Grand Lake Watershed Assessment to Support Nutrient BMP Implementation Targeting

EPA Grant C9-996100-13□□Project 9

Submitted to:

Oklahoma Conservation Commission

Submitted by:

AMEC Earth & Environmental
Boston, Massachusetts

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1.0 INTRODUCTION

The overall objective of this project was to target critical source areas of phosphorus and sediment from sources in the Oklahoma portion of the Grand Lake watershed in northeast Oklahoma and the entire Honey Creek watershed [Oklahoma, Missouri, and Arkansas (Figure 1-1)]. The Grand Lake watershed is impaired by excess nutrients and other pollutants primarily due to non-point source (NPS) loads. The Oklahoma Conservation Commission (OCC) seeks to implement agricultural best management practices (BMPs) within the study area to address the water quality issues. In order to efficiently use available funds, it is necessary for OCC to quantitatively target areas with the highest potential for water quality improvement using common nutrient and sediment reduction BMPS such as filter strips, riparian strips, and various cattle and pasture management BMPs. This study provides the NPS characterization required to support OCC in targeting these efforts.

In order to achieve the project goals, satellite remote sensing images were collected in order to accurately map current landcover within the watershed. These data were integrated with the Soil & Water Assessment Tool (SWAT) to support identification and prioritization of NPS nutrient sources in the Grand Lake and Honey Creek watersheds. Results from this project provide a spatially explicit map prioritizing the subwatersheds that need to be targeted in order to improve water quality. This effort provides OCC a mechanism that will allow them to gain the greatest load reductions for the least amount of dollars invested.

1.1 Study Area

Grand Lake is a large watershed covering over 10,298 square miles in northeastern Oklahoma, Kansas, southwestern Missouri, and northwestern Arkansas (Figure 1-2). Three rivers -- the Neosho River, the Spring River, and the Elk River -- drain into the lake. The watershed includes 389 stream miles and 46,500 lake acres. The spatial extent of the watershed in each state is provided in Figure 1-2. Past studies have identified causes of impairment and suggested possible sources, but little has been done to pinpoint the location or relative contribution of those sources. It is likely that certain portions of the watershed contribute more to the impairment than other areas.

Available resources are inadequate to blanket the entire watershed with BMPs to reduce NPS pollution from all sources. Given OCC's jurisdictional boundaries, the Oklahoma portion of Grand Lake and the Honey Creek watershed (Oklahoma, Missouri, & Arkansas) were selected for this modeling exercise. The program seeks to focus BMP implementation by prioritizing select areas where they are needed the most and where the environmental benefit will be maximized. These areas were targeted using the SWAT model coupled with current landcover data derived from satellite imagery.

Landcover within the Grand Lake and Honey Creek watersheds is described in detail in Appendix A. The watershed overall is dominated by forest and pasturelands. The Oklahoma portion of the Grand Lake watershed is dominated by forest (33.41%) followed by high biomass pasture (32.09%) and low biomass pasture (13.98%). Likewise, the Honey Creek sub-watershed is also dominated by forest (42.47%) followed by high biomass pasture (39.79%) and low biomass pasture (11.43%).

1.2 Water Quality Impairment

The Oklahoma portion of the Grand Lake watershed is Clean Water Act (CWA) Section 303(d) listed as impaired for nutrients, dissolved oxygen, pH, pesticides, metals, and total toxics. The Honey Creek watershed is listed as impaired for nutrients, dissolved oxygen, noxious aquatic plants, ammonia, and unknown toxicity.

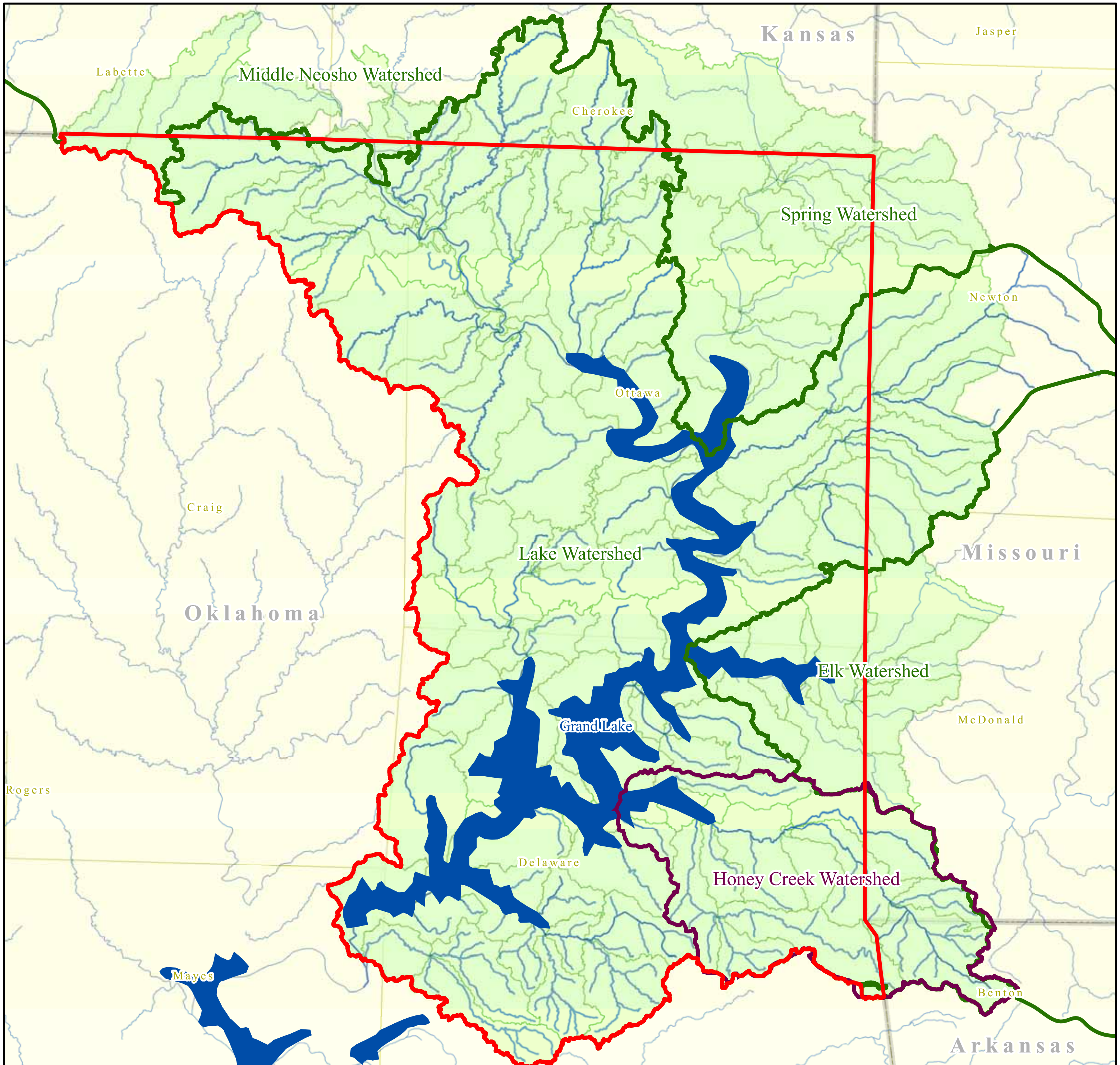
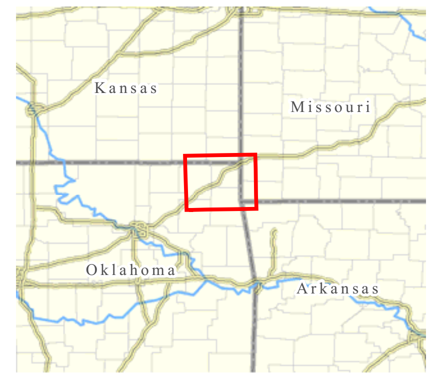


FIGURE 1-1

GRAND LAKE WATERSHED STUDY AREA

SWAT Model Domain

- Rivers & Streams
- Grand Lake Watershed Study Area
- Honey Creek Watershed
- Model Domain Subbasins
- Other Watersheds
- Water bodies



Spatial Data Sources: USGS National Hydrography (NHD) Dataset, USGS National Elevation (NED) Dataset, ESRI.
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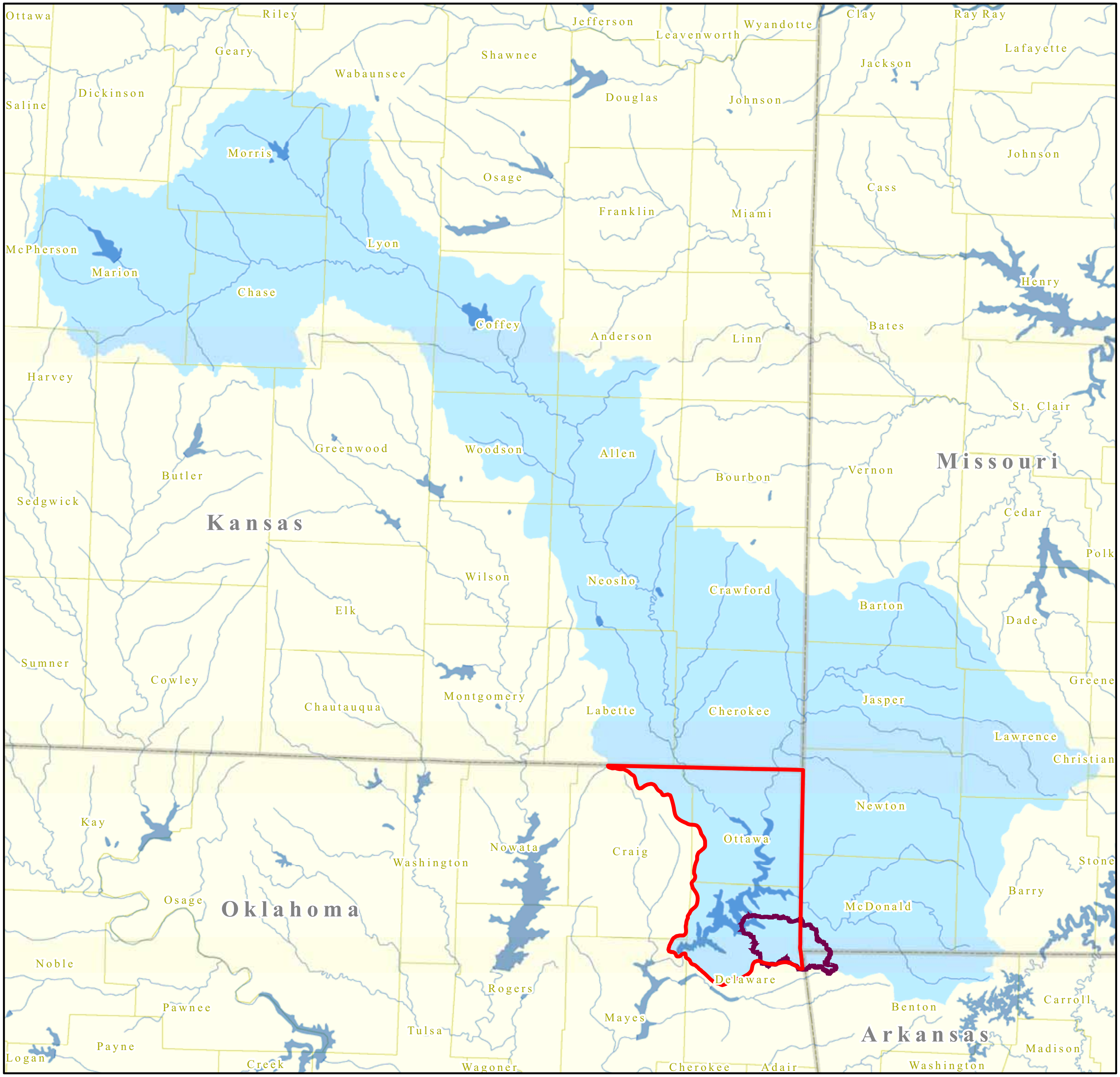

FIGURE 1-2

ENTIRE GRAND LAKE WATERSHED

SWAT Model Domain

- Rivers & Streams
- Grand Lake Watershed
- Grand Lake Watershed Study Area
- Honey Creek Watershed
- Water bodies

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2.0 SEDIMENT AND NUTRIENT LOAD ESTIMATION USING THE SWAT MODEL

The Soil & Water Assessment Tool (SWAT) is a public domain watershed-scale model developed for the USDA Agricultural Research Center. The SWAT model was designed to predict the effects of land management practices on water, sediment, nutrient, and pesticide yields on large river basins. The model simulates weather, surface runoff, percolation, reach routing, nutrient loading, water transfer and other non-point source characteristics. The process of specifying SWAT model parameter values for the Grand Lake application is described below.

2.1 SWAT Model: Specification of Watershed Characteristics

2.1.1 Topography

Topographic data were obtained from a 30 meter Digital Elevation Model (DEM) in the National Elevation Dataset (NED) and is shown in Figure 2-1. THE DEM was used to establish a set of sub-basin parameters associated with slope and stream network.

2.1.2 Soils

Soil data were obtained and applied to specify soil characteristics throughout the model domain (Figure 2-2). Soil data were obtained in GIS format from the State Soil Geographic Database (STATSGO). These data were downloaded from the EPA BASINS dataset. Initially, Soil Survey Geographic (SSURGO) data were evaluated for use in the model, but these data were deemed problematic for integration into SWAT because of missing entries and formatting problems.

2.1.3 Landcover

A detailed set of landcover data were obtained as part of the satellite remote sensing data analysis described in Appendix A. The landcover characterization data provided in Figure 2-3 and Table 2-1 were applied to the SWAT model domain to specify landcover in the Grand Lake model.

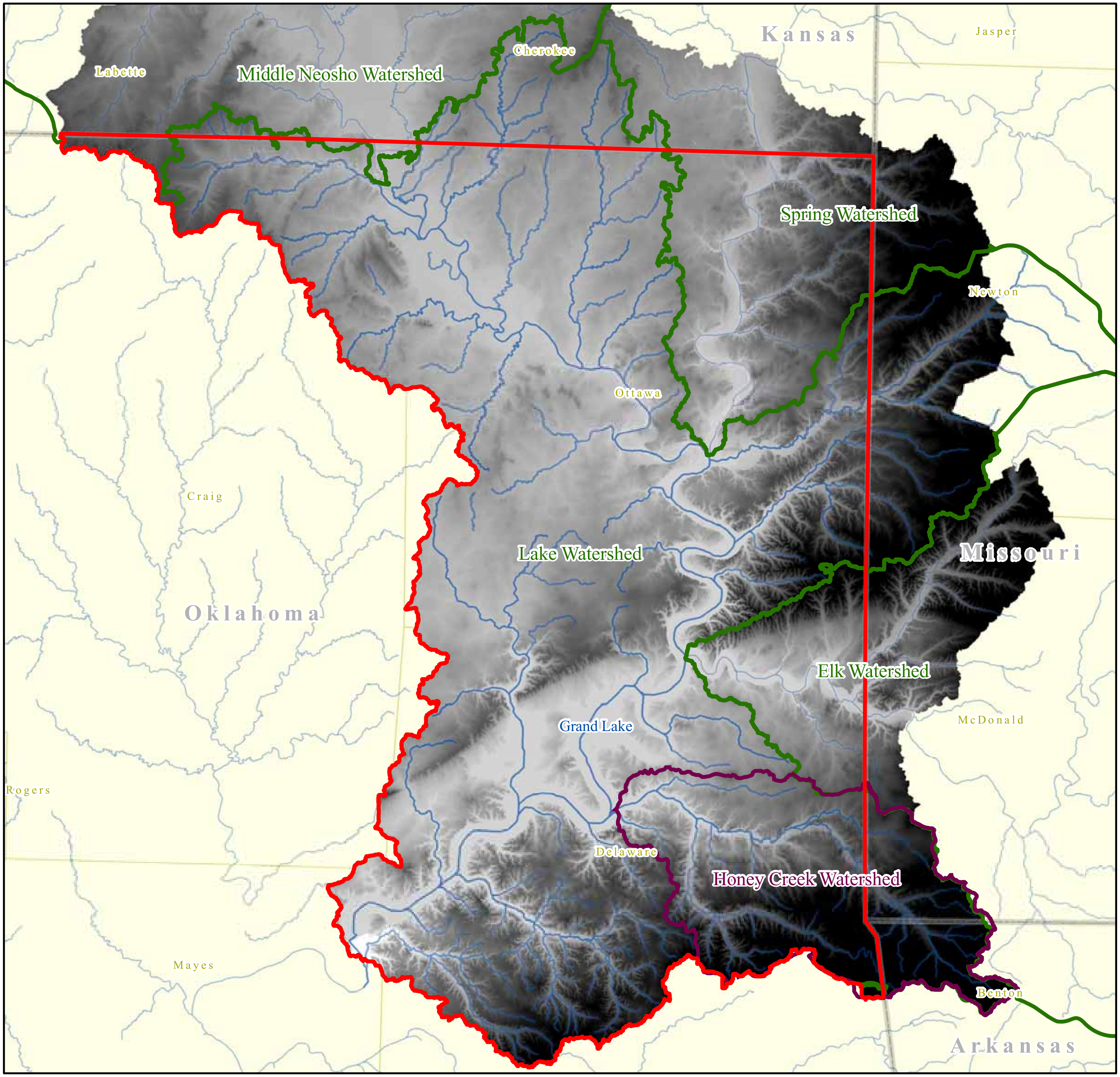


FIGURE 2-1

TOPOGRAPHIC MAP OF THE GRAND LAKE WATERSHED STUDY AREA

SWAT Model Domain

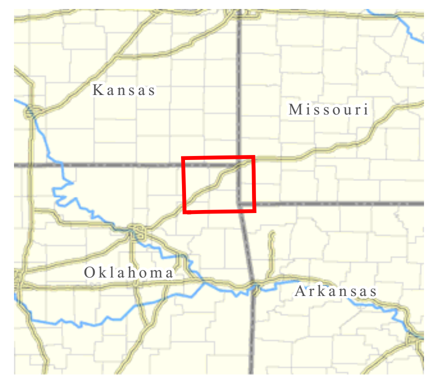
Grand Lake Watershed Study Area
Honey Creek Watershed
Other Watersheds
Rivers & Streams

Digital Elevation Model (meters)

