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Land Use/Land Cover Change and Its Hydrological Impacts from 1984 to 2010 in the Little River Watershed, Tennessee

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I am submitting herewith a thesis written by Chunhao Zhu entitled "Land Use/Land Cover Change and Its Hydrological Impacts from 1984 to 2010 in the Little River Watershed, Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

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Land Use/Land Cover Change and Its Hydrological Impacts from 1984 to 2010 in the Little River Watershed, Tennessee

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ABSTRACT

Land use/land cover (LULC) change, especially the conversion from farmland to residential and commercial land, has led to significant environmental issues in changing fluvial dynamics, accelerating sediment erosion and degrading water quality. The Little River, which provides drinking water for over 100,000 residents in Blount County, Tennessee, and serves as a source of agriculture and recreational activities, was listed as one of the U.S. Environmental Protection Agency's (EPA) Targeted Watersheds because the water quality of its tributaries has become impaired due to several reasons. In this study, a detailed record of LULC change in a roughly 2-year interval was documented from 1984 to 2010 based on the classification of Landsat TM/ETM+ images. The classification accuracy was assessed by the comparison of Google Earth high resolution images in 2010. Then, the Soil and Water Assessment Tool (SWAT), a physically-based distributed hydrological model, was used to quantify the impacts of LULC change on streamflow and water quality in this watershed over this period.

The results showed that Landsat TM/ETM+ images can be classified accurately using the Maximum Likelihood Classification (MLC) algorithm, and the SWAT model can effectively simulate the long-term impact of LULC change on streamflow and non-point source (NPS) pollution in this watershed. Above 80% overall accuracy and the kappa coefficient were achieved in the accuracy assessment of the classification of year 2010. Long-term classified LULC records indicated that urban areas (residential and commercial lands) and forest increased in 1984-2010 from 6.3 to 11.1% and from 65.0 to 69.5%, respectively, whereas agricultural land decreased from 28.3 to 18.9% over the same period.

After calibration and validation, the simulation results indicated that stream flow increased 3% in this whole watershed, but with a very distinct spatial pattern. The model also suggested sediment load and nutrients (total nitrogen and phosphorus) had different degrees of decline. The statistic analysis showed that the increase of streamflow and urban expansion demonstrated a very strong and positive relationship, and water quality change is highly related to the decrease of agricultural land that occurred in this watershed in recent years. This study provides valuable information for watershed management in the efforts to mitigate streamflow increase and water quality degradation caused by LULC change in this critical watershed.

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CHAPTER 1

INTRODUCTION AND OVERVIEW

Nowadays there is a great need to detect spatial patterns of land use/land cover (LULC) change at local, regional and global scales (Doxani et al., 2011). Understanding LULC change is of fundamental importance for environmental monitoring, urban planning, and governmental decision-making around the world (Ji et al., 2006). One particular consequence of LULC change is its considerable impacts on hydrological processes by affecting the nature of surface runoff and water quality, hence further impact on ecosystems, biotic systems, and even on human health (Gordon et al., 1992; Novotny and Olem, 1994; Rogers 1994; Paul & Meyer, 2001; Frumkin, 2002).

More specifically, expanded impervious surface created by urbanization, blocks the infiltration of precipitation into the soil to the aquifer, and increases both the total volume of surface runoff and the peak discharge of streamflow, which can cause flooding risk to human beings. Second, increased streamflow can pick up large amount of soil contaminants (often containing fertilizers and pesticides) to the streams to contribute non-point source (NPS) pollution, which is also produced from fertilizers used for agriculture. NPS pollution has become the leading cause of degraded water quality in the U.S (Bhaduri et al., 2000). For example, accumulated nutrient (such as nitrogen (N) and phosphorus (P)) in the water body can cause surface and ground water impairment such as nutrient enrichment. Eutrophication and algae blooms can greatly harm aquatic ecosystems by depleting oxygen and killing aquatic plant and animal species (Young et al., 1999; Danovi, 2011). Third, eroded sediment from agricultural land and construction sites is another NPS pollution source. It is carried to nearby streams where it may clog drainage ditches, cause turbidity in water bodies, and increase water-treatment costs (USGS, 2011).

Thus, quantifying the relationship between LULC change and its impact on hydrology including both water quantity and quality would provide valuable information for land use and urban planning, water resource management, and policy decision making (Ma et al., 2009).

