Targeting High Non-Point Source Contributing Areas in the Turkey Creek Basin

Final Report

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1 - Introduction

Sediment is the number one pollutant in Oklahoma’s surface waters (Routledge, 2002). Erosion from upland and riparian areas can be reduced by best management practice (BMP) implementation. Funding for BMP implementation is provided by Section 319 of the Clean Water Act. Section 319(h) establishes funds to help states and tribal nations address nonpoint source water pollution (EPA, 2003). Through this program, the Oklahoma Conservation Commission (OCC) has finite funding available to implement BMPs throughout Oklahoma watersheds. To most efficiently use these funds, it is necessary for the OCC to quantitatively target areas with the highest potential for water quality improvement. The focus of this project is to identify target areas within the Turkey Creek Basin, and to evaluate remotely sensed imagery for the purpose of targeting in riparian corridors.

Turkey Creek is located in west central Oklahoma (Figure 1.1). Sections of Turkey Creek are thought to be impaired by low dissolved oxygen, pathogens (fecal bacteria), nutrients, suspended solids, and turbidity. These problems are not unusual in the region. Dominant agricultural activities in the basin are wheat production and cattle farming. Phosphorus and sediment from nonpoint sources are the focus of this effort.

Targeting in upland areas is performed using a hydrologic model such as the Soil and Water Assessment Tool (SWAT). The SWAT model was applied to a high resolution data set (10 meter) to predict sediment and phosphorus loads within the Turkey Creek Basin. These data were used to identify areas which contribute disproportionate amounts of sediment and phosphorus per unit area. These areas are typically the best places to implement practices which reduce non-point source pollution.

Targeting requires accurate landcover. Landcover can be derived from extensive ground surveys or more limited ground truthing in conjunction with aerial photographs or satellite imagery. The quality and resolution of the landcover is dependent upon the imagery on which it is based and the method of classification. Higher resolution data are generally preferred, but the additional cost may not be justified. The level of detail required for upland targeting using models such as SWAT is far less than that required to target in riparian corridors. It is a simple matter of scale; upland targets are much larger than targets in riparian corridors. A typical riparian corridor is on the order of 4 to 60 meters wide. Even a small agricultural field (20 acres) is 280 meters square. Thirty meter imagery is generally sufficient for targeting in upland areas. However, imagery requirements to target in riparian corridors is not well defined. For this reason we elected to examine imagery section and cost in riparian corridors only.

SWAT Overview

The SWAT 2000 model was used to estimate erosion and nutrient loading from the upland areas of the Turkey Creek Basin. SWAT 2000 is a distributed parameter basin scale model developed by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas. SWAT 2000 is included in the Environmental Protection Agency’s (EPA) latest release of Better Assessment Science

Integrating Point and Nonpoint Sources (BASINS).

An ArcView GIS interface is available to generate model inputs from commonly available GIS data. These GIS data are summarized by the interface and converted to a form usable by the model. GIS data layers of elevation, soils, and land use are used to generate the input files. Observed temperature and precipitation can be incorporated. If no observed weather data are available, weather can be stochastically simulated.

Gridcell Approach

To develop highly detailed targeting maps, the SWAT model was operated in a grid-cell mode. To date, this is the most detailed targeting performed at Oklahoma State University (OSU) for the OCC. There is no interface to operate SWAT at the grid-cell level and thus one was written specifically for this project. It is not currently possible to calibrate a grid-cell model due to the amount of time required to run the model. However, Turkey Creek is well suited for a gridcell model due to lack of suitable streamflow and water quality data which preclude any model calibration.

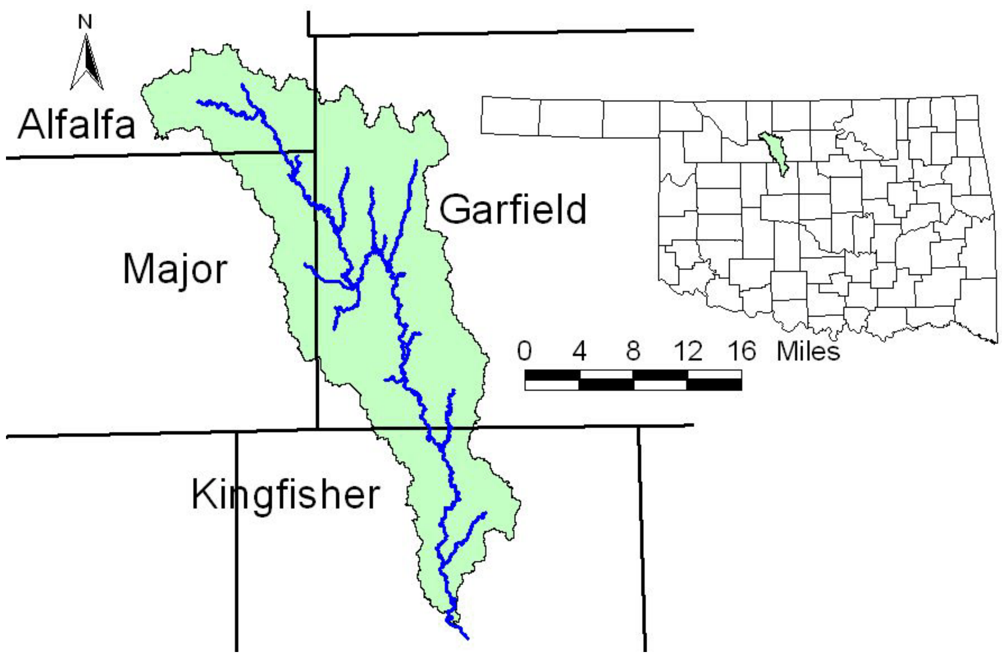

Figure 1.1 Map of the Turkey Creek Basin.

2 - SWAT Input Data

GIS data for topography, soils, land cover, and streams were used in the SWAT model. These data were the most current at the time of compilation. Observed daily rainfall and temperature data were used in all modeling.

Topography

Topography was defined by a 10 meter Digital Elevation Model (DEM) from the National Elevation Dataset (NED) (Figure 2.1). The DEM was used to calculate subbasin parameters such as slope, slope length, and to define the drainage basin of Turkey Creek. The original 10 meter data contained sampling artifacts which were removed using a circular convolution filter with a radius of 30 meters prior to slope estimation. The resulting slopes from a filtered and unfiltered DEM are given in Figure 2.2. Slopes from the filtered DEM were much more realistic. Slope was derived from the filtered DEM to produce a slope grid of the entire basin (Figure 2.3), which was used in the model.

Soils

Soil GIS data are required by SWAT to define soil characteristics. Soils in the Turkey Creek Basin have significant spatial variability (Figure 2.4). It is important to capture as much of this variability in the SWAT model as possible. SWAT uses STATSGO (State Soil Geographic Database) data to define soil attributes for any given soil. STATSGO has been replace by Soil Survey Geographic (SSURGO) for many counties in recent months. SSURGO is a vector format data which was converted to a 10 meter grid. An example comparison of STATSGO and SSURGO is given in Figure 2.5. The SWAT Arcview interface does not support SSURGO natively. An extension to incorporate SSURGO was developed by Peschel et al. (2003). This extension was used to include SSURGO into the SWAT model. An map of SSURGO data used in SWAT is given in Figure 2.6.

Landcover

Landcover is perhaps the most important GIS data used in the model. The landcover grid defines the spatial distribution of pasture, wheat, and forest within the basin. These landcovers are radically different. Forests and pasture areas contribute little to the nutrient loading, while wheat is thought to be the primary source of sediment and phosphorus.

It is important that land cover data be based on the most current data available, since land cover changes over time. Two land covers with differing resolutions (10 and 30 meters) were prepared for this project by a subcontractor, Applied Analysis Inc. (AAI). Generally only one landcover is needed for targeting, but one goal of this project is to determine the most cost effective imagery source for riparian targeting. Landcover was derived from 30 meter Landsat 7 imagery, 10 meter SPOT 5 imagery, digital aerial photos, and ground truth data points provided by the OCC. Landsat 7 imagery captured on June 8, 2003 and SPOT 5 imagery captured May 27, 2003 were obtained and classified by AAI. An unsupervised iterative self-organizing data analysis (ISODATA) clustering algorithm was applied by AAI to define spectral categories. After several iterations these categories were combined into individual land covers (Figure 2.7). The classification report provided by AAI is given in Appendix A. OSU georeferenced both classified images to existing aerial photography. Due to its higher spatial resolution, SPOT imagery was used in the model. Several clouds in the SPOT imagery created holes in the classified image. Therefore, landcover in these areas was determined from the classified Landsat imagery. The final landcover is given in Figure 2.7. The fraction of the basin in each category is given in Table 2.1.

Weather

SWAT can use observed weather data or simulate it using a database of weather statistics from stations across the United States. Observed daily precipitation and minimum and maximum temperature were used. A single Cooperative Observation network (COOP) gage was selected for use in the SWAT model. Normally multiple gages are used to better represent the spatial variability of rainfall which increases calibration accuracy. Because the model was not calibrated, multiple gages were not required. When targeting we prefer to use a single gage unless there are significant differences in climate across the basin. The use of a single gage prevents areas from being targeted due to excessive rainfall reported at one gage and significantly reduces the complexity of a gridcell based model. The COOP station 0340215 was selected to represent the climate in the Turkey Creek. These data were provided by Watershed Dynamics LLC, as a prerelease product without cost.

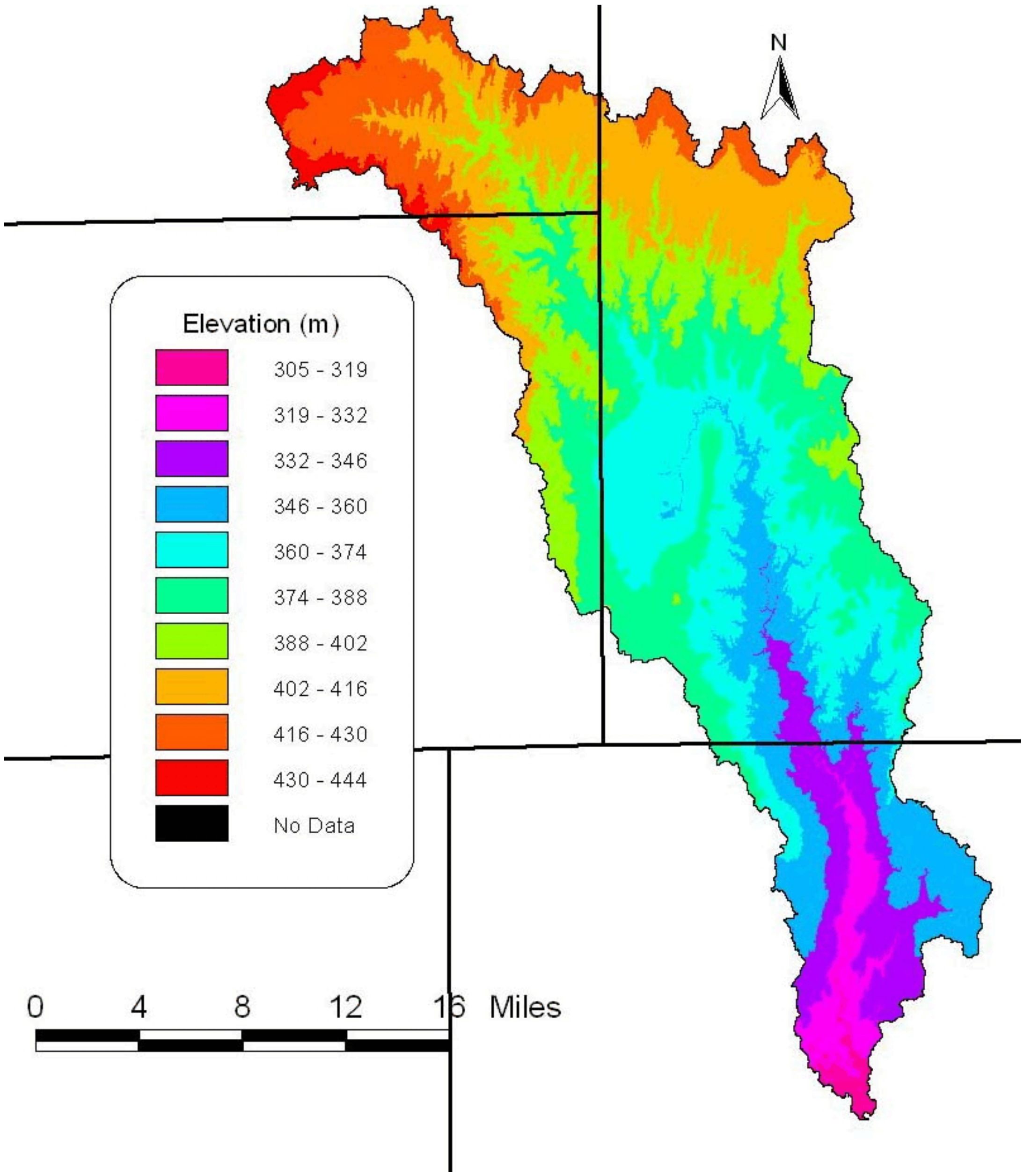

Figure 2.1 National Elevation Dataset (10 meter) for the Turkey Creek Basin.

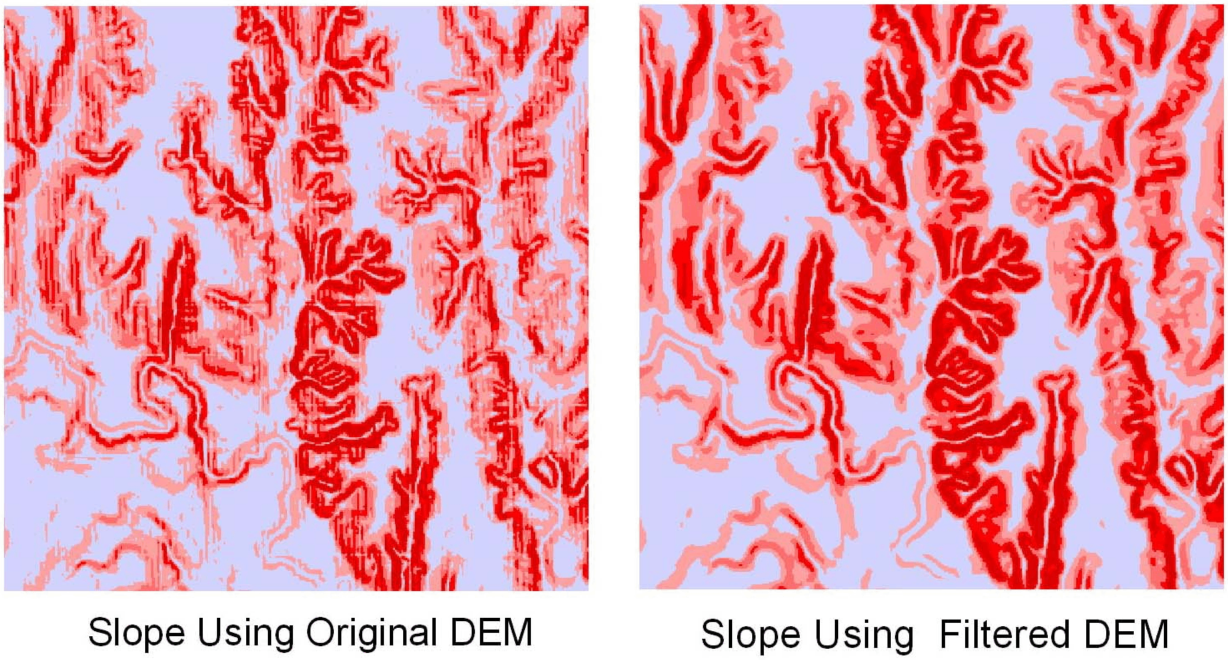

Figure 2.2 Comparison of original 10 meter National Elevation Dataset derived slope and filtered DEM derived slope.

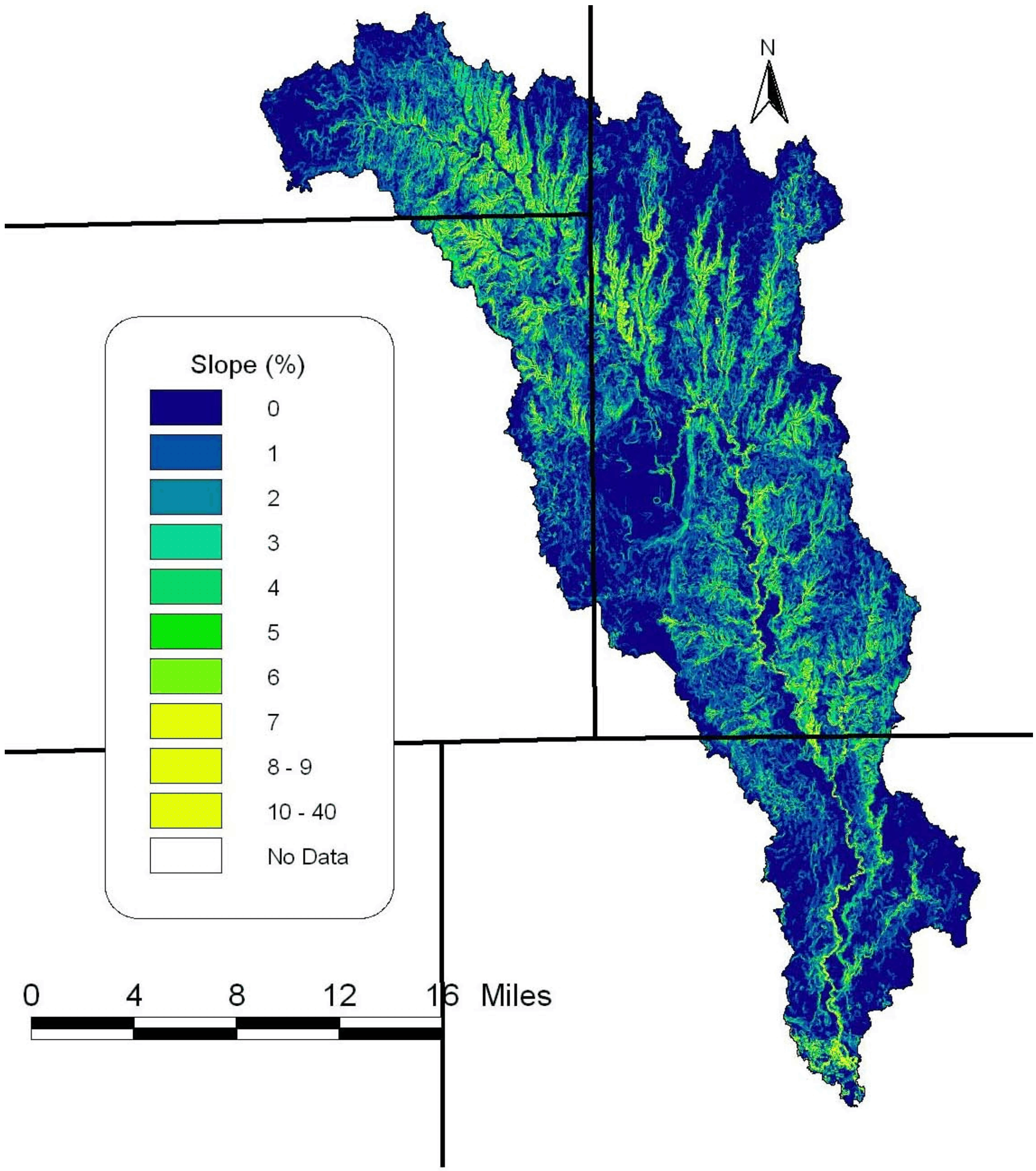

Figure 2.3 Filtered 10 meter National Elevation Dataset derived slope.

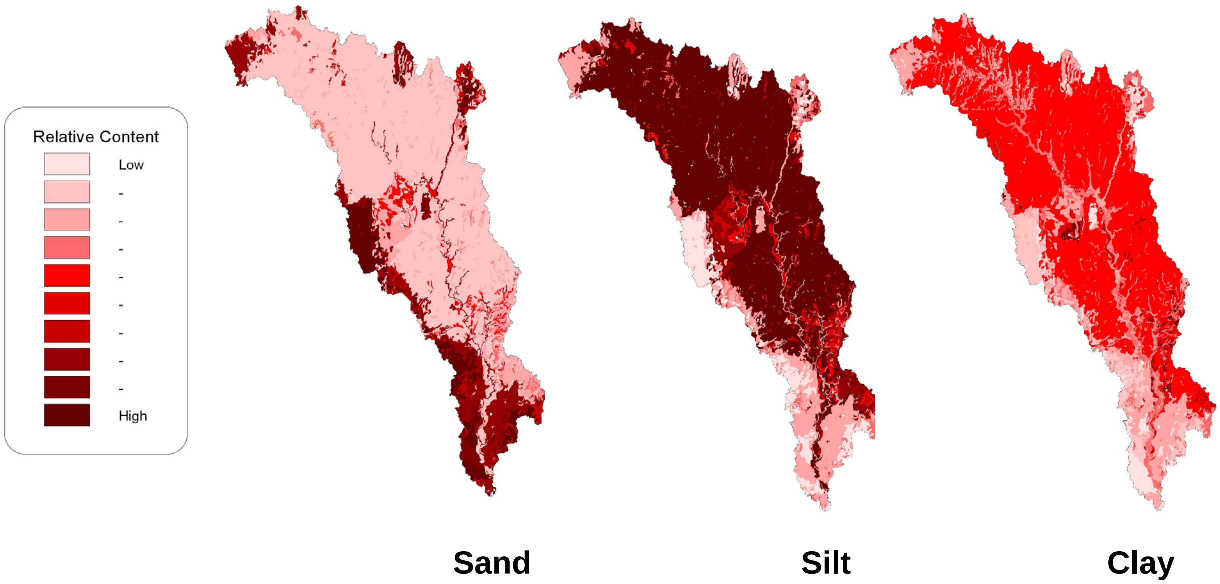

Figure 2.4 Texture of soils in the Turkey Creek Basin. Derived from Soil Survey Geographic (SSURGO) data.