Value

High : 396

Low : 187



Spatial Data Sources: USGS National Hydrography (NHD) Dataset, USGS National Elevation (NED) Dataset, ESRI.
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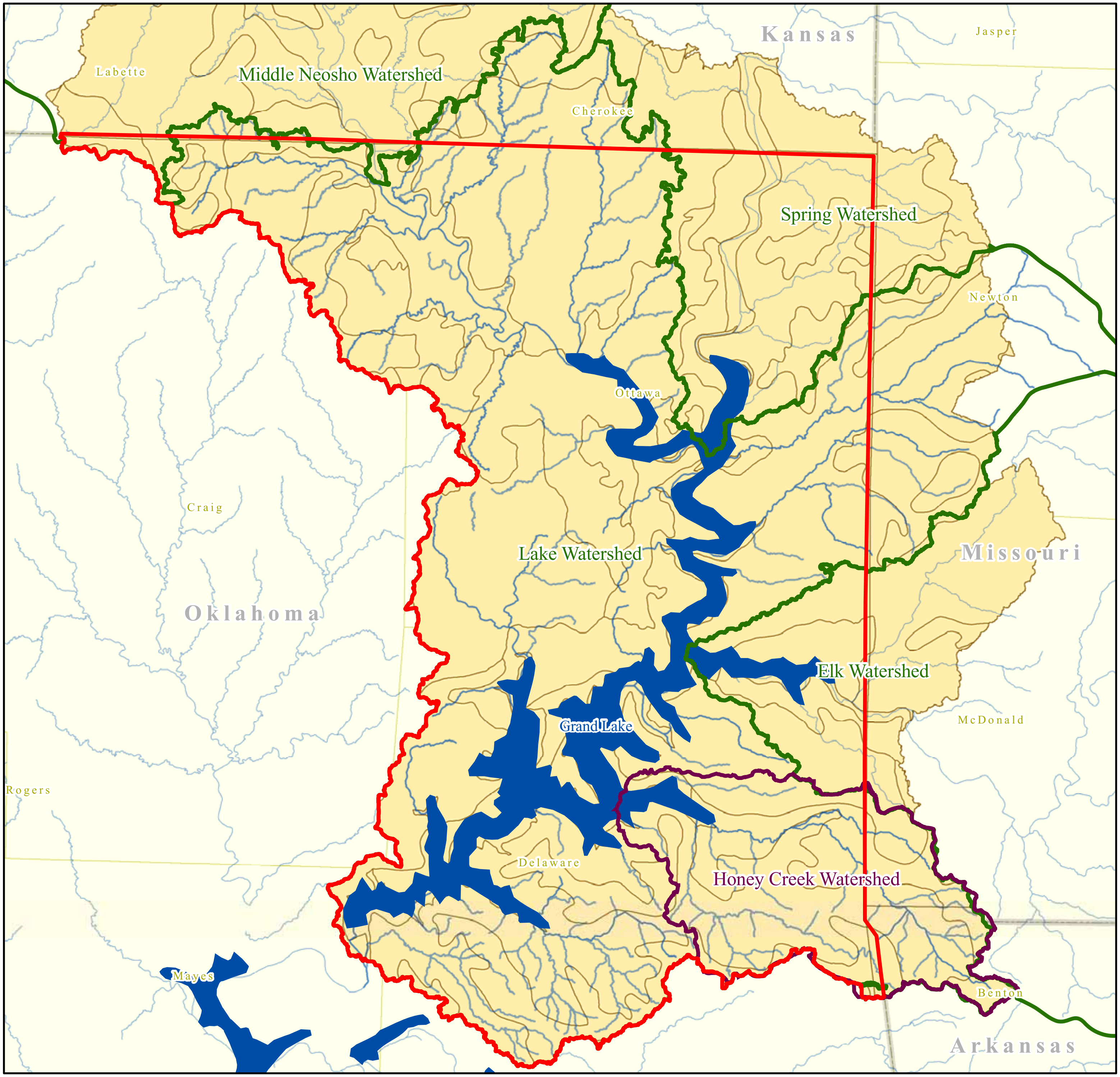

FIGURE 2-2

SOIL MAP OF THE GRAND LAKE WATERSHED STUDY AREA

SWAT Model Domain

- Rivers & Streams
- Grand Lake Watershed
- Honey Creek Watershed
- Other Watersheds
- Water bodies
- STATSGO Soil Delineation

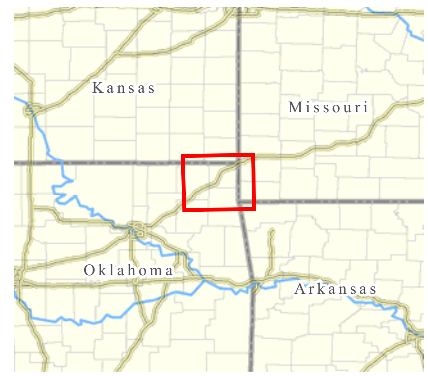

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Figure 2-3. Landcover Map of the Grand Lake Watershed study area

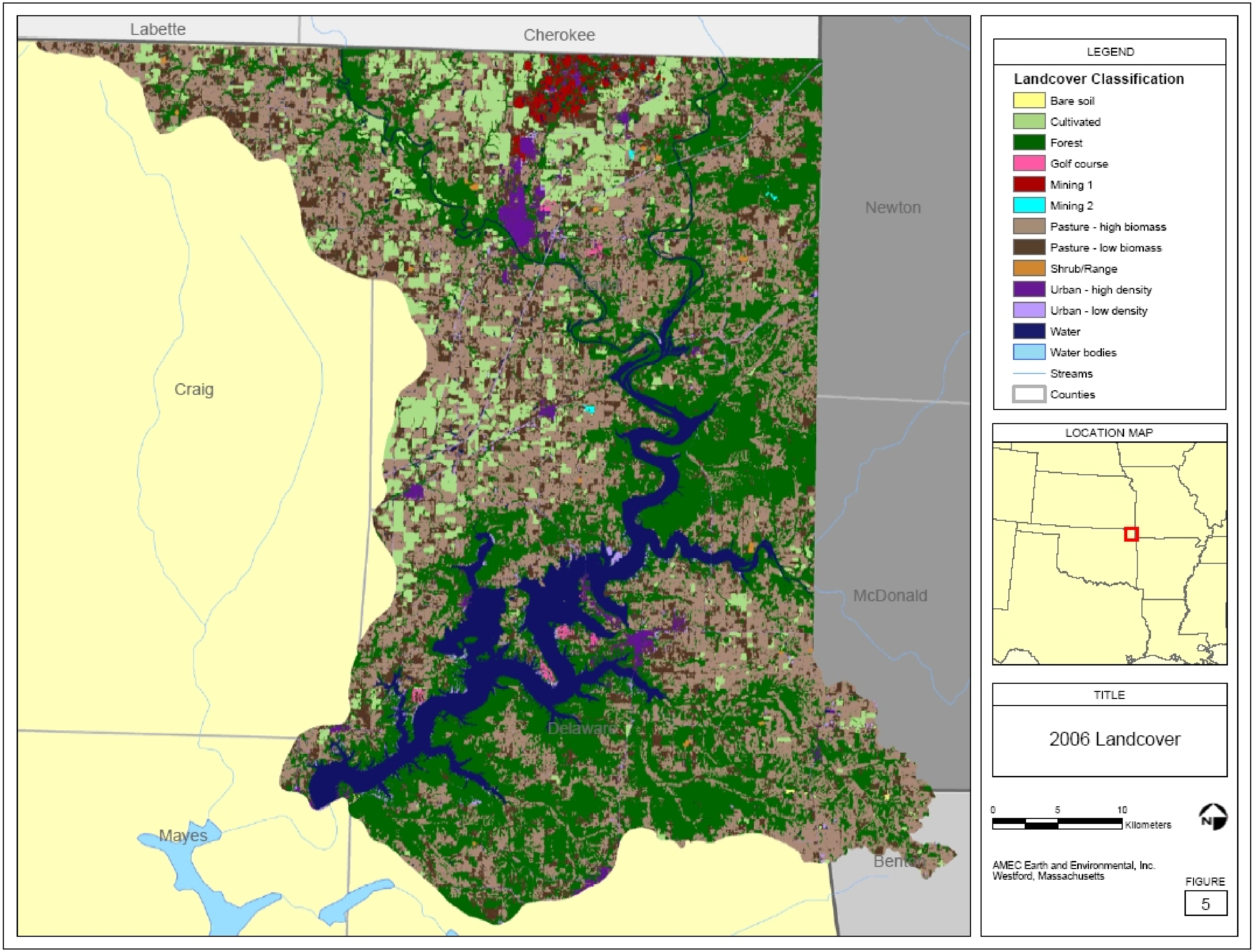


Table 2-1. Summary of SWAT Model Domain Landcover Data

Landcover Type	Area (Ha)	% of Watershed
1. Water	20003.31	8.50%
2. Forest	78633.36	33.41%
3. High Biomass Pasture	75527.73	32.09%
4. Low Biomass Pasture	32913.27	13.98%
5. Cultivated	20299.59	8.62%
6. Shrub / Range	272.70	0.12%
7. Bare soil	59.13	0.03%
8. Low Density Urban	3158.10	1.34%
9. High Density Urban	2738.34	1.16%
10. Golf Course	276.66	0.12%
11. Mining Type 1	1411.83	0.60%
12. Mining Type 2	69.66	0.03%
Total	235363.68	100.00%

2.1.4 Sub-basin Delineation

The SWAT model requires two levels of watershed delineation, the sub-basin level and the Hydraulic Response Unit (HRU) level. The sub-basin level is larger and is defined by contiguous drainage areas within the basin. Sub-basins in the model domain are delineated using the DEM, a threshold drainage area size parameter, and a set of known tributaries.

2.1.5 Hydraulic Response Unit (HRU) Delineation

Each sub-basin in the model domain was divided into HRUs within SWAT. A HRU is defined as a unique combination of soil, landcover and management combinations within a sub-basin. Each HRU is modeled independently within SWAT.

2.1.6 Weather Data

Weather is a driving force for any hydrologic model. Data collected at a few points may be applied to represent an area of hundreds of square miles. Rainfall can be highly variable, especially in the spring when convective thunderstorms produce precipitation with a high degree of spatial variability. It may rain heavily at a weather station, but may be dry a short distance away. On an average annual or average monthly basis, the impact of precipitation distribution errors may be less significant. This limitation, among others, cautions us against using daily model output to support targeting for BMP implementation.

SWAT requires daily weather values of precipitation, maximum and minimum temperature, wind speed, solar radiation and relative humidity. Daily precipitation and temperature maximum and minimums were obtained from National Weather Service Cooperative Observer Program stations shown in Figure 2-4.

2.2 SWAT Model: Specification of Land Management and Nutrient Input Data

Representation of land management practices for poultry operations, cultivated land, pasture, and other land management in the SWAT model is described below.

2.2.1 Poultry Litter Land Application

Land application of poultry litter in the Grand Lake watershed is known to be widespread and extensive. Thus, it is important to include simulation of poultry litter land application in the Grand Lake SWAT model. The process of characterizing poultry litter application in the model was completed as follows:

- Identification and summation of poultry houses in each sub-basin;
- Estimation of litter production rates per poultry house (tons/house/year);
- Specification of land application of poultry litter produced within each sub-basin; and
- Specification of nutrient content of the poultry litter applied.

Each step of this process is described below.

Identification and Summation of Poultry Houses

Poultry house data were acquired from the sources provided in Table 2-2.

Table 2-2. Poultry House Data Sources by State

State	Poultry House Data Source
Oklahoma	David Wheelock of the Oklahoma Department of Agriculture, Food and Forestry; david@oda.state.ok.us. Point coverage of poultry operations in Oklahoma with location and number of birds and houses (2005).
Arkansas	GeoStor, the Arkansas Spatial Data Infrastructure (http://www.geostor.arkansas.gov). GIS shapefile containing location information for individual poultry houses. This file was extracted from the Arkansas Highway and Transportation Department county mapping files (2006).

State	Poultry House Data Source
Missouri	Missouri Spatial Data Information Service (http://msdisweb.missouri.edu) → query NPDES → CAFOS → Chicken/Poultry Point data set depicting outfall locations of wastewater facilities with Missouri NPDES Operating Permits, including poultry houses (2006). Barbara Ruppel, MoDNR, Water Pollution Control Program, (573) 751-6619
Kansas	Robert Gavin of the Bureau of Water - Livestock Waste Management, Kansas Department of Health and Environment; rgavin@kdhe.state.ks.us. Excel file with coordinates of all poultry facilities within Kansas (2007).

Digital data obtained from the sources listed above have been compared to Digital Orthophoto Quadrangles (DOQs) to verify the existence of the poultry houses and their locations. A summary of the process used to identify poultry houses and a description of poultry house data for each state is provided below.

Oklahoma

Comparison of the Oklahoma data layer with the DOQs suggested that points were placed at the center of properties that contained poultry houses and the associated metadata confirmed this relationship. An attribute of the shapefile provided the number of individual houses associated with each point. The indirect placement of the data point does not affect the model process because the litter from a chicken house is assumed to be applied on pasture within the sub-basin in which the point is located.

Arkansas

The GIS shapefile for Arkansas contained individual points for each individual poultry house. This was confirmed by overlaying the data layer on the DOQs. It was noted that in some cases the shapefile was missing locations of poultry houses and in other cases contained locations of poultry houses that had been abandoned. Sharon Baker at the Arkansas State Highway and Transportation Department confirmed that although the data were published in 2006, those for Benton County had not been updated since 2002 (personal communication, 30 January 2007). As a result, the shapefile was modified by AMEC to include new points for poultry houses that had been missing and to remove points that corresponded to abandoned houses. The houses that were considered to be abandoned were either no longer present or were clearly in very poor condition with visible holes in the roof and other such dilapidated features. With the revisions complete, it is reasonable to assume that there are not a significant number of abandoned houses being counted as active.

Missouri

The data layer obtained for Missouri contained the outfall locations of wastewater facilities with NPDES Operating Permits. Those that pertained to poultry houses were identified and subset. Comparison of this subset with the DOQs suggested that each point corresponded to a group of poultry houses. Using the DOQs, the number of individual chicken houses associated with each point was counted and an attribute with this information was added to the shapefile. An additional step was taken to check for poultry houses that were not included in the shapefile, since only facilities beyond a certain size requirement need to obtain NPDES permits. Recent imagery acquired by the National Aerial Imagery Program (NAIP) in 2006 was downloaded from the Missouri Spatial Data Service and a new shapefile was created to account for any poultry houses not included in the previous shapefile. It was assumed that these houses are used for poultry, as opposed to hogs or other types of animal feeding operations. As with the poultry houses in Arkansas, any houses that appeared to be abandoned were excluded.

Kansas

The coordinates obtained for Kansas corresponded to the center of properties that contain the CAFO. A GIS shapefile was created from the coordinates and the number of individual poultry houses associated with each point was added as an attribute. The DOQs were used to determine the number of houses associated with each point. Only a small portion of Kansas was included in the final model domain.

Summary

Poultry houses located within the model domain (Oklahoma portion of the Grand Lake watershed and the entire Honey Creek sub-watershed) are shown in Figure 2-5 and were represented in the model.

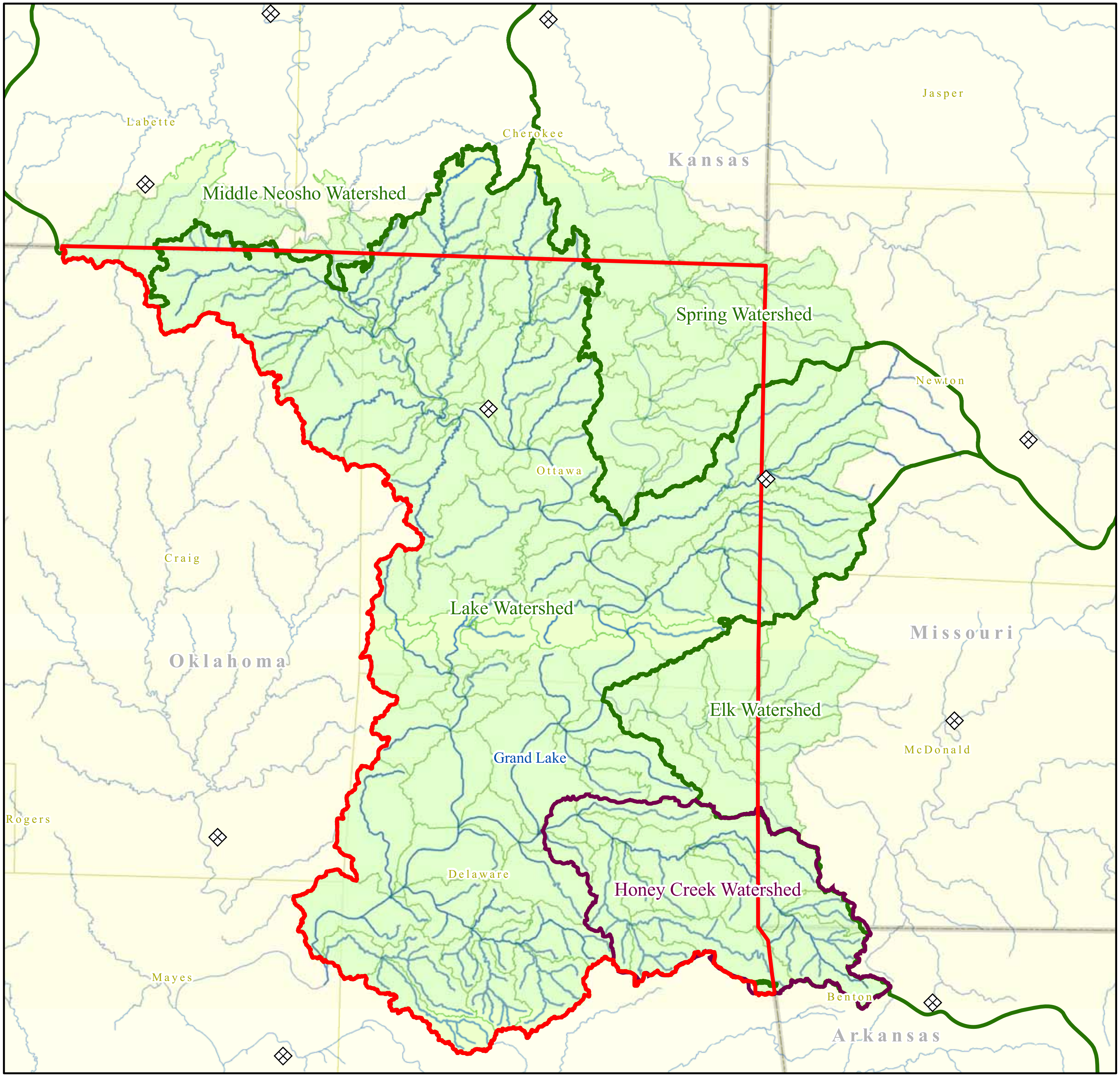
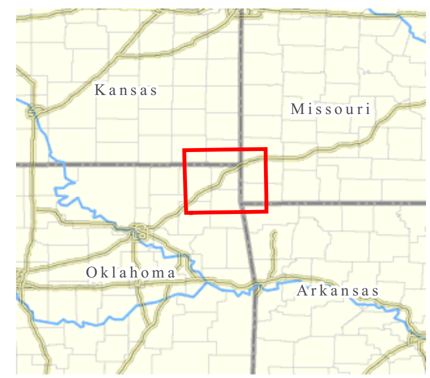


