Sensitivity analysis of the HSPF AGCHEM Model

This analysis was used to get a general understanding for how the AGCHEM model module simulation was reacting to inputs. The Modeling Workgroup determined this initial work should be set aside in favor of a second sensitivity analysis that would be performed based on direct sensitivity test with manipulated inputs.

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Executive summary

The HSPF Watershed Model used within the framework of the Chesapeake Bay Program has two modules for the simulation of nutrient biogeochemical cycles and export at each pervious land segment in the watershed. The two modules are the Agricultural Chemical Model (AGCHEM) and the Pervious Quality Model (PQUAL), where "Quality," in this case, is designated for nutrients. AGCHEM is based on biological and chemical processes with parameterization and simulation of nutrient uptake by plants and trees, remineralization, nitrification, denitrification, nitrogen fixation, volatilization, adsorption, desorption, and temperature influence on process rates. PQUAL, on the other hand, simulates nutrient fluxes using simplified, first-order approximation, specified based on posteriori knowledge and data analysis. Although AGCHEM is a robust module from academic and scientific standpoints, its high level of complexity and non-linearity in simulated results represent a hurdle for comprehension by stakeholders and management communities. For management purposes, a simpler module would be more straightforward for comprehension and decision implementation. PQUAL meets these challenges in the management fields. Therefore, for the 2017 mid-point assessment, it is planned to shift from a combined PQUAL and AGCHEM simulation, which was systematically used in the previous phases of the Chesapeake Bay Program, to a full version of PQUAL. However, the Chesapeake Bay Program must develop a new version of PQUAL as robust as the ACHEM prior to application. To this end, the Chesapeake Bay Program Modeling Team has conducted a series of comprehensive sensitivity analyses of the AGCEHM simulation between all nutrient inputs and outputs over all land segments and all land uses in the Bay watershed. The functions resulted from these sensitivity analyses will be used to specify functional links between nutrient inputs and outputs in the PQUAL version of the Watershed Model.

Fourteen scenarios were included in the sensitivity analysis. These scenarios were thus selected as to cover a wide range of inputs from 1985 to 2011. Some extreme scenarios were included as well, such as "No Action" scenarios, in which all management practices are removed, and "E3" scenarios, in which management practices were assumed to apply to the fullest extent without consideration of physical and economical constraints. These scenarios were simulated over ten years from 1991 to 2000 and average annual data of both inputs and outputs were used for the analyses.

Detailed description on the analysis and results are presented in the main text. Below is the list of final recommendation for each type of land use.

(1) Forest: Forest has only nitrogen atmospheric deposition as loading. For total nitrogen export, the model sensitivity slope is given by the following latitudinal function:

$$TN\_slope = 0.0103Latitude-0.3499$$

For inorganic dissolve nitrogen (DIN) export, the sensitivity slope is described as

$$DIN\_slope=0.0104Latitude-0.3565$$

For organic nitrogen export, the median slope of 0.003 is recommended for all land segments.

(2) High-tillage cropland with manure (hwm): Total nitrogen (or phosphorus) input is recommended as the unique predictor given that multi-variate regression did not provide significantly better prediction. The median sensitivity slope is 0.21 for total nitrogen export, 0.15 for IDN, 0.07 for organic nitrogen, 0.12 for total phosphorus, 0.11 for phosphate and 0.013 for organic phosphorus.

(3) High-tillage cropland without manure (hom): There is no manure application on high-tillage cropland without manure (hom). Multi-varrate regression is recommended for nitrogen export and total input for phosphorus export. Total nitrogen export is determined as:

$$TN\_export = 0.44A+0.23F+0.43L-0.04U+c$$

where A is atmospheric deposition, F is fertilizer, L is nitrogen legume fixation, U is uptake and c is the export in the calibration scenario. DIN export is given as:

$$DIN\_export = 0.43A+0.23F+0.41L-0.05U+c.$$

Organic nitrogen (ON) is described as:

$$ON\_export = 0.012A+0.005F+0.009L+0.006U+c$$

Only one sensitivity slope is needed for phosphorus export prediction that is multiplied to the total phosphorus loading to a specific land segment. The sensitivity slope is 0.1 for both total phosphorus and phosphate exports and 0.0018 for organic phosphorus.

(4) Low-tillage cropland with manure (lwm): Similarly to high-tillage cropland without manure, multi-variate regression is recommended for nitrogen export from lLow-tillage cropland with manure (lwm) and a single predictor of total input for phosphorus exports. Total nitrogen export is described as:

$$TN\_export = 0.33A+0.16M+0.31F+0.36L-0.13U+c$$

where M is manure and other input variables are described above. DIN export is given as:

$$DIN\_export = 0.25A+0.08M+0.21F+0.25L-0.13U+c$$

and organic nitrogen is determined as:

$$ON\_export = 0.07A+0.08M+0.08F+0.1L-0.01U+c$$

The sensitivity slope for phosphorus export is 0.10 for total phosphorus export, 0.09 for phosphate and 0.012 for organic phosphorus.

(5) Hay with nutrient management (hyw): Nitrogen was simulated using PQUAL on hay with nutrient management so that sensitivity analysis is irrelevant. Total phosphorus input is recommended as the single predictor for different constituents export. The sensitivity slope is 0.08 for both total phosphorus and phosphate exports and practically no sensitivity was detected for organic phosphorus export (i.e., sensitivity slope equals to zero).

(6) Hay without nutrient management (hyo): Phosphorus was simulated with PQAUL on hay without nutrient management. Total nitrogen input is recommended as a single predictor for nitrogen exports from hyo. The sensitivity slope is 0.30 for both total nitrogen and DIN exports and 0.005 for organic nitrogen export.

(7) Alfalfa (alf): Legume fixation and uptake were not recorded for alfalfa land use. Phosphorus in atmospheric deposition was not taken into account whereas only phosphorus fertilizer was applied to alfalfa. Consequently, only two types of input were included in the sensitivity analysis on alfalfa: atmospheric deposition (A) and manure (M) for nitrogen exports and

manure and fertilizer (F) for phosphorus export. Multi-variate is recommended for alfalfa land use. Nitrogen and phosphorus exports are determined as:

$$TN\_export=0.22A+0.08M+c$$

$$DIN\_export=0.22A+0.09M+c$$

$$ON\_export=0.0004A+0.0005M+c$$

$$TP\_export=0.15M+0.09F+c$$

$$PO4\_export=0.14M+0.1F+c$$

$$OP\_export=0.002M-0.000F+c$$

where TP is total phosphorus, PO4 is phosphate, OP is organic phosphorus and other variables are defined above.

(8) Pasture (pas): Only nitrogen sensitivity was analyzed given that phosphorus was simulated with PQUAL. Atmospheric deposition, manure and fertilizer are the only input variables on pasture whereas legume fixation and uptake are not applicable. Multi-variate prediction is recommended over a single predictor of total nitrogen input. The prediction functions for different nitrogen constituents are:

$$TN\_export=0.15A+0.06M+0.10F+c$$

$$DIN\_export=0.15A+0.049M+0.09F+c$$

$$ON\_export=0.005A+0.013M+0.01F+c$$

(9) Non-regulated pervious development (npd): Phosphorus was simulated with PQUAL and atmospheric deposition and fertilizer are the only nitrogen inputs on urban development on pervious land. Total nitrogen input predicted nitrogen export equally well so that it is recommended as the unique predictor on non-regulated pervious development. The model sensitivity slope applied to the total nitrogen input is 0.12 for total nitrogen export, 0.10 for DIN export and 0.012 for organic nitrogen export.

All the sensitivity slopes are presented in Tables 1-7 and the red values are the recommendation for the PQUAL specification.

Table 1. Model sensitivity slopes between nutrient export and total loading on different land uses. TN: Total nitrogen, DIN; Dissolved inorganic nitrogen; ON: Organic nitrogen; TP: Total phosphorus; PO4: Phosphate; OP: Organic phosphorus; W: with; w/o: without. Blank cells indicate not applicable. Red values are the recommendation for the PQUAL specification.

Land use	TN	DIN	ON	TP	PO4	OP
Forest (for)	0.05	0.04	0.003			
High-tillage w manure (hwm)	0.21	0.15	0.07	0.12	0.11	0.015
High-tillage w/o manure (hom)	0.48	0.46	0.02	0.10	0.10	0.002
Low-tillage w manure (lwm)	0.19	0.14	0.06	0.10	0.09	0.01
Hay w nutrient management (hym)				0.08	0.08	0.00
Hay w/o nutrient management (hyo)	0.30	0.30	0.005			
Alfalfa (alf)	0.03	0.03	-0.002	0.10	0.10	0.001
Pasture (pas)	0.06	0.05	0.013			
Non-regulated pervious urban (npd)	0.12	0.10	0.012			

Table 2. Model sensitivity slopes of multi-variate regression between total nitrogen (TN) export and different types of loading on different land uses. A: atmospheric deposition; M: Manure; F: Fertilizer; U: Uptake; L: Legume nitrogen fixation; w: with; w/o: without. Blank cells indicate not applicable. Red values are recommended for the PQUAL specification.

Land use	A	M	F	U	L
Forest (for)	0.05				
High-tillage w manure (hwm)	0.35	0.19	0.29	-0.09	0.34
High-tillage w/o manure (hom)	0.44		0.23	-0.004	0.43
Low-tillage w manure (lwm)	0.33	0.16	0.31	-0.13	0.36
Hay w nutrient management (hym)					
Hay w/o nutrient management (hyo)	0.27			0.02	
Alfalfa (alf)	0.22	0.08			
Pasture (pas)	0.15	0.06	0.10		
Non-regulated pervious urban (npd)	0.15		0.07		

Table 3. Model sensitivity slopes of multi-variate regression between dissolved inorganic nitrogen (DIN) export and different types of loading on different land uses. A: atmospheric deposition; M: Manure; F: Fertilizer; U: Uptake; L: Legume nitrogen fixation; w: with; w/o: without. Blank cells indicate not applicable. Red values are the recommendation for the PQUAL specification.

Land use	A	M	F	U	L
Forest (for)	0.06				
High-tillage w manure (hwm)	0.27	0.08	0.19	-0.09	0.20
High-tillage w/o manure (hom)	0.43		0.23	-0.05	0.41
Low-tillage w manure (lwm)	0.25	0.08	0.21	-0.13	0.25
Hay w nutrient management (hym)					
Hay w/o nutrient management (hyo)	0.27		0.02		
Alfalfa (alf)	0.22	0.09			
Pasture (pas)	0.15	0.04	0.09		
Non-regulated pervious urban (npd)	0.14		0.06		

Table 4. Model sensitivity slopes of multi-variate regression between organic nitrogen (ON) export and different types of loading on different land uses. A: atmospheric deposition; M: Manure; F: Fertilizer; U: Uptake; L: Legume nitrogen fixation; w: with; w/o: without. Blank cells indicate not applicable. Red values are the recommendation for the PQUAL specification.

Land use	A	M	F	U	L
Forest (for)	0.04				
High-tillage w manure (hwm)	0.08	0.11	0.08	-0.01	0.11
High-tillage w/o manure (hom)	0.012		0.005	0.006	0.009
Low-tillage w manure (lwm)	0.07	0.08	0.08	-0.01	0.10
Hay w nutrient management (hym)					
Hay w/o nutrient management (hyo)	0.004			0.001	
Alfalfa (alf)	0.0004	0.0005			
Pasture (pas)	0.005	0.013	0.008		
Non-regulated pervious urban (npd)	0.011		0.015		

Table 5. Model sensitivity slopes of multi-variate regression between total phosphorus (TP) export and different types of loading on different land uses. A: atmospheric deposition; M: Manure; F: Fertilizer; U: Uptake; L: Legume nitrogen fixation; w: with; w/o: without. Blank cells indicate not applicable. Red values are the recommendation for the PQUAL specification.

Land use	A	M	F	U	L
Forest (for)					
High-tillage w manure (hwm)		0.13	0.11		
High-tillage w/o manure (hom)			0.10		
Low-tillage w manure (lwm)		0.11	0.09		
Hay w nutrient management (hym)		0.09	0.10		
Hay w/o nutrient management (hyo)					
Alfalfa (alf)		0.15	0.09		
Pasture (pas)					
Non-regulated pervious urban (npd)					

Table 6. Model sensitivity slopes of multi-variate regression between phosphate (PO4) export and different types of loading on different land uses. A: atmospheric deposition; M: Manure; F: Fertilizer; U: Uptake; L: Legume nitrogen fixation; w: with; w/o: without. Blank cells indicate not applicable. Red values are the recommendation for the PQUAL specification.

Land use	A	M	F	U	L
Forest (for)					
High-tillage w manure (hwm)		0.12	0.10		
High-tillage w/o manure (hom)			0.10		
Low-tillage w manure (lwm)		0.10	0.09		
Hay w nutrient management (hym)		0.09	0.10		
Hay w/o nutrient management (hyo)					
Alfalfa (alf)		0.14	0.10		
Pasture (pas)					
Non-regulated pervious urban (npd)					

Table 7. Model sensitivity slopes of multi-variate regression between organic phosphate (OP) export and different types of loading on different land uses. A: atmospheric deposition; M: Manure; F: Fertilizer; U: Uptake; L: Legume nitrogen fixation; w: with; w/o: without. Blank cells indicate not applicable. Red values are the recommendation for the PQUAL specification.

Land use	A	M	F	U	L
Forest (for)					
High-tillage w manure (hwm)		0.02	0.002		
High-tillage w/o manure (hom)			0.002		
Low-tillage w manure (lwm)		0.015	0.005		
Hay w nutrient management (hym)		0.0	0.0		
Hay w/o nutrient management (hyo)					
Alfalfa (alf)		0.002	0.000		
Pasture (pas)					
Non-regulated pervious urban (npd)					

Table 8. Ratio between nutrient exports and total loading on different land uses. TN: Total nitrogen, DIN; Dissolved inorganic nitrogen; ON: Organic nitrogen; TP: Total phosphorus; PO4: Phosphate; OP: Organic phosphorus; W: with; w/o: without. Blank cells indicate not applicable.

Land use	TN	DIN	ON	TP	PO4	OP
Forest (for)	0.29	0.13	0.16			
High-tillage w manure (hwm)	0.28	0.17	0.11	0.10	0.08	0.02
High-tillage w/o manure (hom)	0.23	0.20	0.03	0.10	0.10	0.004
Low-tillage w manure (lwm)	0.26	0.16	0.10	0.09	0.08	0.01
Hay w nutrient management (hym)				0.08	0.08	0.004
Hay w/o nutrient management (hyo)	0.37	0.30	0.07			
Alfalfa (alf)	0.73	0.62	0.11	0.09	0.09	0.003
Pasture (pas)	0.07	0.05	0.02			
Non-regulated pervious urban (npd)	0.22	0.07	0.15			

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1. Introduction

In the context of this report, "sensitivity" means the relationship between the inputs and outputs of nutrients within the framework of the HSPF Watershed Model. Sensitivity analyses are often performed by analyzing the response of an output variable to variations in input variables or controlling parameters. This is usually carried out by series of simulations in which an input variable or controlling parameter is changed with a pre-defined pattern. Changes in the response variable are then expressed as percent change in response to changes in the input variables.

Within the framework of the Chesapeake Bay Program, three hundred scenarios were simulated in the past couple of years using HSPF. A rich data base was established with a large range of input variables. As a result, our analysis was conducted based on the previously established data base and not based on a series of model runs specifically designed for sensitivity analysis. Moreover, functional relationships, instead of percent changes, were sought between nutrients inputs and outputs from the Watershed Model simulation.

HSPF has two major modules to simulate watershed nutrient biogeochemical cycles and loads: AGCHEM and PQUAL. AGCHEM, an agriculture chemical model, is based on biological and chemical principles and dynamics processes. Nutrient uptakes by plants and trees, remineralization, nitrification, denitrification, nitrogen fixation, volatilization, adsorption, desorption and temperature influence on process rates are all parameterized. Although AGCHEM is a robust module from academic and scientific standpoints, its high level of complexity and non-linearity in simulated results represent a hurdle for comprehension by stakeholders and management communities. For management purpose, a simpler module would be more straightforward for comprehension and decision implementation. PQUAL, on the other hand, meets these challenges in the management fields. PQUAL, abbreviated from "Pervious Quality" or "constituents in pervious land" in HSPF, simulates nutrient fluxes using simplified, first-order approximation specified based on posteriori knowledge and data analysis.

The previous applications of the HSPF Watershed Model were carried out with a combined PQUAL and AGCHEM simulation, entitled version Phase 5.3.2. For the mid-point assessment in 2017, it is planned to use a full PQUAL version for clarity and management purposes. Although, PQUAL has simplified parameterization on the nutrient fluxes, it is the Chesapeake Bay Program Modeling Team's intention to develop a PQUAL version that comparable to the Phase 5.3.2 AGCHEM. To this end, a series of sensitivity analyses will be conducted over all land uses, land segments, and nutrient inputs and outputs. The outcomes of these analyses will be used to develop the PQUAL version of HSPF Watershed Model. This report presents the results of analyses, including model sensitivity slops for each nutrient constituent, the robustness of the regression prediction, element ratio between input and output and the final recommendation function for each nutrient constituent on each land use. As the objective of the sensitivity analysis is for the PQUAL specification, only nutrient constituents and land uses that were simulated using AGCHEM are analyzed and presented in the report.

2. Method and data

The sensitivity analysis was based on 14 selected scenarios that were simulated previously (Table 1). These scenarios were selected to cover a wide range of atmospheric deposition, manure, fertilizer and other nutrient loads of to the land surface. They ranged over 26 years from 1985 to 2011 when data from the watershed and the Bay are available to construct scenarios in the watershed and validate the Estuary Model in the Bay. Most of the scenarios were based on realistic data such as land uses, population, point source, tillage, number of animals, fertilizer and manure application, and atmospheric deposition. Some extreme scenarios for sensitivity analysis were included as well in order to cover wide range of inputs. The TMDL run was based on data from 2010 (Scenario 2010P1TMDL2N062411) in which controllable loads were adjusted so that water quality in the Bay meets standards. However, two other extreme scenarios were added as well. One is called "No action scenario" (2010NoActionN050611) in which all management practices were removed. On the other hand, the E3 scenario (2010E3P052411) represents the opposite extreme. E3 stands for Everyone, Everything, and Everywhere. In this scenario, all of the possible management measures were assumed implemented without consideration of physical and economical constraints. The 2007 and 2009 scenarios (2007N051811 and 2009N051811) were based on data of these two years, respectively. Two additional scenarios were included as well (2007N051811AA and 2009N051811AA). In these "AA" scenarios, the atmospheric deposition was assumed to be reduced to the level that air quality meets the standards defined by the Clear Air Act. For the years 2005 and 2011, no calibration runs were carried out in terms of watershed hydrology, calibrated hydrology from 1991-2000 was used, whereas data of point and nonpoint sources specific to each year were used in the simulation.

Modeled data were first processed and formatted with c-shell scripts and the analyses were conducted using R subroutines. Linear regression, multi-variate analysis and curve fitting were the procedures the most called in the R programs. The Watershed Model simulation was conducted over a period of ten years from 1991 to 2000. In the following sections, only analyses based on average annual data (annual data were averaged over the period from 1991 to 2000) are presented.

Input types include atmospheric deposition, manure, fertilizer and legume fixation. Uptake is also included as an independent predictor. Regression analyses were conducted in two steps: first with the total nutrient input as a single predictor and second, multi-variate regression was conducted using all the input types as independent variables. The regression functions were then applied in a forward mode to predict the outcome of the AGCHEM model. The model sensitivity is not applied during the calibration phase of the watershed model (WSM), which is typical constrained by the data observed over the watershed. The sensitivity is applied in the scenario runs once the calibration is achieved. As such, the forward application of the model sensitivity is forced to pass through the calibration point, i.e., the intercept of the regression function is assigned to the calibration result for each land segment and for each nutrient constituent. The goodness of fit is then evaluated using the Nash-Sutcliffe Efficiency coefficient (NSE). When the NSE of multi-variate regression is significantly higher than that produced by the single predictor of the total input, the multi-variate regression function is recommended for the PQUAL specification. Otherwise the total input as a single predictor is recommended given that no gain was obtained by using the more complex multi-variate function. The NSE is based on the comparison between the squared error of prediction with the variance of the data (Nash, J. E. and J. V. Sutcliffe (1970). River flow forecasting through conceptual models part I — A discussion of principles, *Journal of Hydrology*, 10, 282–290):

$$NSE = 1 - \frac{\sum_{i=1}^{N}(C_m(i) - C_o(i))}{\sum_{i=1}^{N}(C_o(i) - \overline{C_o})}$$

where *N* is the total number of data pairs, *Cm* is the model estimate, *Co* is the data (the AGCHEM output in our case), *Co bar* is the mean of the data. It can be seen that NSE=1 indicates a perfect match between the regression prediction and the data, NSE=0 indicates that the error equals to the variance of the data, which can be considered as a plausible prediction because the error may be just caused by the variance. These criteria will be referred in the main text.

The regression analyses were conducted for each land segments. Once the sensitivity slopes were established, they are compared and analyzed with environmental factors to see whether there are spatial distribution patterns that can be described or predicted by environmental factors.

If a significant relationship is found, the relationship function is used to smooth the spatial variation in that particular type of model sensitivity. Geomorphology, latitude, land slope and soil texture (contents of sand, silt and clay) are used as environmental predictors for model sensitivities (Figures 2.1 and 2.2). First, there are 7 types of geomorphology in the Chesapeake Bay Water Shed Figure 2.1): Appalachian Plateau, Appalachian Mountains, Great Valley, Blue Ridge, Piedmont upland, Piedmont lowland, and Coastal Plains. Land slope is high in the mountain areas, low in the coastal plains and piedmont regions and intermediate on the Appalachian Plateau and in the Great Valley. As soil texture is concerned, clay content is higher on the Appalachian Plateau and in the mountain regions, lower on the coastal plains and intermediate in the piedmont and valley regions (Figure 2.2). The spatial distribution of silt is basically the mirror image of the clay distribution: higher on the coastal plains, lower on the Appalachian Plateau and mountain areas and intermediate in the piedmont and valley regions. Sand distribution is similar to that of silt, except on the Appalachian Plateau where intermediate values are found (lower values for silts).

Table 2. 1. Selected scenarios for sensitivity analysis.

Scenario	Description
2010NoActionN050611	2010 land uses and population without any control on point and nonpoint sources.
2010E3P052411	E3 stands for Everyone, Everything, and Everywhere. This scenario projects the outcomes under full application of BMPs (Best management Practices) without consideration of physical and economic constrains.
2010P1TMDL2N062411	The TMDL Scenario. This scenario project the Total Maximum Daily Load of nutrients from each state-basin to meet water quality standards in the Bay.
2009N051811	This scenario uses the estimated 2009 land uses, animal numbers, atmospheric deposition, and point source loads.
2009N051811AA	The same as the 2009 scenario above, but using a different air deposition data set. It uses the CAIR data set which represents emission reductions from regulations implemented through the Clean Air Act to meet National Ambient Air Quality standards.
2007N051811	This scenario uses the estimated 2007 land uses, animal numbers, atmospheric deposition, and point source loads.
2007N051811AA	The same as the 2007 scenario above, but using a different air deposition data set. It uses the CAIR data set which represents emission reductions from regulations implemented through the Clean Air Act to meet National Ambient Air Quality standards.

1985CalYrN081412	This scenario uses the 1991 – 2000 hydrology, but with the estimated land uses, animal numbers, atmospheric deposition, and point source loads for the year 1985.
1990CalYrN080612	This scenario uses the 1991 – 2000 hydrology, but with the estimated land uses, animal numbers, atmospheric deposition, and point source loads for the year 1990.
1995CalYrN080612	This scenario uses the 1991 – 2000 hydrology, but with the estimated land uses, animal numbers, atmospheric deposition, and point source loads for the year 1995.
2000CalYrN080812	This scenario uses the 1991 – 2000 hydrology, but with the estimated land uses, animal numbers, atmospheric deposition, and point source loads for the year 2000.
2005CalYrN110812	This scenario uses the 1991 – 2000 hydrology, but with the estimated land uses, animal numbers, atmospheric deposition, and point source loads for the year 2005.
2011CalYrN110812	This scenario uses the 1991 – 2000 hydrology, but with the estimated land uses, animal numbers, atmospheric deposition, and point source loads for the year 2011.

Figure 2.1. Watershed geomorphology and spatial distribution of land lope of land segment in the Watershed Model (WSM).

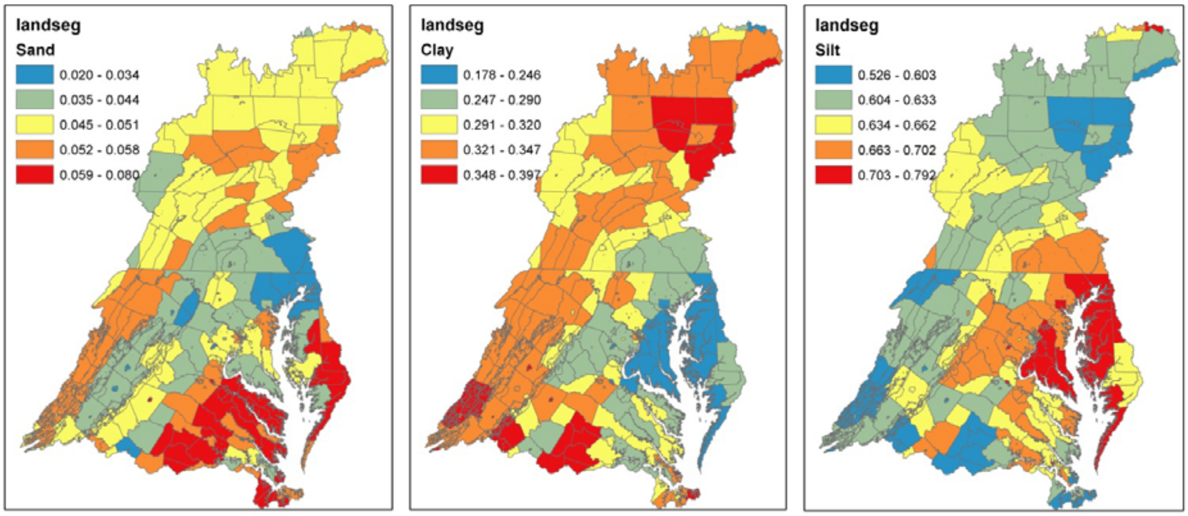

Figure 2.2. Spatial distribution of sediment texture (sand, silt and clay percent) of land segments in the Watershed Model (WSM).

3. Forest

Strong linear relationships were found for most land segments between total nitrogen output and total nitrogen input on forest land use. Figure 3.1 illustrates an example for the segment A24023, Washington County, MD, where linear regression yielded an R^2 of 0.99. Figure 3.2 depicts the frequency distribution of R^2 over all the 367 land segments in the watershed, with 94% of the land segments having an R^2>0.9. While correlation coefficients reflect the strength of the relationship between inputs and outputs, the regression coefficients or slopes determine changes in the output in response to changes in the input and ultimately will be specified in the new PQUAL version of the Watershed Model. The regression slope between total nitrogen input and output (or edge of field loads) ranges from -0.003 to 0.16 with an average of 0.05 and a coefficient of variation 0.52 (Figure 3.3 and Table 3.1). The spatial distribution of the regression slope shows a latitudinal gradient with higher values in the upper Susquehanna and lower values in the James River drainage basin. The regression analysis between the slope and latitude resulted in significant relationship with 37% of variance explained by the regression function *Sensitivity slope=0.0103*Latitude-0.3499* (Figure 3.4). We also analyzed the relationship between the regression slope and other environmental factors such as land slope and contents of clay, silt and sand in soil, total atmospheric deposition, and forest land use percentage of each land segments. Land slope can explain 5% of the total variance of the regression slope, but all other analyzed factors did not show significant correlation with the regression slope. Lower recycling processes on forest land use at higher latitudes may explain in part the latitudinal relationship, but the mechanisms behind the relationship between latitude and the regression slope remain to be invested. Regardless the mechanism, this latitudinal relationship represents a significant predictor to parameterize the slope spatial variation in the watershed of interest and thus can be used in the PQUAL version of the watershed model. A multi-variate regression for the regression slope versus latitude and land slope was also conducted, but this did not significantly improve the prediction of the regression slope. The multi-variate regression resulted in a function as:

$$\text{Sensitivity slope} = (0.001 * \text{Latitude}) + (0.03 * \text{Land slope}) - 0.34.$$

with R^2 = 0.381 and adjusted R^2 = 0.378 while the original R^2 between regression slope and latitude alone was 0.369. Using the latitudinal function, robust regression prediction of the

AGCHEM results was obtained (Figure 3.5). The NSE, measuring the goodness of fit of the regression prediction, amounts to 0.77 (Table 3.1). As the statistics of the sensitivity slope is concerned, the average and median of sensitivity slope between total nitrogen export and total nitrogen input are both 0.05 (atmospheric deposition is the only nitrogen source on forest land use). However, the ratio between total nitrogen export and total input is 0.29, i.e., 6 times the slope. Mathematically this difference between slope and output/input ratio is accounted for by the intercept of the regression function (2.33 lbs/ac). Practically this can be explained by the natural storage of nutrient in the forest. Even without nutrient input, there is nutrient export from forest.

Quite similar results were obtained for dissolved inorganic nitrogen (DIN) export (Figures 3.6-3.8). The sensitivity slope between DIN export and atmospheric deposition ranges from 0 to 0.156 (Figure 3.6), with an average of 0.05 and a median of 0.04. It also displays a latitudinal distribution pattern, with higher values at higher latitudes in the upper Susquehanna drainage basin and lower values at lower latitudes on the York River and James River drainage basins. Indeed, regression analysis revealed a significant relationship between the sensitivity slope and latitude with an R^2=0.3694 and regression function: *Sensitivity slope = 0.0104Latitude-0.3565* (Figure 3.7). Using this latitudinal function, regression function reproduced relatively well the outcome of the AGCEHM simulation with an NSE=0.71 (Figure 3.8). Again the average sensitivity slope (0.05) is much lower than the ratio between DIN export and atmospheric deposition (0.13), due to the high intercept (average over all land segments 0.84 lbs/ac). In this case, the latitudinal function of the sensitivity slope is recommended for PQUAL specification.

