservation crop land, the nitrogen loading rate for fertilizer, manure, and atmospheric deposition is 102.2 kg/ha-yr, 26.7 kg/ha-yr, and 11.5 kg/ha-yr respectively. For phosphorus the average loading rate is 28.2 kg/ha-yr for fertilizer and 7.4 kg/ha-yr for manure.

Figure 18 describes average simulated cropland nitrogen dynamics for the Phase 4.2 calibration. The primary fates of nitrogen and phosphorus applied to crop land are uptake and harvest of crops, at 116.0 kg/ha-yr and 27.9 kg/hr-yr respectively. Export to rivers accounts for 23.8 kg/ha-yr nitrogen and 2.1 kg/ha-yr for phosphorus on average. The remainder is incorporated into the soil, attenuated in low order streams, or, for nitrogen, lost through volatilization or denitrification.

Hay Cropland

Cropland in hay is a major land use in the Chesapeake watershed. Input to cropland in hay is primarily fertilizers. In some regions of high animal populations, manure loads are also applied to hay land. Hay cropland is calibrated the same as conventional and conservation tilled cropland. Figures 19-20 are plots of hay nutrient export relative to application loads. Figures 21-22 show the gamma frequency distribution of the hay cropland nutrient export. As in cropland, The Watershed Model loads of nitrogen are higher than those of Beaulac and Reckhow, but are in good agreement for phosphorus (Figure 23-24). The spatial distribution of total nitrogen and total phosphorus loads on an annual edge-of-stream basis is shown in Figures 25-26.

Using the Phase 4.2 calibration data, the average nutrient dynamics for cropland in hay simulated in the WSM are described in Figure 27. Nitrogen input rates of fertilizer, manure, and atmospheric deposition are 19.3 kg/ha-yr, 13.2 kg/ha-yr, and 11.5 kg/ha-yr respectively. Phosphorus inputs to hay land are 17.0 kg/ha-yr for fertilizer and 3.7 kg/ha-yr for manure. Crop uptake and harvest accounts for 53.1 kg/ha-yr for nitrogen and 14.3 kg/ha-yr for phosphorus. Export to rivers is 12.0 kg/ha-yr and 1.1 kg/ha-yr for nitrogen and phosphorus respectively. These average Phase 4.2 values of hay cropland will be updated for the Phase 4.3 calibration.

Pasture

Inputs to pasture are from manure of pastured animals and atmospheric deposition. Manures are applied daily in the pasture simulation. Application rates are based on the number of pastured animals as estimated from the Agricultural Census and an estimate of the portion of time each animal type spends on pasture (Palace et al., 1998). A consistent nutrient uptake rate for pasture grass is applied throughout the watershed. Pasture total nitrogen exports follow closely the application rates on pasture, particularly for the manure application rate (Figure 28). The exported nutrient loads from pasture reflect the stocking rate and are driven by the Agricultural Census numbers of pastured animals and acres of pasture. For phosphorus, the export rate is a function of both the application rate and on the fraction of the pasture that is wooded (Figures 29-30). The frequency distributions are shown in Figures 31 and 32 for pasture total nitrogen and total phosphorus loads respectively. Consistent with literature values for woody pasture, the areas of wooded pasture are assumed to be on areas of steeper slopes and have relatively higher sediment and phosphorus loads.

As expected, the higher stocking rates on some pastures, as determined by the Agricultural

Census data of animal numbers and pasture land acres, causes these distributions to be skewed to the right, i.e., most of the exported load is clustered around the median value, but a few model segments have much higher exports due to higher estimated stocking rates. Comparisons with literature values are shown in figures 33-34. The spatial distribution on a pounds export per unit acre edge-of-stream basis are shown for the ten year average in figures 35-36.

Average nitrogen dynamics for pasture as simulated in the Phase 4.2 Watershed Model are described in Figure 37. Annual average input rates of nitrogen in manure and atmospheric deposition are 42.4 kg/ha-yr and 11.5 kg/ha-yr respectively. Phosphorus loads to pasture from manure are estimated to be 11.4 kg/ha-yr. Grass uptake and harvest, presumably by pastured animals, accounts for the greatest portion of the input nitrogen fate. Transport to rivers accounts for 9.3 kg/ha-yr of the nitrogen load and 0.38 kg/ha-yr of the phosphorus load. These data will be updated to the Phase 4.3 calibration values.

Urban Land

Urban land in the WSM includes anthropogenically altered landscapes that are not forest or agricultural land. Urban land includes all structures (including farm structures), roads, railroads, airports, transmission right-of-ways, communication facilities, undeveloped urban land, etc. Inputs to urban lands include fertilizers and atmospheric deposition. Urban nonpoint source loads are calibrated, based on the level of imperviousness, to expected urban loads determined by a regression on the National Urban Runoff Program (NURP) data as described by Schueler (1987). Another land use associated with the urban areas is the category of nonagricultural herbaceous. This is an herbaceous land use that does not register as an urban land use in the EMAP LANSAT data, and is not accounted for in the Agricultural Census data. It is thought that nonagricultural herbaceous land use is a combination of urban park land, golf courses, large lot residential, cemeteries, other institutional lands and land in conversion from agriculture to urban. The nonagricultural herbaceous land use is treated by a separate set of calibration rules.

Loads from point sources, CSOs, and OSWDS are associated with urban land and are input directly to the river reach. Point source inputs from municipal and industrial sources are developed from state National Pollution Discharge Elimination System (NPDES) records. If no state NPDES data are available, state and year-specific default data are calculated for each missing parameter and annual estimates of load are based on flow from the wastewater treatment plant. Several cities in the watershed have a sewer system with CSOs including Washington, D.C., Richmond, VA, and Harrisburg, PA. Estimates of the average annual discharge from these CSOs is only available for Washington, D.C. and these data are an estimate of average annual discharge. The annual average discharge is evenly distributed over the simulation period. Detailed information on point source and CSO loads in the Chesapeake Bay watershed can be found in Chesapeake Bay Watershed Model Application and Calculation of Nutrient and Sediment Loads - Appendix F: Point Source Loads (Wiedeman and Cosgrove, 1998).

Loads from OSWDS are compiled using census data and methodology suggested in Maizel and Muehlbach (1995). Onsite Waste Disposal Systems are simulated as a nitrate load discharged to the river. Phosphorus loads are assumed to be entirely attenuated by OSWDS. The OSWDS loads are determined through an assessment of the census records of waste disposal systems associated with households. Standard engineering assumptions of per capita nitrogen waste and standard attenuation of nitrogen in the septic systems are applied. Overall, the assumption of a load of 4.04 kg/person-year is used at the edge of the OSWDS field, all in the form of nitrate. Attenuation through groundwater and though smaller order streams until discharge to a fifth or larger order stream is assumed to be 60%. Total OSWDS loads delivered to the edge-of-stream are 5.9 millions of kilograms of nitrogen (Palace, M.W., et al., 1998).

Impervious urban land is simulated as an impermeable surface which daily accumulates nitrate from dry atmospheric deposition and periodically receives wet deposition loads, when both the wet deposition and the accumulated dry deposition are washed off. The washoff of the accumulated nitrogen occurs after the satisfaction of surface interception, and occurs at a rate proportional to the overland flow. During periods of no rain, nitrate dry deposition is subject to a decay rate which allows atmospheric dry deposition to only build up to an arbitrary maximum accumulation of twenty times the daily dry deposition load. Dry deposition of phosphorus and organic nutrients on impervious urban surfaces are simulated in a similar manner. Pervious urban land is an AGCHEM simulation which incorporates a first order uptake rate for turf.

The calibration sequence for urban land is to first calibrate the impervious urban loads relative to the estimates of the observed atmospheric deposition of wet fall and dry fall nitrogen (Figure 38). There is no estimated cline of observed atmospheric deposition loads of phosphorus. The next step in the calibration of urban land use is to use the known level of urban land imperviousness for the urban land in a segment and the NURP derived regression to calculate an expected urban load for nutrients (Figures 39-40). Deviation from the least squares line is due to differences in precipitation and due to calibration adjustments of the major basins. Frequency distributions for urban TN and TP are more normally distributed due to the distribution of imperviousness in the watershed. Departure from a normal distribution, particularly seen in the TP plot is primarily due to basin-wide calibration needs which adjusted all simulated land uses in a basin (Figures 41-42). Comparison with literature values for urban nutrient loads is shown in Figures 43-44. The SPARROW urban loads are high due to the inclusion of point source loads in the SPARROW estimates. Spatial distribution of urban loads are shown in Figures 45-46.

The calibration of the nonagricultural herbaceous land use is confounded by a lack of data and with a definition which is based on what it is not. Nonagricultural herbaceous is land use in grass that is not agricultural land, but not urban land either. The land use is derived from the difference between what satellite imagery classifies as herbaceous, or grass, and what the Agricultural Census classifies as agricultural land. Nonagricultural herbaceous land use is simulated as part of the pervious urban category, but is given a separate "weight" in terms of land area and loading characteristics. As the nonagricultural herbaceous was thought to be related to some extent to developed land, but the degree of development was considered to be slight, nonagricultural herbaceous land was calibrated to have half the TN and TP loads as that of pervious land use within the segment. Distribution frequencies for nonagricultural herbaceous nutrient loads are given in Figures 47 and 48.

Forest

In the WSM simulation, nitrogen inputs to forests are assumed to be from atmospheric deposition only. Nitrogen fixation can also contribute nitrogen to forest land through certain species of trees and from nonsymbiotic nitrogen fixation, but these loads are not considered in the model. Nonsymbiotic nitrogen fixation in temperate forest may range between 1 to 6 kg/ha-yr (Boring et. al., 1988). Denitrification is an important process in forests having poorly drained soils, but in forests with well drained soils, the denitrification rate may rage from 0.2 to 2.1 kg/ha-yr to as high as 3 to 6 kg/ha-yr in clear-cut forests. Given the spatial heterogeneity of these two processes and their relatively equal rates, nitrogen fixation and denitrification are not explicitly included in the WSM simulation of forests (Hunsacker et al., 1994). Calibration of forest is achieved though the parameterization of the HSPF forest module as suggested by Hunsacker (1994) and by assuming that forests with the highest inputs of atmospheric nitrogen loads export the highest nitrogen load (Figure 49). Frequency distributions for forest TN and TP loads are shown in Figures 50 and 51. Comparisons with literature values from synthesis papers and SPARROW results are shown in Figures 52 and 53 and the spatial distribution of forest edge of stream, per acre loads are shown in Figures 54 and 55.

Phase 4.2 export nitrogen loads from forest are estimated to be 3.4 kg/ha-yr and 0.06 kg/ha-yr for phosphorus loads. Forest average nitrogen dynamics simulated in the WSM are described in Figure 56. Forest nitrogen dynamics will be updated to Phase 4.3 results. The use of PQUAL to simulate forest phosphorus precludes estimating the phosphorus mass balance.

Animal Waste Areas

Simulated animal waste areas represent in the landscape areas of concentrated manures that are susceptible to runoff including loafing areas, feed lots, and manure piles. Animal waste areas are simulated as an impervious surface. The extent of animal waste area in each model segment is determined by the Agricultural Census estimate of animal numbers and types, and estimates of agricultural practices as described in Tracking Best Management Practice Nutrient Reductions in the Chesapeake Bay Program (Palace et al., 1998).

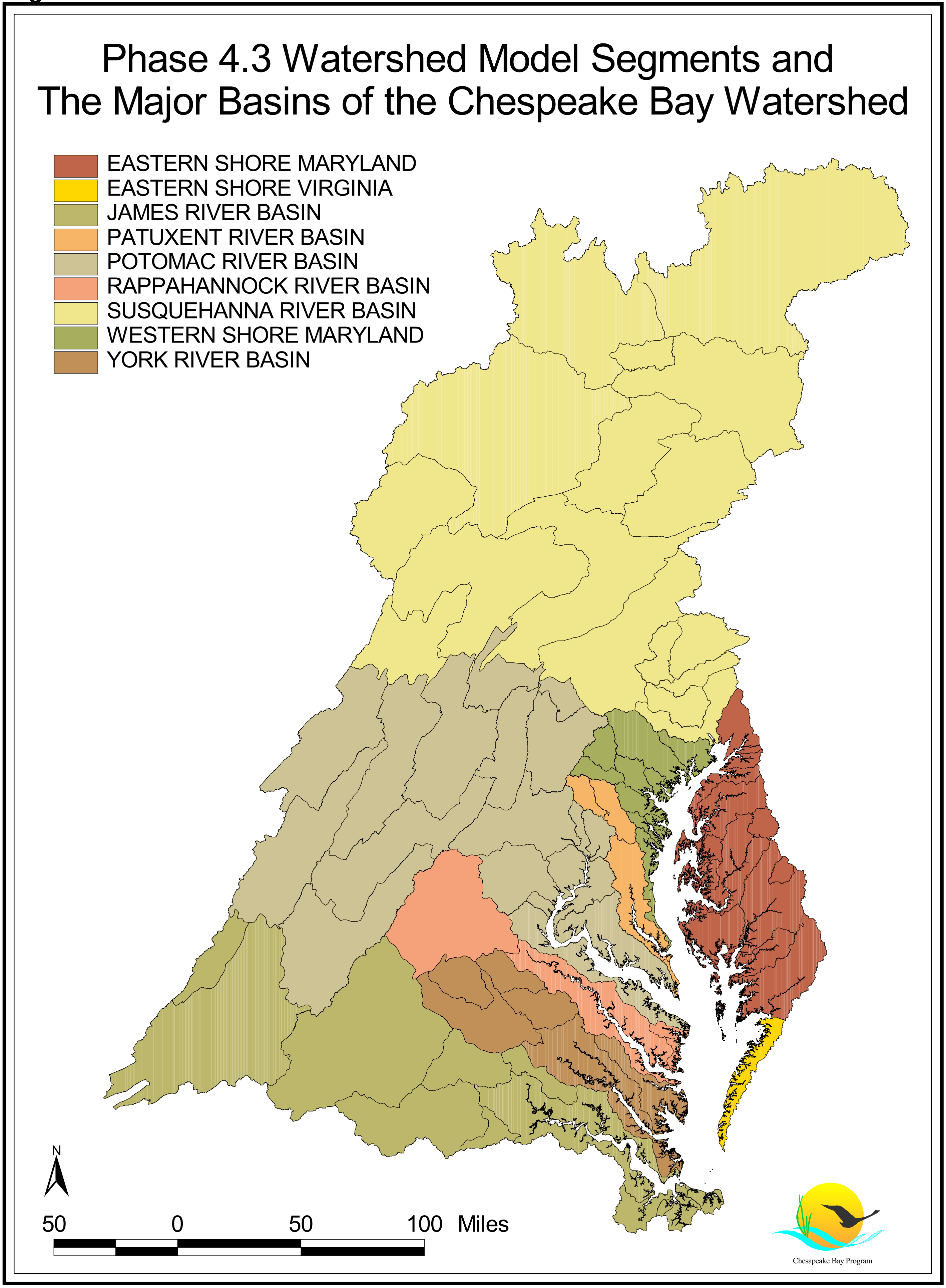
REACH SIMULATION RULES

The riverine simulation includes the HSPF modules simulating sediment transport, oxygen transformations such as reaeration and benthal sediment oxygen demand, ammonification, nitrification and other first order microbially mediated nutrient transformations, and the simulation of periphyton and phytoplankton. Reach calibration of the is to 14 monitoring stations. Paramaterization for a discrete set of reach parameters is fixed to literature values observed in the field or laboratory. These parameters include algal stoichiometry, maximum growth rates, half saturation constants for light and nutrients, etc. Other parameters, such as settling rates, would be expected to change from reach to reach and these parameters are allowed to vary between model segments.

CONCLUSION

Comparisons were made between average annual nutrient export calculated by the WSM by land use type and observed nutrient export data synthesized by Blealock and Reckhow (1982), Sweeney and Chang, or simulated by SPARROW. Overall, the simulation shows good agreement with the nutrient export median and ranges. Where it departs from the reported export ranges the reasons are understood. Extremes in the WSM range of load is primarily due to extremes in nutrient inputs. For example the high nutrient loads on pasture are associated with high stocking rates on pasture as determined by the Agricultural Census. Likewise, high loads in cropland are due to high nutrient loads from fertilizers, manure, or both. Similar patterns found with urban loads, are being driven primarily by the amounts of impervious urban land use. For forests, the primary influence is the amount of atmospheric deposition of nitrogen. The calibration of land use was followed by a calibration of the river reaches and if needed, an iterative approach of calibration of both.

Figure 1


Phase 4.3 Watershed Model Segments and
The Major Basins of the Chespeake Bay Watershed
EASTERN SHORE MARYLAND
EASTERN SHORE VIRGINIA
JAMES RIVER BASIN
PATUXENT RIVER BASIN
POTOMAC RIVER BASIN
RAPPAHANNOCK RIVER BASIN
SUSQUEHANNA RIVER BASIN
WESTERN SHORE MARYLAND
YORK RIVER BASIN
N
50
0
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100
Miles
Chesapeake Bay Program

Figure 2. Quartile Ranges and Extremes of Nitrogen Inputs from Atmospheric Deposition, Fertilizer, and Manure

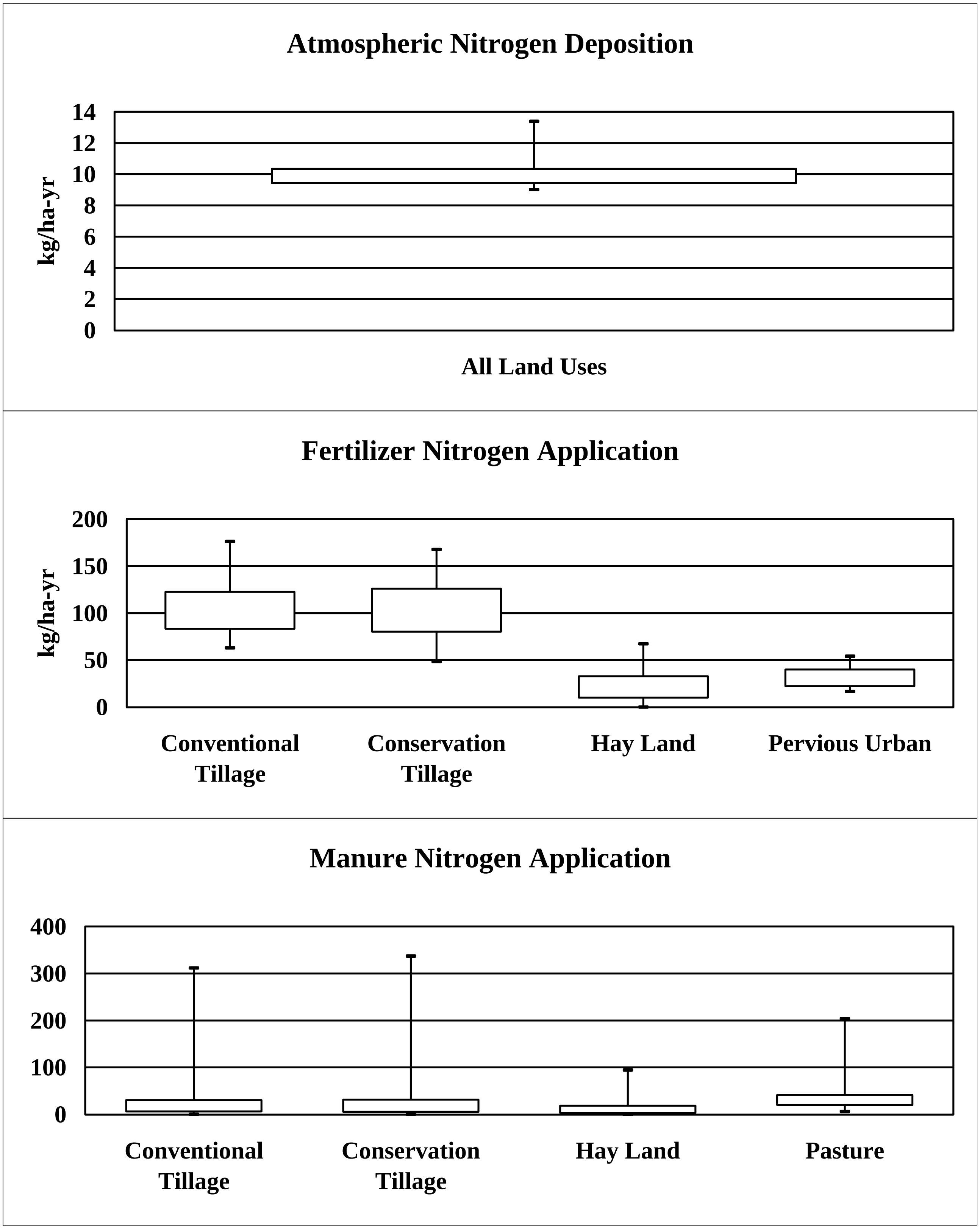


Figure 3. Quartile Ranges and Extremes of Phosphorus Inputs from Fertilizer, Manure, and Mineralization