Over the last decades, using computer-based hydrological model to quantify the hydrologic impact of LULC change garnered considerable attention and was applied in many areas around the world (Fohrer et al., 2001; Defries & Eshleman, 2004; Ngigi et al., 2007; Nie et al., 2011). However, some key gaps still exist. Firstly, one of the major limitations in most studies is the lack of long-term and high temporal LULC records; thus, it is difficult to depict LULC change accurately. Most previous studies investigated LULC change over a long period by comparing just two to three land use maps of different time slices (Weng, 2001; Brannstrom et al., 2008; Ningal et al., 2008; Ghaffari et al., 2010). For example, the most commonly used land-use maps, the National Land Cover Database (NLCD) (1992, 2001), are currently available for the United States, but with a roughly 10-year interval. An additional provisional NLCD (2006) product was just released in 2011 in order to improve the temporal resolution of the land use maps (MRLC, 2011). Some studies used LULC maps collected from different sources such as aerial photos and satellite images. LULC types derived from these sources might have different classification schemes or spatial resolutions, causing uncertainty issues in assessing the long-term hydrological impacts of the LULC change (Bhaduri et al., 2000; Burley, 2008; Li & Wang, 2009; Conaghan, 2010). The recent cost-free accessibility of Landsat images obtained since the 1970s provide a unique opportunity to document detailed records of LULC change in recent decades. Secondly, although many hydrologic models, such as Soil and Water Assessment Tool (SWAT) and Long-Term Hydrologic Impact Assessment (L-THIA), have been developed to simulate the impacts of LULC change on runoff and water quality, few studies have integrated high-resolution temporal LULC maps derived from remote sensing (RS) classification with hydrological modeling to evaluate the long-term hydrological impacts of the LULC change. Since RS classification can provide more continuous and unified LULC information, integrating RS-based high-resolution temporal LULC classification with hydrological modeling would significantly improve the accuracy in simulating the hydrological impacts of the LULC change.

1.1 Research Goals and Objectives

This research was designed to address the limitations discussed above and develop an integrated approach combining RS-based LULC classification and hydrological modeling to assess the long-term hydrological impacts of LULC change in the Little River Watershed (LRW), eastern Tennessee. The LRW was selected due to its environmental protection significance. The Little

River (LR) provides the main source of drinking water for over 100,000 residents in Blount County and is the habitat of many state and federally protected endangered species, including dusky tail darter, fine-rayed pigtoe mussel. (Ezzell et al., 2005; Hart, 2006; Burley, 2008). Although the upper section of the river within the Great Smoky Mountains National Park (GSMNP) has excellent water quality, several downstream tributaries experienced water quality degradation in recent years, mainly caused by substantial urban development. As a result, the LRW was listed on the 2006 Targeted Watersheds Grants, funded by the United States Environmental Protection Agency (Harden et al., 2009). Now, more than 25 agencies at federal, state, and local levels are working to improve and protect the water quality of this watershed. Despite this history and trend of urban growth in the past several decades, there is still insufficient knowledge about the detailed LULC change within the watershed, and few attempts have been made to integrate RS-based LULC classifications with hydrological models.

In this context, my thesis work proposes to examine the impact of LULC change on streamflow and water quality in the LRW from 1984 to 2010, using remote sensing (RS)-based LULC classification and the SWAT model. My detailed research objectives are:

1) To quantify the high resolution temporal pattern of LULC change in the LRW from 1984 to 2010 (in roughly 2-year intervals), based on RS-based classification of Landsat Thematic Mapper/Enhanced Thematic Mapper Plus(TM/ETM+) images;
2) To assess the impacts of LULC change on streamflow, sediment and NPS pollution (total nitrogen and phosphorous) in the LRW using the SWAT model.

This study can significantly improve the understanding of the relationship between LULC change and streamflow increase and water quality degradation in the watershed from 1984 to 2010. More importantly, the integrated approach between RS-based LULC classification and hydrological modeling can be adopted in other regions to document continuous, long-term, and high resolution temporal LULC change and assess its hydrological impacts for the purpose of local water management and environmental protection.