FIGURE 2-4

MAP OF WEATHER STATIONS USED IN THE SWAT MODEL

SWAT Model Domain

Weather Station
Grand Lake Watershed Study Area
Honey Creek Watershed
Other Watersheds
Rivers & Streams
Model Domain Subbasins



Spatial Data Sources: USGS National Hydrography (NHD) Dataset, USGS National Elevation (NED) Dataset, ESRI.
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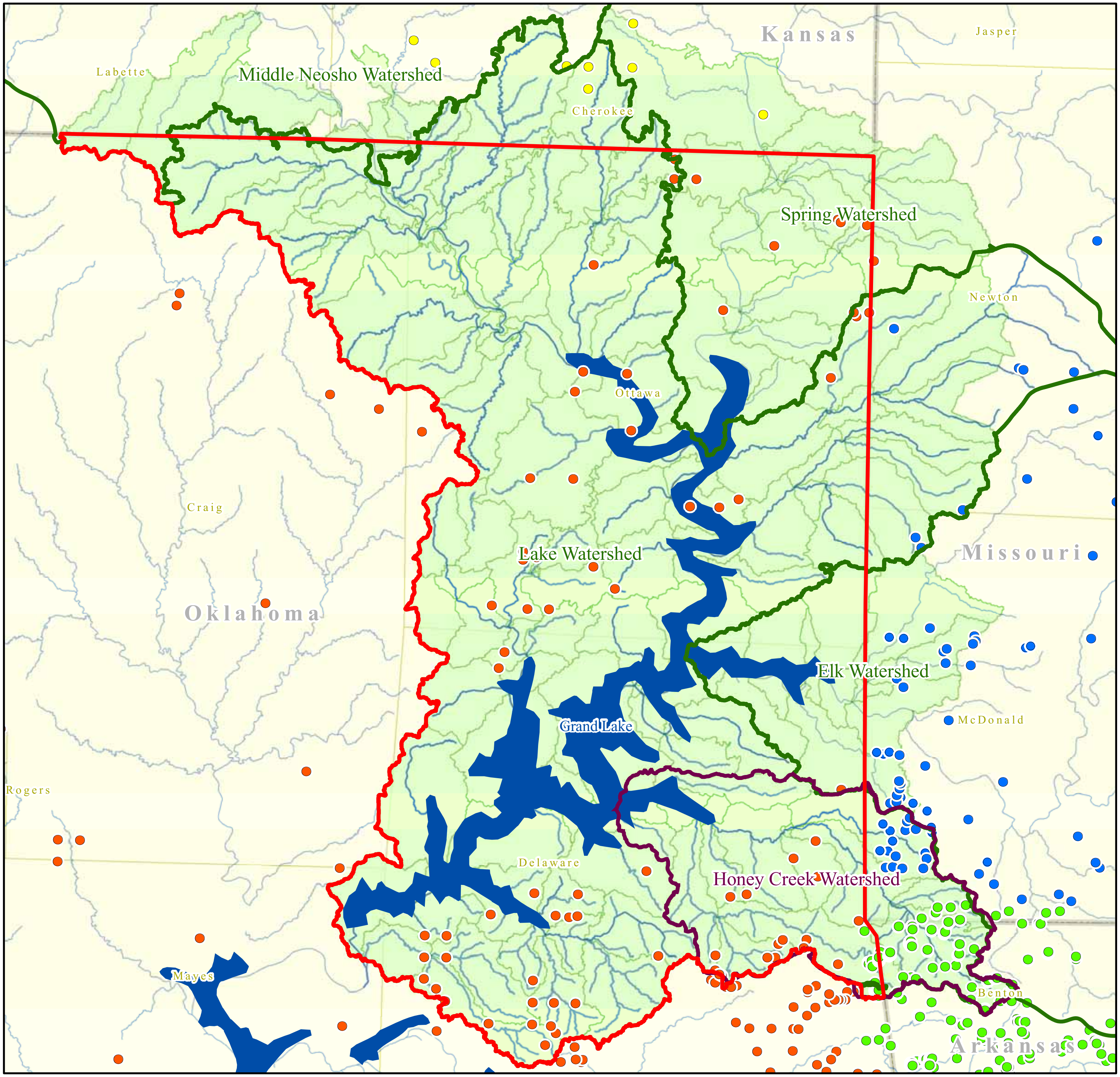
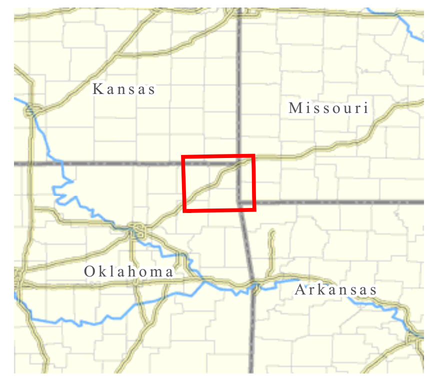


FIGURE 2-5

POULTRY HOUSE LOCATIONS IN THE MODEL DOMAIN

SWAT Model Domain

- Arkansas Poultry Farm
- Kansas Poultry Farm
- Missouri Poultry Farm
- Oklahoma Poultry Farm
- Grand Lake Watershed Study Area
- Honey Creek Watershed
- Other Watersheds
- Water bodies
- Rivers & Streams
- Model Domain Subbasins



Points of poultry farms in Arkansas represent individual poultry houses whereas points of poultry farms in Kansas, Oklahoma and Missouri may represent multiple poultry houses.

Spatial Data Sources: USGS National Hydrography (NHD) Dataset, USGS National Elevation (NED) Dataset, ESRI.
Projection: NAD 83 UTM Zone 15N

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Estimation of litter production rates per poultry house

Review of available litter production estimates yielded a range of rates. The following three sources of litter production rates were deemed most appropriate for use in the SWAT model:

- Poteau River Comprehensive Watershed Management Program TMDL Component Report (Storm et al., 1999) – 100 tons/house/year.
- Frank Jones, Associate Director, Center of Excellence for Poultry Science, University of Arkansas Extension (personal communication, 25 September 2006) – 100 tons/house/year, conservative estimate for 400' house. 135 tons/house/year, 500' house.
- Dan Parish, Director of Water Quality, Oklahoma Department of Agriculture (personal communication, 25 September 2006) - 125 ton/house/year, 400' house.

The estimated total quantity of litter produced per year within the study area, based on each of the estimates listed above, is provided in Table 2-3.

Table 2-3. Calculation of Litter Production using three Litter Production Rate Estimates

Number of Poultry Houses in Area of Concern	Litter Production Rate (tons/house/year)	Total Quantity of Litter Produced (tons/year)
679	100	67,900
679	125	84,875
679	135	91,665

Other more complicated methods for estimating the annual quantity of litter produced include estimating the size of each poultry house and developing a litter production rate per ft^2; or estimating the size of each poultry house, estimating the number of birds per ft^2, and then estimating the litter production per bird per year. Each of these alternative methods was deemed less suitable than the method employed above for this application.

For the Grand Lake SWAT modeling application, a value of 120 tons of litter produced per house per year was assumed, yielding a total quantity of 81,480 tons of litter per year. This litter production rate was chosen because it was agreed with Dan Butler at OCC to represent an appropriate and realistic estimation (personal communication, 07 February 2007). Using a higher litter production rate could bias the calculation by potentially overestimating the amount of litter actually present.

The number of poultry houses in each sub-basin was then summed and multiplied by the mass of litter produced per house per year (120 tons/house/year). The mass of litter produced in each sub-basin was then applied to the land area within that sub-basin in the Grand Lake SWAT model.

Specification of the Nutrient Content of Poultry Litter

Once litter production was estimated, the next step was to estimate the amount of phosphorus contained in the litter. A literature review was conducted and the following estimates of the phosphorus content of poultry litter were obtained:

- The Poteau River Comprehensive Watershed Management Program TMDL Component Report (Storm et al., 1999) assumed phosphorus content of 1.5%.
- In the SWAT model for the Spavinaw Creek watershed, the nutrient content of the litter was estimated using nutrient analyses performed for the court ordered Conservation and Nutrient Management Plans (Storm et al., 2005). These data were collected in 2004-2005 and had an average phosphorus content of 1.5% for broiler litter.

A poultry litter phosphorus content value of 1.5% was selected and applied to the model. The phosphorus content of poultry litter is known to vary depending upon whether the poultry house is comprised of broilers, layers, and pullets, but local data were not readily available regarding this distribution. For the entire model domain, 322 tons of phosphorus is estimated to be applied per year in the form of poultry litter. This is based on a total estimate of 81,480 tons of litter produced annually within the study area.

Specification of Poultry Litter Land Application

Litter is expensive to transport relative to its value. Therefore, it is not economical to transport it very far from where it was produced. In the Grand Lake SWAT model, it was assumed that litter was applied to pastures within close proximity of the point of production. This assumption is consistent with the approach applied for similar modeling projects in Oklahoma (Storm et al., 2005; Storm et al., 1999). The litter application rate for each sub-basin was determined by the number of poultry houses and the area of pasture within each. All litter produced within a sub-basin was applied uniformly to pastures within that sub-basin in the Grand Lake SWAT model.

Limitations

One of the limitations of the model is the exclusion of poultry litter that is transported into the Grand Lake watershed from a different watershed. It is reported by Dan Butler at the OCC that BMPs Inc. has transported poultry litter into the Grand Lake watershed from the Lake Eucha / Spavinaw Creek watershed over the last 2 to 3 years, as has the Oklahoma Natrual Resources Conservation Service (NRCS) through the Environmental Quality Incentives Program (EQIP) (personal communication, 07 February 2007). Due to the lack of readily available data on the quantity of litter and the sub-watersheds in which it is spread, this input was excluded from the analysis.

2.2.2 Soil Test Phosphorus

Soil test phosphorus (STP) data were obtained for each state in the study area. STP data were applied in the SWAT model to specify mass of phosphorus per land area and to support simulation of phosphorus transport from cultivated land to receiving waters. STP data were acquired from the sources provided in Table 2-4.

Table 2-4. Sources of Soil Test Phosphorus Data by State

State	STP Data Source
Oklahoma	Hailin Zhang of Oklahoma State University Laboratory. 1997-2004
Arkansas	The University of Arkansas Laboratory Site http://www.uark.edu/depts/soiltest/ 2002-2004
Missouri	Manjula V. Nathan Asst. Professor/Director of MU Soil Testing and Plant Diagnostic Service Laboratories Division of Plant Sciences University of Missouri Columbia, MO 65211; Tel: (573)-882-3250; Fax: (573)-884-4288 Email: nathanm@missouri.edu URL: http://soilplantlab.missouri.edu/soil

STP values obtained from the above sources were allocated to appropriate landcover categories. For each landcover type, a single STP value was assigned, based on area-weighted county averages. Table 2-5 provides a summary of estimated STP loading by landcover. The highest STP loadings were observed to be associated with cultivated, urban, and pasture land (ranging from 111 to 149 lb/acre). Forest, shrub-range, and golf course landcovers were assigned typical background concentration values of 30 lbs/acre. Mining areas were assumed to be nearly devoid of vegetation and were assigned an STP value of ½ typical background values (15 lbs/acre).

Table 2-5. Estimated Soil Test Phosphorus Loading by Landcover

Landcover	STP lb/acre
Cultivated	149
Urban High	148
Urban Low	148
Pasture-Low	111
Pasture-High	111
Forest	30
Shrub/Range	30
Bare Soil	30
Golf Course	30
Mine 1-Tar Creek	15
Mine 2-Quarries	15

2.2.3 Land Management

A description of the land management practices applied to the Grand Lake SWAT model for cultivated, pasture and mining is provided below.

Cultivated

According to conversations with Joe Schneider of the Oklahoma Conservation Commission, two types of crop management are dominant in the Oklahoma portion of Grand Lake watershed and the Honey Creek subwatershed, as follows:

- In the Oklahoma portion of the Grand Lake watershed (excluding the Honey Creek watershed), a two-year cycle featuring double-cropping is dominant; and
- In the Honey Creek subwatershed, single-cropping generally is practiced.

These two cultivated land management practices were applied to the SWAT model, as specified in Table 2-6 (Grand Lake) and Table 2-7 (Honey Creek) below. Note that only fertilizers with a phosphorous component were included in the simulation. For double-cropping scenarios, generic fall tillage was specified as having a mixing depth of 150mm and a mixing efficiency of 0.95, while the generic spring plowing operation had a mixing depth of 125mm and a mixing efficiency of 0.5.

Table 2-6. Agricultural Land Management Operations in the Grand Lake Watershed

Management Operation	Year	Date	Type Crop/Note
Till	1	01-Apr	Generic Spring
Plant/Begin Growing	1	20-Apr	Grain Sorghum
Harvest/Kill	1	30-Sep	
Till	1	07-Oct	Generic Fall
Fertilize	1	15-Oct	200lb/ac 18-18-18
Plant/Begin Growing	1	15-Oct	Wheat
Harvest/Kill	1	15-Jul	
Plant/Begin Growing	2	15-Jul	Soybeans
Harvest/Kill	2	30-Oct	

Table 2-7. Agricultural Land Management Operations in the Honey Creek Watershed

Management Operation	Year	Date	Type Crop/Note
Till	1	15-Sep	Fall Generic
Plant/Begin Growing	1	21-Sep	Wheat
Fertilize	1	21-Sep	200 lb 18-18-18
Harvest/Kill	1	01-Jul	

Pasture

In 2006, a survey was distributed to OCC personnel within the watershed to support characterization of pasture area land management. Operational input to the Grand Lake SWAT model was based on the survey response and NRCS guidelines, as described below and summarized in Table 2-8.

Table 2-8. Oklahoma Conservation Commission Management Operations Survey Results

		High Biomass (70% of Pastures)		Low Biomass (30% of Pastures)	
Management Operation	**Date**	**60% Bermudagrass (PHBB)**	**40% Fescue (PHBF)**	**60% Bermudagrass (PLBB)**	**40% Fescue (PLBF)**
Begin Growing Season	-	30-Apr	30-Sep	30-Apr	30-Sep
Graze	-	1/3 AU/ac when 1800 kg/ha (~4" forage) June-November	1/3 AU/ac when 1800 kg/ha (~4" forage) Dec-May	1/3 AU/ac when 1800 kg/ha (~4" forage) June-November	1/3 AU/ac when 1800 kg/ha (~4" forage) Dec-May
Fertilize	March 15th	50% of Litter	50% of Litter	50% of Litter	50% of Litter
Fertilize	-			200 lb/ac 18-18-18 (April 1st)	200 lb/ac 18-18-18 (March 1st)
Fertilize	April 15th	50% of Litter	50% of Litter	50% of Litter	50% of Litter
Cut/Harvest	June 15th	None		Harvest	

The remote sensing data analysis (Appendix A) classified pasture into high biomass and low biomass fields. Low biomass landcover areas are characterized as hayed, while high biomass areas are not. The remote sensing analysis results were observed to be in agreement with the percentage of hayed pastures suggested by the 2006 pasture management survey. Low and high biomass landcover categories were further split into cool and warm season pasture components. Cool season grasses begin the growing season in September and are grazed during winter months. Warm season pastures are planted in April and grazed during the summer months.

Mining

Mining activity in the study area has been split into two categories. One category consists of the former lead and zinc mines of the Tar Creek area, which have reportedly remained dormant for 40 years. This landcover type was simulated using characteristics similar to that of low density residential areas. Specifically, these mining areas were represented as 50% impervious surface and minimal plant growth and nutrient buildup. The second mining category consists of five crushed stone mines, two clay pits and one silica mine. These mine areas were simulated as bare ground.

Golf Courses

Golf course management input is based on surveys of the golf course industry in Oklahoma, as summarized by Oklahoma State University turfgrass specialist Dennis Martin (personal communication, 07 February 2007). All golf course land was simulated as Bermuda grass, with area-weighted averages for maintained biomass and fertilizer applications. A phosphorus value of 3.49 kg/ha was applied monthly during the growing season of April through October.

2.2.4 Point Source Nutrients

Point sources were initially identified using the Comprehensive Study of the Grand Lake Watershed: Initial Report (2004). The majority of the facilities listed were located in Oklahoma. Listed facilities were then verified against those displayed by the OK DEQ GIS Data Viewer. All of the facilities that were identified were then queried online using the EPA's Permit Compliance System (PCS) (http://www.epa.gov/enviro/html/pcs/index.html). State environmental departments were then contacted in Arkansas, Kansas, Missouri and Oklahoma for additional point source data.

The process of screening point sources for inclusion in the SWAT model was as follows. Any permitted facilities that were specified as either inactive or discontinued were excluded from the analysis. Only those point sources with a discharge of greater than or equal to one million gallons per day (MGD) or designated as a major facility by EPA were considered. EPA designates facilities as major or minor based on a point system. Generally, but not always, facilities that discharge over 1 MGD are considered major. In addition, facilities that discharge stormwater were excluded along with those categorized as limestone quarries. A total of 15 facilities met these criteria.

Only one of these facilities was located within the study area. The point source was situated in the Honey Creek watershed, upstream of the gage that was used for calibration. The facility was the Simmons Food, Inc. (NPDES permit number MO0036773), which is used for poultry slaughtering and processing. Monthly data for flow, sediments, and phosphorus were available from June 1999 through January 2007 and were applied to the SWAT model.