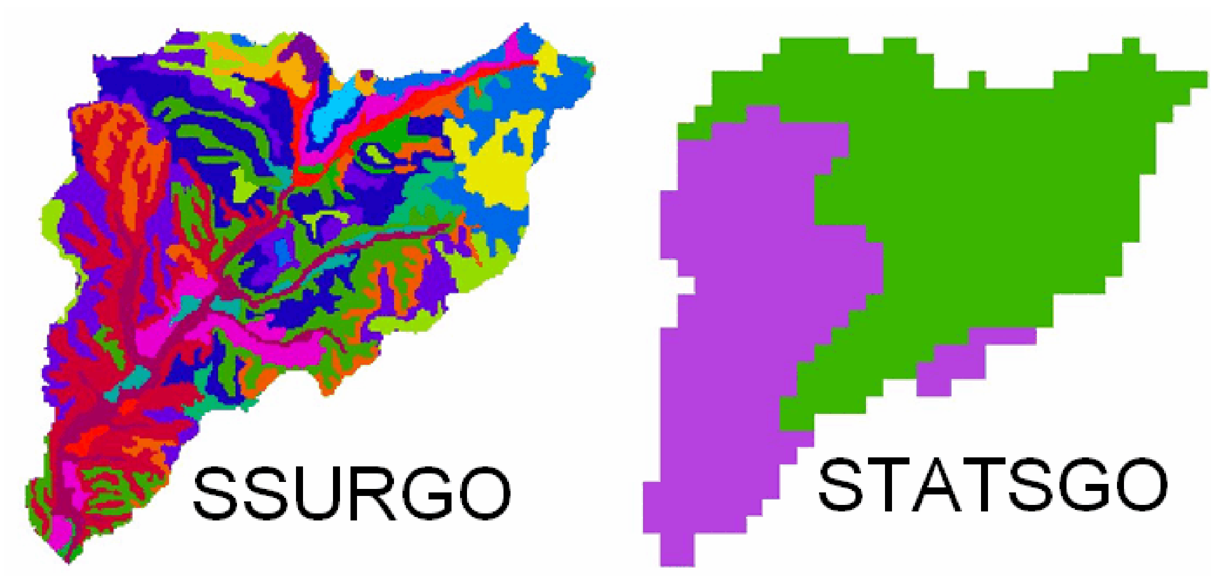

Figure 2.5 Comparison of SWAT Standard State Soil Geographic (STATSGO) and Soil Survey Geographic (SSURGO) data.

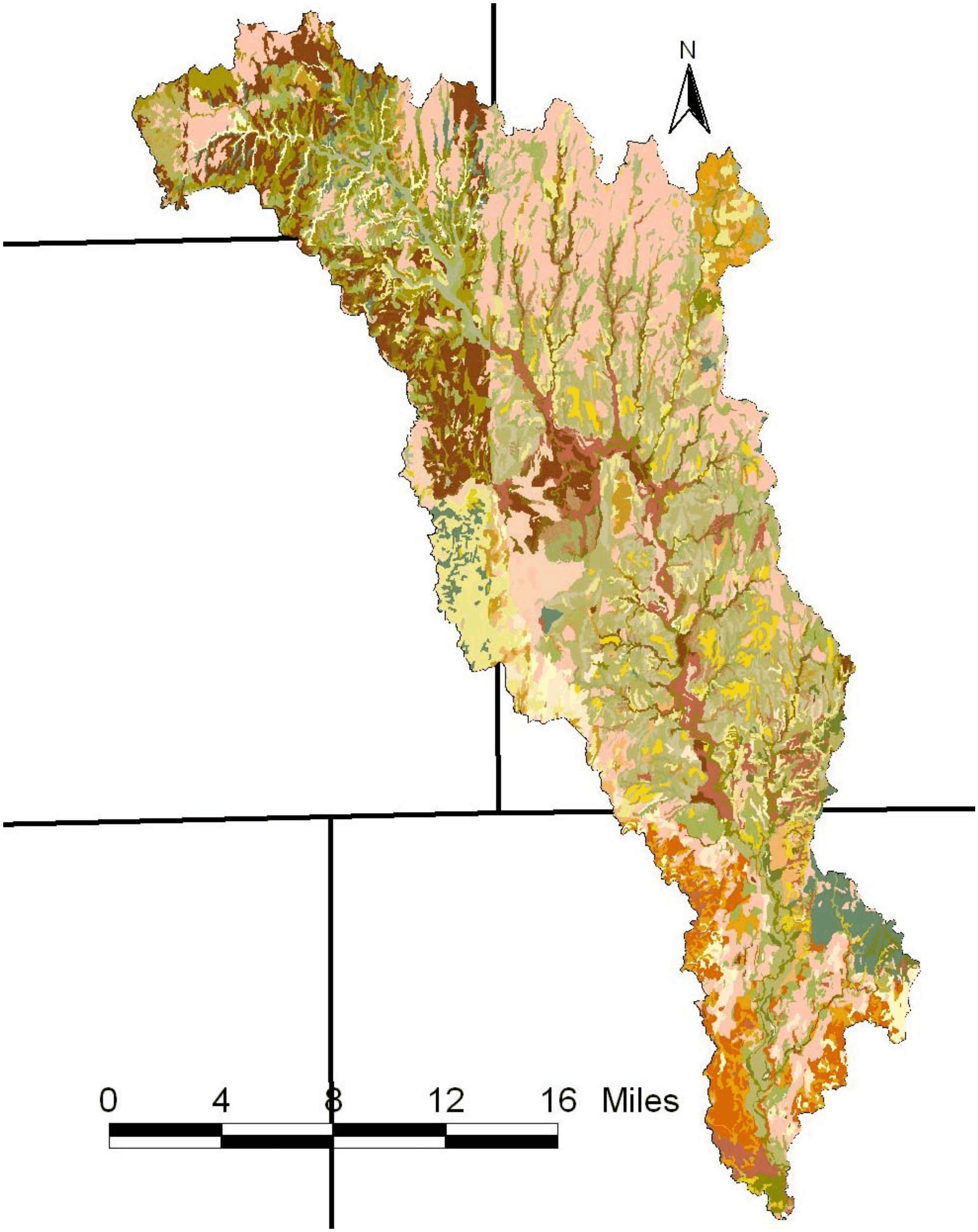

Figure 2.6 Soil Survey Geographic (SSURGO) data for the Turkey Creek Basin. Legend excluded due to excessive number of soils for display purposes.

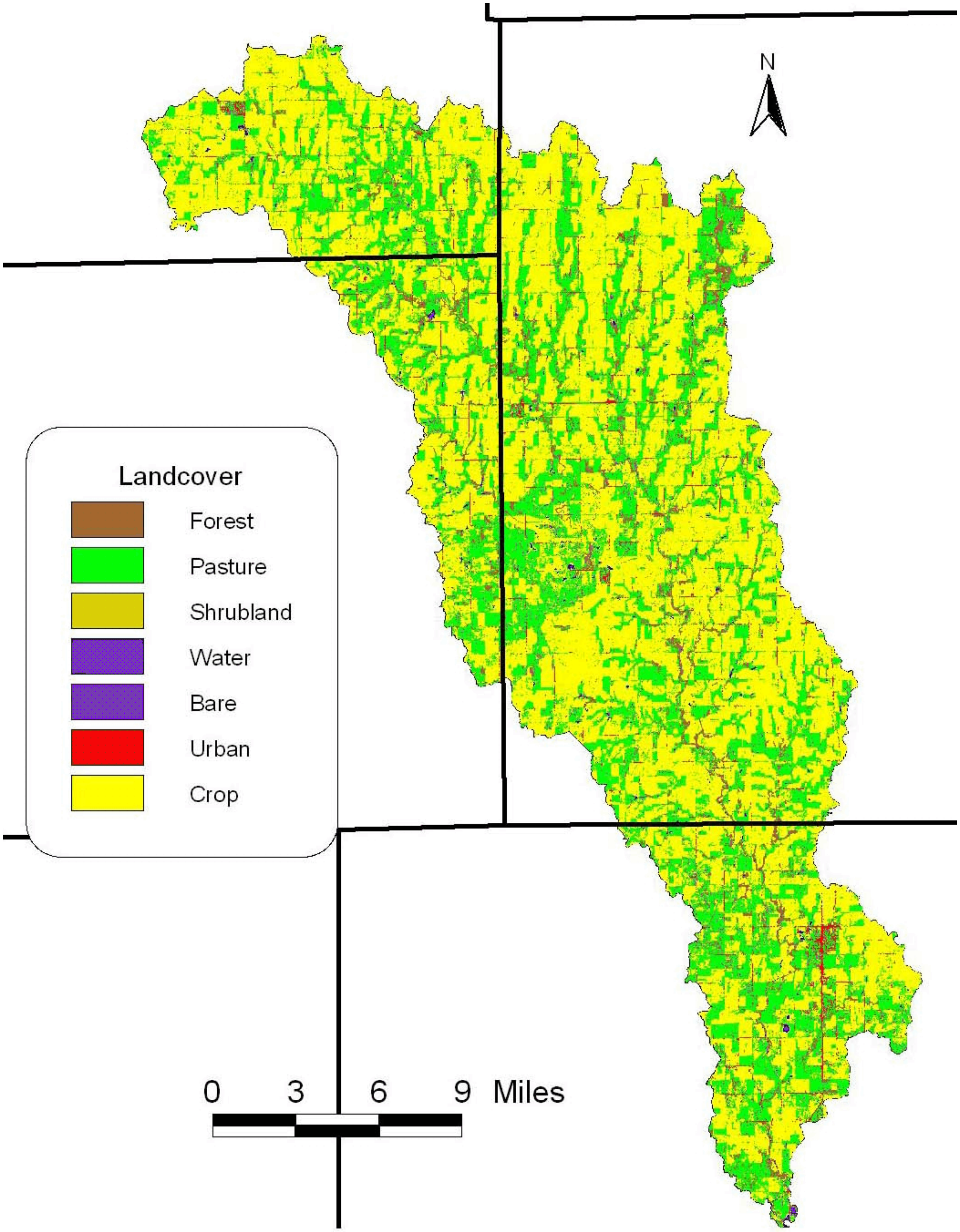

Figure 2.7 SPOT 5 derived land cover data for the Turkey Creek Basin.

Table 2.1 Land cover fractions in the Turkey Creek Basin.

Land Cover	Fraction (%)
Water	0.4%
Pasture	30.7%
Crop	61.4%
Forest	3.9%
Shrubland	0.6%
Bare Soil	1.5%
Urban/Roads	1.5%

Table 2.2 Average slope (%) by land cover in the Turkey Creek Basin.

Land Cover	Slope (%)
Pasture	5.3
Urban	5.7
Forest	12.0
Cultivated	2.5
Stream	7.0
Bare	6.0
Rangeland	5.6
Water	0.0

3 - SWAT Management and Soil Nutrient Input Data

Management and soil test phosphorus (STP) are landcover specific. Each landcover type is managed in a different way. Fertilization influences STP, thus the two are linked. Information from past modeling projects, local agricultural extension agents and OSU crop recommendations were used to formulate management operations for each landcover type. Extension agents in all counties in the Turkey Creek basin were contacted. However, only Keith Boevers (Kingfisher County) and Bart Cardwell (Garfield County) replied with information used to refine these management practices.

Commercial Fertilizer Usage

Commercial fertilizers are used on pastures, urban areas, and cultivated areas. No reliable estimates of fertilizer sales or usage exist for this area. Dramatic shifts in the geology and fraction of arable land across counties in the basin reduce the applicability of county level estimates. This reason coupled with limited county level data suggest that the experience of local extension agents and OSU fertilizer recommendation are likely more reliable. Fertilization and yield goals of wheat are well established.

Urban areas were fertilized with 100 lbs/acre nitrogen, a rate determined from previous modeling efforts (Storm et al., 2005). Since nitrogen loss is not a focus of this effort, the actual rate has minimal impact. Cultivated areas received both nitrogen and a small amount of phosphorus as average STP results (60 lbs/acre) indicate only a mild phosphorus deficiency. Cultivated areas defined by the AAI classified landcover were determined to be wheat, which received 60 lb/acre of nitrogen and 12 lbs/acre P_2O_5 per year. These rates were estimated from Storm et al. (2005) a modeling project in the neighboring Cobb Creek Basin, and were not disputed by local sources.

Pastures received nitrogen only, at a rate of 50 lbs/acre. STP for pastures averaged 71 lbs/acre which indicates no phosphorus deficiency. According to local sources, only about half the pastures are fertilized, and those that are get about 100 lbs/acre (2 ton/acre forage yield goal). Again since nitrogen is not the focus, these rates are of little concern.

Soil Test Phosphorus

STP data are required by the model to set the initial amount of phosphorus in the soil. The amount of phosphorus in the soil is tracked on a daily basis by SWAT, and thus these data are only used on the first day of the simulation. STP data for wheat were gathered from the OSU Soil, Water & Forage Analytical Laboratory (1994 to 2004). Wheat STP county averages were weighted by the fraction of each county in the basin to estimate the basin average. The average 60 lbs/acre, was used in the SWAT model for all cultivated areas. Pastures averaged 71 lbs/acre using the same method. All other landcover were set to a value of 15 lbs/acre as no data exists to characterize them. Fifteen lbs/acre STP was assumed to be an approximate background value for the area. Unmanaged areas are rarely soil tested.

Management Operations

A uniform set of management practices was required for each land cover. It is not our intent to simulate every combination of practices which occur in the basin since we do not have sufficient information to generate management scenarios on a field by field basis. We chose a reasonable set of management operations by land cover only. This approach is commonly used in basin scale modeling efforts. Curve Numbers selected for each land cover type are given in Table 3.1.

Pasture

Pastures were simulated as Bermuda grass and were assumed to be grazed all year. Grazing was assumed to occur when there was more than 1800 kg/ha of biomass available. This equates to about 4 inches of forage. Commercial fertilizer was applied April 1 each year. These pastures were hayed once on August 1 of each year.

Shrubland

Shrubland was considered unmanaged, ungrazed, and brushy.

Wheat

Wheat was assumed to be grazed and harvested for grain. Wheat was planted September 1. Grazing begins November 1 and continues until March 1 at a stocking rate of 1/3 animal unit per acre. Grazing was not allowed if the standing biomass was less than 800 kg/ha. Harvest was set at June 20 and the field was disked shortly after for weed control. Fertilization was just prior to fall tillage which consisted of a chisel and finishing harrow. Tillage was complete just prior to planting.

Urban

Urban management was set to represent typical turf management. Turf was maintained at 2000 kg/ha of biomass, and excess biomass was converted to residue on a daily basis. This simulated mowing without removal of the grass clippings. Fertilization occurred April 1 each year.

Bare

The “Bare” land cover category covered only 1.5% of the basin. Bare areas were determined via careful examination of aerial photography to be pastures with little vegetation. These areas were likely transitory in nature. Only a very small fraction appeared to be habitually bare for long periods of time. We therefore selected a poor condition pasture type management. Grazing only occurred when there was more than 500 kg/ha of biomass available, which is less than1/3 the grazing cutoff used in other pastures. This equates to about 1.5 inches of good condition forage. No commercial fertilizer was applied. These areas were not hayed.

Forests

Forested areas were unmanaged and simulated as mixed forest, primarily deciduous.

Table 3.1 Curve Numbers used in the SWAT model by land cover type.

SWAT Land Covers	Type	Condition	A	B	C	D
Wheat	Small Grains Contoured	Good	61	73	81	84
Bare	Pasture	Poor	68	79	86	89
Pasture	Pasture	Fair	49	69	79	84
Urban	Pasture	Good	39	61	74	80
Forest	Woods	Good	25	55	70	77
Shrubland			39	61	74	80

4 - Gridcell Model

The SWAT model can be run using a grid-cell based discretization scheme. However no interface exists on which to generate the vast input files required. A traditional grid-cell model is simply not feasible given the currently available computer technology. The Turkey Creek basin contains 10,834,080 - 10 meter gridcells. The resulting model would require 125 days to run on a 2800 MHz desktop computer. This example illustrates why there has been no development in SWAT grid-cell interfaces. For the purpose of targeting fields with high sediment and phosphorus yields, we made some simplifications to reduce the time required to run the model without adversely effecting the quality of the results.

Model Simplifications

The method for simplifying the model is to reduce the spatial variability of GIS data used in the SWAT model where possible. To reduce the number of gridcells to be modeled, we modeled only unique grid cells, and applied those results to all matching grid cells within the data set. Many gridcells are identical due to a high correlation between soils, landcover, and slope. We eliminated weather variability by using only a single weather station. STP values were constant for each landcover. Slopes were rounded from a continuous surface to the nearest percent to reduce the number of unique combinations. The result is only 7,407 unique grid cells in the Turkey Creek Basin, a 1,463 fold (146,300%) reduction. The resulting model required only 4 hours to run on a desktop computer.

Nutrient and Water Quality Data

Insufficient nutrient and water quality data exist with which to calibrate the SWAT model. Calibration is the process by which a model is adjusted to make its predictions agree with observed data. No recent streamflow data exist within the basin. The only streamflow gage was Turkey Creek near Drummond, which was taken out of service in 1970. The model cannot be calibrated for streamflow without several years of observed stream flow records.

Some water quality data have been collected in recent years. The OCC collected data from 1998 to 2003, and the US Geological Survey (USGS) had data from 2002-2003. Unfortunately without daily streamflow these data are of little utility for the calibration of a model or the prediction of sediment and phosphorus loads. For this reason the model was not calibrated for nutrients either. However, because the model is being used to generate relative predictions this is not viewed as a serious limitation.

SWAT Denitrification Modification

The SWAT model may dramatically over predict denitrification. Denitrification is loss of plant available nitrogen as gaseous nitrogen by bacteria under reduced oxygen or anoxic conditions. The primary parameter governing denitrification (a water content threshold value of 0.9) is not editable by the user. A specialty compiled version of the SWAT model was prepared using a less aggressive parameters setting (a water content threshold value of 1.1) . This adjusted model was demonstrated to perform better in the Cobb Creek Basin which is just south of Turkey Creek (Storm et al., 2005). The modified model was used for all simulations of Turkey Creek.

Model Details

The soils, landcover and slope data layers were combined in ArcView to generate 7,407 unique combinations (Figure 4.1). Each of these 7,407 unique grid-cell types were run one at a time in a single HRU SWAT model. All SWAT parameters not specifically detailed in this report were left at default values. Significant software development was required to achieve this level of automation. The Visual Basic 6.0 source code is given in Appendix B. The AvSWAT interface was used only to delineate the precise drainage basin of Turkey Creek.

Discussion

The use of SWAT for targeting is appropriate with an uncalibrated model since the model is used in a “relative” mode, i.e. it is not intended to generate absolute predictions of load or concentration. The model is being used to locate areas with higher than average phosphorus and sediment loss. The actual magnitude of the loss is less important than the ratio of the loss at any given location to the basin average.

