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Scale Effects of STATSGO VS. SSURGO Soil Databases on Water Quality Predictions

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ABSTRACT

Soil information is one of the crucial inputs needed to assess the impacts of existing and alternative agricultural management practices on water quality. Therefore, it is important to understand the effects of spatial scale at which soil database is developed. In the United States, STATSGO and SSURGO are most commonly available soil databases. This study attempts to quantify the effect of scale by employing STATSGO (1:250,000) and SSURGO (1:24,000) soil databases by predicting and comparing flow, sediment, nitrate and phosphorus losses for High Island Creek, a minor agricultural watershed located in south-central Minnesota. For this purpose, a water quality model was calibrated for flow, sediment, nitrate and phosphorus losses for two years (2001-2002) using STATSGO and SSURGO soil databases. Further, the calibrated model was used to evaluate alternative tillage and fertilizer management practices such as adoption of rate of conservation tillage, rate, timing and method of N– and P-fertilizer applications. Statistical comparison of calibration results with observed data indicated excellent agreement for both (STATSGO with r^2 of 0.95, 0.97, 0.77 and 0.92 and SSURGO with r^2 of 0.90, 0.97, 0.82 and 0.99 for flow, sediment, nitrate and phosphorus losses, respectively) soil databases. However, evaluation of alternative management practices indicated that STATSGO based predicted annual nitrate losses are consistently higher than that for SSURGO data and vice-versa for predicted phosphorus losses. This brings up an important issue in developing TMDLs for impaired watersheds where conflicting interests of stakeholders may opt for soil database that support their interests.

KEYWORDS. ADAPT, TMDLs, scale

INTRODUCTION

Nonpoint source pollution from crop land is a widespread problem in Europe and North America. Concerns typically include sediment, nitrogen and phosphorus, as well as herbicides and pathogen loadings. Researchers and watershed managers are monitoring and/or modeling the transport and fate of agricultural pollutants at different spatial scales. Their aim is to describe the processes and pathways that control the concentration and load of nutrients leaving the source in response to various factors that might include climate, soil, or landscape properties, and management alternatives. In contrast, agency leaders and policy makers are typically concerned about decade or century long regional trends in water quality at the scale of watersheds, basins, counties, provinces, states, countries, and continents. They are typically interested in monitoring and/or modeling regional trends in water quality, identifying the level of impairment, identifying the sources of pollution, and developing goals and strategies for restoring good water quality. Accordingly, model users are deriving input data at a spatial resolution intuitively suitable for intended use of the modeling outcomes. Soil information is one of the crucial inputs needed to assess impacts of existing and alternative agricultural management practices on water quality. So far, a little is known on the effect of spatial scale on water quality when soil input is derived at different spatial resolution. This study attempts to quantify the effect of scale on water quality by

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employing two spatially different soil databases commonly available in the United States.

The Natural Resources Conservation Agency (NRCS) has developed and distributes two digital soil databases, namely, STATSGO (STATe Soils GeOgraphic; 1:250,000 scale) and SSURGO (Soil SURvey GeOgraphic; (1:12,000 to 1:63,360), which can be used to derive soil input data needed for water quality simulation. The amount of time and resources needed to use them varies significantly based on which soil database is used. The smallest soil map unit represented in STATSGO is about 625.1 ha, whereas it is about 2 ha in the SSURGO database. The main objective of this study was to determine if there are significant differences between modeled water quality outcomes based on using SSURGO versus STATSGO soil input databases. This was achieved by (1) calibrating a spatial-process model that uses the ADAPT model, a field scale water table management model and GIS to predict flow, sediment, nitrogen and phosphorus losses on a 3,856 ha minor agricultural watershed in Sibley County, MN; and (2) applying the calibrated spatial-process model to determine the sensitivity of sediment, nitrate, and phosphorus losses to various agricultural management practices. Evaluated management practices include changes in adoption of conservation tillage, rate and timing of N- and P-fertilizers and method of animal manure applications, using SSURGO and STATSGO soil databases.

ADAPT MODEL

The ADAPT model is a daily time step field scale water table management model which was developed as an extension of the GLEAMS model (Leonard et al., 1987). GLEAMS algorithms were augmented with algorithms for subsurface drainage, subsurface irrigation, and deep seepage and related water quality processes (Desmond et al., 1996). Complete details of the model are presented by Chung et al. (1992), Ward et al. (1993), and Desmond et al. (1996). Gowda et al. (1999) developed and tested a spatial process model that uses the ADAPT model for predicting flow and nutrient discharges at a watershed scale, and successfully used this model in many water quality studies in Minnesota (Davis et al., 2000; Dalzell, 2000).