3.0 SWAT MODEL CALIBRATION AND VALIDATION

This section presents a summary of the calibration and validation of the SWAT hydrologic and water quality modeling application for Grand Lake. Model calibration is a process of comparing model predictions to field measurements and adjusting model parameter values to make predictions more closely match field measurements. Model validation includes a similar comparison without the adjustment process and serves as a check on the model calibration process.

The model simulation period was 13 years, from 1992 to 2004. The first five years served as the model warm-up period to allow the model to equilibrate and to eliminate the need for specification of initial conditions. The Grand Lake hydrologic model was calibrated and validated by matching measured flows at the USGS stream gage in Honey Creek (Figure 3-1) to model predicted flows at that location for a four year period from January 1, 1998 to December 31, 2001. The water quality model was calibrated to total phosphorus and total suspended solids measurements collected in Honey Creek near Grove, OK (Figure 3-1) during the same time period.

Model calibration was conducted in the Honey Creek watershed and not in other major watersheds that extend beyond the Oklahoma study area. Other watersheds that extend beyond the Oklahoma border contain areas that are not within the study area. As a result, flows and nutrient loads measured within Oklahoma include contributions from outside of Oklahoma and beyond the model domain. Thus, comparison of field measurements and model predictions at these locations is not useful for calibration purposes.

The SWAT model calibration process was conducted in accordance with the approved Grand Lake Modeling Quality Assurance Project Plan (AMEC, 2006). In general, the hydrologic calibration and validation was conducted first and a series of statistical tests were conducted to ensure that the model calibration was successful. Next, the water quality model calibration and validation was conducted with focus on total phosphorus and total suspended solids load predictions. The water quality calibration was also tested using a set of statistical analysis tools. The Grand Lake model calibration is described below.

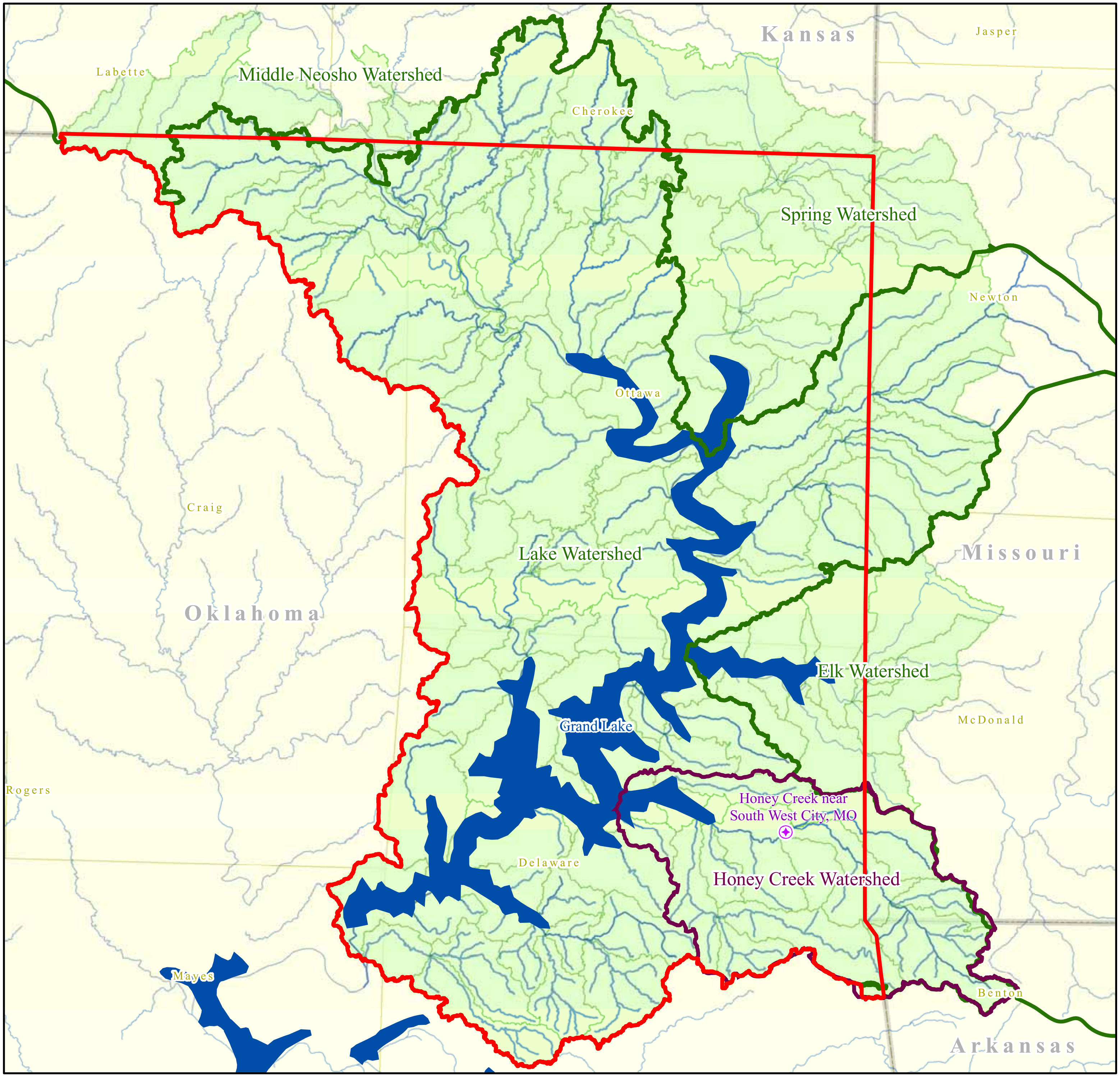
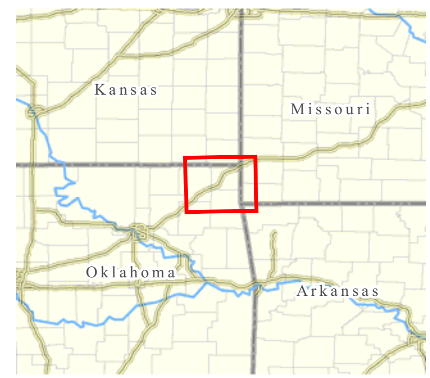


FIGURE 3-1

MAP OF HONEY CREEK WATERSHED WITH MODEL CALIBRATION LOCATION INDICATED

SWAT Model Domain

- USGS Stream Gauging Station
- Grand Lake Watershed Study Area
- Honey Creek Watershed
- Other Watersheds
- Water bodies
- Rivers & Streams
- Model Domain Subbasins



Spatial Data Sources: USGS National Hydrography (NHD) Dataset, USGS National Elevation (NED) Dataset, ESRI.
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3.1 Hydrologic Model Calibration

The hydrologic model was calibrated using measured and predicted streamflow at the USGS Honey Creek gauge near South West City (Figure 3-1). The calibration period spanned four years, from January 1, 1998 to December 31, 2001. Streamflow was calibrated to annual and monthly averages of total flow, surface runoff, and baseflow. The calibration was conducted by adjusting selected model parameters so that the various runoff processes more closely represented the watershed processes of baseflow and surface flows.

Hydrograph Separation into Baseflow and Surface Flow Components

Streamflow was separated into its baseflow and surface runoff components using the USGS HYSEP Sliding Interval Method. The duration of surface runoff is calculated from the empirical relation:

$$N = A^{0.2}$$

where N is the number of days after which surface runoff stops, and A is the drainage area in square miles. Hydrographs are separated based on an interval of 2N*, which is the odd integer between 3 and 11 nearest to 2N. The sliding interval method finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered, which is assigned as the baseflow for that day. Surface runoff for that day is defined as the total flow minus the assigned baseflow value.

Hydrologic Model Calibration Criteria

Graphical and statistical metrics are used to determine how well simulated values matched observed values. Model performance metrics were pre-selected and are described in the modeling QAPP (AMEC, 2006). Thus, model calibration includes comparison of actual model performance to model predictions using statistical analyses.

Statistical analyses provide tests of model calibration and confidence in predicted values and model performance. This study utilized: (1) relative error; (2) the Nash-Sutcliffe coefficient; and (3) the correlation coefficient to quantify model error. In accordance with the project QAPP(AMEC, 2006), SWAT model performance goals were: (1) the relative error of the hydrologic calibration is within 10%; (2) the Nash-Sutcliffe coefficient is greater than 0.4; and (3) the correlation coefficient is greater than 0.5 (Ramanarayanan et al., 1997). These model calibration performance metrics help to ensure that model performance is tested in a comparable and objective manner.

Hydrologic Model Parameter Adjustment

Calibration is the process of modifying parameter values within a reasonable range such that model predictions best match observed conditions. This is an iterative process with increasingly accurate model predictions. The set of hydrologic calibration parameters that were adjusted is provided in Table 3-1. Table 3-1 also provides default (initial) and final adjusted values for each parameter.

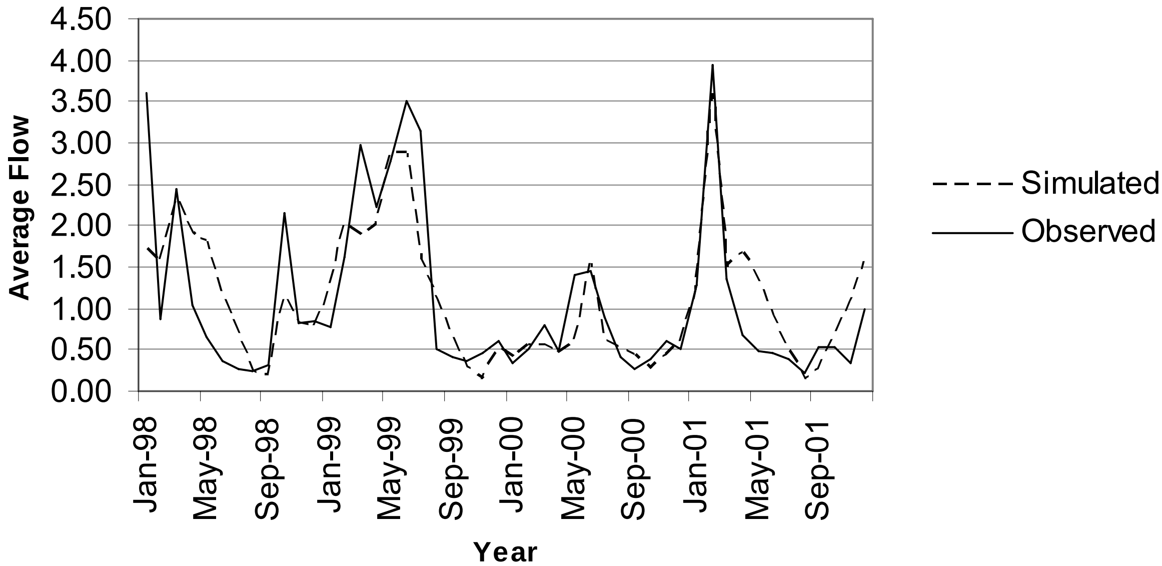
Table 3-1. Hydrologic Calibration Parameters Adjustments

Parameter Name	Parameter Description	Default Value	Final Value
CN2	Curve Number	Varies by Landcover (range 55 to 92)	Reduced 25% (range 41 to 69)
RECHG_DP	Deep Aquifer Percolation Factor	0.05	0
ESCO	Soil evaporation compensation factor	0.95	0.3
GWQMN	Threshold depth of water in the shallow aquifer return flow to occur (mmH2O)	0	15
REVAPMN	Threshold depth of water in the shallow aquifer for “revap” or percolation to occur (mmH2O)	1	30
PET	Potential ET calculation method	Priestley-Taylor Method	Hargreaves method

Hydrologic Model Calibration Results

Figure 3-2 provides measured and predicted monthly average flow at the Honey Creek USGS gage location. Visual inspection of Figure 3-2 suggests that measured and predicted flows are closely matched. Hydrologic model performance was tested using the three established statistical analyses; relative error, Nash-Sutcliffe coefficient, and correlation coefficient.

Figure 3-2. Measured and Predicted Monthly Average Flows at the Honey Creek USGS Gage



Relative Error

Statistical analysis found that predicted hydrologic total, surface, and base flow are all within a relative error of 5%, as shown in Table 3-2. These calibration values are well within the target range of less than 10% error.

Table 3-2. Statistical Analysis of Calibrated Hydrologic Model Performance

Flow	Simulated	Observed	Relative Error (%)
Total	1.11	1.09	**1.8%**
Surface	0.36	0.35	**4.5%**
Base	0.74	0.74	**0.5%**

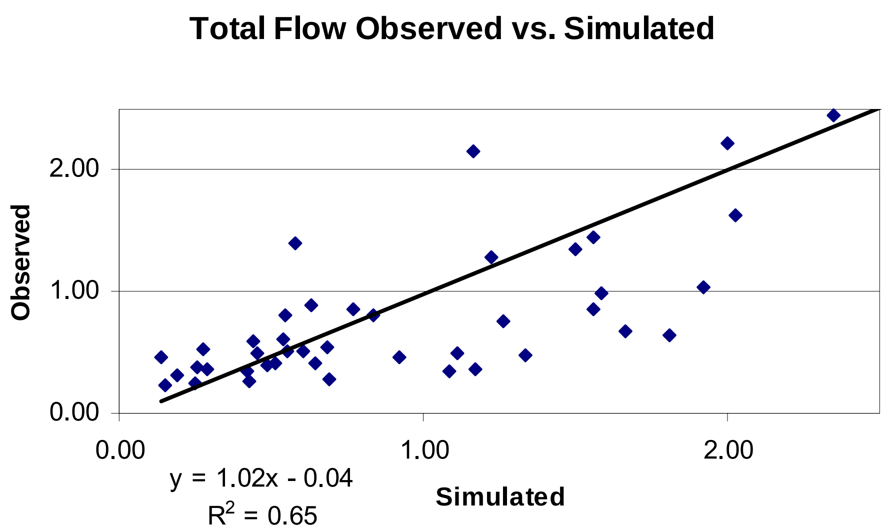
Nash-Sutcliffe Coefficient

A Nash-Sutcliffe coefficient value of 0.65 was calculated for the calibrated hydrologic model. This value is well within the target range of greater than 0.4.

Correlation Coefficient

The total flow correlation is plotted in Figure 3-3. A correlation coefficient value (R2) of 0.65 was calculated for the calibrated hydrologic model. This value is within the target range of greater than 0.5.

Figure 3-3. Hydrologic Model Calibration: Total Flow Correlation



3.2 Water Quality Model Calibration

The Grand Lake Targeting model was calibrated for total phosphorous (TP) and total suspended solids (TSS) near the USGS Honey Creek gage near South West City (Figure 3-1). Observed data were provided by the OCC and collected by the Oklahoma Water Resource Board (OWRB). The data collection site is called Honey Creek near Grove and is situated near the USGS gage used for flow calibration.

The water quality model was calibrated by comparing field measurements to model predictions of TP and TSS. The field measurement dataset was converted from a discrete set of measurements to a continuous record using Load Estimator or LOADEST. LOADEST is a program distributed by the USGS that estimates loads in streams and rivers using regression and rating curve methods. Daily observed streamflows were combined with synoptic field measurements of sediment and phosphorous to provide continuous estimates of phosphorus and sediment loads at the calibration point.

The SWAT model was calibrated by comparing field measurements, temporally interpolated using LOADEST, to model predictions and adjusting the parameter values described below to achieve a good match.

Table 3-3. Water Quality Parameters Adjusted During Calibration

Phosphorous Calibration Parameters Adjustments			
Parameter Name	**Parameter Description**	**Default Value**	**Final Value**
PHOSKD	Phosphorous Soil partitioning coefficient (m^3/mg)	175	300
PSP	Phosphorous Availability Index	0.4	0.8
PPERCO	Phosphorous Percolation Coefficient	10	5

SWAT predictions of TP and TSS at the Honey Creek calibration location matched well. In general, the model tended to slightly overestimate sediment (+5.9%) and phosphorous (+15.7%), as shown in Table 3-4. The calibrated values for TP and TSS were well within the relative error of 25% for these parameters specified in the QAPP.

Table 3-4. Average Annual SWAT Calibration Results

	Observed (mtons/year)	Predicted (mtons/year)	Relative Error
Sediment	4,563	4,309	5.9%
Phosphorous	4.25	3.68	15.7%

3.3 Model Validation

The hydrologic model validation period was from 2002 to 2004. For the hydrologic model, the relative error of total flow was -9.3%, within the target range of less than 10%. The Nash-Sutcliffe coefficient for the hydrologic validation was 0.4, within the target range of 0.4. The correlation coefficient for the hydrologic validation was 0.6, also within the target range of greater than 0.5. Thus, the hydrologic model validation satisfied statistical tests indicating that the hydrologic model was successfully calibrated.

The water quality model was validated from 2002 to 2004 for total phosphorous. For the water quality model validation, a relative error in predicted TP of 23.4% was observed, within the target range of less than 25%.

3.4 Model Limitations

It is important to note that a properly calibrated model will never perfectly match observed data, since hydrologic and water quality models are by definition simplifications of complex real world processes. In addition, there are inherent errors in the observed flow and water quality data. Therefore, rather than trying to match each observed data point, we try to appropriately simulate watershed processes.

In general, a set of simplifying assumptions is made to enable simulation of natural conditions. When the model is applied, the limitations associated with these assumptions become model limitations and result in uncertainty in model predictions. Overall, the results indicate that the Grand Lake SWAT model is well-calibrated, demonstrating good agreement between field data and model predictions. A discussion of some key SWAT model limitations is provided below.

<u>Weather</u>

Weather is a driving force for any watershed hydrologic model. In some cases, the largest source of error in hydrologic model has been attributed to the precipitation. Localized rainfall and quick moving storm events are difficult to capture with only a few, widely-spaced precipitation gages. Rainfall can be highly variable, particularly in the spring when convective thunderstorms produce spatially discrete precipitation. It may rain heavily at a weather station, but may be dry a short distance away. On an average annual or average monthly basis, the impact of precipitation variability on model predictions may be reduced.

<u>Simulation of Conditions Different from Calibration</u>

Scenarios involving simulation of conditions that are very different from the conditions that the model was calibrated for result in greater uncertainty. The SWAT model is calibrated using estimates of what was occurring in the basin during the calibration and validation period. If conditions vary dramatically from those conditions in the future (e.g, large changes in land management or precipitation conditions), then increased levels of uncertainty in model predictions will occur.