The sensitivity slope of organic nitrogen export with atmospheric deposition on forest is presented in Figure 3.9. There is no particular distribution pattern that can be described by the environmental factors analyzed. On the other hand, the spatial variation is limited with coefficient of variability of 0.5 (Table 3.1). Under these circumstances, the median slope represents a plausible approach for the regression prediction of organic nitrogen export on forest land use. Using the median slope, the regression function reproduces relatively well the outcome of the AGCHEM simulation, with an NSE of 0.71. Note that the median slope of organic nitrogen export is about 1 order of magnitude lower than that of total nitrogen and DIN. However, the ratio between organic nitrogen export over total nitrogen input (0.16) is higher than that of DIN export (0.13; Table 3.1). This indicates that even if the sensitivity of organic nitrogen export is lower than that of DIN export, organic nitrogen export contributes more than DIN in the total nitrogen export from forest, most likely due high organic nitrogen export from forest storages.

As final recommendation of model sensitivity for forest land use, the following latitudinal function is recommended for total nitrogen export:

*Sensitivity slope=0.0103*Latitude-0.3499.*

For dissolved inorganic nitrogen (DIN) export, the following latitudinal function is recommended:

*Sensitivity slope=0.0104*Latitude-0.3565.*

For organic nitrogen export, the median sensitivity slope of 0.003 is recommended. Given the large contribution of organic nitrogen and the different biogeochemical characteristic between organic nitrogen and DIN, separated prediction of organic nitrogen and DIN is recommended over the prediction of total nitrogen export.

Phosphorus on forest was original simulated with PQUAL so that sensitivity analysis was not conducted.

Table 3. 1. Summary of regression slopes and Nash-Sutcliffe Efficiency (NSE) coefficients of regression prediction for forest land use (for). Atm. Dep.: Atmospheric deposition; N: Nitrogen; DIN: Dissolved inorganic nitrogen; STD: Standard deviation; Input: Total nitrogen (or phosphorus) input;. Atmospheric deposition is the only nutrient input on forest. Latitudinal functions are recommended for the sensitivity slope of TN and DIN on forest: TN_slope=0.0103Latitude-0.3499 and DIN_slope=0.0104Latitude-0.3565. Red value and function are the final recommendation.

Constituents	Output/Input	NSE	Statistics of slope	Atm. Dep.
Total N	0.29	0.77	Mean	0.05
			Median	0.05
			STD	0.02
DIN	0.13	0.75	Mean	0.05
			Median	0.04
			STD	0.03
Organic N	0.16	0.71	Mean	0.004
			Median	0.003
			STD	0.002

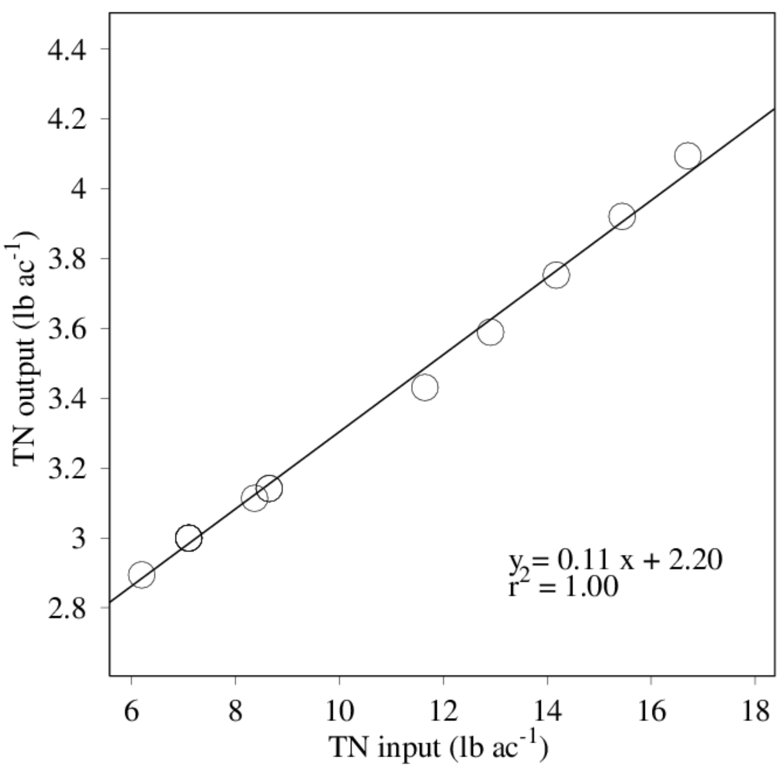

Figure 3. 1. Example of regression function between total nitrogen atmospheric deposition (TN input) and output on forest land use of the land segment A24023, Washington County, MD. Atmospheric deposition is the only type of input on forest.

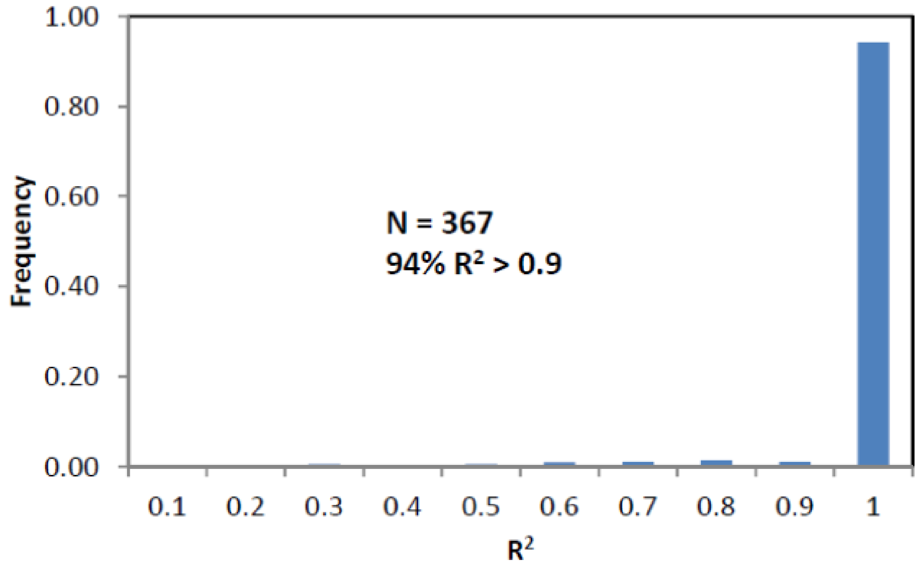

Figure 3. 2. R^2 frequency distribution of regression between total nitrogen output and inputs on forest land use. There are 367 segments in total.

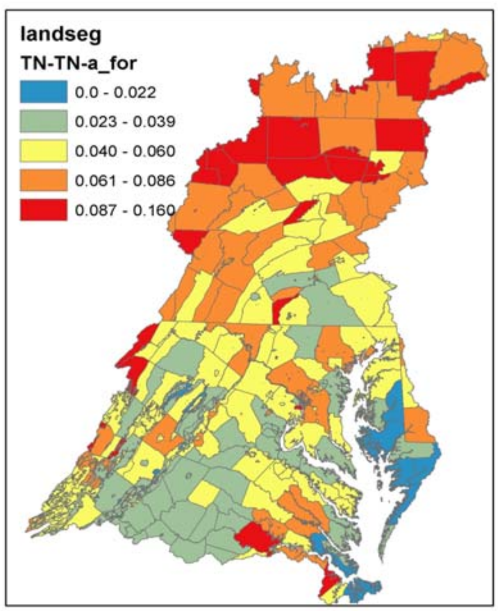

Figure 3. 3. Spatial distribution of sensitivity slope between total nitrogen export and input on forest land use.

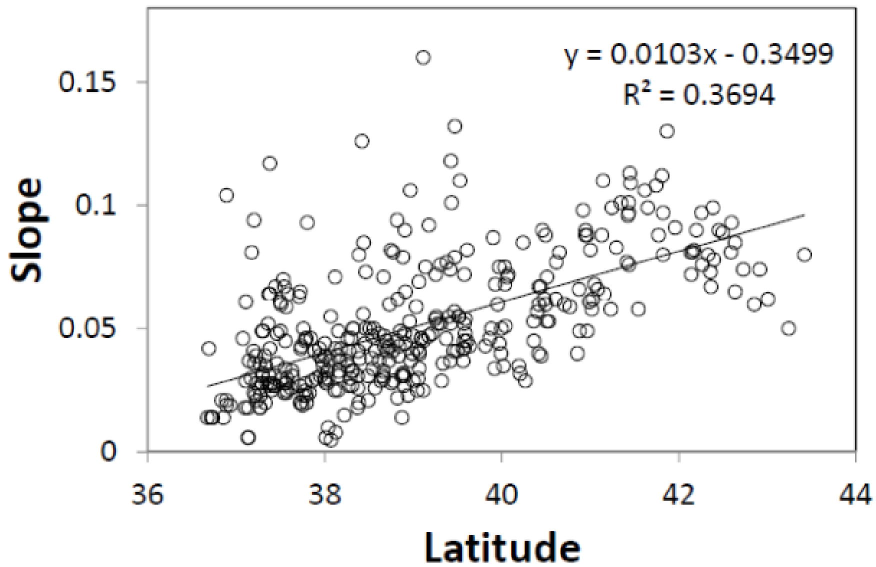

Figure 3. 4. Relationship between latitude and sensitivity slope of total nitrogen input and output on forest land use.

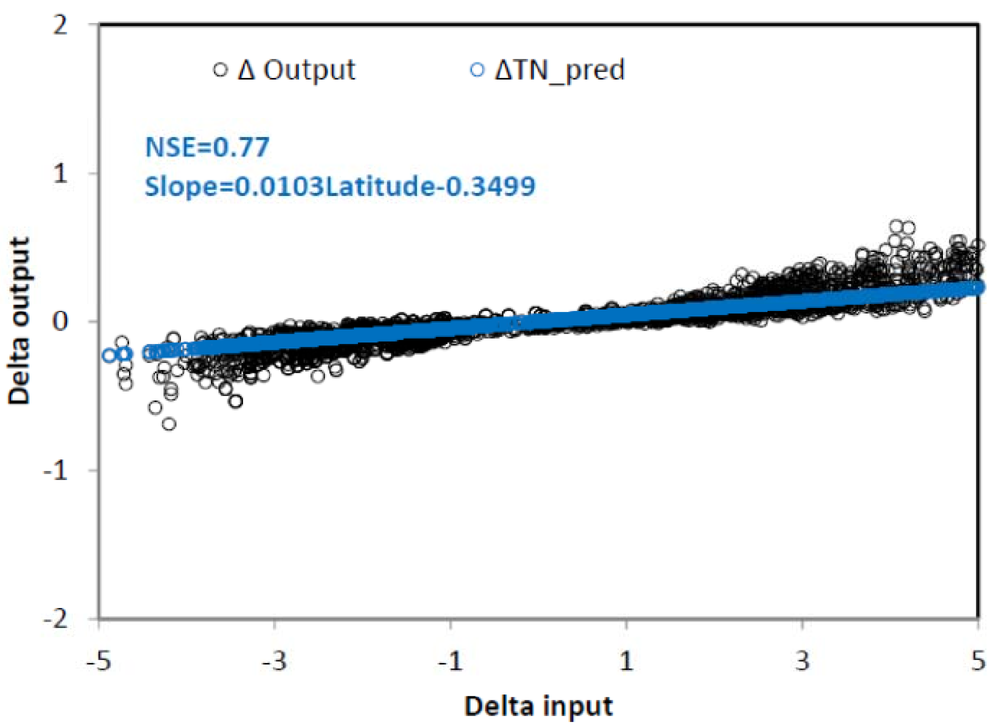

Figure 3. 5. Robustness of total nitrogen export regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on forest land use (HSPF code: for). Delta input on the abscissa is the demeaned atmospheric deposition and delta outputs on the ordinate are the demeaned outputs from AGCHEM (black dots) and regression prediction (blue dots). Atmospheric deposition is the only input on forest.

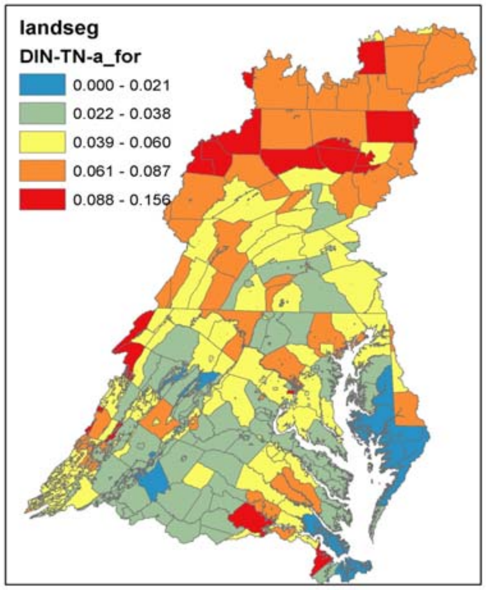

Figure 3. 6. Spatial distribution of sensitivity slope between DIN export and total nitrogen input on forest land use.

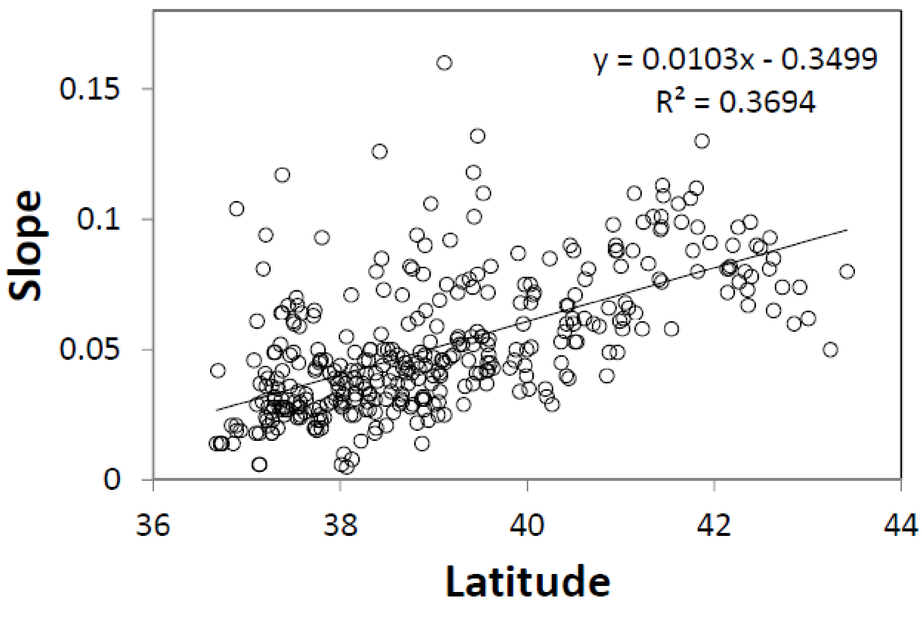

Figure 3. 7. Relationship between latitude and sensitivity slope of dissolved inorganic nitrogen (DIN) export versus total nitrogen input on forest land use.

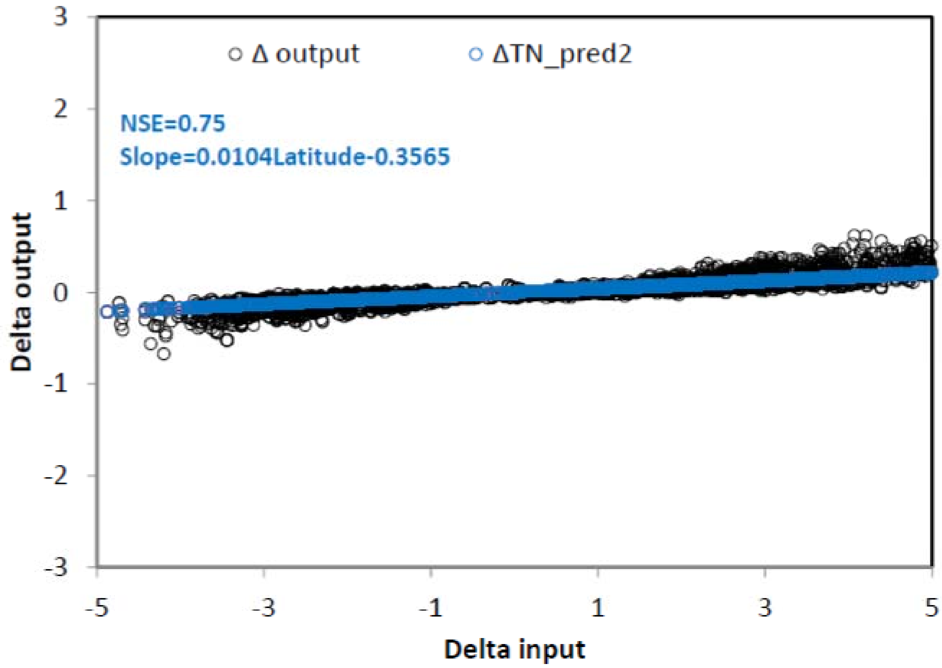

Figure 3. 8. Robustness of DIN output regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on forest land use (HSPF code: for). Delta input on the abscissa is the demeaned total nitrogen input and delta outputs on the ordinate are the demeaned outputs from AGCHEM (black dots) and regression prediction (blue dots) Atmospheric deposition is the only input on forest.

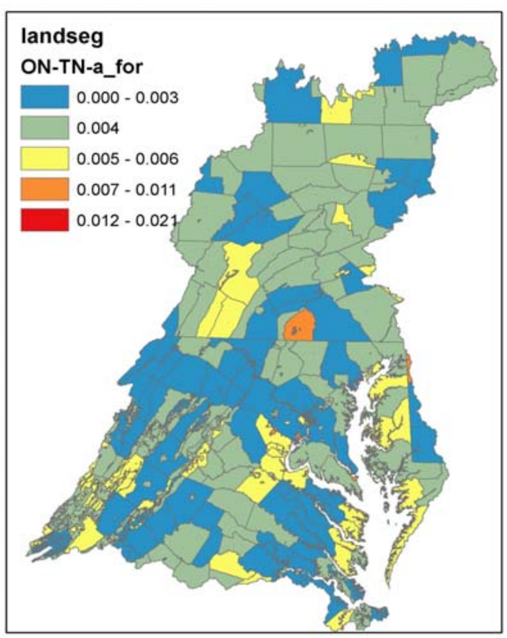

Figure 3. 9. Spatial distribution of sensitivity slope between organic nitrogen export and total nitrogen input on forest land use.

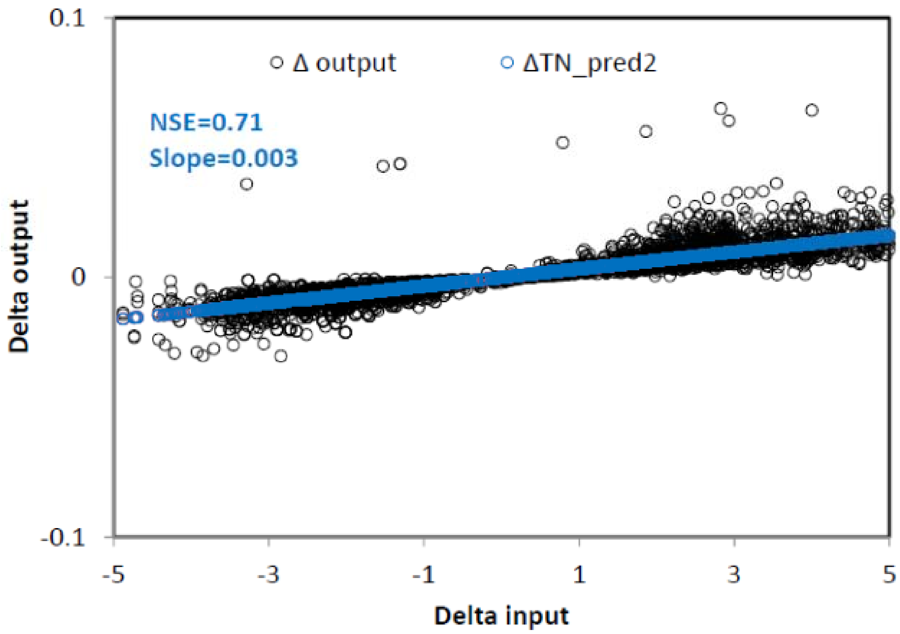

Figure 3. 10. Robustness of organic nitrogen export regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on forest land use (HSPF code: for). Delta input on the abscissa is the demeaned atmospheric deposition and delta outputs on the ordinate are the demeaned outputs from AGCHEM (black dots) and regression prediction (blue dots). Atmospheric deposition is the only input on forest.

4. High-tillage cropland with manure (hwm)

The scenario builder provided nitrogen uptakes for high-tillage cropland (hwm). However, these uptakes were used only as a constraint as the maximum uptake to the AGCHEM simulation. The actually simulated uptake is smaller than this maximum. The AGCHEM predicted uptake cannot be used as a predictor of model sensitivity given that it is an output of the model. Consequently, we first determine the ratio between the actual uptake and the maximum uptake, then applied this ratio to the scenario-builder estimate maximum uptake. Figure 4.1 depicts the spatial distribution of the uptake ratio. It does not display patterns that can be explained by the environmental factors presented in Section 2, i.e., land slope, sediment texture or latitude. On the other hand, there is a predominant mode (around 0.6) in the frequency distribution of the uptake ratio (Figure, 4.2). Consequently, the median slope represents a plausible choice for the sensitivity analysis. The product of the maximum uptake and the uptake radio is then used as the uptake predictor (or dependent variable) in determining the model sensitivity. The total nitrogen input (the sum of atmospheric deposition, manure and fertilizer application and legume nitrogen fixation) was also subtracted by the uptake estimates.

The regression slope between total nitrogen output and input did not display predictable pattern that can be described by latitude, land slope and sediment texture (Figure 4.3). Consequently, the median slope (0.21) is recommended for the entire watershed. Note that the standard deviation is only 0.23, which indicates that slope between the total nitrogen output and input did not considerably change over the entire watershed. Median slope is recommended over the mean slope to avoid overwhelming influence by extreme values. Multi-variate analysis did not reveal predictable patterns in the partial slopes of each input (Figure 4.4) and the median slope for each input type is selected for the PQUAL specification. Atmospheric deposition has the highest regression slope (0.35) in the multi-variate analysis, followed by fertilizer (0.29) and manure (0.19). The median slope of legume nitrogen fixation (0.34) is higher than that of manure and fertilizer, but the mean is actually lower (Table 4.1). As uptake is concerned, both the mean and the median are negative, indicating that uptake reduces nutrient discharge at the edge of field.

As a unique value of the median slope is recommended for the PQUAL simulation, a key question is how a unique slope can predict the output of the AGCEHM over all the land segments of the watershed. To this end, we applied the regression slope in a forward mode to reproduce nutrient discharge at edge of field based on the inputs of all the scenarios analyzed. As the PQUAL version of the watershed model will be calibrated to target values of nutrient discharge and other scenarios will be then simulated based on the calibration and the sensitivity slope, the regression function is applied by passing the calibration points of each land segment. The regression prediction is then compared with the AGCHEM prediction. The robustness of the regression prediction is evaluated by using the Nash-Sutcliffe Efficiency (NSE) coefficient determined between the regression and AGCHEM predictions (Figure 4.5). Both the total nitrogen input and the multi-variate analysis predicted relatively well the outcome of the AGCHEM model, with an NSE of 0.77 and 0.79 respectively. Multi-variate regression predicted to certain extent the variations or scattering of the AGCHEM simulation, but as a whole, the NSEs are comparable between the two methods. As the total nitrogen input regression is simpler, total nitrogen input recommended in this case.

Similarly for DIN, there is no spatial pattern that can be predicted by environmental factors (Figure 4.5). Only for atmospheric deposition tends the slope to have higher values in the upper Susquehanna on the Appalachian Plateau, but there is no latitudinal pattern that can be predicted by latitude as in the case of forest land use. Also the slope for legume nitrogen fixation appears to be lower in the northern states from the Mason-Dixon line including Pennsylvania and New York than in the southern states, but the distribution is pretty scattered that cannot be described by a specific function, particularly in the southern states. As for the case of total nitrogen, the median slopes provided robust prediction of nutrient loadings at the edge of field (Figure 4.6). Although the AGCHEM predictions of DIN discharges at the edge of field are relatively scattered, the regression prediction with both total nitrogen input and multi-variate analysis yield relatively high NSEs, 0.72 and 0.75, respectively (Figure 4.6 and Table 4.1). As such, the median slope on model sensitivity is a plausible recommendation for the PQUAL specification for DIN on high-tillage croplands with manure.

The regression slopes for organic nitrogen output do not have patterns that can be described by the environmental factors in consideration. As a result, the median slopes are suggested for the PQUAL specification (Table 4.1). The model sensitivity between organic nitrogen export and total nitrogen input is significantly lower than that between DIN export and total nitrogen input (0.07 vs. 0.15). In the multi-variate analysis, the sensitivity slopes of organic nitrogen export are also lower than that for DIN export (Table 4.1). Also the sensitivity of DIN output is higher with fertilizer (0.19) than with manure (0.08), but reversed for organic nitrogen output: 0.11 with manure and 0.08 with fertilizer. With these median sensitivities, the NSE is 0.50 for the regression with total nitrogen prediction and 0.66 for multi-variate prediction. In this case, the multi-variate regression provides a better prediction than using the total nitrogen input.

For phosphorus, there are only two types of inputs: manure and fertilizer. Phosphorus in atmospheric deposition was not taken into account given that terrestrial sources largely dominate and there is no legume fixation. The watershed model does not record phosphorus uptake neither. Under these circumstances, phosphorus uptake was not subtracted from total phosphorus input as what was done for total nitrogen input. The spatial distribution of regression slopes of total phosphorus is illustrated in Figure 9. It can be seen that there is no specific patterns that can be predicted by environmental function so that median slope is recommended for the PQUAL specification. As in the case of nitrogen, regression prediction provided robustness reproduction of the AGCHEM output with NSE=0.79 for total phosphorus input prediction and 0.82 for multi-variate regression prediction. Similarly for phosphate and organic phosphorus, the distribution of the model sensitivity slopes are not predictable with environmental factors and the median slopes are recommended (Figures 11 and 13 and Table 4.1). Also these median slopes provided robust prediction of the AGCHEM outcomes with an ESN of 0.75 and 0.80 for phosphate and 0.64 and 0.82 for organic phosphorus prediction by total phosphorus input and multi-variate regression, respectively. Using total phosphorus input, the model sensitivity for organic phosphorus is about 1 order of magnitude smaller than that for phosphate. For multi-variate regression, similar model sensitivity slopes were found between manure and fertilizer for phosphate, but for organic phosphorus, the model sensitivity slope with manure is significantly higher than that of fertilizer (Table 4.1).

Only for organic nitrogen and organic phosphorus did the multi-variate approach yield better prediction in terms of NSE whereas similar results were obtained for other constituents. Given that the organic constituents contribute a small share in the total export on hwm, specification using total nitrogen and phosphorus input regression appears appropriate for this type of land use.

Table 4. 1. Summary of regression slopes and Nash-Sutcliffe Efficiency (NSE) coefficients of regression prediction for high-tillage cropland with manure (hwm). Input: Total nitrogen (or phosphorus) input; TIP: Total Input Prediction; MVP: Multi-variate prediction; STD: Standard deviation; Atm. Dep.: Atmospheric deposition; Legume: Legume nitrogen fixation; N: Nitrogen; P: Phosphorous. Red values are the final recommendation.

Constituents	Output/ Input	NSE of TIP	NSE of MVP	Statistics of slope	Total	Atm. Dep.	Manure	Fertilizer	Legume	Uptake
Total N	0.28	0.77	0.79	Mean	0.24	0.38	0.21	0.26	0.18	-0.06
				Median	0.21	0.35	0.19	0.29	0.34	-0.09
				STD	0.23	0.45	0.43	0.60	1.81	0.79
DIN	0.17	0.72	0.75	Mean	0.16	0.26	0.10	0.17	0.09	-0.04
				Median	0.15	0.27	0.08	0.19	0.20	-0.09
				STD	0.22	0.36	0.40	0.36	1.7	0.02
Organic N	0.11	0.50	0.66	Mean	0.07	0.12	0.11	0.09	0.09	-0.02
				Median	0.07	0.08	0.11	0.08	0.11	-0.01
				STD	0.07	0.21	0.09	0.22	0.54	0.28
Total P	0.10	0.79	0.82	Mean	0.12		0.14	0.12		
				Median	0.12		0.13	0.11		
				STD	0.09		0.12	0.14		
PO4	0.08	0.75	0.80	Mean	0.11		0.12	0.13		
				Median	0.11		0.12	0.10		
				STD	0.09		0.12	0.15		
Organic P	0.02	0.64	0.82	Mean	0.015		0.022	0.002		
				Median	0.013		0.017	0.006		
				STD	0.017		0.022	0.03		

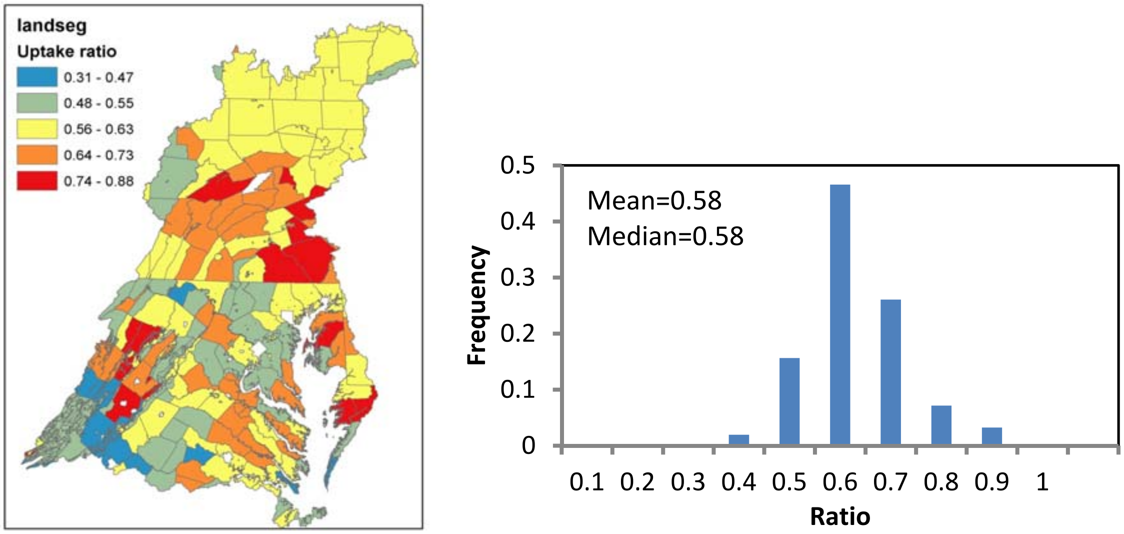

Figure 4. 1. Spatial distribution of the ratio between the Watershed Model-predicted nitrogen uptake and scenario builder-provided maximum uptake (left panel) and frequency distribution of the uptake ratio (right panel).