MATERIALS AND METHODS

Study Area and Water Quality Data: The study area comprises two minor watersheds in the High Island Creek watershed in southeastern Minnesota. Hereafter, the study watershed is referred to as the High Island Creek minor watershed. Since April 2001, the watershed has been monitored for flow, sediment, nitrogen and phosphorus losses as part of the Clear Water Partnership Program involving the Minnesota Pollution Control Agency and Soil and Water Conservation District of Sibley County. Topography of the watershed is relatively flat, and soils are poorly drained. The Clarion-Nicollet-Canisteo (Typic Hapludolls-Aquic Hapludolls-Typic Haplaquolls) soil association predominates with Webster (Typic Haplaquolls), Harps (Typic Calciaquolls), Okoboji (Cumulic Haplaquolls), and Klossner (Terric Medisaprists) soils occupying the closed depressions. About 70% of the land uses a corn (Zea Mays L.) and soybean (Glycine Max L.) crop rotation, and is tile drained. Discharges at the outlet were measured by a 1-stage measuring device which is connected to a Campbell Scientific Inc. (CSI) CR10 data logger. Sampling interval for water quality was based on the rate of change in water level, with more frequent water samples during storm events. In addition to automated collection, water quality samples were collected manually on a biweekly basis and after major rainfall events by dipping sterilized glass bottles into stream flow.

Model Input: Climatic data such as daily values of precipitation and mean temperature used in the water quality simulation were the daily averages of data recorded at four weather stations within the study watershed to account for spatial variability. Other climatic data such as average relative humidity, solar radiation and wind speed were obtained from a weather station located in Jordan, MN.

Soil properties such as the depth of each horizon, particle size distribution, organic matter content, vertical hydraulic conductivity, and soil water release curve for each of the SSURGO and STATSGO soil map units were derived from the Map Unit Use File (MUUF) soil database (Baumer et al., 1994). In the summer of 2001, a detailed land use survey was conducted in the High Island watershed to identify crop types at the field level. Aerial photos acquired by the USDA Farm Service Agency were used in conjunction with field survey to develop a land use map for the watershed. This information was stored in GIS format.

Site-specific information on planting and harvesting dates and tillage management practices for 2001 have been collected for each field within the High Island Creek watershed. Also, data were collected on timing, method of application, and type of fertilizer or manure through a landowners-operators survey within the watershed as well as from a detailed land owners-operators survey (as part of another watershed project) in the Huelskamp Creek watershed located on south-side of the study watershed. These data were linked to each field in the land use layer attributes. Land use attributes were linked to the tillage and nutrient management data associated with each field.

The spatial process model used in this study requires a set of modeling units known as Transformed Hydrologic Response Units (THRUs, Gowda et al., 1999) for the study watershed. This involves identifying unique hydrologic response units as a first step, by overlaying available hydrologically sensitive spatial data layers of the area of interest. In this study, unique HRUs were identified by overlaying soil, tillage, land use, and manure applied land layers using Arcview 3.0 GIS software (ESRI, 2000). The unique HRUs with similar watershed characteristics were grouped to form THRUs. Also, a 50-meter buffer (Gburek et al, 2000) on each side of the ditches within the watershed was formed to vary sediment delivery ratio based on proximity to nearby streams.

Model Calibration: The spatial process model was calibrated and validated using the water quality data measured at the outlet of the High Island Creek watershed from April to September in 2001 and from April to June in 2002. The calibration of the model for flow was done by adjusting initial depth of water table, soil water release curve, soil porosity, leaf area index, and depth and hydraulic conductivity of the impeding layer. Sediment delivery ratios of 0.10 and 0.05 were used for THRUs outside and inside of the buffer, respectively. Improvements in the nitrogen and phosphorus loss predictions were made by adjusting initial total nitrogen and phosphorus and nitrate and labile phosphorus levels in the soil horizons. Statistical measures such as mean and Root Mean Square Error (RMSE), coefficient of determination (r^2) and slope and intercept of the least square regression line between measured and predicted values, and index of agreement (d), were used to evaluate the match between measured and predicted flow and nitrate discharges for the calibration period.