<u>Small Landcovers</u>

Landcover types representing small areas are not represented in the SWAT model. Landcovers that occupy limited areas such as unpaved roads, bare areas, construction sites, and some row crops may not be simulated. In addition, most of these features may not be depicted in the available landcover. Some of these small areas may contribute many times more sediment on a per unit area basis than rangeland. Although significant, they may not be able to be simulated with the currently available data.

Hydrologic Response Unit (HRU) Characteristics

Each HRU is assumed to have the uniform characteristics by the SWAT model. An HRU is a unique combination of soil and landcover within a sub-basin. Each portion of the HRU has the same characteristics regardless of its location within that HRU. Local factors such as slope are not considered variable within an HRU, even though slope is an important factor in both sediment and nutrient contributions.

Management Uncertainty

There is always uncertainty associated with land management. Management varies significantly from field to field, landowner to landowner. It is not possible to readily determine what is happening where or to simulate all these activities in the model. Therefore, categories are created to cover management practices based upon local knowledge obtained from the Conservation District Staff.

Summary

The Grand Lake SWAT model is limited due to the issues described above as all models are subject to limitations and uncertainty. The Grand Lake SWAT model is sufficiently robust to support targeting of priority areas for nutrient BMP implementation.

4.0 SWAT MODEL APPLICATION AND RESULTS

The SWAT model of the Oklahoma portion of the Grand Lake watershed in northeast Oklahoma and the entire Honey Creek watershed was applied to support targeting of critical phosphorus sources areas. Phosphorus and sediment loads for each of 144 sub-basins were predicted and compiled using the SWAT model. Sub-basins were then ranked by predicted phosphorus and sediment loads per unit area to provide quantitatively targeted areas with the highest potential for water quality improvement using common nutrient and sediment reduction BMPs.

Figure 4-1 provides targeted areas in the Grand Lake watershed in terms of phosphorus loss per unit area as predicted by the SWAT model. Sub-basin load predictions are mapped from highest phosphorus loss to lower phosphorus loss using a color-coding format. Specifically, the top 5% of sub-basins in predicted phosphorus loss per unit area were color coded red; the top 5 to 10% loss sub-basins were colored dark orange; and the top 10 to 20% sub-basins were colored light orange. Target area observations are provided below.

Targeted Northern Border Sub-basins

Several of the top phosphorus loss sub-basins are situated in the northern portion of the study area and are co-located with large agricultural land management and other land uses (Figure 4-1). Several of the top phosphorus source sub-basins are along the Kansas border and along the Missouri border. Prioritized sub-basins in the north-central area were co-located with urban areas as well as agriculture and other land uses.

Targeted Southwestern Sub-basins

Several other top priority sub-basins are situated in the southwestern portion of the watershed near Grand Lake. These sub-basins contain a combination of pasture, agriculture and other land uses. Two small sub-basins situated along Grand Lake had high predicted phosphorus loss (top 5%) and are co-located with golf courses, residential development, and other land uses.

Targeted Honey Creek Sub-basins

Three sub-basins in the Honey Creek watershed were prioritized (top 10 to 20%) for phosphorus mitigation. These sub-basins are co-located with poultry operations, pasture, and other land uses.

Figure 4-2 provides targeted areas in the Grand Lake watershed in terms of sediment loss as predicted by the SWAT model. Sub-basin load predictions are mapped from highest sediment loss to lower sediment loss using the same color-coding format as described for Figure 4-1.

Targeted sediment loss areas are identified as situated along the northern border, in the north-central area, and in the southwestern area (Figure 4-2). The distribution of targeted sediment loss areas was generally similar to the phosphorus target areas. The Honey Creek Watershed and the sub-basins on Grand Lake, however, were targeted for phosphorus mitigation, but were not targeted for sediment mitigation.

Summary

The Grand Lake SWAT model predictions provide quantitative information to support targeting of priority areas for optimal BMP implementation. Top priority sub-basins in terms of phosphorus loss, as shown in Figure 4-1, are optimal candidates for BMP mitigation projects.

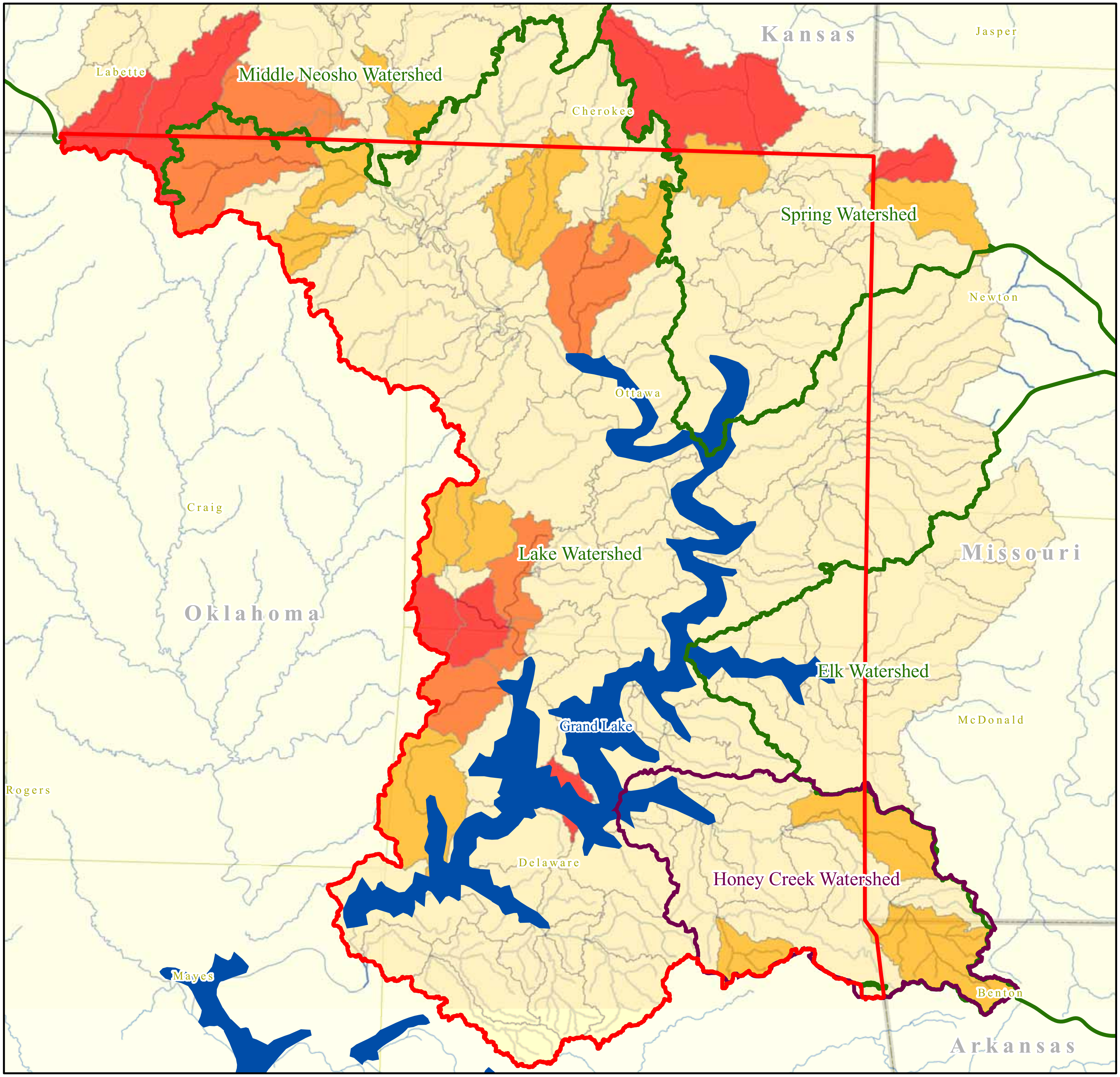


FIGURE 4-1

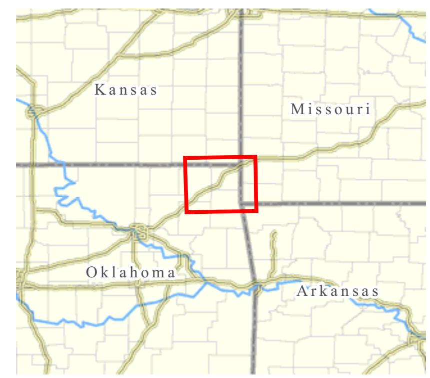
TARGETED PHOSPHORUS SOURCES AREAS IN THE GRAND LAKE WATERSHED

SWAT Model Domain

- Grand Lake Watershed Study Area
- Honey Creek Watershed
- Other Watersheds
- Water bodies

Targeted Subbasins

- 1 - 5%
- 5 - 10%
- 10 - 20%
- Other
- Rivers & Streams



Spatial Data Sources: USGS National Hydrography (NHD) Dataset, USGS National Elevation (NED) Dataset, ESRI.
Projection: NAD 83 UTM Zone 15N

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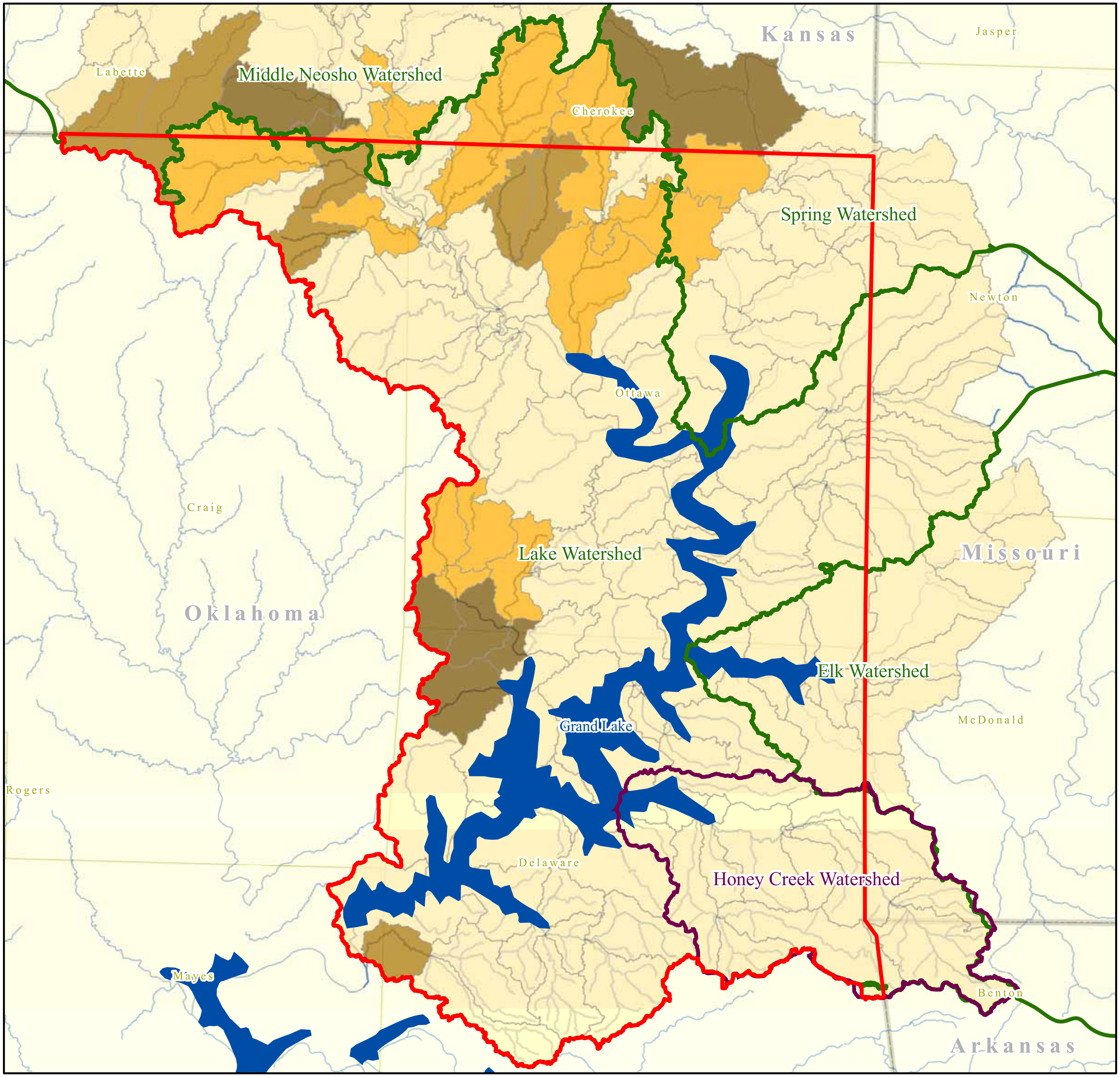


FIGURE 4-2

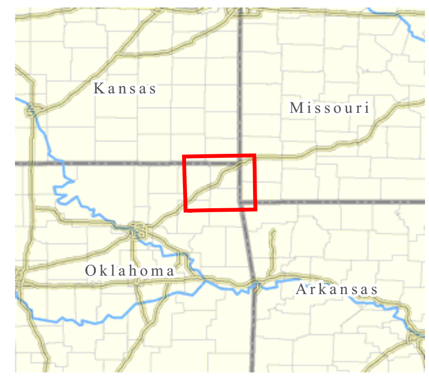
TARGETED SEDIMENT SOURCES AREAS IN THE GRAND LAKE WATERSHED

SWAT Model Domain

- Grand Lake Watershed Study Area
- Honey Creek Watershed
- Other Watersheds
- Water bodies

Targeted Subbasins

- 1 - 5%
- 5 - 10%
- 10 - 20%
- Other
- Rivers & Streams



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APPENDIX A

Utilization of Remotely Sensed Data for Targeting Implementation of Best Management Practices within the Grand Lake Watershed, Oklahoma

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Utilization of Remotely Sensed Data for Targeting Implementation of Best Management Practices within the Grand Lake Watershed, Oklahoma

INTRODUCTION

The Oklahoma Conservation Commission (OCC) has begun using satellite remote sensing in conjunction with water quality modeling to effectively target the implementation of agricultural best management practices (BMPs). This combination allows for the development of up-to-date accurate landcover data and an estimation of potential pollutant loads. Identification of potential critical source areas of pollutants allows for more efficient use of available funds by targeting locations with the highest potential for water quality improvement using common nutrient and sediment reduction BMPs such as filter strips, riparian strips, and various cattle and pasture management BMPs.

The Grand Lake (Lake O' the Cherokees) watershed spans the boundaries of Kansas, Arkansas, Missouri and Oklahoma as shown in Figure 1. The Oklahoma portion of the Grand Lake watershed encompasses parts of Craig, Ottawa, Mayes and Delaware Counties. The Honey Creek watershed is a sub-watershed of the Grand Lake watershed. It is primarily located in Oklahoma, but also contains portions of southeast Missouri and northwest Arkansas.

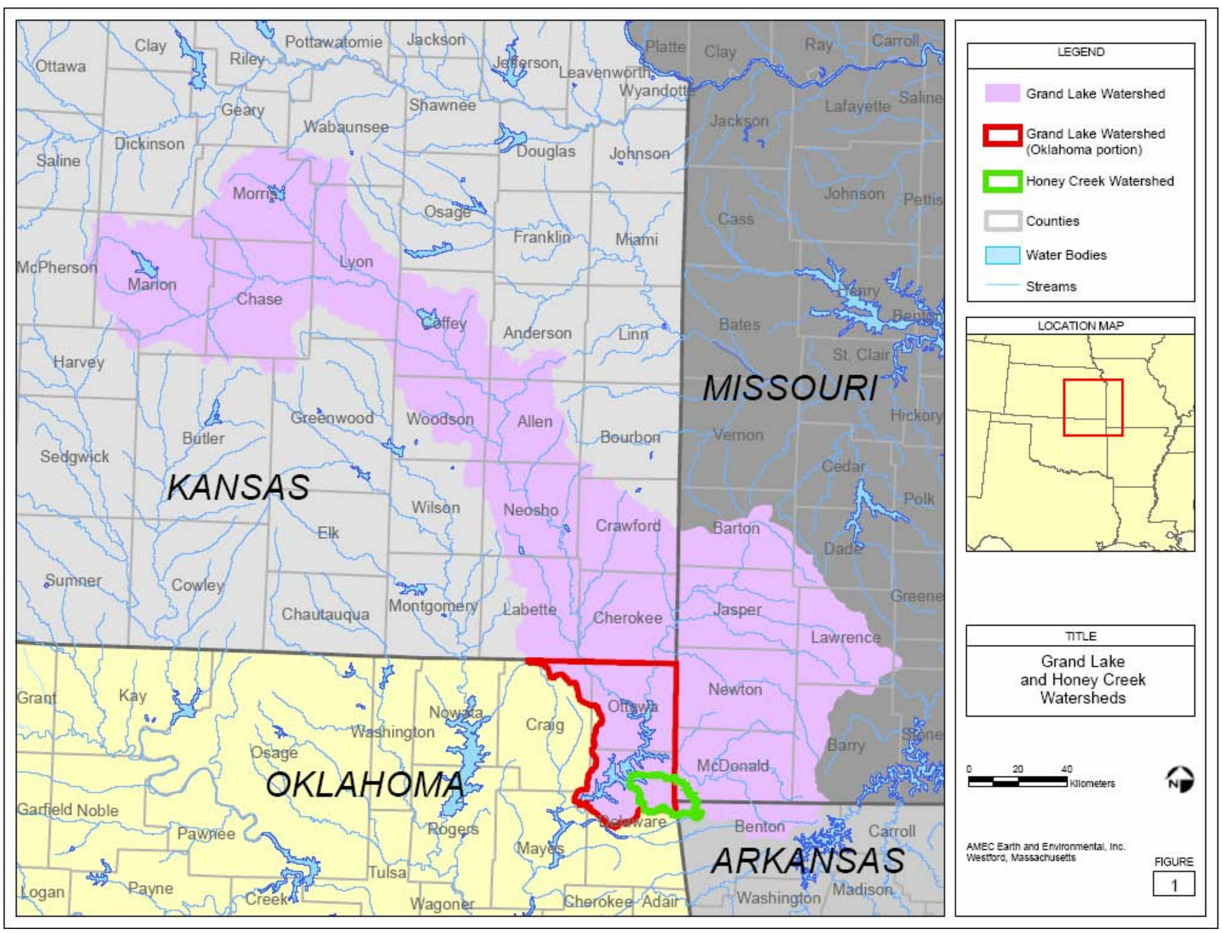

Figure 1 Location of the Grand Lake watershed

The Grand Lake watershed consists of approximately 46,500 lake acres and 389 stream miles in the State of Oklahoma. Its watershed is listed on the State's 303(d) list for nutrients, dissolved oxygen, pH, pesticides, metals, and total toxics. The Honey Creek sub-watershed has been placed on the State's 303(d) list for nutrients, dissolved oxygen, noxious aquatic plants, ammonia, and unknown toxicity.