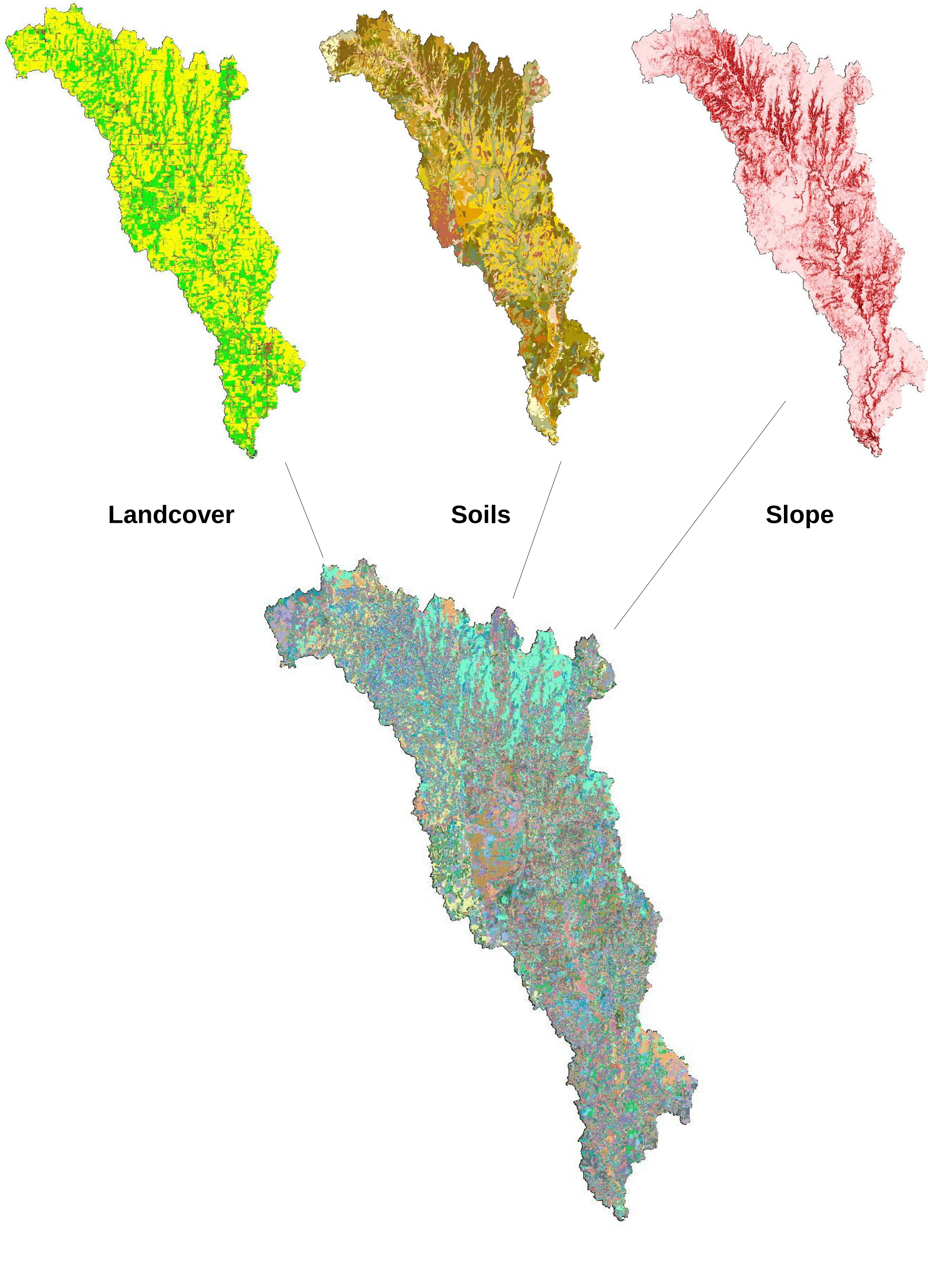

Figure 4.1 Unique gridcells are produced by unique combinations of landcover, soils, and slope. 7,470 unique combinations were modeled in the Turkey Creek Basin.

5 - Grid Cell Targeting Results

Sediment and Phosphorus Targeting

Some areas within the Turkey Creek Basin contribute disproportionately large phosphorus and sediment loads. The SWAT 2000 Model predicted that 45% of the phosphorus and sediment originate from only 10% of the basin. These areas would be ideal sites to implement erosion control practices. Figure 5.1 illustrates how only a small portion of the basin contributes a large fraction of the total load. Both sediment and phosphorus load follow almost identical curves, indicating that phosphorus and sediment are linked. Phosphorus transport from cultivated fields is predominantly in sediment-bound forms.

The Turkey Creek Basin is 61% wheat, which has the second highest average sediment and phosphorus yield of all landcovers present in the basin. Table 5.1 lists sediment and phosphorus loss by landcover as predicted by the SWAT 2000 model. Bare areas had slightly higher sediment and phosphorus than wheat, but covered only 1.5% of the basin. This is likely due to the increased runoff from bare areas as compared to wheat fields even though they have some vegetation year round.

Wheat fields were more likely to be targeted than any other landcover. Figure 5.2 illustrated the difference in landcover composition between targeted and non-targeted areas. These differences are given in greater detail in Table 6.2, which breaks the basin into classes based on their sediment load. For example the 0% -2.5% class represents the worst 2.5% of the basin, while the 75%-100% class represents the 25% of the basin with the least sediment yield. Landcovers such as forest and shrubland which do not generate much sediment are primarily in the 75% to 100% class. Only classes less than 10% were considered targets.

The grid-cell model predicts sediment and phosphorus yields with high spatial detail (Figures 5.3 and 5.4). Targeted areas are defined at the worst 5% and 10% of the basin. These maps are given in Figures 5.5 and 5.6. The detail of these maps cannot be appreciated at the scale shown in this document. Larger 36" by 48" maps were developed to show these areas in more detail for use by OCC field personnel. Figure 5.7 illustrates a small section of the basin which is heavily targeted on aerial photography. Often only a section of a field is targeted. This is often a steeper portion of the field or a more erosive soil. Figures 5.8 - 5.10 show the spatial variability in slope, hydrologic soil group, and erodibility across the basin. These variables often drive the targeting as they strongly influence erosion.

Fecal Coliform Targeting

The SWAT model is not the best tool with which to locate sources of fecal coliform. Fecal coliform is generally associated with the application of animal manures. Manure may be directly deposited by animals or stored and spread by humans. Manure deposited in streams or riparian areas may directly contribute to coliform counts. Circumstances which lead to contamination by fecal coliform are very site specific, which make targeting sources at the basin scale difficult. We simply do not have enough information about the location and management of animals in the basin to generate reliable targeting information for fecal coliforms.

Concentrated Animal Feeding Operations

Because fecal coliforms come from animals, areas with high concentrations of animals are more likely to contribute excess fecal coliforms. However, the actual contribution is highly dependant upon site specific management and stream proximity. The Oklahoma Department of Agriculture keeps records of Concentrated Animal Feeding Operations, which are often thought to be sources of fecal coliforms. Only two registered CAFOs exist in the basin according to their records. However, upon inspection via aerial photography at the listed coordinates, no CAFOs were found. Locations listed are often the residence of the owner and not the location of the facility. This is a documented limitation of these data which severely limits their utility for environmental studies. Phone interviews with county extension agents (Tommy Puffenberger - Alfalfa county, Keith Boevers - Kingfisher County, Jeff Biedwell - Major County, Bart Cardwell - Garfield County) and careful review of aerial photography revealed no significant CAFOs in the area. The largest facility identified was a dairy with approximately 350 animals just east of Lahoma in Garfield County. Swine CAFOs were identified just outside the watershed boundary in Kingfisher County. Several sources indicated that the City of Lahoma waste water lagoons have been compromised by flood water in the recent past.

Targeting

Without additional information, fecal coliform targeting was performed using SWAT 2000 predicted runoff volume, stocking rates, and grazing durations. The average annual stocking rate was calculated for each grid cell in the basin. Pastures were assumed to have an average annual stocking rate of 0.167 au/acre while wheat had a stocking rate of 0.11 au/acre average. This value was multiplied by the SWAT predicted runoff volume for that gridcell. This produces an index which identifies areas with higher concentrations of cattle and high runoff. The result is given in Figure 5.11. This approach only attempts to account for fecal coliform transported in runoff from unconfined animals outside riparian areas. Cattle intrusion into riparian areas and areas of high animal density are significant, even dominant sources when present. Septic tanks and other human waste sources may be significant. We do not have enough information to account for these sources.

The fecal coliform targeting presented in this report has severe limitations and should be used with these limitation in mind. In order to help address these limitations, bacteria data from surface water sampling will be required to calibrate the model, and detailed spatial data on animal stocking rates will need to be input into the model. Even with these additional data, improved SWAT model routines will likely need to be developed in order to accurately target potential bacteria sources.

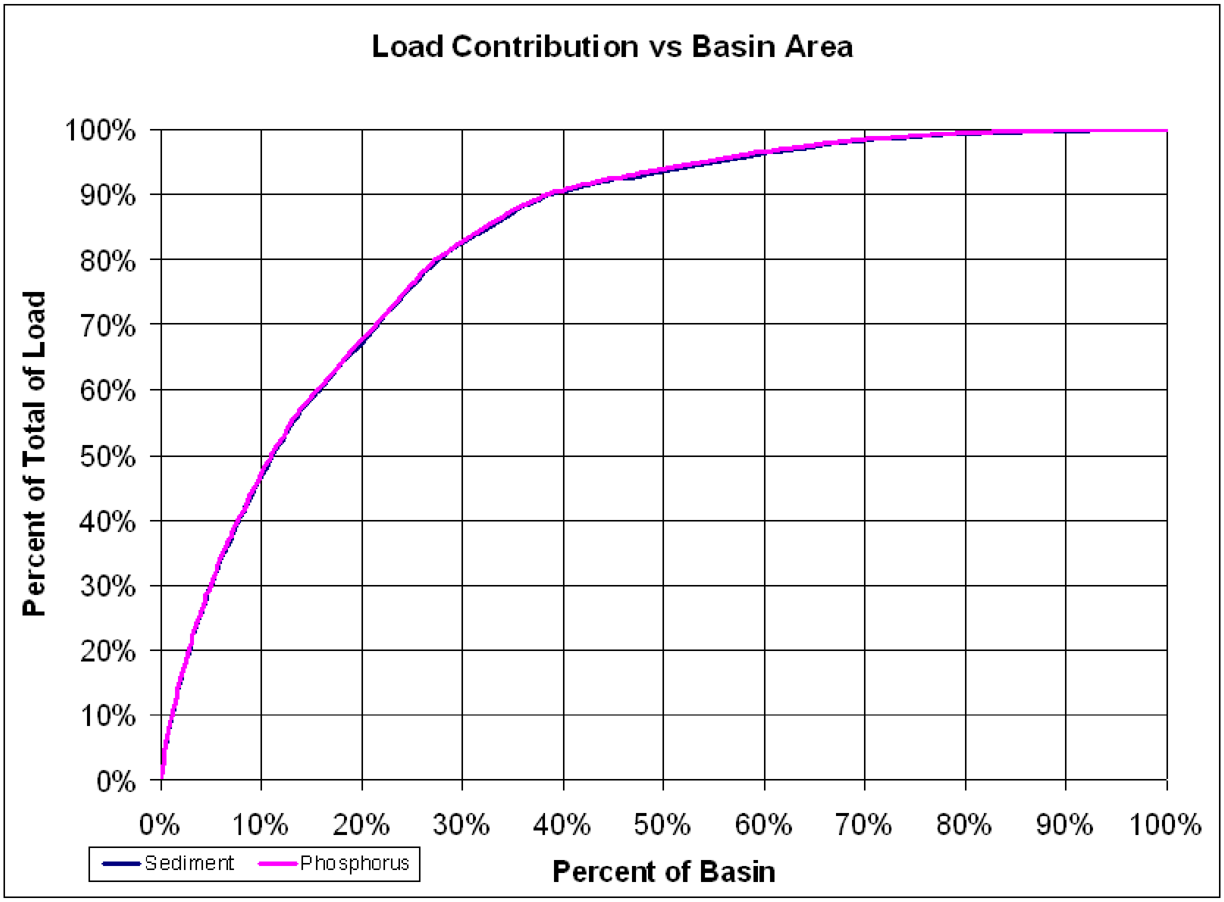

Figure 5.1 Faction of basin phosphorus and sediment loads from upland sources vs fraction of basin area. Based on SWAT simulations. Sediment and phosphorus curves are nearly identical.

Table 5.1 Average sediment and phosphorus by landcover in the Turkey Creek Basin as predicted by the SWAT 2000 model.

Landcover	Fraction of Basin (%)	Surface Runoff (mm)	Sediment Yield (Mg/ha)	Total Phosphorus (kg/ha)
Bare	1.5%	206	5.95	2.12
Forest	3.9%	38	0.009	0.01
Pasture	30.7%	114	0.42	0.24
Shrubland	0.6%	65	0.055	0.03
Urban	1.5%	149	0.42	0.17
Water	0.4%	0	0.00	0.00
Wheat	61.4%	138	5.12	2.09

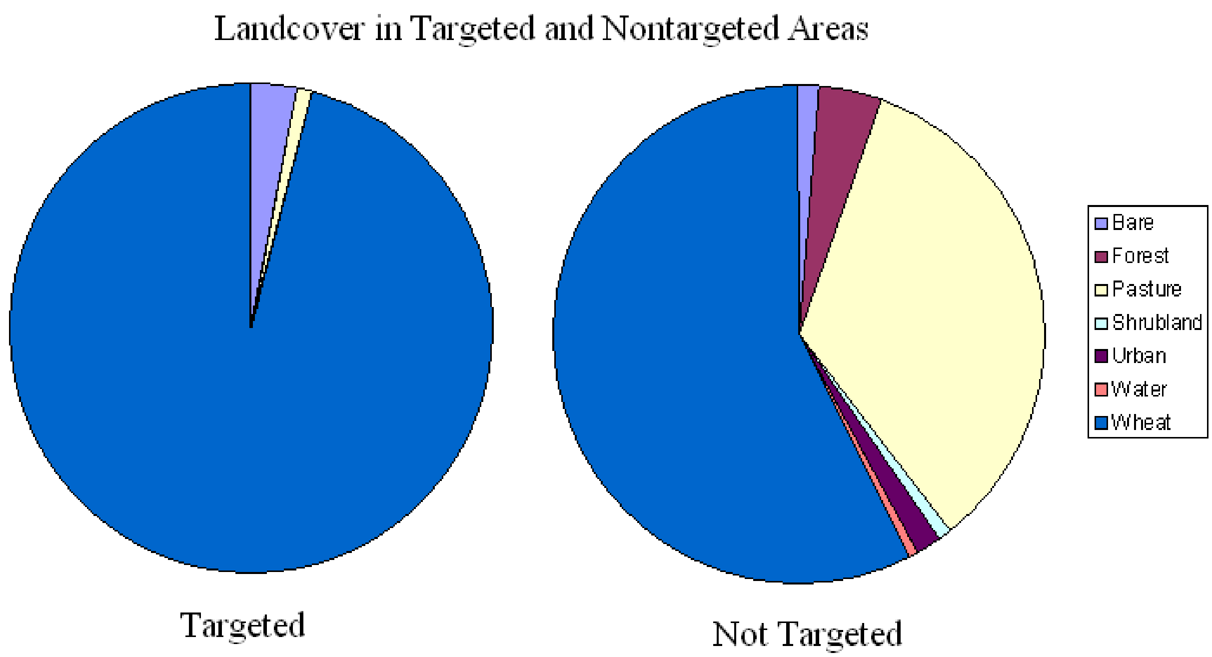

Figure 5.2 Landcover in areas targeted at the 10% or greater level and in the remainder of the basin.

Table 5.1 Landcover breakdown at different targeting levels.

	Landcover Breakdown per Targeting Level									
Landcover	**0%-2.5%**	**2.5%-5%**	**5%-10%**	**10%-15%**	**15%-20%**	**20%-30%**	**30%-40%**	**40%-50%**	**50%-75%**	**75%-100%**
Bare	3.3%	2.8%	2.5%	3.3%	0.7%	1.3%	2.5%	2.3%	1.1%	0.4%
Forest	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	16.0%
Pasture	0.2%	0.3%	1.8%	7.7%	2.7%	7.2%	26.2%	38.3%	21.3%	72.2%
Shrubland	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	2.0%
Urban	0.1%	0.0%	0.1%	0.3%	0.0%	0.2%	1.2%	2.2%	1.4%	3.3%
Water	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.8%
Wheat	96.5%	96.9%	95.6%	88.7%	96.5%	91.2%	70.1%	57.1%	76.0%	4.3%

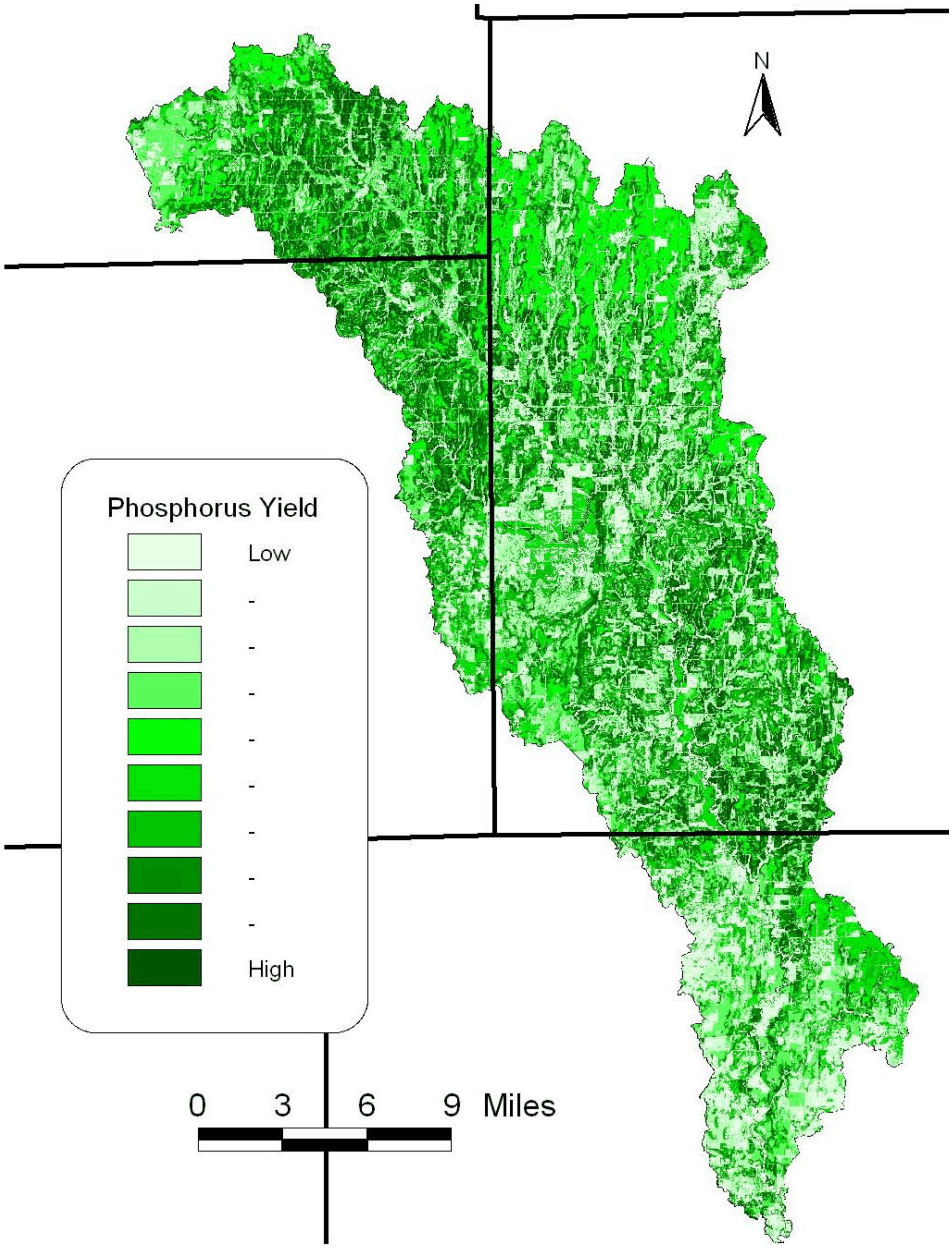

Figure 5.3 Relative phosphorus yield as predicted by SWAT 2000 in the Turkey Creek Basin.

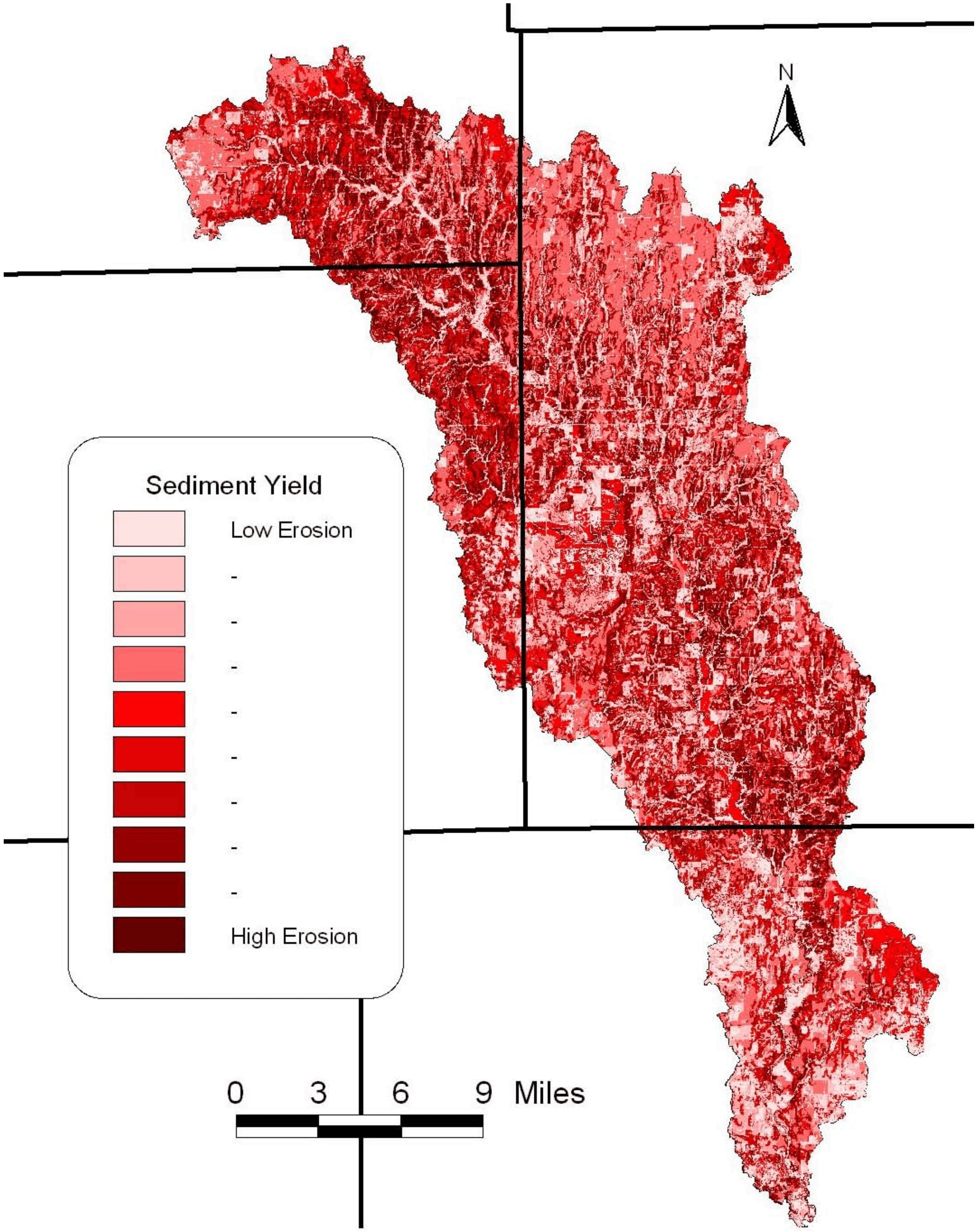

Figure 5.4 Relative sediment yield as predicted by SWAT 2000 in the Turkey Creek Basin.