1.2 Thesis Organization

This thesis consists of four chapters. Chapters 2 and 3 were written in the manuscript format, which would be submitted to relevant journals as independent papers. The first chapter explains research background, introduces overall objectives, and describes the format and organization of the thesis and how these chapters are organized. The second chapter focuses on the application of the remote sensing classification technique to examine the LULC change in the LRW from 1984 to 2010. The complete procedure of classification and accuracy assessment is introduced and roughly biennial land-use changes on forest, agriculture (mainly grass), commercial areas, residential areas, and water are quantified. The third chapter uses SWAT model to assess the long-term hydrological impacts of LULC change on streamflow and NPS pollution. The SWAT model was calibrated using observed daily runoff data in 2009-2010 obtained from the U.S. Geological Survey (USGS). The calibrated model was then applied to each land-use scenario from 1984 to 2010 to assess the hydrological impacts of LULC change in different sub-watersheds. The last chapter summarizes major findings of this thesis, discusses the limitations, and suggests potential improvements in future studies. The appendix includes figures and tables that are not listed in each chapter.

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CHAPTER 2

HIGH RESOLUTION TEMPORAL LAND USE/LAND COVER CHANGE FROM 1984 TO 2010 OF THE LITTLE RIVER WATERSHED, TENNESSEE, INVESTIGATED USING REMOTE SENSING AND GOOGLE EARTH IMAGES

This chapter is in preparation for submission to the journal *GISciences & Remote Sensing* by Chunhao Zhu and Yingkui Li.

My primary contribution to this paper include: (1) gathering data and reviewing literature, (2) processing experimental data, (3) design and conducting the experiments, (4) analyzing and interpretation of experimental data, (5) most of the writing.

Yingkui Li's contribution to this paper include: (1) identification of research objectives, (2) design the experiments, (3) revise writing.

Abstract

The Little River Watershed (LRW) in Tennessee has experienced rapid land use/land cover (LULC) change in recent decades. However, a detailed long-term record of LULC change is still lacking. Here, we examined the pattern of LULC change from 1984 to 2010 in roughly 2-year intervals using the Maximum Likelihood Classification (MLC) of Landsat TM/ETM+ images. The accuracy of the classification was assessed by comparing classified LULC classes with their corresponding classes identified from Google Earth high resolution imagery (representing "ground truth"). An overall accuracy of 89.7% and a kappa coefficient of 85.8% were achieved for the classification of 2010. Change detection of classified LULC maps indicated that urban areas (residential and commercial lands) and forest increased in 1984-2010 from 6.3 to 11.1% and from 65.0 to 69.5%, respectively. In contrast, agricultural land decreased from 28.3 to 18.9%. The increase in urban areas is consistent with the population increase in the watershed in recent decades, and the increase in forest is probably due to the protection effort of the Great Smoky Mountains National Park, as well as the natural conversion of abandoned agricultural land because more and more local farmers find jobs in cities. This detailed long-term record of LULC change would provide valuable information for local land-use planning and management and help assess the potential impacts of LULC change in this watershed.

Keywords: Land use/Land cover (LULC) change, Little River Watershed, Maximum likelihood classification, Google Earth, remote sensing

2.1 Introduction

Land use/land cover (LULC) change affects both human and physical environments and plays a fundamental role in various environmental and socioeconomic applications from local, regional, to global scales (Vitousek, 1994; Foody, 2002). In particular, LULC change has considerable impacts on streamflow and non-point source (NPS) pollution (Bhaduri et al., 2000). Therefore, a detailed long-term record of LULC change is of critical importance for urban planning and water resource management (DeFries & Townshend, 1999; Jat et al., 2008). However, most studies associated with LULC change mainly compared two or three land use maps over a long period (with large time intervals) due to the limited availability of LULC maps (Brannstrom et al., 2008; Ningal et al, 2008). For instance, the National Land Cover Database (NLCD) (1992, 2001) is widely used in the United States, but only two years of LULC maps are available with a roughly 10-year interval (Anderson et al., 1976; Ralston, 2004; Jensen, 2005). Recently, the free access of Landsat satellite images provides a unique opportunity to document detailed long-term historical LULC change for a specific area.

Interpreting LULC changes using satellite images usually requires a certain classification algorithm or a combination of several classification algorithms. The Maximum Likelihood Classification (MLC) is the most frequently used algorithm and has a very wide range of applicability in the remote sensing field (Wu & Shao, 2002; Lee & Yeh, 2009). It assumes that each spectral class can be described adequately by a multivariate normal probability distribution in a feature space (McIver & Friedl, 2002; Lu & Weng, 2007). As such, those training areas characterize the mean vector, variance, covariance, and other parameters for each class. MLC uses a statistical decision rule to examine the probability function of a pixel for each class and assigns the pixel to the class with the highest probability (Pal & Mather, 2001; CCRS, 2010; Liu et al., 2011). Other classification algorithms, such as Decision Tree (DT), Artificial Neural Network (ANN), Support Vector Machines (SVM), and Object-Oriented (OO) image segmentation, have also been widely applied due to their conceptual simplicity and computational efficiency (Pal & Mather, 1997; Benz et al., 2004; USGS, 2010).

