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Field-Scale Targeting of Cropland Sediment Yields Using ArcSWAT

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Abstract

Soil erosion and sedimentation are fundamental water quality and quantity concerns throughout the United States. Agricultural fields are known to be a major contributor of sediment into surface waters. The objectives of this study were to evaluate different methods of identifying the agricultural fields with greatest soil erosion potential in Black Kettle Creek Watershed using readily available landuse and soil inputs, and to demonstrate a method of field-scale targeting using ArcSWAT. Black Kettle Creek watershed (8,000 ha) is a subwatershed in Little Arkansas Watershed (360,000 ha) in south-central Kansas. An ArcGIS toolbar was developed to post-process SWAT HRU output to generate sediment, nitrogen, and phosphorus yields for individual fields. A RUSLE-based model was also developed using model builder in ArcGIS. Results are presented that quantify the relative impact of each input and method type on selecting target fields with the greatest pollutant yields. The fields ranked by SWAT in the top 10% by sediment yields changed with soil data inputs used (STATSGO vs. SSURGO) by up to 37%, with landuse inputs used (Field vs. NLCD vs. NASS) by up to 95%, and with model type (SWAT vs. RUSLE) by 75%. As modeling results are used to target BMP implementation efforts, extreme care should be used in selection of both model and input data.

Keywords: Field Scale, Targeting, SWAT, RUSLE

Introduction

Soil erosion and sedimentation are fundamental water quality and quantity concerns throughout the United States. Soil erosion from agricultural fields is known to be a major contributor of sediment yields into surface waters.

The City of Wichita in south-central Kansas undertook the Equus Beds Aquifer Storage and Recovery (ASR) Project which diverts water during high flows from the Little Arkansas Watershed through bank storage (diversion) wells. In 2007, there was approximately 1.3 million m^3 (350 million gallons) of water injected into the *Equus* Beds aquifer. It was noted that on average, for every 3,800 m^3 (1 million gallons) of water injected, there was approximately 6.4 Mg (7 tons) of sediment that was removed from the treatment facility (Steele, 2006). Removing sediment from the water and then injecting water to Equus bed requires high treatment costs. Steele (2006) conducted a water quality monitoring study and concluded that the Black Kettle Creek subwatershed of Little Arkansas Watershed delivered the greatest sediment yields compared to other subwatersheds. Substantial funding from a USDA-NRCS Conservation Innovation Grant (CIG) will be used to address sediment yields from Black Kettle Creek Watershed by supporting implemention of targeted conservation practices in agricultural fields with greatest soil erosion potential.

The objectives of this study were to evaluate different methods of identifying the agricultural fields with greatest soil erosion potential in Black Kettle Creek Watershed using readily available landuse and soil inputs, and to demonstrate a method of field-scale targeting using ArcSWAT.

Study Area

Black Kettle Creek Watershed is a 7,818 ha (19,295 ac) subwatershed of Little Arkansas River Watershed located within McPherson and Harvey Counties in south-central Kansas (Figure 1). Primary land use in the watershed is cropland (84% of total area), including wheat (65%), corn (8%), grain sorghum (15%), soybeans (11%) and alfalfa (1%). Rangeland comprises 12% of the total land area and urban area occupies 2%, followed by forests with 2%. The major pollutant concerns in this watershed are sediment and phosphorus.

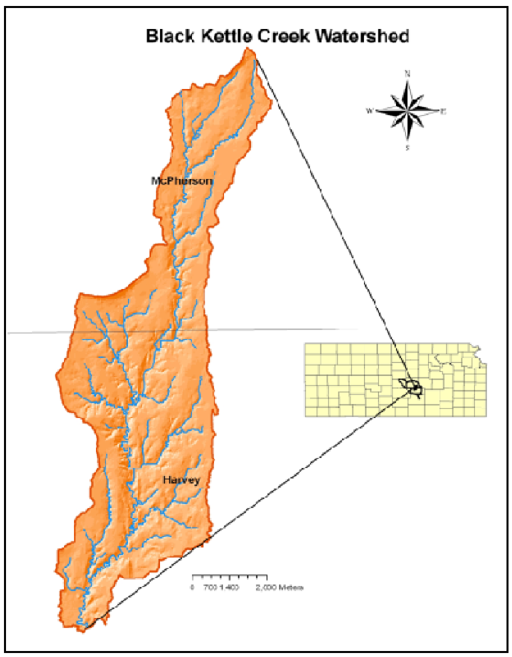

Figure 1: Black Kettle Creek Watershed

Materials and Methods

Soil and Water Assessment tool (SWAT) method and GIS-based RUSLE method (Renard, 1997) were used to identify and target the specific fields with greatest soil erosion potential.