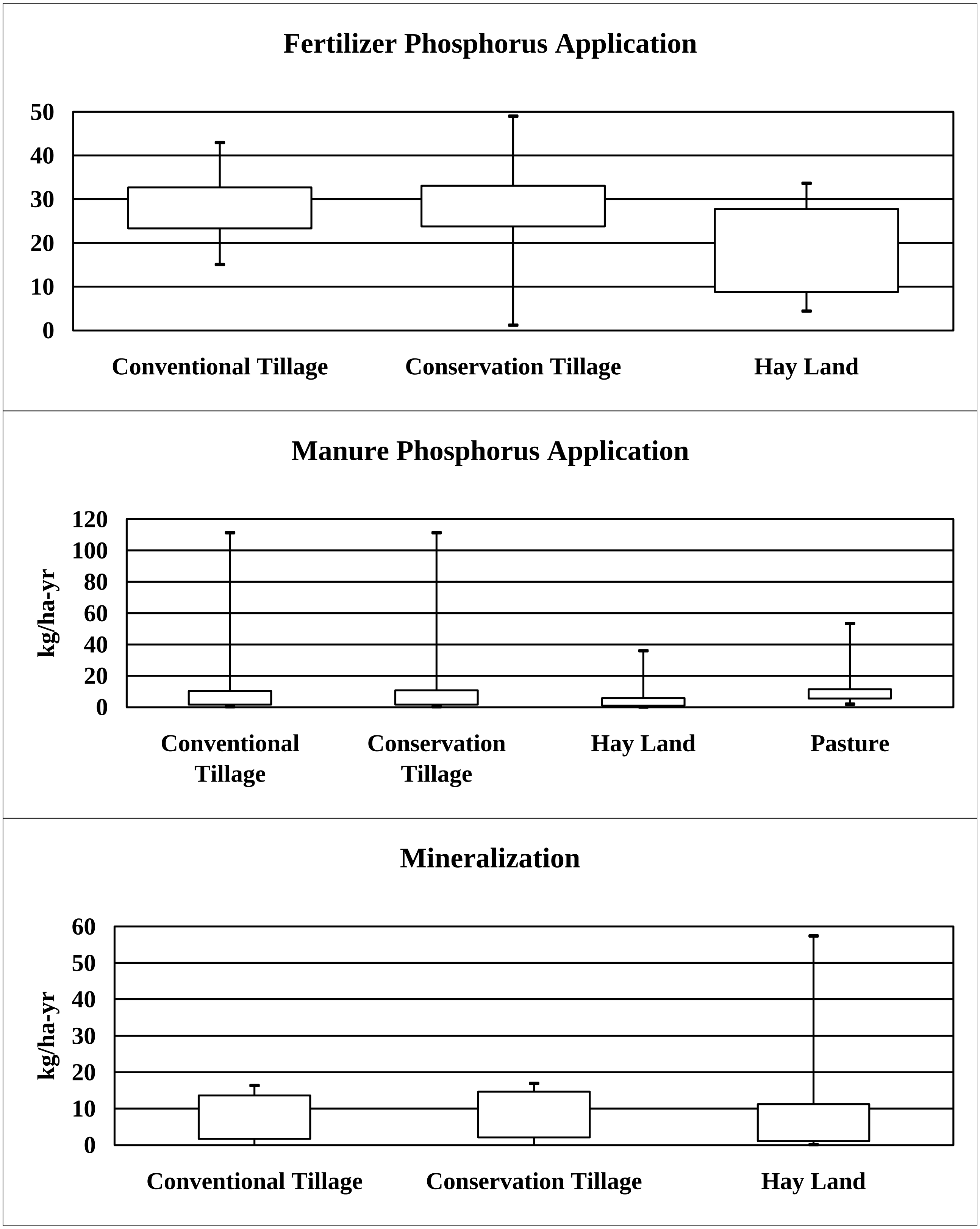


Figure 4. High Tillage TN Export vs TN applications

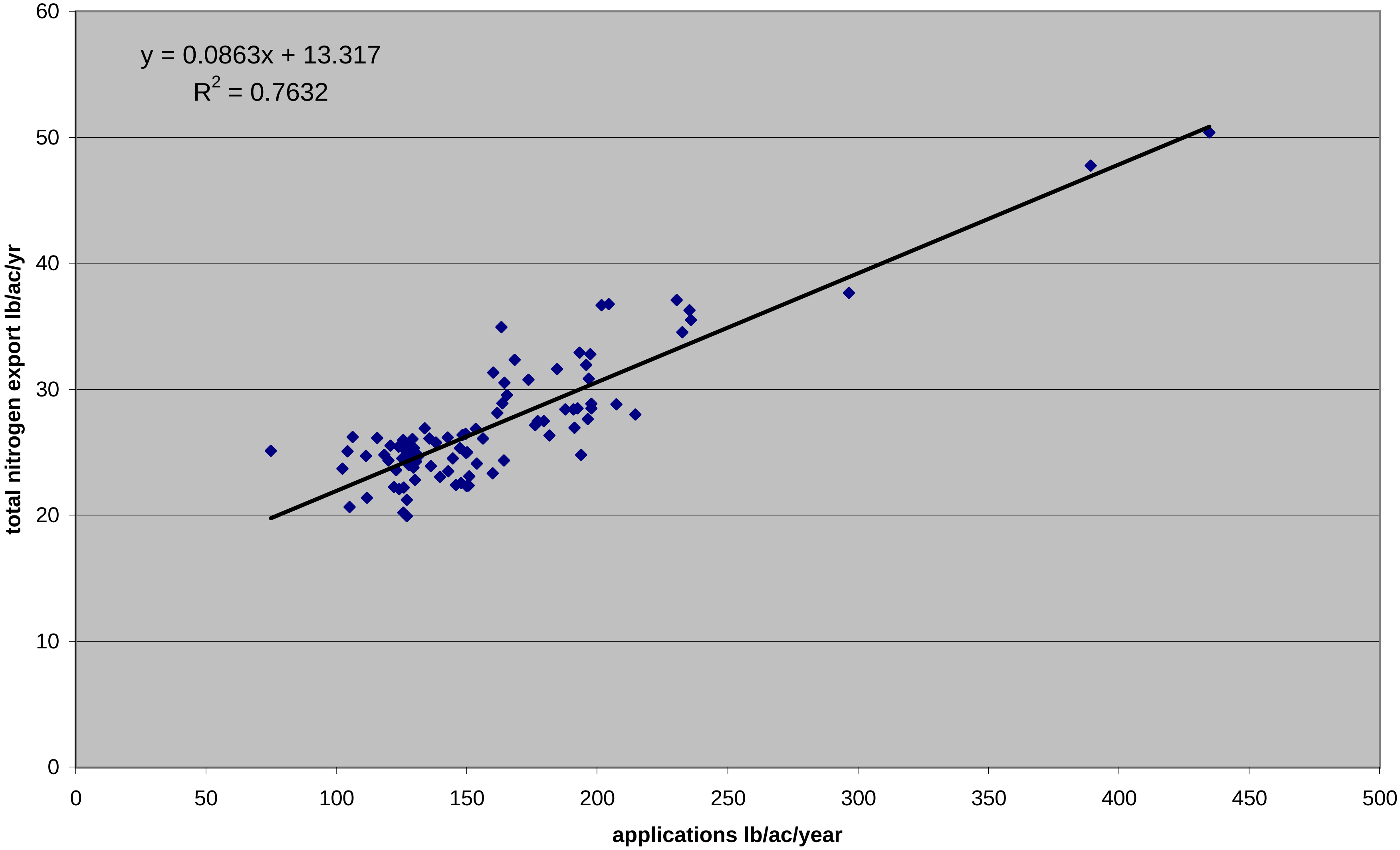


Figure 5. Low Tillage TN Export vs TN applications

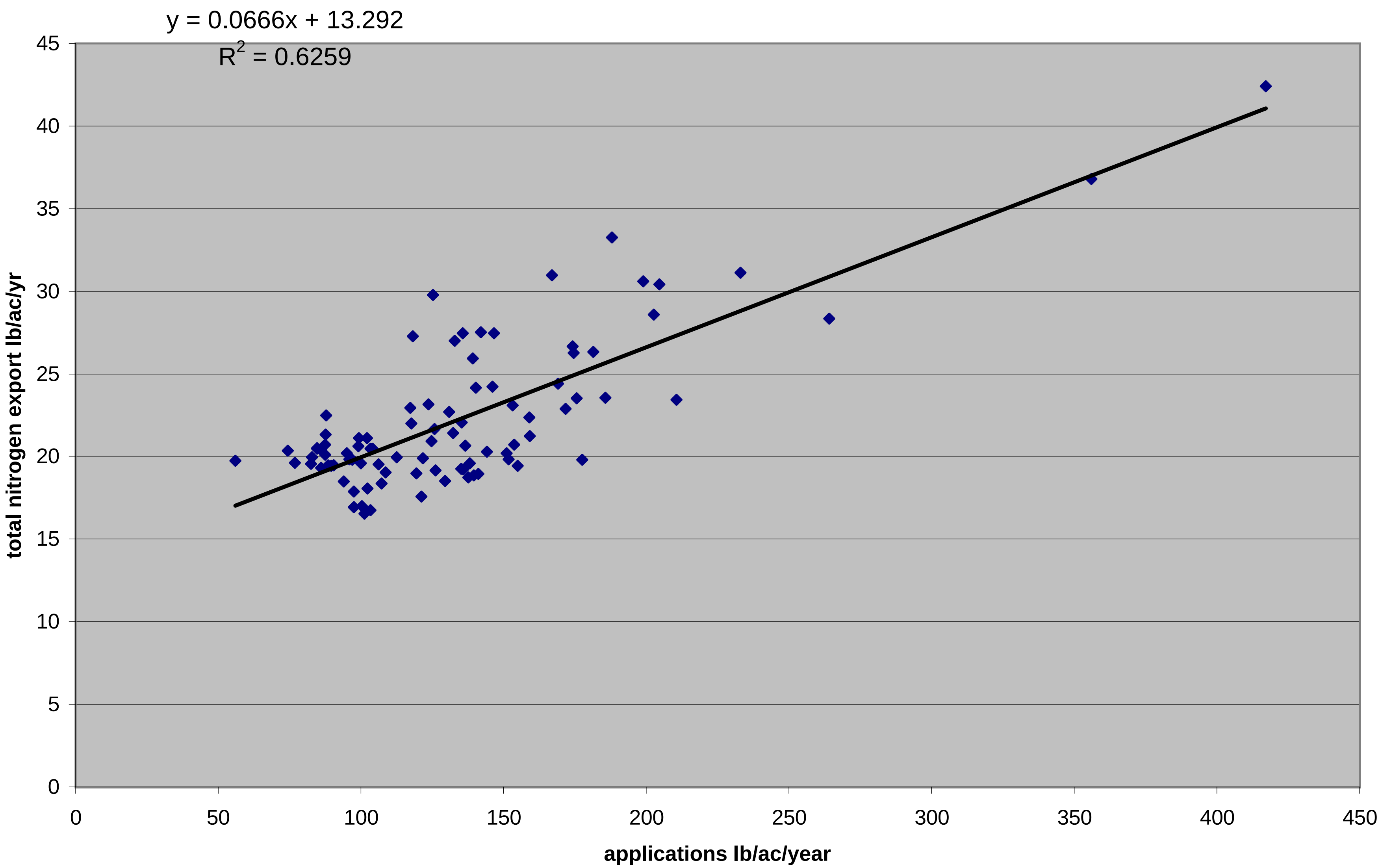


Figure 6. High Tillage TP Export vs TP applications

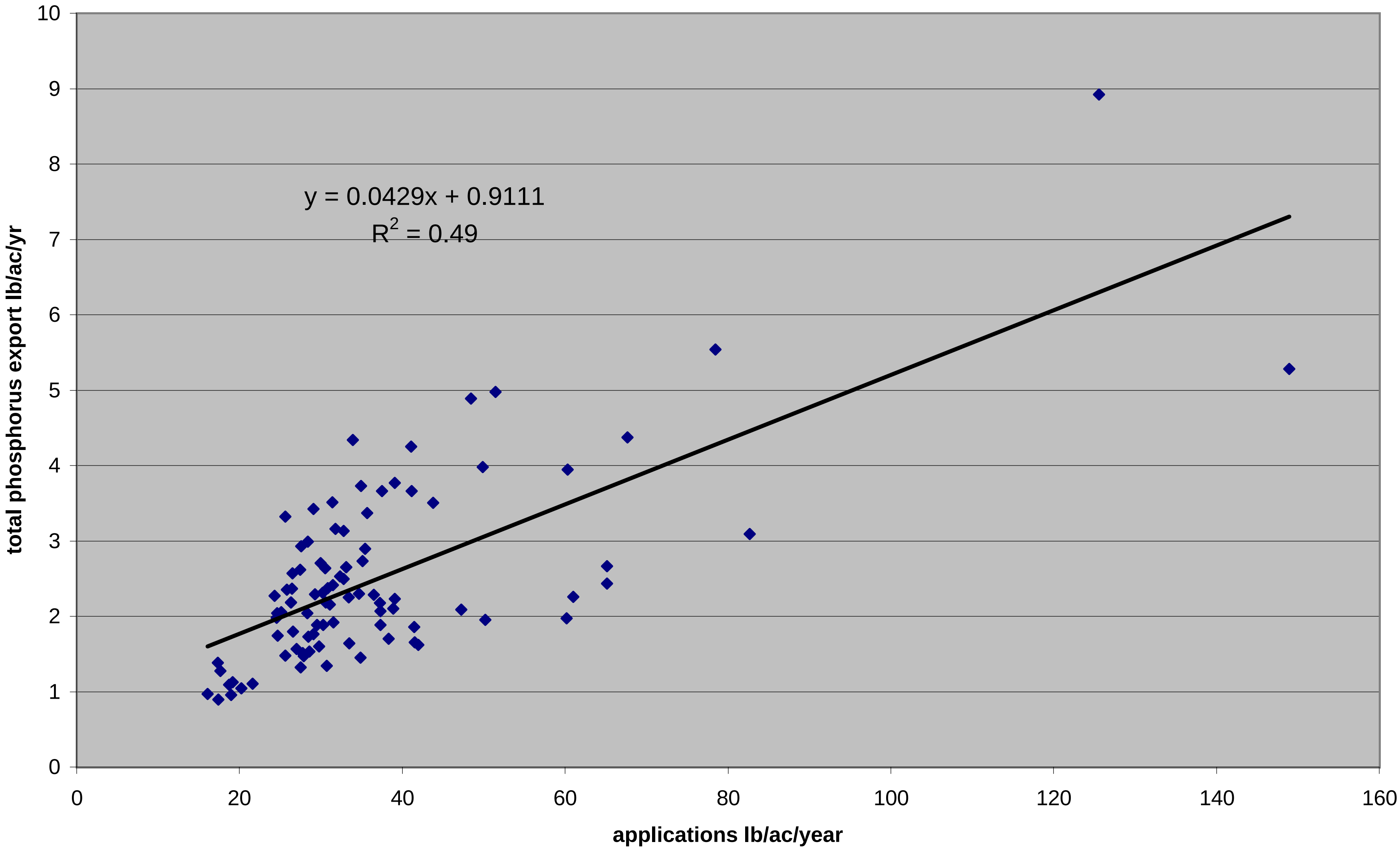


Figure 7. Low Tillage TP Export vs TP applications

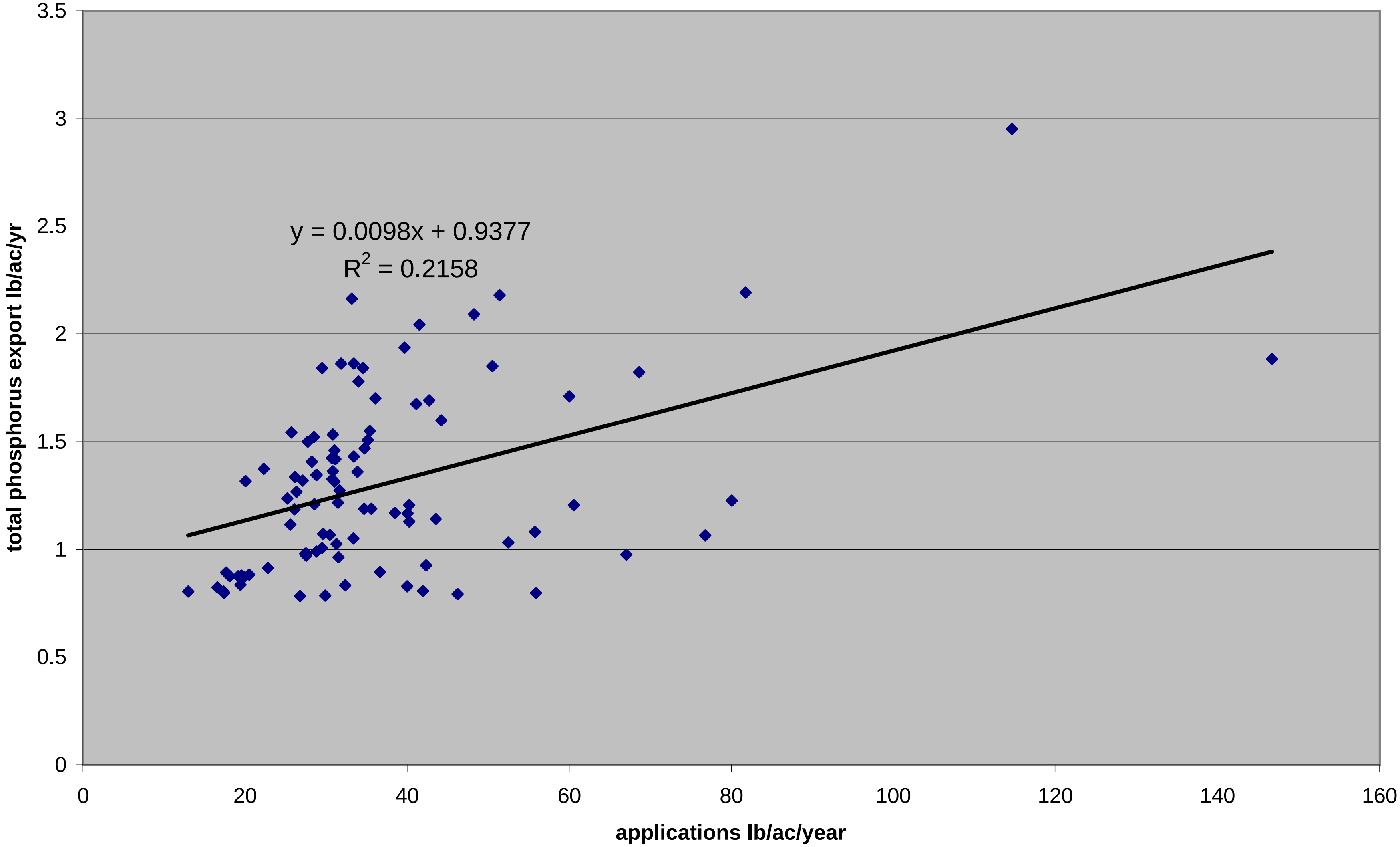


Figure 8. Total Nitrogen High Tillage Crop Export

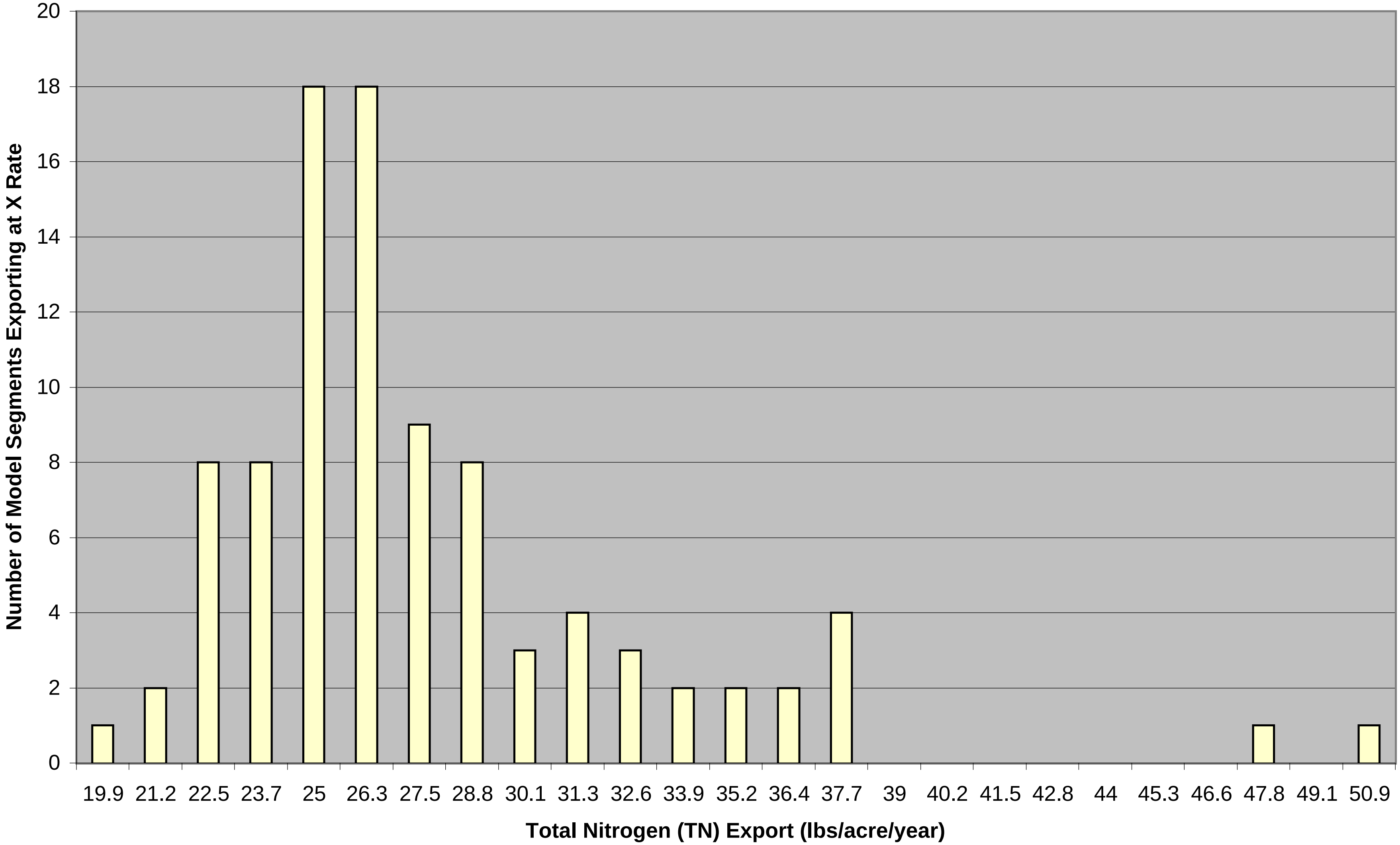


Figure 9. Total Nitrogen Low Tillage Crop Export

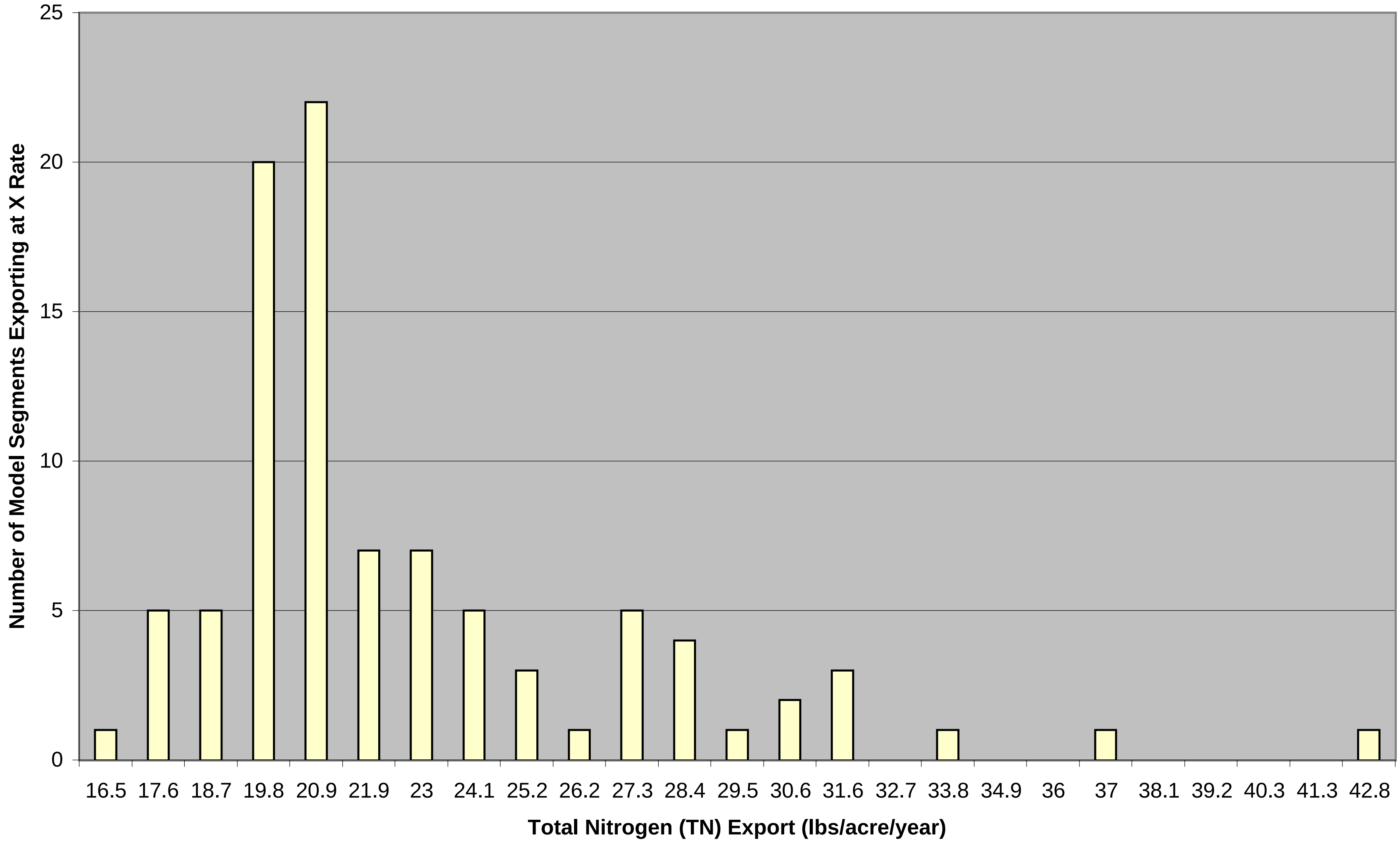


Figure 10. Total Phosphorous High Tillage Crop Export

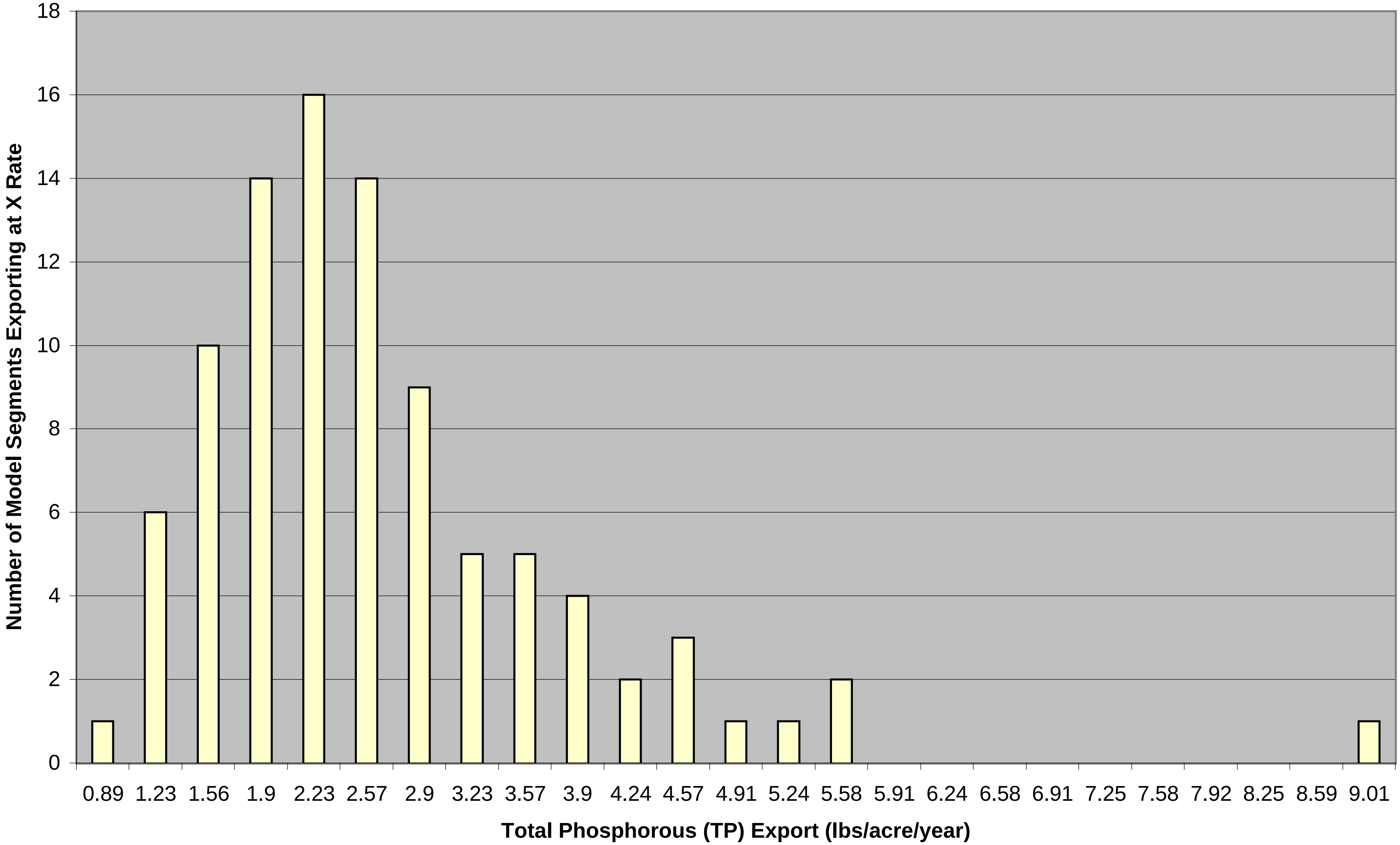


Figure 11. Total Phosphorous Low Tillage Crop Export