A critical step in the LULC classification is to assess the accuracy of the classification. Studies suggested that >80% overall classification accuracy is required to guarantee the quality of the LULC classification (Li & Wang, 2009). Traditional approaches to assess the accuracy required field surveys or high-resolution aerial photos to obtain "ground truth" land use/land cover information. However, field survey is usually costly and time consuming, whereas aerial photos may not be available for some areas (Jat et al., 2008). In addition, field survey may be restricted due to terrain conditions or land ownership issues which would curtail or deny the access of ground reference data (Jensen, 2005). Recently, Google Earth has provided access to high resolution satellite images (15 m or higher, 1 m resolution in most urban areas of the U.S.) in an interactive three-dimensional (3-D) visual environment (Clarke et al., 2010). These images provide a potential alternative way to obtain "ground truth" information for the LULC classification.

The purpose of this paper is to establish a detailed long-term record of LULC change from 1984 to 2010 in the Little River Watershed, Tennessee, and examine spatial and temporal patterns of LULC change based on remote sensing classification of Landsat TM/ETM+ and Google Earth high-resolution images. The results and findings of this paper provide valuable information for local land use planning and management and help assess the potential impacts of LULC change in this critical watershed.

2.2 Study Area

The Little River Watershed is located around 35°44′N and 83°46′ W in Eastern Tennessee, with elevations ranging from 245 m to 2010 m above sea level (a.s.l.) (Foster, 2010; U.S. NPS, 2010) (Fig. 2-1). It drains approximately 981 km^2, encompassing portions of Blount, Knox, and Sevier Counties. Of these, the largest portion (702.5 km^2) is located in Blount County. According to the detailed visual interpretation of color aerial photography taken on February 21, 2000, by the Tennessee Valley Authority (TVA) (TVA, 2003), the main land uses within the watershed are forest (approximately 60%), agriculture, residential, and commercial/industrial (Hart, 2006; Harden et al., 2009).

This watershed can be further divided into three distinct geographic regions (Ezzell et al., 2005). Most of the upper portion (source to Townsend) of the watershed is covered by mixed forest and belongs to the Great Smoky Mountain National Park (GSMNP), the most visited national park in the United States. Agricultural land is dominant in the middle portion (Townsend to Walland), and mainly composed of hay and pasture for livestock and cultivated crops such as corn, soybeans, and winter wheat (Dr. Erich Henry, Director of Conservation, Blount County Government, personal communication, April 2011; USDA, 2011). The lower (northwestern) portion of the watershed includes more urban areas especially on the west corner of the watershed (Maryville and Alcoa in Blount County).

2.3 Method

LULC classification

In this study, we examined the spatial and temporal pattern of LULC change in the Little River Watershed from 1984 to 2010 based on the classification of a set of Landsat TM/ETM+ images, downloaded from the U.S. Geological Survey (USGS)'s Global Visualization Viewer (USGS, 2011). In order to detect change over time, we composited a roughly biennial image dataset from 1984 to 2010, including years of 1984, 1986, 1988, 1989, 1991, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2007, 2008, and 2010 (Table 2-1). Only one image in each year with the best quality and low cloud cover during late March or early October was selected for the classification because the bare soil of forest or harvested cropland is minimized during this "leaf on" season, and also pasture and forest can be distinguished effectively from urban areas.

These Landsat images were already geometrically and radiometrically corrected by the USGS EROS Digital Image Processing Center (USGS, 2007). All non-thermal bands were stacked and clipped using the boundary of the watershed to establish the dataset just within the watershed. In addition, although only images with low cloud cover were downloaded, small areas on the images covered by sporadic clouds and cloud shadow in certain years were replaced by corresponding pixels of the image from the closest period.