SWAT Methodology

Inputs to the SWAT model: Table 1 shows input data sources that were used in the SWAT model to develop different scenarios.

Table 1: Input data sources for the SWAT model.

Topography	Landuse	Soils	Slope	Weather Data
•10m DEM	•NLCD 2001 •NASS 2007 •field landuse	•SSURGO •STATSGO	•0-2,2-4, and 4 -9999 %	•1995 to 2006 (12 year period)

The field landuse was developed manually using the CLU (Common Landuse Unit or FSA) field boundary shapefile. Each field landcover was manually edited based on field by field survey conducted in the watershed. The SSURGO soil layer was prepared using SSURGO processing tool (Sheshukov et al, 2009) that converts the SSURGO data to a format compatible with ArcSWAT.

SWAT model setup: Six different SWAT scenarios were conducted by varying landuse and soil inputs during each SWAT run (Table 2). The DEM, slope and weather inputs were held the same for each SWAT scenario. The thresholds for landuse/soil/slope were set to 0% so that all land cover, soil and slope combinations (HRUs) in the watershed were represented. The model creates a FullHRU feature class (shapefile) containing polygons representing all the HRUs within the watershed. Table 2 gives the different SWAT scenarios names, number of subbasins and HRUs that were generated during each scenario.

Table 2: Model scenarios, number of subasisns and HRUs

Scenario	Model	Land Use Data	Soil Data	No. Subbasins	No. HRUs
S/FLD/SS	**SWAT**	**Field Survey**	**SSURGO**	9	1169
S/FLD/ST	**SWAT**	**Field Survey**	**STATSGO**	9	319
S/NAS/SS	**SWAT**	**NASS**	**SSURGO**	9	1133
S/NAS/ST	**SWAT**	**NASS**	**STATSGO**	9	344
S/NLC/SS	**SWAT**	**NLCD**	**SSURGO**	9	800
S/NLC/ST	**SWAT**	**NLCD**	**STATSGO**	9	216
R/FLD/SS	**RUSLE**	**Field Survey**	**SSURGO**	N/A	N/A

Each SWAT scenario was simulated for the period 1992 to 2006 (15 years). The first three years (1992 to 1994) were used for model initialization; all analyses were conducted on the remaining 12 years (1995 to 2006). The HRU, Subbasin and Reach outputs files were exported and written as tables in the access database (SWATOutput.mdb).

SWAT post processing and Targeting: Identifying the fields that most produces sediment yields involves the following steps after SWAT runs (Figure 2).

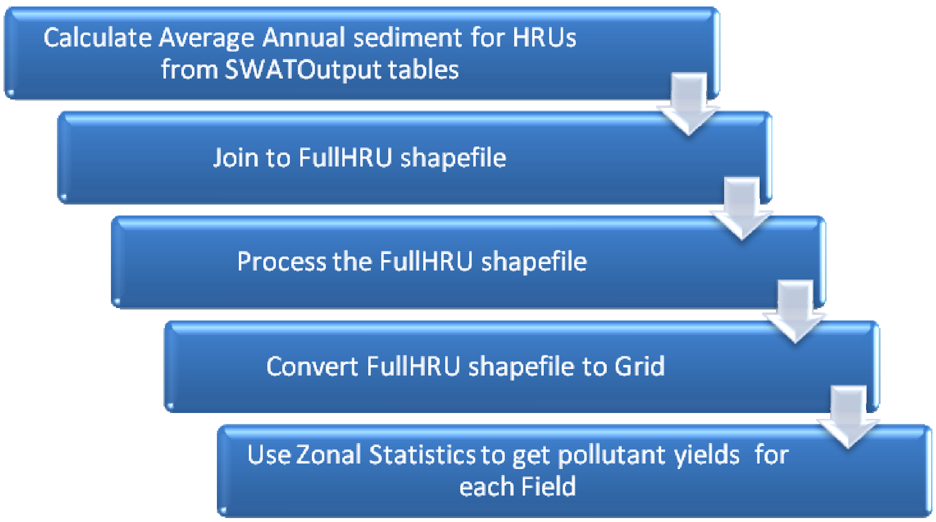

Figure 2: Steps to get pollutant yields on field basis.