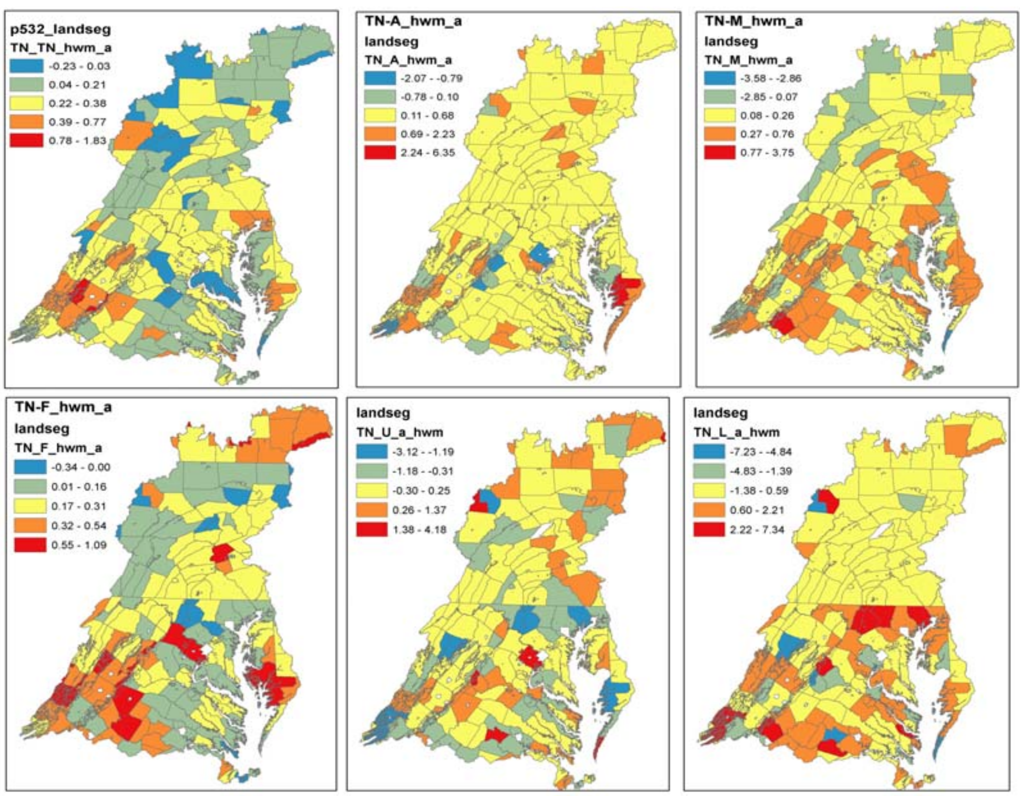

Figure 4. 2. Sensitivity slopes for total nitrogen output at edge of field on high-tillage cropland with manure (hwm). Upper panels from left to right are total nitrogen input (TN), atmospheric deposition (A) and manure (M). Lower panels are fertilizer (F), uptake (U) and legume nitrogen fixation (L).

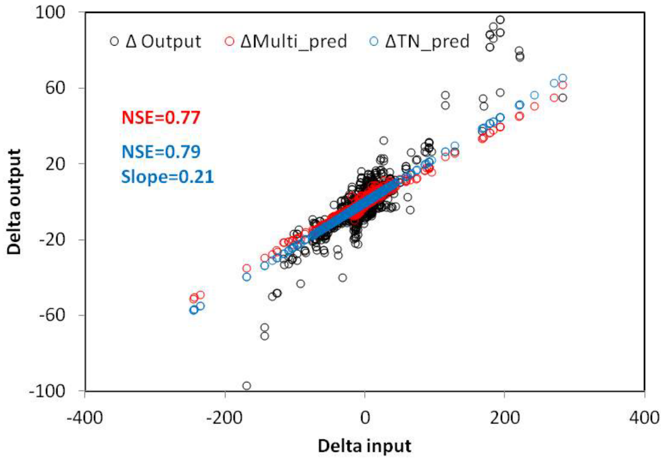

Figure 4. 3. Robustness of TN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on high-tillage cropland with manure (hwm). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

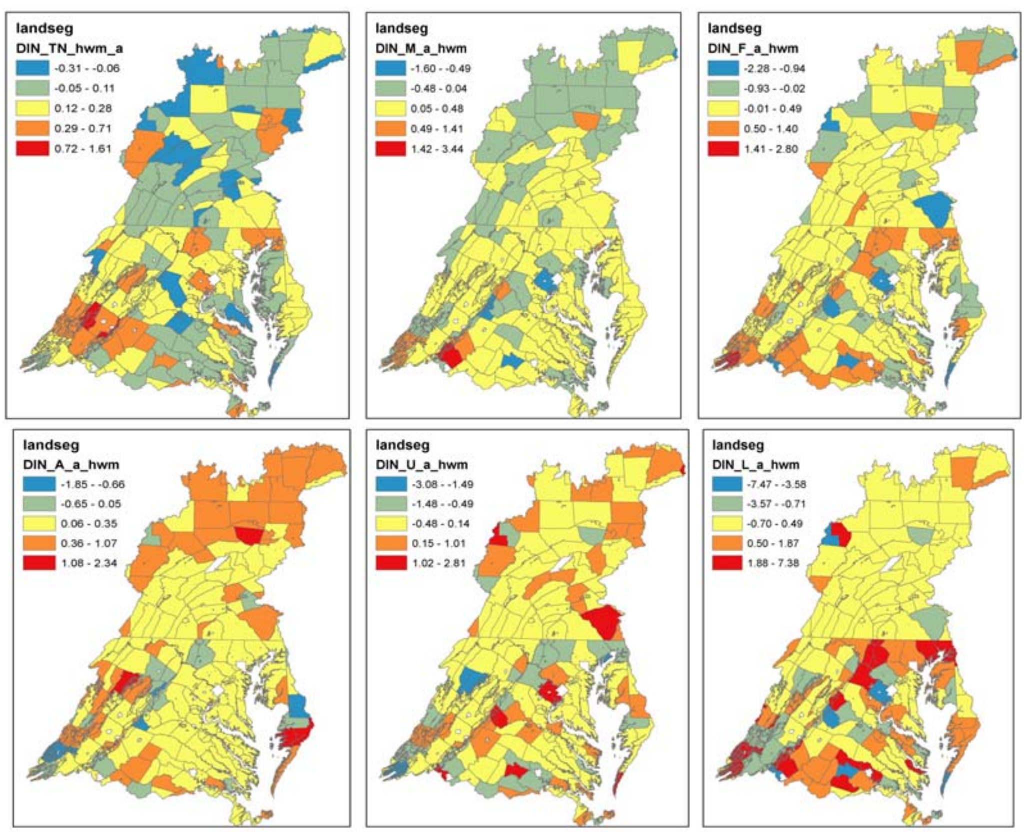

Figure 4. 4. Sensitivity slopes for DIN on high-tillage cropland (hwm). Upper panels from left to right are total nitrogen input (TN), manure (M), fertilizer (F) and lower panels are atmospheric deposition (A), uptake (U) and legume nitrogen fixation (L).

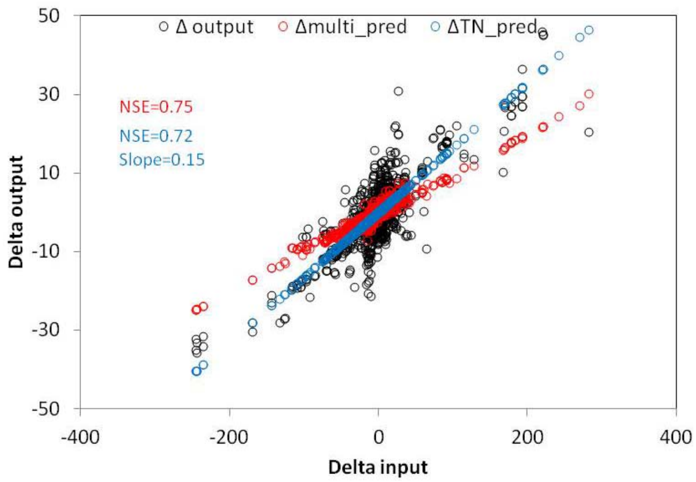

Figure 4. 5. Robustness of DIN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction. Delta input is the demeaned total nitrogen input and delta outputs are the demeaned of outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

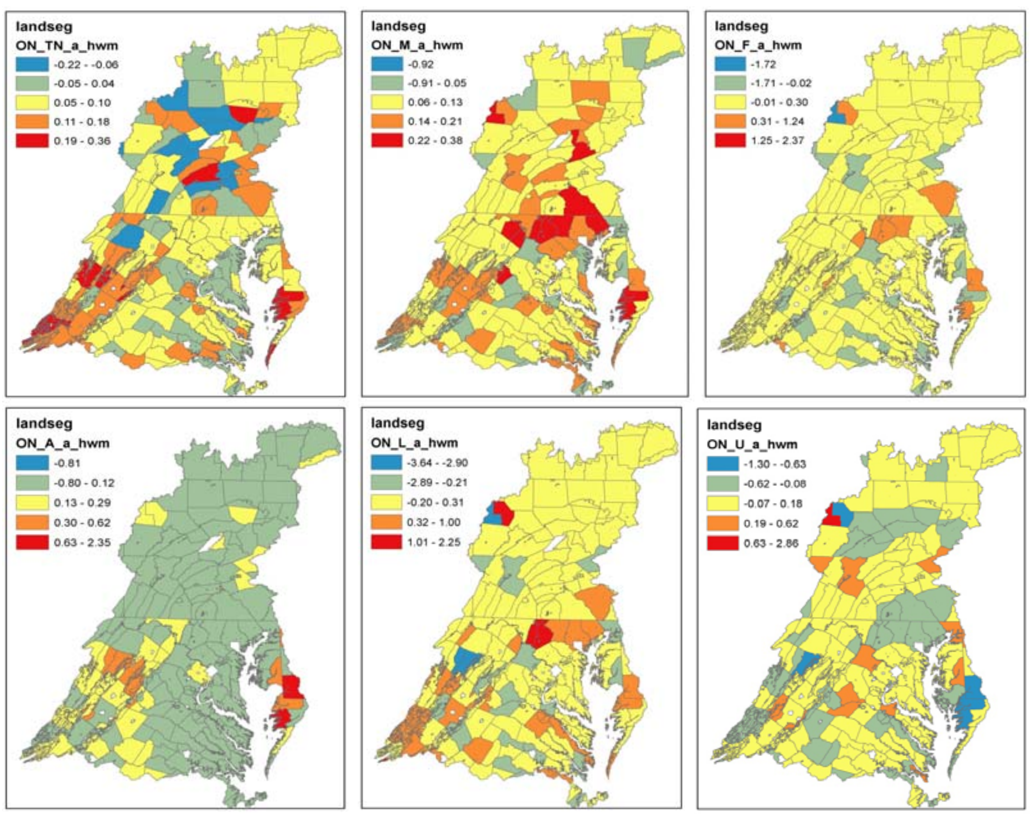

Figure 4. 6. Sensitivity slopes for organic nitrogen (ON) on high-tillage cropland (hwm). Upper panels from left to right are total nitrogen input (TN), manure (M), fertilizer (F) and lower panels are atmospheric deposition (A), legume nitrogen fixation (L) and uptake (U).

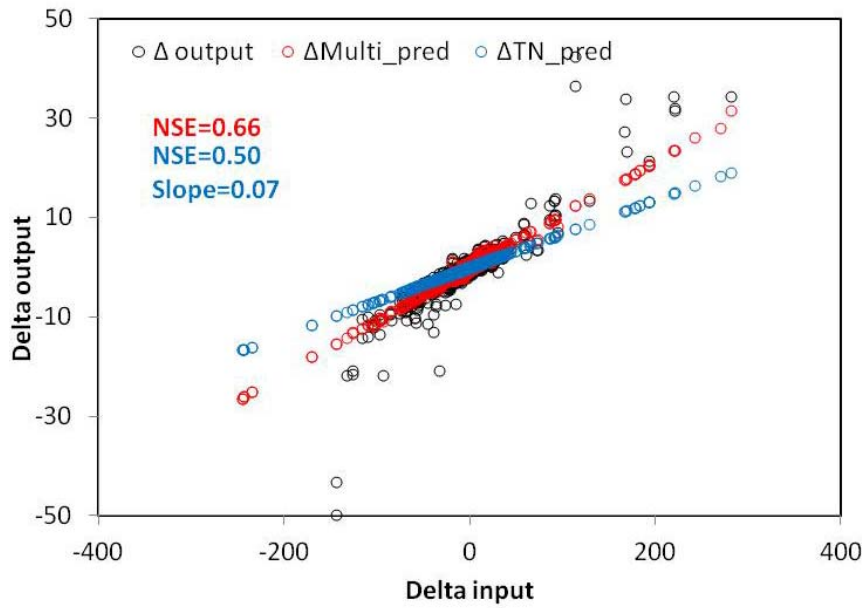

Figure 4. 7. Robustness of organic N regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction. Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

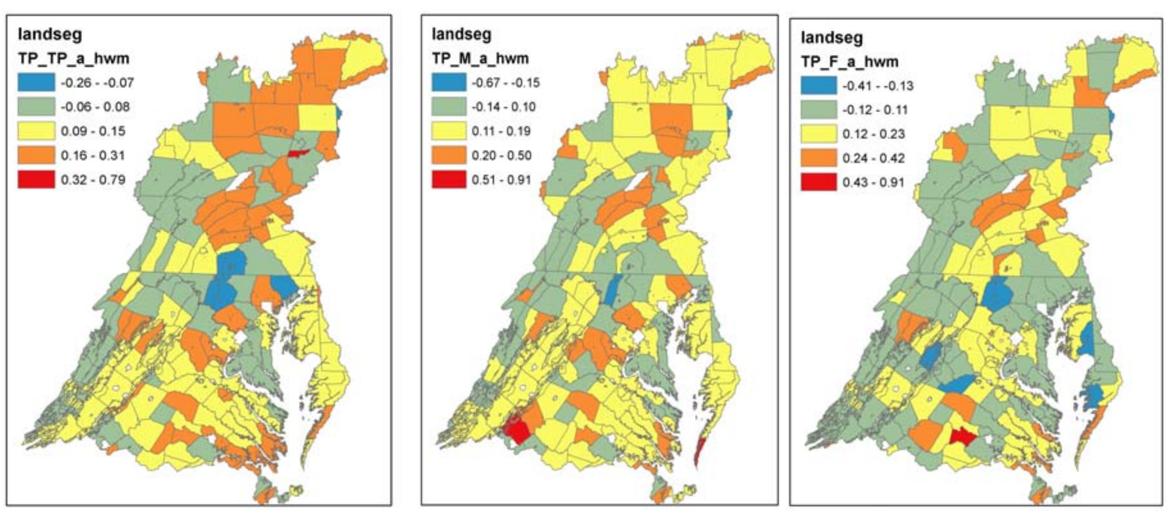

Figure 4. 8. Sensitivity slopes for total phosphorus (TP) on high-tillage cropland (hwm). Left panel is total phosphorus input (TP), middle panel is manure (M), and right panel is fertilizer (F).

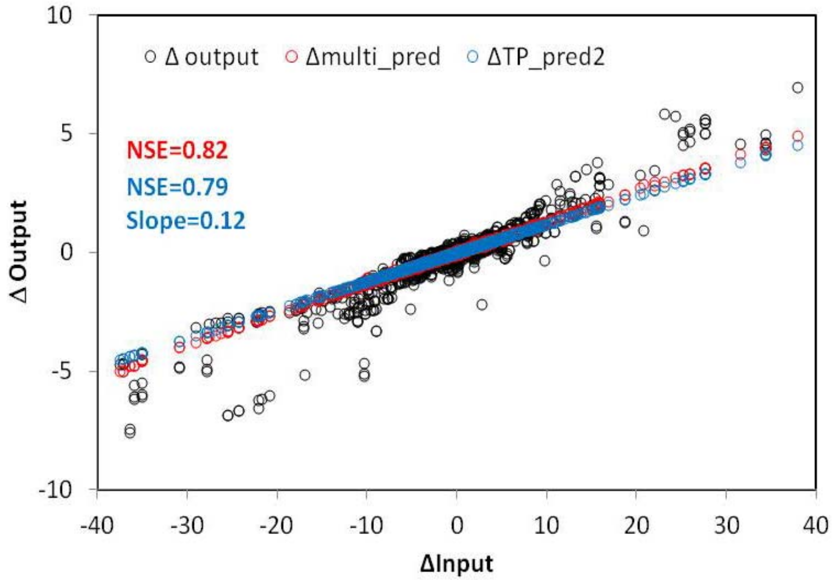

Figure 4. 9. Robustness of total phosphorus (TP) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction. Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

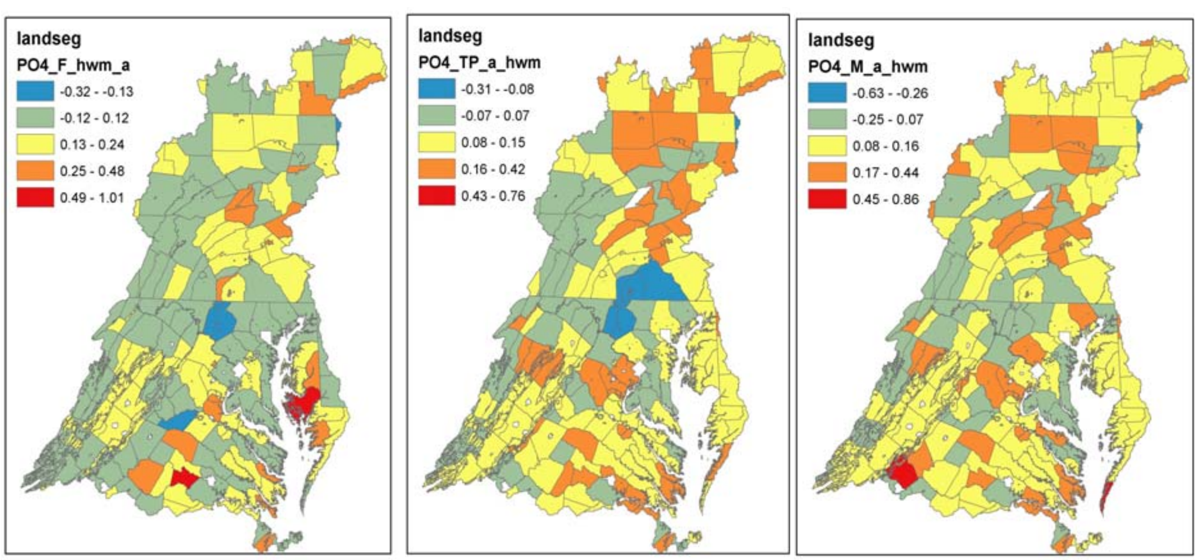

Figure 4. 10. Sensitivity slopes for phosphate (PO4) on high-tillage cropland (hwm). Left panel is total phosphorus input (TP), middle panel is manure (M), and right panel is fertilizer (F) slopes.

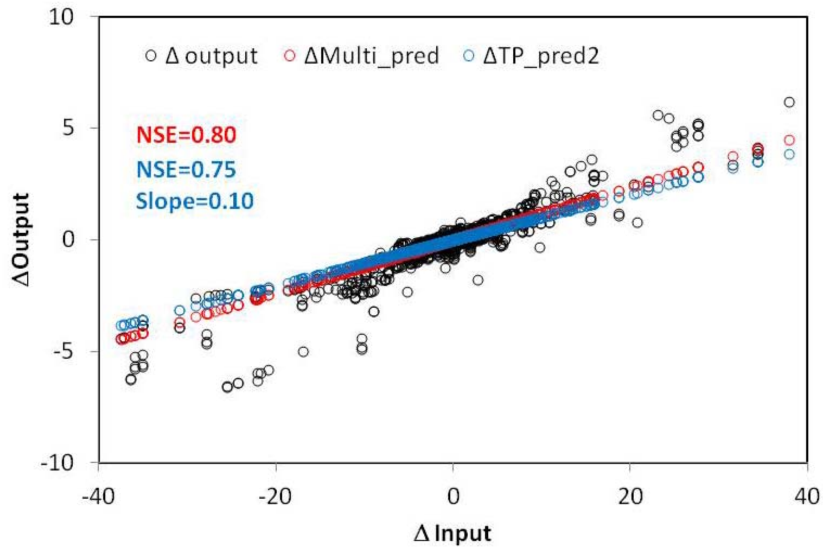

Figure 4.11. Robustness of phosphate (PO4) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction. Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

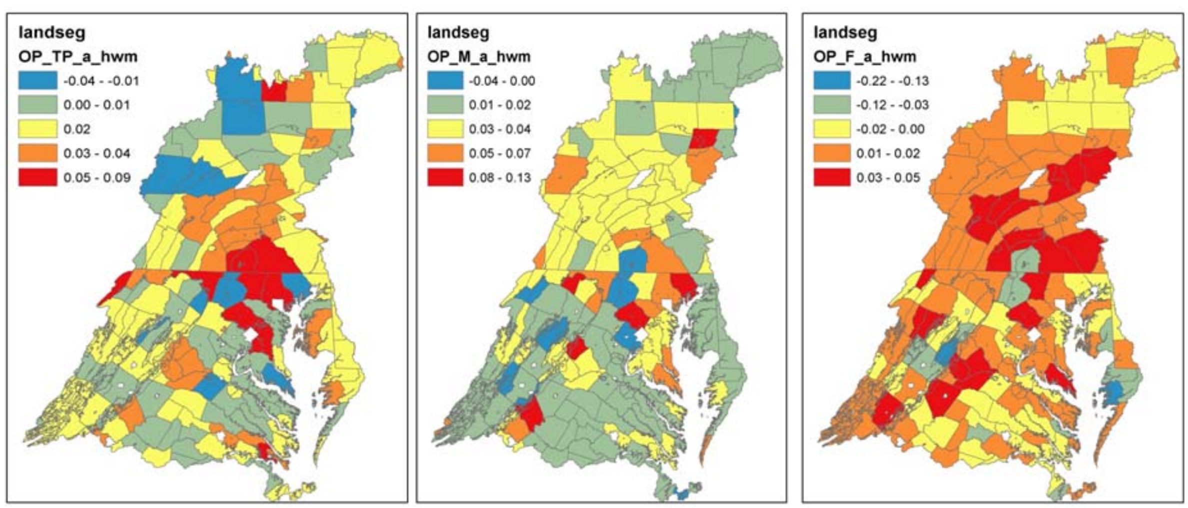

Figure 4. 12. Sensitivity slopes for organic phosphorus (OP) on high-tillage cropland (hwm). Left panel is total phosphorus input (TP), middle panel is manure (M), and right panel is fertilizer (F) slopes.

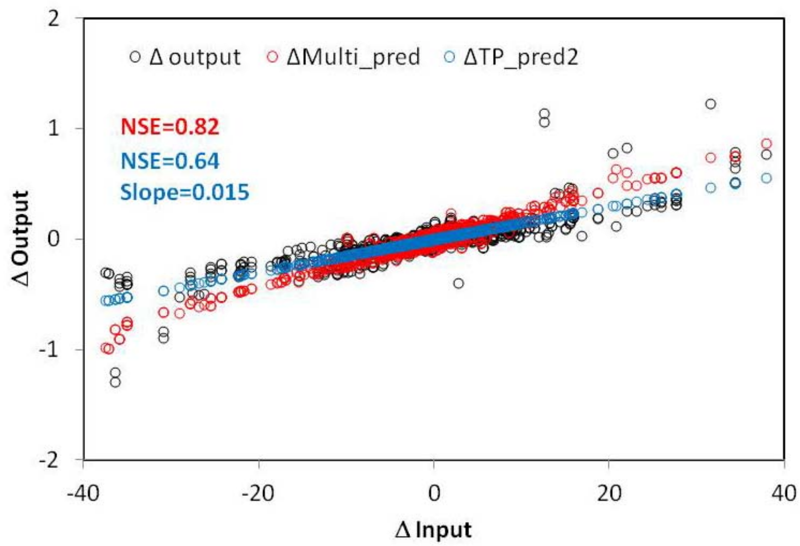

Figure 4. 13. Robustness of organic phosphorus (OP) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction. Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

5. High-tillage cropland without manure (hom)

The uptake ratio between the watershed model simulation and the scenario-builder maximum uptake on high-tillage croplands without manure (hom) does not show specific patterns that can be predicted by environmental factors (Figure 5.1, left panel). The uptake ratio appears slightly lower on the Virginia portion of uplands, but cannot be generalized as a predictable distribution. The uptake ratio on hom is relatively high, basically ranging from 0.7 to 1.0 as compared to that on high-tillage cropland with manure (hwm) presented in the previous section, with 40% of land segments having a ratio > 0.9 (Figure 5.2, right panel). The high uptake ratio indicates an agreement between the watershed model simulation and the scenario-builder estimates of the maximum uptake. As no predictable patterns were found, the median of the uptake ratio (0.86) was used in the following sensitivity analysis, which means that the product of maximum uptake and the uptake ratio was used as an independent variable in the multi-variate analysis and also subtracted from the total nitrogen uptake.

Similarly, the model sensitivity slopes for the total nitrogen output prediction do not show predictable spatial distribution patterns neither (Figure 5.2). The only describable pattern is that the fertilizer slope appears slightly lower on the northern side of the Mason-Dixon Line that on the southern side, but this does not represent a predictable pattern that can be specified in the PQUAL version of the watershed model. Consequently the medians of the slopes are recommended for the PQUAL specification. The median sensitivity slope between total nitrogen output and input is 0.48, much higher than that on forest land (0.05) and also higher than that on high-tillage cropland with manure (0.21). In the multi-variate regression slopes for the prediction of total nitrogen output, atmospheric deposition has the highest value (0.44), followed by legume nitrogen fixation (0.43) whereas that of fertilizer is much smaller (0.23). As for high-tillage cropland with manure, uptake has a negative impact on the output of total nitrogen on high-tillage cropland without manure, which means that uptake reduces nitrogen loads from the watershed. With the median sensitivity slopes, the regressions functions provided robust prediction of the outcome of the AGCHEM model, with the NSE of 0.74 for total input prediction and 0.85 for multi-variate prediction. In this case, multi-variate function provides better prediction than using the total nitrogen input.

Similar results were obtained for dissolved inorganic nitrogen (DIN) output. No predictable patterns were found in the spatial distribution of the sensitivity slopes (Figure 5.4). On the other hand, the median slopes provided robust prediction of the AGCHEM output of DIN, with an NSE of 0.73 for total input prediction and 0.84 for multivariate prediction (Figure 5.5). In this case, multivariate regression provided a better prediction than using the total nitrogen input. Similarly, the median model sensitivity slopes are recommended in the case of organic nitrogen output due to the lack of predictable distribution patterns. Note that the median slopes for organic nitrogen output are lower by more than one order of magnitude than that for DIN and total nitrogen output in most cases (Table 5.1). For total nitrogen input, the slope for organic nitrogen output is 0.015 whereas that for TN and DIN are 0.48 and 0.46, respectively. Large differences of more than one order of magnitude were also found in the multivariate analysis for atmospheric deposition and legume nitrogen fixation. For fertilizer input, the slope is also considerably lower for organic nitrogen output (0.07) than for DIN and TN (0.23 in both cases). Organic nitrogen export accounts for 13% of the total nitrogen export on high-tillage cropland without manure (Table 5.1). The sensitivity slope between organic nitrogen output and uptake is positive (0.01) whereas negative values were found for TN and DIN output (Table 5.1). This indicates that a part of the uptake, once converted into organic substances, is flushed away from the land as organic nitrogen loads at the edge of field.

In the case of phosphorus output on high-tillage cropland without manure, fertilizer is the only input so that multivariate analysis and total input regression resulted in the same sensitivity (Figures 5.8 – 5.13; Table 5.1). The sensitivity slope between total phosphorus output and input appears to be higher in general at low latitude on the Virginia portion of coastal plain and piedmont region and lower at high latitude in Pennsylvania and New York, but regression analysis did not result in a significant relationship between the slope and latitude as in the case of forest land use. The regression slope between latitude and the total phosphorus sensitivity is negative, which is in agreement with the previous observation, but the squared correlation coefficient is only 0.13. Given the low portion of variance explained by such a relationship, the median slopes remain an appropriate recommendation for the PQUAL specification. As a general observation, the sensitivity slopes for phosphorus output is much lower than that for nitrogen output. With the total input, the sensitivity slope is 0.1 for both total phosphorus and phosphate output, whereas it is as higher as 0.48 and 0.46 for total nitrogen and dissolved inorganic nitrogen output. Using the median sensitivity slopes, robust predictions were obtained for total phosphorus and phosphate output (Figures 5.9 and 5.11 and Table 5.1). The NSE is 0.86 for total phosphorus prediction and 0.85 for phosphate prediction. The NSE is relatively low for the organic phosphorus prediction (0.26), but the model sensitivity is also very low (0.0018). Basically, organic phosphorus output stayed at approximately constant level without significant changes between scenarios (Figure 5.13). Organic phosphorus export accounts for only 4% of the total phosphorus export. Under such a circumstance, prediction using a constant sensitivity slope will not generate significant biases.

As multi-variate approach generated significantly higher NSE for the exports of nitrogen constituents, it is recommended for high-tillage cropland without manure. As for phosphorus prediction, total phosphorus input predicts relatively well the exports of all constituents.

Table 5. 1. Summary of regression slopes and Nash-Sutcliffe Efficiency (NSE) coefficients of regression prediction for high-tillage cropland without manure (hom). Input: Total nitrogen (or phosphorus) input; TIP: Total Input Prediction; MVP: Multi-variate prediction; STD: Standard deviation; Atm. Dep.: Atmospheric deposition; Legume: Legume nitrogen fixation; N: Nitrogen; P: Phosphorous. Red values are the final recommendation.