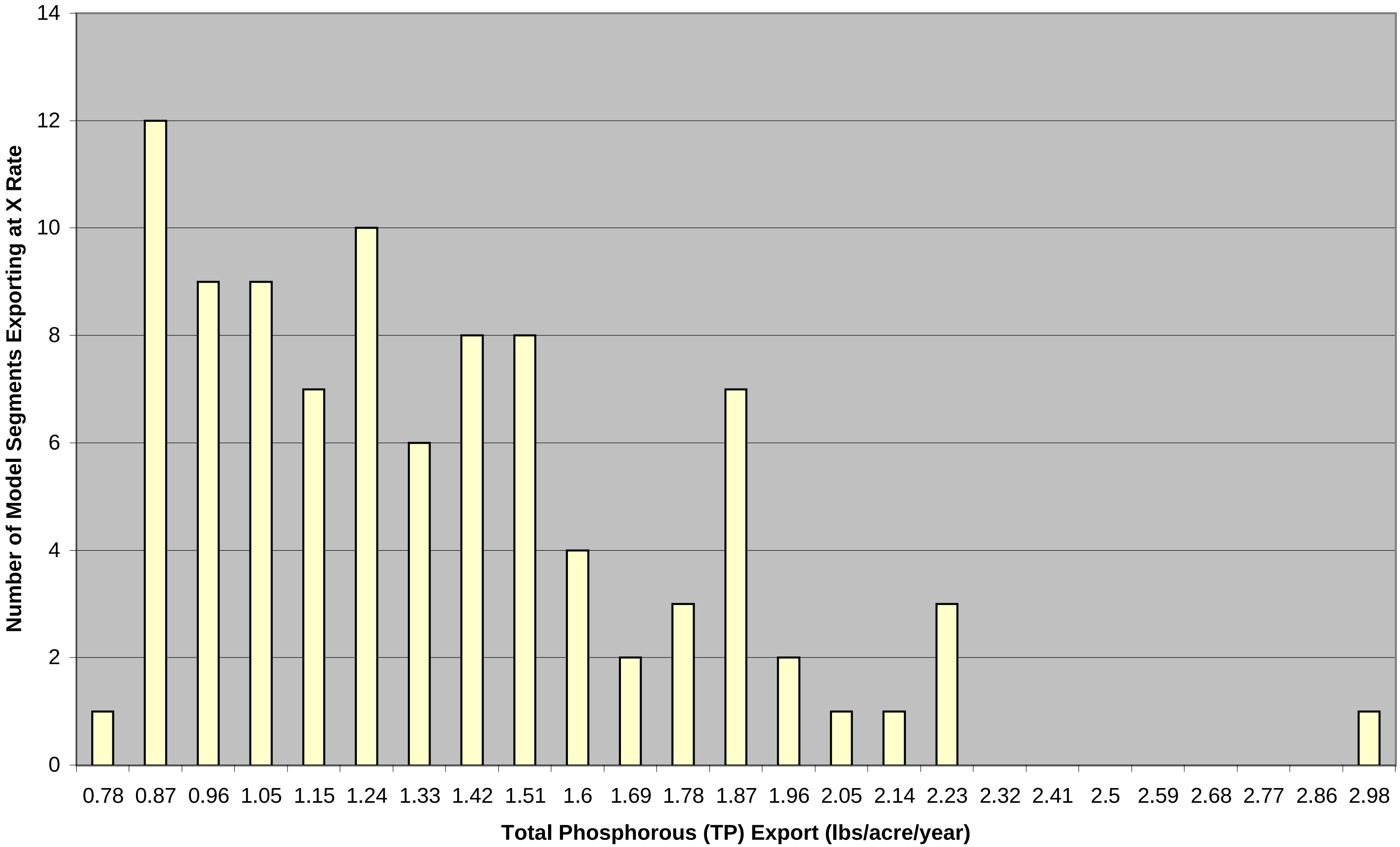


Figure 12. Crop Nitrogen

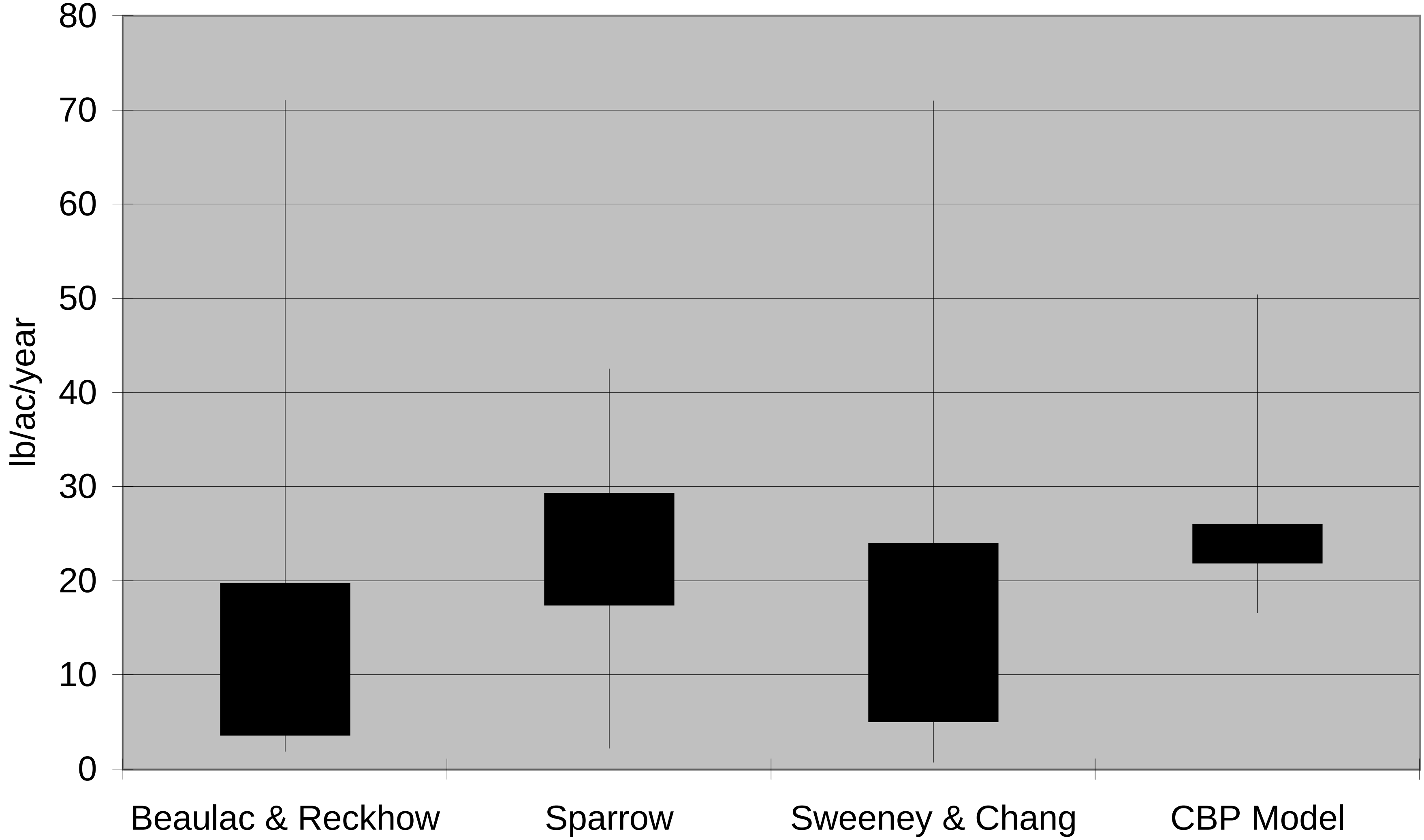


Figure 13. Crop Phosphorus

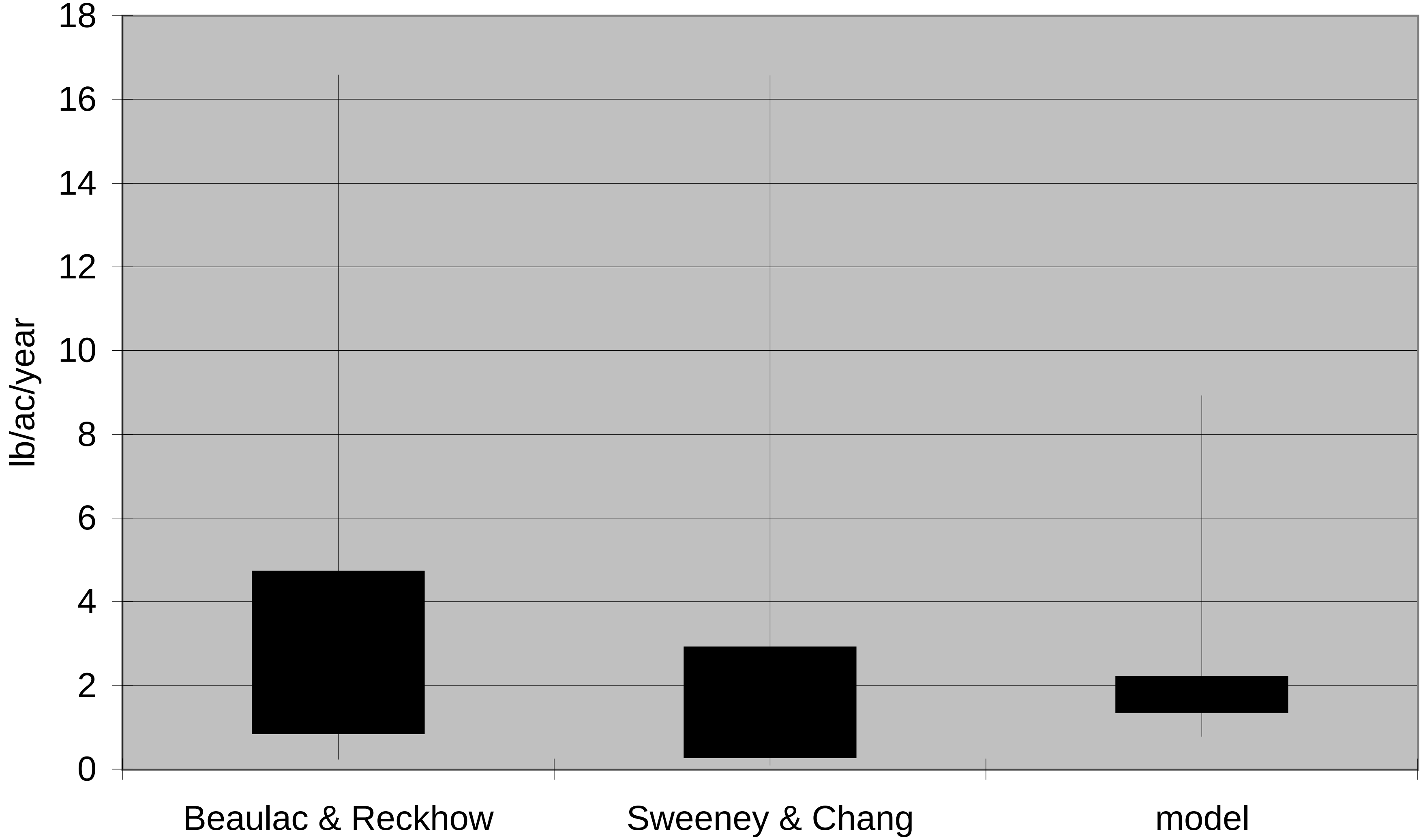


Figure 14.

Phase 4.3 Watershed Model Land Use Loads

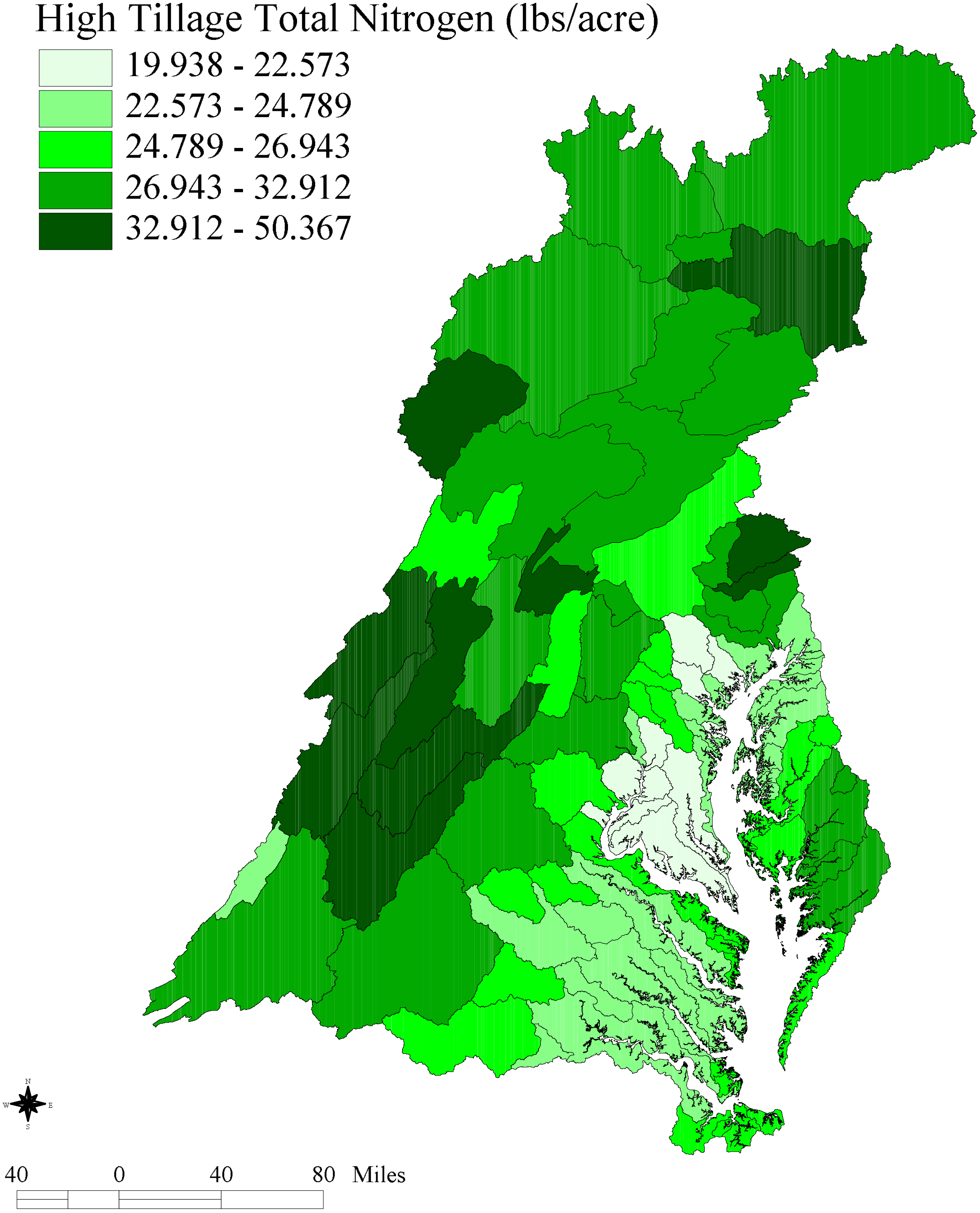


Figure 15.

Phase 4.3 Watershed Model Land Use Loads

Low Tillage Total Nitrogen (lbs/acre)

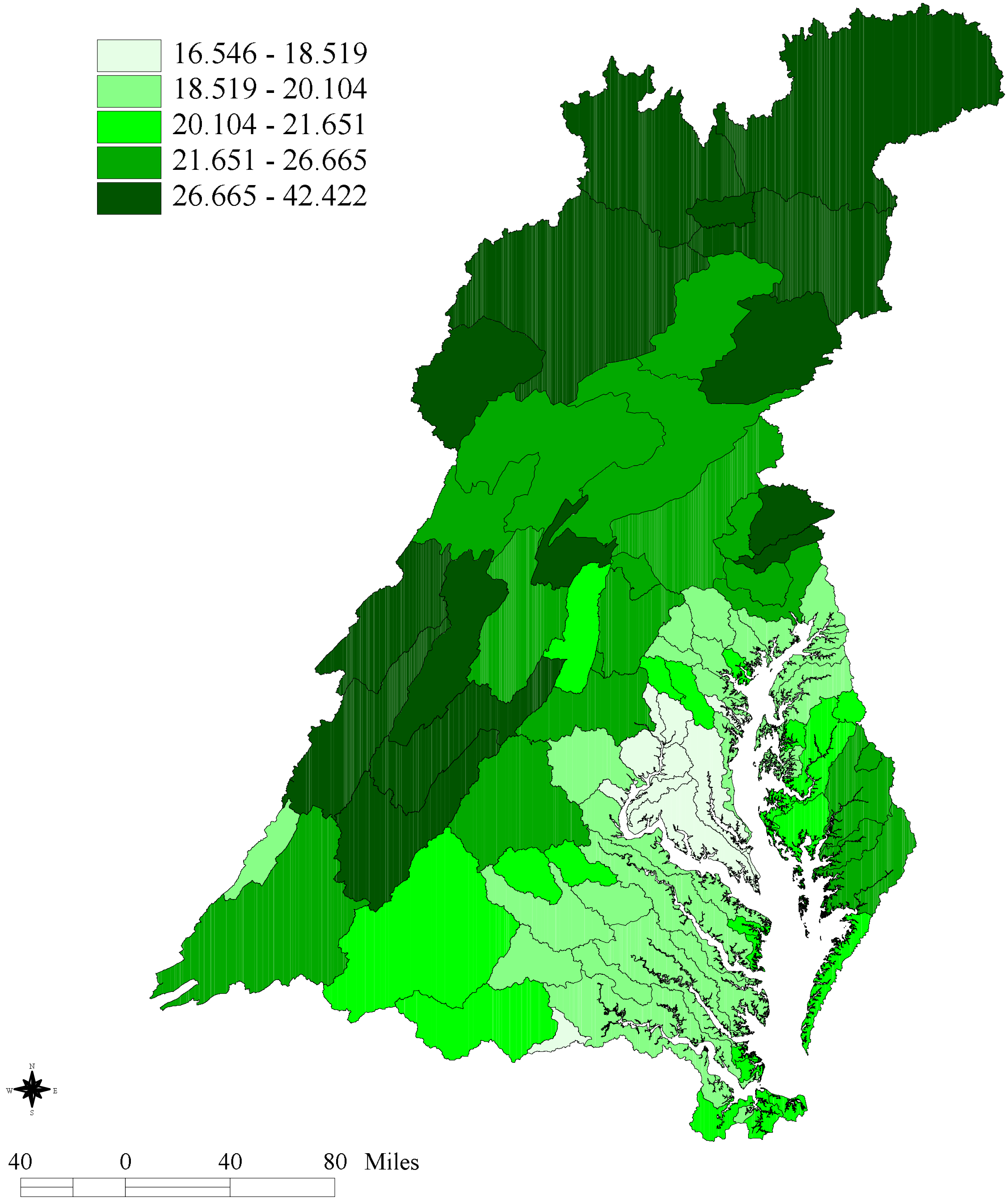


Figure 16.

Phase 4.3 Watershed Model Land Use Loads

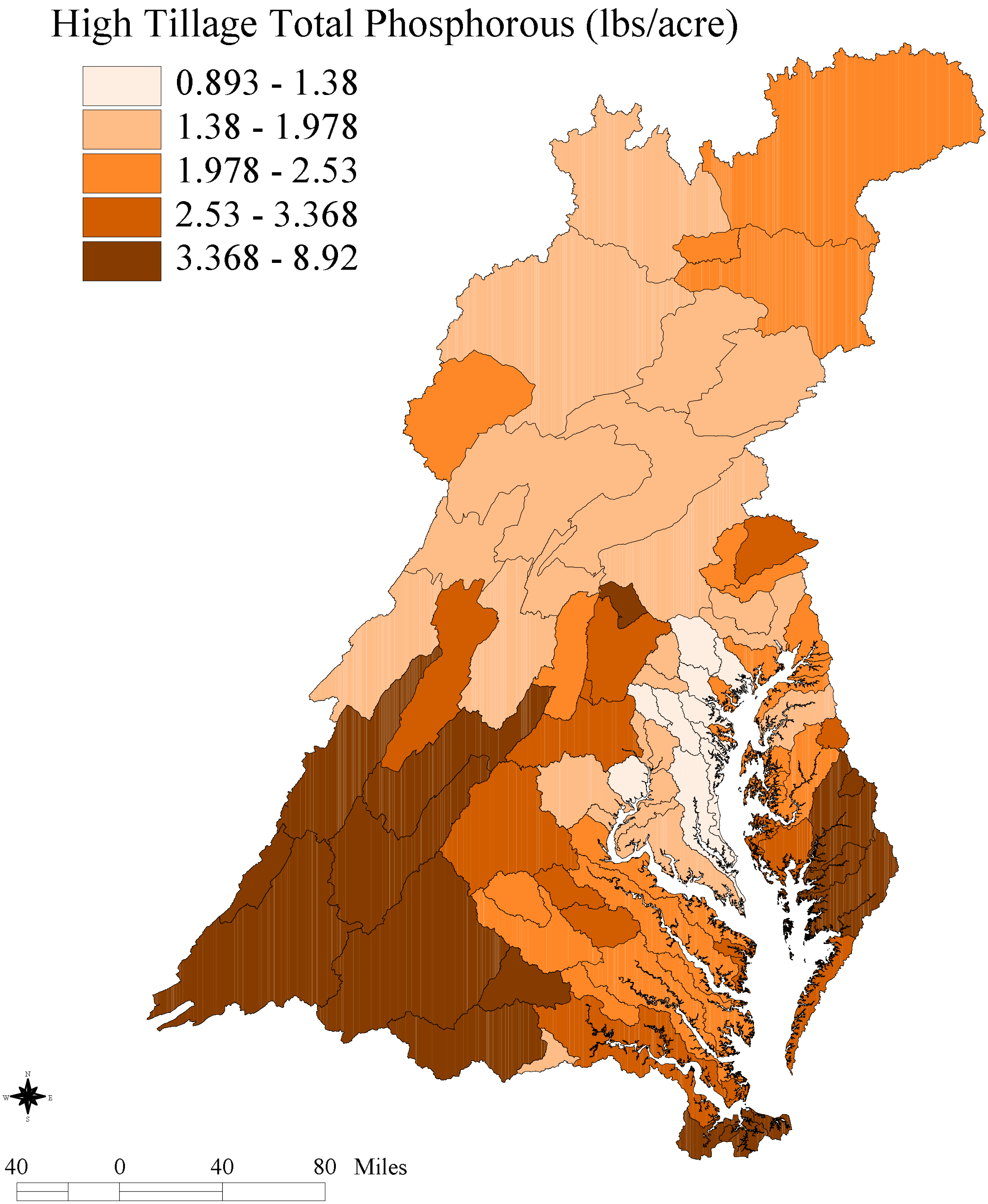


Figure 17.

Phase 4.3 Watershed Model Land Use Loads

Low Tillage Total Phosphorous (lbs/acre)

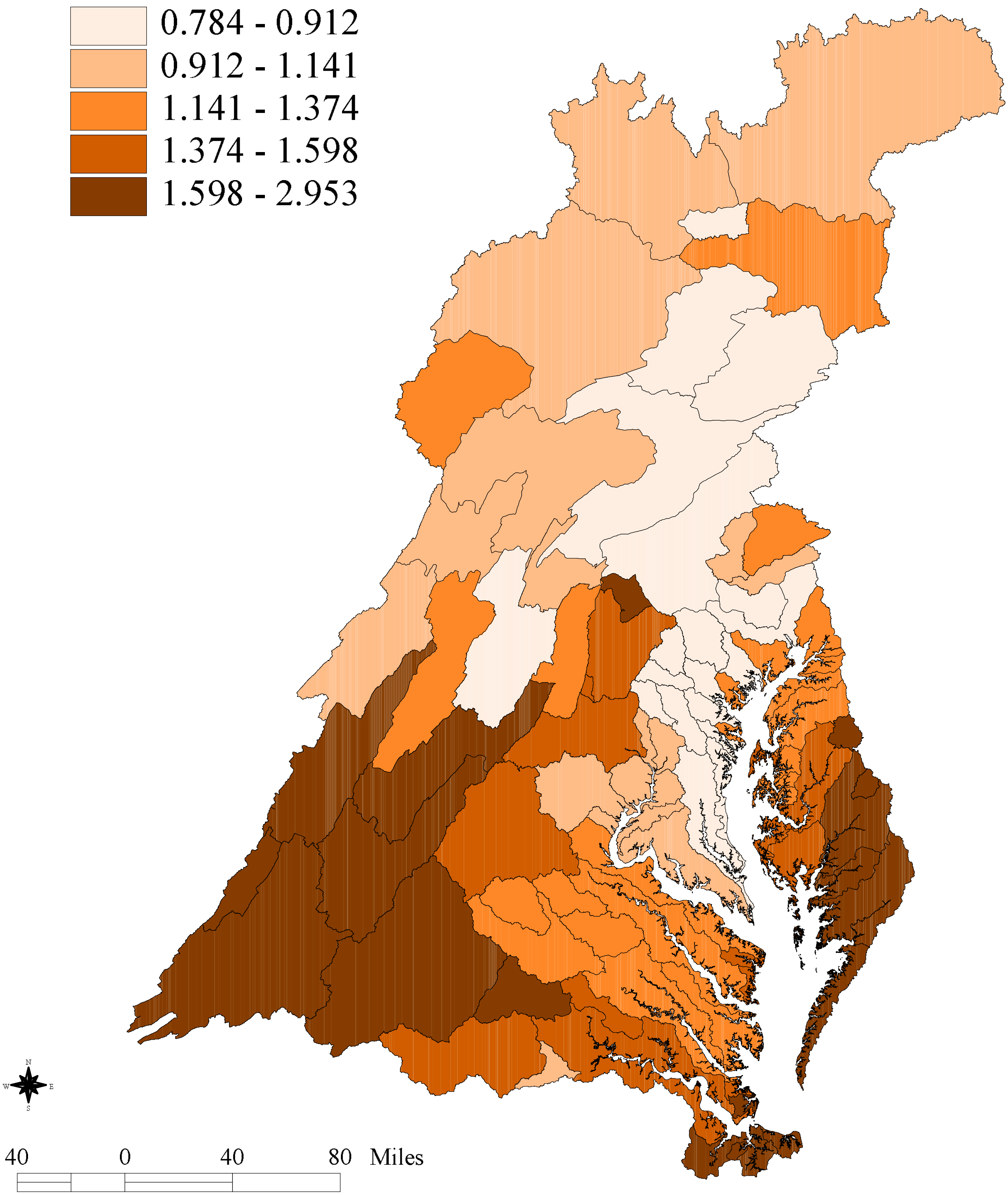
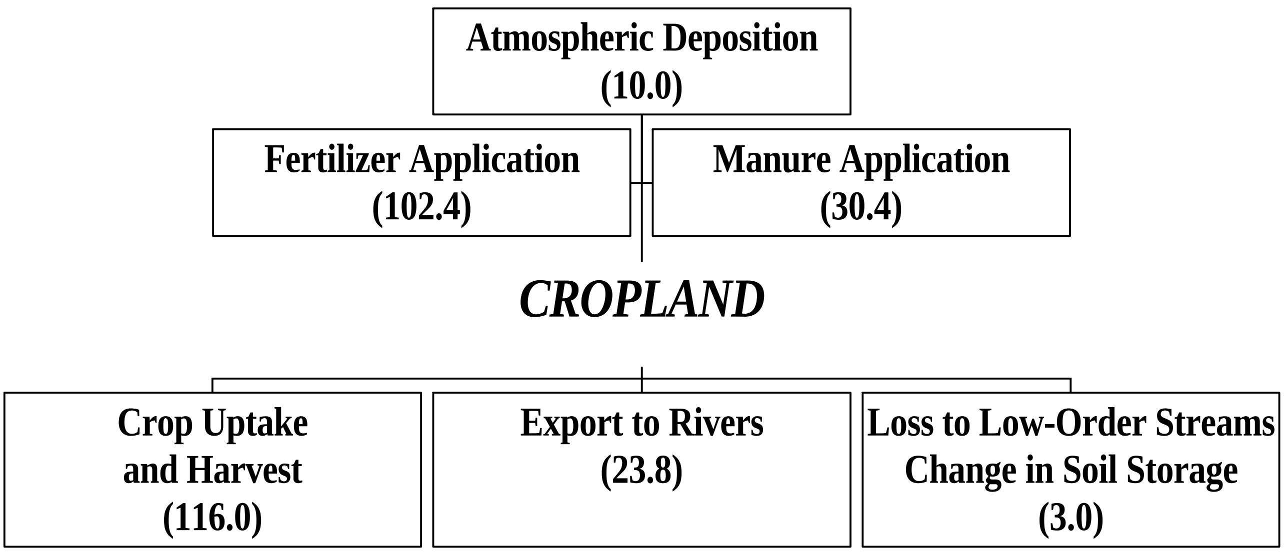


FIG. 18. Cropland Total Nitrogen and Total Phosphorus Mass Balance (kg/ha-yr)