The above mentioned steps are time consuming and labor intensive. Therefore, an ArcGIS based *SWAT targeting toolbar* was developed using ArcGIS-Visual Basic to post process the SWAT output and prepare maps of sediment, total phosphorus and total nitrogen yields for a user-defined land-area boundary. The toolbar is divided into two menu items: SWAT Output Processing and Targeting (Figure 3).

SWAT Output Processing: The SWAT Output Processing menu opens up the Excel based *SWAT Output Processing Tool*. This tool reads the SWAT output tables that are stored in access database (SWATOutput.mdb) and exports average annual sediment, total nitrogen and total phosphorus yields for HRUs and subbasins.

Targeting: The Targeting menu opens up the *Watershed Targeting Model* that was build using Model Builder in ArcGIS Environment. This tool needs outputs from the *SWAT Output Processing Tool*, FullHRU shapefile (generated in SWAT model run) and boundary of interest (e.g., fields, subbasins, counties). Once the inputs are satisfied, the tool produces maps of area-weighted average annual pollutant yields (sediment, total phosphorus and total nitrogen yields) for the user defined boundary. In this study, the CLU field boundary shapefile was used. Since this project involves identifying most sediment producing fields, we used only maps of fields with sediment yields. Figure 3 summarizes the functions of the toolbar.

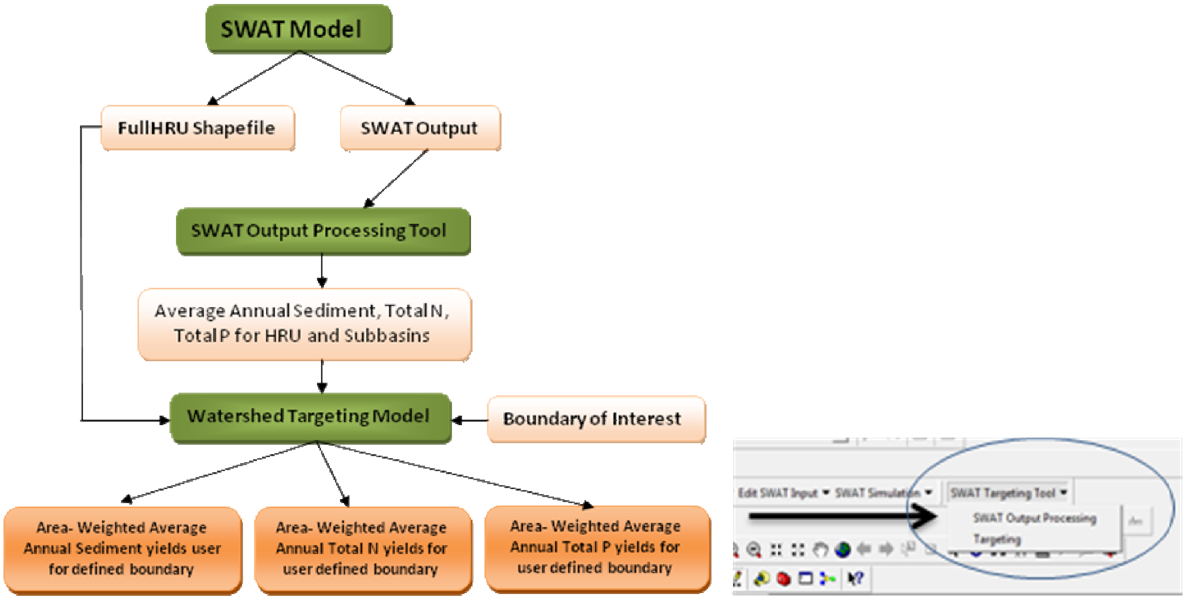

Figure 3: Overview of SWAT Targeting Toolbar

Using these tools and procedures, area-weighted average annual sediment yields for each field for different SWAT runs was developed.

RUSLE Methodology

A user-friendly RUSLE model was developed based on the RUSLE equation (Renard, 1997) using Model Builder in ArcGIS Environment (Figure 4). This particular model uses readily downloadable data from the internet and produces maps of area-weighted annual average sediment yields for user-defined boundary in the watershed.