Constituents	Output/ Input	NSE of TIP	NSE of MVP	Statistics of slope	Total	Atm. Dep.	Manure	Fertilizer	Legume	Uptake
Total N	0.23	0.74	0.85	Mean	0.53	0.45		0.25	0.44	-0.017
				Median	0.48	0.44		0.23	0.43	-0.04
				STD	0.39	0.56		0.72	0.62	1.25
DIN	0.20	0.73	0.84	Mean	0.52	0.43		0.24	0.43	-0.03
				Median	0.46	0.43		0.23	0.41	-0.05
				STD	0.37	0.57		0.68	0.60	1.2
Organic N	0.03	0.53	0.73	Mean	0.017	0.016		0.07	0.01	0.013
				Median	0.015	0.012		0.005	0.009	0.006
				STD	0.013	0.026		0.08	0.04	0.11
Total P	0.10	0.86	0.86	Mean	0.1			0.1		
				Median	0.1			0.1		
				STD	0.04			0.04		
PO4	0.10	0.85	0.85	Mean	0.1			0.1		
				Median	0.1			0.1		
				STD	0.04			0.04		
Organic P	0.004	0.26	0.26	Mean	0.0016			0.0016		
				Median	0.0018			0.0018		
				STD	0.0028			0.0028		

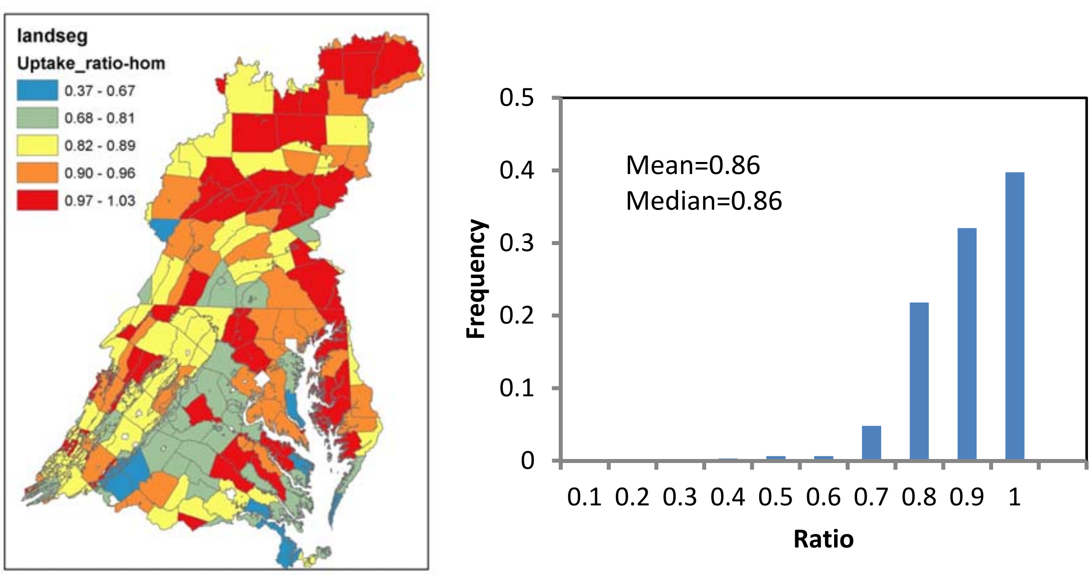

Figure 5.1. Spatial distribution of the ratio between the watershed model-predicted nitrogen uptake and scenario-builder provided maximum uptake (left panel) and frequency distribution of the uptake ratio (right panel) on high-tillage cropland without manure (hom).

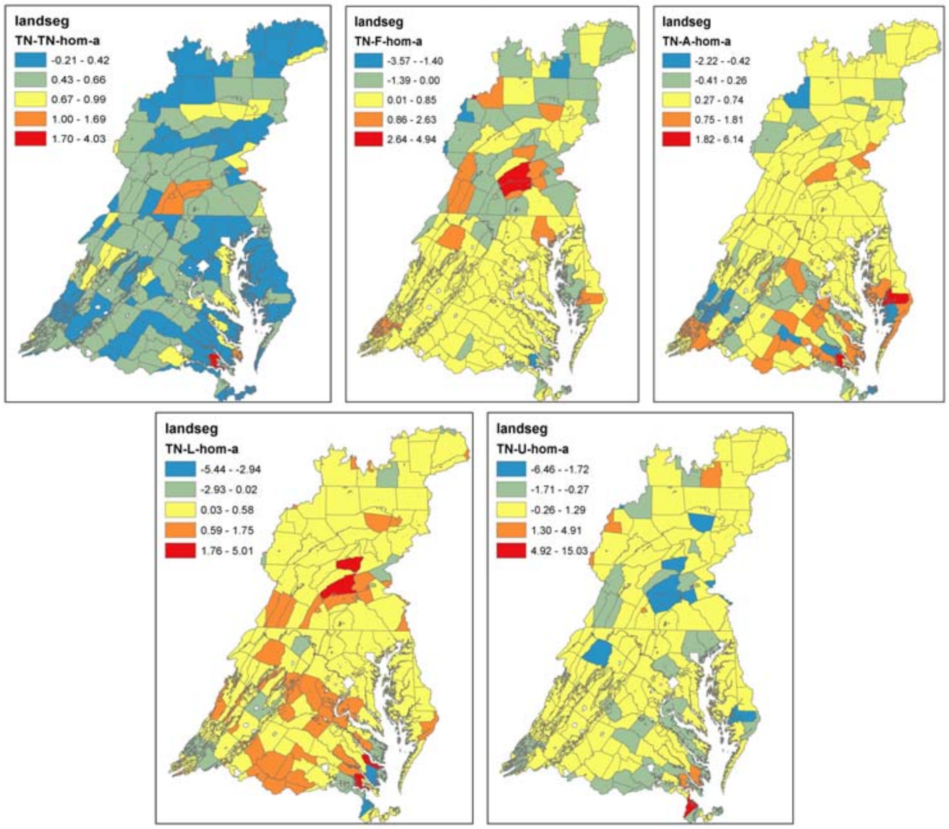

Figure 5. 2. Sensitivity slopes for total nitrogen output of high-tillage cropland without manure (HSPF code: hom). Upper panels from left to right are total nitrogen input (TN), fertilizer (F) and atmospheric deposition (A). Lower panels are legume nitrogen fixation (L) and uptake (U).

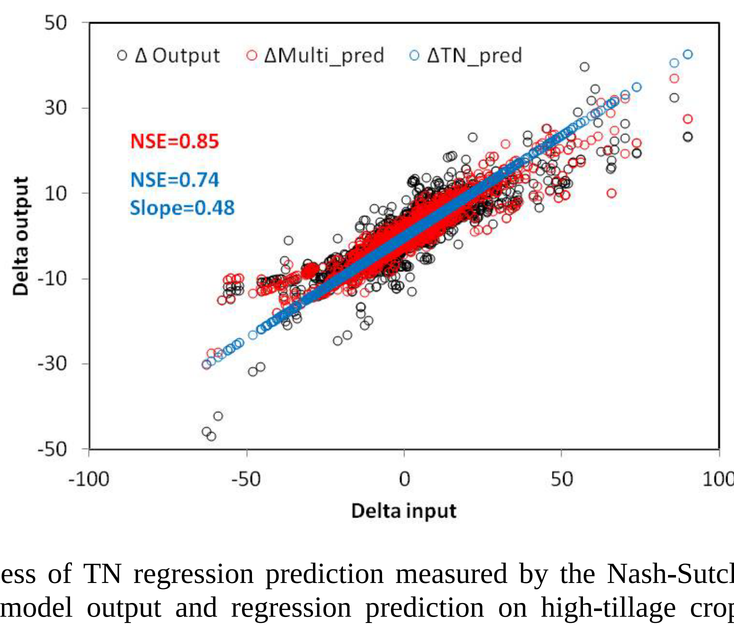

Figure 5. 3. Robustness of TN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on high-tillage cropland without manure (hom). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned output AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

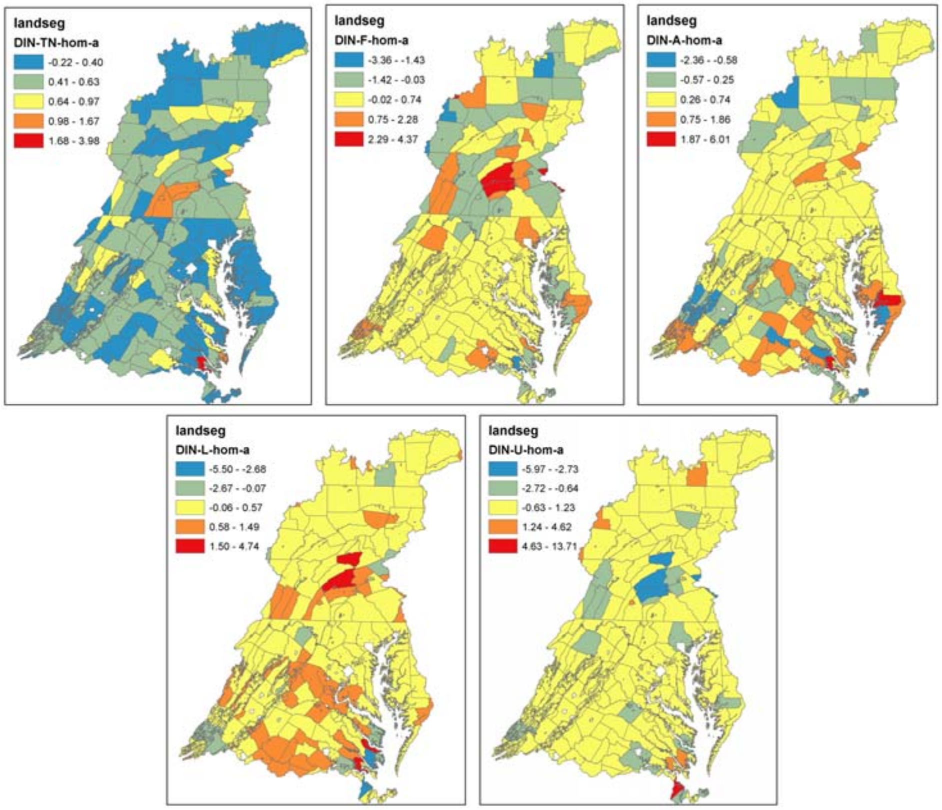

Figure 5. 4. Sensitivity slopes for DIN on high-tillage cropland without manure (hom). Upper panels from left to right are total nitrogen input (TN), fertilizer (F) and atmospheric deposition and lower panels are legume nitrogen fixation (L) and uptake (U).

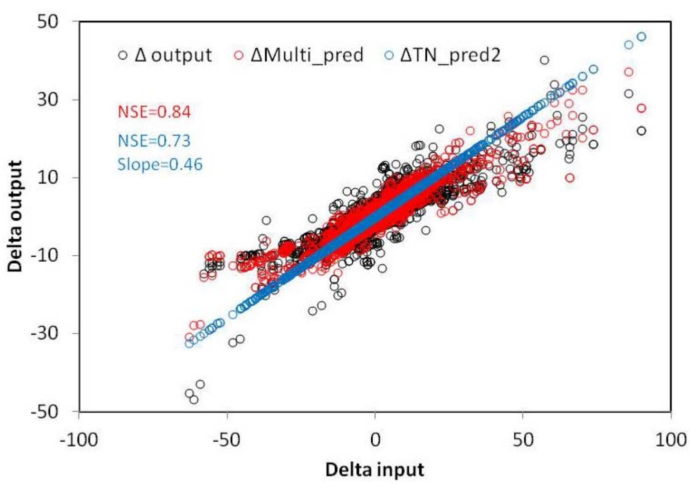

Figure 5. 5. Robustness of DIN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on high-tillage cropland without manure (hom). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned output from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

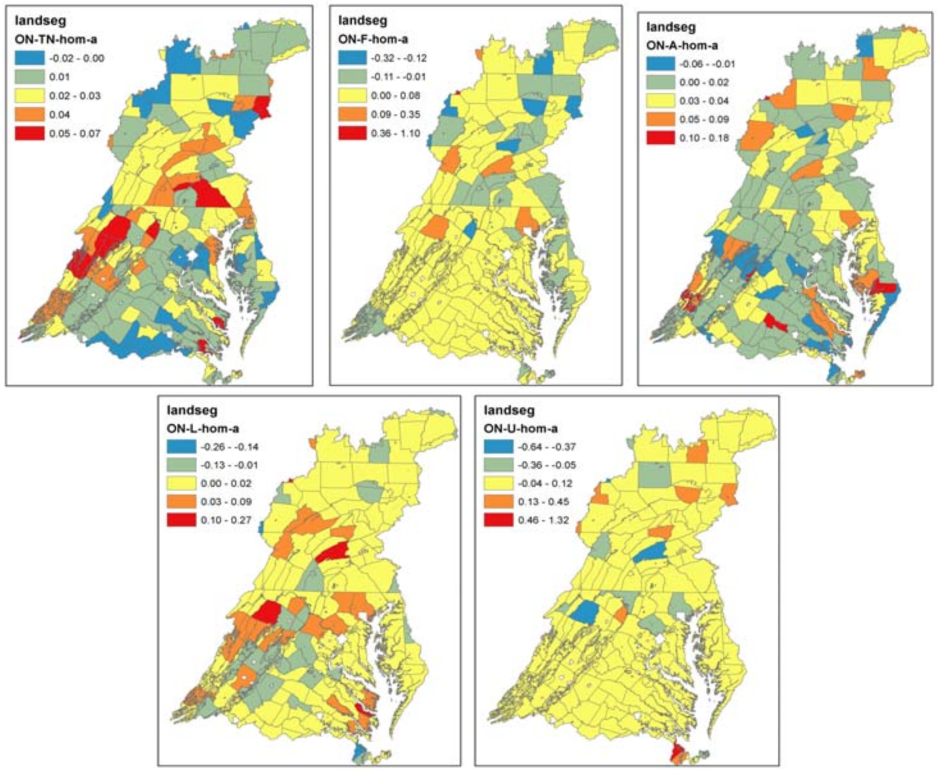

Figure 5. 6. Sensitivity slopes for organic nitrogen (ON) on high-tillage cropland without manure. Upper panels from left to right are total nitrogen input (TN), fertilizer (F) and atmospheric deposition (A) and lower panels are legume nitrogen fixation (L) and uptake (U).

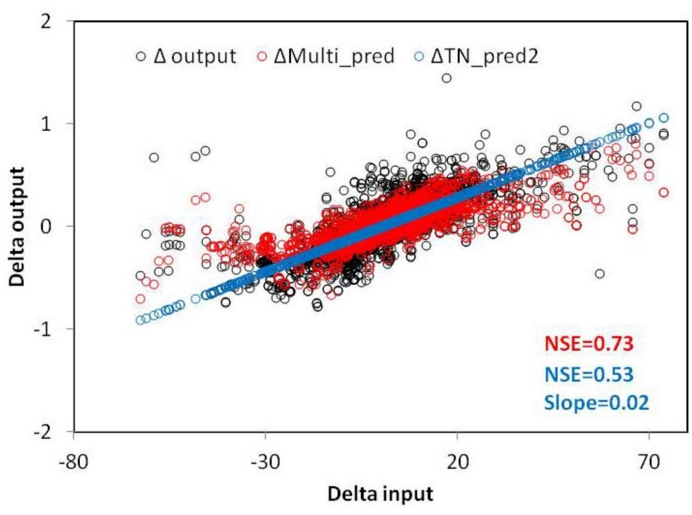

Figure 5. 7. Robustness of organic N regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on high-tillage cropland without manure (hom). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

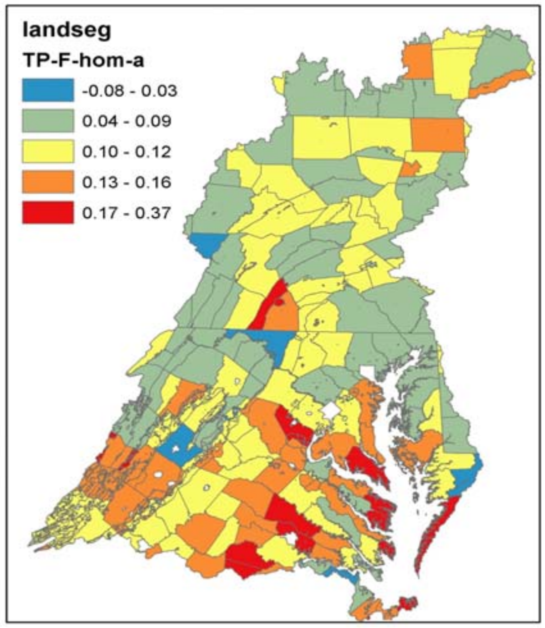

Figure 5. 8. Sensitivity slopes for total phosphorus (TP) on high-tillage cropland without manure (hom). Fertilizer is the only type of input on hom.

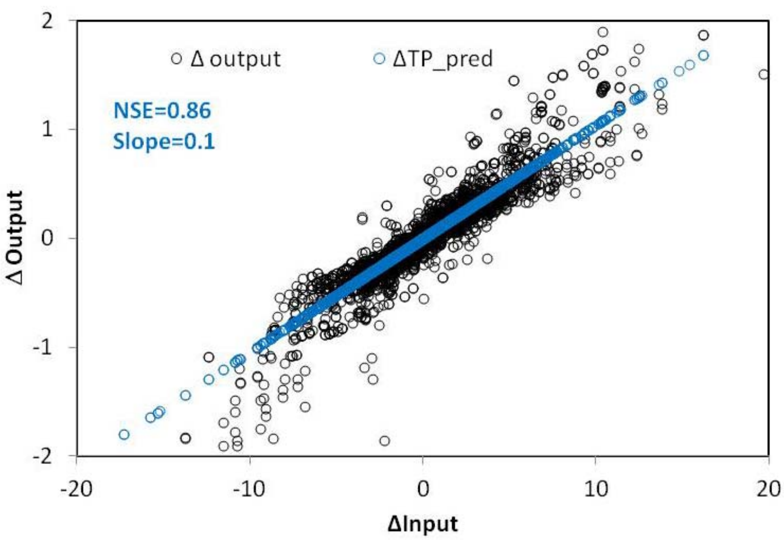

Figure 5. 9. Robustness of total phosphorus (TP) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on high-tillage cropland without manure (hom). Delta input is the demeaned total phosphorus input and delta outputs are the demeaned output from AGCHEM (black dots) and regression prediction using fertilizer phosphorus input (blue dots), the only type input for phosphorus on hom.

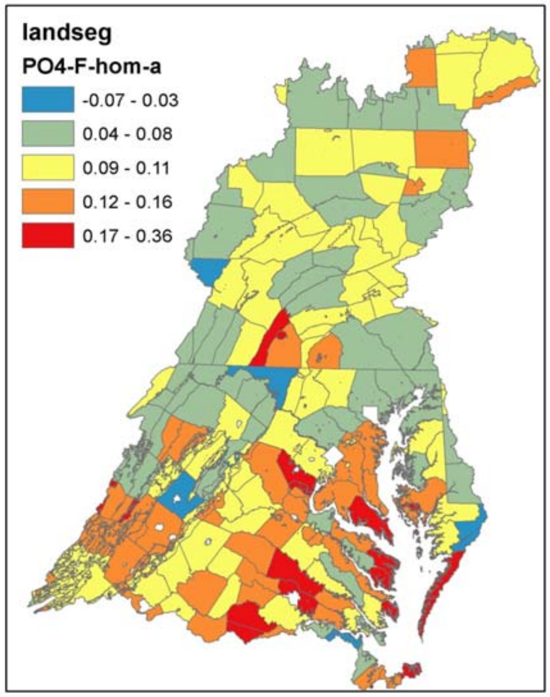

Figure 5. 10. Sensitivity slopes for phosphate (PO4) with fertilizer on high-tillage cropland without manure (hom). Fertilizer is only type of phosphorus input on hom.

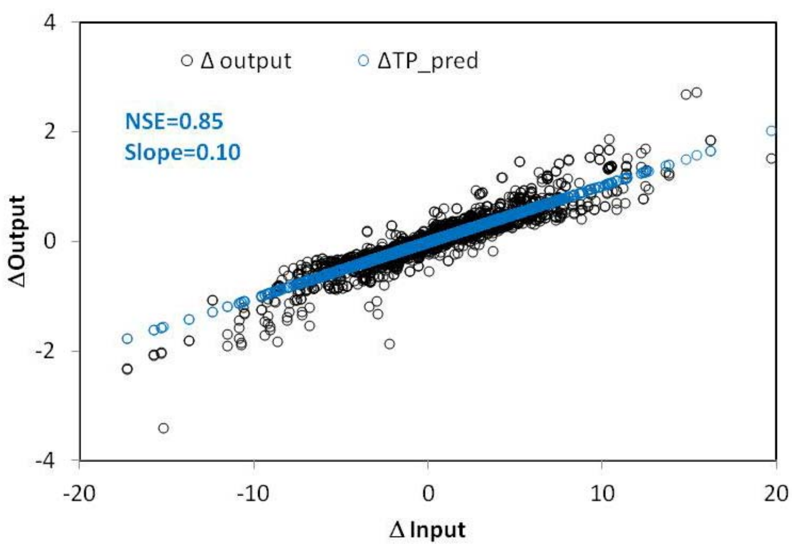

Figure 5. 11. Robustness of phosphate (PO4) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on high-tillage cropland without manure (hom). Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction. Fertilizer is the only phosphorus input on hom.

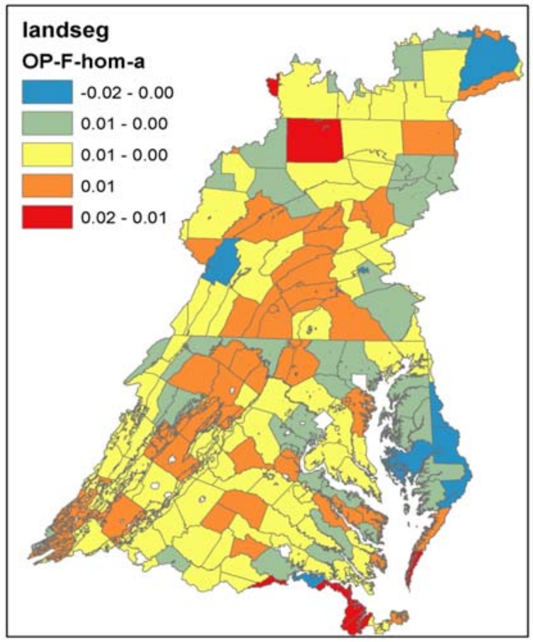

Figure 5. 12. Sensitivity slopes for organic phosphorus (OP) on high-tillage cropland without manure (hom). Fertilizer is only type of phosphorus input on hom.

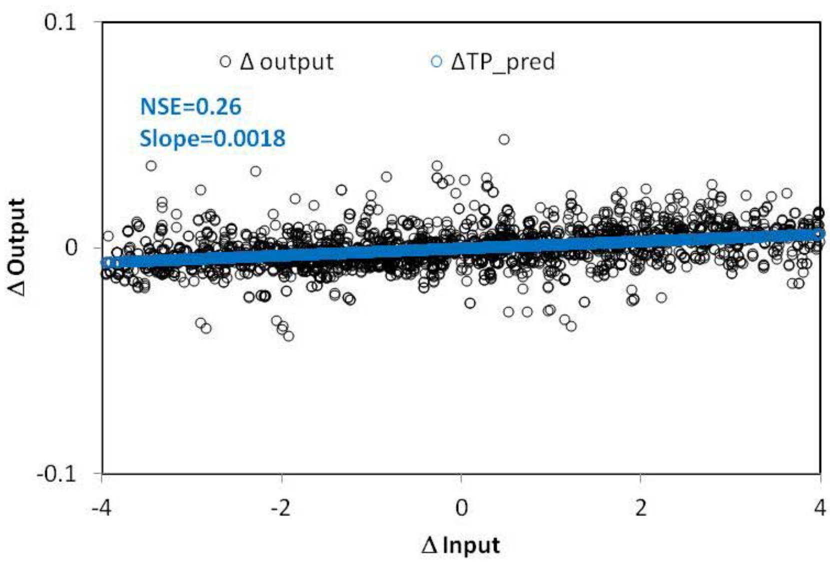

Figure 5. 13. Robustness of organic phosphorus (OP) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on high-tillage cropland without manure (hom). Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction (blue dots). Fertilizer is the only input type of phosphorus on hom.

6. Low-tillage cropland with manure (lwm)

The ratio between the watershed model- predicted uptake and the maximum uptake on low-tillage cropland with manure (lwm) is illustrated in Figure 6.1. The uptake ratio is relatively homogeneous at high latitude in the upper Susquehanna drainage basin, but more scattered at low latitude. The frequency distribution shows a dominant mode around 0.6, with an average of 0.58 and a median of 0.57. As the previous cases, the median ratio was used for the model sensitivity analysis. The sensitivity slopes for total nitrogen output are depicted in Figure 6.2 for both total nitrogen input and multi-variate regression. No particular spatially distribution patterns were found, except that the slope with atmospheric deposition and legume fixation showed certain homogeneity in the Susquehanna drainage basin. As a result, the median slope is recommended for the PQAUL specification. The median slope for total nitrogen input is 0.19 with the coefficient of variation around 1. For the multi-variate regression, atmospheric deposition, fertilizer and legume nitrogen fixation have similar sensitivity slopes ranging from 0.31 to 0.36, whereas manure has a relative low sensitivity (0.16). Uptake yielded a negative slope of -0.13 (Table 6.1). With these median slopes, the AGCHEM prediction was relatively well predicted, with an NSE 0f 0.67 for both total nitrogen input and multi-variate regression (Table 6.1).

Similar results were obtained for DIN and organic nitrogen that scattering dominates in the spatial distribution of sensitivity slopes without predictable pattern (Figures 6.4 and 6.6). The sensitivity slope between DIN output and atmospheric deposition appears to be relatively higher on the Appalachian Plateau in the upper Susquehanna drainage basin than in the rest of the same drainage basin, but there is no other describable pattern that can be predicted by using environmental factors. On the other hand, relatively robust prediction was obtained using the median slopes (Figures 6.5 and 6.7). The NSE for total nitrogen input prediction is 0.40 and 0.58 for DIN and organic nitrogen prediction using total nitrogen loadings and 0.54 and 0.67 using multiples inputs as predictors, respectively (Table 6.1). In this case, the NSE using multiple predictors is more than 10% higher than that using total nitrogen input so that multi-variate sensitivity slopes are recommended over total nitrogen input. In the multi-variate regression slopes, atmospheric deposition, legume fixation and fertilizer have similar sensitivity slopes for

DIN prediction (0.25, 0.25 and 0.21, respectively), whereas manure has a relatively low slope (0.08). For organic nitrogen prediction, atmospheric deposition has the highest slope (0.19), followed by legume fixation (0.11), manure (0.10) and fertilizer (0.08). The slope with uptake is negative for both DIN and organic nitrogen prediction (Table 6.1).

Only manure and fertilizer are involved in the prediction of phosphorus output. Atmospheric deposition and legume fixation do not contribute to phosphorus input and phosphorus uptake was not recorded in the watershed simulation. The spatial distribution of sensitivity slopes are depicted in Figures 6.8, 6.10 and 6.12 for total phosphorus, phosphate and organic phosphorus prediction, respectively. None of them show predictable pattern and consequently median slopes are used to predict the outcome of the AGCHEM simulation. The NSE values for phosphorus prediction are even higher than that for nitrogen prediction (Table 6.1 and Figures 6.9, 6.11 and 6.13), ranging from 0.78 to 0.91. There is no significant difference between predictions using total phosphorus and multiple types of inputs. Prediction using total phosphorus is thus recommended for the PQUAL specification for phosphorus prediction. The model sensitivity slopes are significantly lower for phosphorus prediction than for nitrogen and among the phosphorus species, the slopes for organic phosphorus output is approximately one order of magnitude lower than that for phosphate and total phosphorus prediction (Table 6.1).

As final recommendation, multi-variate regression should be used for nitrogen export whereas total input can be used for phosphorus prediction. Slope values are listed in Table 6.1.

Table 6. 1. Summary of regression slopes and Nash-Sutcliffe Efficiency (NSE) coefficients of regression prediction for low-tillage cropland with manure (lwm). Input: Total nitrogen (or phosphorus) input; TIP: Total Input Prediction; MVP: Multi-variate prediction; STD: Standard deviation; Atm. Dep.: Atmospheric deposition; Legume: Legume nitrogen fixation; N: Nitrogen; P: Phosphorous. Red values are the final recommendation.

Constituents	Output/ Input	NSE of TIP	NSE of MVP	Statistics of slope	Total	Atm. Dep.	Manure	Fertilizer	Legume	Uptake
Total N	0.26	0.67	0.67	Mean	0.21	0.43	0.21	0.28	0.30	-0.20
				Median	0.19	0.33	0.16	0.31	0.36	-0.13
				STD	0.22	1.1	0.43	0.73	2.2	1.3
DIN	0.16	0.40	0.54	Mean	0.15	0.24	0.12	0.19	0.19	-0.13
				Median	0.14	0.25	0.08	0.21	0.25	-0.13
				STD	0.21	0.56	0.41	0.59	1.8	0.95
Organic N	0.10	0.58	0.67	Mean	0.06	0.19	0.10	0.08	0.11	-0.07
				Median	0.06	0.07	0.08	0.08	0.10	-0.01
				STD	0.06	1.0	0.12	0.46	1.1	0.56
Total P	0.09	0.82	0.85	Mean	0.10		0.13	0.11		
				Median	0.10		0.11	0.09		
				STD	0.09		0.16	0.15		
PO4	0.08	0.79	0.83	Mean	0.08		0.11	0.11		
				Median	0.09		0.10	0.09		
				STD	0.09		0.16	0.14		
Organic P	0.01	0.84	0.91	Mean	0.012		0.019	0.002		
				Median	0.01		0.015	0.005		
				STD	0.015		0.019	0.03		

Figure 6. 1. Spatial distribution of the ratio between the watershed model-predicted nitrogen uptake and scenario-builder provided maximum uptake (left panel) and frequency distribution of the uptake ratio (right panel) on low-tillage cropland with manure (lwm).