Adoption of Conservation Tillage Practices: The effects of various levels of adoption of conservation tillage practices on water quality in study watershed were evaluated by changing the amount of row crop land under conservation tillage. Based on our field data and questionnaire surveys, adoption of conservation tillage (more than 30% of the topsoil covered with crop residue after planting) in the watershed was about 24.2%. About 61.5% of row crop land that adopted conventional tillage had a crop residue level of 0-15%, the remaining 14.3% had residue levels of 15-30%. Levels of adoption of conservation tillage used in the simulations include 0.0 (100% conventional tillage), 24.2% (existing), and 100% of the crop land in the watershed. Under the 100% conventional tillage scenario, two separate simulations were made by changing the crop residue levels on all row crop land to 0-15% and 15-30% to quantify the effect of commonly adopted crop residue levels on water quality in the watershed.

N– and P-Fertilizer Application Rate and Timing*:* Several simulations were made for the period from 2001-2002 to determine the effect of variation in the rate and timing of fertilizer application on nitrogen and phosphorus losses. Input parameters used in the simulations for evaluating various practices were the same as those used in the model calibration, unless otherwise mentioned. Five N and P application rates (by changing the existing rate by -20, -10, 0, +10, and +20) and in addition, two application timings (fall and spring for N-fertilizer only) were used for this purpose. The use of multiple application rates and timings was to demonstrate the sensitivity of nitrogen and phosphorus losses to variation in precipitation as the application rate and timing changed.

Scale Effects: The effects of using soil databases of different scales on model predictions were evaluated at two levels by: (1) comparing the statistical performance of the model for SSURGO (1:24,000) database against that for STATSGO (1:250,000) database; and (2) comparing the magnitude of predicted water quality loadings for above-mentioned alternative management practices using SSURGO against that for STATSGO database.

RESULTS AND DISCUSSIONS

GIS overlay analysis resulted in 224 and 29 THRUs for SSURGO and STATSGO soil databases, respectively. Although the corn-soybean or soybean-corn rotation was followed on about 70% of the crop land, a high number of THRUs with SSURGO database was the result of its higher spatial resolution. Soils in High Island Creek minor watershed were represented by only one soil map unit (MN046) with STATSGO and 15 soil map units with SSURGO database. Corn received a fall application of anhydrous ammonia at 163 or 170 kg/ha N with or without animal manure, respectively. About 18% of the crop land received animal manure, and of this 61.5, 14.2 and 24.2 percent received manure through broadcasting, incorporation or injection methods, respectively.

Model Calibration: In the calibration phase, attempts were made to minimize the RMSE and obtain r^2 and d values closest to a value of unity. Table 1 shows excellent agreement between model predictions and measured flow, sediment, nitrogen and phosphorus losses, with both SSURGO and STATSGO soil data, for the calibration period. Comparison of measured and calibrated values of mean monthly flow shows that the magnitude of the predicted monthly flow closely matched with the measured data. However, the model over predicted measured mean monthly flow (0.37 m^3/sec) by 14% with the STATSGO database. Statistical evaluation of measured and predicted flow gave an r^2 value of 0.95, with a slope and intercept of 0.91 and -0.01 m^3/sec, respectively with STATSGO soil data, whereas model predictions with SSURGO soil data gave an r^2 value of 0.90 with slope and intercept of 0.99 and 0.01 m^3/sec, respectively. The indices of agreement were close to value of 1 (Table 1) and RMSE were about 12 and 15% of the observed mean monthly flow for STATSGO and SSURGO data, respectively.

For both STATSGO and SSURGO data, the model predicted 97% of the variability in sediment losses observed at the outlet of the High Island Creek watershed. The predicted mean monthly sediment losses (48.7 tons for STATSGO and 47.4 tons for SSURGO) were closely matched with measured losses (50.6 tons). The model gave an RMSE equivalent to 19.9% of the measured mean monthly sediment losses using STATSGO data, which is 45% higher than that for SSURGO data.

Table 1. Model performance statistics for predicted monthly flow, sediment, nitrate and phosphorus discharges in High Island Creek watershed for calibration period.