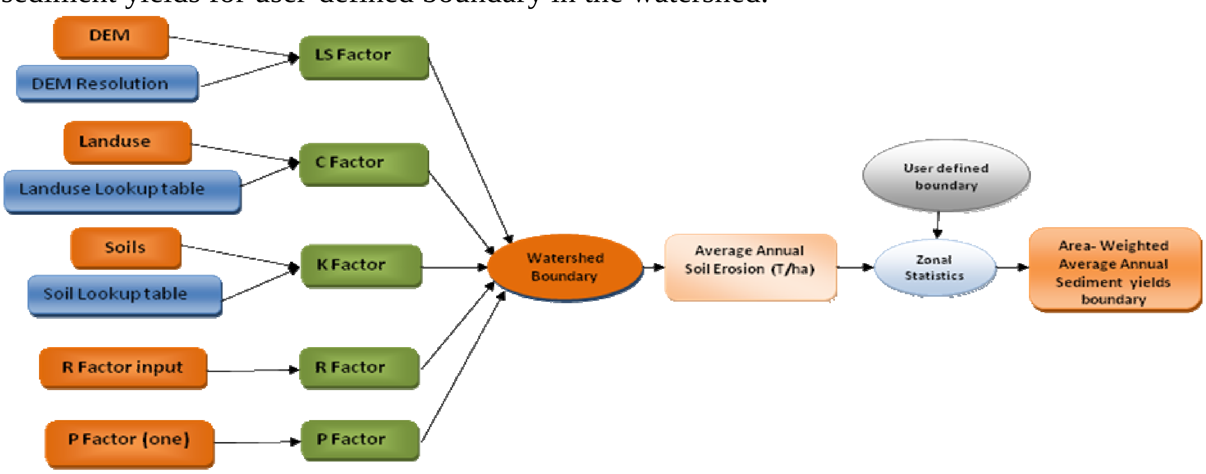

Figure 4: Overview of RUSLE Model.

RUSLE Model Setup: The model requires Digital Elevation Model (DEM) grid, DEM resolution as number, landuse grid, SSURGO soils (shapefiles), watershed boundary, boundary of interest (e.g., CLU field boundary or subbasin boundary), R factor as number, and P factor as number. The landuse lookup table and the soil lookup table needs to be prepared separately and provided as input to the model. Once these inputs are provided to the model, the model produces maps of area-weighted average annual sediment yields for user defined boundary of interest. In this study, 10-m DEM, field landuse grid (prepared for SWAT model), SSURGO soils, R factor of 185, and P factor of 1 were used.

Top 10 and 20 percent calculations: For each modeling scenario, field-scale sediment yields (Mg/ha) for each of 677 fields in the watershed were ranked from high to low. We used four subsets of this ranking for comparison: the top 10% of fields (68 fields), top 20% of fields (135 fields), fields with the top 10% of sediment yields, and fields with the top 20% of sediment yields. The number of fields that constituted the top 10% or 20% of sediment yields is varied by scenario. These methods were referred to as the top "10% of fields", "20% of fields", "10% of yields", and 20% of yields".

Analysis: The individual fields identified as in the top percentages of fields and top percentages of yields were compared among modeling scenarios. The S/FLD/SS scenario (Table 2) was considered to be the baseline scenario because manually developed field landuse and SSURGO soils were considered to be the inputs that best represented actual conditions of the watershed. Comparisons were conducted by spatially overlapping each modeling scenario to the baseline scenario using GIS. The SWAT baseline scenario (S/FLD/SS) was also compared to the RUSLE method (R/FLD/SS) to evaluate different methods/models for targeting recommendations.

Results and Discussions

Output maps of the top 10 and 20% ranked by fields and yields were prepared for all modeling scenarios. Examples are shown (Figure 5) for maps of top 20% by fields and by yields for S/FLD/SS and R/FLD/SS scenarios. The number of fields, percent of total area, and spatial location of fields in the watershed varied between scenarios and methods (by field vs. by yield).