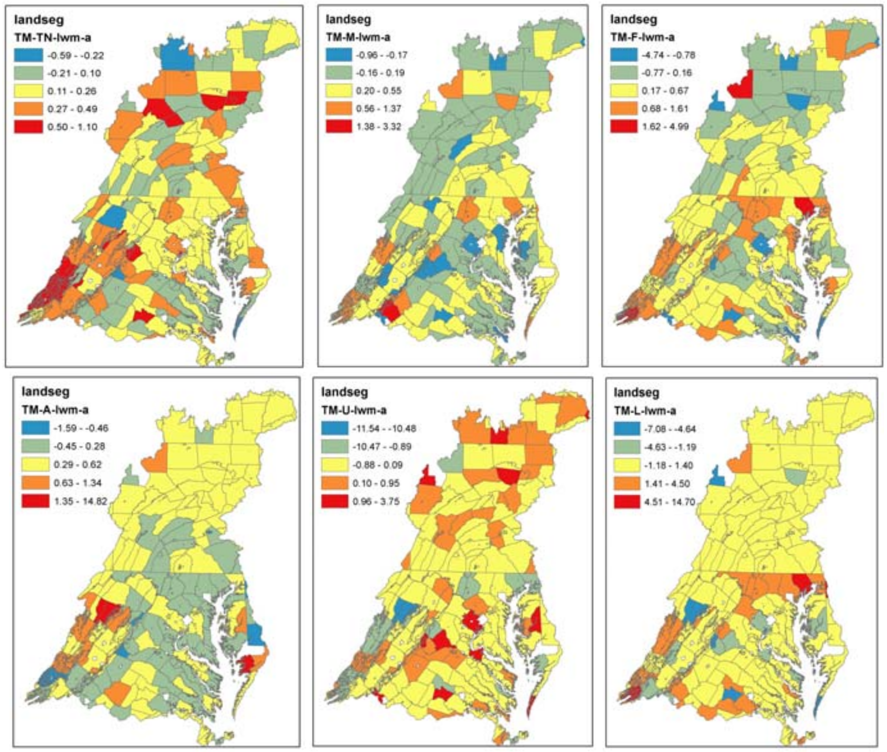

Figure 6. 2. Sensitivity slopes for total nitrogen output of low-tillage cropland with manure (HSPF code: lwm). Upper panels from left to right are total nitrogen input (TN), manure (M) and fertilizer (F). Lower panels are. Atmospheric deposition (A), uptake (U) and legume nitrogen fixation (L).

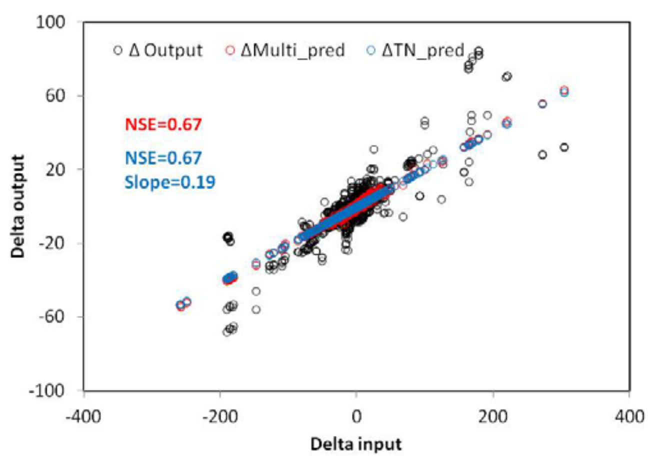

Figure 6. 3. Robustness of TN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on low-tillage cropland without manure (lwm). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

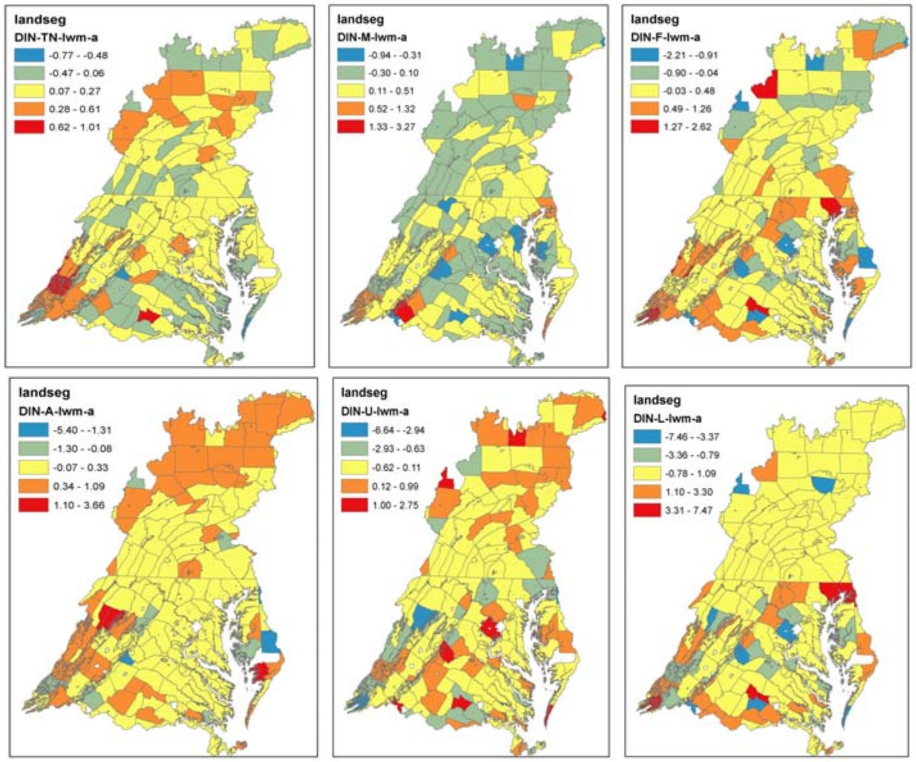

Figure 6. 4. Sensitivity slopes for DIN on low-tillage cropland with manure (lwm). Upper panels from left to right are total nitrogen input (TN), manure (M), fertilizer (F) and lower panels are atmospheric deposition (A), uptake (U) and legume nitrogen fixation (L).

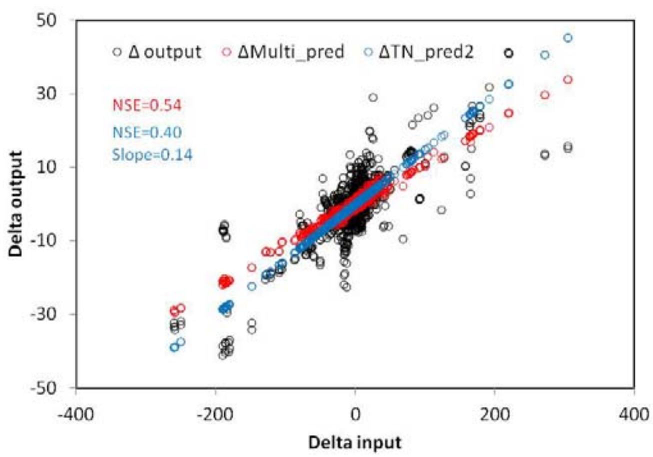

Figure 6. 5. Robustness of DIN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on low-tillage cropland without manure (lwm). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

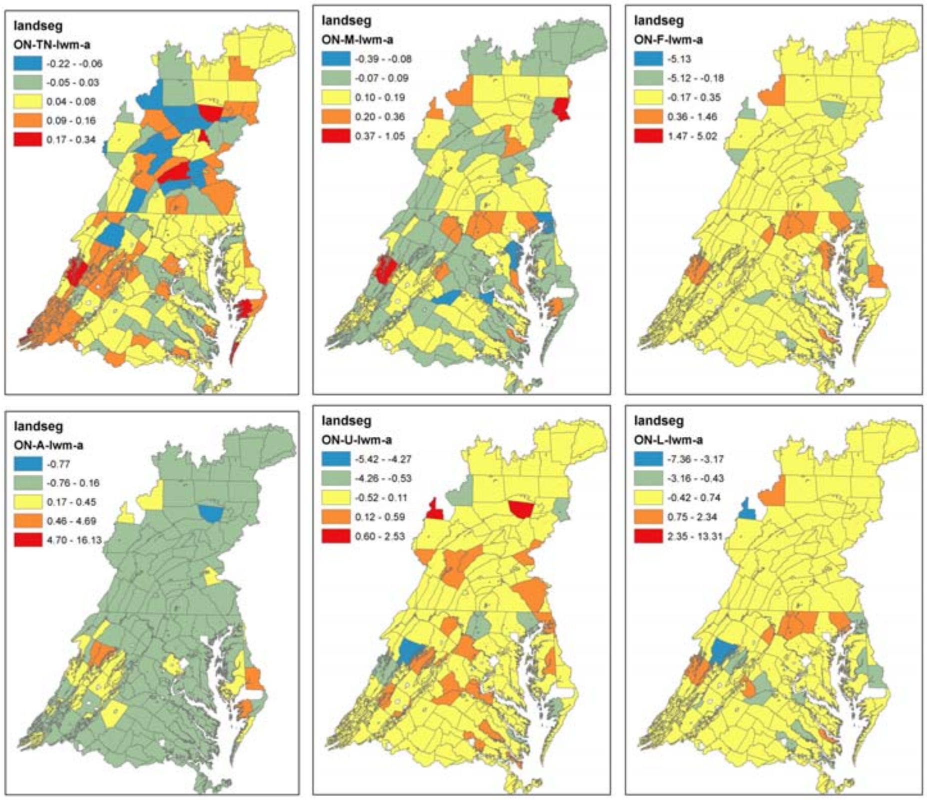

Figure 6. 6. Sensitivity slopes for organic nitrogen (ON) on low-tillage cropland with manure (lwm). Upper panels are total nitrogen input (TN), manure (M), fertilizer (F) and lower panels are atmospheric deposition (A), uptake (U) and legume nitrogen fixation (L).

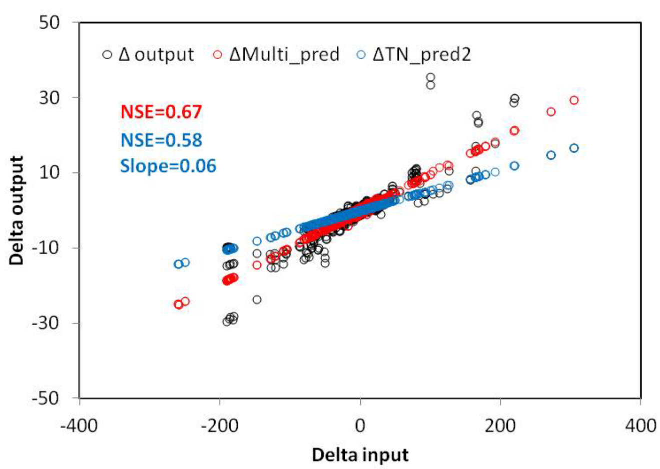

Figure 6. 7. Robustness of organic N regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on low-tillage cropland with manure (lwm). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

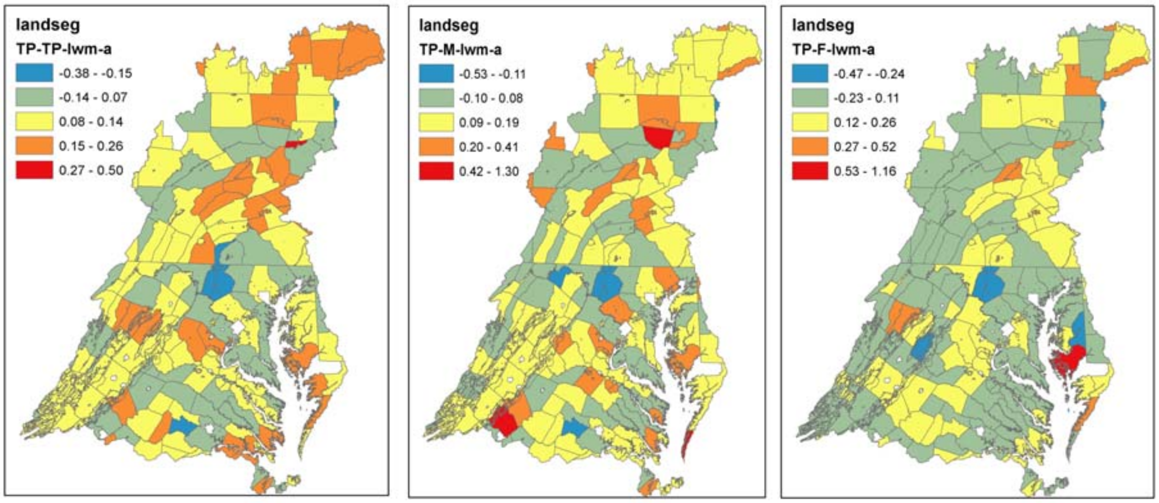

Figure 6. 8. Sensitivity slopes for total phosphorus (TP) on low-tillage cropland with manure (lwm). Panels from left to right are total phosphorus input, manure and fertilizer.

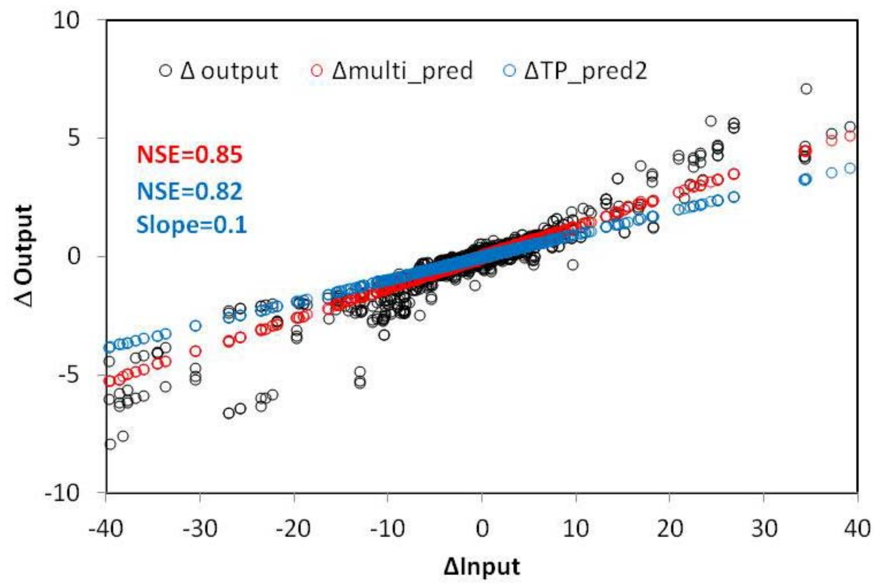

Figure 6. 9. Robustness of total phosphorus (TP) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on low-tillage cropland with manure (lwm). Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using total phosphorus input (blue dots) and multi-variate regression (red dots).

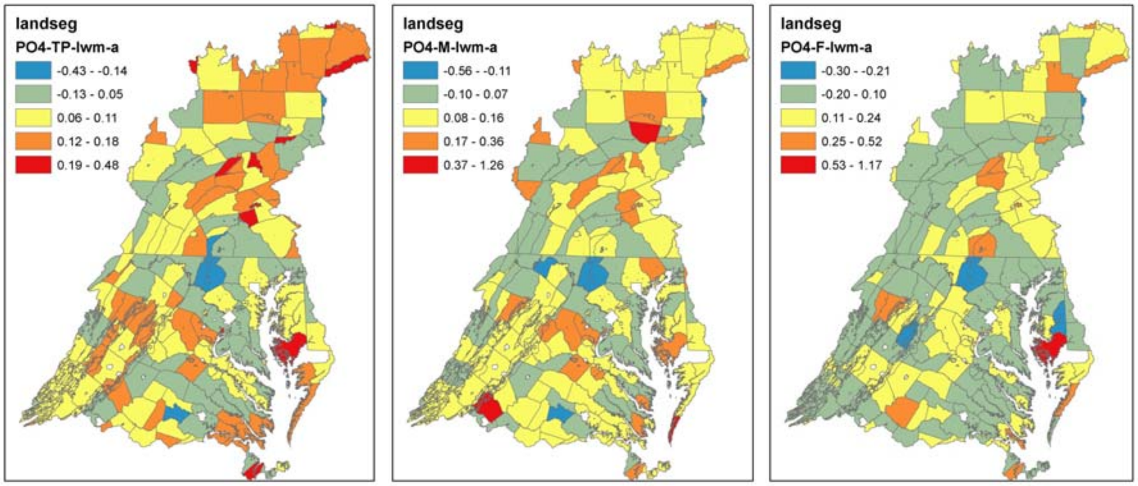

Figure 6. 10. Sensitivity slopes for phosphate (PO4) on low-tillage cropland with manure (lwm). Left panel is total phosphorus input (TP), middle panel is manure (M), and right panel is fertilizer (F).

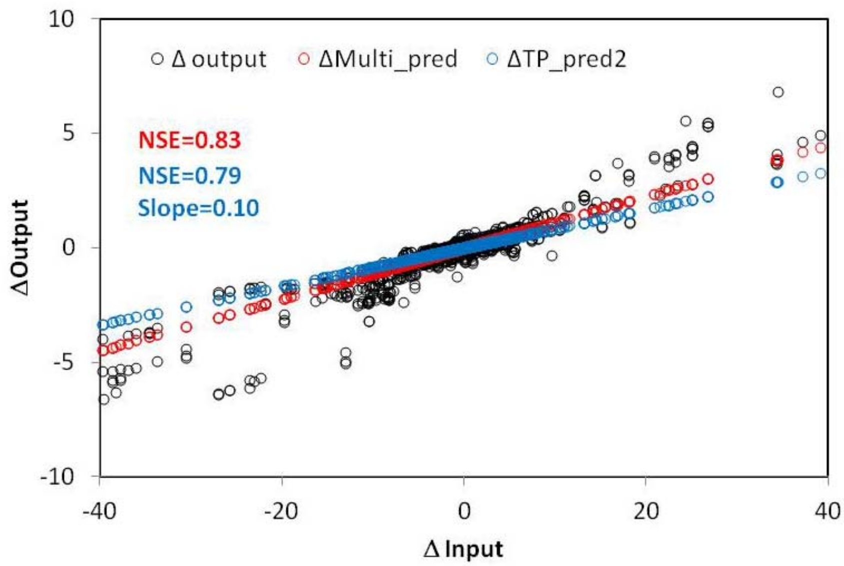

Figure 6. 11. Robustness of phosphate (PO4) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on low-tillage cropland with manure (lwm). Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots), and regression prediction using total phosphorus input (blue dots) and multi-variate analysis (red dots).

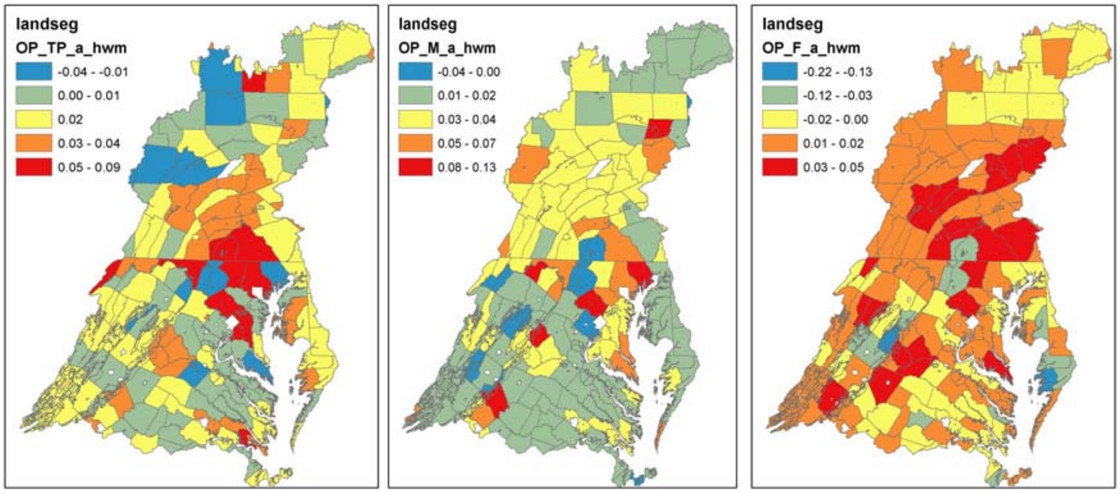

Figure 6. 12. Model sensitivity slopes for organic phosphorus output (OP) on low-tillage cropland with manure (lwm). Panels from left to right are total phosphorus input (TP), manure (M) and fertilizer (F).

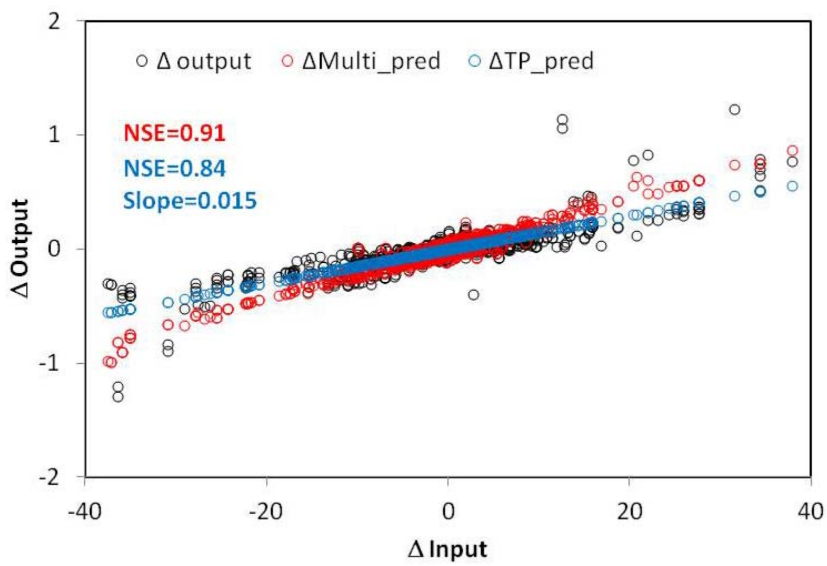

Figure 6. 13. Robustness of organic phosphorus (OP) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on hom. Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using total phosphorus input and multi-variate analysis.

7. Hay with nutrient management (hyw)

Nitrogen on hay with nutrient management (hyw) was simulated with PQUAL so that sensitivity analysis is not needed. The model sensitivity slopes for total phosphorus output are presented in Figure 7.1 and for phosphate output in Figure 7.3. The spatial distributions of sensitivity slopes are quite similar for total phosphorus and phosphate prediction. The slopes with total phosphorus input and manure are scattered over the watershed without particular patterns. For the slope with fertilizer, a particularly high value of 52 was obtained in the Cumberland County (VA). High regression slopes up to 24 were also obtained for Rockingham County (VA) as well. These extreme high slope values were set off by large negative incept values generated over these specific land segments, which have the potential to alter the mean slope over the entire watershed. In fact, the average slope with fertilizer is 0.89 for total phosphorus prediction and 0.90 for phosphate, which are much higher than that on most of the land segments and also higher than that on other land uses. However, the median values are plausible, 0.1 for both total phosphorus and phosphate prediction. With median slopes, plausible prediction was obtained, with an NSE of 0.70 for using total phosphorus input and 0.72 for using multi-variate analysis for both total phosphorus and phosphate prediction (Table 7.1). As there is no significant difference between the predictions using total phosphorus input and multiple types of inputs, total phosphorus input is sufficient as a single predictor on this type of land use. For the case of organic phosphorus, the output did not show significant response to change in inputs based on the scenarios included. The sensitivity slope is practically zero with all the types of inputs and, as a result, the NSE was not determined. This means that a constant discharge of organic phosphorus based on the calibration scenario can be used for the other scenarios with a range of total phosphorus input.

As final recommendation, total phosphorus input can be used as the independent predictor on hay with nutrient management (hyw) and the median slope values are given in Table 7.1.

Table 7. 1. Summary of regression slopes and Nash-Sutcliffe Efficiency (NSE) coefficients of regression prediction for hay with nutrient management (hyw). Input: Total nitrogen (or phosphorus) input; TIP: Total Input Prediction; MVP: Multi-variate prediction; STD: Standard deviation; Atm. Dep.: Atmospheric deposition; Legume: Legume nitrogen fixation; P: Phosphorous; ND: Not determined. Nitrogen was simulated using PQAUL in the previous scenarios so the sensitivity analysis is irrelevant. Red values are the recommendation for the PQUAL specification.

Constituents	Output/ Input	NSE of TIP	NSE of MVP	Statistics of slope	Total	Atm. Dep.	Manure	Fertilizer	Legume	Uptake
Total P	0.08	0.70	0.72	Mean	0.09		0.08	0.89		
				Median	0.08		0.09	0.10		
				STD	0.08		0.08	4.4		
PO4	0.08	0.70	0.72	Mean	0.09		0.08	0.90		
				Median	0.08		0.09	0.10		
				STD	0.08		0.08	4.4		
Organic P	0.004	ND	ND	Mean	0		0	0		
				Median	0		0	0		
				STD	0		0	0		

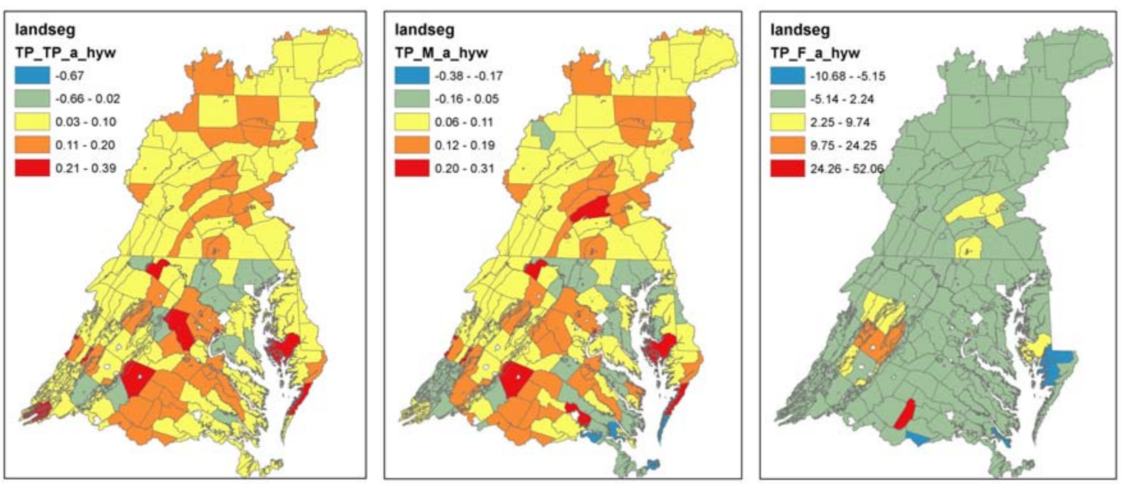

Figure 7. 1. Sensitivity slopes for total phosphorus (TP) on hay with nutrient management (hyw). Panels from left to right are total phosphorus input (TP), manure (M) and fertilizer (F).

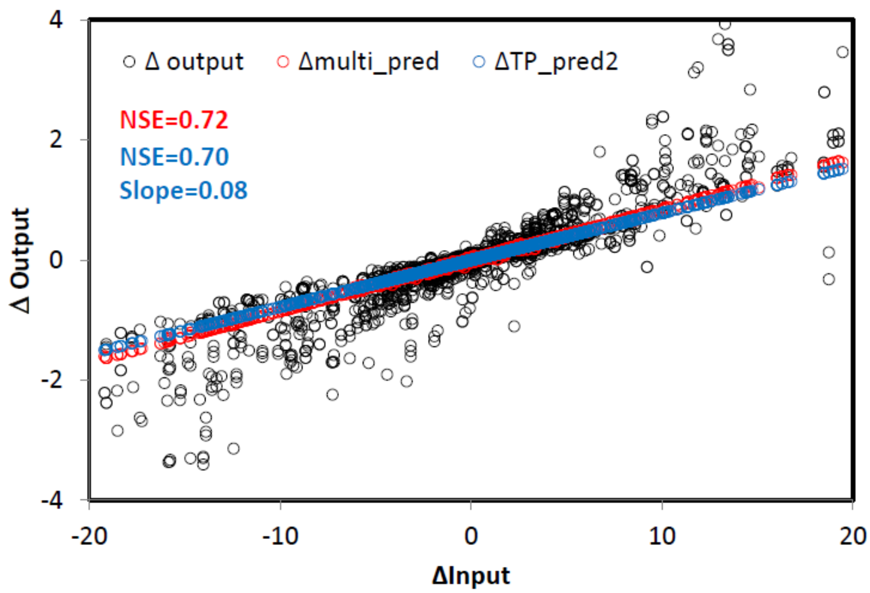

Figure 7. 2. Robustness of total phosphorus (TP) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on hay with nutrient management (hyw). Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using total phosphorus input (blue dots) and multi-variate regression (red dots).

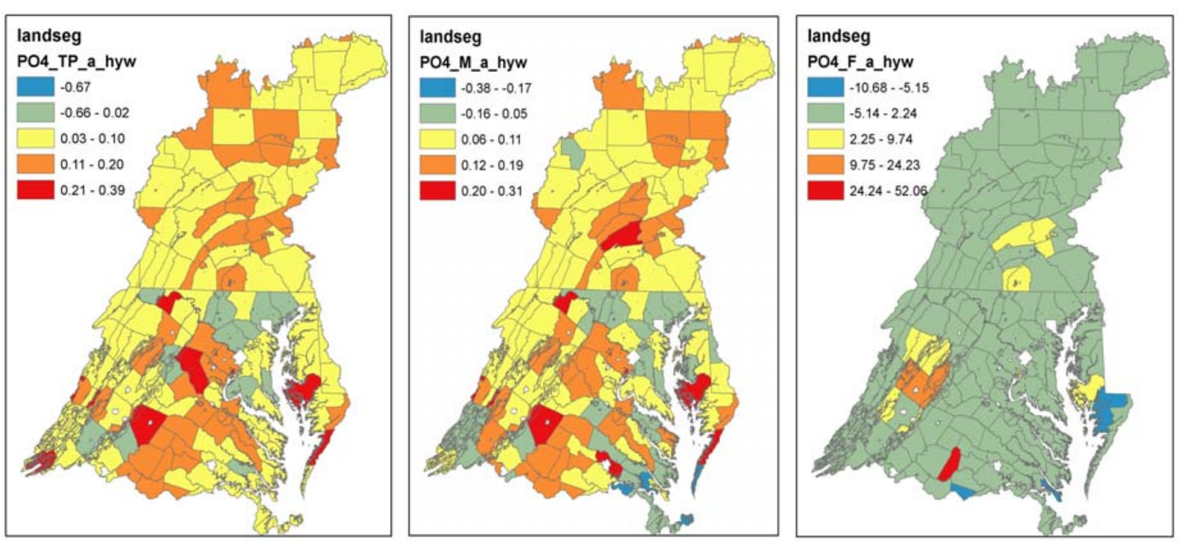

Figure 7. 3. Sensitivity slopes for total phosphate (PO4) on hay with nutrient management (hyw). Left panel is total phosphorus input (TP), middle panel is manure (M), and right panel is fertilizer (F).