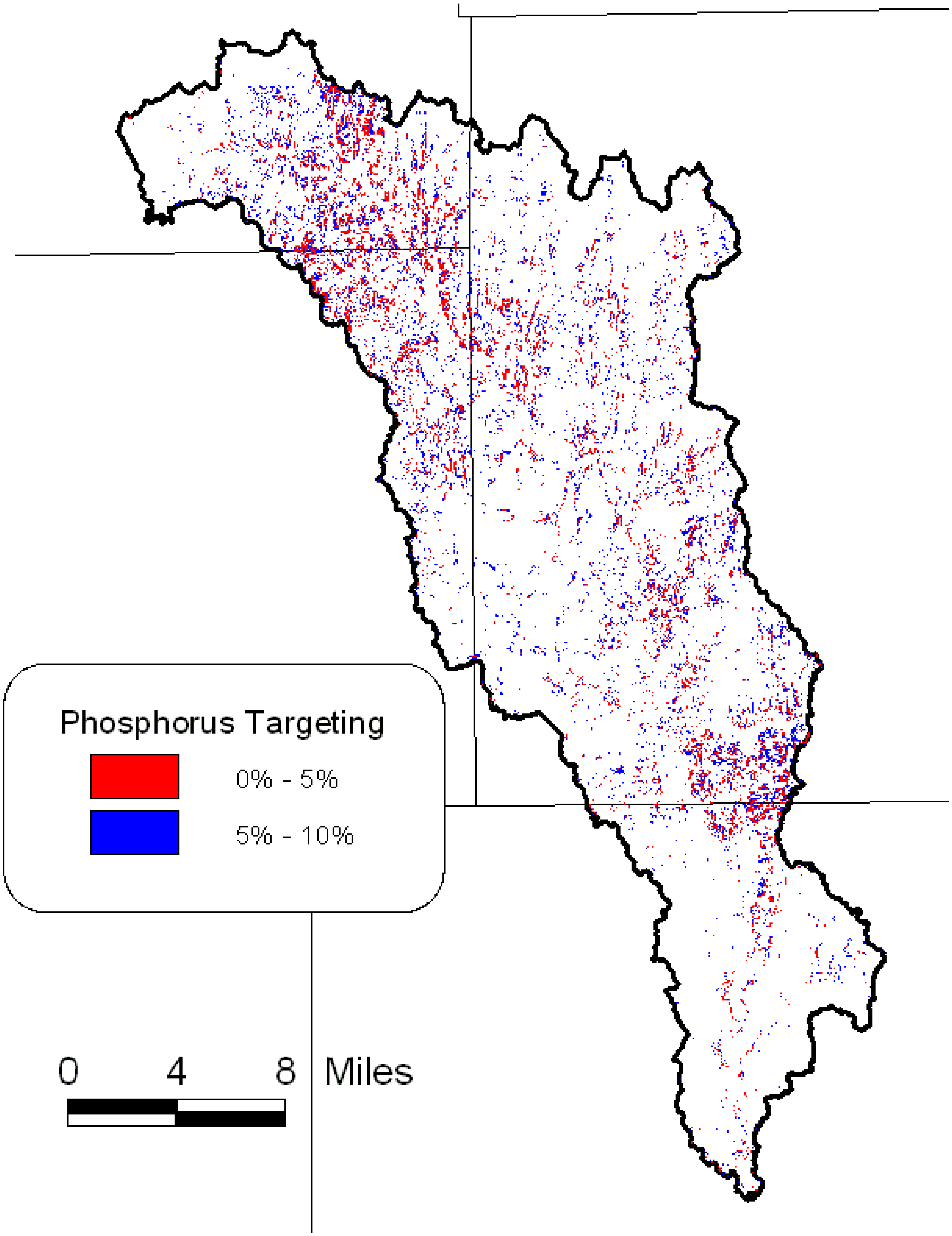

Figure 5.5 Phosphorus targeting as predicted by SWAT 2000 in the Turkey Creek Basin.

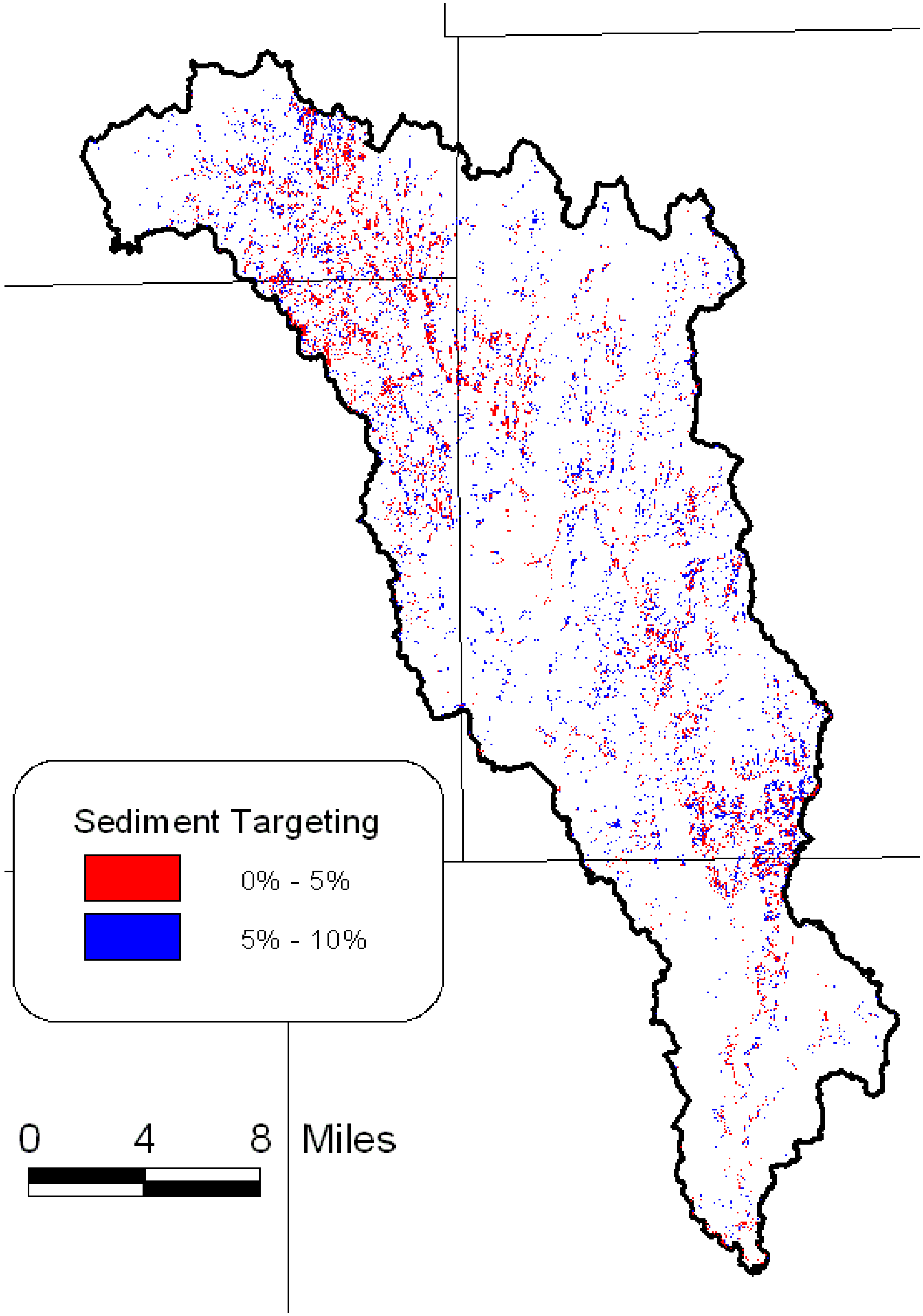

Figure 5.6 Sediment targeting as predicted by SWAT 2000 in the Turkey Creek Basin.

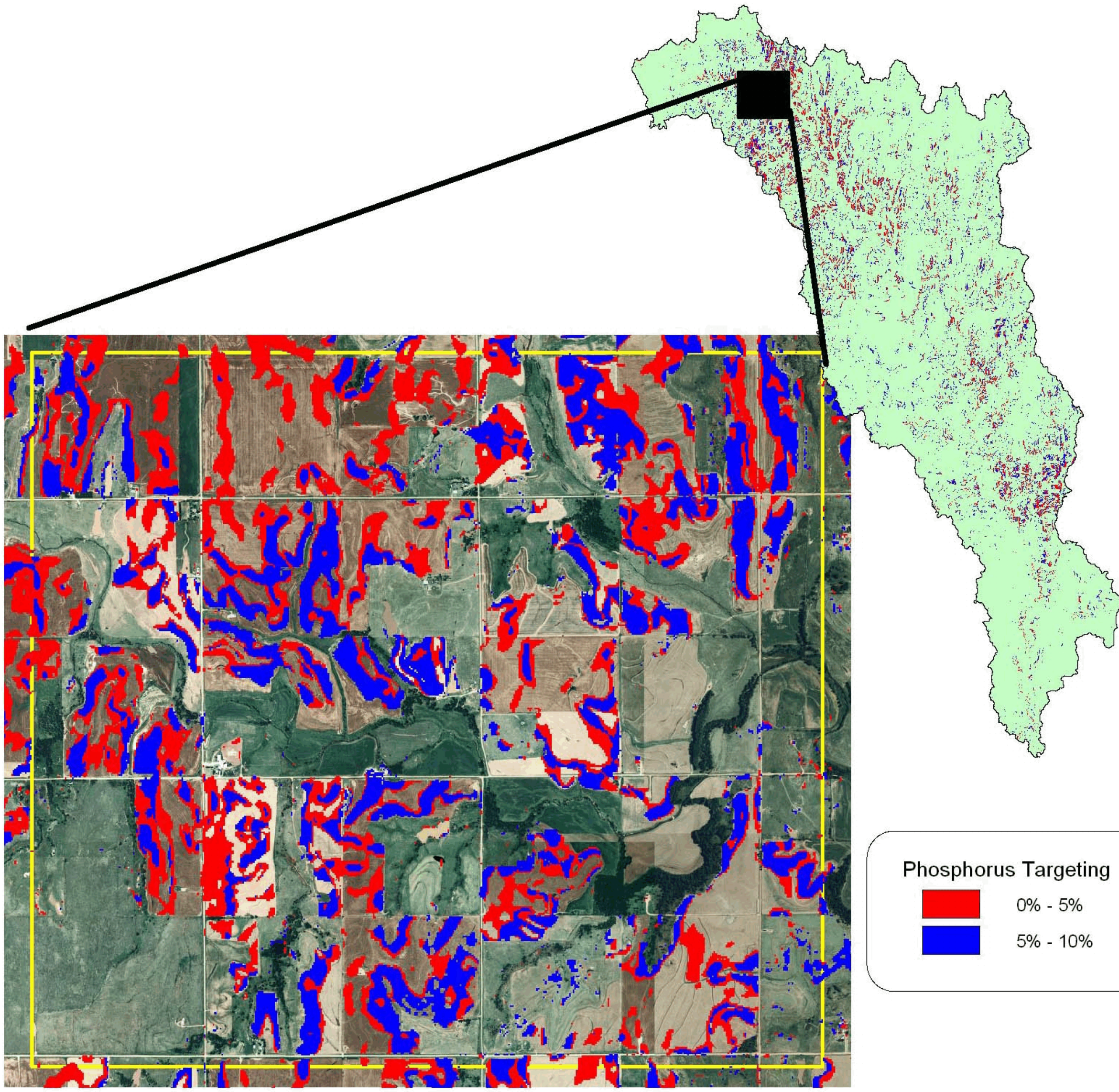

Figure 5.7 Close up view of phosphorus targeting on aerial photography. As predicted by the SWAT 2000 model in the Turkey Creek Basin.

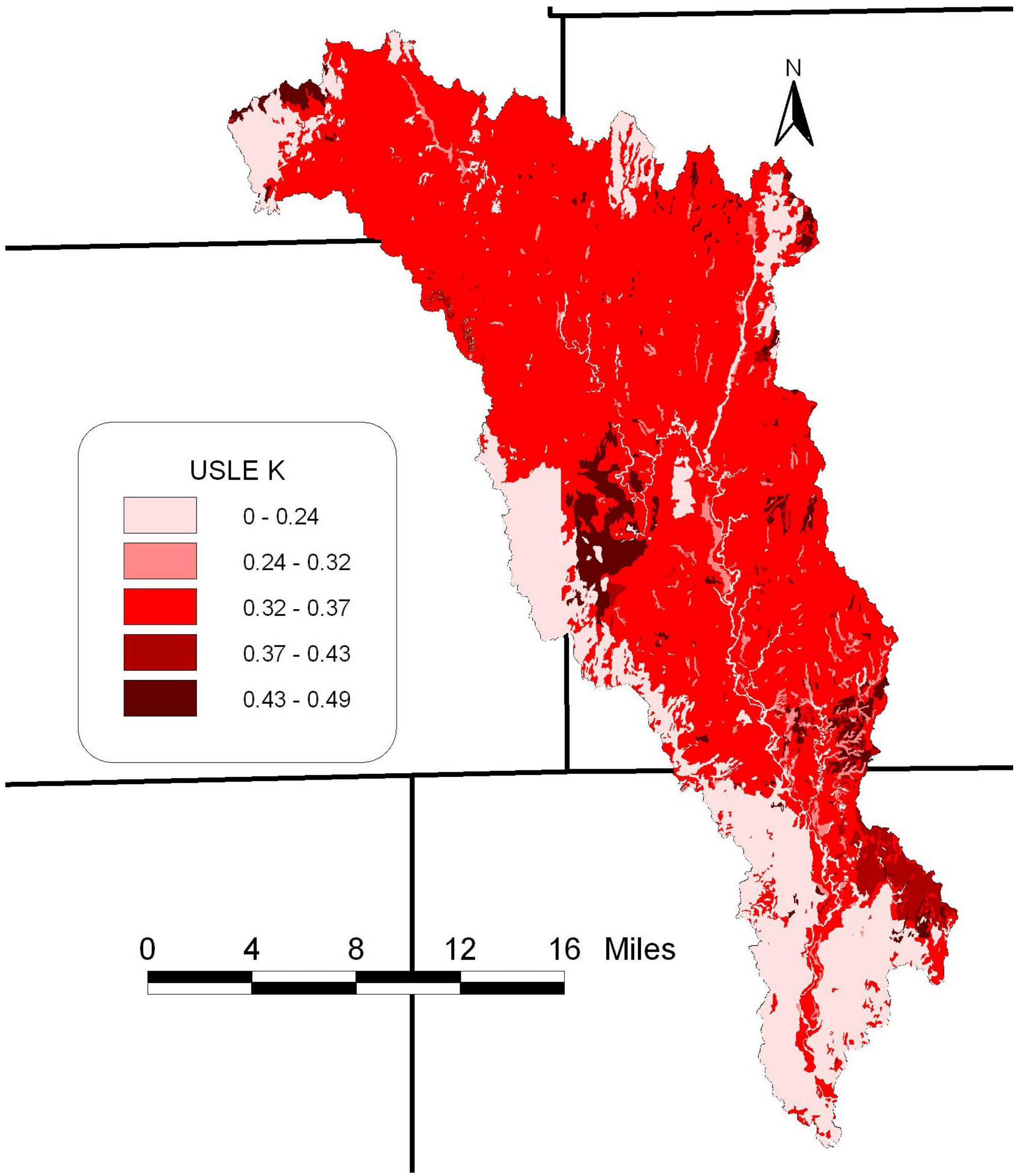

Figure 5.8 Soil erodibility as defined by Universal Soil Loss Equation (USLE) K factor. Derived from State Soil Geographic (SSURGO) data.

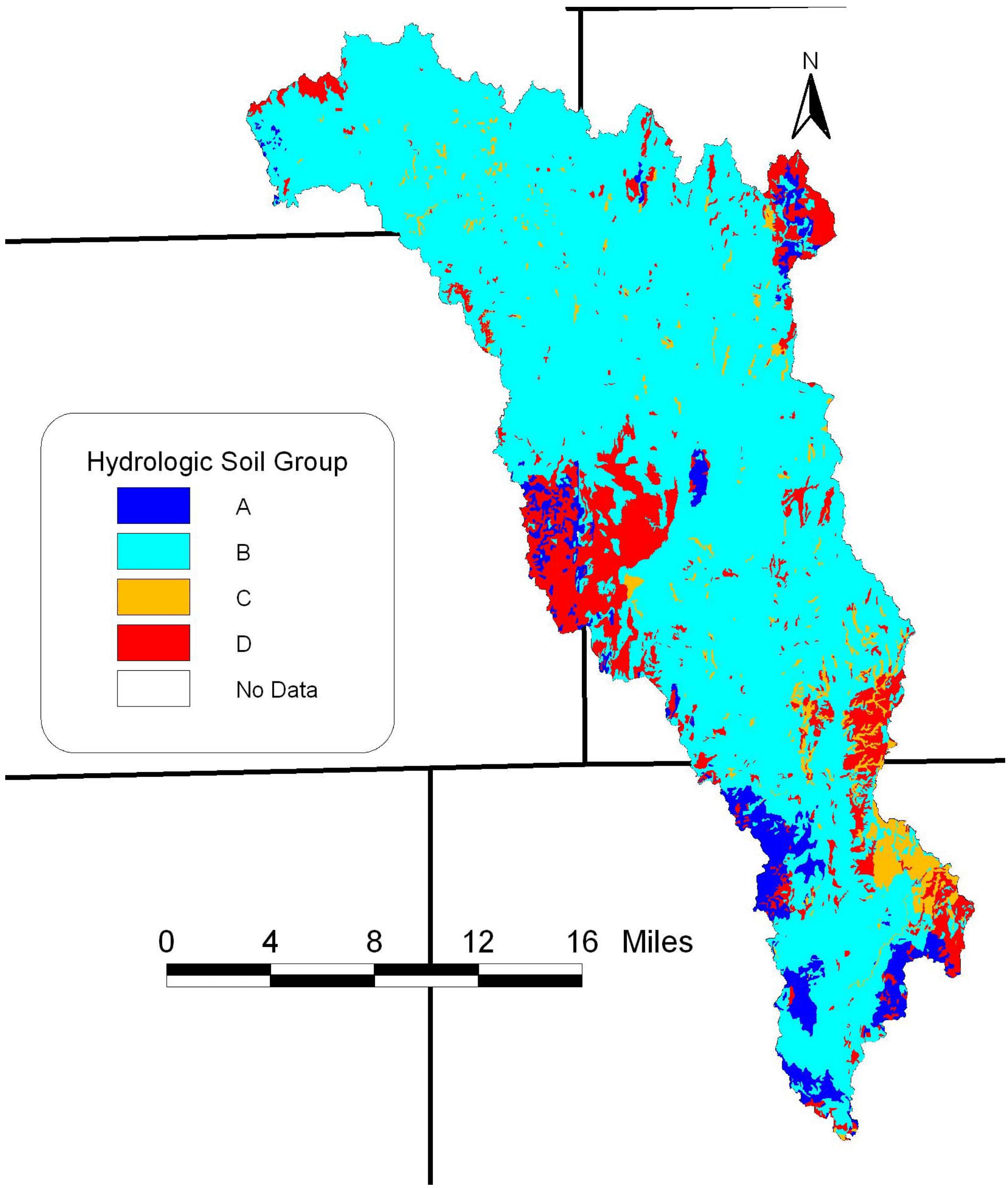

Figure 5.9 Soil hydrologic group, derived from State Soil Geographic (SSURGO) Data.