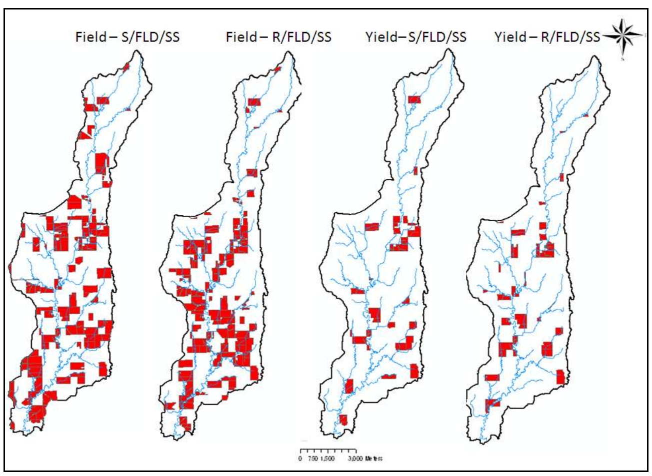

Figure 5: Top 20% based on fields and sediment yields for S/FLD/SS and R/FLD/SS scenarios

The number of targeted fields based on top 10% of fields was 68 and top 20% fields was 135 (Table 2). The number of targeted fields based on top 10% of sediment yields ranged from 8 to 49 and to 20% of yields ranged from 22 to 81. The percent of total area that needs targeting based on top 10 and 20% fields ranged from 6.5 to 13.5% and 15.5 to 24.6%. The percent of total area that needs targeting based on top 10 and 20% sediment yields ranged from 1.9 to 4.4% and 4.6 to 10.7% (Table 2).

Table 2: Percent area and number of fields based on field and sediment yield methods

Top 10% based on Fields			Top 10% based on Yields		
Scenario	Percent of total area	No of fields	Scenario	Percent of total area	No of fields
R/FLD/SS	7.20%	68	R/FLD/SS	1.90%	20
S/FLD/SS	12.50%	68	S/FLD/SS	2.30%	20
S/FLD/ST	12.80%	68	S/FLD/ST	2%	19
S/NAS/SS	13.33%	68	S/NAS/SS	2.10%	8
S/NAS/ST	13.50%	68	S/NAS/ST	2%	9
S/NLC/SS	6.50%	68	S/NLC/SS	4.40%	49
S/NLC/ST	6.50%	68	S/NLC/ST	3.70%	48
Top 20% based on Yields			**Top 20% based on Yields**		
Scenario	Percent of total area	No of fields	Scenario	Percent of total area	No of fields
R/FLD/SS	16.90%	135	R/FLD/SS	5	45
S/FLD/SS	24.60%	135	S/FLD/SS	5.1	35
S/FLD/ST	23.70%	135	S/FLD/ST	4.6	33
S/NAS/SS	25.10%	135	S/NAS/SS	5.4	23
S/NAS/ST	23.9	135	S/NAS/ST	5	22
S/NLC/SS	18	135	S/NLC/SS	10.7	86
S/NLC/ST	15.5	135	S/NLC/ST	8.5	81

The importance of SSURGO and STATSGO soil data in developing targeting recommendations was evaluated by spatially overlapping fields targeted by the S/FLD/SS scenario compared with S/FLD/ST scenario, S/NAS/SS with S/NAS/ST, and S/NLC/SS with S/NLC/ST for each field ranking method (top 10 and 20%, by fields and by yields). The results (Table 3) showed that use of SSURGO vs. STATSGO soil datasets changed a meaningful portion of the targeted fields in each case. The agreement in specific fields selected using the two soil databases ranged from 75 to 82% when the top 10% of fields were targeted and from 63 to 95% when the top 10% of sediment yields were targeted (Table 3). These results indicate differences (up to 37% difference) in which fields were targeted depending on which soil database was used.

Table 3: Scenario comparisons to evaluate SSURGO (SS) and STATSGO (ST) soils.

Top 10% based on fields			Top 10% based on Yields		
Scenario	No of fields	Percentage overlap	Scenario	No of fields	Percentage overlap
S/FLD/SS	67	82%	S/FLD/SS	20	95%
Overlap of S/FLD/SS with S/FLD/ST	55		Overlap of S/FLD/SS with S/FLD/ST	19	
S/NAS/SS	67	81%	S/NAS/SS	8	63%
Overlap of S/NAS/SS with S/NAS/ST	54		Overlap of S/NAS/SS with S/NAS/ST	5	
S/NLC/SS	67	75%	S/NLC/SS	49	67%
Overlap of S/NLC/SS with S/NLC/ST	50		Overlap of S/NLC/SS with S/NLC/ST	33	
Top 20% based on Fields			**Top 20% based on Yields**		
Scenario	No of fields	Percentage overlap	Scenario	No of fields	Percentage overlap
S/FLD/SS	135	86%	S/FLD/SS	35	71%
Overlap of S/FLD/SS with S/FLD/ST	116		Overlap of S/FLD/SS with S/FLD/ST	25	
S/NAS/SS	135	85%	S/NAS/SS	23	78%
Overlap of S/NAS/SS with S/NAS/ST	115		Overlap of S/NAS/SS with S/NAS/ST	18	
S/NLC/SS	135	78%	S/NLC/SS	86	74%
Overlap of S/NLC/SS with S/NLC/ST	105		Overlap of S/NLC/SS with S/NLC/ST	64	