The overall objectives of this project were to integrate satellite remote sensing with Soil and Water Assessment Tool (SWAT) modeling to identify potential critical source areas of pollutants in the Oklahoma portion of the Grand Lake watershed and the entire Honey Creek sub-watershed.

Digital landcover maps representing the Oklahoma portion of the Grand Lake Watershed and the entire Honey Creek watershed were developed using multispectral imagery from the Landsat 5 TM satellite (30 meter resolution). Two images were required to cover the entire extent of the watershed. A total of four images were acquired for the dates scenes listed below:

1. Path 25, Row 34
    a. 25 January 2006
    b. 02 June 2006

2. Path 26, Row 35
    a. 25 January 2006
    b. 02 June 2006

The locations of the Oklahoma portion of the Grand Lake watershed and the entire Honey Creek sub-watershed as well as the spatial extent of the two Landsat 5 TM scenes are displayed in Figure 2.

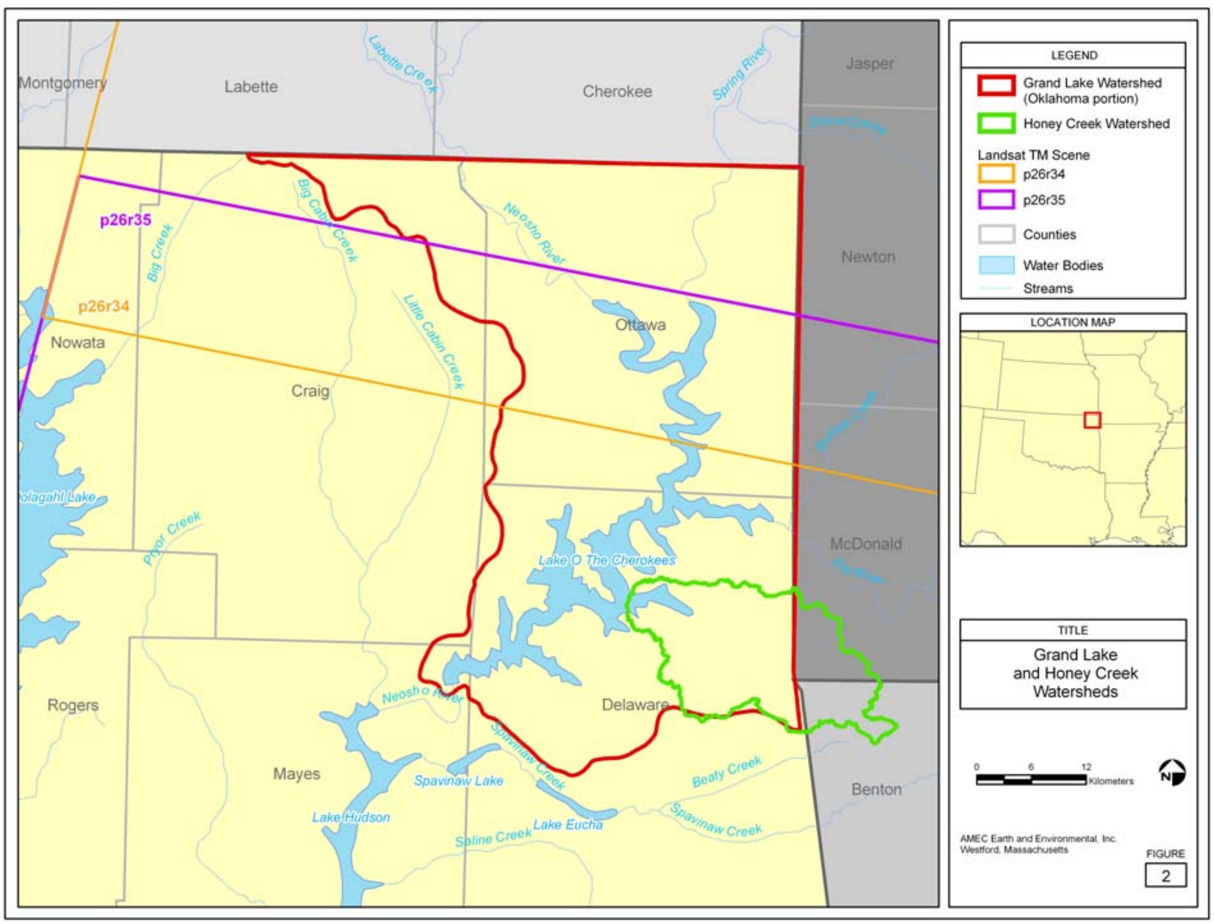

Figure 2 Location of the Oklahoma portion of the Grand Lake watershed and the entire Honey Creek sub-watershed.

Due to their temporal coincidence, the January pair was mosaicked together and classified as a single image, as was the June pair of images. The January images were cloud-free within both the Oklahoma portion of the Grand Lake watershed and the entire Honey Creek sub-watershed. A small cloud and its associated shadow were present in the June images and encompassed approximately 5 hectares. This area was classified using only the January data.

A traditional unsupervised classification method was used as the basis for generating the landcover maps. Digital image processing techniques involving the statistical analysis of image data representing various portions of the electromagnetic spectrum allow for delineation of areas that reflect solar radiation in a similar manner. Pixels with similar spectral characteristics are clustered into categories that represent patterns or landcover features that can be recognized or identified with help from additional sources, such as field data, aerial imagery (photography, orthophoto quads), or maps. AMEC Earth & Environmental (AMEC) relied on local sources to assist in the collection of georeferenced ground-truth data to ensure the accuracy of the final products.

The landcover categories of interest were as follows:

1. Forest
2. Pasture
    a. High Biomass
    b. Low Biomass
3. Cultivated
4. Shrub / Range
5. Bare Soil
6. Urban
    a. High Density
    b. Low Density
7. Golf Course
8. Mining
    a. Type 1
    b. Type 2
9. Water

GROUND-TRUTH DATA

Field data were collected by members of OCC and included GPS coordinates, landcover type, and photographs. Descriptions were also included in a spreadsheet to aid the analyst in understanding these data. The descriptions for pasture and cultivated landcover types included information about the average vegetation height, presence or absence of hay bales, and the following ratings on a scale of 1 to 10: cover of standing biomass, measure of uniformity, and level of confidence. Additional characteristics that were noted for pasture fields included the type of grass, the presence or absence of cattle and the amount of visible bare soil on a scale of 1 to 10. The descriptions for cultivated fields included information about the crop type such as wheat, corn, alfalfa, soybeans or sorghum, as well as the presence of any wheat stubble from the grain harvest.

These ground-truth data included two data sets for a total of 174 surveyed locations that were distributed throughout the Oklahoma portion of the watershed. The first set consisted of 74 locations and was collected July 24-31, 2006 and August 25-30, 2006. This set was used to identify spectral classes, refine the classification, and label the classes. The second set consisted of 100 locations and was collected October 19-24, 2006. It was used to assess the accuracy of the classification. These sites were selected using a stratified random sampling design within a ¼ mile buffer of roads located within the Oklahoma portion of the Grand Lake watershed. This procedure allowed for the entire area of interest to be covered within easily accessible areas. A minimum of ten sites were selected for each landcover category and the remaining sites were distributed randomly amongst the categories, resulting in more sites for those categories comprising a larger percentage of the watershed.

METHODS

All images were imported into Erdas IMAGINE, Version 9.0 and verified for quality assurance. No interior or edge artifacts were detected in any of the four images. It was noted, however, that the p26r34_25Jan06 image had minor striping in band two and the remaining three images had minor striping in bands two and three. Such striping is commonly found within Landsat 5 TM imagery.

All four images were subset to an area encompassing approximately 9,800 sq km that included the Oklahoma portion of the Grand Lake watershed and the entire Honey Creek sub-watershed.. The entire area that was classified for landcover is displayed in Figure 3.

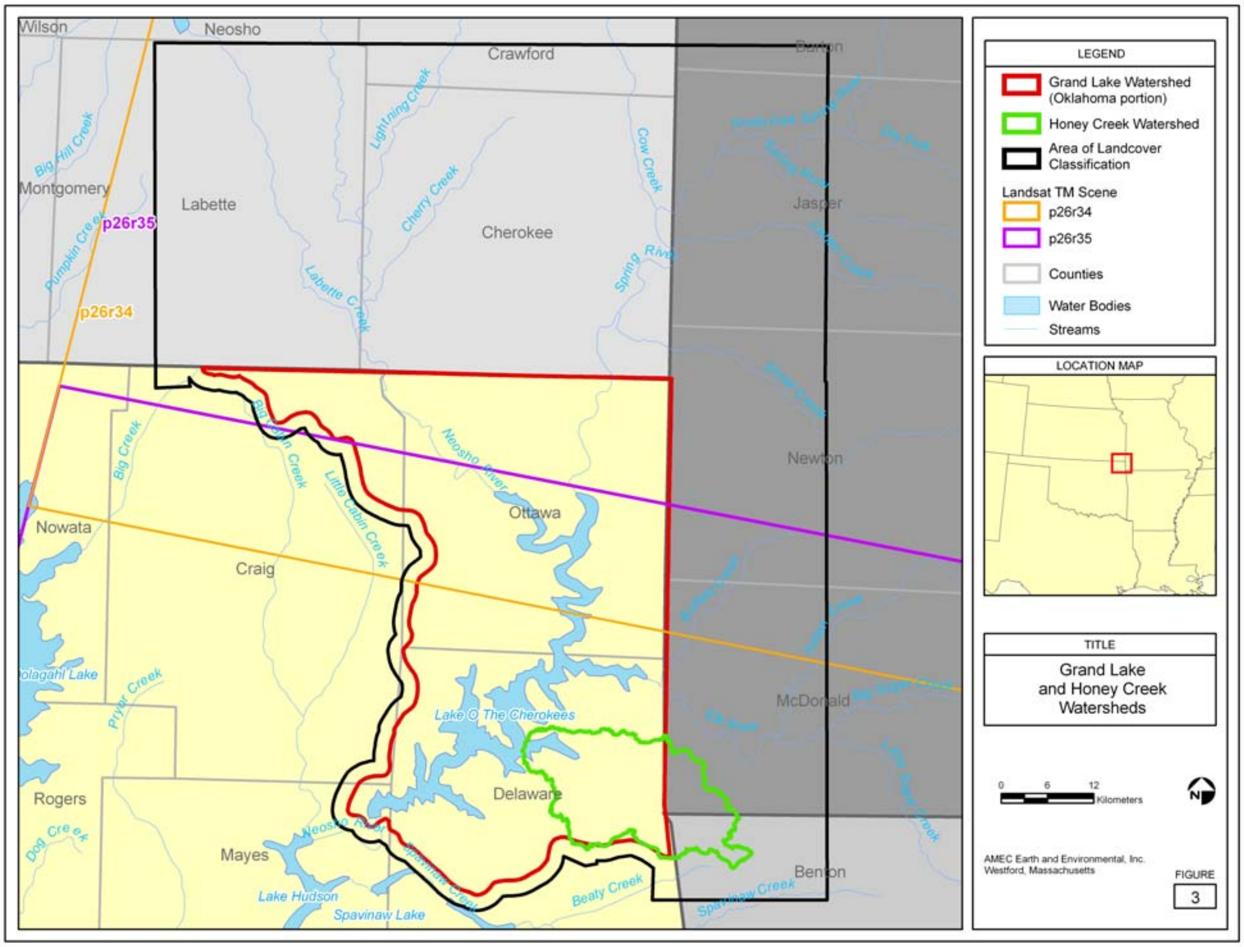

Figure 3 Location of the Oklahoma portion of the Grand Lake watershed, the Honey Creek sub-watershed, and the area classified for landcover.

The two January images were collected 24 seconds apart, as were the two June images.. The digital numbers (DNs) in all six bands were compared for several pixels located within the common area of path 26, row 34 and path 26, row 35 for January and for June. In both cases, only a few pixels were found to differ and those that did differed by only 1 DN in a few bands. This confirmed that normalization was unnecessary and that it was safe to assume that the atmosphere did not change significantly during the 24-second window between image acquisitions. The two June images were color balanced and then mosaicked into a single image. The same routine was also completed for the two January images.

Digital Orthophoto Quarter Quadrangles (DOQQs) were downloaded for each county within the area of interest. The year and source of the DOQQs are provided in Table 1.

Table 1 Year and source of Digital Orthophoto Quarter Quadrangles (DOQQs) by state

State	Year	Source
Arkansas	2005	GeoStor, the Arkansas Spatial Data Infrastructure (ASDI) http://www.cast.uark.edu/cast/geostor/
Kansas	2002	Kansas Geospatial Community Commons, http://www.kansasgis.org
Oklahoma	2005	University of Oklahoma Geo Information Systems, http://www.geo.ou.edu
Missouri	2005	Missouri Spatial Data Information Service, http://msdisweb.missouri.edu

The June mosaic was geo-registered to the DOQQs, which is an accurately geo-referenced data source. This registration was completed using a simple shift of 135 meters east and 245 meters north. The January mosaic was then co-registered to the registered June mosaic to allow for accurate discrimination of landcover type. This step was completed by shifting the image 105 meters to the east and 215 meters to the north.

A Normalized Difference Water Index (NDWI) was used to identify open water features such as lakes, ponds, rivers, and streams in the June mosaic. This index is computed by dividing the difference of the visible green (0.52 – 0.60 µm) and near-infrared (0.76 – 0.90 µm) bands by their sum (McFeeters, 1996). For Landsat 5 TM data, this ratio equates to (band 2 – band 4)/(band 2 + band 4). This index is able to delineate open water features by utilizing the green and near infrared bands to enhance the low near infrared reflectance by water features. The output is an image with real values between -1.0 and 1.0. Water features were identified as those pixels with positives values. These pixels were recoded as water and then masked from the image. Some mixed pixels that likely contained both water and upland were not identified using NDWI. These pixels remained in the image and were included in the subsequent processing steps. Some on-screen digitization was utilized to separate extraneous urban pixels that were incorrectly detected as water by the NDWI.

A Normalized Difference Vegetation Index (NDVI) was used to identify photosynthetically-active vegetation in the January mosaic consisting of winter wheat, coniferous trees, and cold season grasses. This index is computed by dividing the difference of the near-infrared (NIR) (0.76 – 0.90 µm) and visible red (0.63 – 0.69 µm) bands by their sum (Rouse et al., 1973). For Landsat 5 TM data, this ratio equates to (band 4 – band 3)/(band 4 + band 3). This index is indicative of photosynthetically-active vegetation because the NIR band is sensitive to chlorophyll and will increase as vegetation becomes greener. The output is an image with real values between -1.0 and 1.0. Photosynthetically active vegetation was identified as those pixels with NDVI values greater than 0.26. These pixels were recoded as cultivated and then masked from both the January and June images. Some on-screen digitization was utilized to separate some pasture fields and forest from cultivated fields.

A whole pixel classification technique that utilizes an unsupervised iterative self-organizing data analysis (ISODATA) clustering algorithm was used to map landcover types across the Grand Lake and Honey Creek watersheds. ISODATA is a widely-used clustering algorithm that makes a large number of passes (i.e., iterations) through an image using a minimum spectral distance routine to form clusters. This iteration process continues until a specified percentage of pixels defined by the user are classified the same from one iteration to the next with slightly varying cluster boundaries. This percentage is referred to as the spectral convergence threshold and once attained, the pixels are considered to be clustered into statistically distinct features.

Due to the complex nature of the landcover types across the watershed and the spectral similarity among these landcover categories, multiple iterations of ISODATA clustering were required to accurately map the landcover types. The initial unsupervised classification was conducted on the January mosaic to produce 100 classes using 20 iterations. The spectral convergence threshold was set to 97 percent for all classifications, indicating that the classification process would cease as soon as 97% or more of the pixels were classified the same from one iteration to the next (or 3% or fewer of the pixels changed).

The classification layer was displayed on top of the raw Landsat TM imagery, the field data and the DOQQs. By visually inspecting these layers, spectral classes containing pixels of only a single landcover type were identified. These “pure” classes for the first classification iteration consisted of a majority of the forest cover, urban areas and the remaining water pixels. On-screen digitization was utilized to separate water that was spectrally inseparable from forest, particularly shadowed forest.

Spectral classes that contained a mix of forest and pasture were recoded and used as a mask. The output masked image was the January mosaic with only those pixels contained in these particular spectral classes. This image was then used as the input for a second unsupervised classification that generated 50 spectral classes using the same number of iterations and convergence threshold as previously described. This classification was used to identify and separate the remaining forest pixels from any pasture areas. The classification results were again displayed on the Landsat TM imagery and the same approach was used to identify the spectral classes that only contain pixels of a single landcover type. A minimal amount of on-screen digitization was required to separate forest that was spectrally inseparable from pasture.

At this stage, the majority of the forest cover, urban areas, and water had been classified. These layers were recoded and used as a mask on the June mosaic. The output masked image was the June mosaic with only those pixels that had not yet been classified. This image was then used as the input for a third unsupervised classification that generated 100 classes using the same number of iterations and convergence threshold as previously described. The classification results were again displayed on the Landsat TM imagery and the same approach was used to identify the spectral classes that only contain pixels of a single landcover type. These “pure” classes consisted of cultivated fields, pasture fields and urban areas.

Spectral classes that contained a mix of forest and pasture were recoded and used as a mask. The output masked image was the June mosaic with only those pixels contained in these particular spectral classes. This image was then used as the input for a fourth unsupervised classification that generated 50 spectral classes using the same number of iterations and convergence threshold as previously described. This classification was used to identify and separate the remaining forest pixels from pasture areas.

Likewise, spectral classes that contained a mix of urban and pasture were recoded and used as a mask. The output masked image was the June mosaic with only those pixels contained in these particular spectral classes. This image was then used as the input for a fifth unsupervised classification that generated 50 spectral classes using the same number of iterations and convergence threshold as previously described. This classification was used to identify and separate the remaining urban pixels from any pasture areas.