We applied the MLC algorithm to classify the images. As a supervised classification method, the MLC algorithm requires the selection of training areas. To help the selection of training areas from the image, we used Principal Component Analysis (PCA) to enhance the contrast between commercial and residential lands. Five to ten relatively homogeneous regions of interest (ROI) were selected as training samples for each classification to ensure a sufficient number of training pixels (Lu & Weng, 2007). After the ROIs were selected, MLC was used to classify the images. Five main LULC classes were classified: water, commercial land, residential land, mixed forest, and agricultural land. Mixed forest mainly includes the deciduous leafy hardwood growing in the lower elevations of the park (including maple, oak, horse chestnut and many wild flowers) and evergreen trees predominating in the higher altitudes of the park (including hemlock, pine, cove hardwoods, northern hardwoods, spruce-fir forests). Agricultural land includes pasture and cultivated crops such as corn, soybeans, and winter wheat. In order to improve the classification accuracy, we initially classified nine classes using the MLC algorithm and then combine them to create the final five classes (Fig. 2-2). As illustrated by Fig. 2-3, approximately nine classes defined by combinations of bands 5 (mid-infrared), 4 (near infrared), and 3(red) were water, agricultural land showing green color, agricultural land showing pink, agricultural land showing other colors, bare soil in the forest, shadow (caused by mountains blocking the sun but still belongs to the forest after visual interpretation), forest showing green color, commercial/industrial land, and residential land.

Accuracy assessment

2010 LULC classification from a TM image (taken on October 2, 2010) was selected for the accuracy assessment. A Google Earth high-resolution imagery (taken on October 8, 2010) was used to obtain “ground truth” data. The similar dates of the TM and Google Earth images can reduce potential errors caused by different seasons. An equation based on multinomial distribution was used to calculate the sample size (N) of the “ground truth” data needed for the accuracy assessment (Congalton & Green, 1999; Jensen, 2005):

$$N = \frac{B\prod_i (1-\prod_i)}{b_i^2} \quad (1)$$

Where $\prod_i$ is the area percentage of the *i*th class out of total k land-use classes, the area percentage of the *i*th is closest to 50% of the total area, b_i is the desired precision range of this class, B is expressed as $\chi^2_{(1,1-\frac{a}{k})}$, meaning upper ($\frac{a}{k}$) $\times$ 100^{th} percentile of the chi square (χ^2) distribution with 1 degree of freedom, and k is the number of classes.

Five classes (k = 5) were classified in this study. Mixed forest occupied approximately 65% of the whole watershed so the percentage of forest in this watershed is closest to 50% compared to other land-use types. A level of confidence of 85% was used, as it is the conservative standard for many land-use products (Jensen, 2005). The precision range of *b* was 5%. *B* was determined from the χ^2 table with 1 degree of freedom. Calculation indicated that at least 518 "ground truth" samples were required for the accuracy assessment. In ArcGIS, we created 1000 random points to assess the classification accuracy. However, unless there is an extremely large sample size, using simply the random points may cause inadequate sample representation for some critical classes that occupy only a small portion of the study area (Jensen, 2005). In order to generate sufficient sample points for each class, we generated 200 points from the entire Little River watershed, which is dominated by forest and agricultural land, and another 800 points from the lower portion of the watershed where urban land is mainly located (Fig. 2-4). By doing this, we ensure that there are sufficient sample numbers available for each class especially urban areas (commercial and residential lands) to assess the classification accuracy. For each sample point, we used the Google Earth high-resolution imagery to obtain "ground truth" information of the corresponding classified LULC types. Comparing the classified LULC types and Google Earth "ground truth" information, an error confusion matrix can be composited and two indices, the Kappa coefficient and the overall accuracy, can be calculated to assess the classification accuracy (Fig. 2-5).

2.4 Results

As indicated in Table 2-2, the remote sensing classification of the 2010 TM image reached an overall accuracy of 89.7% and a kappa coefficient of 85.8%. This classification accuracy indicated that the MLC algorithm used in this study can be used to achieve an accurate LULC classification for Landsat TM/ETM+ images, making it feasible to establish a detailed long-term record of LULC change from 1984 to 2010 in the Little River Watershed and examine its spatial and temporal changing patterns.

LULC maps classified by the MLC algorithm reflected the spatial and temporal pattern of LULC change over a period of 27 years (from 1984 to 2010) (Fig. 2-6, 2-7). As illustrated in Appendix I, agricultural land decreased from 28.3 to 18.9%, whereas forest increased from 65.0 to 69.5% over the whole period (Fig. 2-8.A, B). Water covers <1% of the watershed and remained relatively constant during the whole period. Corresponding to the decrease in agricultural land, urban areas (residential and commercial lands) underwent a rapid expansion (Table 2-3). In 1984, urban areas were only 6.3% of the watershed, but they had increased to 11.1% by 2010, although the overall percentage was still relatively low. Among urban areas, commercial land represented only 1.0% in 1984, and increased to 2.8% in 2010, while residential land grew from 5.2% to 8.3% (Fig. 2-8.C, D). We can also identify two rapid urbanization periods in 1984-1989 and 2004-2010.