We also evaluated the difference caused by source of landuse data and by model type (SWAT vs. RUSLE) methods in developing targeting recommendations. Each scenario was spatially overlapped with S/FLD/SS scenario (base scenario) for top 10 and 20% fields and yields. The results (Table 4) showed that the other SWAT scenarios agreement in overlap ranging from 5% to 95% among methods. The percentage agreement was higher for S/FLD/SS and R/FLD/SS scenarios when compared to other SWAT scenarios except for the S/FLD/SS.

Table 4: Scenario comparisons to evaluate landuse, soil inputs and modeling methods.

Top 10% based on Fields			Top 10% based on Yields		
Scenario	No of fields	Percentage overlap	Scenario	No of fields	Percentage overlap
S/FLD/SS	67	82%	S/FLD/SS	20	95%
Overlap of S/FLD/SS with S/FLD/ST	55		Overlap of S/FLD/SS with S/FLD/ST	19	
S/FLD/SS	67	40%	S/FLD/SS	20	5%
Overlap of S/FLD/SS with S/NAS/SS	27		Overlap of S/FLD/SS with S/NAS/SS	1	
S/FLD/SS	67	39%	S/FLD/SS	20	10%
Overlap of S/FLD/SS with S/NAS/ST	26		Overlap of S/FLD/SS with S/NAS/ST	2	
S/FLD/SS	67	25%	S/FLD/SS	20	60%
Overlap of S/FLD/SS with S/NCL/SS	17		Overlap of S/FLD/SS with S/NCL/SS	12	
S/FLD/SS	67	24%	S/FLD/SS	20	25%
Overlap of S/FLD/SS with S/NCL/ST	16		Overlap of S/FLD/SS with S/NCL/ST	5	
S/FLD/SS	67	42%	S/FLD/SS	20	25%
Overlap of S/FLD/SS with R/FLD/SS	28		Overlap of S/FLD/SS with R/FLD/SS	5	
Top 20% based on Fields			**Top 20% based on Yields**		
Scenario	**No of fields**	**Percentage overlap**	**Scenario**	**No of fields**	**Percentage overlap**
S/FLD/SS	135	86%	S/FLD/SS	35	71%
Overlap of S/FLD/SS with S/FLD/ST	116		Overlap of S/FLD/SS with S/FLD/ST	25	
S/FLD/SS	135	61%	S/FLD/SS	35	14%
Overlap of S/FLD/SS with S/NAS/SS	82		Overlap of S/FLD/SS with S/NAS/SS	5	
S/FLD/SS	135	58%	S/FLD/SS	35	14%
Overlap of S/FLD/SS with S/NAS/ST	78		Overlap of S/FLD/SS with S/NAS/ST	5	
S/FLD/SS	135	49%	S/FLD/SS	35	49%
Overlap of S/FLD/SS with S/NCL/SS	66		Overlap of S/FLD/SS with S/NCL/SS	17	
S/FLD/SS	135	43%	S/FLD/SS	35	43%
Overlap of S/FLD/SS with S/NCL/ST	58		Overlap of S/FLD/SS with S/NCL/ST	15	
S/FLD/SS	135	60%	S/FLD/SS	35	51%
Overlap of S/FLD/SS with R/FLD/SS	81		Overlap of S/FLD/SS with R/FLD/SS	18	

Conclusions

Agricultural fields with greatest soil erosion potential were identified and targeted using ArcSWAT. Different sources of landuse and soil input data were also evaluated. An ArcGIS toolbar was developed to aggregate SWAT HRU output by field and prepare maps of high priority fields by sediment, total nitrogen, and total phosphorus yields. The fields ranked by SWAT in the top 10% by sediment yields changed with soil data inputs used (STATSGO vs. SSURGO) by up to 37%, with landuse inputs used (Field vs. NLCD vs. NASS) by up to 95%, and with model type (SWAT vs. RUSLE) by 75%.Extreme care should be used in selection of both model and input data since modeling results are used to target BMP implementation efforts.

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