Nitrogen



Phosphorus

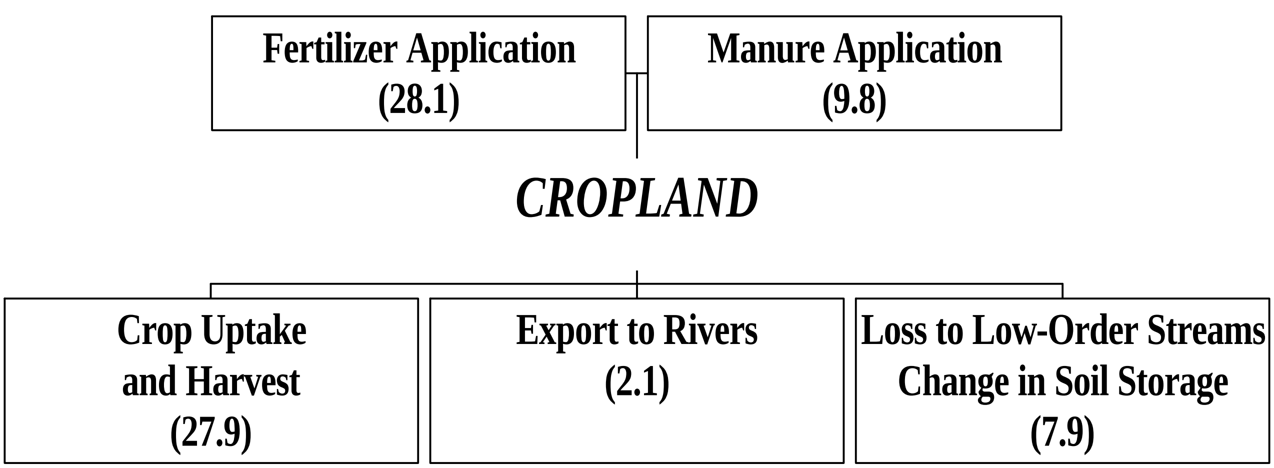


Figure 19. Hay TN Export vs TN applications

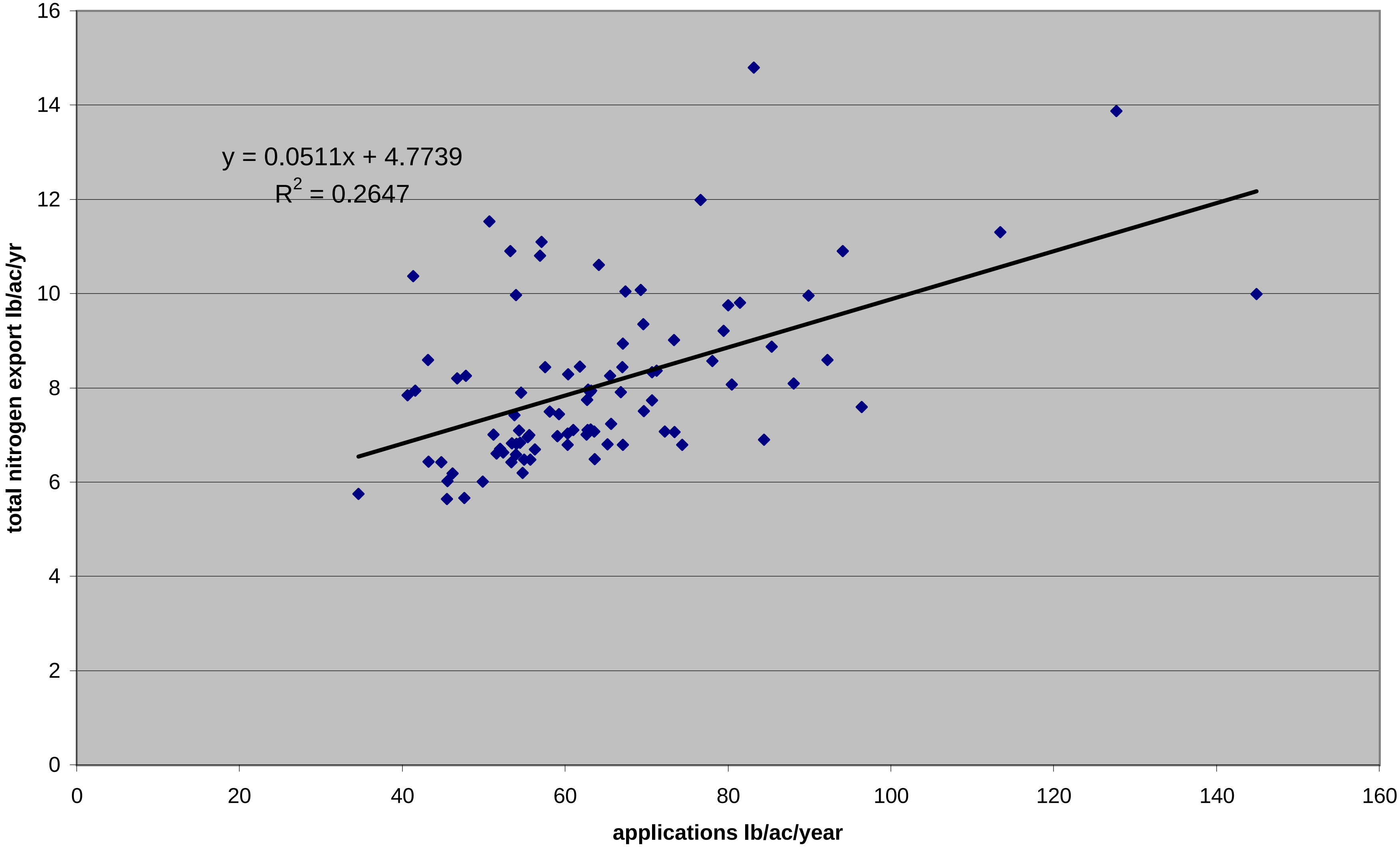
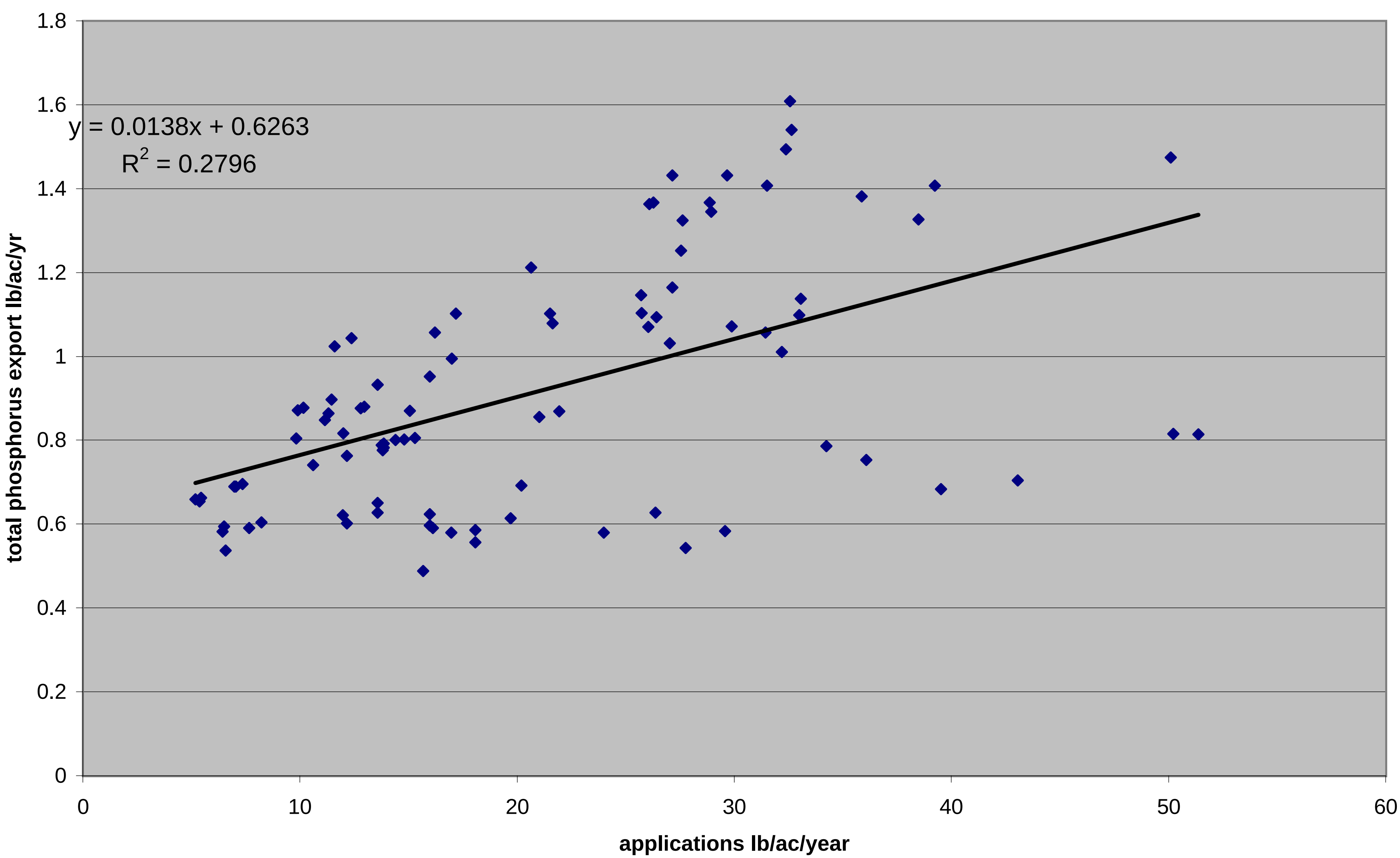


Figure 20. Hay TP Export vs TP applications



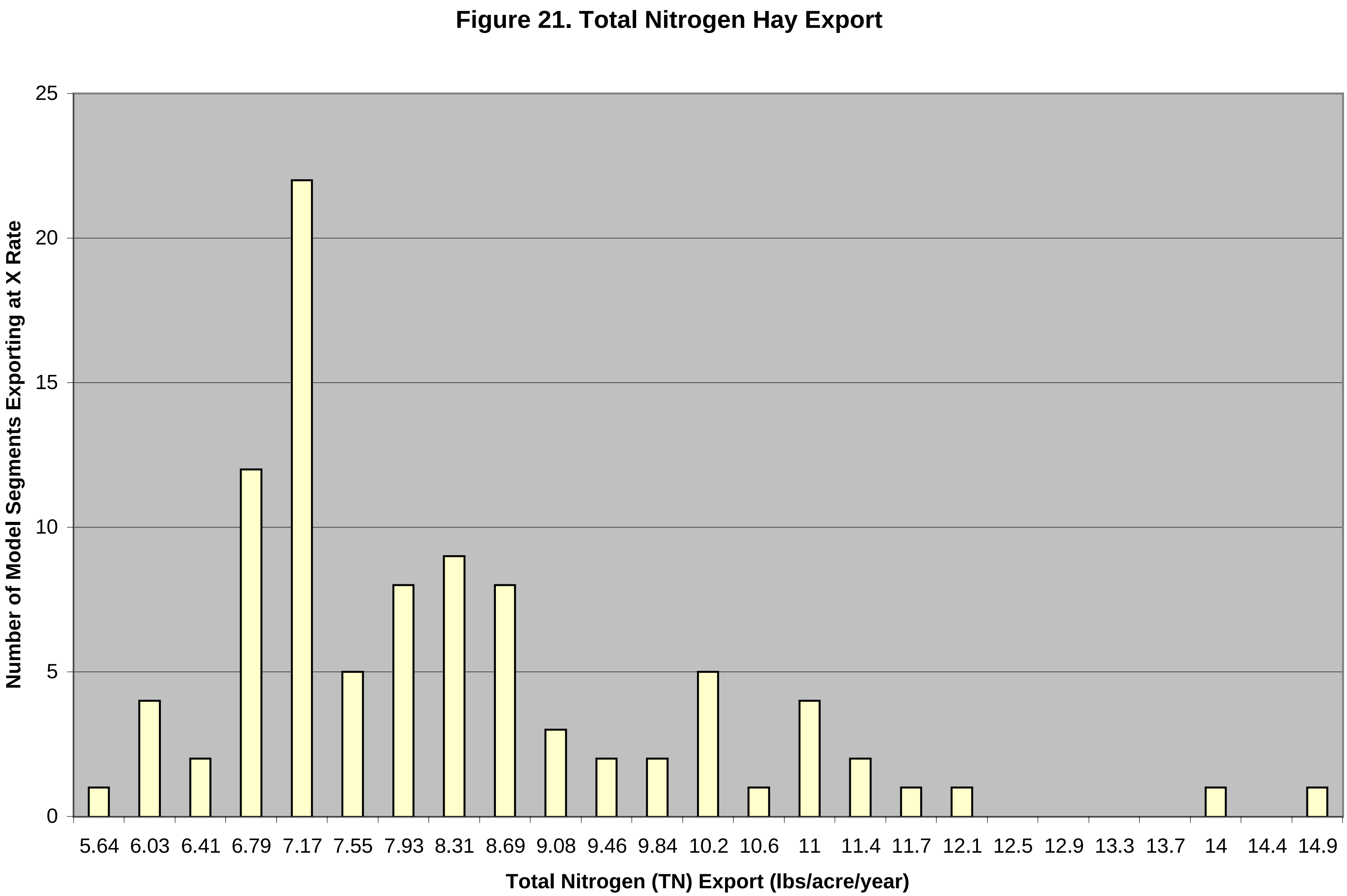


Figure 21. Total Nitrogen Hay Export
25
20
15
10
5
0
Number of Model Segments Exporting at X Rate
5.64
6.03
6.41
6.79
7.17
7.55
7.93
8.31
8.69
9.08
9.46
9.84
10.2
10.6
11
11.4
11.7
12.1
12.5
12.9
13.3
13.7
14
14.4
14.9
Total Nitrogen (TN) Export (lbs/acre/year)

Figure 22. Total Phosphorous Hay Export

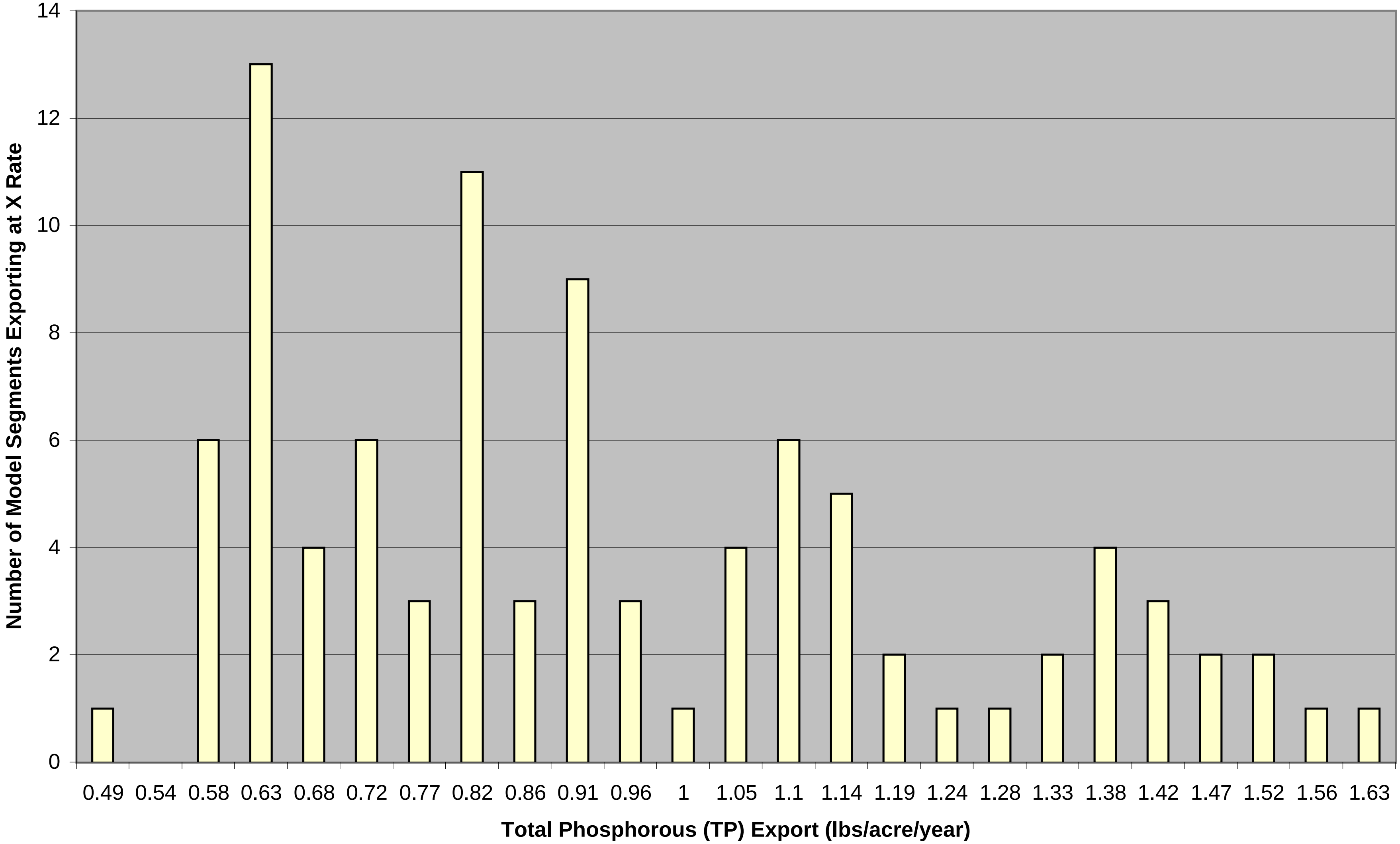


Figure 23. Hay Nitrogen

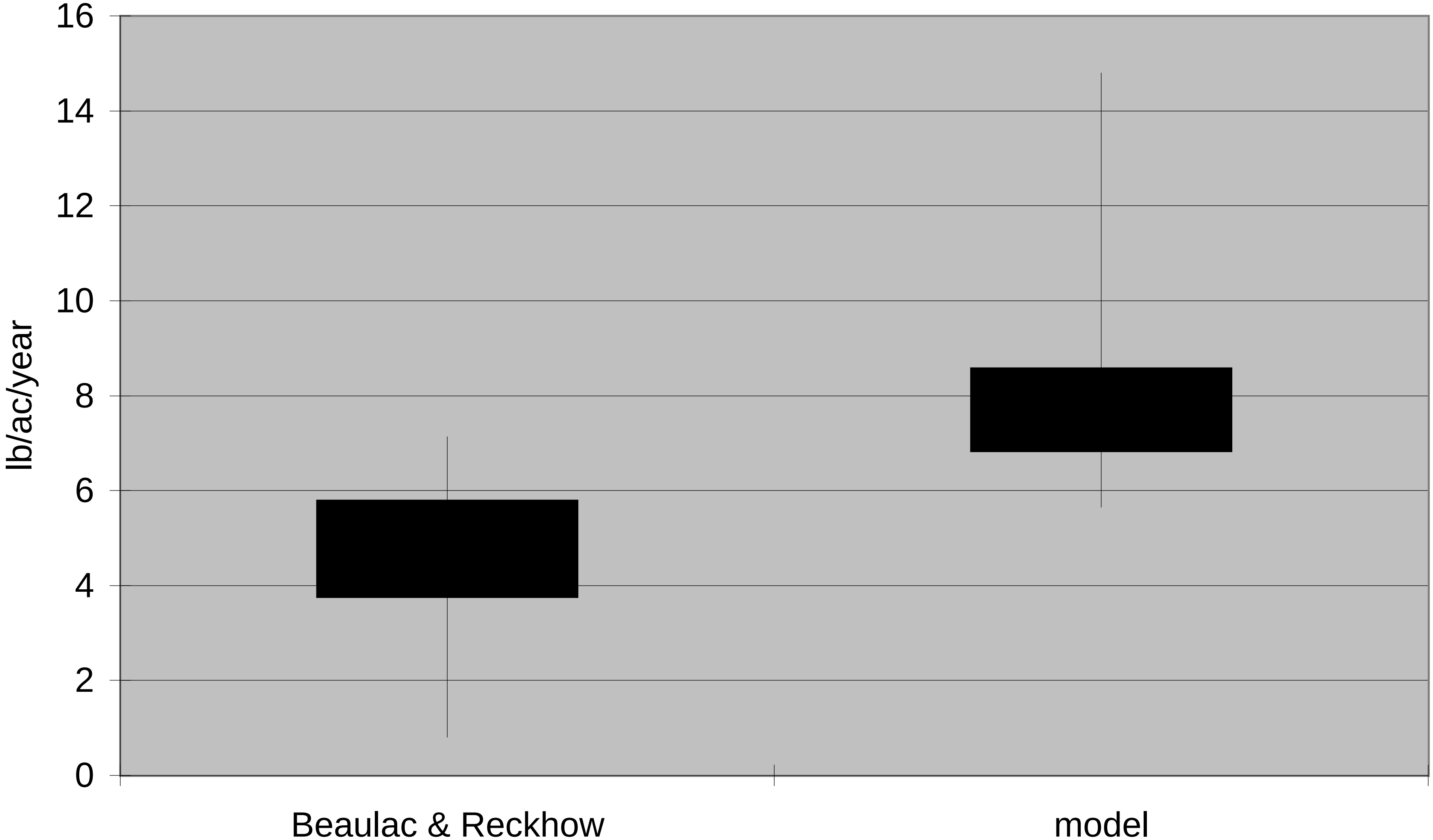


Figure 24. Hay Phosphorus

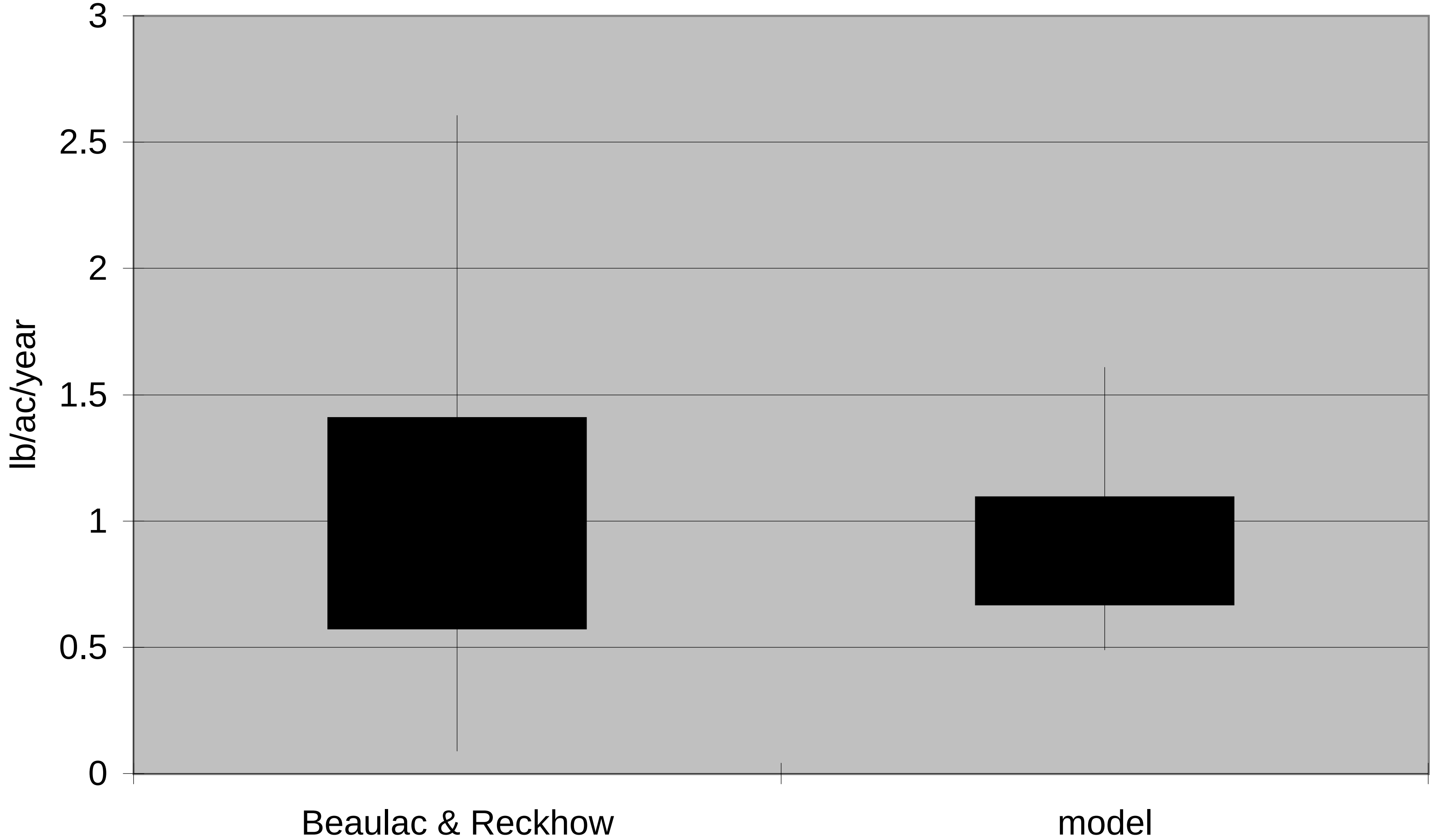


Figure 25.

Phase 4.3 Watershed Model Land Use Loads

Hay Land Total Nitrogen (lbs/acre)

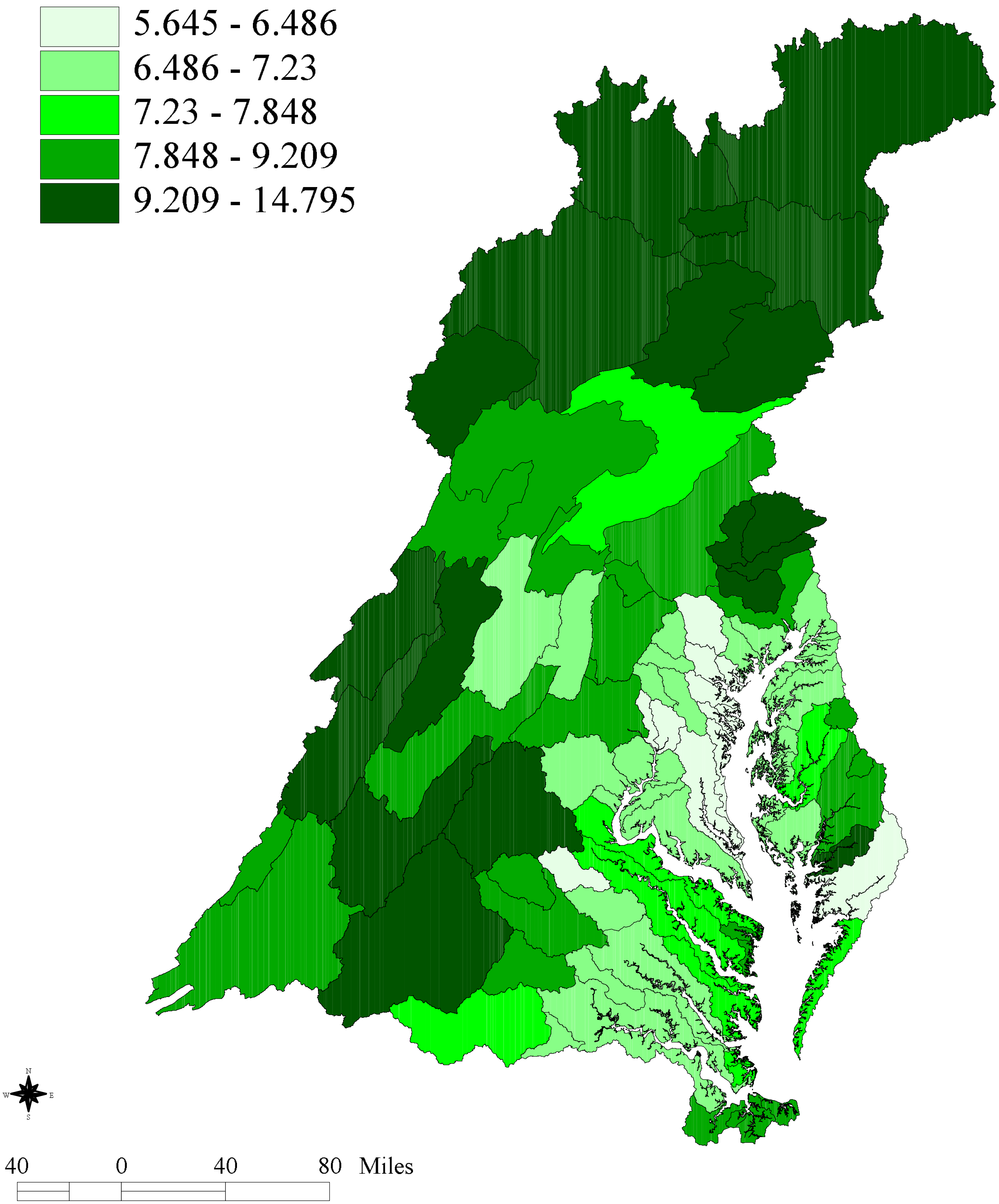


Figure 26.