Urbanization mainly occurred in the lower portion of the watershed, especially in the center and northern parts of Blount County within and around the cities of Maryville and Alcoa. Within the city, the main urban growth occurred along the main streets of Maryville, including Broadway to the northeast and southwest, Lamar Alexander Parkway to the east and west, Alcoa Highway to the north, and Sevierville Road. An example of the urban growth is the extension of the Pellissippi Parkway. The first section of this highway project appeared along the western edge of the watershed, intersecting with US 129 (Alcoa Highway) in 1991. Then, it was gradually extended eastward to reach the Cusick Road in 2003, and finally connected to State Route 33 in 2005. This pattern of development was confirmed by the official report of the Tennessee Department of Transportation (TDOT, 2010). Residential land showed very rapid expansion as well, extending along major corridors. Some new densely populated regions also appeared around Maryville. In contrast, agricultural land around the center of Blount County and along Sevierville Road to the north of the watershed was continuously shrinking. Not only numerous houses and country roads were built on former agricultural land, but many agricultural lands were used also for subdivisions, shopping centers, and other urban uses. In addition, some agricultural land was also converted to forest. Personal communication with local residents revealed that this conversion is attributed to the decrease of livestock-dependent farmers because more and more people worked full-time or part-time in cities. As a result, open agricultural lands were abandoned and gradually replaced by the forest (TDA, 2011) (Fig. 2-9).

The middle portion of the watershed was relatively rural but still experienced scattered urban development, especially along the E. Lamar Alexander Parkway toward Townsend and Miller's Cove. As indicated in LULC maps, Townsend experienced urban growth over the whole period, although the extent was not as noticeable as the urban development in Maryville and Alcoa. Most urban development in Townsend occurred around the main road after 1999. This is due to the fact that Highway 321 through Townsend used to be two lanes. In 1999-2001, this road was widened to four lanes. Miller's Cove only had a slight urban development around Walland, but conversion from agricultural land to mixed forest was evident. Almost no change in forest coverage occurred in the upper portion of the watershed, due to the protection of the national park.

2.5 Discussion

The free availability of Landsat TM/ETM+ offers a unique opportunity to detect detailed historical LULC change in images with high temporal resolution. However, uncertainty can also be introduced in remote sensing classification (Foody & Atkinson, 2002). Since the spatial resolution of Landsat TM/ETM+ images is about 30 meters, each pixel of the image is mixed in nature, especially in transition boundaries among different LULC classes. For example, accurate classification of residential land using the MLC algorithm was challenging especially for the selection of training areas because surface features of residential land are relatively complex. Although a reasonable accuracy level can be achieved by careful selection of training areas (Appendix II), the accuracy for residential land is a little lower than for other classes, such as forest and agricultural land (Table 2-2). Classification uncertainty prevented our initial effort to reconstruct annual historical LULC change in the watershed; instead, we composited a roughly 2-year interval record of LULC change.

Most of the Little River Watershed lies within Blount County, including the cities of Maryville, Alcoa, Townsend, and the unincorporated community of Walland. The areas outside of Blount County in this watershed mainly belong to the Great Smoky Mountain National Park and are relatively unpopulated. Therefore, urbanization mainly occurred in Blount County. LULC results indicated that urban areas had about 78% expansion in 1984-2010, from 6.3% to 11.1% (Fig. 2-8.E). According to the U.S. Census data, Blount County experienced 52.7% population growth from 1984 to 2009 (U.S. Census Bureau, 2010) (Fig. 2-8.F). Therefore, the increase in urban areas is closely related to the population growth. This is consistent with the results from other regions, such as Nashville and Charlotte. These cities also showed a close relationship between population growth and urban sprawl.

The results of this research indicated that the urban area in Blount County has almost doubled in size from 1984 to 2010. There is no doubt that Blount County's growth is expected to continue in the future. By 2025, the population in Blount County is predicted to reach 144,000, with an annual growth rate of approximately 1.4% (Blount County, 2010). To keep up with the pace of the population growth, more urban areas will be developed, causing the watershed to become more densely settled. The continuous increase in urban areas would be likely to have various impacts on the environment, especially on the degradation of water quality.