Statistic		Flow (m^3/sec)	Sediment (ton)	Nitrogen (ton)	Phosphorus (ton)
Mean	Observed	0.37	50.59	12.00	0.40
	STATSGO	0.42	48.68	10.49	0.47
	SSURGO	0.37	47.39	10.95	0.35
RMSE[1]	STATSGO	0.12	19.92	8.69	0.21
	SSURGO	0.15	13.71	8.28	0.10
R^2	STATSGO	0.95	0.97	0.77	0.92
	SSURGO	0.90	0.97	0.82	0.99
Slope	STATSGO	0.91	0.84	1.34	0.94
	SSURGO	0.99	0.95	1.45	1.12
Intercept	STATSGO	-0.01	9.81	-2.04	-0.05
	SSURGO	0.01	5.36	-3.92	0.01
d[1]	STATSGO	0.99	0.99	0.89	0.98
	SSURGO	0.97	0.99	0.90	0.99

[1] RMSE - Root Mean Square Error, d - index of agreement.

Predicted mean monthly nitrate losses were in close agreement with the measured data. However, the model under predicted mean monthly nitrate (12 tons) by 12.6 and 8.8% for STATSGO and SSURGO data, respectively. The STATSGO based predictions accounted for about 77% of the variations in the measured nitrate loadings compared to 82% with SSURGO based predictions. The indices of agreement were similar for both databases. Overall, the model seems to predict nitrate losses reasonably well, irrespective of soil database used as input data.

Predicted mean monthly phosphorus losses for both soil databases were similar to that in the measured data. The predicted mean monthly phosphorus losses for STATSGO data over predicted the measured losses (0.40 ton) by 17.5%, whereas SSURGO based modeling under predicted by 12.5%. For phosphorus, the STATSGO based model predictions explained 92% of the variability in losses observed at the outlet of the High Island Creek watershed, compared with 99% for SSURGO based predictions. The model gave an RMSE equivalent to 21 and 10% of the measured mean monthly phosphorus losses for STATSGO and SSURGO data, respectively.

Adoption of Conservation Tillage Practices: Table 2 presents annual sediment and nutrient losses under existing versus various alternative conversation tillage adoption rates. It also compares SSURGO versus STATSGO based model predictions to quantify the effect of differences due to spatial scale. With SSURGO data, annual sediment losses delivered to the mouth of the watershed under existing tillage practices (24.2% conservation tillage) averaged about 0.06 ton/ha. Compared to this, no change was predicted with a scenario in which all crop land had crop residue levels of 0-15%. However, if all crop land had 15-30% crop residue levels, sediment losses would have been reduced by 16.7% and they would have been doubled if conservation tillage was adopted on all crop land. A similar trend was predicted with annual nitrogen and phosphorus losses, except in a scenario where no change was predicted with all crop land converted to conservation tillage.

With the STATSGO database, the predicted annual sediment, nitrogen and phosphorus losses were averaged about 0.06 ton/ha, 14.3 kg/ha, and 0.62 kg/ha, respectively, under existing tillage practices (Table 2). Compared to this, a 16.6% increase in sediment losses was predicted when the adoption rate of conservation tillage was decreased from an existing 24.2% to zero, with a corresponding adoption of 0-15% crop residue levels on all crop land. However, this change reduced annual nitrogen and phosphorus losses by 3.6 and 3.2%, respectively. When it was assumed that all crop land uses conservation tillage, a 4.8% reduction in existing phosphorus losses is possible, however, at the cost of increased nitrogen losses (by 4.6%). This is due to the fact that the adoption of conservation tillage practices decreases surface runoff and soil erosion and increases subsurface drainage. With complete adoption of conservation tillage, a 33.3% reduction in annual sediment losses was predicted. On the other hand, if all crop land had 15-30% crop residue levels, no change in sediment losses were predicted compared to existing conditions. However, annual nitrogen and phosphorus losses were increased by 4.3 and 4.8%, respectively.