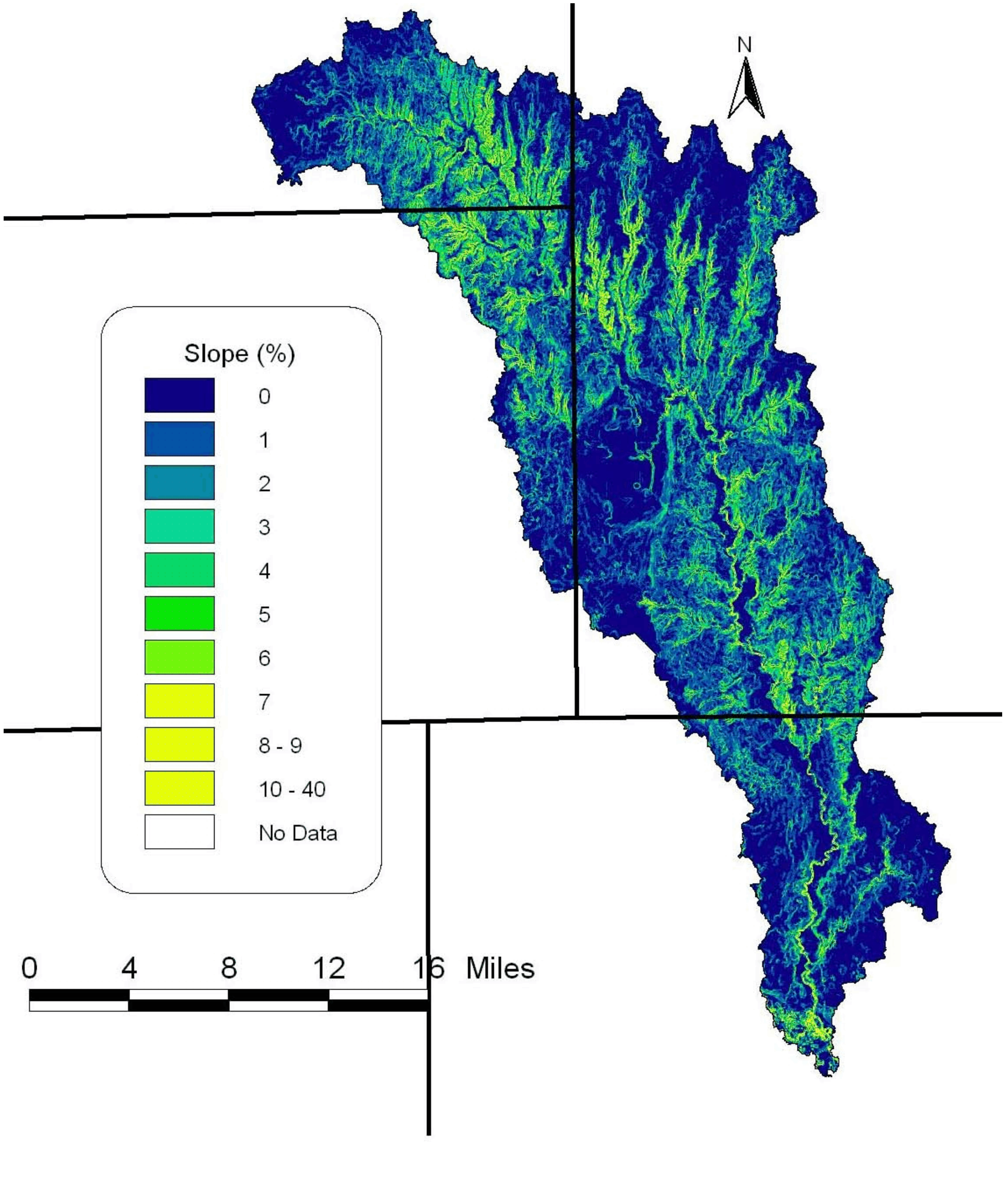

Figure 5.10 Slope derived from 10 meter National Elevation Dataset (NED).

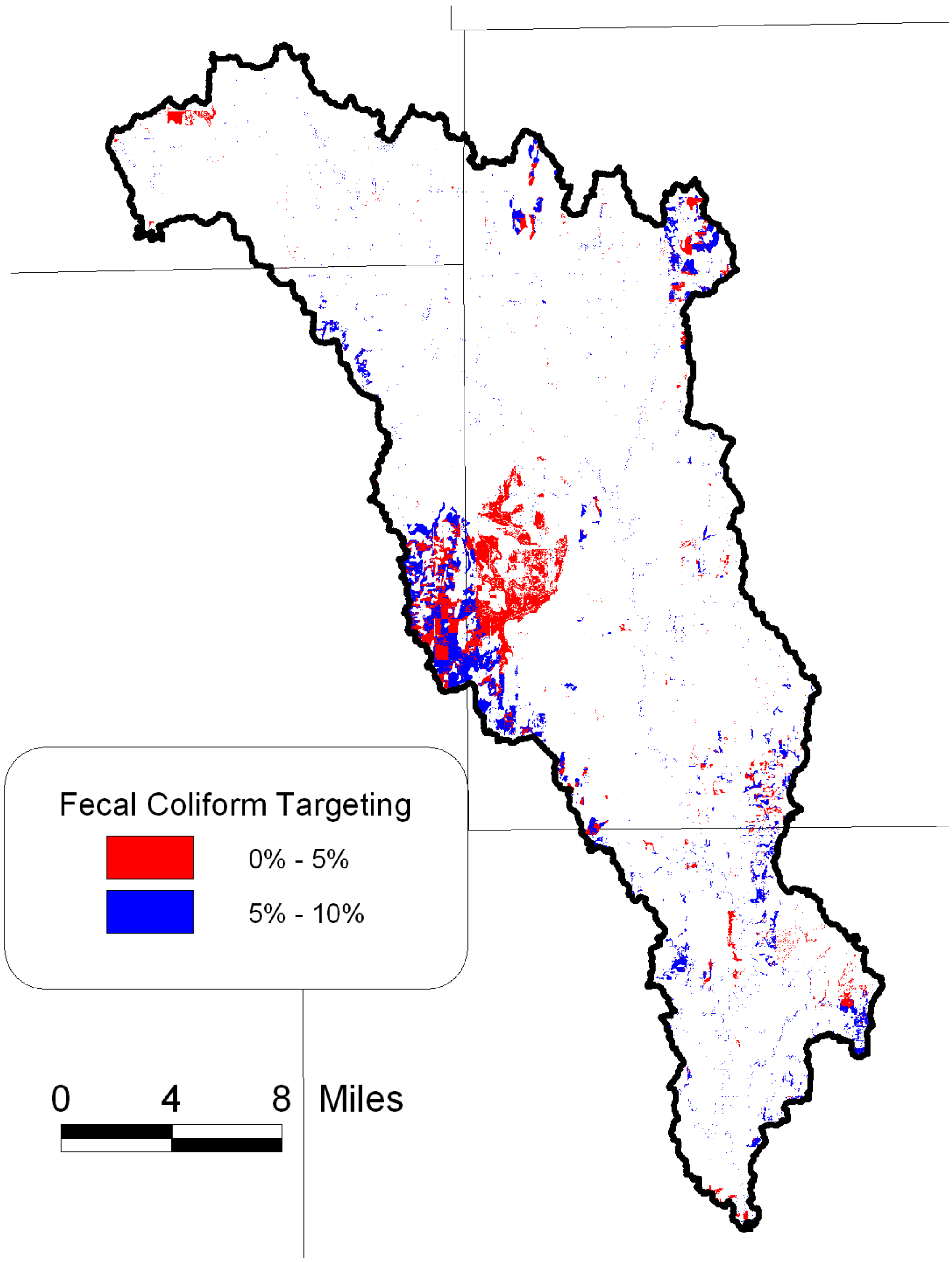

Figure 5.11 Fecal coliform targeting from upland sources the Turkey Creek Basin. Based on SWAT predicted runoff and average stocking rate. Does not include site specific sources such as cattle in riparian areas, feeding areas, CAFOs, etc.

6- Evaluating Imagery for Riparian Targeting

Targeting critical sediment source areas requires accurate and current landcover data. These data are typically generated by one of two ways: extensive ground surveys or more limited ground truthing in conjunction with aerial photographs or satellite imagery. For large areas, aerial photography and satellite imagery are far less expensive and less time consuming than ground surveys. Using landcover, soil, and topography, targeting for BMPs can be performed using hydrologic/water quality models.

In previous imagery comparison studies, differing conclusions were drawn based on the level of detail needed. In a satellite imagery and aerial photography comparison, Mosbech et al. (1994) studied large tracts of arctic land. It was concluded that using satellite imagery was less expensive and less time consuming than using aerial photography. However, it was also deduced that the satellite imagery was inadequate at identifying minor differences in landcover (Mosbech et al., 1994). In a South African riparian study, Rowlinson et al. (1999) stated that satellite imagery should only be used for areas of large continuous landcover. It was concluded that aerial imagery was the most accurate and the most cost effective for the high level of detail needed (Rowlinson et al., 1999). For the project presented here, much like in Rowlinson et al. (1999), identification of fine features is vital for accurate erosion targeting.

Imagery

This project utilized aerial photography and two types of satellite imagery, SPOT 5 and Landsat 7 (Figure 6.1). The Landsat program is a joint effort by the United States Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA). Landsat 7 was launched in 1999, and its primary sensor, the Enhanced Thematic Mapper (ETM), provides multispectral imagery at a 30 m resolution. The SPOT program is primarily funded through Centre National D'Etudes Spatiales (CNES), the French space agency. SPOT 5 was launched in 2002 with a multi-spectral resolution of 10 m.

Objectives

The primary objective of this project was to compare the accuracy of classified SPOT 5 and Landsat 7 imagery for identifying landcovers thought to be critical sources of erosion in the riparian corridor. Several secondary objectives included:

- Compare total classified land cover percentages between images
- Develop a method to quantify the extent of misclassified areas
- Develop visuals to illustrate location and magnitude of errors
- Perform cost comparison between aerial photography, Landsat 7, and SPOT 5
- Evaluate riparian corridor width for impacts on accuracy for erosion targeting

Riparian Corridor and Landcover Development

A private contractor, Applied Analysis, Inc. (AAI), obtained the raw satellite imagery and performed an unsupervised landcover classification for the entire watershed. Only the perennial streams were analyzed for this portion of the project. Initially, data from the National Hydrography Dataset (NHD) was used to identify perennial and intermittent streams. However, these data contained significant errors in perennial and intermittent classification. The NHD data mislabeled all streams in Major County as perennial. In order to obtain correct stream type data, 1:24000 Digital Raster Graphs (DRGs) were used (Oklahoma State GIS Council). These DRGs were created from topographic maps dating between 1969 and 1982. The perennial streams were digitally adjusted to account for stream migration occurring between the creation of the topographic maps and recent aerial photographs.

Based on the perennial stream layer, a 90 meter riparian buffer layer was created. Land cover within the buffer was manually digitized from National Agriculture Imagery Program (NAIP) 2003 aerial photography. For consistency, the same land cover categories utilized by AAI were used to digitize the aerial photography. These categories included:

- Water – visible water in stream beds or ponds
- Shrub – sparse woody vegetation
- Bare Soil – dry stream beds and areas of no vegetation
- Crop – cultivated areas with tramlines from farm equipment or obvious rows
- Forest – dense stands of trees
- Pasture – visually similar to crop but no signs of cultivation; differentiated from shrub by its higher management and fertility levels
- Urban – farm homesteads, roads, and commercial buildings

In order to minimize misclassifications in landcover digitized from aerial photography, ground truthing was performed on June 18th and June 30th, 2004. Next, 90, 60, and 30 meter riparian buffers were defined. For each buffer width, the percentage of each land cover type was calculated. Of the three landcovers, the landcover digitized from aerial photography was assumed to be most accurate due to a validation with ground truthing. These data will be referred to as the “truth”.

Analysis

The amount of area that was misclassified between each satellite image and the truth land cover was calculated using contingency tables. These tables displayed a matrix of the area in each dual classification. For targeting high erosion areas, a misclassification involving bare soil would have a greater impact than a misclassification involving forest. To compare the magnitude of errors between image types, it was necessary to differentiate between error types. In order to do this, weighting factors were needed to quantify each error in a non-arbitrary fashion. While sediment yields were utilized for this purpose, they were not intended to be interpreted as true measures of erosion.

Nearly all sediment yields were extrapolated from two sources. The sediment yields for crop and forest were taken from a study of Fort Cobb watershed which is located approximately 100 km southwest of Turkey Creek (Storm et al., 2003a). Modeling results from Turkey Creek were not available at the time. The Ft. Cobb study was selected due to similar topography and precipitation to Turkey Creek. Due to their unavailability in Storm et al. (2003a), the sediment yields for shrub, pasture, and urban areas were taken from Storm et al. (2003b). Because most of the urban land cover in this study was county dirt roads, it was decided to use the sediment yield for roads (Storm et al., 2003b) as the weighting factor for the urban land cover. None of the available studies provided sediment yields for bare soil. In order to estimate it, a USLE Cover Management (C) factor ratio method was used. Due to the proportional relationship between the C factors and the sediment yields in the USLE, the bare soil sediment yield was estimated to be 4.5 times the crop sediment yield or 28.7 Mg/ha (Haan et al., 1994).

Once the sediment yields were estimated, an error weighting factor matrix was calculated (Table 6.1). Errors were calculated as the difference in sediment yields based on the satellite imagery and the truth layer. This table provided a specific error value for each particular misclassification. Once the error matrix was completed, it was multiplied by the percent area contingency tables, yielding an area weighted error factor for each classification comparison.

The truth and satellite layers were converted to grids and combined. The combined grid contained an attribute table with a column of satellite derived land covers and a column of truth land covers. This was joined to a second table which contained the weighting factor for each type of land cover error. Images were then created based on the error associated with each area.

Results and Discussion

From the landcover percentage graph (Figure 6.3), it can be seen that the satellite classifications remain consistent with each other but not always with the aerial classification. This is especially apparent in the pasture and shrub categories. The relative likeness in appearance of these landcover types may be a possible source of error. For all three buffer widths, the satellite imagery identified a large percentage of shrub as pasture. However, due to the small weighting factors for errors between these categories, this error did not play a significant role in the overall net weighted error.

Taking the area calculations a step further, the contingency tables defined the buffer area percentage in each classification comparison. Table 6.2 shows that out of the entire 90 m buffer, 7.0% was forest and misclassified as pasture using Landsat 7, while 3.6% was forest and misclassified as pasture using SPOT. When all correct satellite classifications were summed in Table 6.22, Landsat 7's total accuracy was 45% while SPOT's total accuracy was 50%. Table 6.3 shows the total accuracy for all buffer widths.

Multiplying Table 6.2 by the error matrix (Table 6.1) and dividing by 100 percent allowed more quantifiable comparisons for use as targeting data. The resulting weighted error factors were summed over the entire table to give the net weighted error. Table 6.4 shows the net weighted error by buffer width. A negative error indicated that the satellite classification on average over predicted sediment yield as compared to the truth landcover. For example, when a forested area with a very small sediment yield was misclassified using the satellite as crop, which had a relatively higher sediment yield, the resulting error was negative. Likewise, a positive error indicated sediment yield was under predicted using the satellite imagery.

The negative errors identify areas where there was actually less erosion occurring than what the satellite classification indicated. If satellite images were used for targeting, these areas might be incorrectly identified as BMP investment sites. On the other hand, the positive errors indicated areas where there was actually more erosion occurring than shown by the satellite classification. If satellite images were used for targeting in these cases, areas with positive error may be missed for BMP implementation consideration.

As the buffer width changed, the net error changed for both image classifications. For the SPOT 5 classification, as the buffer narrowed, the bare soil/water errors in the stream channel became a larger percentage of the buffer. Because of the large weighting factor for bare soil errors, the net error increased. In reality, these bare soil areas within the channel should not be considered in the upland sediment yield estimates. Thus this increase in error was a result of the strict classification of bare soil as a highly erodible landcover regardless of its location. For the Landsat 7 classification, average error decreased as the buffer narrowed which suggested greater accuracy with narrower widths. Because its resolution was relatively large compared with the buffer width, this may have been a spurious conclusion. While the majority of the area was classified correctly using Landsat 7, small details were typically misclassified.

The error images allowed visual representation of the magnitude of the weighted errors (Figure 6.3). The darker blues indicated areas in which sediment yield was over predicted using the satellite classification as compared to the truth landcover. The darker greens indicated areas in which sediment yield was under predicted. White represented areas with no error. One possible source of error is that landowners rotate between crop and pasture. This was an unavoidable issue because all images were captured in summer 2003 while the ground truthing was performed in summer 2004. Aerial photographs were taken in summer 2003, the Landsat 7 images were captured on June 8, 2003 and the SPOT images were captured on May 27, 2003. These temporally coincidental effects and the varying quality of the individual aerial mosaics were sources of error.

Lastly, cost estimates in 2005 dollars were compared. Although the aerial images used in this project were purchased from the USDA Aerial Photography Field Office for $200, the cost to do an independent flyover is shown in Table 6.5. Also note that the raw imagery costs listed are for one Landsat 7 image and two SPOT 5 images. Though the study size was only 2,400 ha, this number of images was necessary based on location and would vary from project to project. For the Turkey Creek watershed, doubling the study area would increase the number of aerial photography scenes required but not the number of satellite scenes. Therefore, the aerial raw imagery cost as well as the aerial processing cost would increase but the satellite total costs would remain constant. This increased total cost of the aerials would exceed the total cost of the Landsat 7 imagery. Based on the number of images used in this project and the amount of manually classified area, it would be most cost effective to use aerial imagery on areas under twice this study size.

In general, with increasing area size, more images are needed. For large scale projects, satellite imagery is more cost effective than aerial photography (Figure 6.4). Landsat 7 imagery is more cost effective than aerial photography at greater than 5,000 ha and is always more cost effective than SPOT 5 imagery. SPOT 5 imagery is more cost effective than aerials at approximately 6,500 ha. However, it is important to note that the level of accuracy needed as well as cost must be considered in choosing imagery type.

Conclusions

The percent area comparison graph (Figure 6.2) showed that the classifications of the two satellite images were similar especially when compared with the manually classified aerial imagery. Also, the total accuracy (Table 6.3) was similar between the satellites. These factors, along with the cost comparison (Table 6.5 and Figure 6.4), indicate Landsat 7 is a better satellite option than SPOT 5 for this application.

There was not enough available data to make substantial conclusions regarding riparian corridor width effects on accuracy. It was determined that the accuracy was driven more by the size and type of features rather than the width of the buffer.

Considering the cost comparison, aerial images are recommended for study areas less than 5,000 ha and Landsat 7 images are recommended for areas greater than 5,000 ha. This critical number was approximately twice the study size of 2400 ha. These conclusions are based only on this study, which utilized one Landsat 7 image and two SPOT images. In general, for studies requiring fine-scale detail, aerial photography can be used cost effectively for areas up to 5,000 ha.

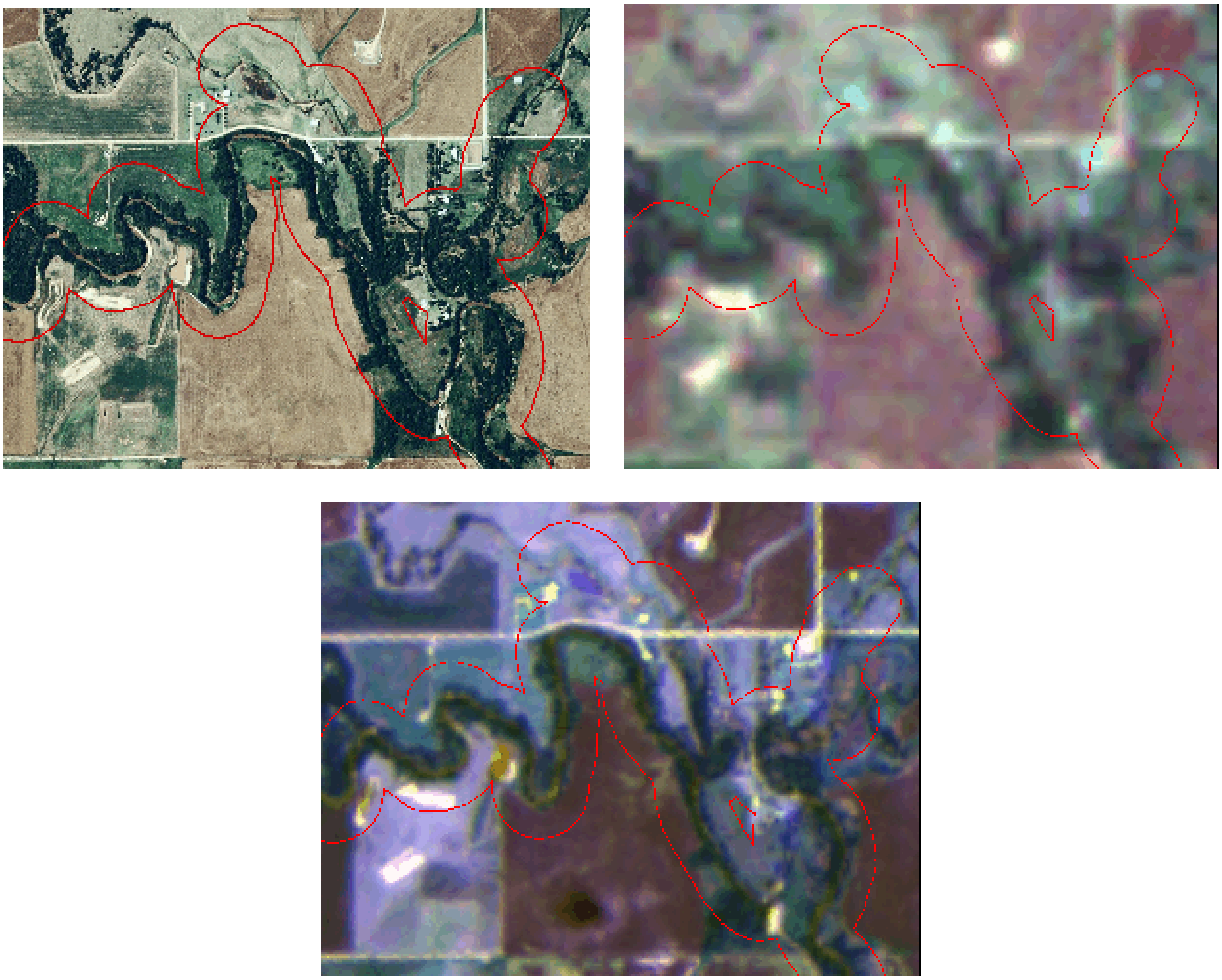

Figure 6.1 A 90 m riparian corridor in the Turkey Creek watershed (outlined in red) for different image types (listed clockwise): aerial photograph, Landsat 7 , and SPOT 5.