2.6 Conclusions

This paper examined the long-term LULC change in the Little River Watershed, Tennessee from 1984 to 2010. LULC maps of 14 individual years were classified based on Landsat TM/ETM+ images using the MLC algorithm (Appendix III). The accuracy of the classification was assessed by comparing classified LULC classes with their corresponding classes identified from Google Earth high resolution imagery (representing "ground truth"). Both overall classification accuracy and Kappa value are higher than 84% for the classification of 2010, suggesting that LULC maps can be used to document the historical LULC change that occurred in this watershed from 1984 to 2010.

Changing detection of classified LULC maps indicated that urban areas (residential and commercial lands) and forest increased in 1984-2010 from 6.3 to 11.1% and from 65.0 to 69.5%, respectively. In contrast, agricultural land decreased from 28.3 to 18.9%. The increase in urban areas mainly occurred around cities and is consistent with the population increase in the watershed in recent decades. The increase in forest is probably due to the protection effort of the

Great Smoky Mountains National Park, as well as the natural conversion of abandoned agricultural land because more and more local farmers find jobs in cities. This detailed long-term record of LULC change would provide valuable information for local land-use planning and management and help assess the potential impacts of LULC change in this watershed.

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Table 2-1

Landsat TM/ETM+ images used for this study.

	Date(Year/Month/Day)	Download ID	Landsat images
1	1984/09/08	LT50190351984252XXX08	TM
2	1986/06/26	LT50190351986177XXX04	TM
3	1988/08/18	LT50190351988231XXX04	TM
4	1989/05/17	LT50190351989137XXX03	TM
5	1991/09/28	LT50190351991271XXX02	TM
6	1993/07/31	LT50190351993212XXX02	TM
7	1995/09/07	LT50190351995250XXX02	TM
8	1997/05/07	LT50190351997127AAA02	TM
9	1999/09/10	LE70190351999253EDC00	ETM+
10	2001/10/01	LE70190352001274EDC00	ETM+
11	2003/04/14	LE70190352003104EDC00	ETM+
12	2005/09/18	LT50190352005261EDC00	TM
13	2008/07/24	LT50190352008206EDC00	TM
14	2010/10/02	LT50190352010275EDC00	TM

Table 2-2

Error matrix and associated accuracy using 1000 points after combination.

Ground truth	Water	Forest	Agricultural land	Commercial land	Residential land	Total
Classified as						
Water	9	3	1	2	1	16
Forest	0	320	11	2	11	344
Agricultural land	0	16	258	1	19	294
Commercial land	0	0	3	94	6	103
Residential land	0	4	12	11	216	243
Total	9	343	285	110	253	1000

Overall Classification Accuracy: 89.7%; Kappa Value: 85.8%.

Table 2-3

The statistics of LULC change in 1984 and 2010.

LULC	1984 (km^2)	2010 (km^2)	Net increase (km^2)	Net rate of increase	Annual growth (km^2)	Annual growth rate
Forest	637.7	682.0	44.4	7.0%	1.6	0.3%
Agricultural land	277.3	185.5	-91.8	-33.1%	3.4	1.2%
Commercial land	10.2	27.8	17.6	172.6%	0.7	6.4%
Residential land	51.3	81.2	30.0	58.5%	1.1	2.2%