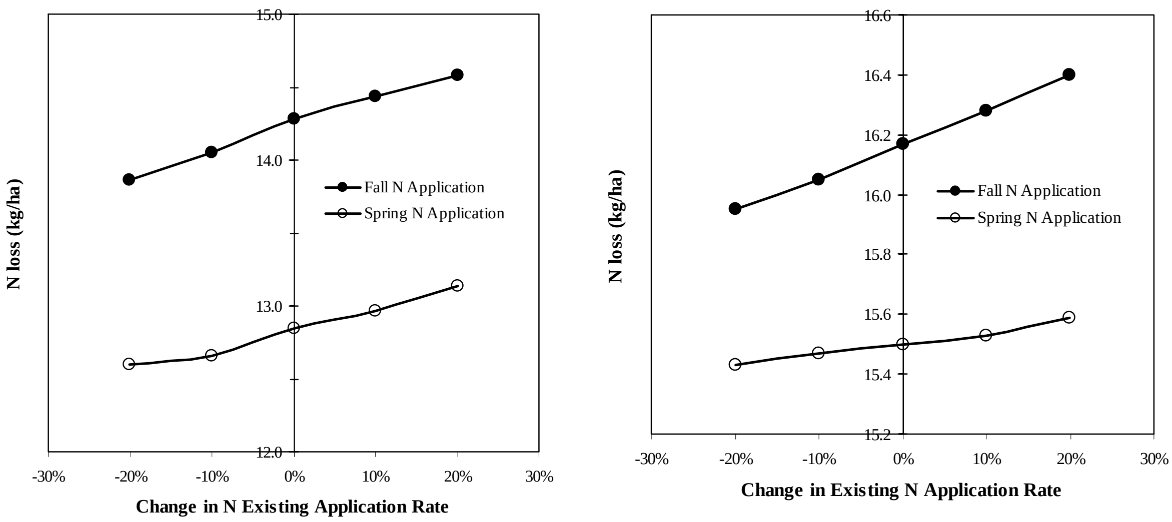
Table 2. Predicted annual sediment, nitrogen, and phosphorus losses to existing and various alternative conservation tillage adoption rates in High Island Creek watershed in 2001-2002.

Water Quality Parameter	Soil Database	Row Crop Land in Conservation Tillage						
		Existing Loss[1]	100% in 0-15% Residue Cover		100% in 15-30% Residue Cover		100% in > 30% Residue Cover	
			Loss	% Change from Existing Loss	Loss	% Change from Existing Loss	Loss	% Change from Existing Loss
SSURGO	Sediment (ton/ha)	0.06	0.06	0.0	0.05	-16.7	0.04	-33.3
	Nitrogen (kg/ha)	16.17	16.17	0.0	16.85	4.2	16.18	0.1
	Phosphorus (kg/ha)	0.47	0.47	0.0	0.49	4.3	0.47	0.0
STATSGO	Sediment (ton/ha)	0.06	0.07	16.6	0.06	0.0	0.04	-33.3
	Nitrogen (kg/ha)	14.28	13.77	-3.6	14.90	4.3	14.93	4.6
	Phosphorus (kg/ha)	0.62	0.60	-3.2	0.65	4.8	0.59	-4.8
SSURGO Vs. STATSGO	Sediment (% Difference)	0.00	14.29	-	16.67	-	0.00	-
	Nitrogen (% Difference)	-13.23	-17.43	-	-13.09	-	-8.37	-
	Phosphorus (% Difference)	24.19	21.67	-	24.62	-	20.34	-

[1] - 61.5, 14.2 and 24.3% of the row crop land were in 0-15%, 15-30%, and >30% crop residue levels, respectively.

Comparison of model predictions based on SSURGO versus STATSGO data indicated that the trends in predicted annual sediment, nitrogen and phosphorus losses were similar when the percentage of crop land under conservation tillage changed from existing to various scenarios. However, the magnitudes of predicted losses were consistently different for nitrogen and phosphorus losses. For example, STATSGO based predictions of annual nitrogen losses were 8-17% lower than the SSURGO based predictions. Similarly, STATSGO based annual phosphorus losses were 20 to 25% higher than phosphorus losses predicted using SSURGO data. However, with STATSGO or SSURGO data, the model predicted about a 33% reduction in sediment losses if all row crop land was converted into conservation tillage. This variation is due to the influence of initial nitrogen and phosphorus concentrations in soil which were varied with soil types in SSURGO data, whereas they were uniform across the watershed with STATSGO data. Variations in predicted sediment losses with SSURGO data can be attributed to changes in the water storage capacity as a result of changes in the adoption rate of conservation tillage in the watershed. The ADAPT model uses the Universal Soil Loss Equation (USLE) for estimating soil erosion, and crop management factors used in the model were based on tillage practices.

N– and P-Fertilizer Application Rate and Timing: With STATSGO data, annual nitrate losses in the High Island Creek watershed were about 14.3 kg/ha under prevailing management conditions. These conditions include a fall application of 170 kg N/ha as anhydrous ammonia (163 kg N/ha for manured land) to corn fields and a spring application of 19 kg/ha (14 kg/ha for manured land) of phosphorus as orthophosphate to corn fields. Nitrate losses were sensitive to both application rate and timing of application (Figure 1a). Reductions in nitrate losses were proportional to reductions in N fertilizer application rates. For example, annual nitrate losses were reduced from 14.6 to 13.9 kg/ha (4.8% change) when fall applied N was reduced from +20 to -20% of the baseline rate. When the existing N application rate was kept constant, nitrate losses were 10% greater for fall application than for spring application. Of the simulated scenarios, the greatest reduction (11.8%) in nitrate losses was associated with a 20% reduction in applied fertilizer application rate, combined with a switch from fall to spring application.