Table 6.1 Error matrix for landcover misclassifications composed of estimated sediment yield differences.

Truth	Satellite Imagery						
	Crop (6.38)[a,b]	Pasture (0.40)[c]	Shrub (0.20)[c]	Forest (0.01)[b]	Urban (13.3)[c]	Bare Soil (28.71)[d]	Water (0.00)
Crop (6.38)[a,b]	0	5.98	6.18	6.37	-6.92	-22.33	6.38
Pasture (0.40)[c]	-5.98	0	0.2	0.39	-12.9	-28.31	0.4
Shrub (0.20)[c]	-6.18	-0.2	0	0.19	-13.1	-28.51	0.2
Forest (0.01)[b]	-6.37	-0.39	-0.19	0	-13.29	-28.7	0.01
Urban (13.3)[c]	6.92	12.9	13.1	13.29	0	-15.41	13.3
Bare Soil (28.71)[d]	22.33	28.31	28.51	28.7	15.41	0	28.71
Water (0.00)	-6.38	-0.4	-0.2	-0.01	-13.3	-28.71	0

[a] Landcover (weighting factor in units of Mg/ha)
[b] Storm et al. 2003a
[c] Storm et al. 2003b
[d] Haan et al. 1994

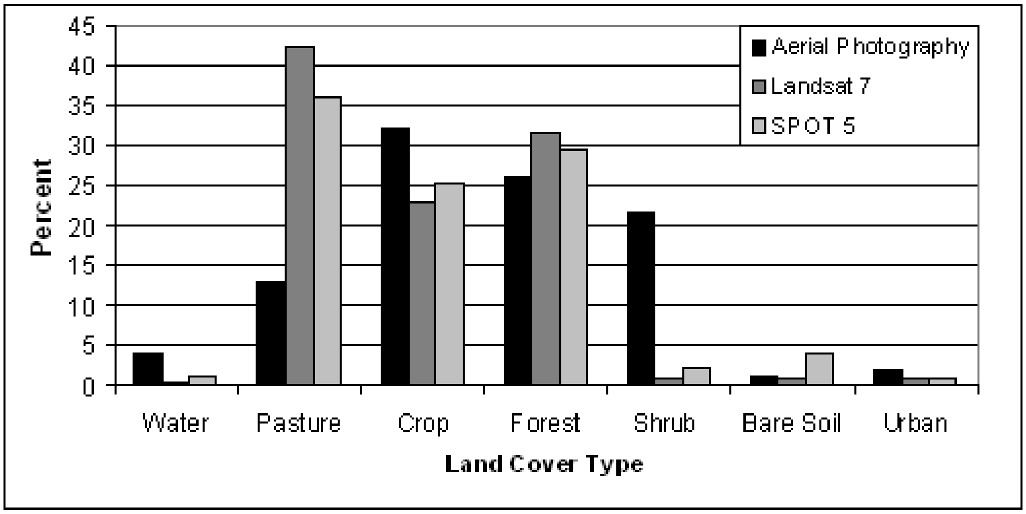

Figure 6.2 Ninety meter buffer landcover percentages by imagery for the Turkey Creek riparian corridor.

Table 6.2 Dually classified landcover percentages for Landsat 7 (a) and SPOT 5 (b) within the 90 m riparian corridor.

2a.		**Landsat 7 Satellite**							
		Crop	Pasture	Shrub	Forest	Urban	Bare Soil	Water	**Total**
Truth	Crop	17.7	10.0	0.19	3.53	0.42	0.14	0.06	**32.0**
	Pasture	0.57	9.93	0.20	1.98	0.08	0.16	0.04	**13.0**
	Shrub	2.06	12.9	0.24	5.89	0.23	0.25	0.08	**21.7**
	Forest	1.98	7.00	0.13	16.9	0.09	0.10	0.05	**26.2**
	Urban	0.21	1.13	0.08	0.26	0.14	0.03	0.02	**1.88**
	Bare Soil	0.17	0.50	0.02	0.42	0.01	0.05	0.02	**1.18**
	Water	0.32	0.91	0.02	2.67	0.02	0.07	0.04	**4.06**
	Total	**23.0**	**42.4**	**0.88**	**31.7**	**0.98**	**0.80**	**0.32**	**100.0**
2b.		**SPOT 5 Satellite**							
		Crop	Pasture	Shrub	Forest	Urban	Bare Soil	Water	**Total**
Truth	Crop	19.5	10.3	0.15	1.32	0.17	0.46	0.03	**32.0**
	Pasture	0.77	9.13	0.59	1.91	0.06	0.52	0.02	**13.0**
	Shrub	2.00	11.5	0.96	5.95	0.19	0.88	0.24	**21.7**
	Forest	1.25	3.60	0.38	19.7	0.05	0.86	0.22	**26.1**
	Urban	0.30	0.87	0.01	0.05	0.45	0.21	0.01	**1.90**
	Bare Soil	0.53	0.32	0.01	0.09	0.02	0.13	0.09	**1.19**
	Water	1.34	0.56	0.02	0.80	0.01	0.88	0.47	**4.09**
	Total	**25.7**	**36.3**	**2.13**	**29.9**	**0.95**	**3.94**	**1.07**	**100.0**

Table 6.3 Total percent accuracy for each buffer width by satellite type.

	Buffer Width		
Image Type	30 meter	60 meter	90 meter
Landsat 7	37.2	41.4	45.0
SPOT 5	42.0	47.5	50.4

Table 6.4 Average Weighted Error for each buffer width by satellite type in units of Mg/ha.

	Buffer Width		
Image Type	30 meter	60 meter	90 meter
Landsat 7	0.12	0.49	0.73
SPOT 5	-2.00	-0.84	-0.32

Table 6.5 Imagery cost comparison for the Turkey Creek watershed project in 2005 dollars.

Image type	Raw imagery cost per scene	Processing cost	Number of scenes	Total cost
Aerial Photography	$9,000	$2,600	N/A	$11,600
Landsat 7	$600	$20,000	1	$20,600
SPOT 5	$7,000	$30,000	2	$44,000

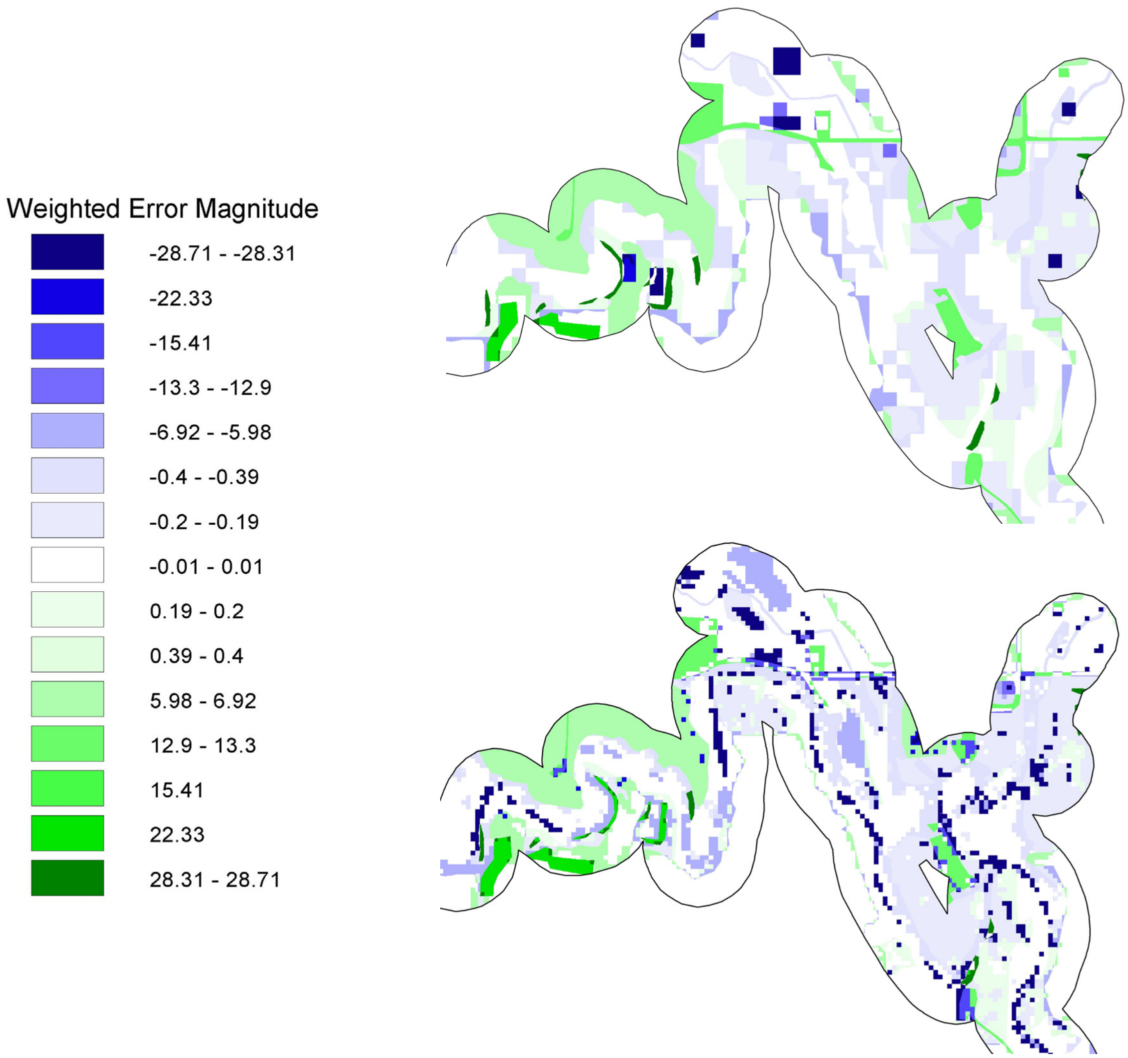

Figure 6.3 Weighted errors for a typical Landsat 7 (top) and SPOT 5 (bottom) ninety m buffer riparian corridor in the Turkey Creek watershed.

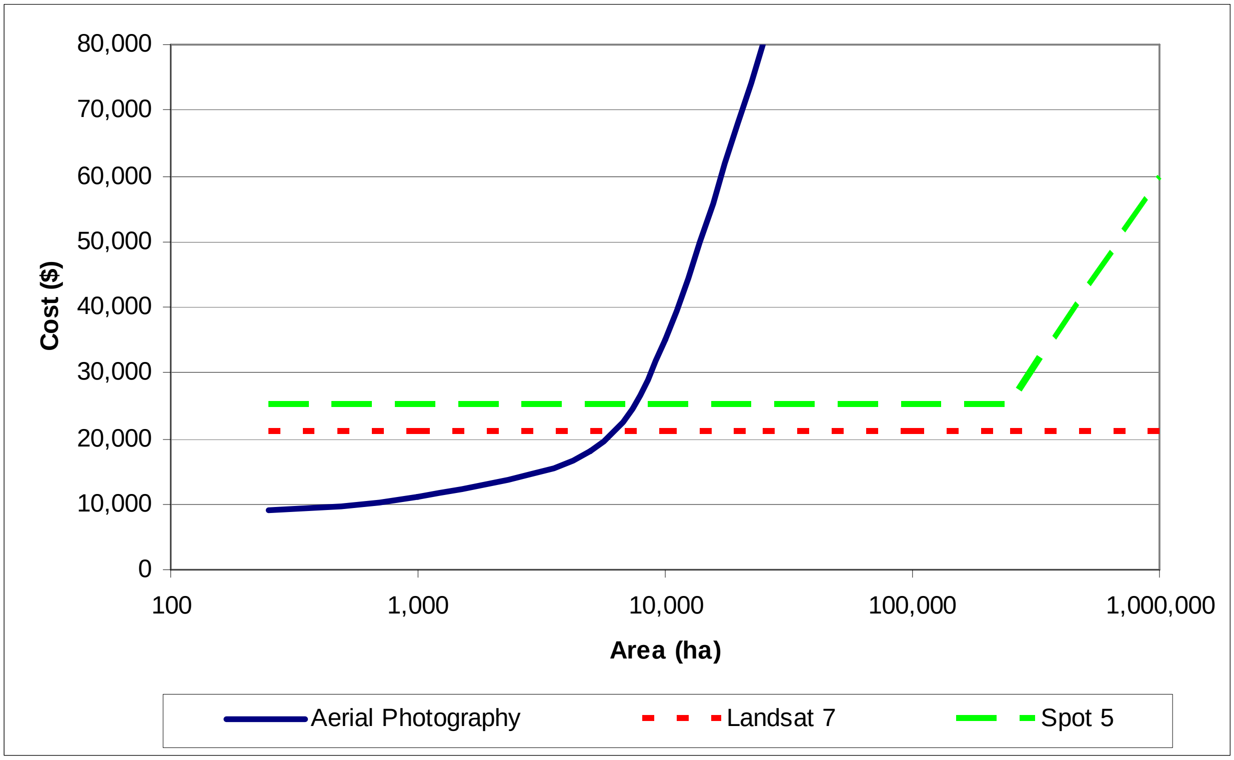

Figure 6.4 Imagery cost comparison.

7- Study Limitations

Hydrologic models are often used to provide decision makers with guidance to manage water quality issues. The uncertainty associated with model predations is often underestimated or ignored completely. In this project, we made no attempt to quantify the uncertainly, as the vast majority of modeling efforts do not. It is not possible to calculate the true uncertainty associated with our predictions given the available data and current generation of models. Uncertainty can however be managed. The targeting was performed using the model in a relative difference mode, which reduces uncertainty still further. We are confident that all reasonable steps to combat uncertainty were employed.

There are several other limitations that should be noted. Limitations may be the result of data used in the model, inadequacies in the model, or using the model to simulate situations for which it was not designed. Hydrologic models will always have limitations, because the science behind the model is not perfect nor complete, and a model by definition is a simplification of the real world. Understanding the limitations helps assure that accurate inferences are drawn from model predictions.

There is uncertainty associated with specifying uniform management for a landcover category. It is not practical to specify management for every field in the basin, and thus a typical management was selected and applied basin-wide for each landcover type. A farmer can dramatically affect the phosphorus or sediment load from a field by changing how it is managed. These data are incomplete for determining where these activities can occur. In addition, these management change from year to year at the field scale. We will never know exactly how every field is managed.

The SWAT model assumes total phosphorus includes labile, active, and stable forms in a fixed ratio. Phosphorus loading from pasture originates primarily from labile forms of soil phosphorus due to low erosion. Phosphorus loading from crops, where erosion is high, contains all forms of soil phosphorus including labile, active and stable forms. The SWAT model calculates stable mineral phosphorus based on active and labile phosphorus. We assume that Mehlich III soil test is equal to the sum of the labile and active mineral forms, which is model input. The ratio of active to stable forms at equilibrium is set via a single basin-wide model input in SWAT. The equilibrium ratio of active and stable forms is fixed in SWAT, although both ratios may vary with soil type.

Fecal coliform targeting is problematic at the basin scale. The causes of contamination by fecal coliform are very site specific, without site specific information throughout the basin we cannot place much confidence in those predictions.

Companions of satellite imagery for the purpose of targeting was limited to the Turkey Creek Basin. Although we believe these results should be applicable to other riparian corridors, we cannot be certain. These results do hinge on the accuracy of the landcover digitized from aerial photography which was considered the standard by which the other landcovers were compared. These data do contain a degree of subjectiveness because they were classified by human interpretation. However, we are confident that these data were far more accurate than either of the classified satellite images.

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APPENDIX A

Development & Comparison of Digital Landcover Data Using Landsat 7 and SPOT 5 Imagery for the Turkey Creek Watershed

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May 27th, 2004

Turkey Creek Watershed Project

Introduction

Satellite imagery has been used since the 1970's as an accurate and cost effective tool for deriving vegetation and landcover information. Digital processing techniques involving the statistical analysis of image data representing various portions of the electromagnetic spectrum allows for definition of areas that reflect solar radiation in a similar manner. These areas may then be related to landcover or vegetation types through the use of ground truth information.

The purpose of this project was to develop two digital landcover data layers using separate multispectral datasets. Our objective was to determine if there is any meaningful benefit to utilizing the more expensive, higher resolution data for targeting purposes. The first dataset analyzed was a recent (08 June 2003) 30 m resolution Landsat 7 (ETM) image. The second dataset was comprised of two 10 m SPOT 5 images collected on 27 May 2003. These SPOT images were mosaic'd to encompass the entire extent of the Turkey Creek watershed.

For this project, a traditional classification method was used where pixels are selected that represent patterns or landcover features that can be recognized or identified with help from other sources, such as ground data, aerial sources (photography, orthophoto quads) or maps. Knowledge of the types of information desired in the end product is required prior to the onset of classification. By identifying patterns, the software is trained to identify pixels with similar characteristics. Applied Analysis Inc. (AAI) relied on local sources to assist in collection of georeferenced ground truth data to ensure the accuracy of the final products. This type of landcover data can be used to conduct watershed assessments, resource inventories, and to detect change in ecosystems.

Ground Truth

Ground truth data and ancillary information were provided to Applied Analysis, Inc by Monty Ramming, Oklahoma Conservation Commission (OCC) and Dr. Daniel Storm, Oklahoma State University (OSU). The ground truth data included Digital Orthophoto Quarter Quads (DOQQ) for the entire Turkey Creek watershed obtained from the State of Oklahoma. This data is low altitude panchromatic photography provided at 1 meter spatial resolution. Additional ground truth information included a detailed ground survey of 10, 1 square mile quads located within the watershed. These quads were selected because they contained a representative sample of all the cover types of interest in the watershed and exhibited a high level of spectral variability in the Landsat and SPOT images. AAI provided OCC copies of the DOQQ's for these quad areas. OCC conducted an extensive ground survey to locate and map large contiguous areas of each cover type. This field survey was used to generate an accuracy assessment matrix for both the SPOT and Landsat classifications.

Methods

This project mapped landcover types across the Turkey Creek watershed using a whole pixel classification technique. In this study, we used an unsupervised iterative self-organizing data analysis (ISODATA) clustering algorithm. ISODATA is a widely used clustering algorithm that makes a large number of passes through an image using a minimum spectral distance routine to form clusters. It begins with an arbitrary cluster mean and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration. This iteration process continues until statistically distinct features emerge. The same methodology was used to generate the final cover type maps for the Landsat and SPOT imagery. The consistency of the protocol used in deriving these land cover maps allows for direct comparison between these multispectral datasets and conclusions can be drawn regarding sensor utility for targeting purposes.

Due to the complex nature of the landcover types across the watershed and the spectral similarity between these landcover categories, four iterations of ISODATA clustering were required to accurately map landcover types. Every subsequent iteration of classification generated 100 spectral classes. Spectral convergence threshold was set to 95 percent. The initial classification produced 100 classes which were displayed on top of the Landsat/SPOT image and DOQQ's as a thematic layer. By visual interpretation of the Landsat/SPOT imagery and DOQQ's, a set of spectral classes was identified as containing the majority of the forest cover types. The thematic layer was then recoded such that all identified forest classes were recoded to "0" and all other classes were recoded to "1". This layer was saved as a separate file and used as a mask. The mask was applied to the original Landsat/SPOT image and all pixels that fell within the forest classes were removed. The output masked image was the original image with all forest pixels removed. This image was then used as the input for the second ISODATA clustering.

The second classification iteration generated 100 spectral classes using the same number of iterations and convergence threshold. This classification was used to extract water from the imagery. The classification results were again displayed on the Landsat/SPOT and DOQQ imagery. A set of spectral classes was identified for the category. The set of spectral classes were recoded and saved as a separate file. This file was used as a mask to remove water features from the original image. The output image was the original Landsat/SPOT image with all forest and water pixels removed. This image (containing mainly pasture and cropland fields) was used as the input for the third classification.