Landcover Criteria

A set of decision criteria was established to guide the labeling of spectral classes into landcover categories. The decision criteria are as follows:

1. *Forest*
    a. Areas dominated by trees (deciduous and conifers).
    b. Forest is spectrally distinct by its dark brown or dark green color in the January Landsat TM image in false color combination bands 5,4,3.

2. *Pasture*
    a. *High Biomass*: pasture fields with a high to moderate vegetative biomass state; fields relatively homogeneous in their vegetative spectral response and in their apparent dark green color in the June Landsat TM imagery in false color combination bands 5,4,3. Pasture areas with NDVI values greater than or equal to 0.54. Note that the NDVI for this determination was derived from the June imagery.
    b. *Low Biomass*: pasture fields with low vegetative biomass or the presence of senescent vegetation; fields relatively heterogeneous in their soil spectral response

and in their apparent pink color or "mottled" dark green and pink color in the June Landsat TM imagery in false color combination bands 5,4,3. Pasture areas with NDVI values less than 0.54. Note that the NDVI for this determination was derived from the June imagery.

3. *Cultivated*
   a. Areas of crops including wheat and row crops.
   b. Includes fields that are relatively homogeneous in their vegetative spectral response and their apparent bright green color in the January Landsat TM imagery in false color combination 5,4,3.
   c. Includes fields that are relatively homogenous in their soil spectral response and their apparent bright pink or bright green color in the June Landsat imagery in false color combination 5,4,3.

4. *Shrub / Range*
   a. Areas with a high to moderate vegetative biomass state.
   b. These areas are characterized by the presence of shrubs/bushes and exhibit a "mottled" appearance across the landscape in the Landsat TM imagery due to the mixture of grasses, shrubs, bushes, and trees. These areas also include abandoned cropland.
   c. Due to their vegetative composition and inherent spectral confusion with forested areas and pasture fields, shrub/range fields were manually refined to accurately separate them from spectrally confusing landcover categories.

5. *Bare soil*
   a. Areas with extremely low or no vegetative biomass, primarily located along dry stream beds or near mining activities.

6. *Urban*
   a. *High density*: Areas including urban development, roads, and impervious surfaces that fall within city and town boundaries in Oklahoma, Kansas, Arkansas and Missouri as defined below.
   b. *Low density*: Areas including urban development, roads, and impervious surfaces that fall outside the city and town boundaries in Oklahoma, Kansas, Arkansas and Missouri as defined below.
      i. The boundaries for the following five cities in Oklahoma were contained in a shapefile created by the U.S. Census Bureau and obtained from the University of Oklahoma Geo Information Systems website (http://www.geo.ou.edu/): Picher, Commerce, Miami, Grove and Jay. The boundaries of the following twelve towns in Oklahoma were contained in the afore-mentioned shapefile: Cardin, Quapaw, North Miami, Peoria, Wyandotte, Fairland, Afton, Bernice, Ketchum, Grand Lakee, Disney, and Langley.
      ii. A shapefile of town boundaries created by the Arkansas Highway and Transportation Department (2003) was obtained from the GeoStor website (http://www.cast.uark.edu/cast/geostor/). No towns in this shapefile were located within the Honey Creek sub-watershed.
      iii. The boundaries of the following two towns in Missouri were contained in a shapefile created by the U.S. Census Bureau (1994) and obtained from the Missouri Spatial Data Information Service website (http://msdisweb.missouri.edu/): Seneca and South West City.
      iv. The boundaries for the following two cities in Kansas were contained in a shapefile created by the U.S. Census Bureau (2000) and obtained from the Kansas GeoSpatial Community Commons website (www.KansasGIS.org): Baxter Springs and Chetopa,.
   c. Note that only portions of most roads were classified as urban. This is largely due to the presence of mixed pixels.

7. *Golf course*
    a. Golf courses are characterized by their recognizable long and narrow shape in conjunction with their apparent light green to yellow color in the June Landsat TM image in false color combination bands 5,4,3.

8. *Mining*
    a. Areas of past and present mining activity including chat piles and disturbed soils as defined below:
        i. Areas (except those classified as water) that fall within the boundaries of chat piles in the Oklahoma portion of the Tar Creek Superfund Site contained in a polygon shapefile created by the Tulsa District of the U.S. Army Corps of Engineers and obtained from the OCC (2000).
        ii. Areas that were spectrally classified as bare soil that fall within the boundaries of soils disturbed by mining in the Oklahoma portion of the Tar Creek Superfund Site contained in a polygon shapefile created by the Tulsa District of the U.S. Army Corps of Engineers and obtained from the OCC (2001).
        iii. Areas (except those classified as water) that fall within the Kansas portion of the Tar Creek Superfund site were hand digitized based on the apparent light blue color in the January Landsat TM image in false color combination bands 5,4,3 and the 2005 DOQQ.
        iv. Additional areas of mining activity were located based on a point shapefile of active mines and mineral processing plants in the U.S. (2003) that was created by and obtained from the U.S. Geological Survey. The spatial extent of these locations was digitized based on their appearance in the Landsat TM images and the 2005 DOQQs.
    b. Areas of mining activity were differentiated into two types as described below:
        I. Mining Type 1
            i. Areas associated with the Tar Creek Superfund Site in Oklahoma and Kansas, as well as areas associated with abandoned lead mines in Jasper County, Missouri (per conversation with Dan Butler, OCC, 16 January 2007).
        II. Mining Type 2
            i. All other areas of mining consisting of quarries for crushed stone, silica mines, and common clay and shale mines.

9. *Water*
    a. Lakes, ponds, streams and reservoirs.
    b. Although some small streams were detected spectrally in the imagery, many were not classified by this process due to the presence of mixed pixels.

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 identify specific landcover types. The decision criteria were then used to label that class to the appropriate landcover category. Once all the spectral classes were labeled to the appropriate landcover category, the pixels from all of the classification iterations were added together and the image was recoded such that each landcover category was given a unique identifier.

An additional step was conducted on the pasture fields in order to separate between high biomass pastures and low biomass pastures. Pixels classified as pasture were recoded and masked from the June mosaic. NDVI was run on these pixels and those with an NDVI value greater than or equal to 54 were classified as high biomass. Pixels with an NDVI value less than 54 were classified as low biomass pasture. This threshold value was the mean NDVI value of all pixels that were classified as pasture.

An additional operation of spatial filtering was used to eliminate isolated, artifact pixels within most classes. The smoothing process is a standard image processing technique to remove “noise” or spurious pixels classified to a different landcover category within a large contiguous field. For example, a large area classified as forest may have several individual pixels with the spectral characteristics of a pasture or bare soil. The smoothing process removes these “noise” detections and replaces them with forest detections. The smoothing process scans the unsmoothed classification layer with a 3x3 pixel majority filter. This filter analyzes the 3x3 area around each pixel and reassigns the target pixel to the majority class in its local area. The result in the example discussed previously would be that the individual pixels of pasture within the forest area would be replaced with forest detections in the final output. For this project, the smoothing process was only applied to the large macro classes (forest, pasture, cultivated, and shrub/range). Due to their limited spatial extent, the urban, bare soil, golf, mining, and water classes were not subjected to this spatial filtering. Also, to preserve single pixels and small clusters of forest, the unsmoothed forest layer was combined with the smoothed layer to add back the pixels that were eliminated by the smoothing process. Overall, approximately 7.0% of pixels within the Oklahoma portion of the Grand Lake watershed were altered by this process.

The final landcover map was clipped to the Oklahoma portion of the Grand Lake watershed as well as to the entire Honey Creek sub-watershed using GIS shapefiles provided by the OCC. This subset was converted to a GRID format for use as an input to the SWAT model. An accuracy assessment was performed on the final landcover classification of the Oklahoma portion of the Grand Lake watershed.

RESULTS

Landcover Statistics

The final landcover mapping results were grouped into 12 landcover classes. A quantitative representation of the final landcover map for the Oklahoma portion of the Grand Lake watershed in 2006 is presented below in Table 2. A qualitative representation of the percentage of each landcover type is displayed in Figure 4 and the spatial distributions are displayed in Figure 5.

Table 2 2006 Landcover (by area and percentage) within the Oklahoma portion of the Grand Lake watershed.

Landcover Type	Area (Ha)	% of Watershed
1. Water	20003.31	8.50%
2. Forest	78633.36	33.41%
3. High Biomass Pasture	75527.73	32.09%
4. Low Biomass Pasture	32913.27	13.98%
5. Cultivated	20299.59	8.62%
6. Shrub / Range	272.70	0.12%
7. Bare soil	59.13	0.03%
8. Low Density Urban	3158.10	1.34%
9. High Density Urban	2738.34	1.16%
10. Golf Course	276.66	0.12%
11. Mining Type 1	1411.83	0.60%
12. Mining Type 2	69.66	0.03%
Total	235363.68	100.00%

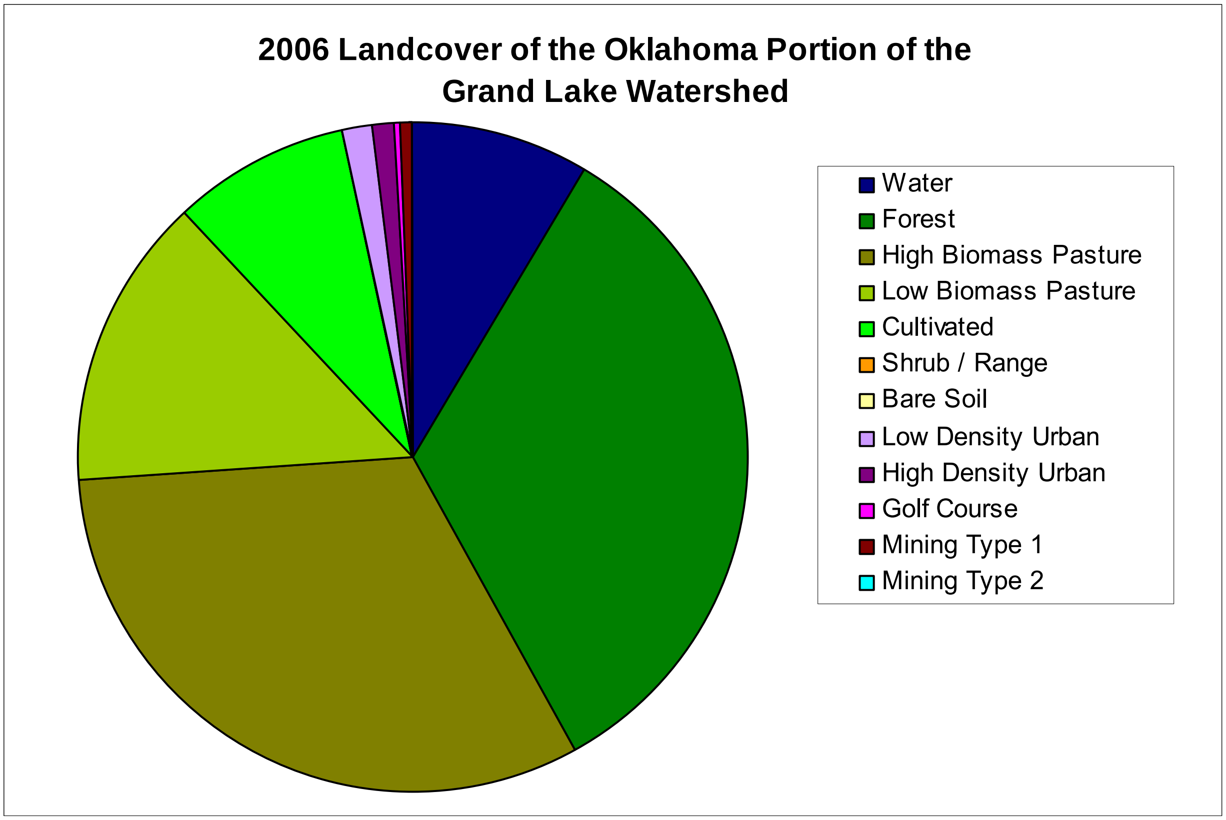

Figure 4 Percentage of landcover types within the Oklahoma portion of the Grand Lake watershed in 2006.

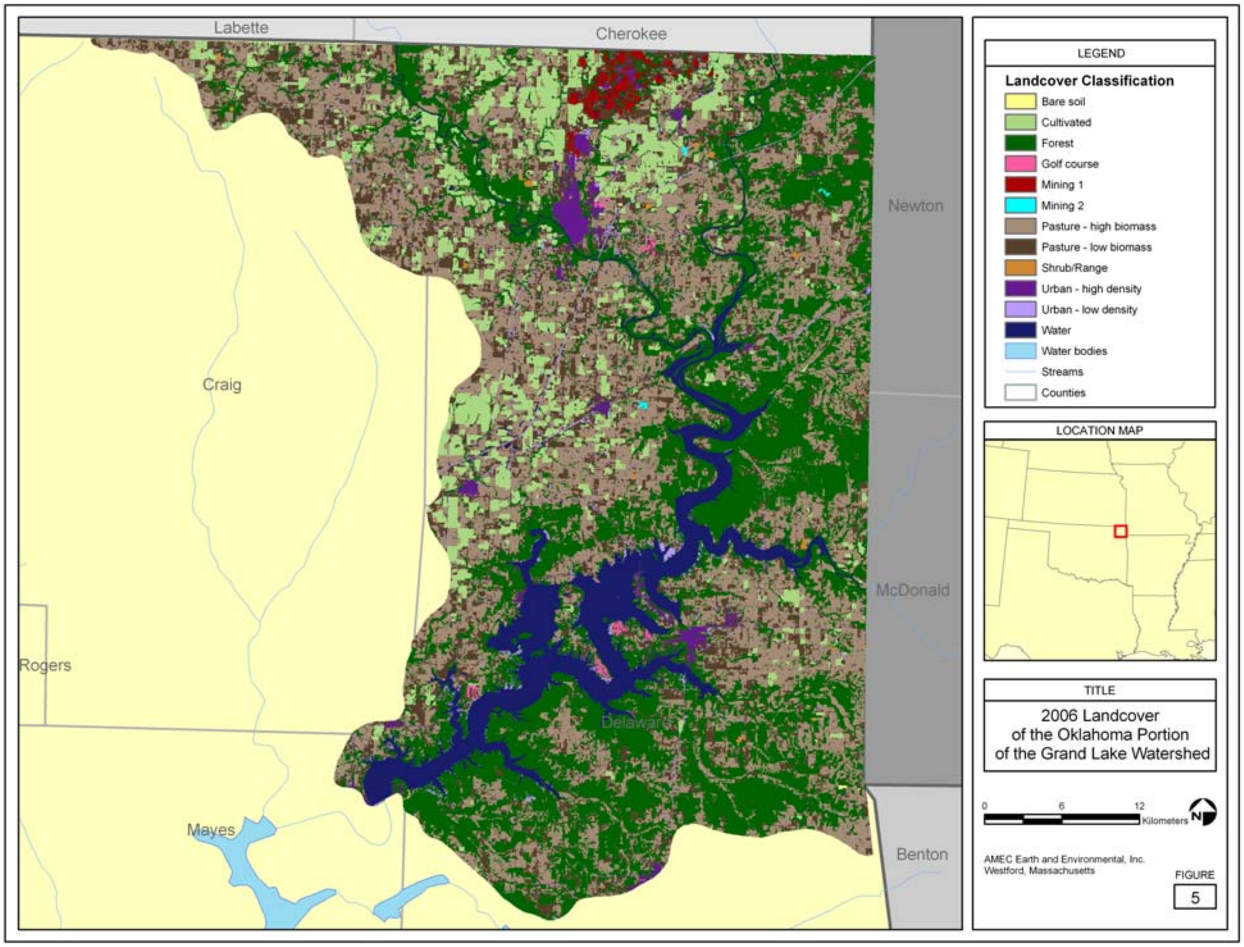

Figure 5 2006 Landcover map for the Oklahoma portion of the Grand Lake watershed.

A quantitative representation of the final landcover map for the entire Honey Creek sub-watershed in 2006 is presented below in Table 3. A qualitative representation of the percentage of each landcover type is displayed in Figure 6 and the spatial distributions are displayed in Figure 7.

Table 3 2006 Landcover (by area and percentage) within the Honey Creek sub-watershed.

Landcover Type	Area (Ha)	% of Watershed
1. Water	878.58	2.75%
2. Forest	13555.89	42.47%
3. High Biomass Pasture	12699.54	39.79%
4. Low Biomass Pasture	3649.59	11.43%
5. Cultivated	585.27	1.83%
6. Shrub / Range	27.18	0.09%
7. Bare Soil	35.37	0.11%
8. Low Density Urban	251.10	0.79%
9. High Density Urban	233.46	0.73%
10. Golf Course	0.00	0.00%
11. Mining Type 1	0.00	0.00%
12. Mining Type 2	0.00	0.00%
Total	31915.98	100.00%

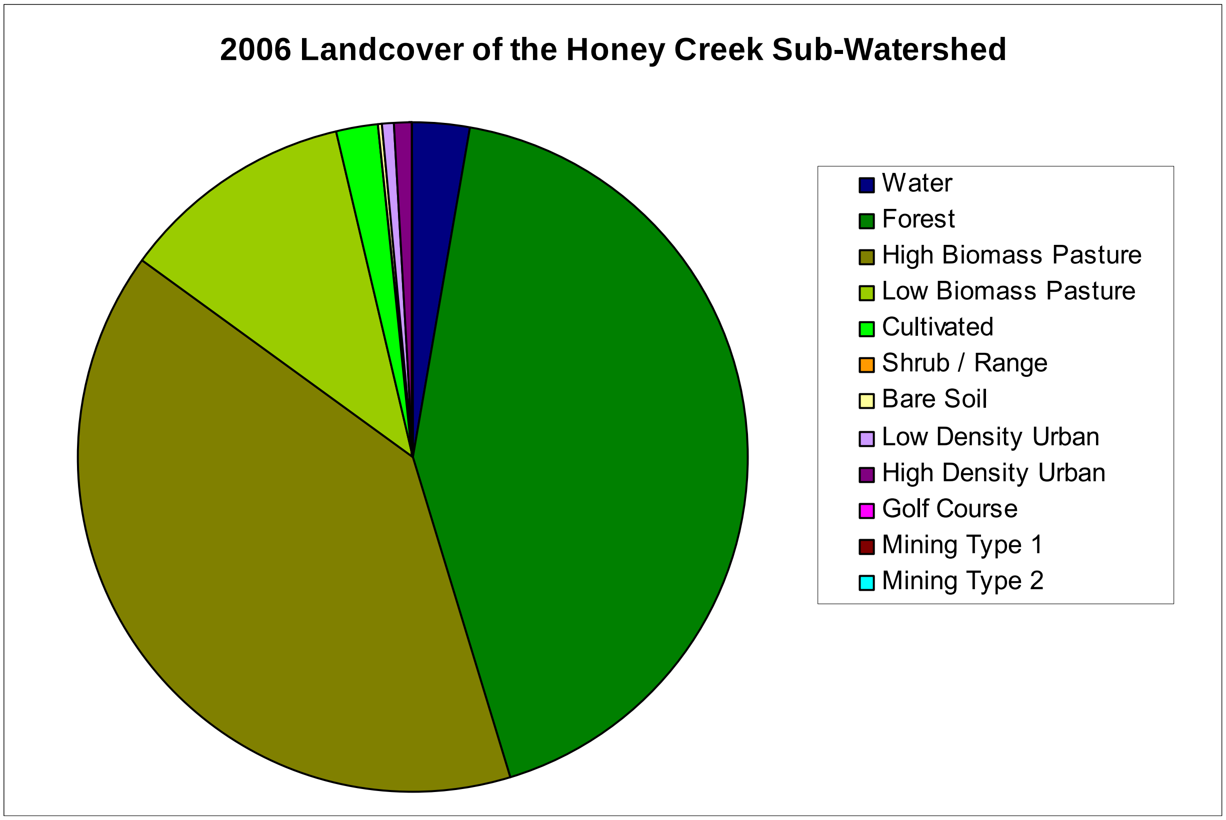

Figure 6 Percentage of landcover types within the Honey Creek sub-watershed in 2006.