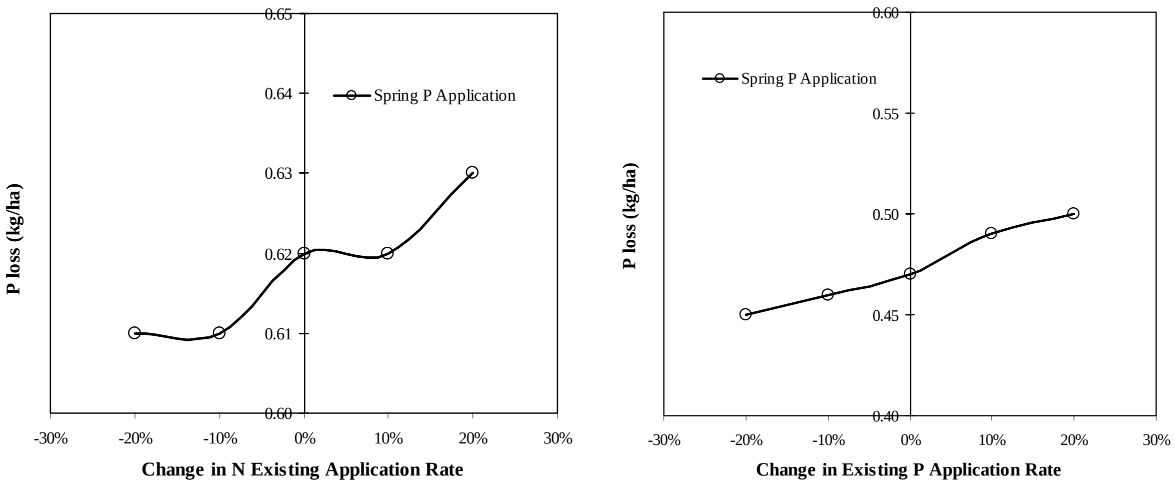


a) STATSGO b) SSURGO

Figure 1. Predicted annual nitrate losses for changes in timing and fertilizer rate in High Island Creek minor watershed.

The trend in the predicted annual nitrate losses using SSURGO data was similar to that using STATSGO data (Figures 1a & b). However, the magnitude of nitrate losses with SSURGO data was at least 10% higher than with STATSGO data. Annual nitrate losses in the High Island Creek watershed were about 16.2 kg/ha. Of the simulated scenarios, the greatest reduction in nitrate losses (4.6%) was associated with a 20% reduction in applied fertilizer application rate combined with a switch from fall to spring application. This is less than half of the reduction in nitrate losses predicted with STATSGO data.

Predicted annual phosphorus losses in the High Island Creek watershed were about 0.62 and 0.47 kg/ha using STATSGO and SSURGO data, respectively. Reductions in phosphorus losses were proportional to reductions in P fertilizer application. For example, annual phosphorus losses were reduced from 0.62 to 0.61 kg/ha using STATSGO data, and from 0.47 to 0.45 kg/ha using SSURGO data when spring applied phosphorus was reduced from +20 to -20% of the baseline rate (Figures 2a & b).



a) STATSGO b) SSURGO

Figure 2. Predicted annual P losses for changes in fertilizer rate in High Island Creek minor watershed.

CONCLUSIONS

A spatial-process model that uses GIS and the ADAPT, a field scale daily time-step continuous water table management model, was calibrated and validated for flow sediment, nitrate and phosphorus discharges from the High Island Creek watershed. The model was calibrated using STATSGO and SSURGO soil data. The calibrated model was used to investigate sediment, nitrate and phosphorus loss responses to alternative tillage and nutrient management scenarios such as adoption rate of conservation tillage, rate and timing and method of fertilizer applications. For the calibration period, the observed and predicted flow, sediment, nitrate and phosphorus discharges were in excellent agreement irrespective of the soil database used to derive soil input. However, evaluation of alternative management practices indicated that STATSGO based nitrate loss predictions are consistently higher than that for SSURGO data and vice-versa for phosphorus loss predictions.

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