The third classification iteration produced 100 spectral classes. This classification was used to identify and map *Pasture*, *Crops*, *Urban* and *Shrubland* areas. There is tremendous temporal change within and between these cover types. For example, a typical field in the Turkey Creek Watershed can be rotated amongst a variety of cultivated crops and pasture types. Because of this temporal change and lack of temporal coincidence between the imagery acquisition and ground truth data collection, the ground truth data could not be relied upon solely to guide the selection of spectral classes for the pasture and cultivated categories. A set of decision criteria was established to guide the labeling of spectral classes into landcover categories. The decision criteria are as follows:

1. *Pasture*
    a. Fields with a high to moderate vegetative biomass state;
    b. These fields were relatively homogeneous in their spectral response and in their apparent color in the Landsat and SPOT imagery;
    c. These fields included cultivated pasture, native pasture and rangeland.

1. *Crops*
    a. Fields with a low or no vegetative spectral response;
    b. These fields were relatively heterogeneous in their apparent color in the Landsat and SPOT imagery;
    c. These fields a significant soil component;
    d. Contiguous fields > 1 acre.

1. *Bare Soil*
    a. Fields with no vegetative biomass;
    b. Contiguous fields sized < 1 acre.

1. *Urban*
    a. Areas including urban development, roads and impervious surfaces.

2. *Shrubland*
    a. Areas with a high to moderate vegetative biomass state;
    b. These areas were located adjacent to forest stands and in and along agricultural fields;
    c. These areas were relatively homogeneous in their spectral response and displayed a “speckled” appearance across the landscape in both the Landsat and SPOT imagery.

These decision criteria were used as a guide for labeling spectral classes into landcover types. The primary means for labeling these spectral classes was the apparent color of the pixels in the imagery. Each spectral class was analyzed to see what cover types it was detecting. The decision criteria were then used to label that class to an appropriate landcover type.

The third classification was also used to identify any additional forest or water pixels that may have been missed in the two previous classification iterations. Once all the spectral classes were labeled to the appropriate landcover category, the image was recoded such that each landcover category was given a unique identifier.

Both the Landsat and SPOT imagery, showed a significant amount of bare soil fields across the Turkey Creek watershed. The reason for this, according to the Oklahoma Conservation Commission, was that the wheat harvest was underway at that time. Recently harvested wheat fields exhibit an overwhelming soil spectral response in multispectral imagery. Additionally, due to their lack of chlorophyll, standing dry wheat fields exhibit a similar spectral response as bare soil. Because of the large temporal difference between imagery and ground truth, we were unable to identify which of these spectrally bright fields were standing wheat fields or bare soil. It should be noted that this spectral similarity does not preclude detection of dry wheat fields in spectral imagery. If temporally coincident ground truth data and imagery are acquired, there are several spectral techniques that could be used to detect this crop condition.

An additional analysis of *Clump* and *Sieve* was used to separate these bare soil fields between the landcover types of *Crop* and *Bare Soil*. *Clump* and *Sieve* are spatial analysis tools used to analyze raster data based on class identity and spatial relationship. The fields classified as *Crop* in the third classification were run through a clump and sieve routine. All contiguous bare soil fields larger than one acre were left classified as *Crop*. All contiguous bare soil fields one acre or less were reclassified as *Bare Soil*.

Because of the spectral similarity of *Urban* features to *Bare Soil*, especially in 4-band SPOT imagery, the third ISODATA classification overestimated the amount of *Urban* areas in the watershed. A multi-step, spectral and spatial technique was used to accurately separate the *Urban* land cover type. First, the larger *Urban* areas were visually identified and subset from the Landsat and SPOT imagery. These subset areas were aggressively classified (ISODATA) as *Urban*. Other cover types included within these subset areas were classified to the appropriate categories.

Smaller urban/impervious surface areas within the imagery such as ranchettes and roads that were not included in these subset areas were extracted using spatial techniques. A road vector layer for the Turkey Creek watershed was obtained from the Oklahoma Digital Atlas. The road layer was accurately registered to the SPOT and Landsat imagery. A 100 m buffer was created around all road features and applied as a mask on the *Urban* category in the SPOT and Landsat classifications. All *Urban* features that fell within the buffer remained classified as *Urban*. All *Urban* features that fell outside the buffer were reclassified as *Crop*. This technique preserved the accurate urban and road classifications in both datasets and eliminated false alarm areas.

The final landcover maps for the 08 June 2003 Landsat 7 ETM+ image and 27 May 2003 mosaic'd SPOT 5 image were produced using standard image overlay techniques. Finally, the classes were color coded and output to a final thematic map. The data was also smoothed in order to give the client an opportunity to use either the smoothed or unsmoothed data for their modeling purposes. Further explanation of smoothing is provided in the Discussion Section of this report. These images and maps were FTP'd to Oklahoma State University and their receipt has been verified by Mike White.

A riparian habitat assessment was also performed in the Turkey Creek watershed. Hydrologic data layers for the basin were acquired from the USGS via the Oklahoma Digital Atlas. A 90 meter buffer was extended from these hydrologic features to create and assess the spatial distribution of landcover types in the riparian zone. Due to the differences in pixel dimensions between the Landsat and SPOT sensors, the data had to be vectorized in order to achieve a fair riparian comparison of the data results. If left as raster data when buffered, the riparian area varied in width for the Landsat sensor as the buffering technique would include entire pixels that may have only partially fallen within the 90 meters.

Results

The final results were grouped into 7 landcover classes for the Landsat image and 8 landcover classes for the SPOT image. The additional category in the SPOT classification represents *Clouds/Cloud Shadows* present in that image. The final percentages for landcover in the Turkey Creek watershed were calculated for two spatial extents:

1. Watershed level; and
2. Riparian Area.

The watershed level classification includes landcover types within the entire Turkey Creek watershed area. The riparian area contains the landcover types within a 90 m buffer from the hydrologic features within the watershed. The results of the final Smoothed and Unsmoothed landcover maps for both spatial extents are presented below.

Table 1. Unsmoothed Landcover (by percentage) within the Turkey Creek Watershed.

Landcover Type	**Landsat 08 June 2003**	**SPOT 27 May 2003**
Water	0.39	0.48
Pasture	33.94	32.56
Crop	59.66	58.43
Forest	2.89	3.52
Shrub	0.71	0.54
Bare Soil	0.59	1.53
Urban	1.82	1.60
Cloud/Cloud Shadow	0.00	1.35
Total	100	100

Table 2. Smoothed Landcover (by percentage) within the Turkey Creek Watershed

Landcover Type	Landsat 08 June 2003	SPOT 27 May 2003
Water	0.38	0.48
Pasture	32.10	30.46
Crop	61.17	60.16
Forest	3.26	3.88
Shrub	0.71	0.54
Bare Soil	0.59	1.53
Urban	1.80	1.60
Cloud/Cloud Shadow	0.00	1.35
Total	100	100

Table 3. Unsmoothed Landcover (by percentage) within the 90m Riparian Buffer

Landcover Type	Landsat 08 June 2003	SPOT 27 May 2003
Water	0.95	1.15
Pasture	52.91	48.81
Crop	33.93	33.16
Forest	8.82	10.52
Shrub	1.33	1.33
Bare Soil	0.85	2.54
Urban	1.21	1.03
Cloud/Cloud Shadow	0.00	1.46
Total	100	100

Table 4. Smoothed Landcover (by percentage) within the 90m Riparian Buffer

Landcover Type	Landsat 08 June 2003	SPOT 27 May 2003
Water	0.95	1.15
Pasture	50.56	46.50
Crop	35.06	34.34
Forest	10.04	11.61
Shrub	1.33	1.33
Bare Soil	0.85	2.54
Urban	1.21	1.03
Cloud/Cloud Shadow	0.00	1.46
Total	100	100

The watershed was dominated by Crops (60% -62%) followed next by Pasture (30% -32%). The other classes exhibited smaller percentages. While this watershed is dominated by these two landcover types, the other classes may be underrepresented due to their small spatial size relative to the pixel size of the Landsat (30 m) and SPOT (10 m) imagery. For example, the small, discrete occurrences of bare soil can go undetected or classified with another neighboring landcover type in course resolution Landsat imagery.

Results- Accuracy Assessment

An accuracy assessment was conducted on both the Landsat and SPOT landcover classification maps and is displayed below in Figures 1 and 2, respectively. These accuracy assessment matrices were derived from the smoothed watershed level landcover classifications. The ground truth data was collected by OCC personnel in collaboration with Oklahoma State University. Overall accuracy of the 08 June 2003 Landsat land cover map was 81%. Overall accuracy of the 27 May 2003 SPOT 5 land cover map was 74%.

The accuracy assessment was conducted on the smoothed landcover classifications due to the spatial scale of the ground truth information. The ground truth data was collected at the field level scale (large contiguous fields were identified). Because the ground truth was collected at this scale, using the smoothed (field level) classification was the most appropriate.

	Ground Truth									
Classified		Forest	Crop	Pasture	Water	Shrub	Urban	Total		User's Accuracy
	Forest	**7**		1		1		10		0.70
	Crop		**136**	25			1	162		0.84
	Pasture	1	33	**131**		3	1	169		0.78
	Water			1				1		0.00
	Shrub					**3**		3		1.00
	Urban						**1**	1		1.00
	Total	8	169	158	0	7	3	**345**		
	Producer's Accuracy	0.88	0.80	0.83	0.00	0.43	0.33			
	Overall Accuracy									**0.81**

Figure 1. 08 June 2003 Landsat Accuracy Assessment

		Ground Truth								
Classified		Forest	Crop	Pasture	Water	Shrub	Urban	Total		User's Accuracy
	Forest	**4**		3		1		8		0.50
	Crop		**129**	34		1	1	165		0.78
	Pasture	4	40	**120**		5		169		0.71
	Water			1				1		0.00
	Shrub							0		0.00
	Urban						**2**	2		1.00
	Total	8	169	158	0	7	3	**345**		
	Producer's Accuracy	0.50	0.76	0.76	0.00	0.00	0.67			
	Overall Accuracy									**0.74**

Figure 2. 27 May 2003 SPOT Accuracy Assessment

Discussion

The landcover classification for the watershed and riparian zone maps the spatial distribution of landcover throughout the Turkey Creek watershed. The results indicate a watershed dominated by agricultural production in the form of crops and pastures. It is believed that these landcover types are spatially and temporally dynamic. Due to temporal change and lack of temporal coincidence between the imagery acquisition and ground truth data collection, the ground truth data could not be relied upon solely to guide the selection of spectral classes for the pasture and cultivated categories. This limits the ability of the analyst to most accurately map these landcover types using remote sensing data that was collected a year previous to the ground truth data collection.

The higher accuracy of the Landsat data was predictable given the nature of the collected ground truth data. Unfortunately, most (94.7%) of the data collected as ground truth was pasture and crop. These are large macro classes in the watershed and therefore are less likely to be missed in course spatial resolution Landsat imagery. Landsat also possesses higher spectral resolution (6 band versus 4 band) that will yield a more accurate classification than SPOT on these targets. It should also be noted that due to the lack of temporal coincidence between image acquisition and ground truth data collection, that this processed imagery could be more accurate overall than noted due to changes in land-use in the year between data collections.

The accuracy assessment does not reflect well the under-represented classes such as urban, water, and bare soil categories. These small features, while not captured effectively in the accuracy assessment are definitely more accurately classified in the SPOT imagery than Landsat. These features are somewhat spectrally unique even at the lower spectral resolution of SPOT imagery. The higher spatial resolution of SPOT allows accurate discrimination of small, spatially discrete features like the Urban, Water and Bare Soil categories within the watershed. These features tend to be smaller than a Landsat pixel and therefore are often caught up in a mixed pixel and are misclassified.

The riparian zone classification offers a qualitative targeting method to spatially locate high risk landcover types within the riparian corridor. These highest risk landcover types would include bare soil, pasture, and crops. When combined with estimates of nonpoint source loadings attributed to subwatersheds through SWAT modeling, it is anticipated that the combination will provide the watershed project coordinator with a mechanism to proactively identify and recruit landowners that are likely contributing to the overall degradation of water quality within the Turkey Creek Watershed.

The final land cover maps for the Turkey Creek watershed have been provided in both Smoothed and Unsmoothed data format. The smoothing process is a standard image processing technique to remove “noise” or spurious pixels classified to a different land-use within a large contiguous field. For example, a large field classified as crop may have several individual pixels with the spectral characteristics of a pasture. In the unsmoothed classification, these individual pixels are maintained as pasture in the final output. The smoothing process will remove these pasture detections and replace them with crop detections. The smoothing process scans the unsmoothed classification layer with a 3x3 pixel majority filter. This filter analyses the 3x3 area around each pixel and will reassign the target pixels to the majority class in its local area. The result in the example above would be that the individual pixels of pasture within the crop field would be replaced with crop detections in the final output. For this project, the smoothing process was only applied to the large macro classes (crop, pasture, forest and shrub) and not applied to the spatially small land-use categories (water, bare soil and urban). The results section above reports the percent of the watershed and riparian area by land-use category for both the unsmoothed and smoothed products. Note that the water, bare soil and urban percentages are the same in both the smoothed and unsmoothed statistics.

The smoothing methods implemented were designed to maintain the value of the land cover maps as a qualitative targeting mechanism to spatially locate high risk land-use types. The highest risk land-use type, bare soil, was maintained in these analyses at both the watershed and riparian area scales for both the smoothed and unsmoothed products.

Conclusion

Without the support of ground truth data that is temporally coincident, it is difficult to determine the true benefit of using SPOT versus Landsat in an application of this nature. In addition to collecting temporally coincident ground truth data, it is equally important to ensure that staff in the field take great measure to ensure that they collect the under-represented features within the watershed. Due to the lack of temporally coincident data, it is believed that the accuracy assessment conducted in this project is artificially deflating the true accuracy of the products. This is primarily due to the temporally dynamic nature of the watershed in that crops and pastures are rotated.

Oklahoma State University will be working further with this data over the course of the Summer in 2004. They have students who will be spending time out in the field measuring the accuracy of the riparian habitat assessment. Results from that project will be the determining factor in whether use of the more expensive SPOT imagery holds value in being able to more accurately identify critical areas in need of mitigation efforts within the riparian buffer area.