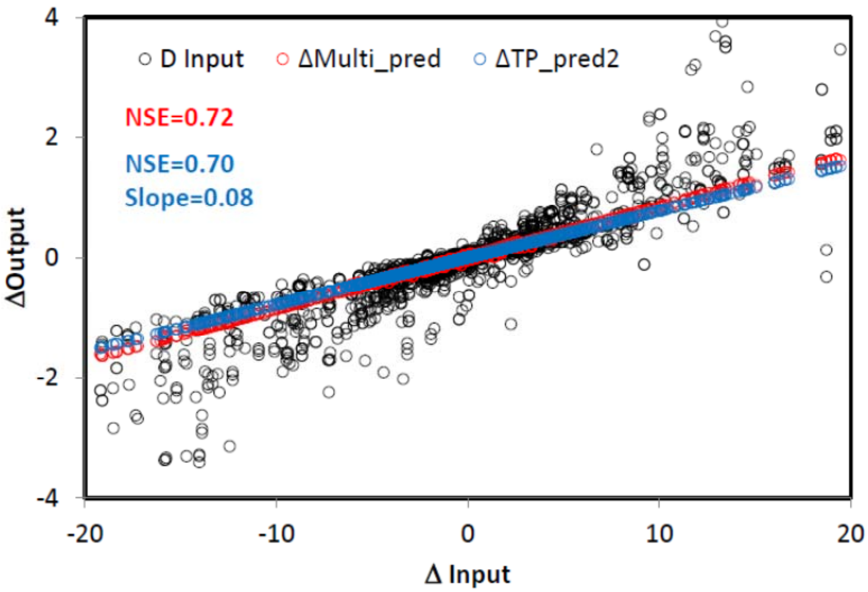

Figure 7. 4. Robustness of total phosphate (PO4) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on hay with nutrient management (hyw). Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using total phosphorus input (blue dots) and multi-variate analysis (red dots).

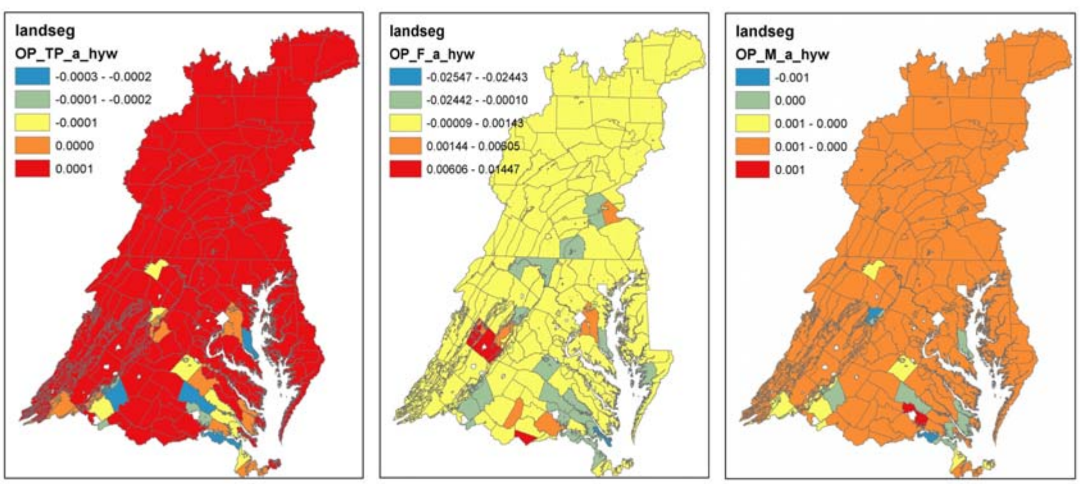

Figure 7. 5. Model sensitivity slopes for organic phosphorus output (OP) on hay with nutrient management (hyw). Panels from left to right are total phosphorus input (TP), manure (M) and fertilizer (F).

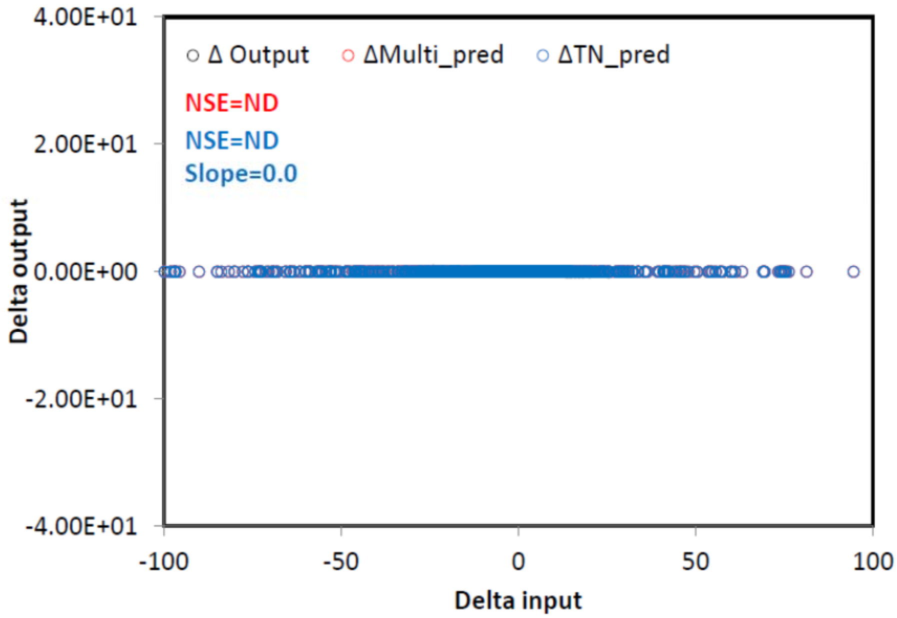

Figure 7. 6. Robustness of organic phosphorus (OP) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on hay with nutrient management (hyw). Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using total phosphorus input (blue dots) and multi-variate analysis (red dots).

8. Hay without nutrient management (hyo)

The uptake ratio between the watershed model-predicted and the maximum uptake provided by the scenario builder on hay without nutrient management (hyo) is depicted in Figure 8.1. The ratio ranges from 0.06 to 0.29. Low values are mostly found on the Appalachian Plateau in the upper Susquehanna River drainage basin and high values are mostly in the Potomac and James rivers drainage basins. However, the ratio does no show a regular variation with latitude, with more scattered variation in the southern part of the domain. Regression analysis revealed a weak link between the uptake ratio and latitude, with an R^2 of 0.19. Moreover, the uptake ratio did not change much in terms of absolute values, with a coefficient of variation of 0.3. The frequency distribution shows predominant mode. Consequently, the median value of 0.12 was used in this sensitivity analysis. On hay without nutrient management, no manure or fertilizer are applied so that the input is essentially atmospheric deposition and the output is also influenced by the uptake.

The model sensitivity slopes for total nitrogen prediction resulted from regression analyses on hyo are illustrated in Figure 8.2. The sensitivity slopes between total nitrogen output with total nitrogen input and atmospheric deposition appears to be relatively lower on the Appalachian Mountain and piedmont regions in the middle of the Susquehanna River drainage area as compare with in the upper Susquehanna at high latitude and in the mountain region at lower latitude. On the other hand, the sensitivity slope with uptake rate displays opposite distribution, with high values in the middle of the watershed model domain. Changes of the sensitivity slopes over the simulation domain are limited, with coefficient of variation of 0.3 for the slope with total nitrogen input and 0.2 for the slope with atmospheric deposition (Table 8.1). The sensitivity slope between total nitrogen output and uptake rate is positive on hay without nutrient management, whereas it is negative on most of the other land uses. As no nutrients are applied on hyo, nutrient uptake from the soil may lead to nutrient export through mineralization and recycling. The slope with uptake is very small, 0.02 for total nitrogen export. With the median sensitivity slopes, robust prediction was obtained for total nitrogen export, with an NSE as high as 0.97 for multi-variate prediction and 0.90 for the prediction using the total nitrogen input.

Similar results were obtained for DIN export in terms of spatial distribution of sensitivity slopes and NSEs for regression prediction (Figures 8.4 and 8.5). Lower slopes were found in the middle of the watershed domain with total input and atmospheric deposition of nitrogen and higher values with uptake in the middle domain. The NSE reaches to 0.97 for multi-variate prediction and 0.90 for the prediction using total nitrogen input. The spatial distribution of sensitivity slopes for organic nitrogen export slightly differs from that for total nitrogen and DIN exports (Figure 9.6). Lower values are essentially in the northern part of the watershed in the Susquehanna drainage basin and high values in the southern part of the domain except in the coastal plains. However, the sensitivity slopes for organic nitrogen are very low, approximately lower by 2 orders of magnitude than that of total nitrogen and DIN exports. Consequently, organic nitrogen export is almost negligible on hay without nutrient management. Robust prediction using the median slopes was also obtained for organic nitrogen export, with an NSE of 0.95 for multi-variate prediction and 0.84 for the prediction using total nitrogen input. As the NSE difference between multi-variate and total nitrogen input predictions is less than 10% for both total nitrogen and DIN export, using total nitrogen input as the predictor is plausible for hay without nutrient management. The final recommendation is to use the median slope of 0.3 for both total nitrogen and DIN exports and 0.005 for organic nitrogen export prediction.

Phosphorus simulation on hay without nutrient management was based on PQUAL so that the model sensitivity is irrelevant.

Table 8. 1. Summary of regression slopes and Nash-Sutcliffe Efficiency (NSE) coefficients of regression prediction for hay without nutrient management (hyo). Input: Total nitrogen (or phosphorus) input; TIP: Total Input Prediction; MVP: Multi-variate prediction; STD: Standard deviation; Atm. Dep.: Atmospheric deposition; Legume: Legume nitrogen fixation; N: Nitrogen. Red values are the final recommendation.

Constituents	Output/ Input	NSE of TIP	NSE of MVP	Statistics of slope	Total	Atm. Dep.	Manure	Fertilizer	Legume	Uptake
Total N	0.37	0.90	0.97	Mean	0.32	0.28				0.02
				Median	0.30	0.27				0.02
				STD	0.10	0.05				0.2
DIN	0.30	0.90	0.97	Mean	0.32	0.27				0.02
				Median	0.30	0.27				0.02
				STD	0.10	0.05				0.2
Organic N	0.07	0.84	0.95	Mean	0.005	0.004				0.001
				Median	0.005	0.004				0.001
				STD	0.002	0.001				0.003

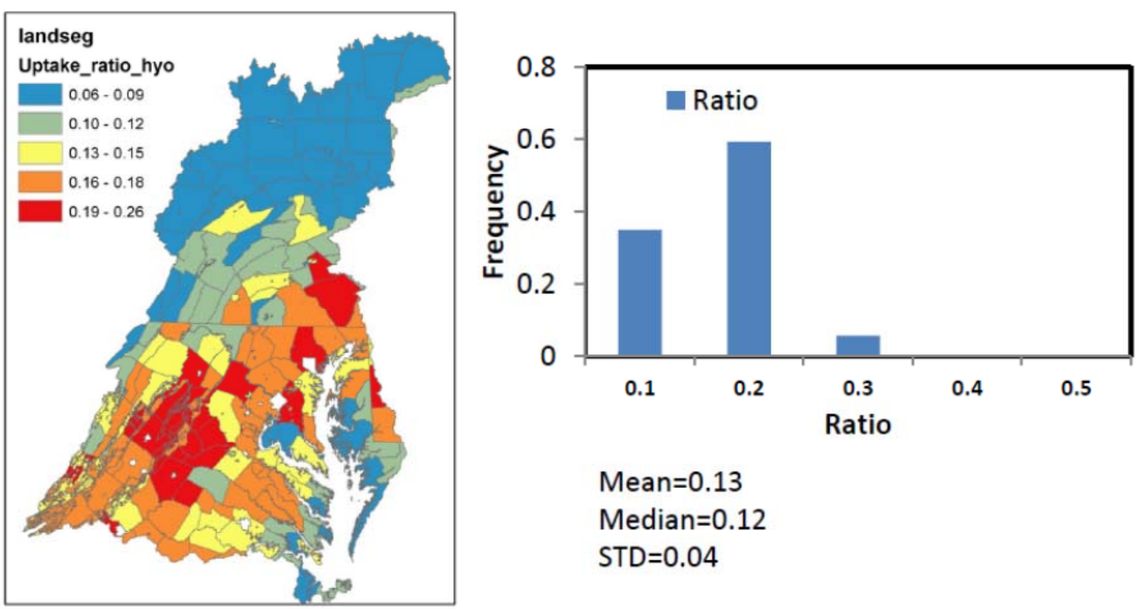

Figure 8. 1. Spatial distribution of the ratio between the watershed model- predicted nitrogen uptake and scenario-builder-provided maximum uptake (left panel) and frequency distribution of the uptake ratio (right panel) on hay without nutrient management (hyo).

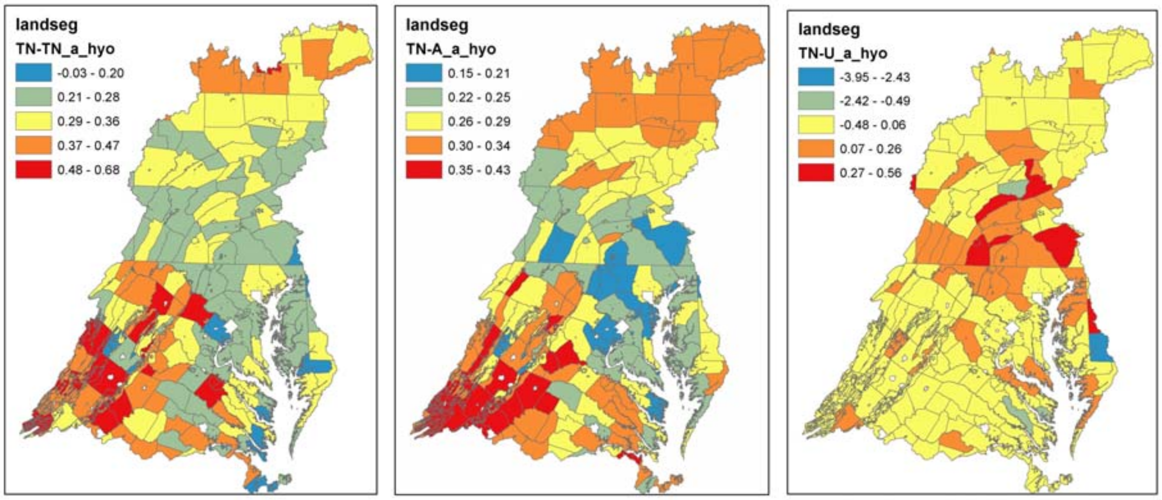

Figure 8. 2. Sensitivity slopes for total nitrogen output on hay without nutrient management (HSPF code: hyo). Panels from left to right are total nitrogen input (TN), atmospheric deposition (A) and uptake (U).

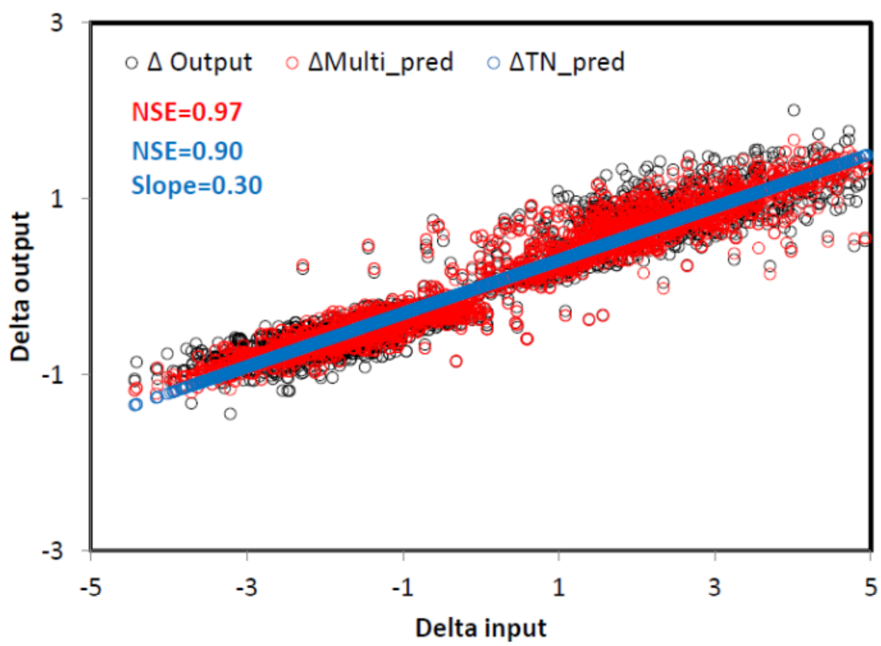

Figure 8. 3. Robustness of TN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on hay without nutrient management (hyo). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

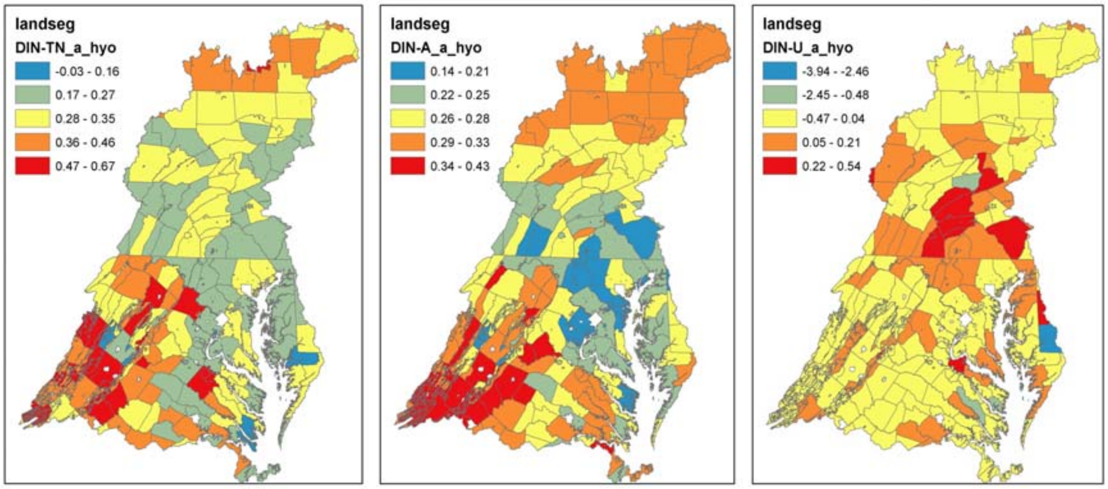

Figure 8. 4. Sensitivity slopes for DIN on hay without nutrient management (hyo). Panels from left to right are total nitrogen input (TN), atmospheric deposition (A) and uptake (U)

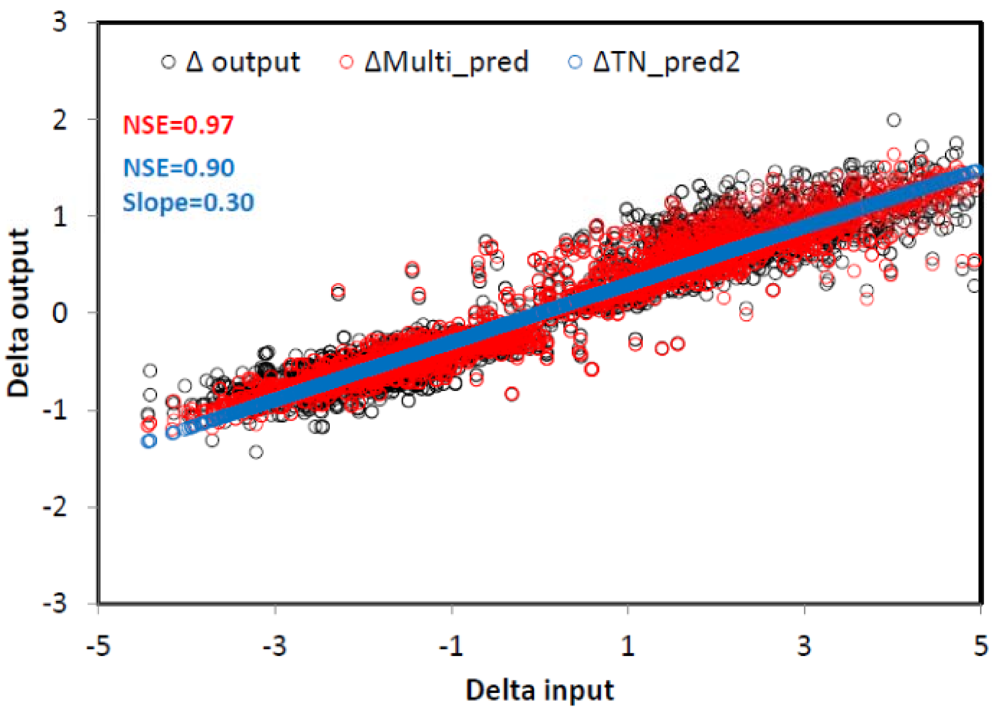

Figure 8. 5. Robustness of DIN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on hay without nutrient management (hyo). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

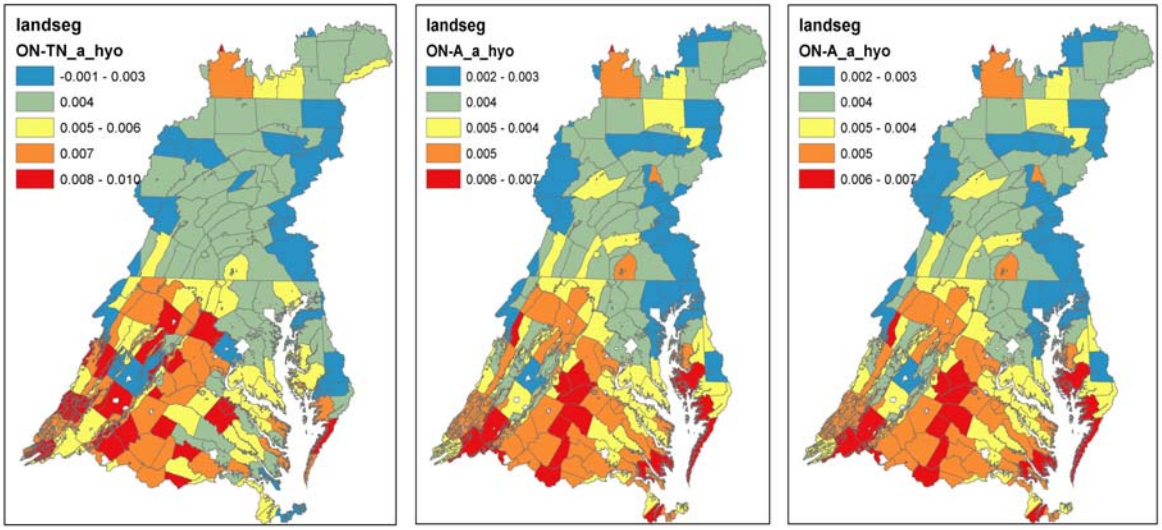

Figure 8. 6. Sensitivity slopes for organic nitrogen (ON) on hay without nutrient management (hyo). Panels from left to right are total nitrogen input (TN), atmospheric deposition (A) and uptake (U).

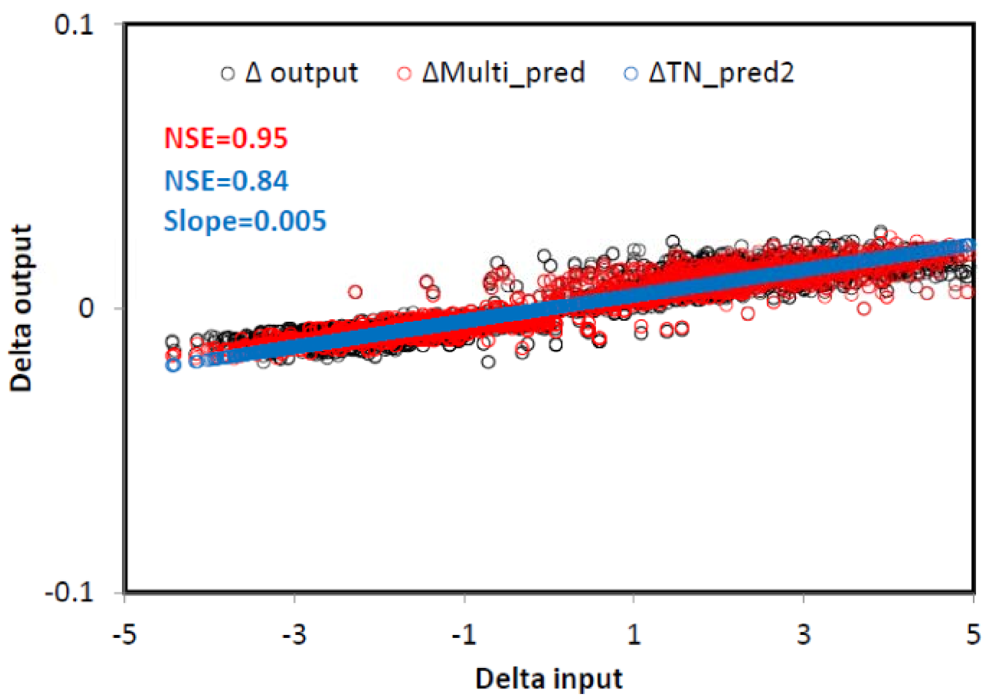

Figure 8. 7. Robustness of organic N regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on hay without nutrient management (hyo). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

9. Alfalfa (alf)

The ratio between the watershed model-estimated uptake rate and the maximum uptake on alfalfa is illustrated in Figure 9.1. Low values are mostly found in the upper Susquehanna drainage basin and higher values in the coastal plains, but scattering distribution dominates over predictable patterns using environmental factors. The uptake ratio is relatively lower on alfalfa than on other land use, with an average of 0.075 and a median of 0.07. Given the lack of predictable distribution patterns, the median uptake ratio was used in the following sensitivity analysis.

The model sensitivity slopes between total nitrogen export and total nitrogen loadings show lower values in the upper Susquehanna drainage basin at high latitude and higher values in the James and Potomac River drainage basins (Figure 9.2), but regression between latitude and the slope did not yield and significant relationship, with an R^2 of 0.09. As a result, the median slope was used to test the robustness of the regression prediction. Similarly, the median slopes of multi-variate regression were also used due to the lack of predictable distribution pattern. Note that only a few land segments have manure application. Also, only phosphorus fertilizers were applied to alfalfa given that it is a type of nitrogen fixation. However, legume nitrogen fixation data were not available for the model simulation so that this type of nutrient input was not taken into account. Even with these shortages in data information, the median sensitivity slopes provided reasonable prediction of the AGCHEM simulation (Figure 9.3). The NSE for regression prediction using total nitrogen input stands as 0.48 and that using multiple input types reaches 0.81 (Table 9.1). Given that the NSE from multi-variate regression prediction is much higher than that using a single predictor of total nitrogen input, multi-variate regression is recommended to total nitrogen export prediction on alfalfa. Similar results were obtained for dissolved inorganic nitrogen (Figures 9.4 and 9.5). Basically lower slopes were found in the upper Susquehanna drainage basin and higher values in the James and Potomac river drainage basins, but there is not specific distribution patterns in the slopes of multi-variate analysis. On the other hand, relatively robust prediction was obtained using the median slopes of sensitivity analysis. The NSE of regression prediction is 0.47 using a single predictor of total nitrogen input and up to 0.78 using multi-variate prediction. As the NSE is significantly higher in the later case, multi-variate regression is also recommended for the PQUAL specification for DIN prediction on alfalfa. For organic nitrogen export on alfalfa, the sensitivity slopes are very low (Figure 9.6 and Table 9.1). For the case with total nitrogen input as a single predictor, the median slope turned to be negative, though the value is only -0.0004. As we mentioned earlier that legume nitrogen fixation data were not available for the analysis, which may deteriorate the analysis. Under such circumstances, the scientific interpretation of the sensitivity slopes should be cautious. With the median slope, The NSE of regression prediction using total nitrogen input is minus -0.29, which means that the mean squared error of the regression prediction is 0.29 times larger than the standard deviation of the AGCHEM simulation. For the prediction using the median slopes of mutli-variate regression, the NSE is 0.45, i.e., the mean squared error of the regression prediction is 0.45 time smaller than the standard deviation of the AGCEHM simulation. Given that the multi-variate regression provided a much better prediction than that using a single predictor of total nitrogen input, multi-variate regression is recommended for the PQUAL specification.

For phosphorus, there is no input from atmospheric deposition and legume fixation. Uptake rate was not recorded in the watershed model neither. The regression analyses were conducted with manure and fertilizer data only. As in the case of nitrogen, only a few land segments have manure application (Figure 9.8). The majority of land segments have only fertilizer application. There is no particular distribution pattern in the sensitivity slopes for total phosphorus export (Figure 9.8) and the median slopes provided relatively good prediction of the AGCHEM simulation, with an NSE of 0.60 for the prediction using the total phosphorus input as a single predictor and 0.76 for the prediction using multi-variate regression (Figure 9.9 and Table 9.1). As the later provided better prediction, multi-variate regression is recommended for total phosphorus export prediction on alfalfa. Similar results were obtained for phosphate export (Figures 9.10 and 9.11 and Table 9.1). The NSE is 0.61 for the prediction using total phosphorus input as a single predictor and 0.74 using multiple types of input. The sensitivity slopes for organic phosphorus export are lower by about two orders of magnitude than that for total phosphorus and phosphate (Figures 9.12 and 9.13 and Table 9.1). The NSE is 0.16 for prediction using total phosphorus input as a single predictor and 0.33 using multi-variate prediction. These values are relatively lower than that for total phosphorus and phosphate export predictions, but remain within a reasonable range. Given the low contribution of organic phosphorus export to the total export, the bias caused by the lower predictability of organic phosphorus on alfalfa is limited. Organic phosphorus export contribute only about 3% to the total phosphorus export from alfalfa land use (Table 9.1)

As final recommendation for alfalfa land use, multi-variate regression using the median slopes is recommended for all nutrient constituents (Table 9.1)

Table 9.1. Summary of regression slopes and Nash-Sutcliffe Efficiency (NSE) coefficients of regression prediction for alfalfa (alfa). Input: Total nitrogen (or phosphorus) input; TIP: Total Input Prediction; MVP: Multi-variate prediction; STD: Standard deviation; Atm. Dep.: Atmospheric deposition; Legume: Legume nitrogen fixation; N: Nitrogen; P: Phosphorous. Red values are the final recommendation.