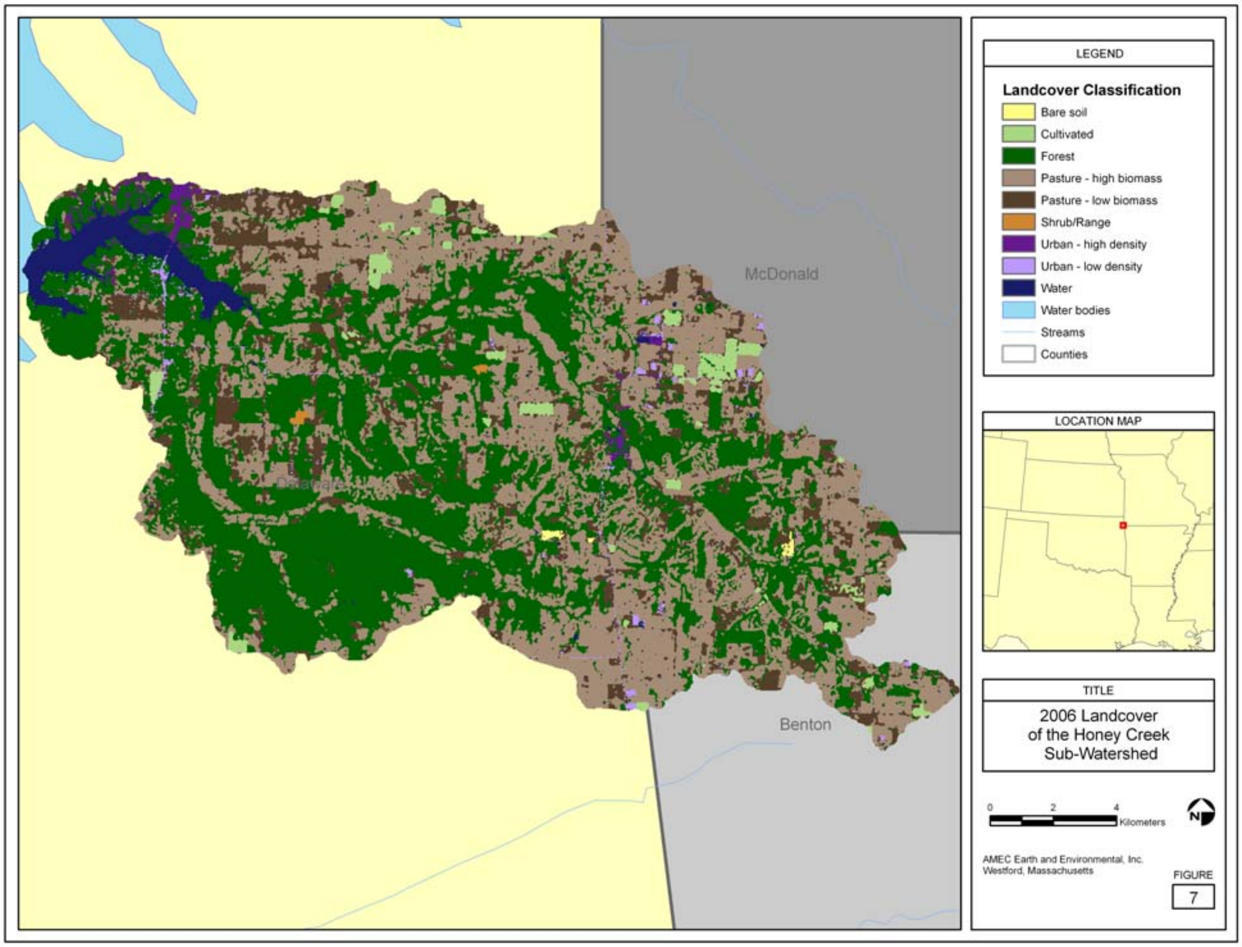

Figure 7 2006 Landcover map for the Honey Creek sub-watershed.

As seen in Table 2, the Oklahoma portion of the Grand Lake watershed in 2006 was dominated by forest (33.41%) followed by high biomass pasture (32.09%) and low biomass pasture (13.98%). The remaining classes were present in significantly smaller percentages with each comprising less than 10% of the watershed.

Likewise, the Honey Creek sub-watershed in 2006 was also dominated by forest (42.47%) followed by high biomass pasture (39.79%) and low biomass pasture (11.43%) as seen in Table 3. The remaining classes were present in significantly smaller percentages with each comprising less than 5% of the sub-watershed.

Accuracy Assessment

After completion of the image classification, 100 sites were selected for collection of ground-truth data to be used for accuracy assessment purposes. The sites were selected using a stratified random sampling design within a ¼ mile buffer of roads in order to cover the entire Oklahoma portion of the Grand Lake watershed within accessible areas. The buffer was created from the 2000 TIGER/Line road files of the Census Bureau for the Counties of Craig, Delaware, Mayes and Ottawa. These files were obtained from the University of Oklahoma Geo Information Systems website.

A minimum of ten sites were selected for each landcover category and the remaining sites were distributed randomly amongst the categories, resulting in more sites for those categories comprising a larger percentage of the watershed. The number of sites that were selected and surveyed for each landcover category is listed in Table 4. Twenty sites were selected for pasture and 10 to 16 sites were selected for the remaining cover types. The bare soil class was not included in the accuracy assessment since it comprised such a small percentage of the landcover (0.03%).

Table 4 Field data collected for accuracy assessment

Landcover type	% of Oklahoma portion of watershed	# Sites Surveyed
Forest	33.41	16
Pasture (high and low biomass)	46.07	20
Cultivated	8.62	12
Shrub/Range	0.12	10
Bare soil	0.03	0
Urban (low and high density)	2.5	11
Golf course	0.12	10
Mining	0.63	10
Water	8.50	11
Total	**100%**	**100**

The field data were collected October 19-24, 2006 by OCC personnel. A Garmin Etrex GPS unit (15 meter RMS accuracy) was used in conjunction with aerial photos to locate the correct site location in the field. The accuracy assessment was conducted on the smoothed landcover classification and the results are shown in Table 5. The smoothed classification was most appropriate for the accuracy assessment due to the spatial scale of the ground-truth information, which was collected at a "field level" scale.

Table 5 Accuracy assessment matrix for the 2006 Landsat TM image classification of the Oklahoma portion of the Grand Lake watershed. Cells outlined in red indicate the number of sites at which the image classification and the field data agree.

Ground-truth (columns); **Classified Image** (rows)

Landcover Classes	Water	Forest	Pasture	Cultivated	Shrub / Range	Mining	Urban	Golf Course	Total	User's Accuracy
Water	11								11	100.0%
Forest		14	1						15	93.3%
Pasture			18	1					19	94.7%
Cultivated			3	9					12	75.0%
Shrub / Range		1	1		8				10	80.0%
Mining						9			9	100.0%
Urban							11		11	100.0%
Golf Course								10	10	100.0%
Total	11	15	23	10	8	9	11	10	97	
Producer's Accuracy	100.0%	93.3%	78.3%	90.0%	100.0%	100.0%	100.0%	100.0%		

Overall accuracy: = 92.8 %

The following set of decision rules was established to guide the assessment of the accuracy of the 2006 landcover classification. The details for each of the 100 selected sites are included in Appendix A.

1. If the field team considered the site to be inaccessible, the site was excluded from the assessment. This was the case for three of the sites.
2. Two of the sites (site #25, 29) that were surveyed were found to be located on county roads. These two sites had the same landcover type on both sides of the road as evidenced by both the

field descriptions and the photos. As specified in the landcover criteria, it was expected that only portions of roads would be classified as urban due to mixed pixels. As a result, these sites were considered to be correctly classified as long as the image classification matched the landcover immediately adjacent to both sides of the road. The ground-truth photos for these two sites are displayed in Figure 8.

3. Upon inspection of the ground-truth photos and field descriptions, it was determined that three sites (site #2, 79, 92) were incorrectly characterized in the field data.
    a. Site #2 was classified as forest in the image, but identified as urban in the field. The photo reveals a small house within a forested lot. Due to tree canopy and the spatial resolution of the imagery, it was decided that the image classification of forest was valid. The ground-truth photo for this site is displayed in Figure 9.
    b. Site #79 was classified as mining in the image, but identified as urban in the field. The field description, however, described the site as "low density, 50% bare or sterile soil in mining area."
    c. Site #92 was classified as mining in the image, but was labeled as "shrubland/mining" by the field team. It was described as "Native grass cover with scattered sycamore and willow trees located between mine spoils."

Figure 8 Ground-truth photos for site #25 (left) and site #29 (right). Both of these sites were located on a county road, but had the same landcover type on each side of the road.

Figure 9 Ground-truth photo for site #2, which was classified as forest in the image but identified as urban in the field. Due to tree canopy and the spatial resolution of the imagery, it was decided that the image classification of forest was valid.

The overall accuracy for the 2006 Landsat TM image classification of the Oklahoma portion of the Grand Lake watershed was 92.8%.

Producer's accuracy is a measure of omission error and indicates the probability of a ground-truth pixel being correctly classified. User's accuracy is a measure of commission and indicates the probability that a pixel classified in the image actually represents that category on the ground (Congalton, 1991). In this case, cultivated had the lowest user's accuracy (75.0%) indicating that 75.0% of the areas classified as cultivated are actually cultivated when visited in the field. However, the producer's accuracy for this category was 90.0%. This indicates that 90.0% of the ground-truth locations are correctly identified as cultivated. In other words, 90% of the ground-truth sites that are actually cultivated are classified as such, but there exist additional locations that are incorrectly classified as cultivated. In general, these data suggest that the cultivated category was slightly over-classified.

The reverse trend exists for pasture. This landcover category had the lowest producer's accuracy (78.3%) indicating that 78.3% of the ground-truth sites that are truly pastures were correctly classified as such. However, the user's accuracy for pasture was 94.7% indicating that 94.7% of the areas classified as pasture are actually pasture when visited in the field. It is therefore likely that the pasture category was slightly under-classified.

It is interesting to note that no ground-truth sites consisting of water, mining, urban or golf courses were found to be incorrectly classified. Therefore, all four of these categories have producer's and user's accuracies of 100%.

DISCUSSION

The landcover classification maps the spatial distribution of landcover throughout the Oklahoma portion of the Grand Lake watershed, as well as the entire Honey Creek sub-watershed. The results indicate that both watersheds are dominated by forest followed by pasture. The final landcover maps have been provided in a smoothed data format. The results section reports the area and percent of the watershed by landcover category.

The minor striping that was present in band two of the p26r34_25Jan06 image and bands two and three of the remaining three images did not adversely affect the classification. Pixels located in these regions did not separate out into any unusual spectral classes during the unsupervised classification process but rather their landcover matched that of the other pixels contained within the same spectral classes.

Although the field data collected for classification (24 - 31 July 2006 and 25-30 August 2006) and accuracy assessment (19-24 October 2006) were not temporally coincident with the imagery acquisition dates (25 January 2006 and 02 June 2006), all data was collected within the same year. As a result, the ground-truth data was easily incorporated into the classification procedure and directly applied for the accuracy assessment.

SUMMARY AND CONCLUSIONS

With the support of ground-truth data collected by OCC personnel, classification of landcover types from Landsat TM imagery collected in 2006 was 92.8% accurate. The results indicate a watershed that is predominately forest, but also possesses a significant percentage of pasture.

The results from this exercise will allow the modelers to estimate nonpoint source loadings using up-to-date landcover data. This process provides the watershed project coordinator with a mechanism by which to proactively identify areas that are likely contributing to the overall degradation of water quality within the Oklahoma portion of the Grand Lake Watershed. The landowners of these areas can then be recruited for participation in the Section 319 program to implement BMPs.

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APPENDIX B: Accuracy Assessment Data

Site ID	Image Classification	Field Identification	Field Comments	Accuracy Assessment Comments
1	Forest	Forest		Agrees
2	Forest	Urban	Residential	Agrees Note: Photo reveals forested lot with small house
3	Pasture	Pasture		Agrees
4	Pasture	Pasture		Agrees
5	Forest	Forest		Agrees
6	Pasture	Pasture		Agrees
7	Pasture	Pasture		Agrees
8	Cultivated	Cultivated		Agrees
9	Forest	Forest		Agrees
10	Forest	Forest		Agrees
11	Pasture	Pasture		Agrees
12	Pasture	Pasture		Agrees
13	Forest	Pasture	Native range that has just been brushhogged; it has seriza lespediza, buckbrush, blackberry vines and woody species regrowth	Disagrees
14	Cultivated	Cultivated		Agrees
15	Pasture	Pasture		Agrees
16	Forest	Forest		Agrees
17	Forest	Forest		Agrees
18	Forest	Forest		Agrees
19	Forest	Forest		Agrees
20	Pasture	Pasture	No access; GPS from closest point	Excluded
21	Forest	Forest		Agrees
22	Pasture	Pasture		Agrees
23	Pasture	Pasture		Agrees
24	Cultivated	Cultivated		Agrees
25	Forest	Urban	Blacktopped county road with oak forest to each side	Agrees
26	Pasture	Pasture		Agrees
27	Pasture	Pasture		Agrees
28	Forest	Forest		Agrees
29	Pasture	Point on county road between bermuda grass pastures	County road between two bermudagrass pastures; W pasture is approx 5" with scattered fescue and a few weeds; E pasture is approx. 2" to 4" fescue with some spots of bermuda	Agrees
30	Forest	Forest		Agrees
31	Forest	Shrubland	Land is locked up and key is only available out-of-state	Excluded

Site ID	Image Classification	Field Identification	Field Comments	Accuracy Assessment Comments
32	Forest	Forest		Agrees
33	Pasture	Pasture		Agrees
34	Pasture	Pasture		Agrees
35	Urban	Urban		Agrees
36	Pasture	Cultivated	Single row crop/soybeans; mature, ready for harvest; most leaves dropped. Scattered Johnsongrass over field.	Disagrees
37	Cultivated	Pasture	Fescue and mixed native grasses with some annual	Disagrees
38	Pasture	Pasture		Agrees
39	Pasture	Pasture		Agrees
40	Pasture	Pasture		Agrees
41	Pasture	Pasture		Agrees
42	Cultivated	Cultivated		Agrees
43	Water	Water		Agrees
44	Golf Course	Golf course		Agrees
45	Cultivated	Cultivated		Agrees
46	Water	Water		Agrees
47	Cultivated	Cultivated		Agrees
48	Cultivated	Cultivated		Agrees
49	Water	Water		Agrees
50	Water	Water		Agrees
51	Cultivated	Pasture		Disagrees
52	Cultivated	Cultivated		Agrees
53	Water	Water		Agrees
54	Cultivated	Pasture		Disagrees
55	Cultivated	Cultivated		Agrees
56	Water	Water		Agrees
57	Water	Water		Agrees
58	Urban	Urban		Agrees
59	Water	Water		Agrees
60	Urban	Urban		Agrees
61	Water	Water		Agrees
62	Water	Water		Agrees
63	Water	Water		Agrees
64	Mining	Mining		Agrees
65	Urban	Urban		Agrees
66	Urban	Urban		Agrees
67	Urban	Urban		Agrees
68	Urban	Urban		Agrees
69	Urban	Urban		Agrees
70	Urban	Urban		Agrees
71	Golf Course	Golf course		Agrees
72	Urban	Urban		Agrees
73	Mining	Mining		Agrees

Site ID	Image Classification	Field Identification	Field Comments	Accuracy Assessment Comments
74	Urban	Urban		Agrees
75	Golf Course	Golf course		Agrees
76	Golf Course	Golf course		Agrees
77	Shrub / Range	Scrubland		Agrees
78	Shrub / Range	Pasture	Same as #51 but with more shrubbrush encroachment	Disagrees
79	Mining	Urban	low density, 50% bare or sterile soil in mining area (Pilcher, OK)	Agrees
80	Mining	Mining		Agrees
81	Golf Course	Golf course		Agrees
82	Mining	Mining		Agrees
83	Shrub / Range	Shrubland		Agrees
84	Mining	Mining	Chat pile; not assessible (photo has sign for Indian cemetary)	Excluded
85	Mining	Mining		Agrees
86	Mining	Mining		Agrees
87	Mining	Mining		Agrees
88	Shrub / Range	Scrubland		Agrees
89	Shrub / Range	Shrubland		Agrees
90	Shrub / Range	Scrubland		Agrees
91	Golf Course	Golf course		Agrees
92	Mining	Shrubland / Mining	Native grass cover with scattered sycamore and willow trees located between mine spoils	Agrees
93	Golf Course	Golf course		Agrees
94	Shrub / Range	Shrubland		Agrees
95	Golf Course	Golf course		Agrees
96	Golf Course	Golf course		Agrees
97	Golf Course	Golf course		Agrees
98	Shrub / Range	Shrubland		Agrees
99	Shrub / Range	Scrubland		Agrees
100	Shrub / Range	Forest		Disagrees