Appendix B
Gridcell Model Software Source Code

```
Private Declare Function OpenProcess Lib "kernel32.dll" (ByVal _
    dwAccess As Long, ByVal fInherit As Integer, ByVal hObject _
    As Long) As Long
Private Declare Function WaitForSingleObject Lib "kernel32" (ByVal _
     hHandle As Long, ByVal dwMilliseconds As Long) As Long
Private Declare Function CloseHandle Lib "kernel32" (ByVal _
     hObject As Long) As Long
Public Declare Sub Sleep Lib "kernel32" (ByVal dwMilliseconds As Long)
Private FSO As New FileSystemObject
Private strm As TextStream
Private strName As String
Dim AllFolders As New Collection
Sub main()
Dim holdit() As String
      Const ForReading = 1, ForWriting = 2, ForAppending = 3
      Set fs = CreateObject("Scripting.FileSystemObject")
mypath = "D:\Projects\turkey\GRIDCELL\Model\BIN"
  mcheck = mypath & "\combo.dbf"
 Dim con As Connection
    Dim rs As Recordset
    Set con = New Connection
    Set rs = New Recordset
    Set myn = New Recordset
With con
    .CursorLocation = adUseClient
    .Provider = "Microsoft.Jet.OLEDB.4.0"
    .ConnectionString = "Data Source=" & mypath & ";" & "Extended Properties=dbase IV;"
    .Open
    rs.Open "combo.dbf", con, adOpenDynamic, adLockBatchOptimistic

    'get value number
    rs.MoveLast
    maxval = rs.Fields(0)
    rs.MoveFirst
    'get names
    Status.Show
    Status.Label1.Caption = "Initilizing Gridcell Model"
    myout = mypath & "\OUTPUTnew3.TXT"
Open myout For Output As #5 ' file that contains all output

 For p = 1 To rs.RecordCount 'Loop through file one line at a time
    myindex = rs.Fields(0)
    myslope = rs.Fields(2)
    mylulc = rs.Fields(3)
    mysoil = rs.Fields(4)
    Status.PBar.Value = myindex / maxval * 100
    Status.Label1.Caption = "Running " & myindex
    Status.Refresh

    ' kill hru mgt chm and sol to prevent duplicate runs on failure
    myfile = mypath + "\000010001.hru"
    If Dir(myfile) <> "" Then Kill myfile
     myfile = mypath + "\000010001.sol"
    If Dir(myfile) <> "" Then Kill myfile
     myfile = mypath + "\000010001.mgt"
    If Dir(myfile) <> "" Then Kill myfile
     myfile = mypath + "\000010001.chm"
    If Dir(myfile) <> "" Then Kill myfile

    'Write each file individually
    'Write HRU File*********************************************************************************
```

```
Dim mytime As String
mytime = Time
Dim mydate As String
mydate = Date
'create title
mytitle = "Created " + mydate + "  " + mytime + "  " + LULC + " Gridcell 1.0 for SWAT 2000"

myfile = mypath + "\000010001.hru"
'open/create the textfile
ChDir mypath
Open myfile For Output As #1
'write title
Print #1, Spc(0); mytitle
Print #1, formater(1, "0000.00000000") 'HRU FRACTION
' calculate slope length
slength = 122.75 * Exp(10.455 * myslope / 100)
If slength < 20 Then slength = 20
Print #1, formater(slength, "0000000.00000"): ' slope lenth
myslope = myslope / 100
Print #1, formater(myslope, "0000000.00000") ' slope
' Calculate Mannings N for this landcover.
If LCase(mylulc) = "pasture" Then MN = 0.41
If LCase(mylulc) = "wwht" Then MN = 0.25
If LCase(mylulc) = "water" Then MN = 0.01
If LCase(mylulc) = "forest" Then MN = 0.8
If LCase(mylulc) = "urban" Then MN = 0.15
If LCase(mylulc) = "bare" Then MN = 0.15
If LCase(mylulc) = "shrubland" Then MN = 0.6
Print #1, formater(MN, "0000000.00000") ' mannings
' print some blanks
For a = 1 To 10
 Print #1, formater(0, "0000000.00000")
Next a
 'set urban flags
If LCase(mylulc) = "urban" Then
   Print #1, formater(1, "0000000.00000")
   Print #1, formater(3, "0000000")
Else
   Print #1, formater(0, "0000000.00000")
   Print #1, formater(0, "0000000")
End If
Print #1, formater(0, "0000000")
Print #1, formater(0, "0000000")
Print #1, formater(0, "0000000")
For a = 1 To 7
   Print #1, formater(0, "0000000.00000")
Next a
Print #1, formater(0, "0000000")
For a = 1 To 5
   Print #1, formater(0, "0000000.00000")
Next a
Print #1, " "
Close #1    ' Close file.
'move Soil File into place**********************************************************************************
mysoilp = mypath + "\soils\" + mysoil + ".sol"
mydest = mypath + "\" + "000010001.sol"
'Kill mydest
FileCopy mysoilp, mydest

'get hydrologic soil group
Set fs = CreateObject("Scripting.FileSystemObject")
Set fl = fs.OpenTextFile(mydest, ForReading, TristateFalse)
myline = fl.ReadLine
myline = fl.ReadLine
myline = fl.ReadLine
holdit() = Split(myline, ":")
fl.Close
```

```
      hygrp = Right(holdit(1), 1)

                                                      '   B   u   i   l   d      C   H   M
File***********************************************************************************************
      If LCase(mylulc) = "pasture" Then STP = 73
      If LCase(mylulc) = "wwht" Then STP = 60
      If LCase(mylulc) = "water" Then STP = 15
      If LCase(mylulc) = "forest" Then STP = 15
      If LCase(mylulc) = "urban" Then STP = 15
      If LCase(mylulc) = "bare" Then STP = 73
      If LCase(mylulc) = "shrubland" Then STP = 15
      Call makechm(mypath, STP)
                                            '  B  u  i  l  d     M  a  n  a  g  e  m  e  n  t
File*****************************************************************************************
      Call makemgt(mypath, mylulc, hygrp)
                                                                          '    R    u    n
SWAT*********************************************************************************************
       'all file complete run SWAT
      Kill mypath + "\basins.sbs"
      SWAT2 = mypath + "\swat2000.exe"
      ChDir mypath
      LaunchApp32 (SWAT2)

      ' write output to file grab the las line of the basins.sbs file
      myfile = mypath & "\basins.sbs"
      If Dir(myfile) = "" Then MsgBox "SWAT run not compete, contact OSU for assistance if the problem persists.": Exit Sub

      Set myrch = fs.OpenTextFile(myfile, 8, TristateFalse)
      maxline = myrch.Line
      myrch.Close
      If maxline > 25 Then
         Set strm = FSO.OpenTextFile(myfile, 1)
         With strm
            For a = 1 To 35
               myline = .ReadLine
            Next a
         End With
         strm.Close
      Else
         myline = "Failed"
      End If
      soilname = mysoil & "   "
       Print #5, Format(myindex, "0000") & "    " & Left(soilname, 3) & "    " & Left(mylulc, 4) & "    " & Format(myslope, "00.00") & "    " &
myline
  Status.Refresh
  DoEvents
  rs.MoveNext
   Next p
   rs.Close
   Close #1
   Close #5
.Close
End With
Unload Status
End Sub

Function LaunchApp32(MYAppname As String) As Integer
 On Error Resume Next
 Const SYNCHRONIZE = 1048576
 Const INFINITE = -1&
 Dim ProcessID&
 Dim ProcessHandle&
 Dim Ret&

 LaunchApp32 = -1
 ProcessID = Shell(MYAppname, vbMinimizedNoFocus)
   If ProcessID <> 0 Then
```

```
        ProcessHandle = OpenProcess(SYNCHRONIZE, True, ProcessID&)
        Ret = WaitForSingleObject(ProcessHandle, INFINITE)
        Ret = CloseHandle(ProcessHandle)

      Else
         MsgBox "ERROR : Unable to start " & MYAppname
         LaunchApp32 = 0
   End If
End Function

Function formater(mikesvalue, myformat)
' function to format output values for .mgt files
Dim myout As String
Dim char(10) As String
If mikesvalue = "empty" Then mikesvalue = 0
If mikesvalue = "null" Then mikesvalue = 0
If mikesvalue = "" Then mikesvalue = 0
myout = Format(mikesvalue, myformat)
For a = 1 To 10
char(a) = Mid(myout, a, 1)
If char(a) = "0" Then
Mid(myout, a, 1) = " "
Else
b = "quit"
End If
If char(a) = "." Then
Mid(myout, (a - 1), 1) = "0"
b = "quit"
End If
If char(a) = "" Then
Mid(myout, (a - 1), 1) = "0"
End If
If b = "quit" Then a = 10
Next a
formater = myout
End Function

Sub makechm(mypath, STP)
        Dim mytime As String
        mytime = Time
        Dim mydate As String
        mydate = Date
        'create title
        mytitle = "Created " + mydate + "  " + mytime + "  " + LULC + " GRIDCELL 1.0 for SWAT 2000"
        myfile = mypath + "\" + "000010001.chm"
        ' open/create the textfile
        ChDir mypath
        Open myfile For Output As #1
        'write title
        Print #1, Spc(0); mytitle
        Print #1, Spc(0); "Soil Nutrient Data"
        Print #1, Spc(0); " Soil Layer              :        1         2         3         4         5         6         7         8         9        10"
        Print #1, Spc(0); " Soil NO3 [mg/kg]        :";
        For a = 1 To 10
        Print #1, formater(0, "000000000.00");
        Next a
        Print #1, Spc(0); ""

        Print #1, Spc(0); " Soil organic N [mg/kg]   :";
        For a = 1 To 10
        Print #1, formater(0, "000000000.00");
        Next a
        Print #1, Spc(0); ""

        Print #1, Spc(0); " Soil labile P [mg/kg]    :";
        For a = 1 To 10
        Print #1, formater((STP / 5), "000000000.00");
```

```
      Next a
      Print #1, Spc(0); ""

      Print #1, Spc(0); " Soil organic P [mg/kg]   :";
      For a = 1 To 10
      Print #1, formater(0, "000000000.00");
      Next a
      Print #1, Spc(0); ""

      Print #1, Spc(0); "Soil Pesticide Data"
      Print #1, Spc(0); " Pesticide  Pst on plant    Pst in 1st soil layer Pst enrichment"
      Print #1, Spc(0); "   #          [kg/ha]          [kg/ha]          [kg/ha]"
      For r = 1 To 10
            Print #1, Spc(0); "   0             0.00             0.00             0.00"
      Next r

      Print #1, " "
      Close #1    ' Close file.

End Sub

Function formater(mikesvalue, myformat)
' function to format output values for .mgt files
Dim myout As String
Dim char(10) As String
If mikesvalue = "empty" Then mikesvalue = 0
If mikesvalue = "null" Then mikesvalue = 0
If mikesvalue = "" Then mikesvalue = 0
myout = Format(mikesvalue, myformat)
For a = 1 To 10
char(a) = Mid(myout, a, 1)
If char(a) = "0" Then
Mid(myout, a, 1) = " "
Else
b = "quit"
End If
If char(a) = "." Then
Mid(myout, (a - 1), 1) = "0"
b = "quit"
End If
If char(a) = "" Then
Mid(myout, (a - 1), 1) = "0"
End If
If b = "quit" Then a = 10
Next a
formater = myout
End Function
Sub makemgt(mypath, mylulc, hygrp)
'to increase speed of execution stuff will be placed in arrays
Dim LULC(20, 20, 58) As Variant
Dim CNINDEX(100, 5) As Variant
Dim MGT(20) As Variant
Dim myexists As Boolean
myoutpat = mypath
Dim con As Connection
   Dim rs As Recordset
   Set con = New Connection
   Set rs = New Recordset
   Set myn = New Recordset
   Set lu = New Recordset
   Set CN = New Recordset
   Set ms = New Recordset
  With con
   .CursorLocation = adUseClient
   .Provider = "Microsoft.Jet.OLEDB.4.0"
   .ConnectionString = "Data Source=" & mypath & "\mgt" & ";" & "Extended Properties=dbase IV;"
   .Open
```

```
Dim mytime As String
mytime = Time
Dim mydate As String
mydate = Date
' read in mgtsub and cnindex

mcheck = mypath & "\mgt\CN_index.dbf"
If Dir(mcheck) = "" Then MsgBox "Cannot find " & mcheck: Stop
 CN.Open "CN_index.dbf", con, adOpenDynamic, adLockBatchOptimistic
 For y = 1 To CN.RecordCount
    CNINDEX(y, 0) = CN.Fields(0)
    CNINDEX(y, 1) = CN.Fields(5):
    CNINDEX(y, 2) = CN.Fields(6):
    CNINDEX(y, 3) = CN.Fields(7):
    CNINDEX(y, 4) = CN.Fields(8):
    CN.MoveNext
Next y
    CN.Close

'start loop

    mylulcname = mylulc & ".dbf"
    mcheck = mypath & "\mgt\" & mylulcname
    If Dir(mcheck) = "" Then MsgBox "Cannot find LANDCOVER file " & mcheck: Stop
 'check to see if this lulc exists in the array
 myexists = False
 For u = 15 To 0 Step -1
    If LULC(u, 0, 0) = mylulc Then myexists = True
    If LULC(u, 0, 0) = Empty Then myplace = u
 Next u
 If myexists = False Then  ' add this to the current array
    lu.Open mylulcname, con, adOpenDynamic, adLockBatchOptimistic

        For u = 0 To lu.RecordCount - 1
            For x = 0 To lu.Fields.Count - 1
                If u = 0 Then
                    LULC(myplace, u, x) = lu.Fields(x).Name
                Else
                    LULC(myplace, u, x) = lu.Fields(x) & ""
                End If
            Next x
             If u <> 0 Then lu.MoveNext
        Next u
        LULC(myplace, 0, 0) = landuse
    lu.Close
 End If

 ' copy the values from mgt1 section
      'find the proper position
    For u = 15 To 0 Step -1
        If LULC(u, 0, 0) = mylulc Then lulcnum = u
    Next u
      For g = 1 To 12
          MGT(g) = LULC(lulcnum, 1, g + 44)
          If MGT(g) = Null Then MGT(g) = 0#
      Next g

      'assign variable from array for use in the legacy part of this program
      IGRO = MGT(1)
      NROT = MGT(2)
      NMGT = MGT(3)
      NCRP = MGT(4)
      ALAI = MGT(5)
      BIOMS = MGT(6)
      PHU = MGT(7)
```

```
BIOMIN = MGT(8)
BIOMIX = MGT(9)
CN2 = MGT(10)
USLEP = MGT(11)
HUSC = MGT(12)
ISCROP = MGT(13)

 ' get apropriate management operations for this cover type
'count the operations
For r = 1 To 15
  If LULC(lulcnum, r, 6) <> "" Then mycount = r
Next r

'read in operations
Dim operation(15, 50) As Variant
'maximum of 10 operations
' first op is variable names
For a = 1 To mycount
   For b = 1 To 45
        operation(a, b) = LULC(lulcnum, a, b)
     Next b
Next a

' get the correct AVERAGE ANNUAL curve number
 trip = 0
For y = 1 To 100
   If CNINDEX(y, 0) = CN2 Then
      If hygrp = "A" Then CN2 = CNINDEX(y, 1): trip = 1
      If hygrp = "B" Then CN2 = CNINDEX(y, 2): trip = 1
      If hygrp = "C" Then CN2 = CNINDEX(y, 3): trip = 1
      If hygrp = "D" Then CN2 = CNINDEX(y, 4): trip = 1
      y = 1000
   End If
  Next y

If trip = 0 Then MsgBox ("Annual Curve number index could not found, bailing out!!!"): Stop

mytitle = "Created " + mydate + "  " + mytime + "  " + landuse + "  gridcell 1.0 for SWAT 2000"
'new untested code to limit the comment line in each pnd file to 80 characters
If Len(mytitle) > 79 Then mytitle = Left(mytitle, 79)
' end new code

myfile = mypath + "\" + "000010001.mgt"
' open/create the textfile
ChDir mypath
Open myfile For Output As #1
'write title
Print #1, Spc(0); mytitle
' write line 1 data
Print #1, formater(IGRO, "0");
Print #1, formater(NROT, "000");
Print #1, formater(NMGT, "0000");
Print #1, formater(NCRP, "0000");
Print #1, formater(ALAI, "00000.00");
Print #1, formater(BIOMS, "00000.00");
Print #1, formater(PHU, "00000.00");
Print #1, formater(BIOMIN, "00000.00");
Print #1, formater(BIOMIX, "00000.00");
Print #1, formater(CN2, "00000.00");
Print #1, formater(USLEP, "00000.00")


' write additional lines
For m = 1 To mycount ' loop through the operations
'determine the operation type

If operation(m, 6) = 1 Then 'plant
```

```
Print #1, formater(operation(m, 3), "0000");
Print #1, formater(operation(m, 4), "0000");
Print #1, formater(operation(m, 5), "0000.000");
Print #1, formater(operation(m, 6), "0000");
Print #1, formater(operation(m, 7), "0000.000");
Print #1, formater(operation(m, 8), "0000");
Print #1, formater(operation(m, 9), "0000.000");
Print #1, formater(operation(m, 10), "0000.000");
Print #1, formater(operation(m, 11), "0000.000");
Print #1, Spc(4);
Print #1, formater(operation(m, 12), "00.000");
Print #1, formater(operation(m, 13), "00.000")
End If

If operation(m, 6) = 2 Then 'irrigation
Print #1, formater(operation(m, 3), "0000");
Print #1, formater(operation(m, 4), "0000");
Print #1, formater(operation(m, 5), "0000.000");
Print #1, formater(operation(m, 6), "0000");
Print #1, Spc(12);
Print #1, formater(operation(m, 14), "0000.000")
End If

If operation(m, 6) = 3 Then ' fertilization
Print #1, formater(operation(m, 3), "0000");
Print #1, formater(operation(m, 4), "0000");
Print #1, formater(operation(m, 5), "0000.000");
Print #1, formater(operation(m, 6), "0000");
Print #1, formater(operation(m, 16), "0000.000");
Print #1, formater(operation(m, 17), "0000");
Print #1, formater(operation(m, 18), "0000.000")
End If

If operation(m, 6) = 4 Then 'pesticides ' UNCHECKED MAY CONTAIN ERRORS
Print #1, formater(operation(m, 3), "0000");
Print #1, formater(operation(m, 4), "0000");
Print #1, formater(operation(m, 5), "0000.000");
Print #1, formater(operation(m, 6), "0000");
Print #1, Spc(36);
Print #1, formater(operation(m, 26), "0000");
Print #1, formater(operation(m, 25), "00.000")
End If

If operation(m, 6) = 5 Then  ' harvest/kill
Print #1, formater(operation(m, 3), "0000");
Print #1, formater(operation(m, 4), "0000");
Print #1, formater(operation(m, 5), "0000.000");
Print #1, formater(operation(m, 6), "0000");
Print #1, Spc(46);
Print #1, formater(operation(m, 13), "00.000")
End If

If operation(m, 6) = 6 Then  ' tillage
Print #1, formater(operation(m, 3), "0000");
Print #1, formater(operation(m, 4), "0000");
Print #1, formater(operation(m, 5), "0000.000");
Print #1, formater(operation(m, 6), "0000");
Print #1, Spc(8);
If CInt(operation(m, 26)) <> 0 Then  'for compatabliity with old mgt.dbfs
  Print #1, formater(operation(m, 26), "0000"); 'print from tillage ID
Else
  Print #1, formater(operation(m, 24), "0000"); 'print from pestid
End If
Print #1, Spc(34);
Print #1, formater(operation(m, 13), "00.000")
End If
```

```
    If operation(m, 6) = 7 Then  ' harvest only
    Print #1, formater(operation(m, 3), "0000");
    Print #1, formater(operation(m, 4), "0000");
    Print #1, formater(operation(m, 5), "0000.000");
    Print #1, formater(operation(m, 6), "0000");
    Print #1, formater(operation(m, 27), "0000.000");
    Print #1, Spc(4);
    Print #1, formater(operation(m, 28), "0000.000")
    End If

    If operation(m, 6) = 8 Then  ' kill only
    Print #1, formater(operation(m, 3), "0000");
    Print #1, formater(operation(m, 4), "0000");
    Print #1, formater(operation(m, 5), "0000.000");
    Print #1, formater(operation(m, 6), "0000")
    End If

    If operation(m, 6) = 9 Then  ' graze
    Print #1, formater(operation(m, 3), "0000");
    Print #1, formater(operation(m, 4), "0000");
    Print #1, formater(operation(m, 5), "0000.000");
    Print #1, formater(operation(m, 6), "0000");
    Print #1, formater(operation(m, 29), "0000.000");
    Print #1, formater(operation(m, 30), "0000");
    Print #1, formater(operation(m, 31), "0000.000");
    Print #1, Spc(8);
    Print #1, formater(operation(m, 32), "0000.000");
    Print #1, formater(operation(m, 33), "0000")
    End If

    If operation(m, 6) = 10 Then  ' auto irrigation
    Print #1, formater(operation(m, 3), "0000");
    Print #1, formater(operation(m, 4), "0000");
    Print #1, formater(operation(m, 5), "0000.000");
    Print #1, formater(operation(m, 6), "0000");
    Print #1, Spc(12);
    Print #1, formater(operation(m, 34), "0000.000")
    End If

    If operation(m, 6) = 11 Then  ' auto fert
    Print #1, formater(operation(m, 3), "0000");
    Print #1, formater(operation(m, 4), "0000");
    Print #1, formater(operation(m, 5), "0000.000");
    Print #1, formater(operation(m, 6), "0000");
    Print #1, formater(operation(m, 36), "0000.000");
    Print #1, formater(operation(m, 17), "0000");
    Print #1, formater(operation(m, 37), "0000.000");
    Print #1, formater(operation(m, 38), "0000.000");
    Print #1, Spc(12);
    Print #1, formater(operation(m, 39), "00.000");
    Print #1, formater(operation(m, 40), "00.000")
    End If

    If operation(m, 6) = 12 Then MsgBox ("unsupported urban street sweeping") ' urban
    If operation(m, 6) = 13 Then MsgBox ("unsupported impoundment release") ' street sweep
    If operation(m, 6) = 0 Then Print #1, " " ' end of year flag

    Next m

    Print #1, " "
    Close #1    ' Close file.

errorhandler:
    Dim msg
    ' If an error occurs, construct an error message
    ' Defer error handling.
    ' Check for error, then show message.
```

```
        If Err.Number <> 0 Then
            msg = "Error # " & Str(Err.Number) & " was generated by " _
                    & Err.Source & Chr(13) & Err.Description
            MsgBox msg, , "Error", Err.HelpFile, Err.HelpContext
            GoTo 5000
        End If
End With
5000:
End Sub
Function formater(mikesvalue, myformat)
' function to format output values for .mgt files
Dim myout As String
Dim char(10) As String
If mikesvalue = "empty" Then mikesvalue = 0
If mikesvalue = "null" Then mikesvalue = 0
If mikesvalue = "" Then mikesvalue = 0
myout = Format(mikesvalue, myformat)
For a = 1 To 10
char(a) = Mid(myout, a, 1)
If char(a) = "0" Then
Mid(myout, a, 1) = " "
Else
b = "quit"
End If
If char(a) = "." Then
Mid(myout, (a - 1), 1) = "0"
b = "quit"
End If
If char(a) = "" Then
Mid(myout, (a - 1), 1) = "0"
End If
If b = "quit" Then a = 10
Next a
formater = myout
End Function
```

Soil File maker Source Code

```
Sub makesol(myinpath, myoutpath)
 mcheck = myinpath & "\sol.dbf"
 If Dir(mcheck) = "" Then MsgBox "Cannot find " & mcheck: Stop
Dim con As Connection
   Dim rs As Recordset
   Set con = New Connection
   Set rs = New Recordset
   Set myn = New Recordset
With con
   .CursorLocation = adUseClient
   .Provider = "Microsoft.Jet.OLEDB.4.0"
   .ConnectionString = "Data Source=" & myinpath & ";" & "Extended Properties=dbase IV;"
   .Open
   rs.Open "sol.dbf", con, adOpenDynamic, adLockBatchOptimistic
   rs.MoveLast
   maxsub = rs.Fields(0)
   rs.MoveFirst
   'get names
   Status.Show
   Status.Label1.Caption = "Writing Soils (.sol)"
    For p = 1 To rs.RecordCount 'read a line of data and put in into an arrays
 'read a line of data and put in into an arrays
mysub = rs.Fields(0)

Status.PBar.Value = 5
Status.Refresh
myhru = rs.Fields(1)
LULC = rs.Fields(2)
soil = rs.Fields(3)
snam = rs.Fields(4)
```

```
nlayers = rs.Fields(5)
hygroup = rs.Fields(6)
zmax = rs.Fields(7)
anion = rs.Fields(8)
crk = rs.Fields(9)
texture = rs.Fields(10)
'read  LINE
Dim sol(10, 12)
For l = 1 To nlayers
   For a = 1 To 12
      z = 10 + a + (l - 1) * 12
      sol(l, a) = rs.Fields(z)
   Next a
Next l
      Dim mytime As String
      mytime = Time
      Dim mydate As String
      mydate = Date
      'create title
      mytitle = "Created " + mydate + "  " + mytime + " For Gridcell modeling"

      subf = mysub

      myname = subf + ".sol"
      MYFILE = myoutpath + "\" + myname
      ' open/create the textfile
      ChDir myoutpath
      Open MYFILE For Output As #1
      'write title
      Print #1, Spc(0); mytitle
      Print #1, Spc(0); " Soil Name: " + snam
      Print #1, Spc(0); " Soil Hydrologic Group: " + hygroup
      Print #1, Spc(0); " Maximum rooting depth(m) " + Format(zmax, "0000.00")
      Print #1, Spc(0); " Porosity fraction from which anions are excluded: " + Format(anion, "0.000")
      Print #1, Spc(0); " Crack volume potential of soil: " + Format(crk, "0.000")
      Print #1, Spc(0); " Texture 1                : " + texture

      Print #1, Spc(0); " Depth                [mm]:";
      For l = 1 To nlayers
      Print #1, formater(sol(l, 1), "000000000.00");
      Next l
      Print #1, ""

            Print #1, Spc(0); " Bulk Density Moist [g/cc]:";
      For l = 1 To nlayers
      Print #1, formater(sol(l, 2), "000000000.00");
      Next l
      Print #1, ""

            Print #1, Spc(0); " Ave. AW Incl. Rock Frag  :";
      For l = 1 To nlayers
      Print #1, formater(sol(l, 3), "000000000.00");
      Next l
      Print #1, ""

            Print #1, Spc(0); " Ksat. (est.)      [mm/hr]:";
      For l = 1 To nlayers
      Print #1, formater(sol(l, 4), "000000000.00");
      Next l
      Print #1, ""

            Print #1, Spc(0); " Organic Carbon [weight %]:";
      For l = 1 To nlayers
      Print #1, formater(sol(l, 5), "000000000.00");
      Next l
      Print #1, ""
```

```
            Print #1, Spc(0); " Clay          [weight %]:";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 6), "000000000.00");
    Next l
    Print #1, ""

            Print #1, Spc(0); " Silt          [weight %]:";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 7), "000000000.00");
    Next l
    Print #1, ""

            Print #1, Spc(0); " Sand          [weight %]:";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 8), "000000000.00");
    Next l
    Print #1, ""

            Print #1, Spc(0); " Rock Fragments   [vol. %]:";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 9), "000000000.00");
    Next l
    Print #1, ""

            Print #1, Spc(0); " Soil Albedo (Moist)      :";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 10), "000000000.00");
    Next l
    Print #1, ""

            Print #1, Spc(0); " Erosion K                :";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 11), "000000000.00");
    Next l
    Print #1, ""

            Print #1, Spc(0); " Salinity (EC, Form 5)    :";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 12), "000000000.00");
    Next l
    Print #1, ""

            Print #1, " "
    Close #1    ' Close file.
 rs.MoveNext
   Next p
   rs.Close
.Close
End With
Unload Status
End Sub
```