Constituents	Output/ Input	NSE of TIP	NSE of MVP	Statistics of slope	Total	Atm. Dep.	Manure	Fertilizer	Legume	Uptake
Total N	0.73	0.43	0.81	Mean	-0.04	0.25	0.11			
				Median	0.03	0.22	0.08			
				STD	0.47	0.36	0.08			
DIN	0.62	0.47	0.78	Mean	-0.03	0.25	0.09			
				Median	0.03	0.22	0.09			
				STD	0.45	0.37	0.08			
Organic N	0.11	-0.29	0.45	Mean	-0.007	0.002	0.015			
				Median	-0.002	0.0004	0.005			
				STD	0.012	0.03	0.015			
Total P	0.09	0.60	0.76	Mean	0.13		0.15	0.007		
				Median	0.10		0.15	0.09		
				STD	0.26		0.08	2.0		
PO4	0.09	0.61	0.74	Mean	0.12		0.14	0.01		
				Median	0.10		0.14	0.1		
				STD	0.26		0.08	2.0		
Organic P	0.003	0.16	0.33	Mean	0.003		0.007	-0.001		
				Median	0.001		0.002	-0.000		
				STD	0.02		0.008	0.05		

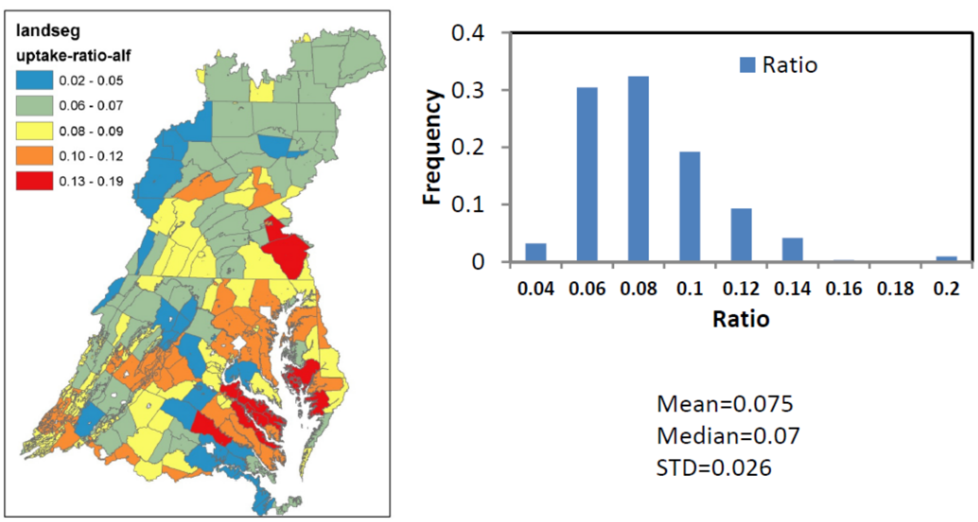

Figure 9.1. Spatial distribution of the ratio between the watershed model-predicted nitrogen uptake and scenario-builder-provided maximum uptake (left panel) and frequency distribution of the uptake ratio (right panel) on alfalfa (alf).

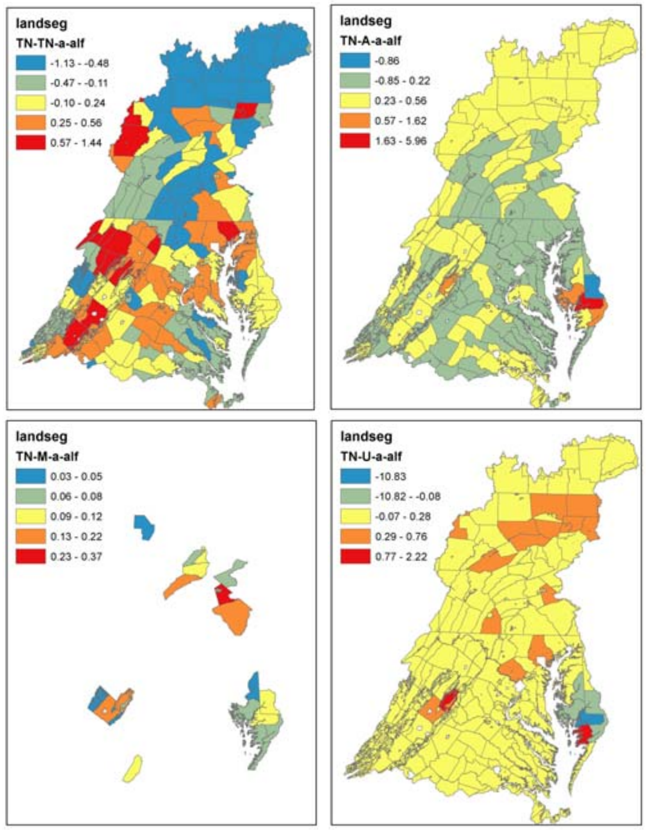

Figure 9. 2. Sensitivity slopes for total nitrogen output at edge of field on alfalfa (alf). Upper panels are total nitrogen input (TN) and atmospheric deposition (A) and lower panels are manure (M) and uptake (U).

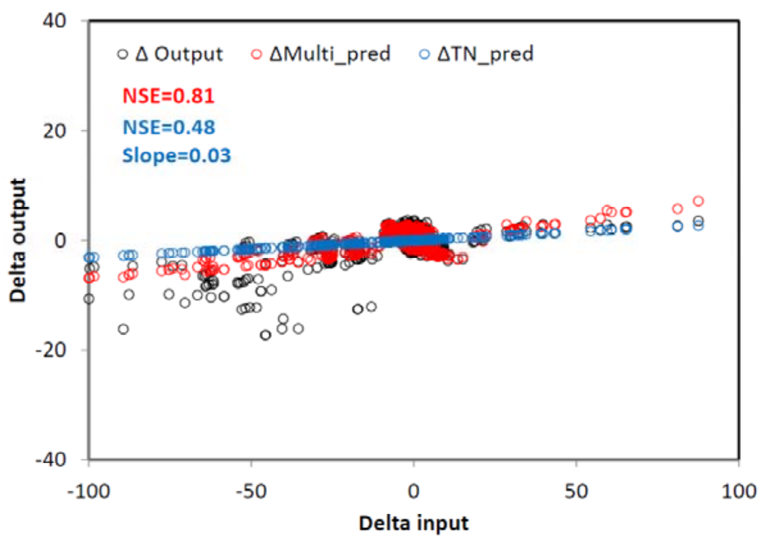

Figure 9. 3. Robustness of TN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on alfalfa (alf). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

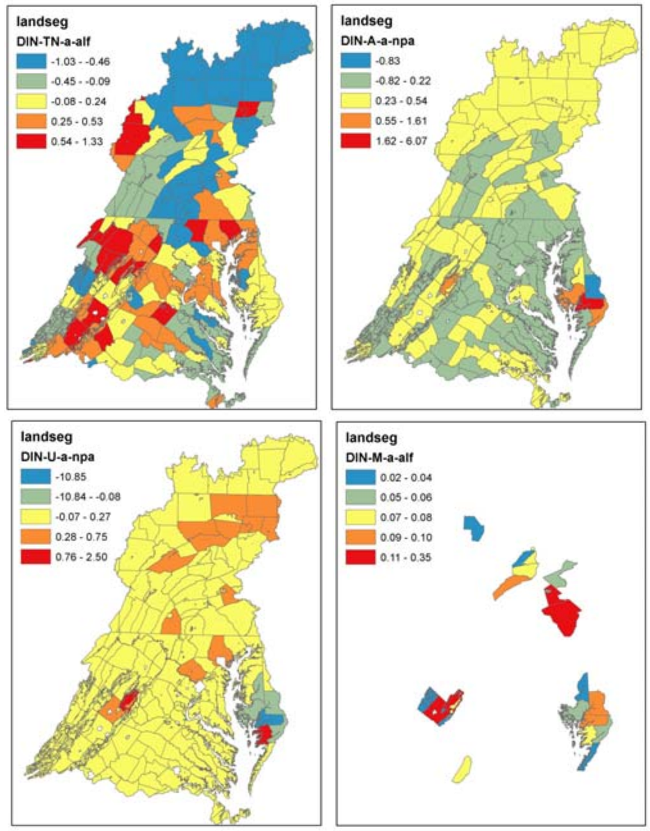

Figure 9. 4. Sensitivity slopes for DIN on alfalfa (alf). Upper panels are total nitrogen input (TN) and atmospheric deposition (A) and lower panels are uptake (U) and manure (M).

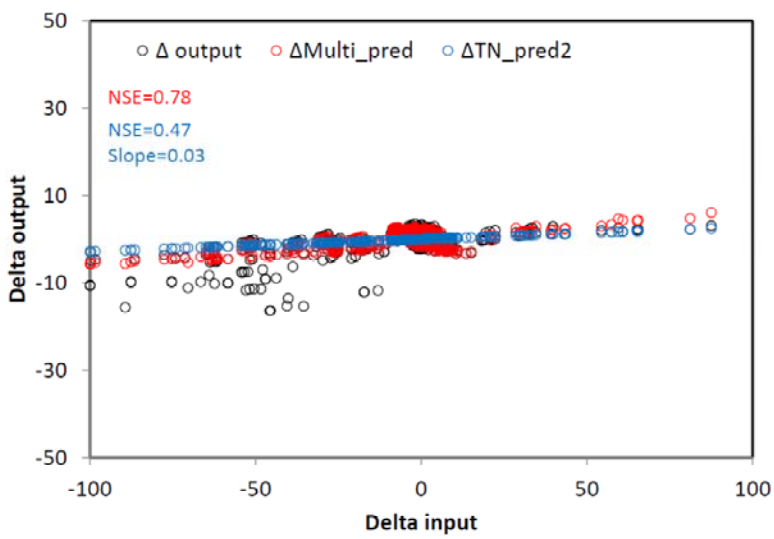

Figure 9. 5. Robustness of DIN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on alfalfa (alf). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned of outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

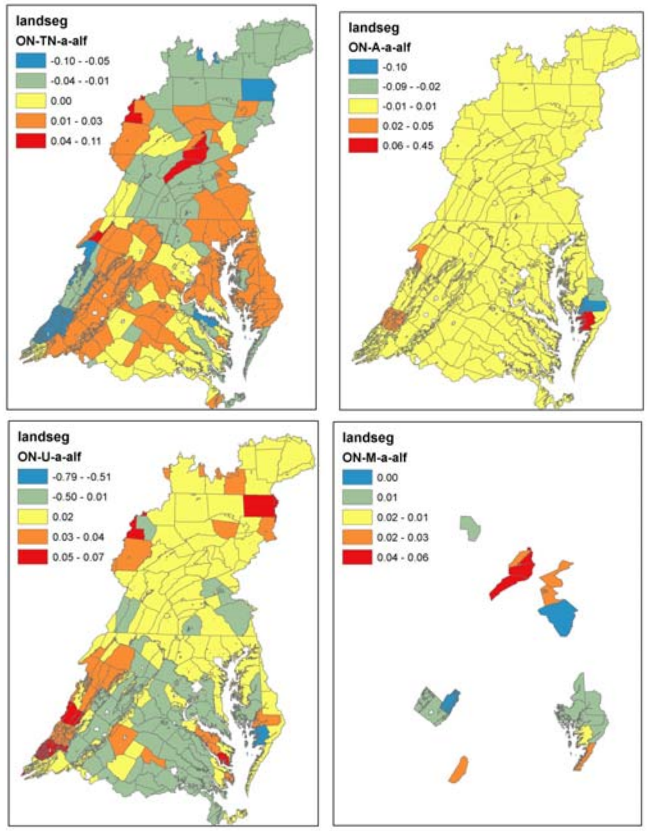

Figure 9. 6. Sensitivity slopes for organic nitrogen (ON) on alfalfa (alf). Upper panels are total nitrogen input (TN) and atmospheric deposition (A) and lower panels are uptake (U) and manure (M) .

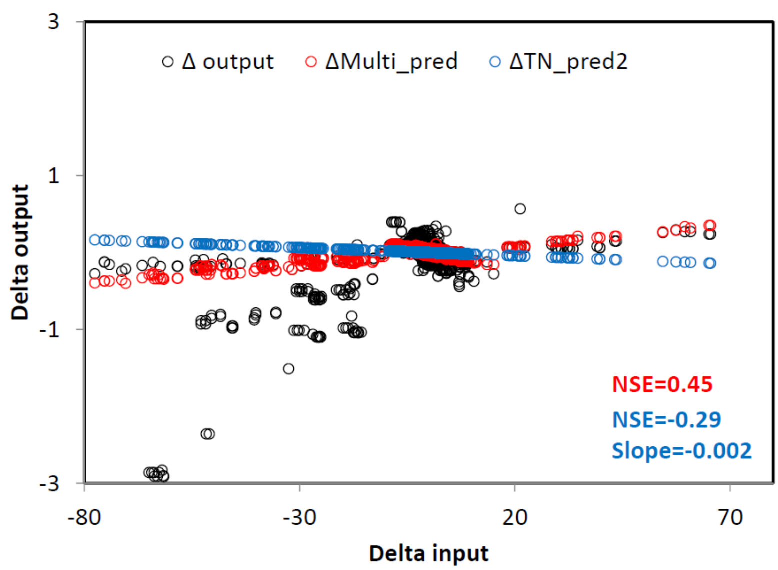

Figure 9. 7. Robustness of organic N regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on alfalfa (alf). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

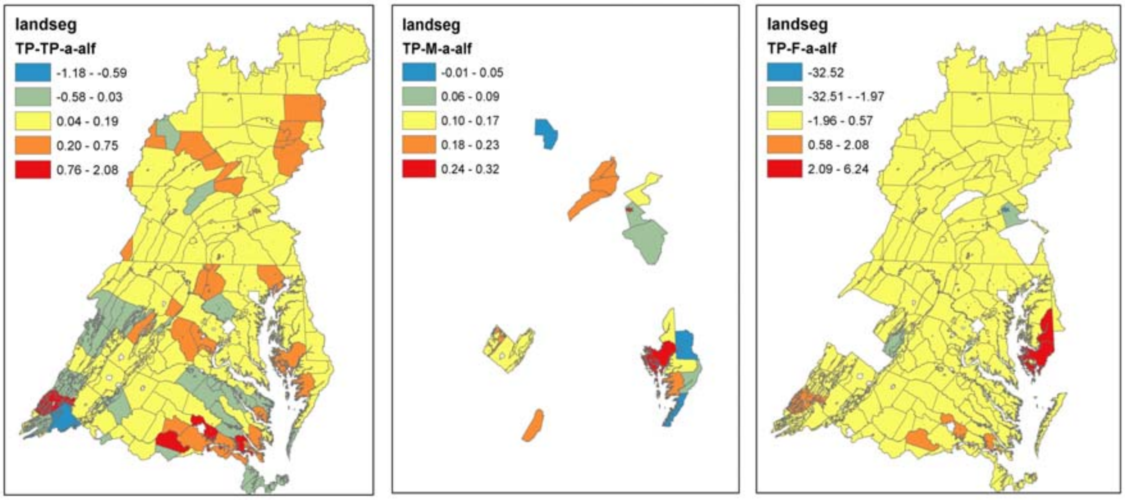

Figure 9. 8. Sensitivity slopes for total phosphorus (TP) on alfalfa (alf). Left panel is total phosphorus input (TP), middle panel is manure (M), and right panel is fertilizer (F).

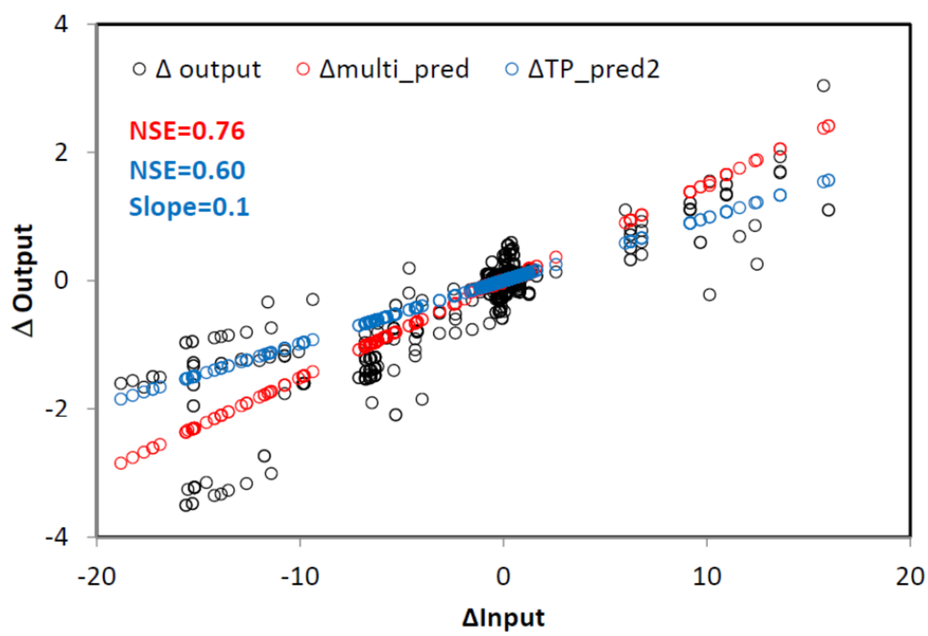

Figure 9. 9. Robustness of total phosphorus (TP) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on alfala (alf). Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

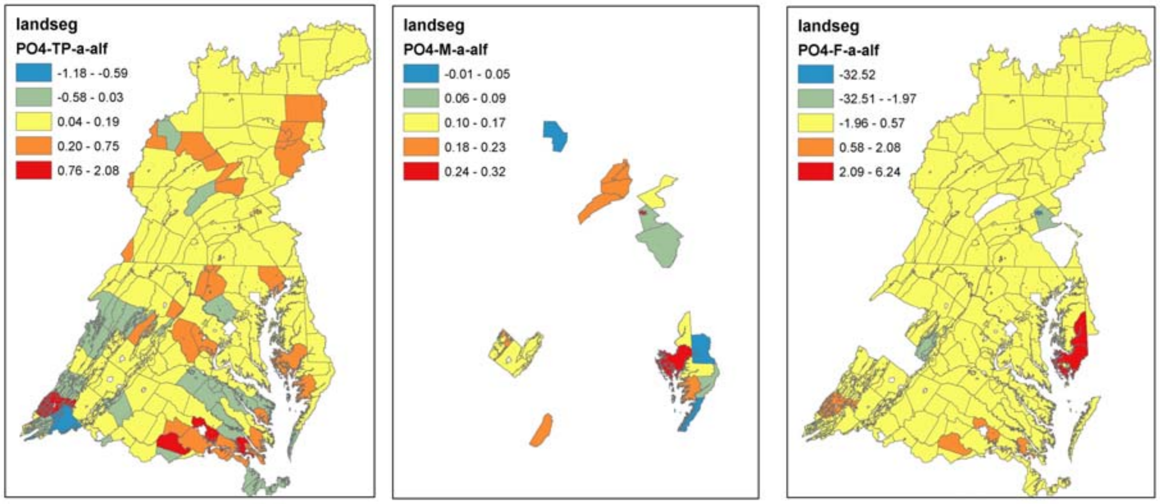

Figure 9. 10. Sensitivity slopes for total phosphate (PO4) on alfalfa (alf). Left panel is total phosphorus input (TP), middle panel is manure (M), and right panel is fertilizer (F).

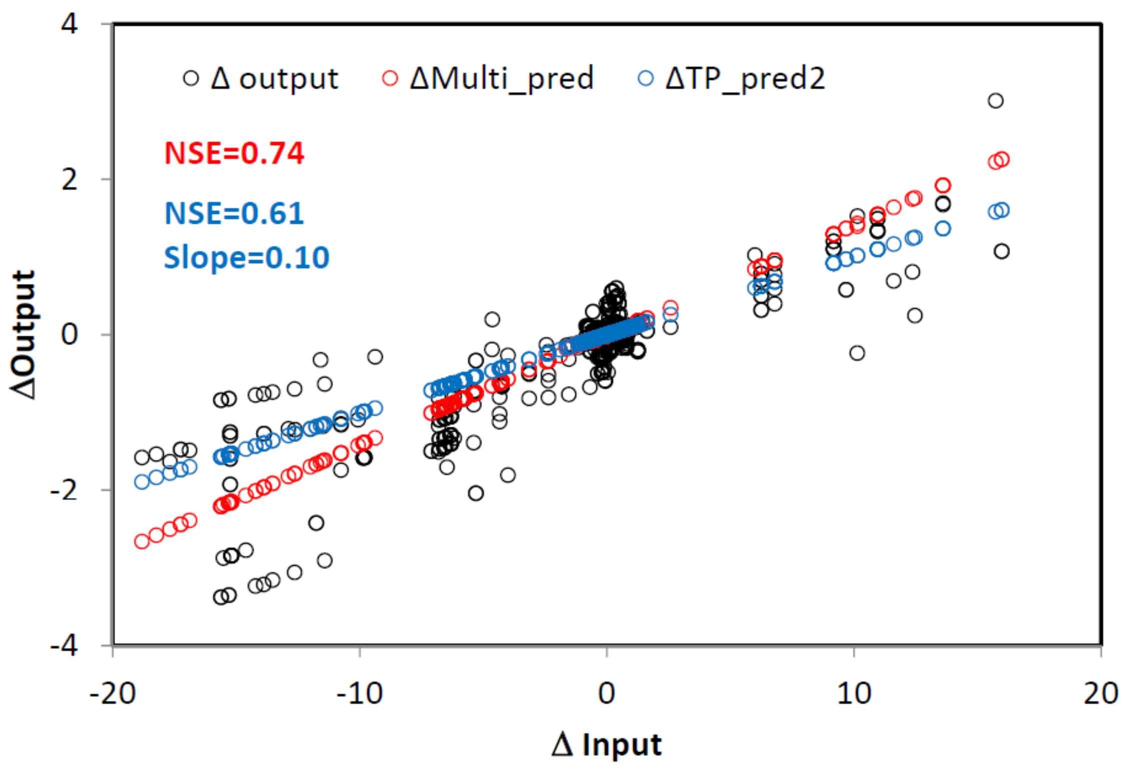

Figure 9. 11. Robustness of total phosphate (PO4) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on alfalfa (alf). Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

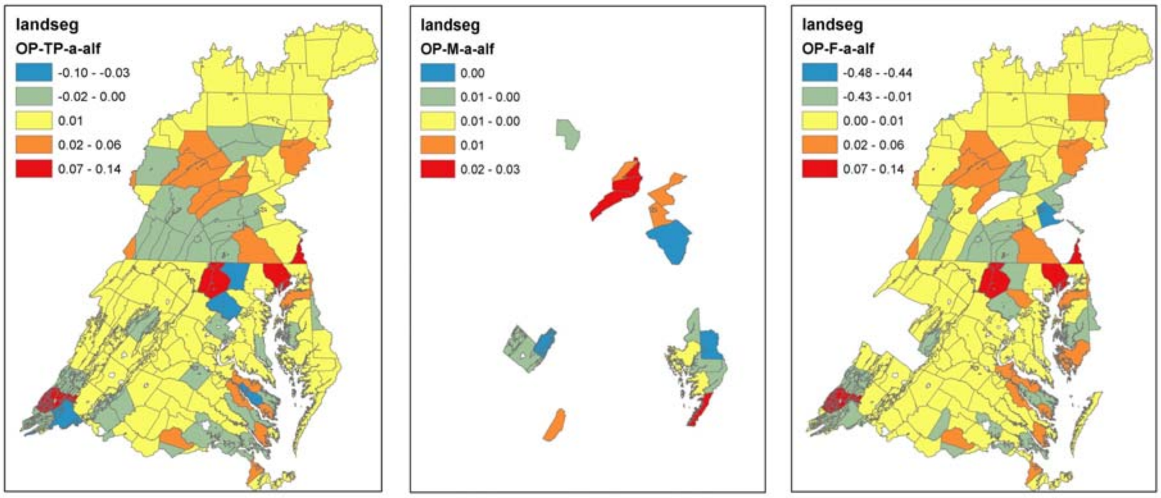

Figure 9. 12. Sensitivity slopes for organic phosphorus (OP) on alfalfa (alf). Left panel is total phosphorus input (TP), middle panel is manure (M), and right panel is fertilizer (F) slopes.

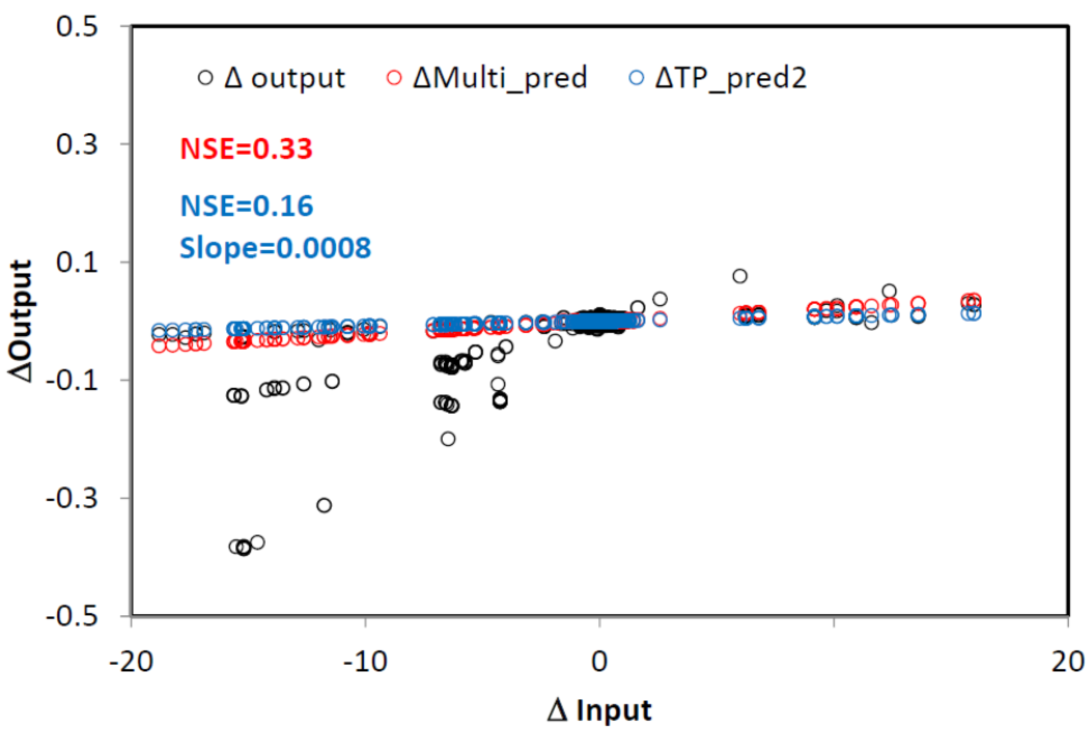

Figure 9. 13. Robustness of organic phosphorus (OP) regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on alfalfa (alf). Delta input is the demeaned total phosphorus input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

10. Pasture

On pasture land use of certain land segments, nutrient export did not respond to changes in nutrient loading (Figure 10.1), which can potentially deteriorate the regression function. In order to obtain more reliable functions, these land segments (18 in total) were removed from the data set prior to the analysis. These segments can be located on Figure 10.2, i.e. the blank spots. There are no particular regions where these segments are located. They are distributed in the Appalachian Mountain and piedmont region in the middle and lower Susquehanna drainage areas, but also on the coastal plains on the eastern shore as well as on the western shore. After the removal of these segments, reasonable response of nutrient output to inputs was obtained, based on which the following regression analyses were conducted.

The sensitivity slopes for total nitrogen export prediction are plotted in Figure 10.2. As most cases, there is no predictable pattern that can be used for the PQUAL specification. The slope between total nitrogen output and atmospheric deposition appears to be a little bit higher at the high latitude in the upper Susquehanna drainage basin than at lower latitude, but this does not constitute a significant function. Regression analysis resulted in an R^2 as low as 0.02. As a result, the median slopes represent a plausible approach. Using these median sensitivity slopes, reasonable prediction of the AGCHEM outcomes was obtained (Figure 10.3). The NSE of total nitrogen input prediction is 0.38 and that using multiple inputs is 0.65 (Figure 10.3 and Table 10.1). In this case, the multi-variate prediction is significantly better than using a single predictor of total nitrogen input and this is recommended for the PQAUL specification. The median slopes is the highest with atmospheric deposition (0.15), followed by fertilizer (0.10) and manure (0.06) on pasture land use.

Similar results were obtained for DIN export (Figure 10.4). The sensitivity slope with atmospheric deposition appears to be slight higher at high latitudes, whereas that with manure is lower, but this does not represent a reasonable specification, particularly in the context of multi-variate prediction that the function is conditioned by the ensemble parameters. The regression prediction of DIN export using the median slopes is illustrated in Figure 10.5. Although the NSE is relatively lower for DIN prediction on pasture as compared with other land uses, the prediction using multiple inputs resulted in a much higher NSE (0.05) than using a single predictor of total nitrogen input (-0.9) (Figure 10.6 and Tale 10.1). The sensitivity slopes for organic nitrogen export and NSEs of the regression prediction using the median slopes are presented in Figures 10.6 and 10.7. High NSEs were obtained using both single predictor of total nitrogen input and multi-variate regression. To conform to the prediction of total nitrogen and DIN export on the same land use, multi-variate function can be used as well. As final recommendation for PQUAL specification on pasture land use, multi-variate function using the median slopes is selected.

Table 10. 1. Summary of regression slopes and Nash-Sutcliffe Efficiency (NSE) coefficients of regression prediction for pasture land use (pas). Input: Total nitrogen (or phosphorus) input; TIP: Total Input Prediction; MVP: Multi-variate prediction; STD: Standard deviation; Atm. Dep.: Atmospheric deposition; Legume: Legume nitrogen fixation; N: Nitrogen. Red values are the final recommendation.