Phase 4.3 Watershed Model Land Use Loads

Hay Land Total Phosphorous (lbs/acre)

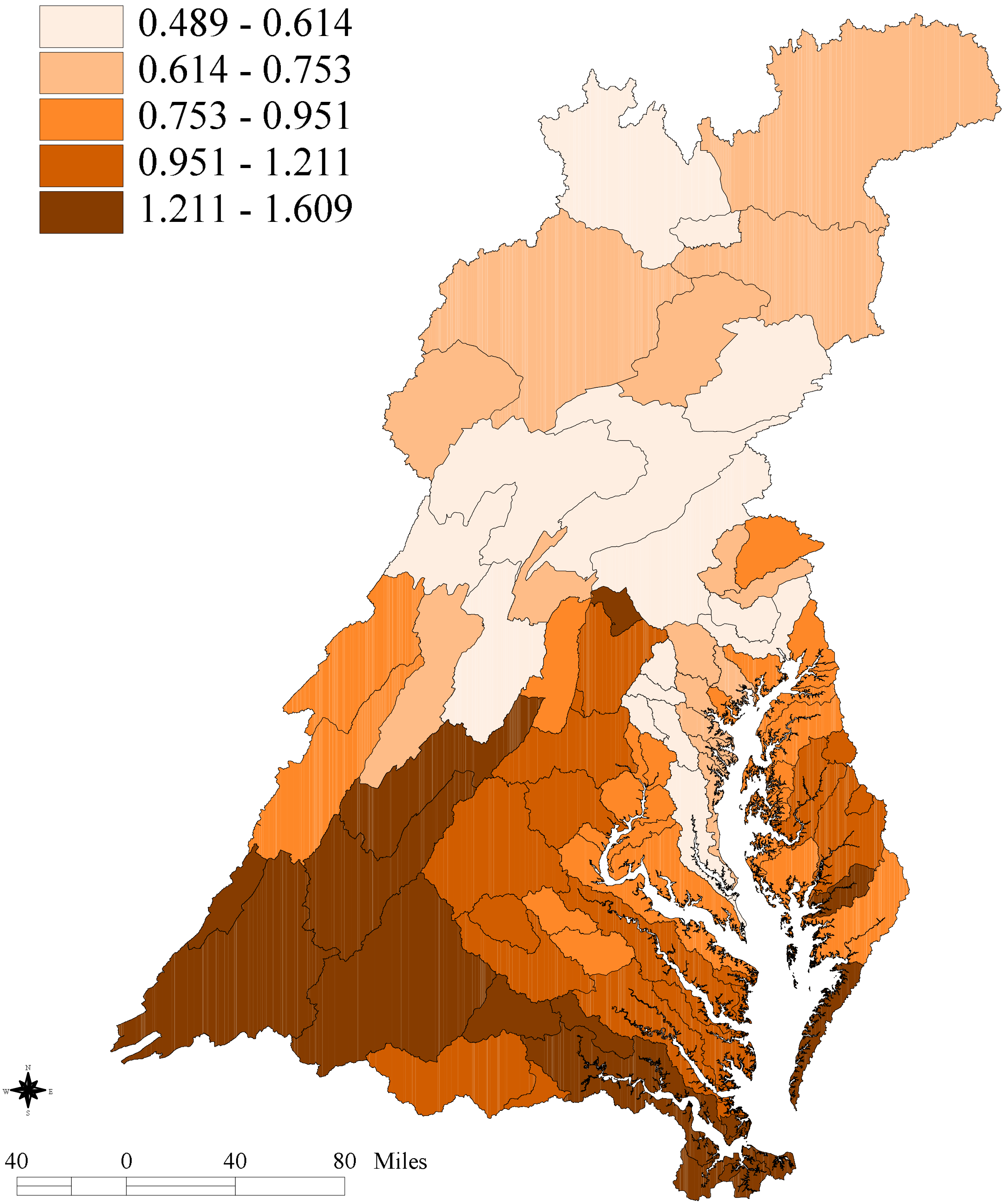
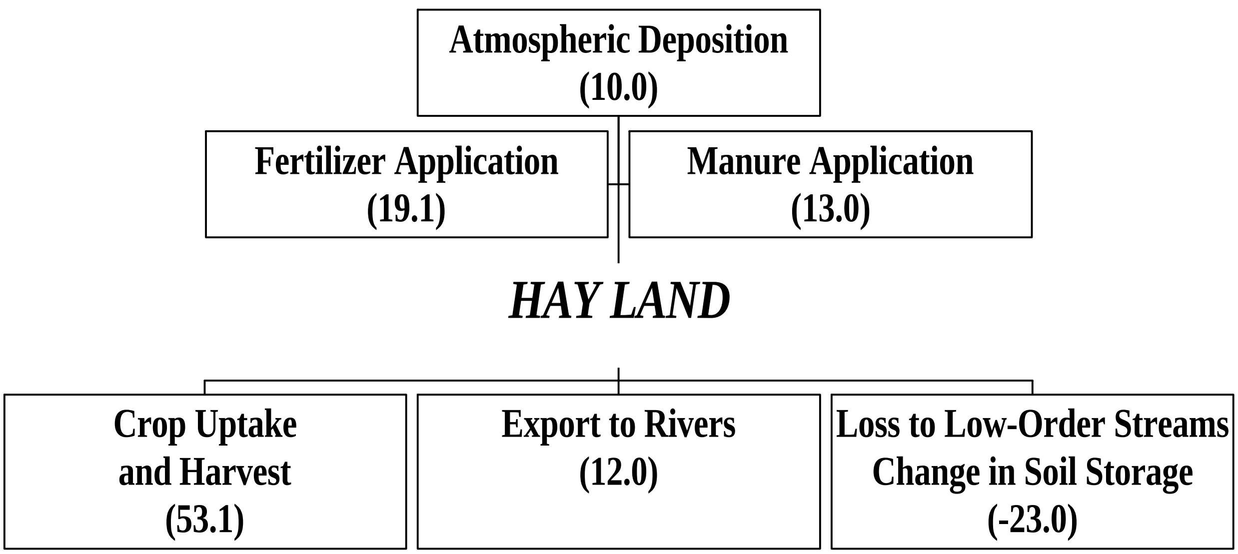


FIG. 27. Hay Land Total Nitrogen and Total Phosphorus Mass Balance (kg/ha-yr)

Nitrogen



Phosphorus

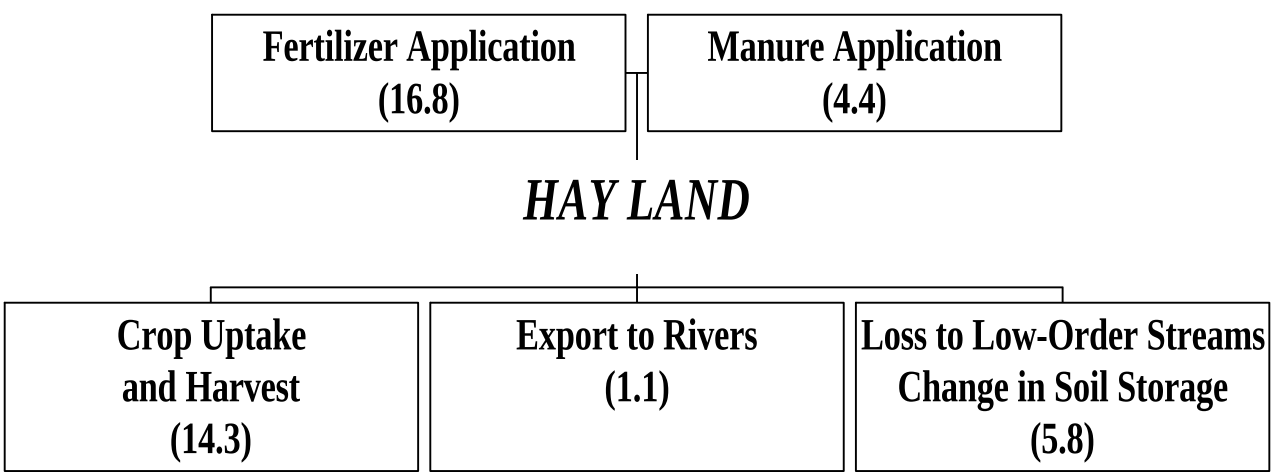


Figure 28. Pasture TN Export vs TN applications

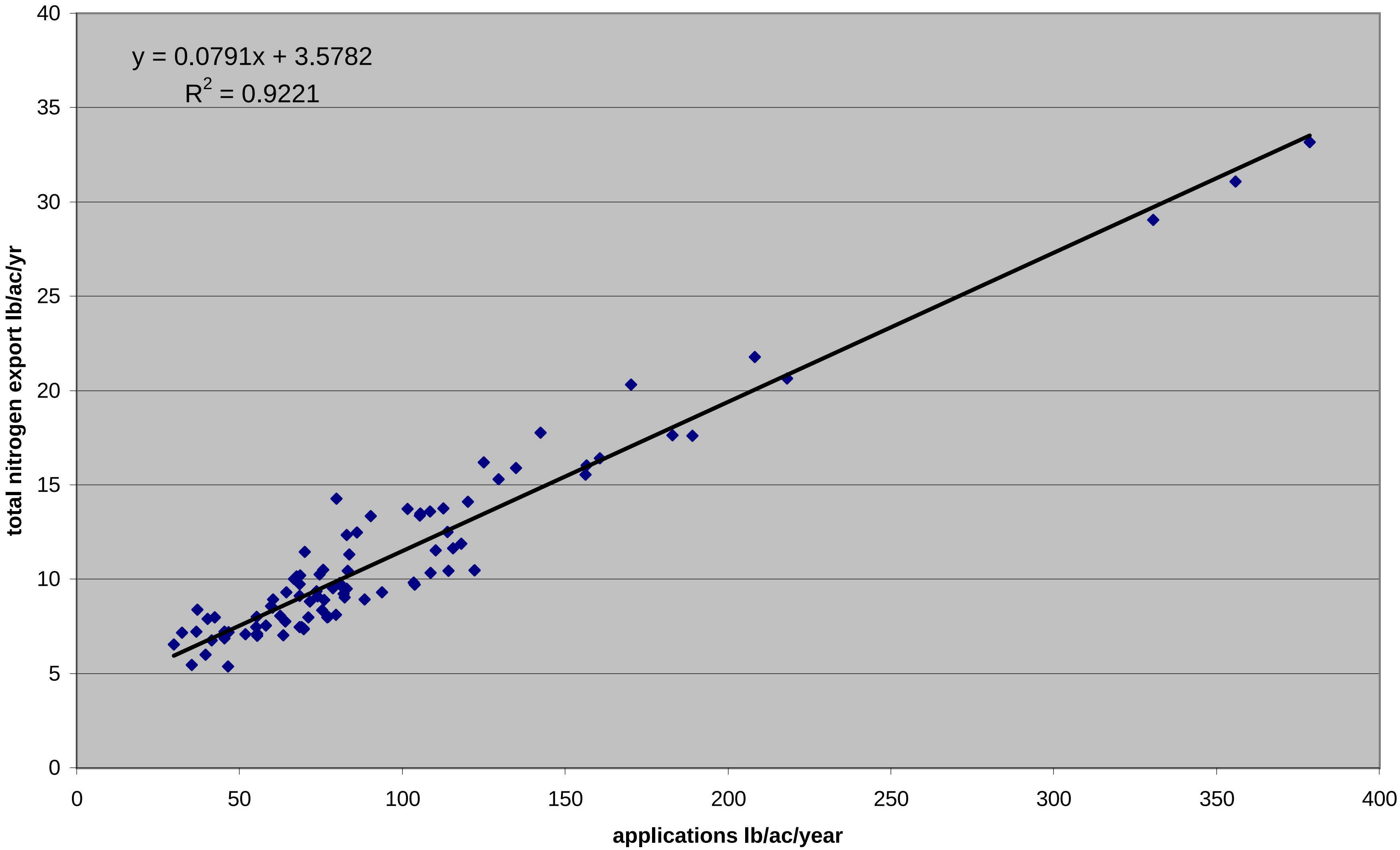


Figure 29. Pasture TP Export vs TP applications

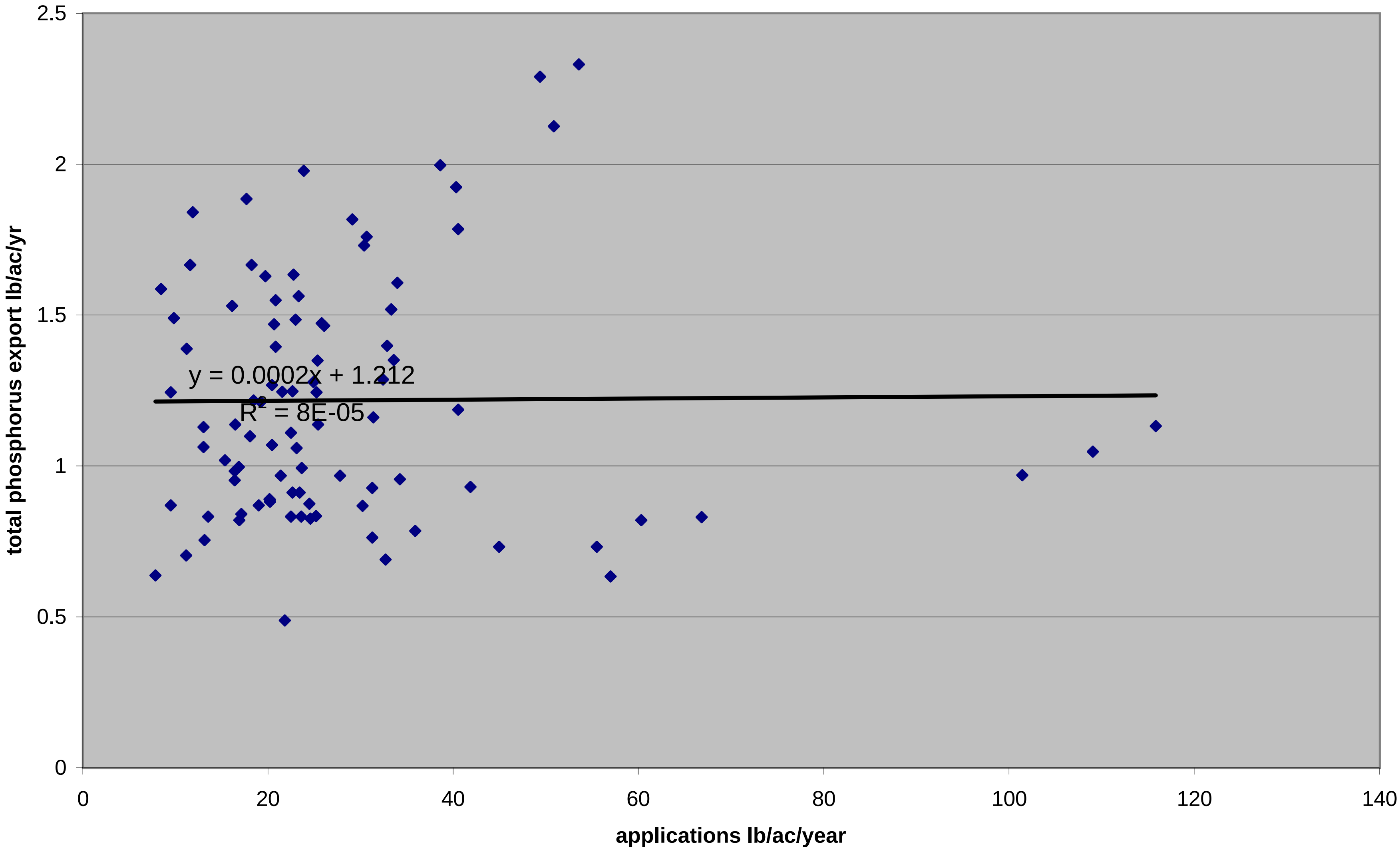


Figure 30. Pasture TP vs. fraction woody

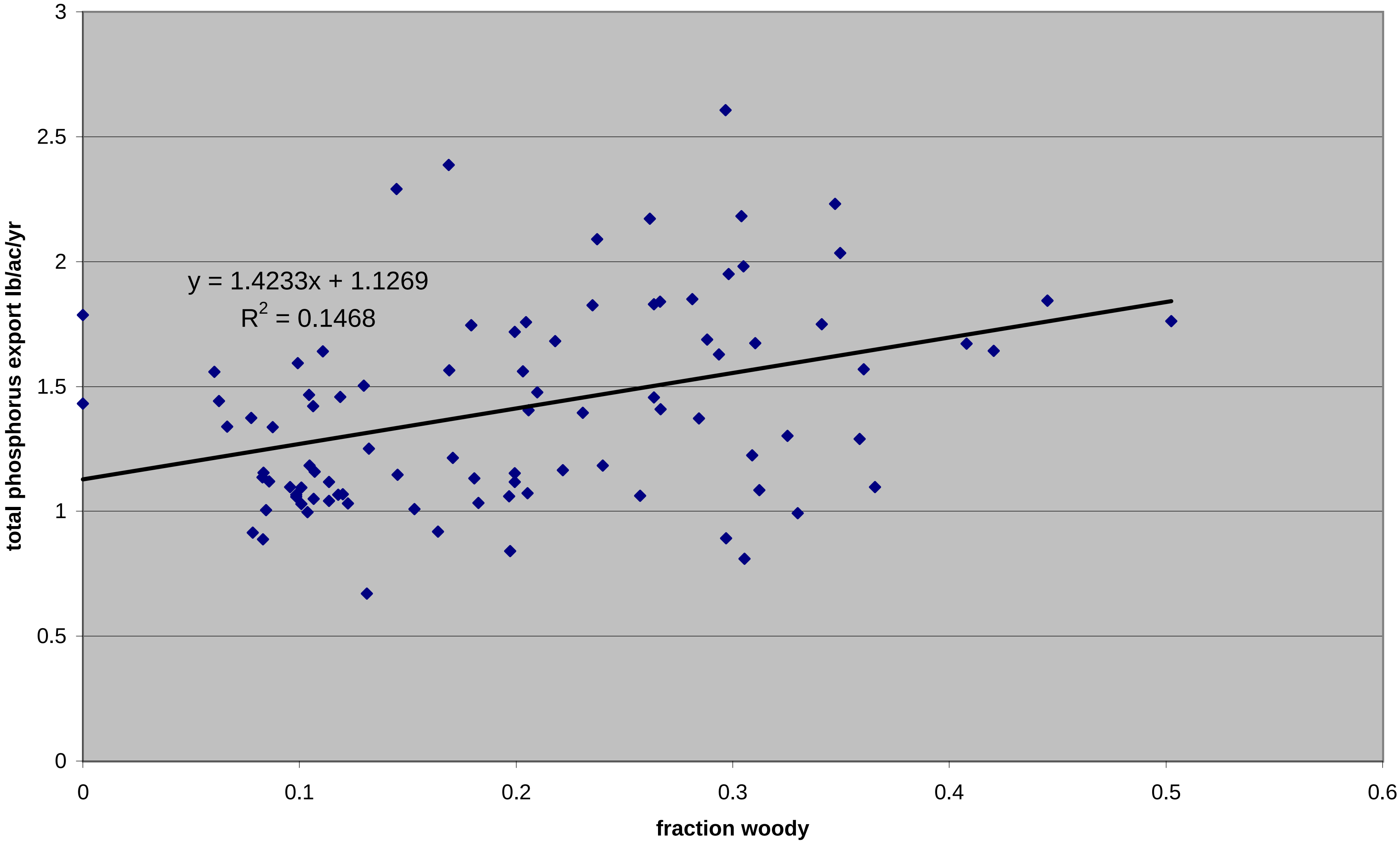


Figure 31. Total Nitrogen Pasture Export

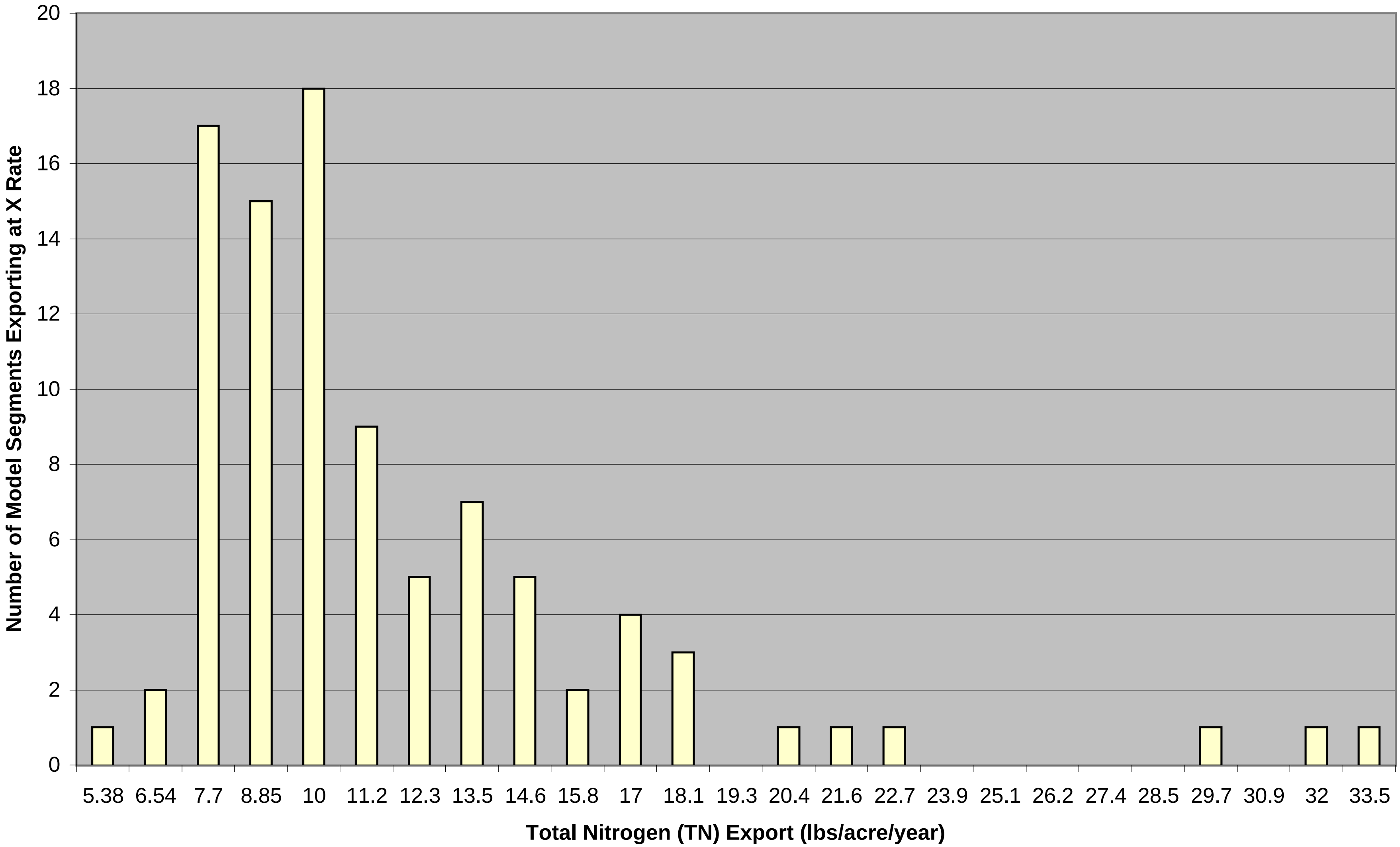


Figure 32. Total Phosphorous Pasture Export

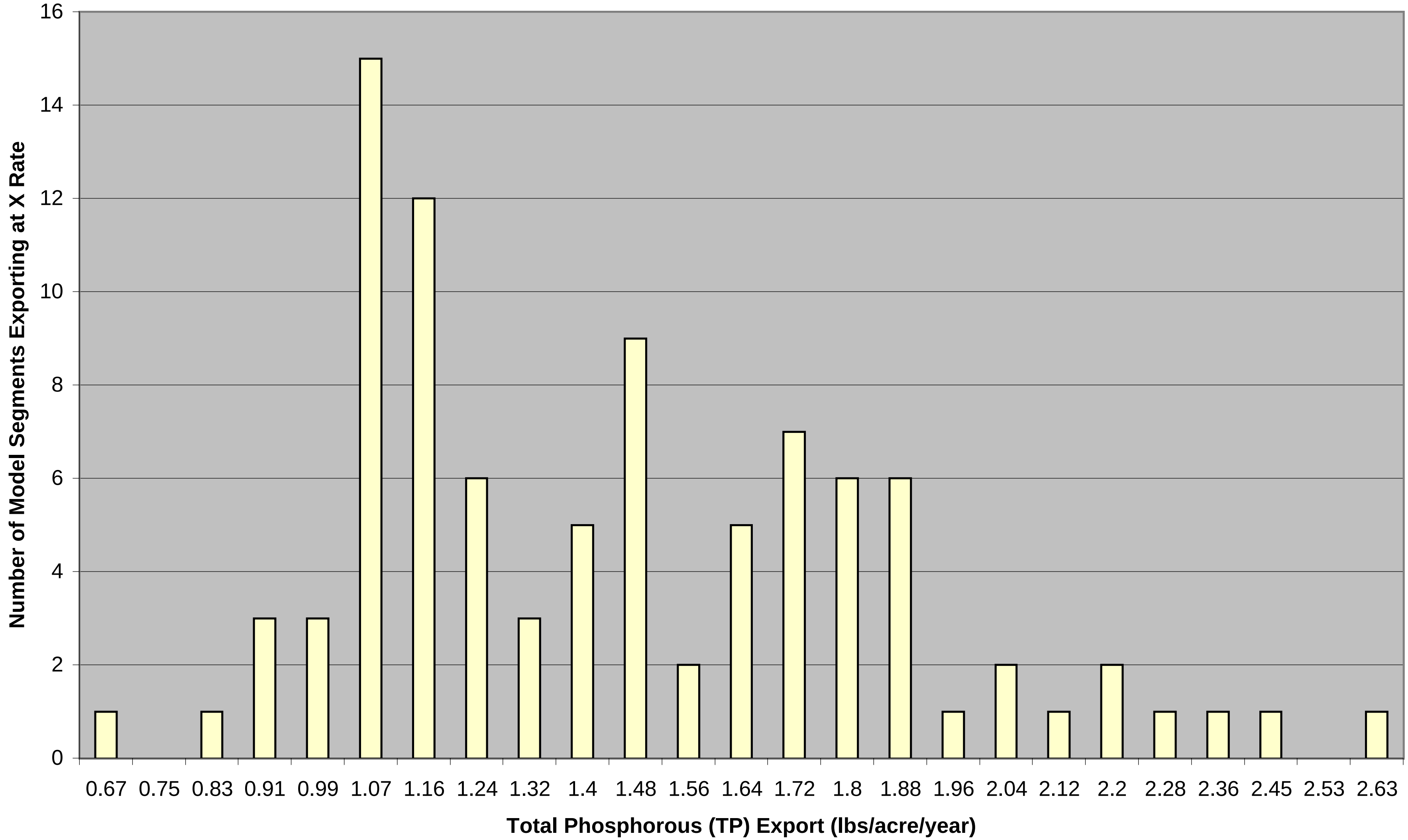


Figure 33. Pasture Nitrogen

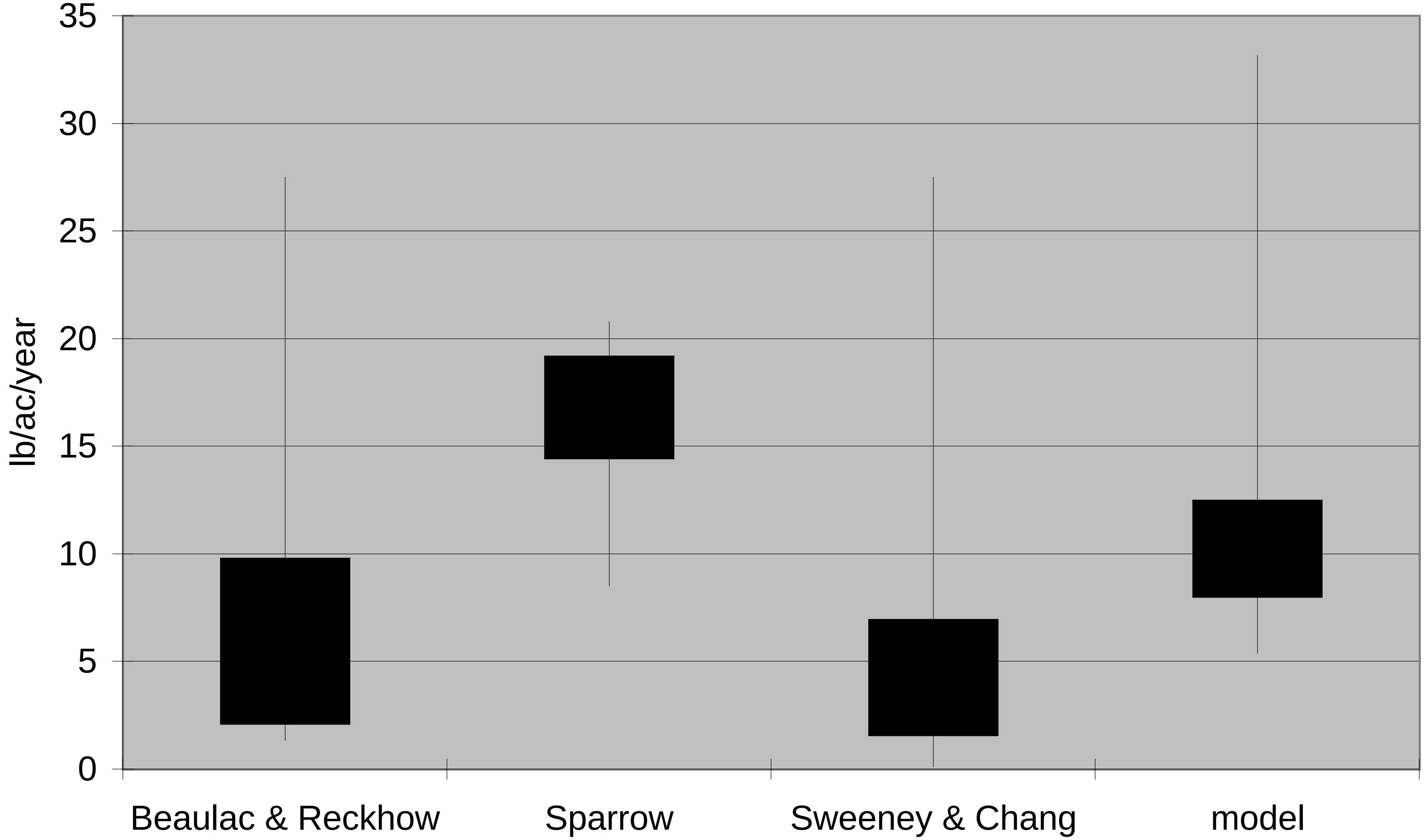


Figure 34. Pasture Phosphorus

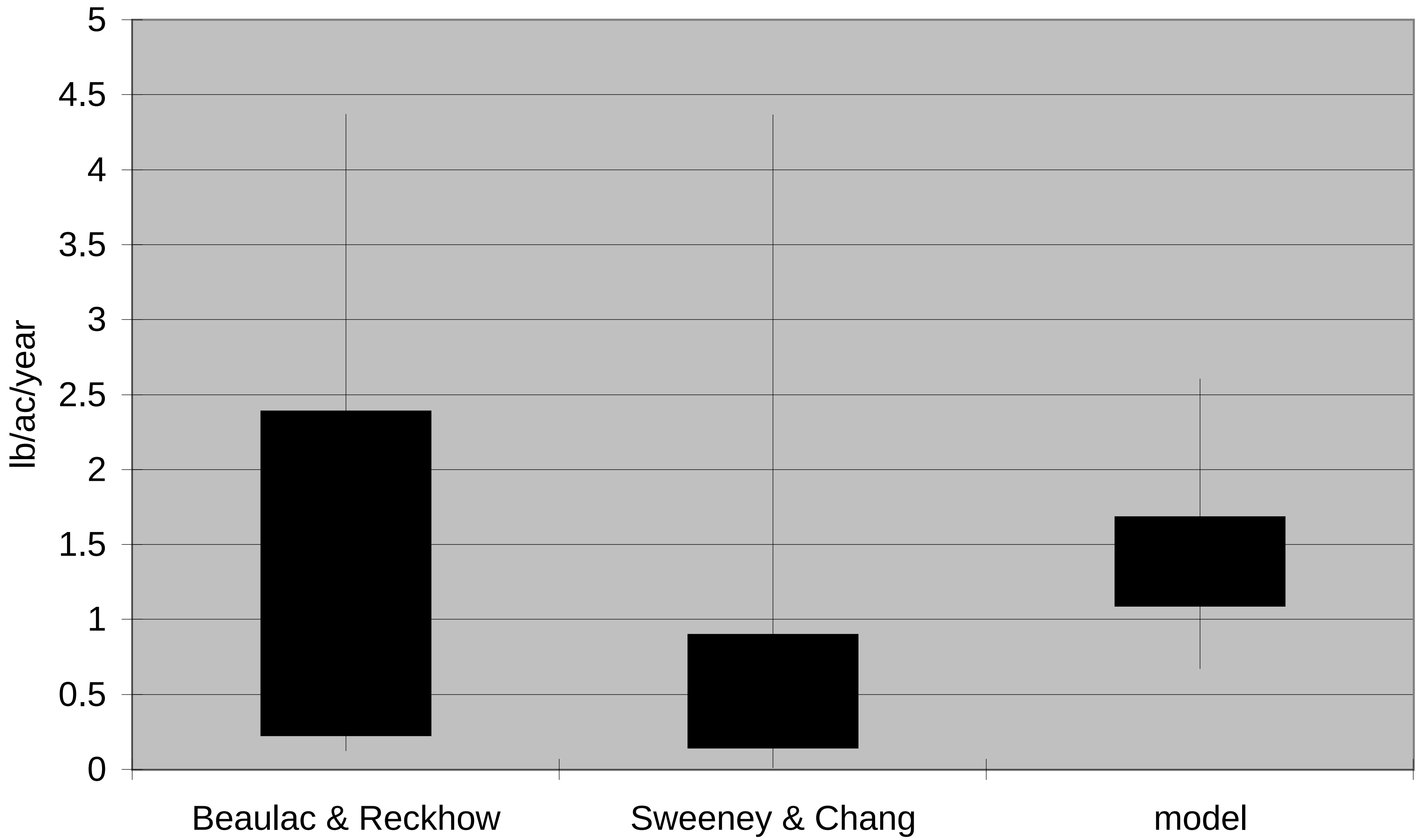


Figure 35.

Phase 4.3 Watershed Model Land Use Loads

Pasture Land Total Nitrogen (lbs/acre)

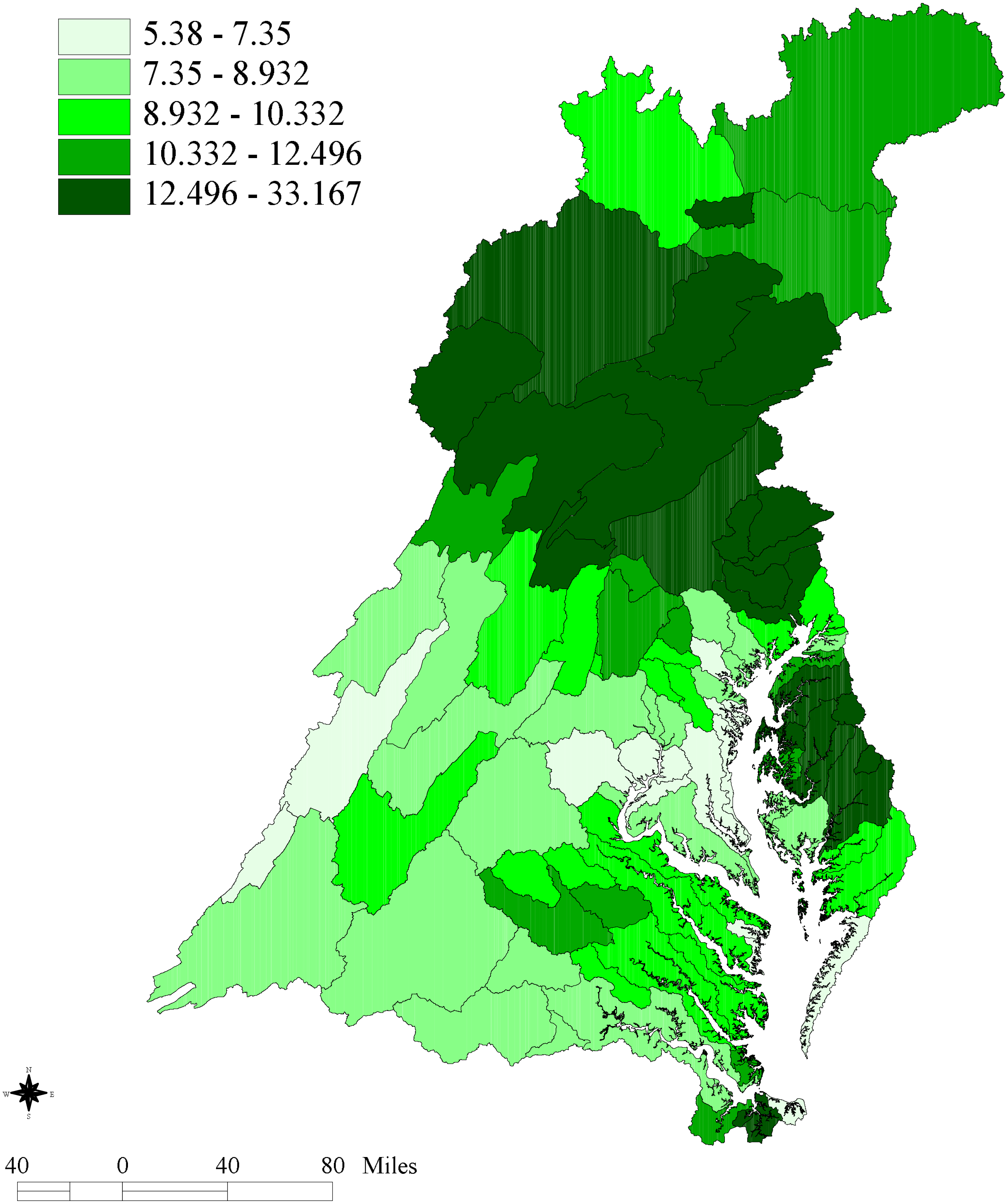


Figure 36.

Phase 4.3 Watershed Model Land Use Loads

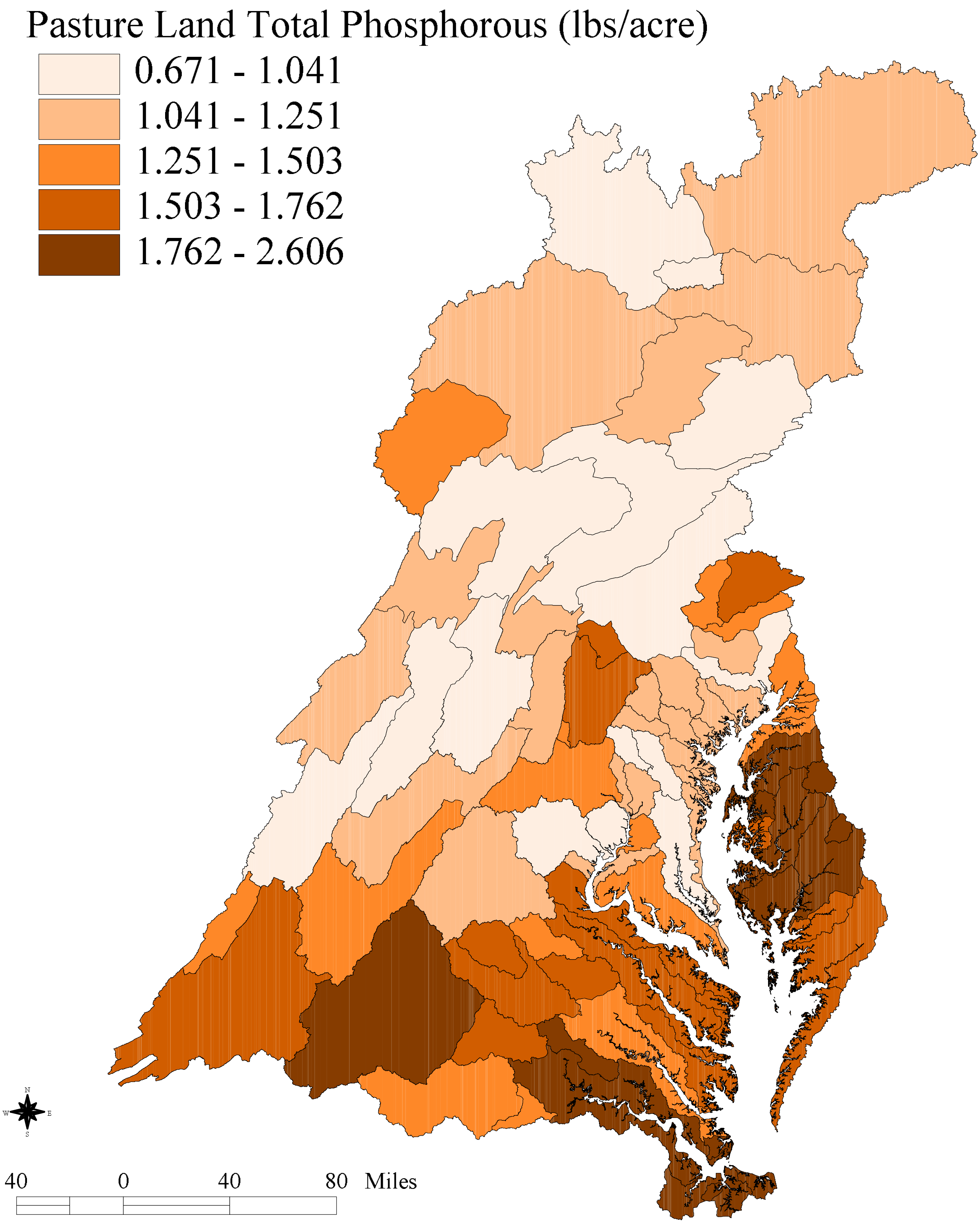
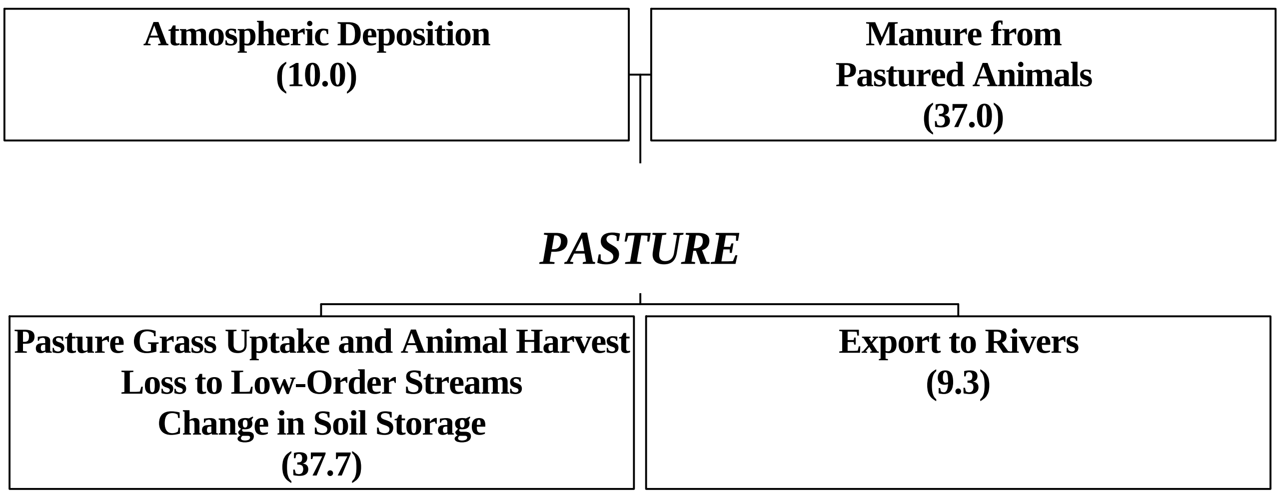


FIG. 37. Pasture Total Nitrogen and Total Phosphorus Mass Balance (kg/ha-yr)