Constituents	Output/ Input	NSE of TIP	NSE of MVP	Statistics of slope	Total	Atm. Dep.	Manure	Fertilizer	Legume	Uptake
Total N	0.07	0.38	0.67	Mean	0.065	0.31	0.06	0.12		
				Median	0.06	0.15	0.06	0.10		
				STD	0.05	1.8	0.05	0.37		
DIN	0.05	-0.9	0.05	Mean	0.05	0.25	0.04	0.08		
				Median	0.05	0.15	0.04	0.09		
				STD	0.05	0.89	0.03	0.19		
Organic N	0.02	0.84	0.84	Mean	0.014	0.13	0.014	0.04		
				Median	0.013	0.005	0.013	0.01		
				STD	0.011	1.9	0.011	0.28		

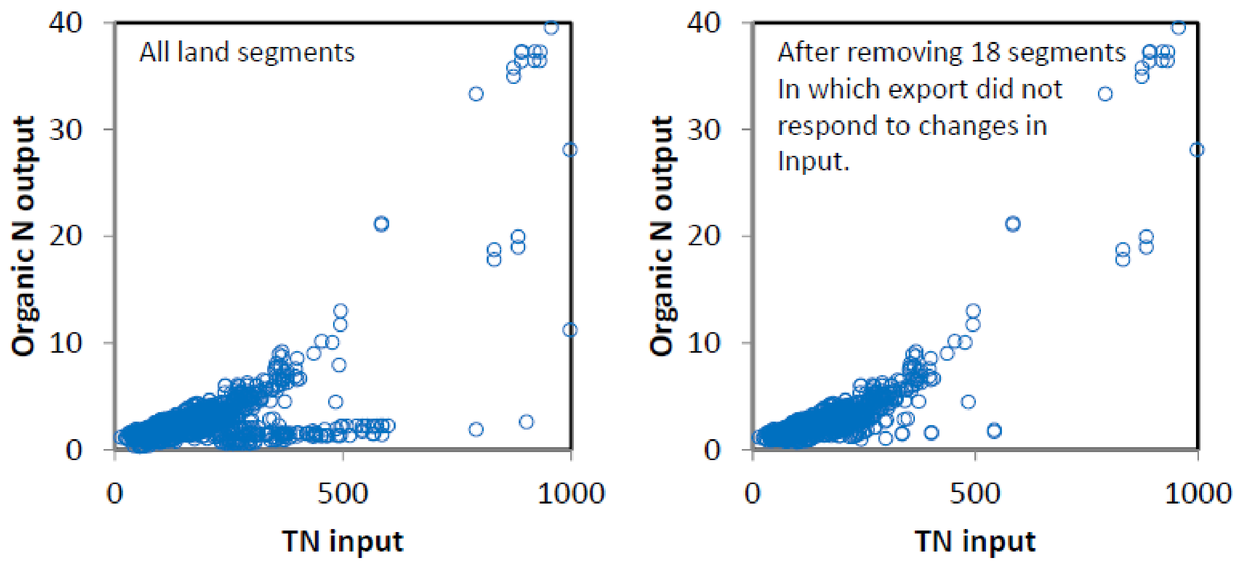

Figure 10.1. Response of organic nitrogen export to total nitrogen input on pasture land uses. Since nitrogen export did not respond to changes in input on certain land segments, these segments were removed before the sensitivity analysis to improve the reliability of the regression functions.

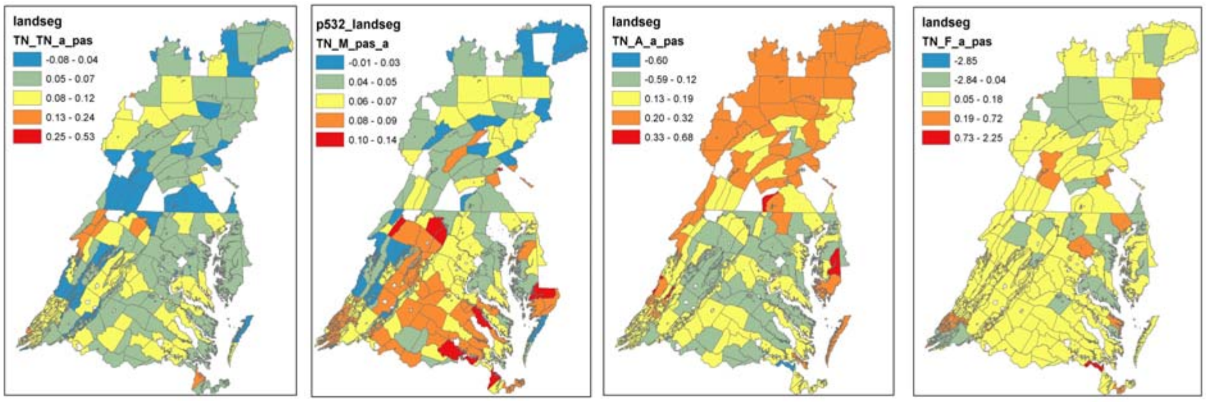

Figure 10. 2. Sensitivity slopes for total nitrogen output on pasture (HSPF code: pas). From left to right are total nitrogen input (TN_TN), manure (TN_M), atmospheric deposition (TN_A) and fertilizer (TN_F).

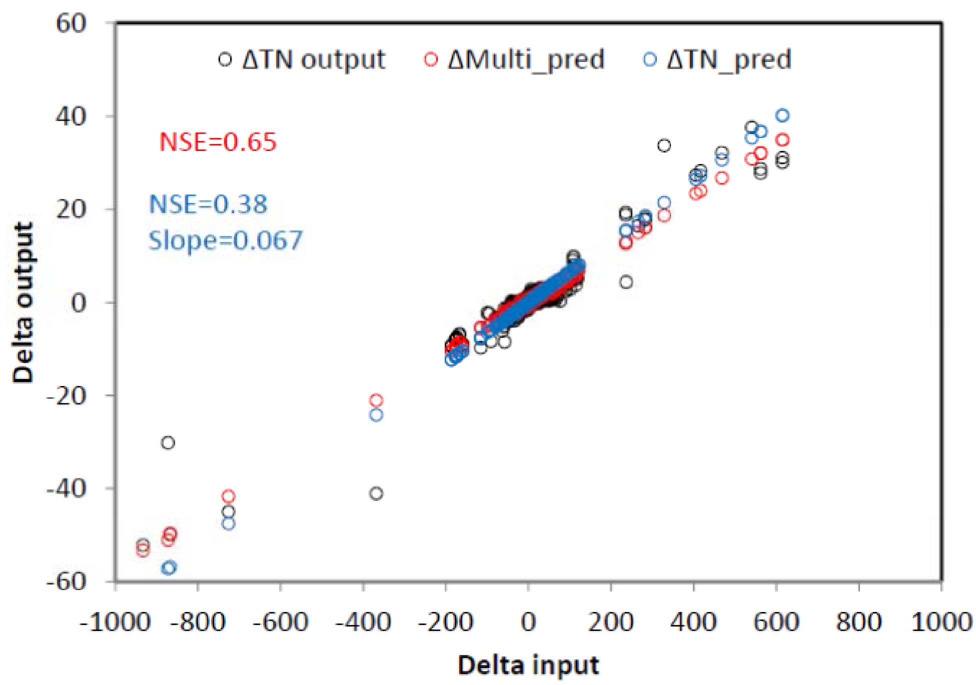

Figure 10. 3. Robustness of TN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on pasture (pas). Delta input on the abscissa is the demeaned total nitrogen input and delta outputs on the ordinate are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots) on the ordinate.

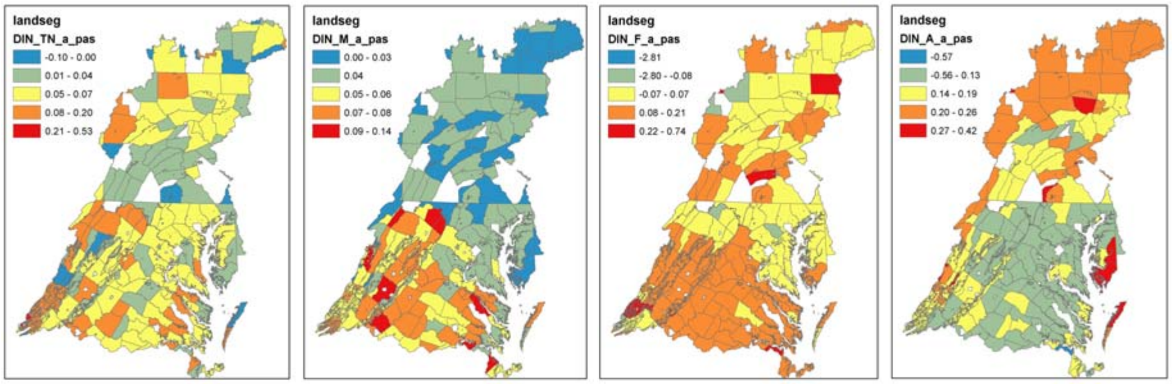

Figure 10. 4. Sensitivity slopes for DIN output on pasture land use (pas). From left to right are total nitrogen input (DIN_TN), manure (DIN_M), fertilizer (DIN_F) and atmospheric deposition (DIN_A).

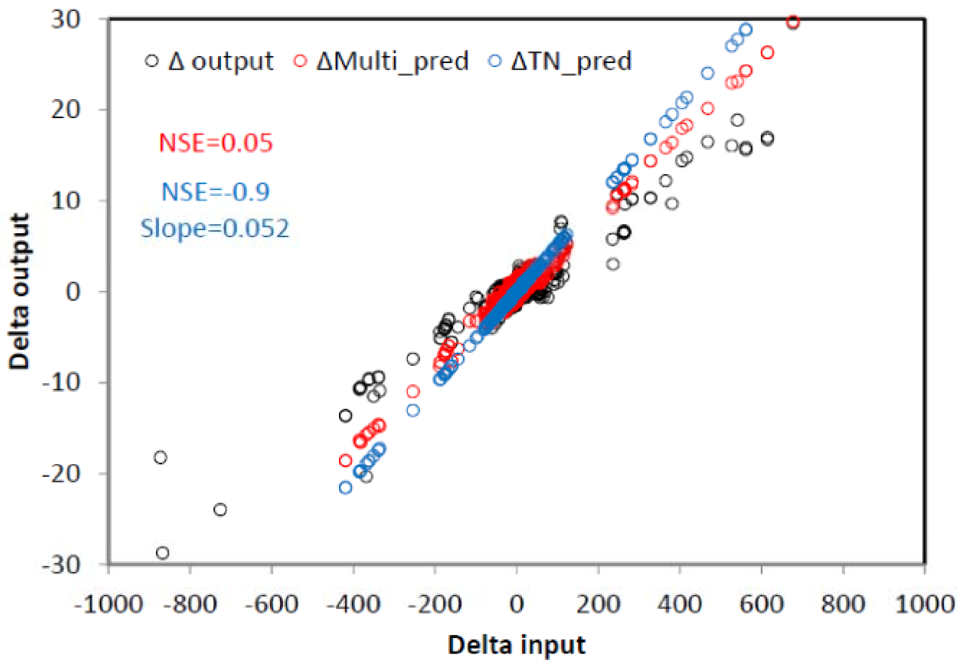

Figure 10. 5. Robustness of DIN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on pasture (pas). Delta input on the abscissa is the demeaned total nitrogen input and delta outputs on the ordinate are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

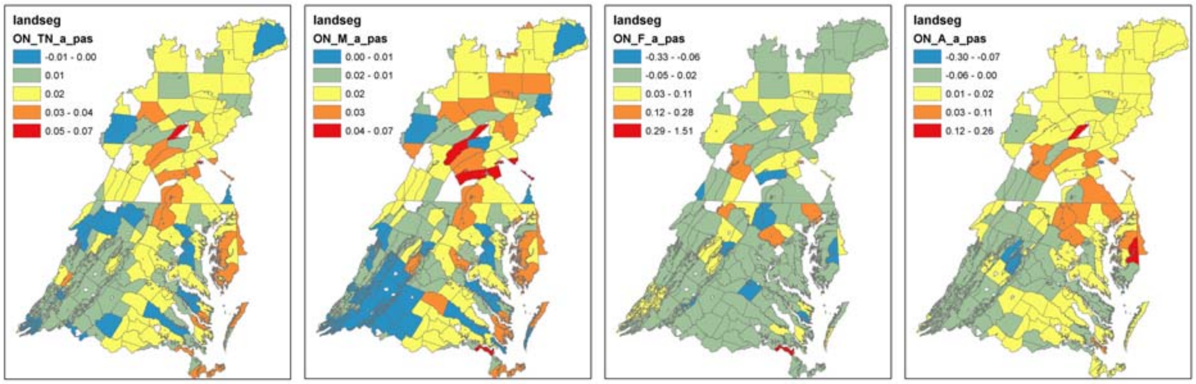

Figure 10. 6. Sensitivity slopes for organic nitrogen (ON) on pasture (pas). From left to right are total nitrogen input (ON_TN), manure (ON_M), fertilizer (ON_F) and atmospheric deposition (ON_A).

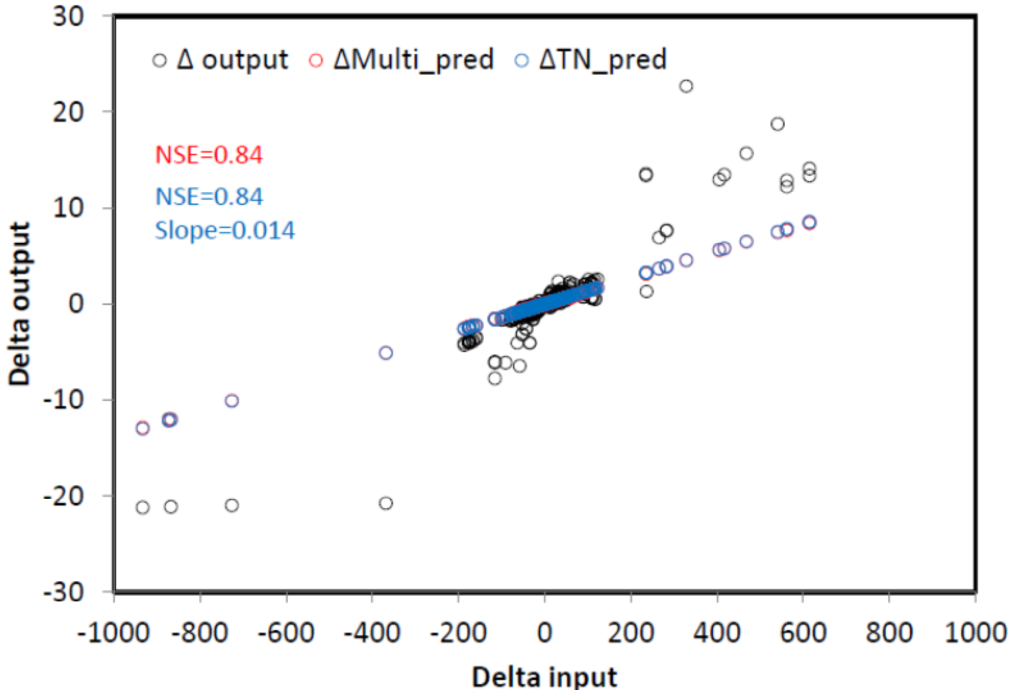

Figure 10. 7. Robustness of organic N regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on pasture (pas). Delta input on the abscissa is the demeaned total nitrogen input and delta outputs on the ordinate are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

11. Non-regulated pervious development (npd)

No maximum uptake rate was estaimted on non-regulated pervious development (npd) so that uptake was not included in the sensitivity analysis on this type of land use. The sensitivity slopes resulted from regression analysis are presented in Figure 9.1 for the prediction of total nitrogen export. The sensitivity slopes with total nitrogen input and fertilizer show lower values in the Potomac, York and James rivers drainage areas and higher values in the Susquehanna drainage basin, but the variations did not typical follow the latitude as in the case of forest land use. Regression analysis revealed a low correlation between latitude and the sensitivity slopes, with R^2 of 0.20. Moreover, the coefficient of variation of sensitivity slopes is only 0.29 for total nitrogen input prediction and 0.33 for atmospheric deposition. Under these circumstances, addition of a function between the sensitivity slopes and latitude does not provide significant improvement in the predictability of the AGCHEM output, as such, the median slopes appears to be a reasonable choice for the PQAUL specification for total nitrogen export prediction. Note that in the multi-variate analysis, the sensitivity slope with fertilizer is less than half of that with atmospheric deposition (Table 9.1). The median sensitivity slope with atmospheric deposition is 0.15 and that with fertilizer is only 0.07. The NSE is 0.86 using total nitrogen input as a single predictor and 0.92 for multiple types of input including both atmospheric deposition and fertilizer (Figure 9.2). The difference in NSE between the two methods is less than 10% so that total nitrogen input can be used as the predictor in the PQUAL specification. There is a discontinuation in the total nitrogen input on the abscissa of Figure 9.2. In fact, only two values of fertilizer were use among the difference scenarios: the value used in the calibration run and the value used in E3 scenario. Except the E3 scenario, all other scenarios use the calibration value for fertilizer application on non-regulated pervious development land use.

Results of high similarity were obtained for DIN export to that of total nitrogen export (Figures 9.3 and 9.4) so that all description above applies. For organic nitrogen export, the sensitivity slopes are lower approximately by one order of magnitude than that for total nitrogen and DIN exports (Figures 9.5 and 9.6). The spatial distribution patterns of the sensitivity slopes for organic nitrogen export is somehow opposite to that observed in the slopes for total nitrogen and DIN exports (Figure 9.5). Higher values are mostly observed in the northern part of the watershed and lower values in the southern part of the watershed domain. Similarly, variability of the sensitivity slopes is quite low, 0.23 and 0.27 respectively with total nitrogen input and atmospheric deposition. In the case of organic nitrogen export, the slope with fertilizer is higher than that with atmospheric deposition, opposite to that for DIN export where the slope with atmospheric deposition is higher. Similar NSE was obtained between total nitrogen input and multiple types of inputs as independent predicting variables.

As final recommendation, total nitrogen input can be used as independent predictor instead of splitting into multiple types of inputs for nitrogen export prediction on non-regulated pervious development land use. The median slopes are recommended: 0.30 for total nitrogen export, 0.32 for DIN export and 0.005 for organic nitrogen export.

Table 11. 1. Summary of regression slopes and Nash-Sutcliffe Efficiency (NSE) coefficients of regression prediction for non-regulated pervious development (npd). Input: Total nitrogen (or phosphorus) input; TIP: Total Input Prediction; MVP: Multi-variate prediction; STD: Standard deviation; Atm. Dep.: Atmospheric deposition; Legume: Legume nitrogen fixation; N: Nitrogen. Red values are the final recommendation.

Constituents	Output/ Input	NSE of TIP	NSE of MVP	Statistics of slope	Total	Atm. Dep.	Manure	Fertilizer	Legume	Uptake
Total N	0.22	0.86	0.92	Mean	0.12	0.16		0.07		
				Median	0.12	0.15		0.07		
				STD	0.035	0.05		0.02		
DIN	0.07	0.84	0.91	Mean	0.11	0.15		0.06		
				Median	0.10	0.14		0.06		
				STD	0.03	0.04		0.02		
Organic N	0.15	0.91	0.92	Mean	0.013	0.011		0.015		
				Median	0.012	0.011		0.015		
				STD	0.003	0.003		0.004		

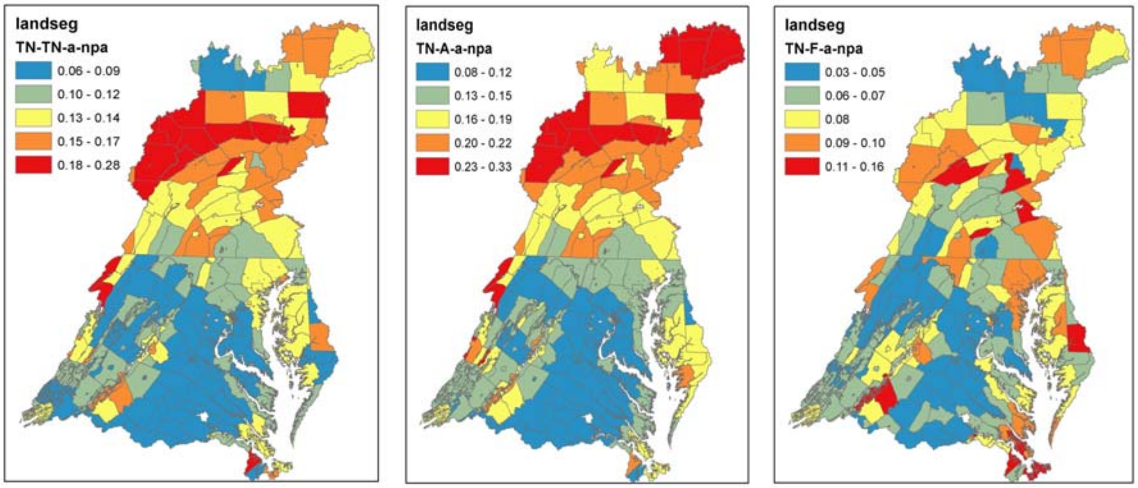

Figure 11. 1. Sensitivity slopes for total nitrogen output on non-regulated pervious development land use (HSPF code: npd). Panels from left to right are total nitrogen input (TN), atmospheric deposition (A) and fertilizer (F).

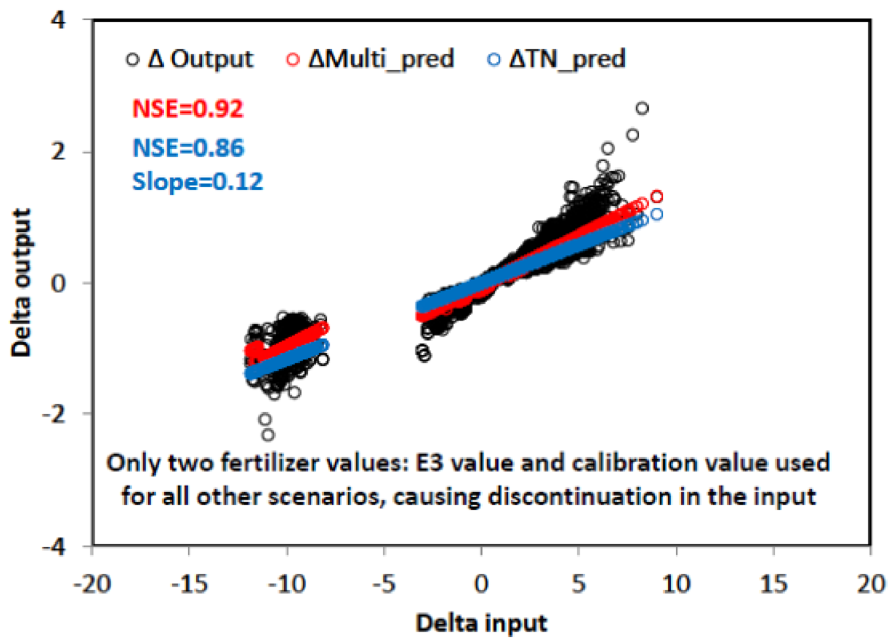

Figure 11. 2. Robustness of TN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on non-regulated pervious development land use (npd). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

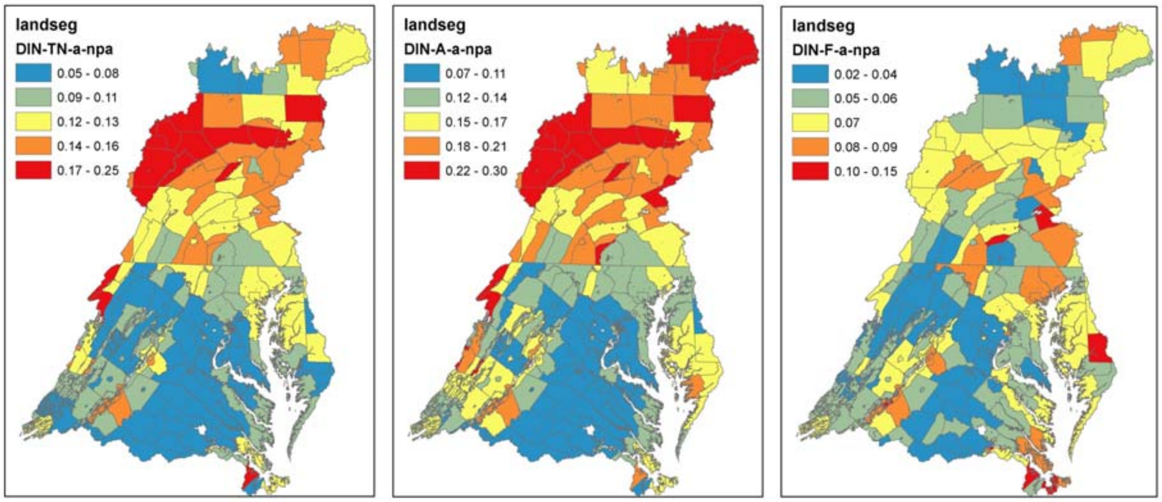

Figure 11. 3. Sensitivity slopes for DIN export on non-regulated pervious development (npd). Panels from left to right are total nitrogen input ITN), atmospheric deposition (A) and fertilizer (F).

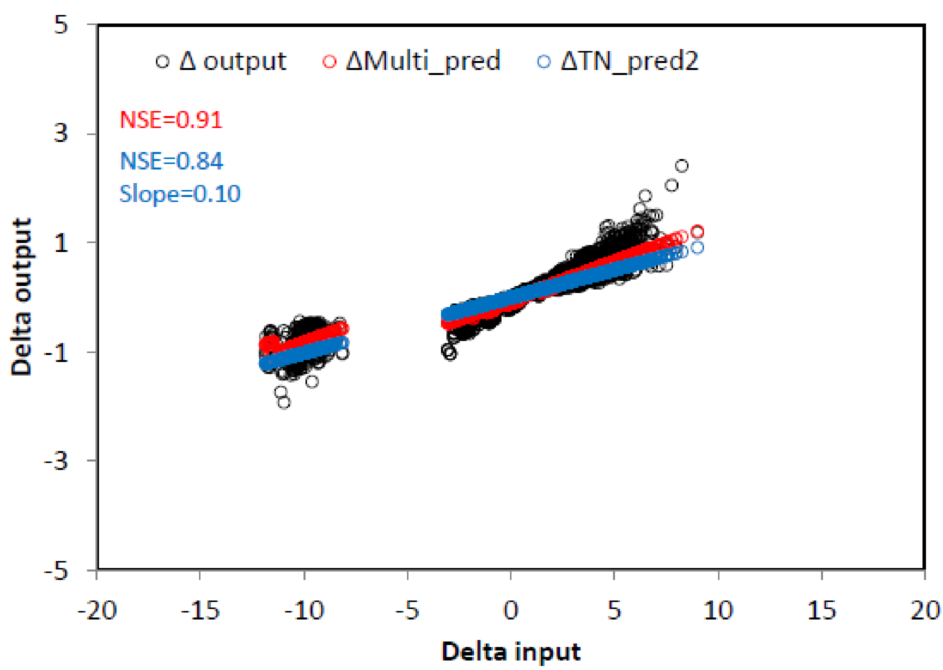

Figure 11. 4. Robustness of DIN regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on non-regulated pervious development land use (npd). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).

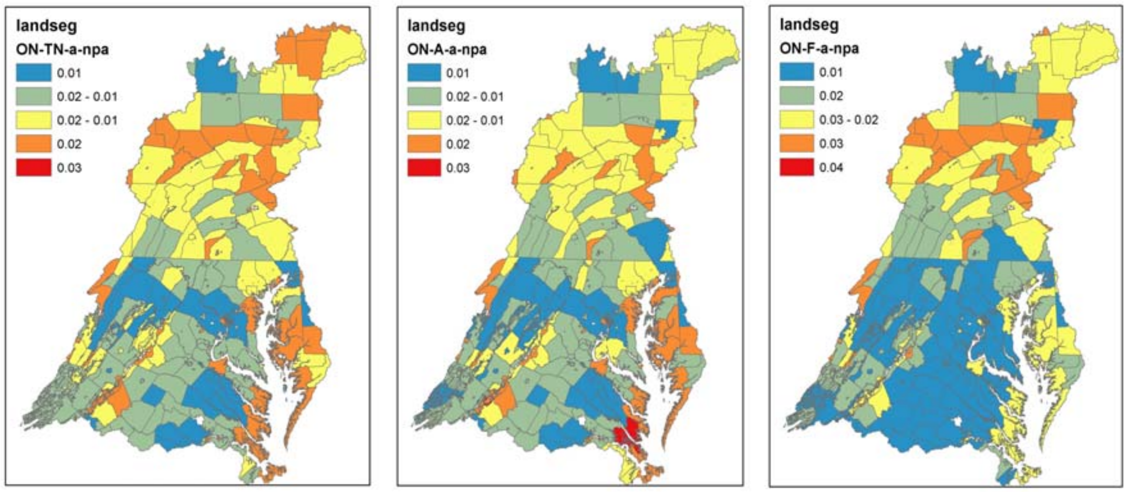

Figure 11. 5. Sensitivity slopes for organic nitrogen (ON) export on non-regulated pervious development land use (npd). Panels from left to right are total nitrogen input (TN), atmospheric deposition (A) and fertilizer (F),

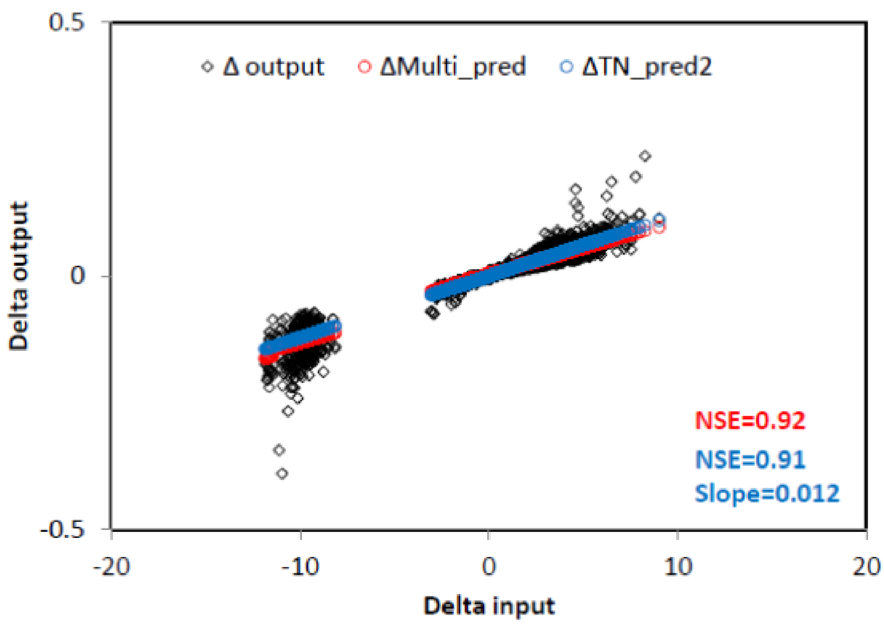

Figure 11. 6. Robustness of organic N regression prediction measured by the Nash-Sutcliffe Efficiency (NSE) coefficient between model output and regression prediction on non-regulated pervious development land use (npd). Delta input is the demeaned total nitrogen input and delta outputs are the demeaned outputs from AGCHEM (black dots) and regression prediction using both total nitrogen input (blue dots) and multi-variate regression analysis (red dots).