Nitrogen



Phosphorus

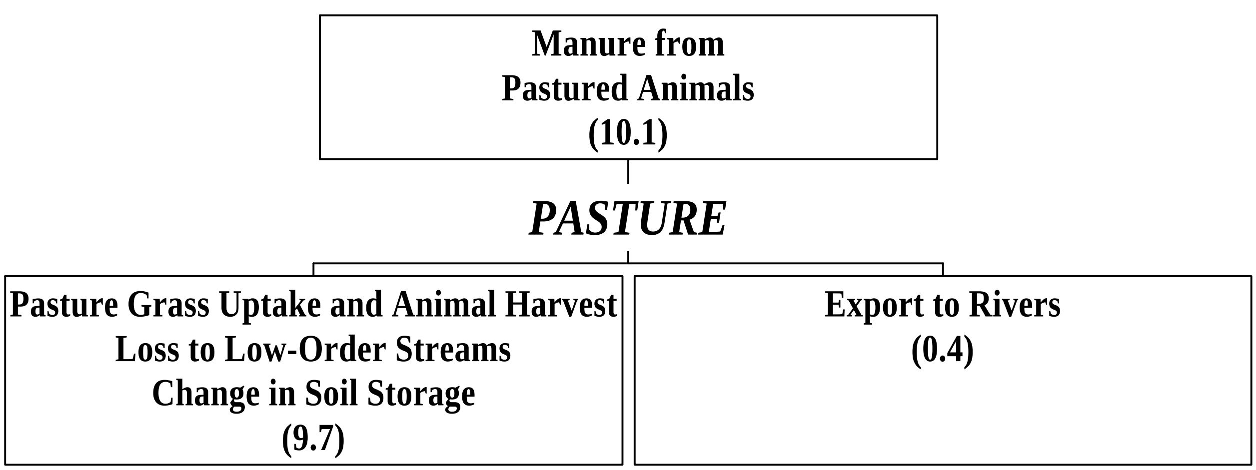


Figure 38. Impervious Urban TN Export vs TN applications

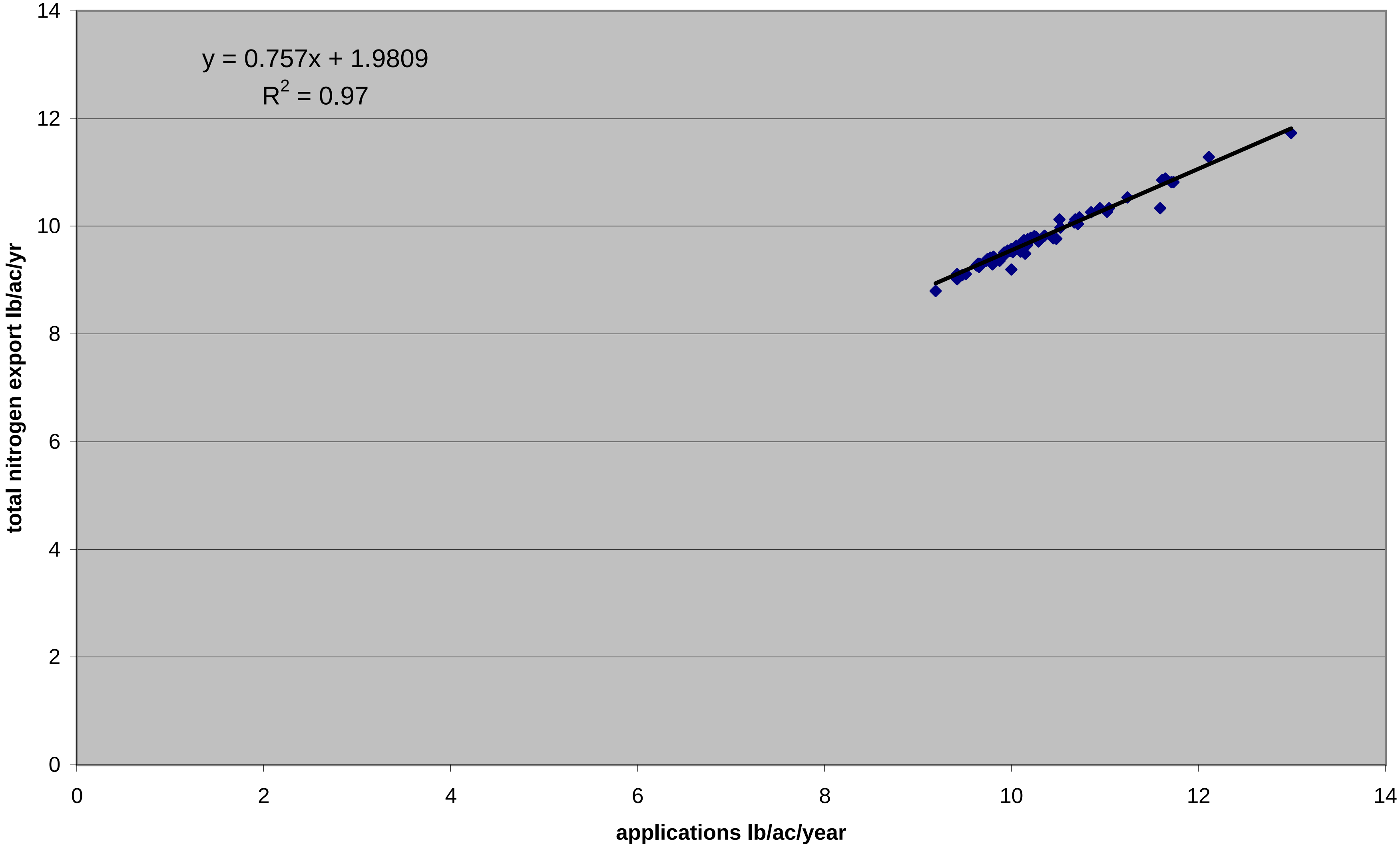


Figure 39. Urban TN vs % impervious

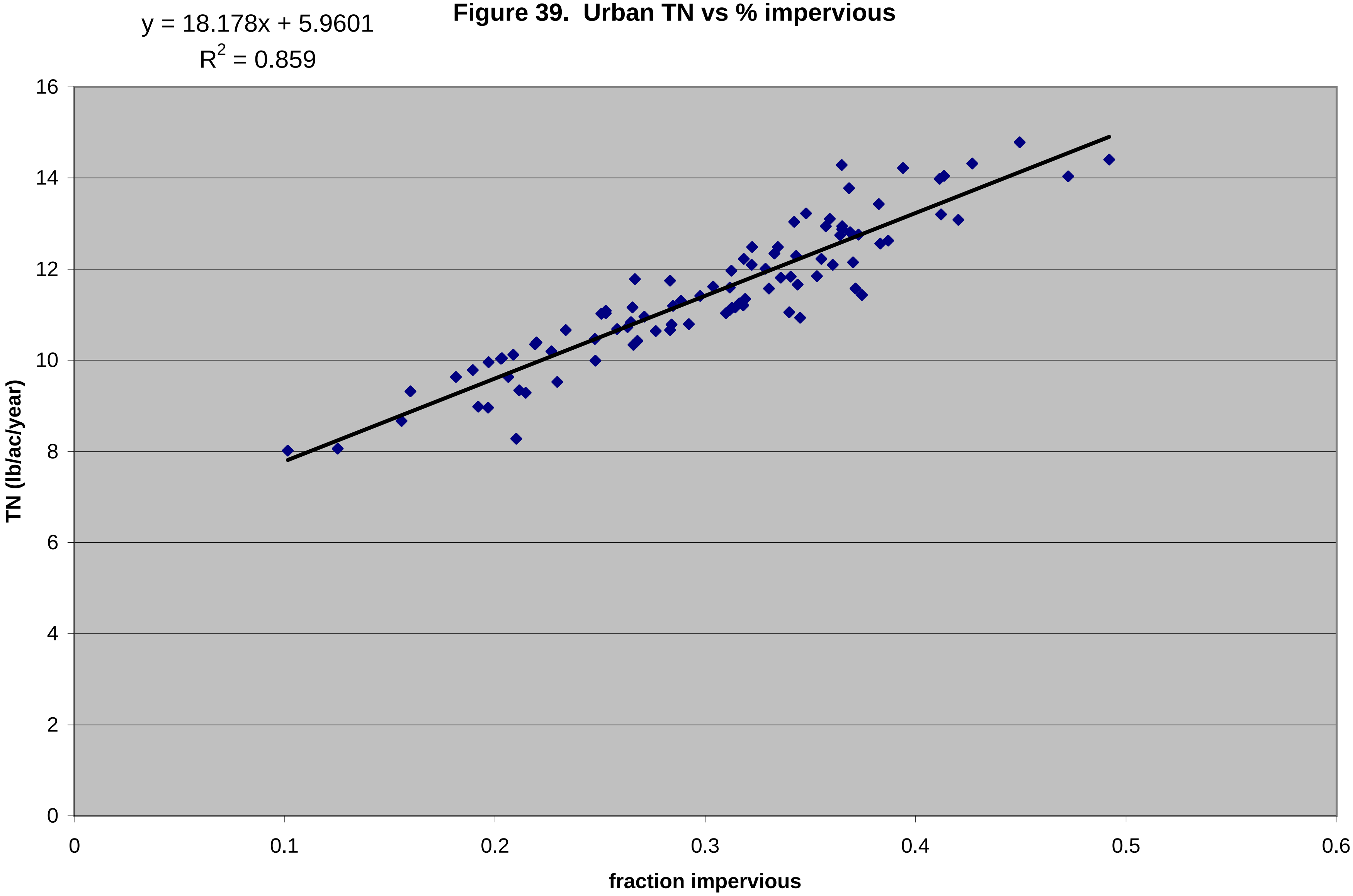


Figure 40. Urban TP vs % impervious

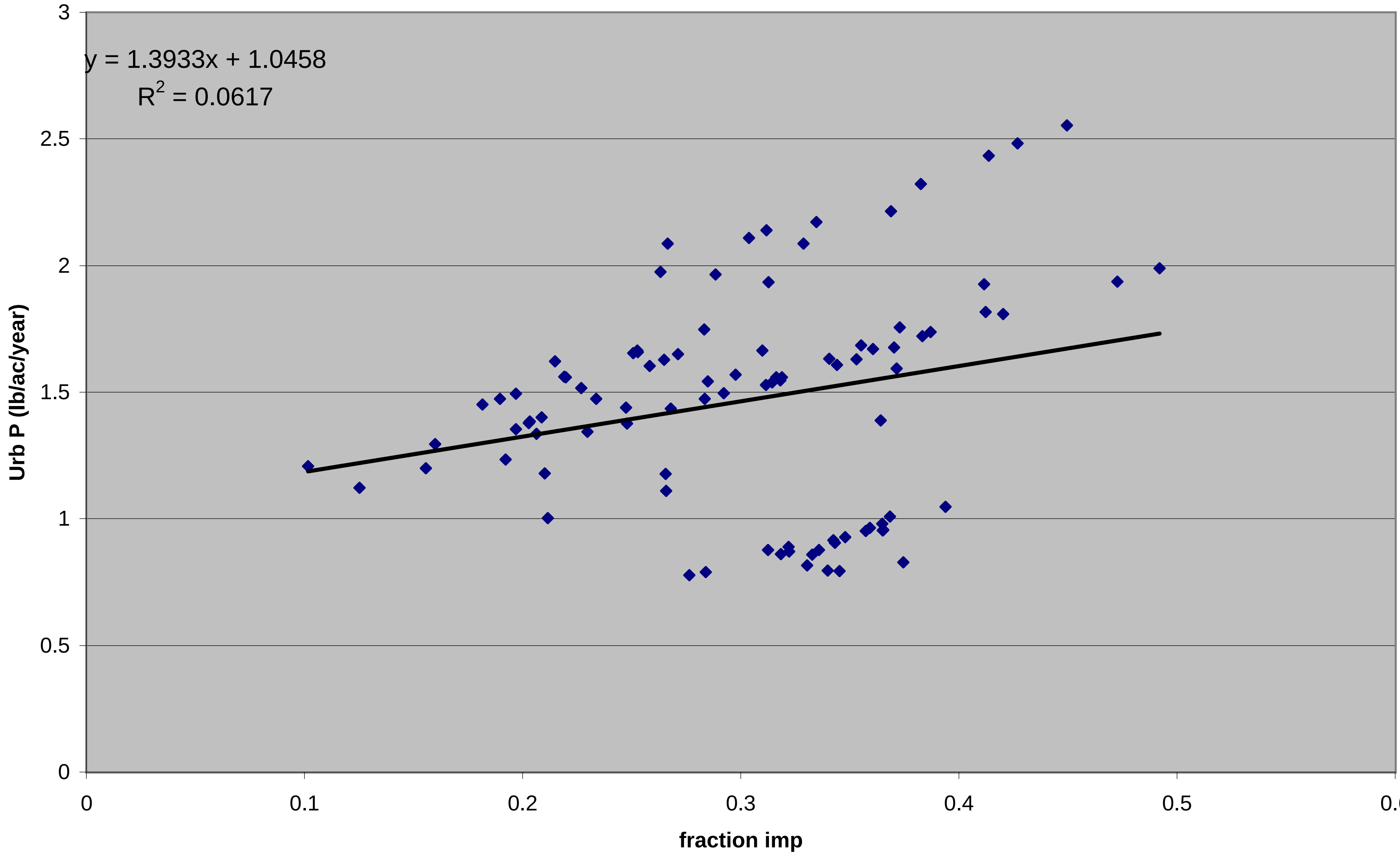


Figure 41. Total Nitrogen Urban Export

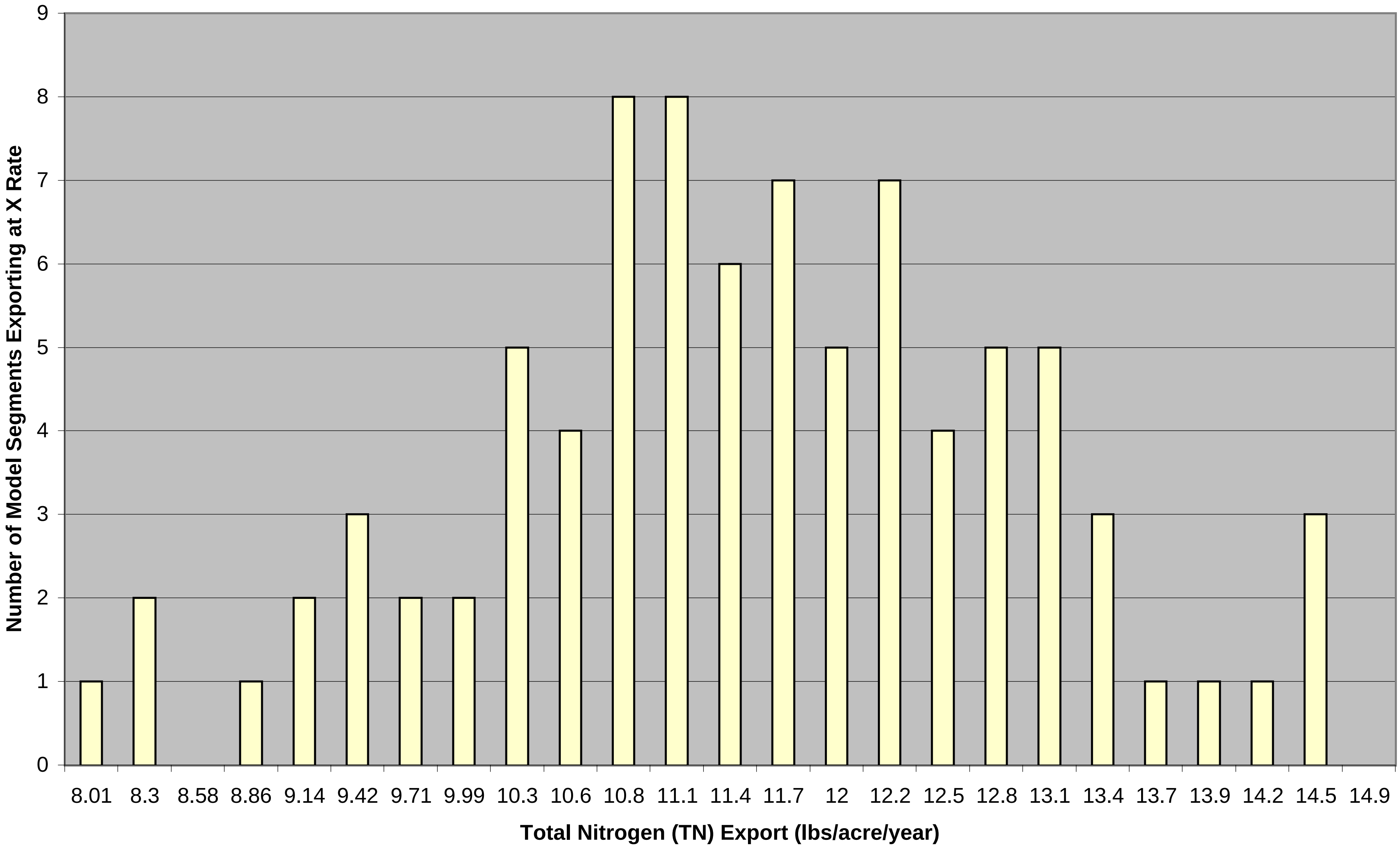


Figure 42. Total Phosphorous Urban Export

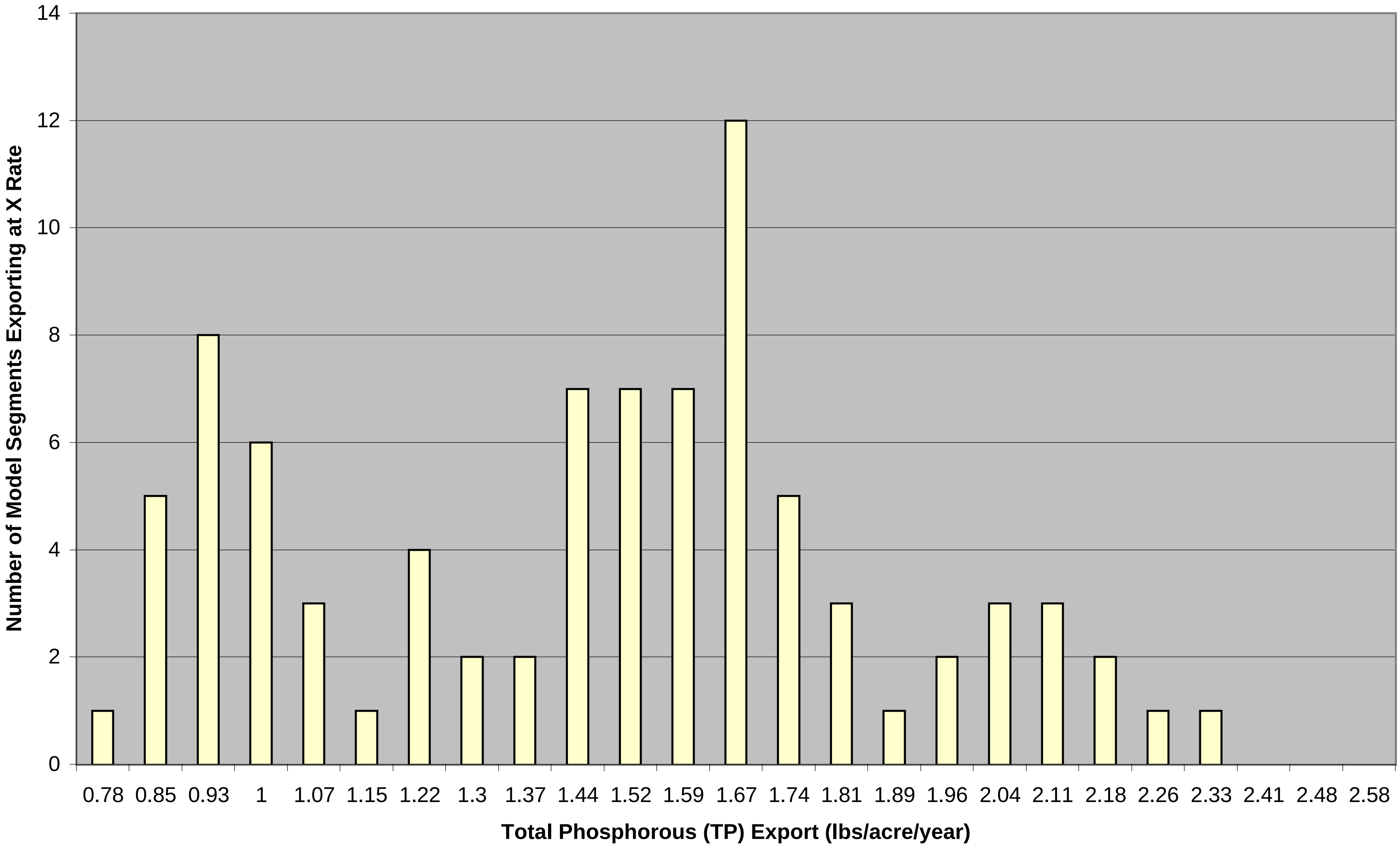


Figure 43. Urban Nitrogen

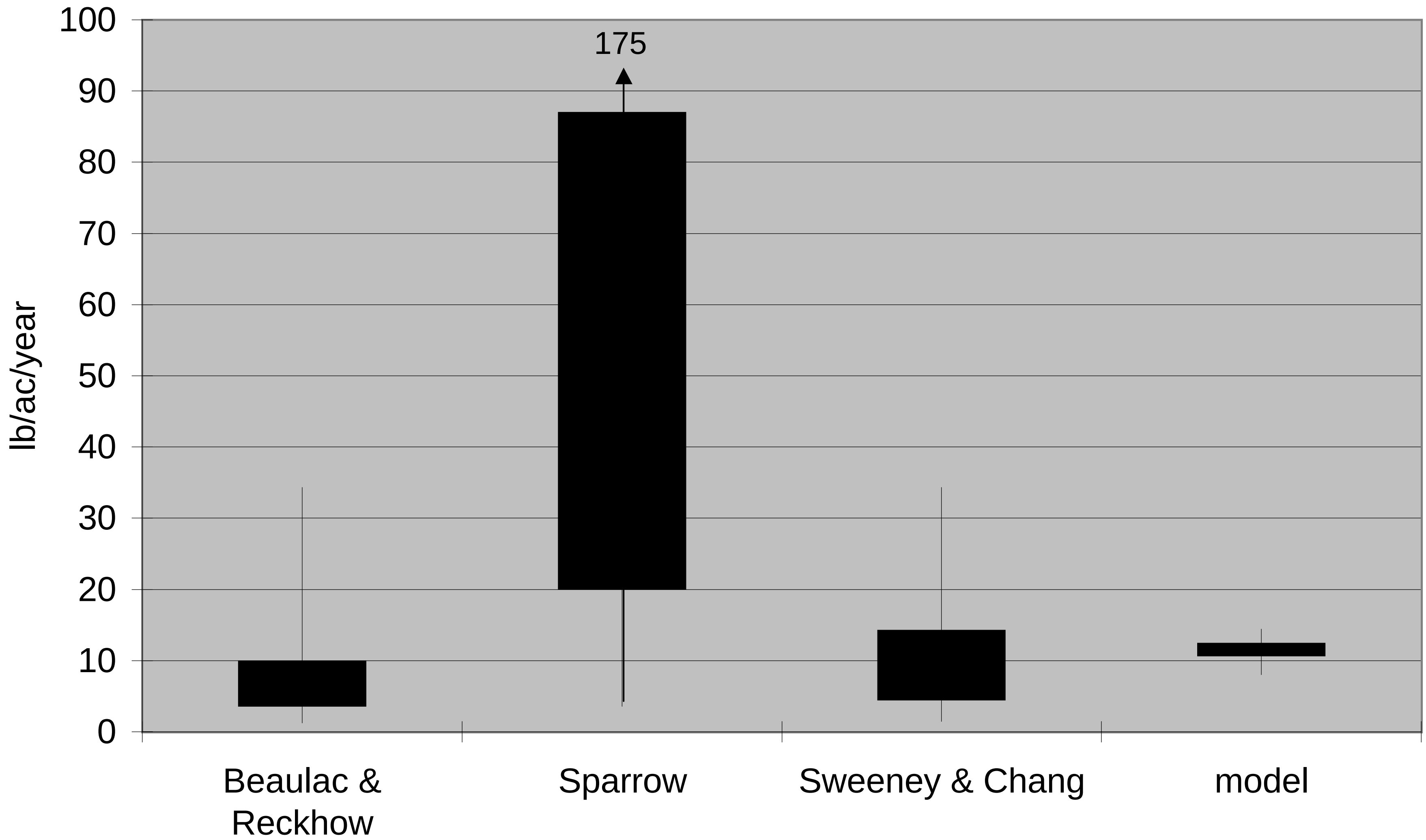


Figure 44. Urban Phosphorus

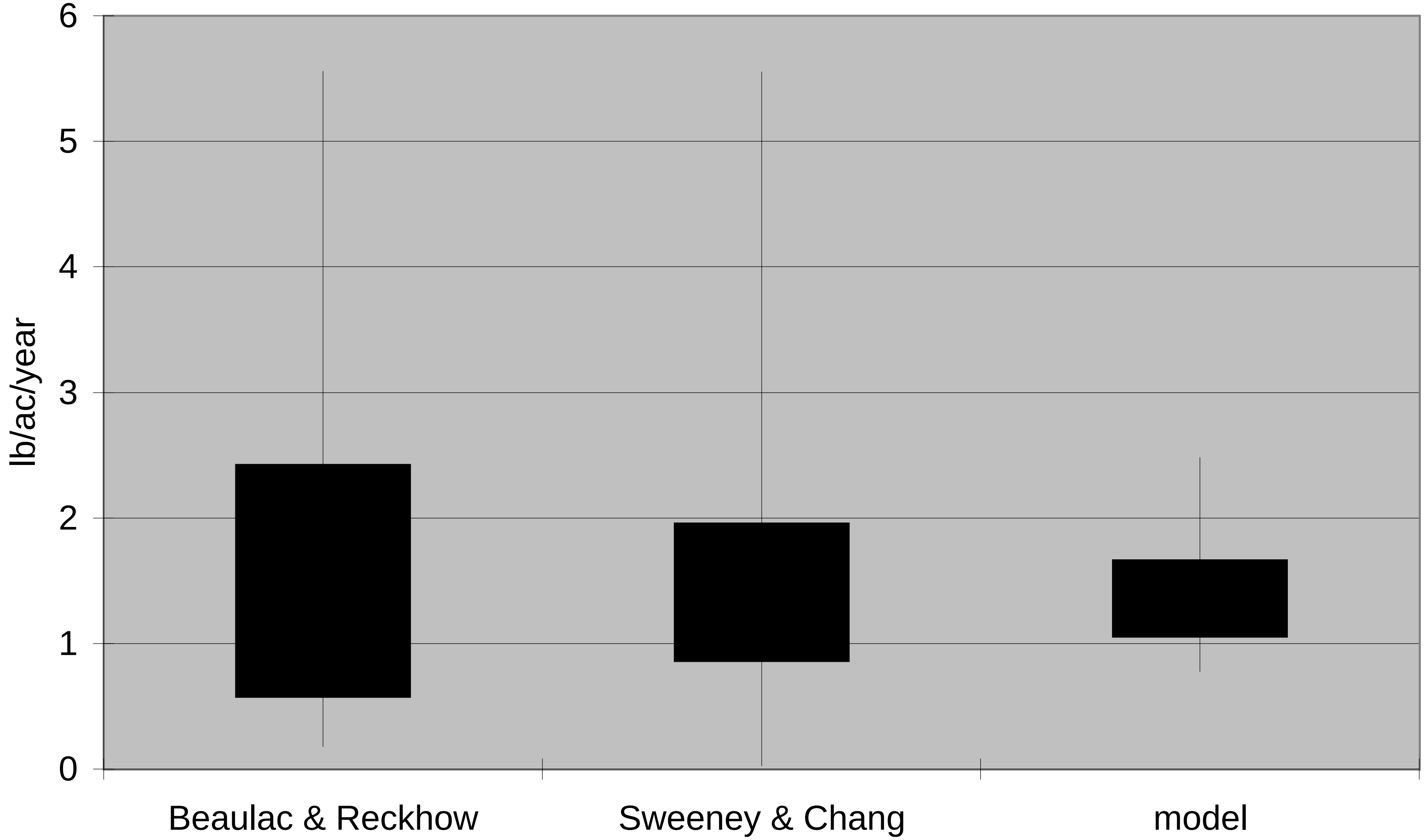


Figure 45.

Phase 4.3 Watershed Model Land Use Loads

Urban Land Total Nitrogen (lbs/acre)

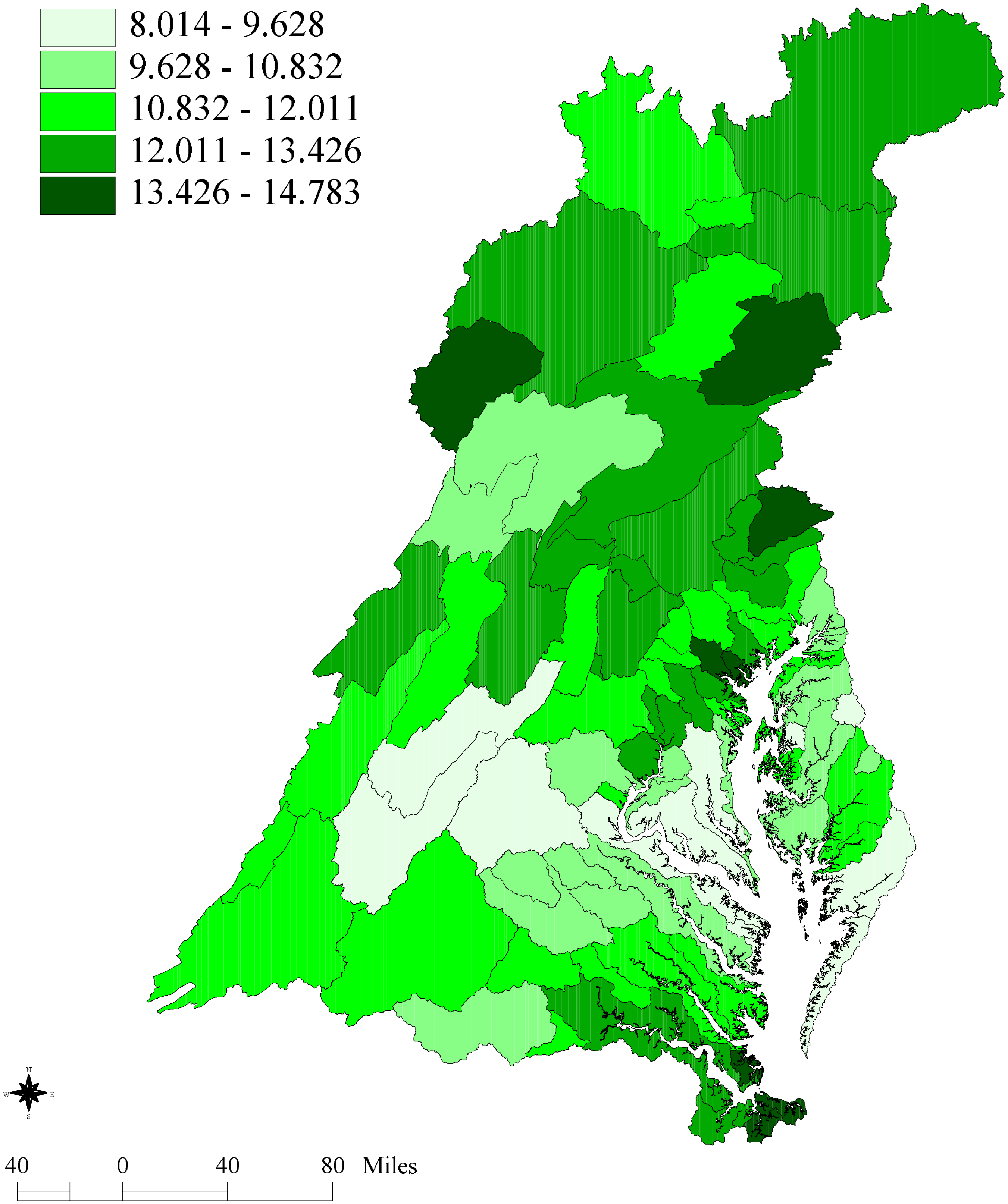


Figure 46.

Phase 4.3 Watershed Model Land Use Loads

Urban Land Total Phosphorous (lbs/acre)

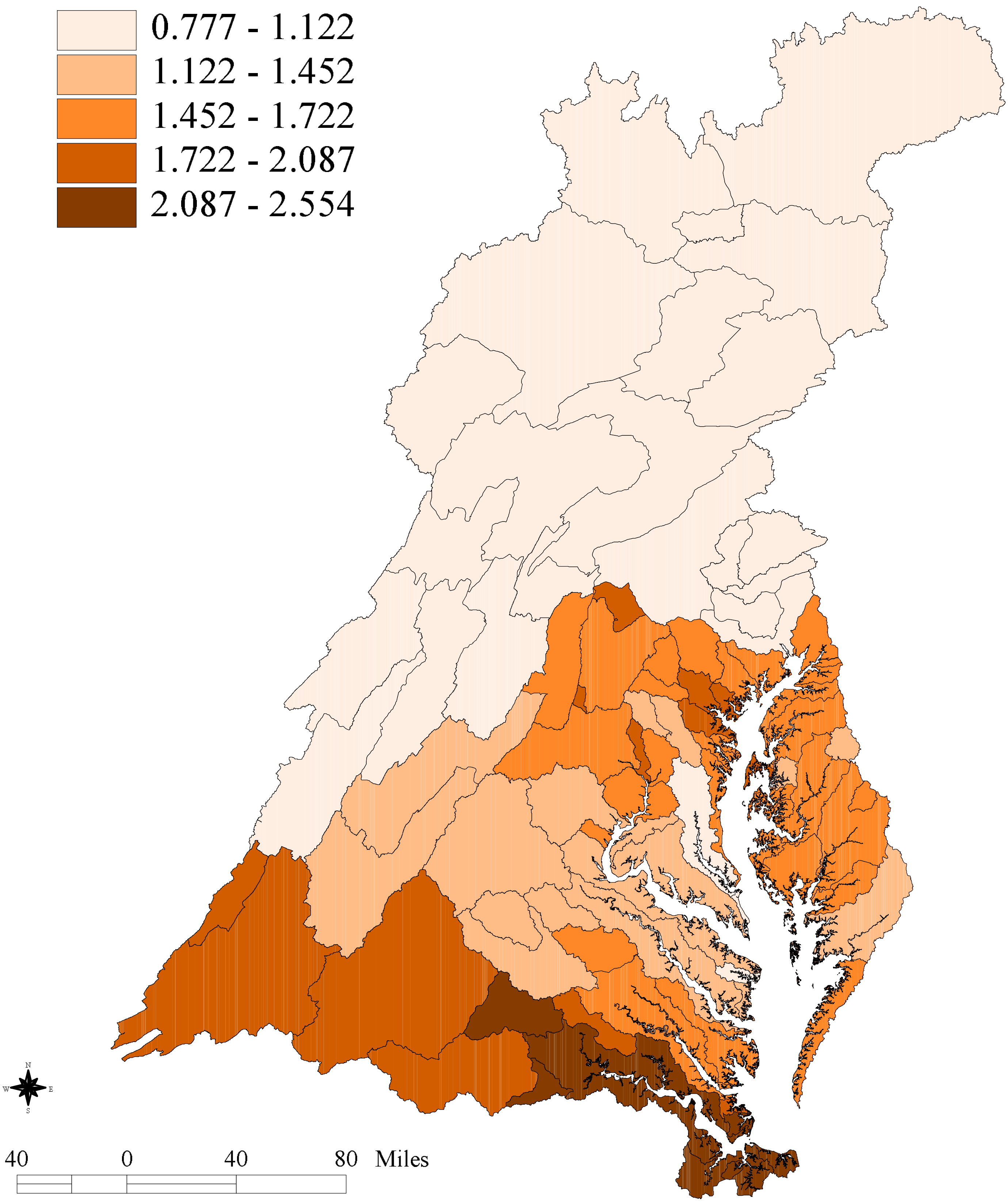


Figure 47. Total Nitrogen Non-Agricultural Herbaceous Export

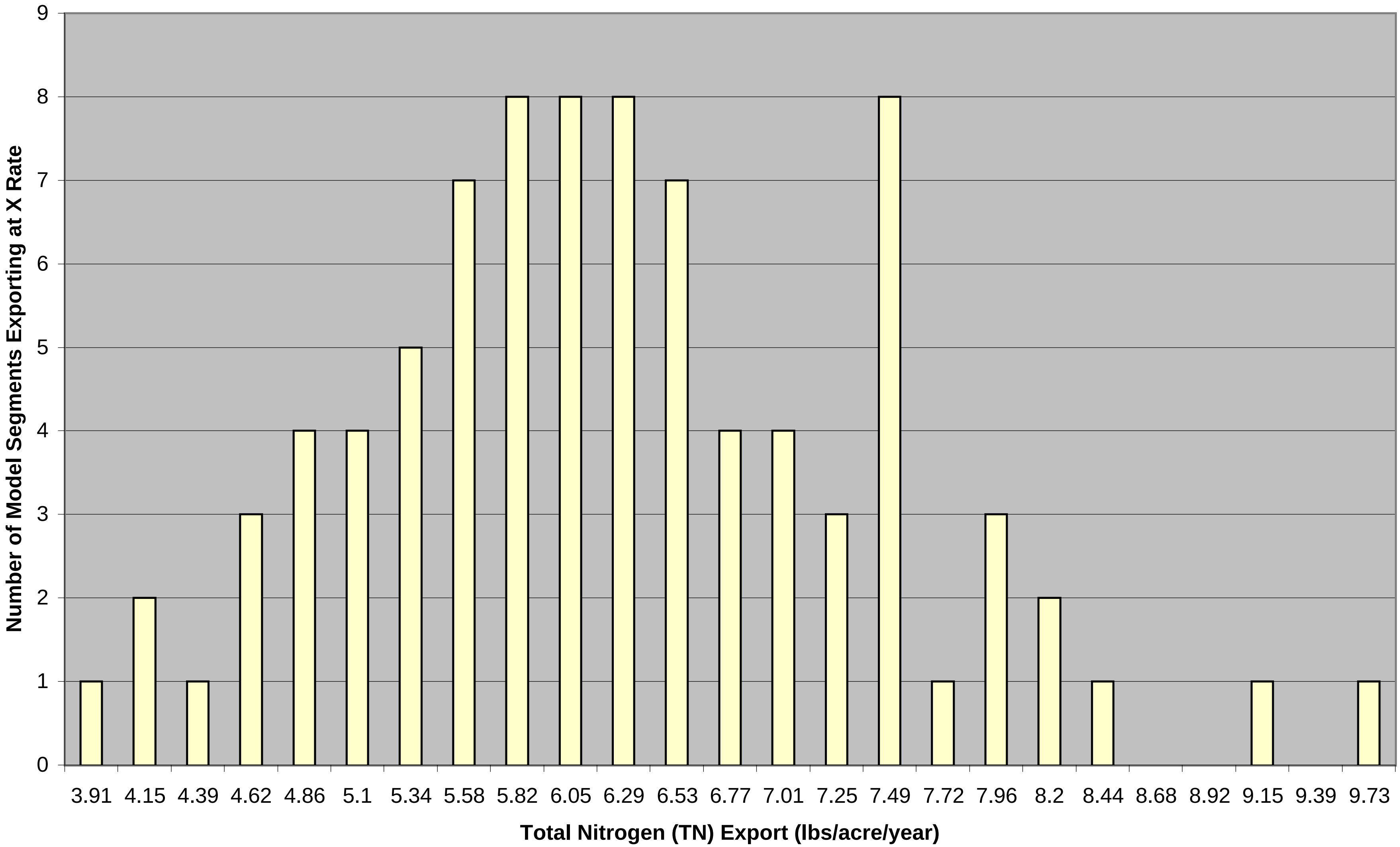


Figure 48. Total Phosphorous Non-Agricultural Herbaceous Export

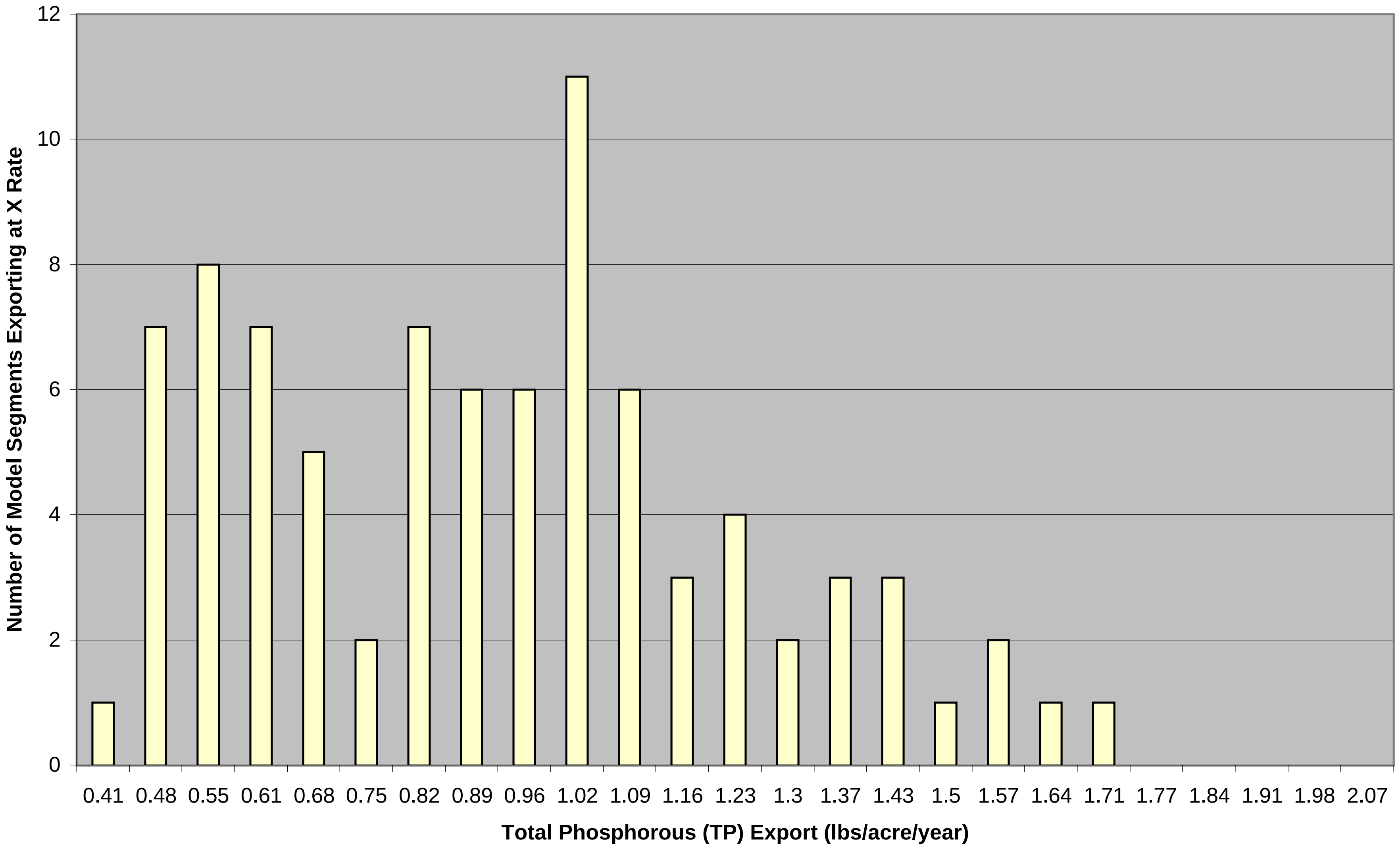


Figure 49. Forest TN vs atmospheric deposition

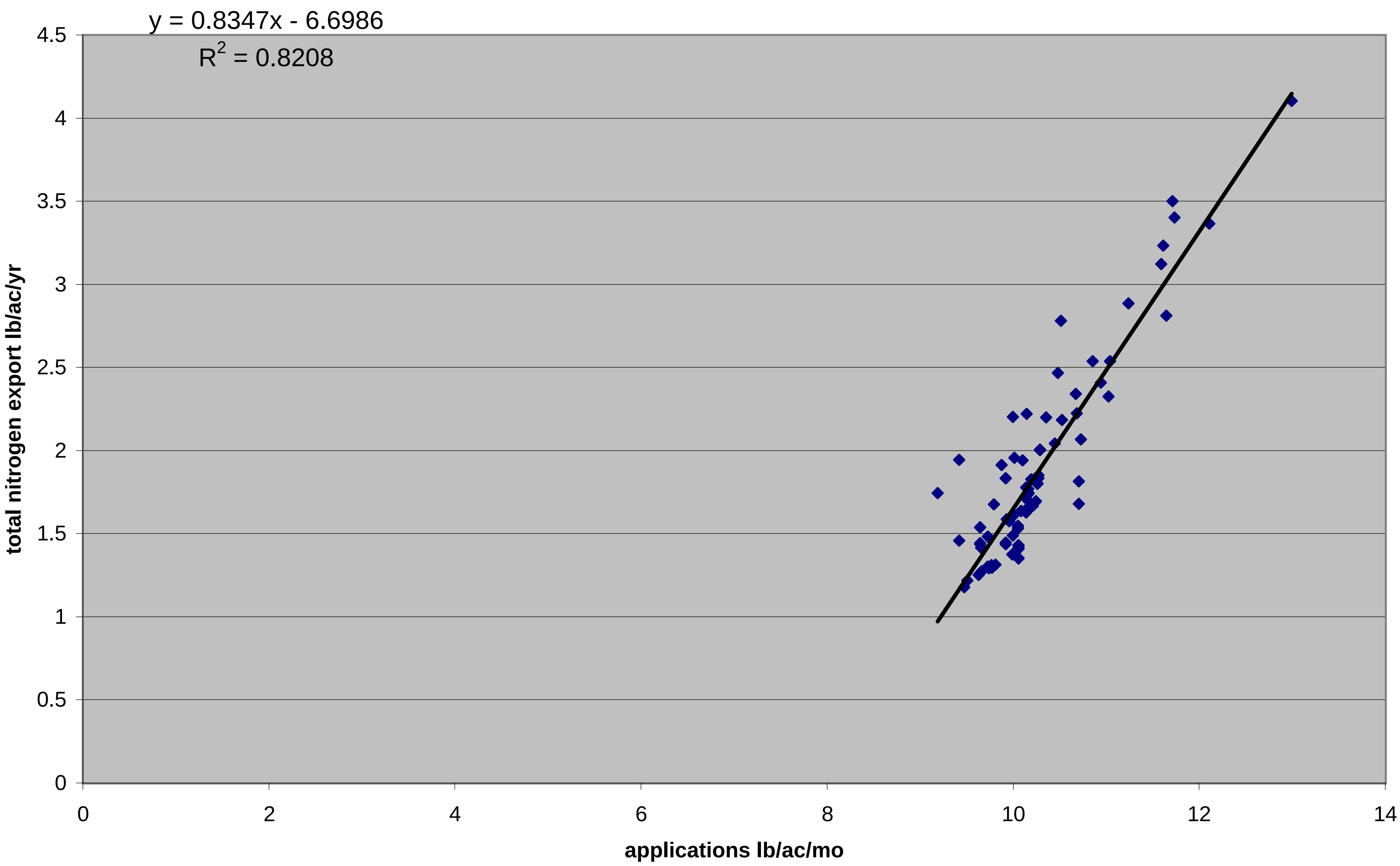


Figure 50. Total Nitrogen Forest Export

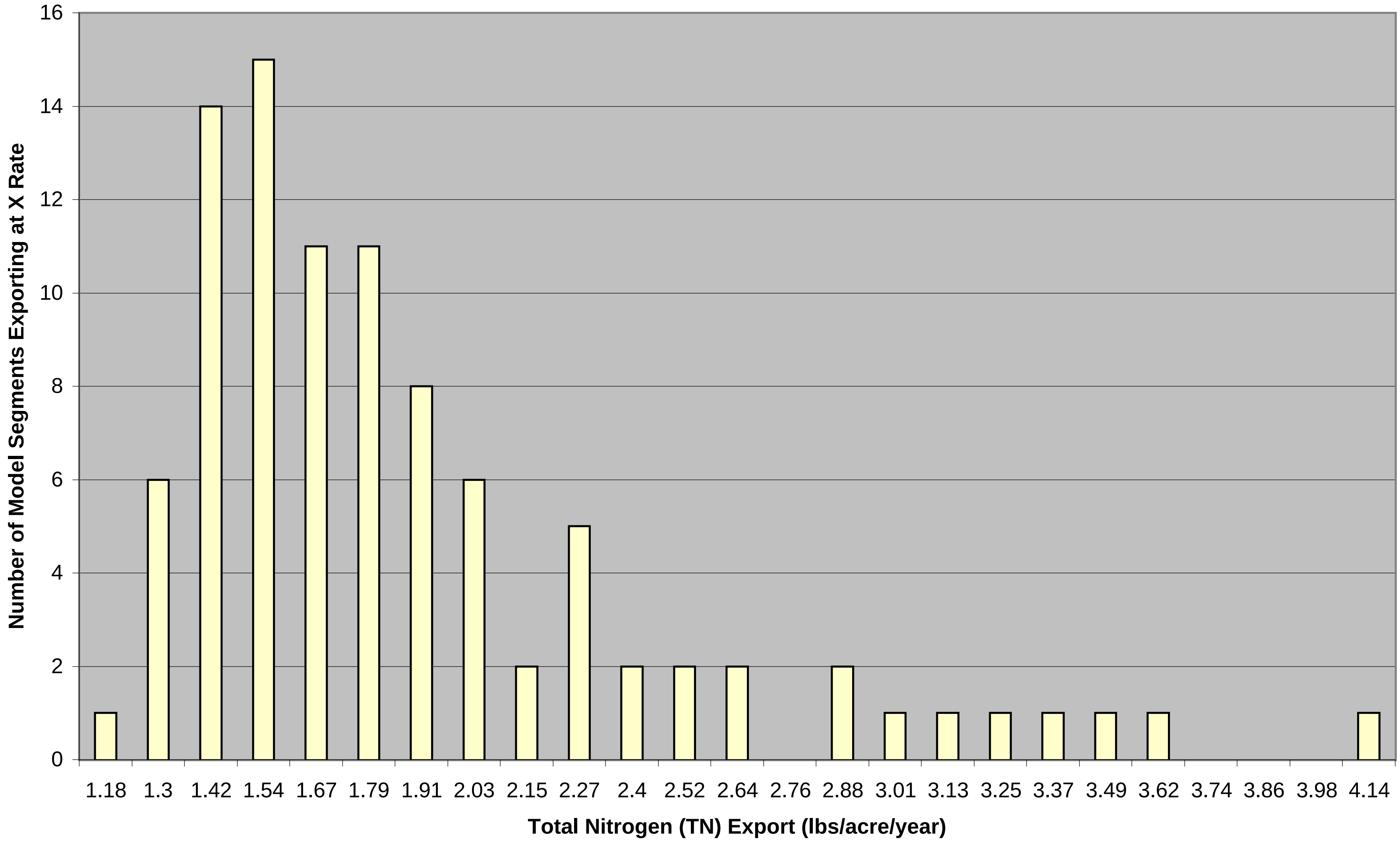


Figure 51. Total Phosphorous Forest Export

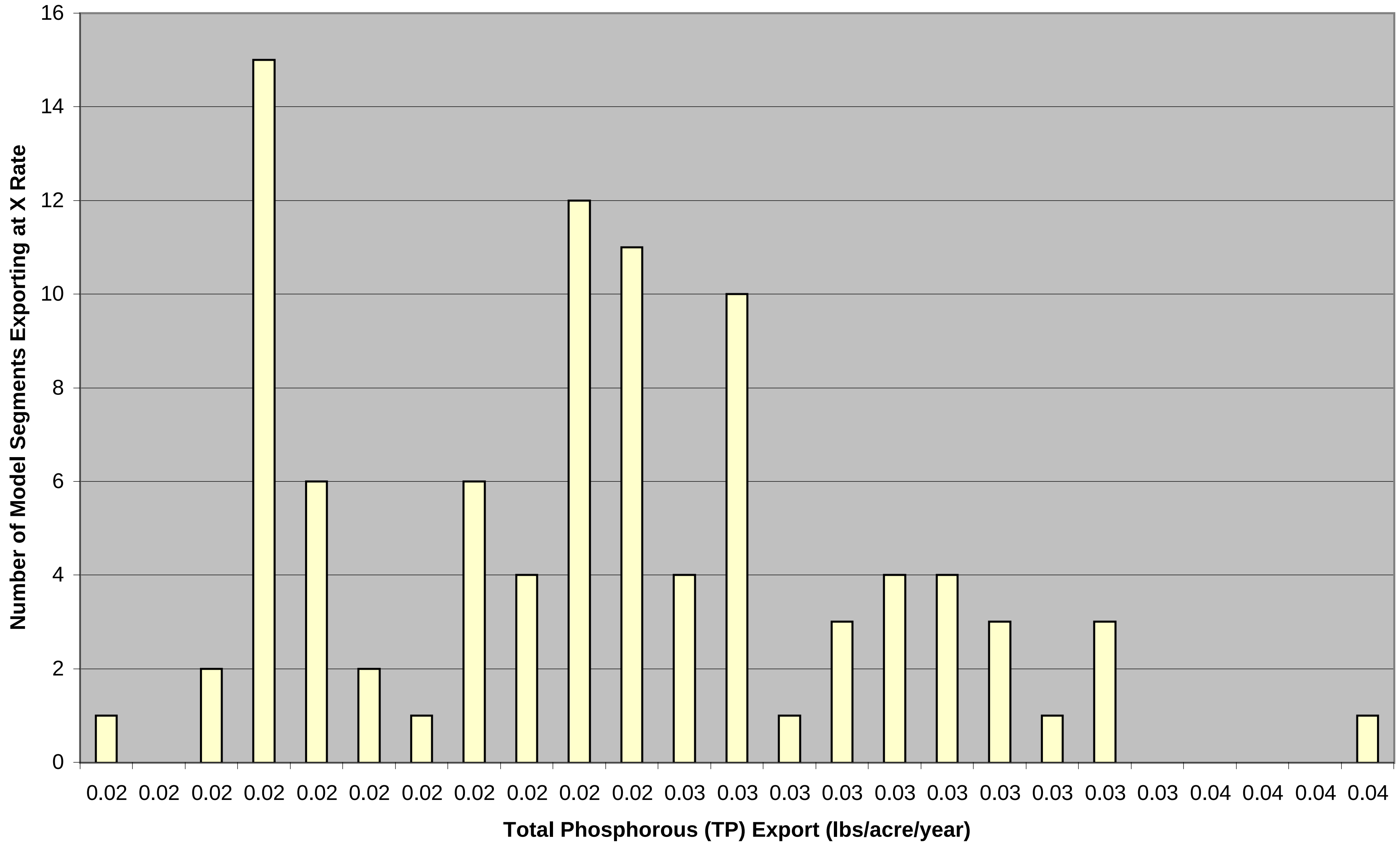


Figure 52. Forest Nitrogen

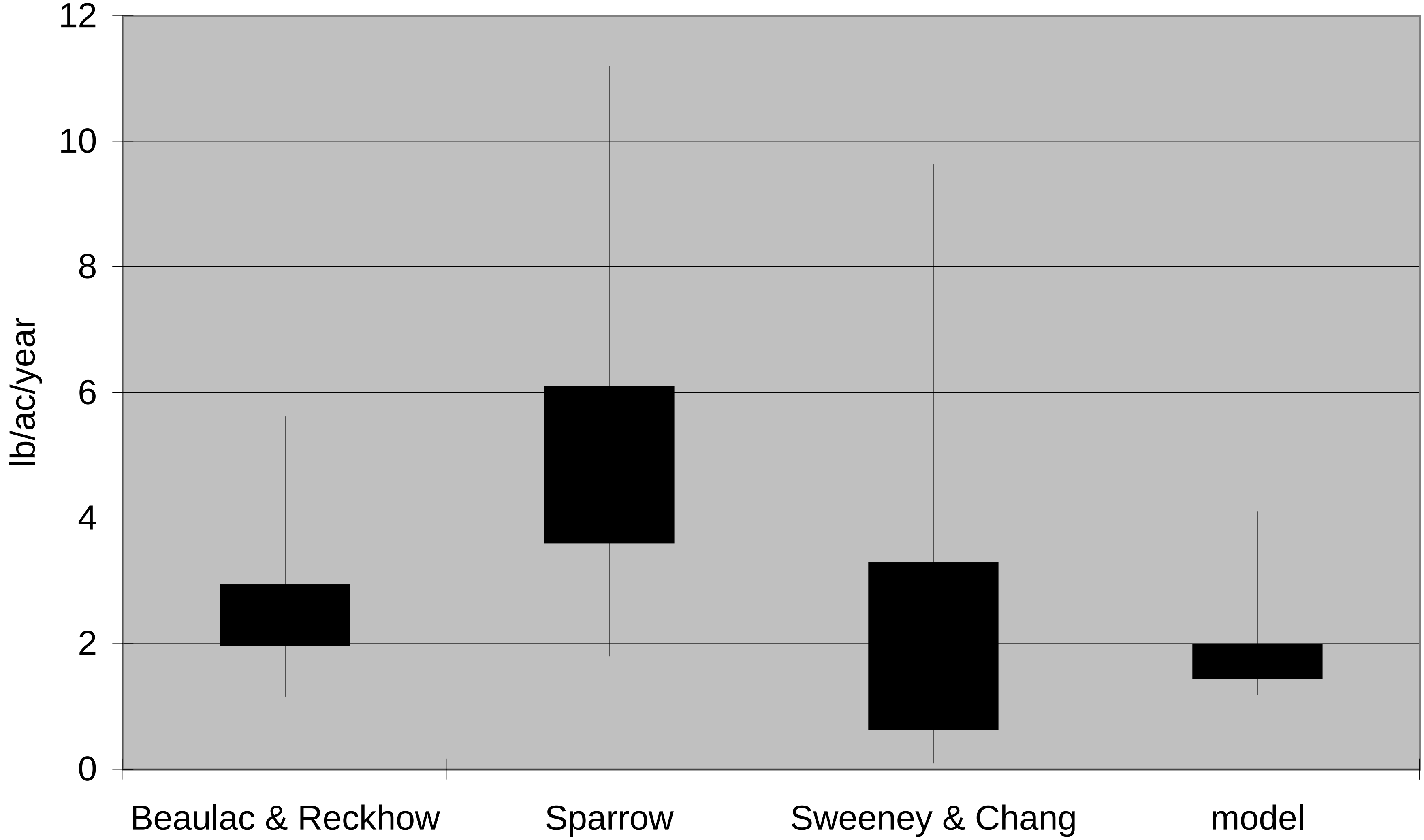


Figure 53. Forest Phosphorus

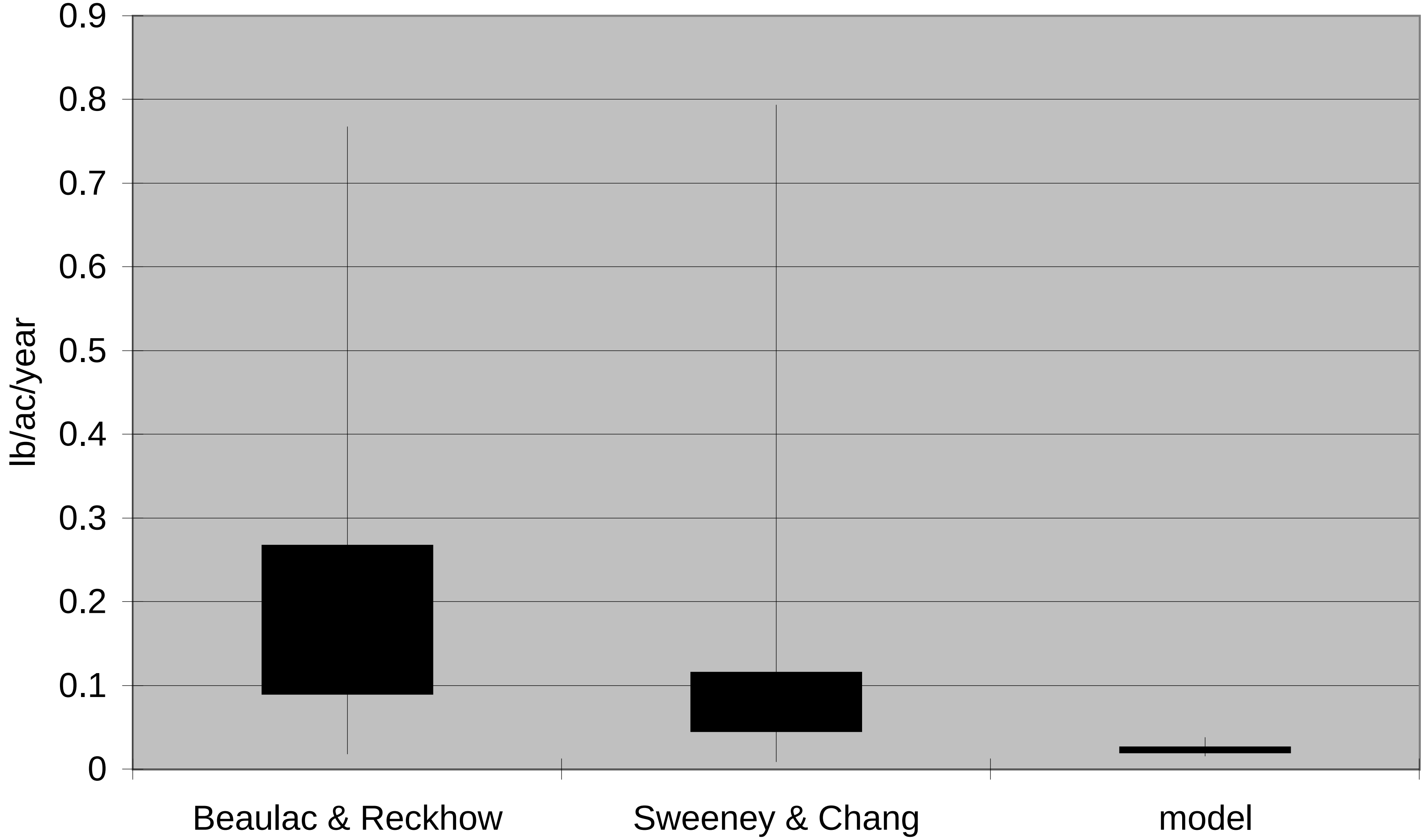


Figure 54.

Phase 4.3 Watershed Model Land Use Loads

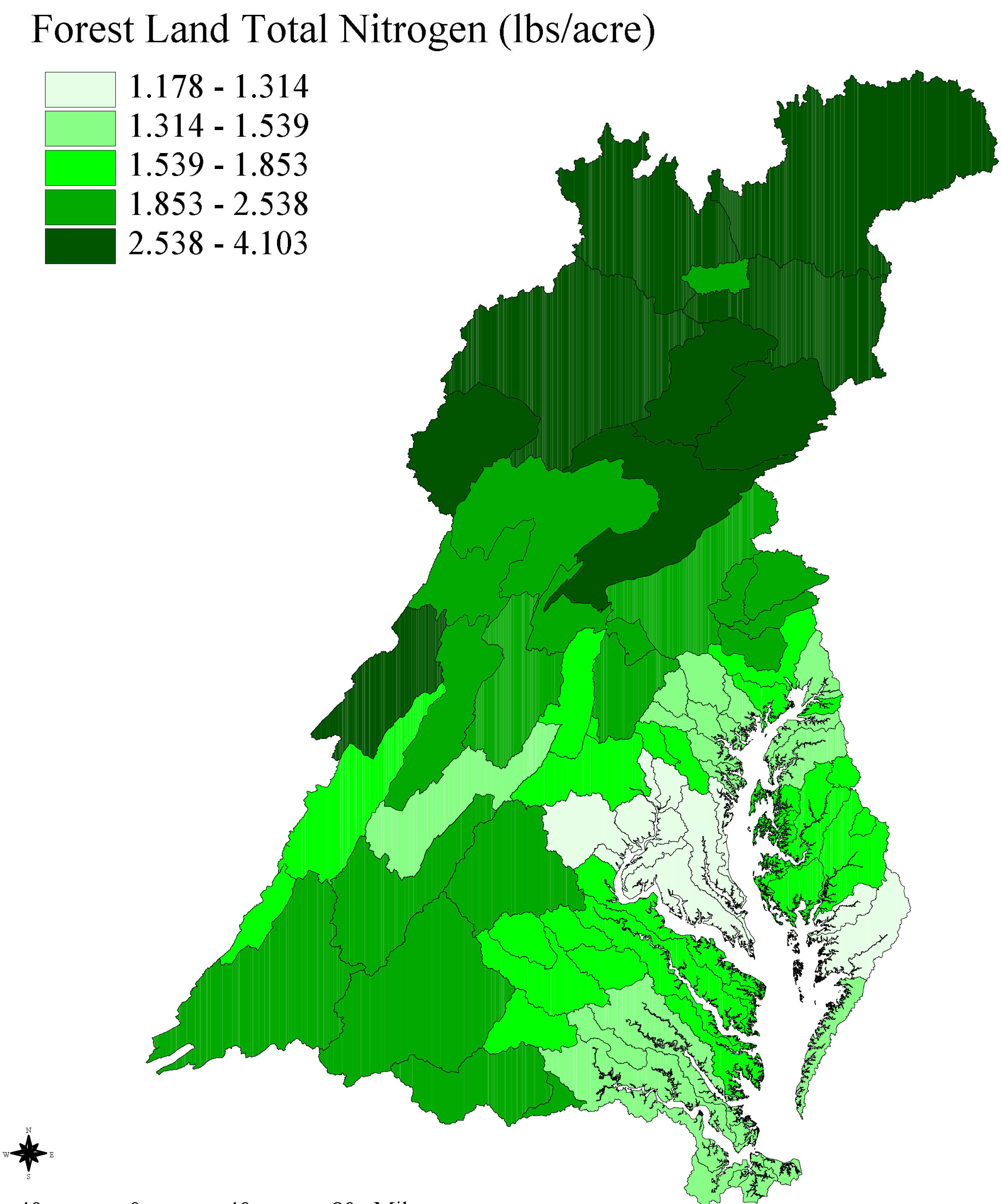


Figure 55.

Phase 4.3 Watershed Model Land Use Loads

Forest Land Total Phosphorous (lbs/acre)

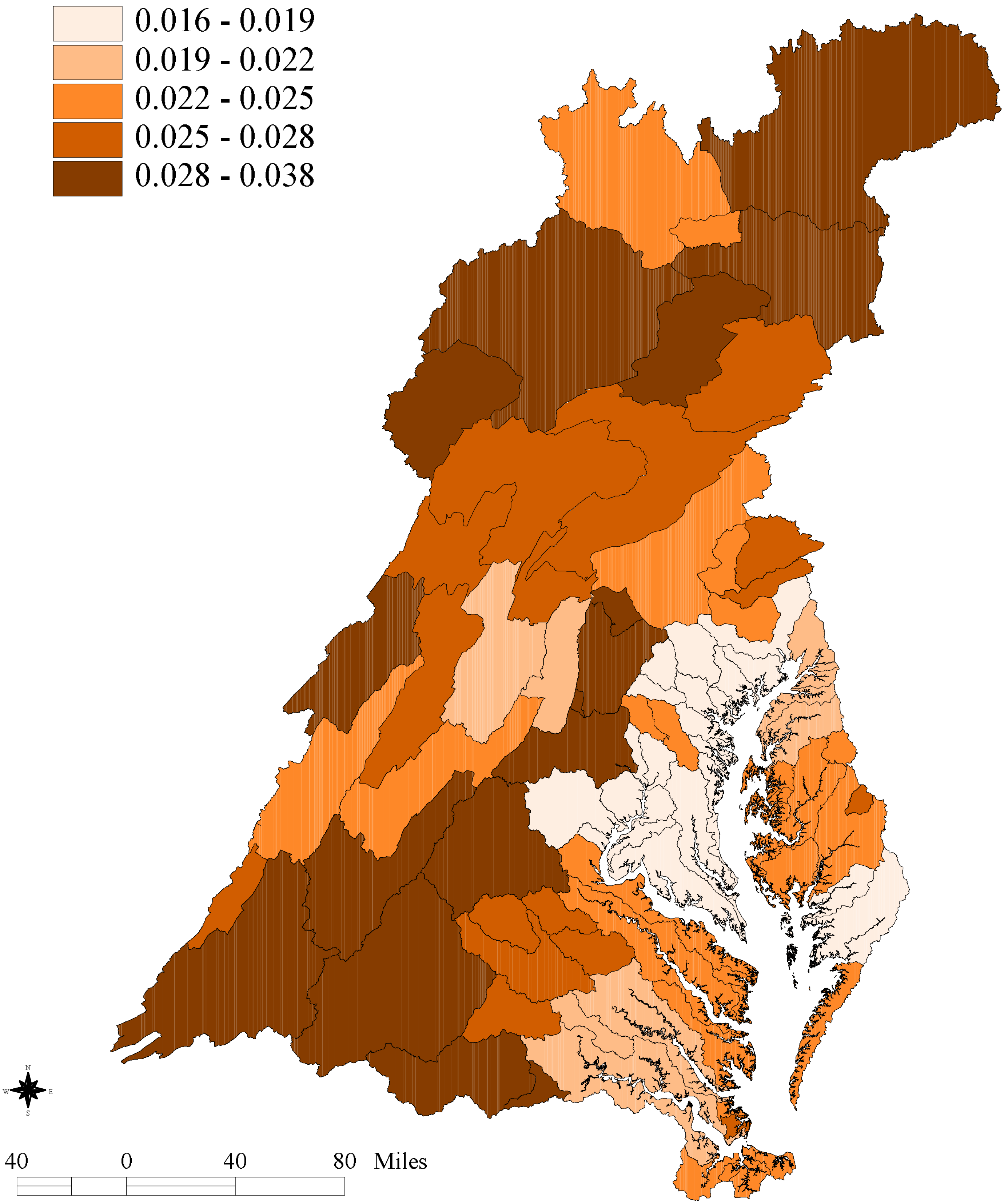
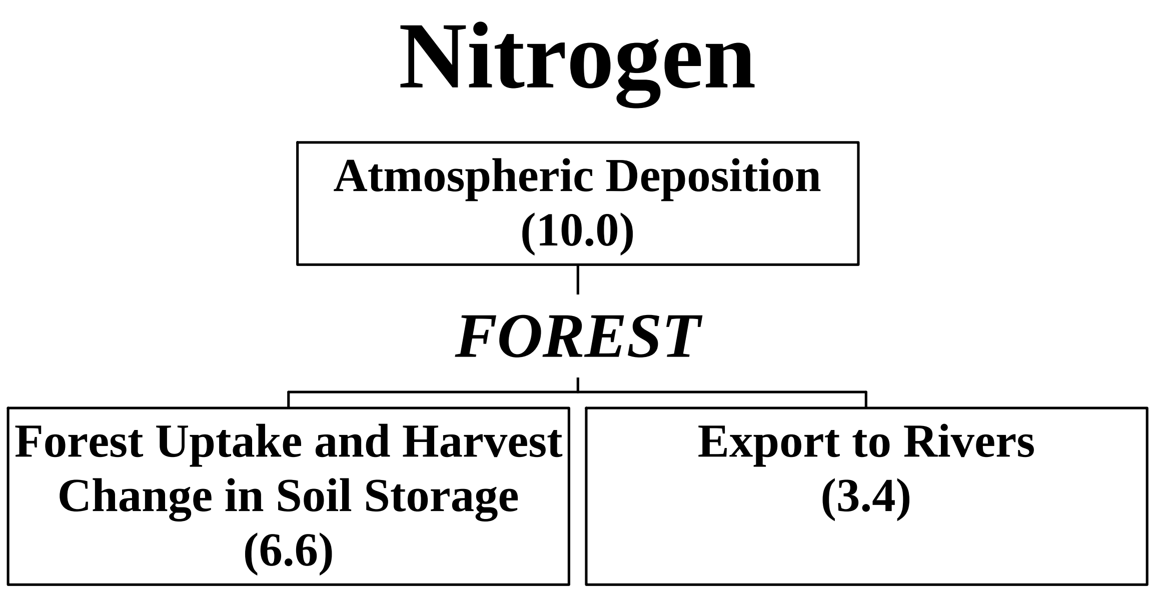


FIG. 56. Forest Total Nitrogen Mass Balance (kg/ha-yr)



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