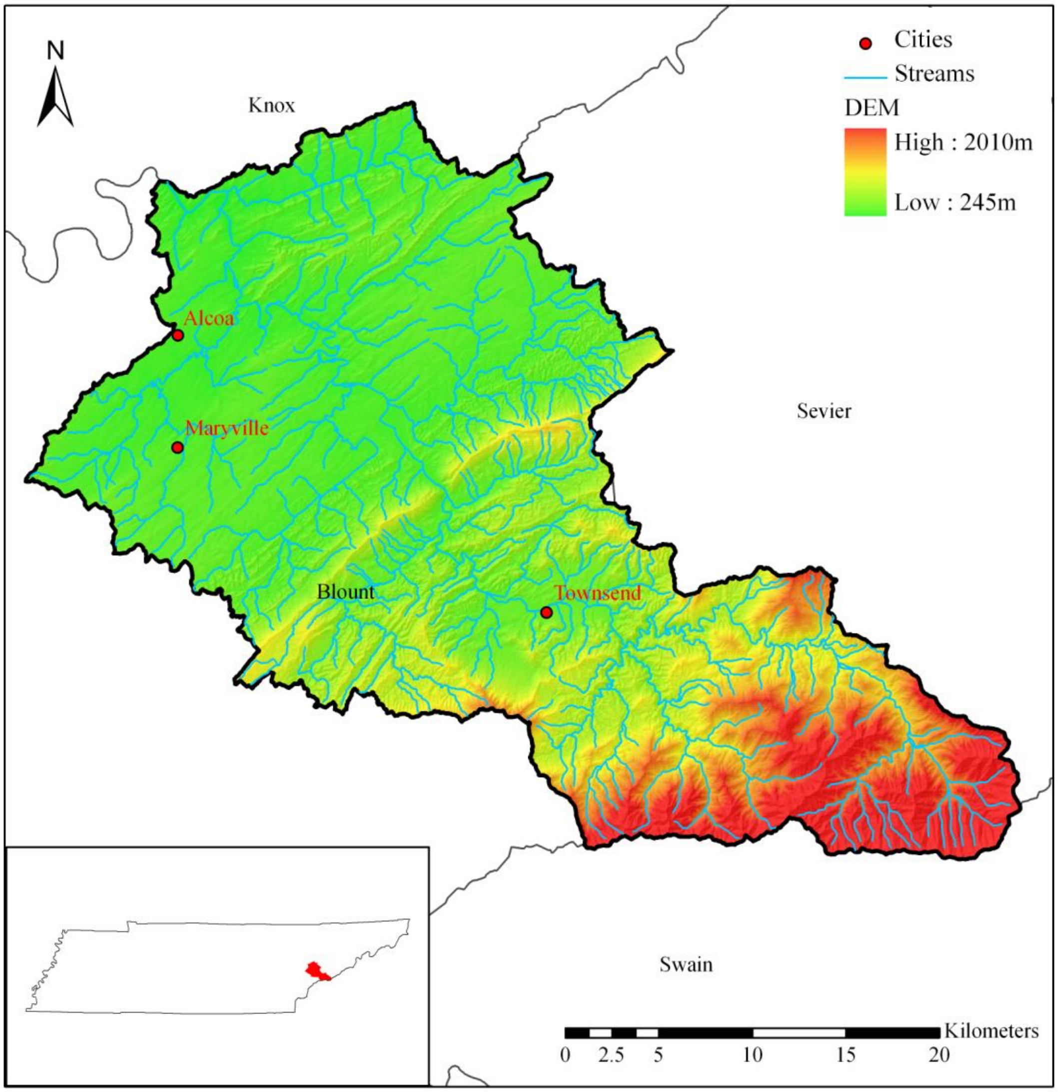

Fig. 2-1. Location of the Little River Watershed in Eastern Tennessee.

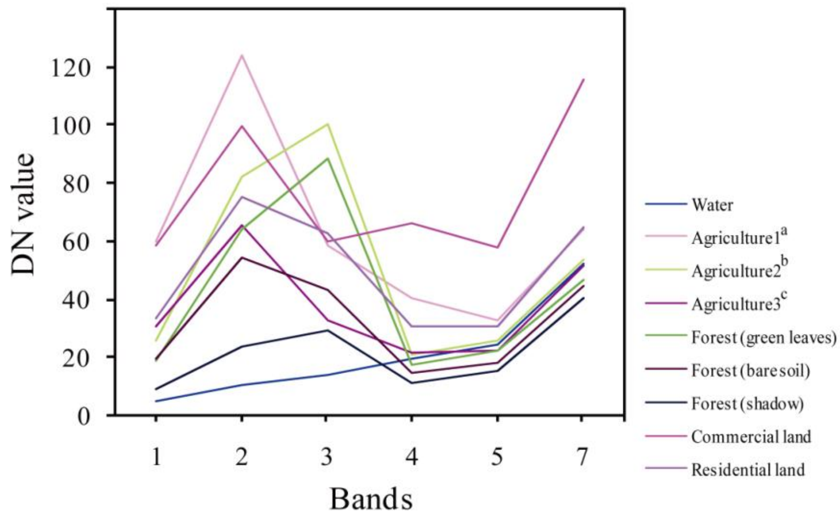

Fig. 2-2. Spectral curves of different land use types, Landsat TM image, 2010/10/02.
(a: agricultural land showing pink color; b: agricultural land showing green color; c: agricultural land showing other color)

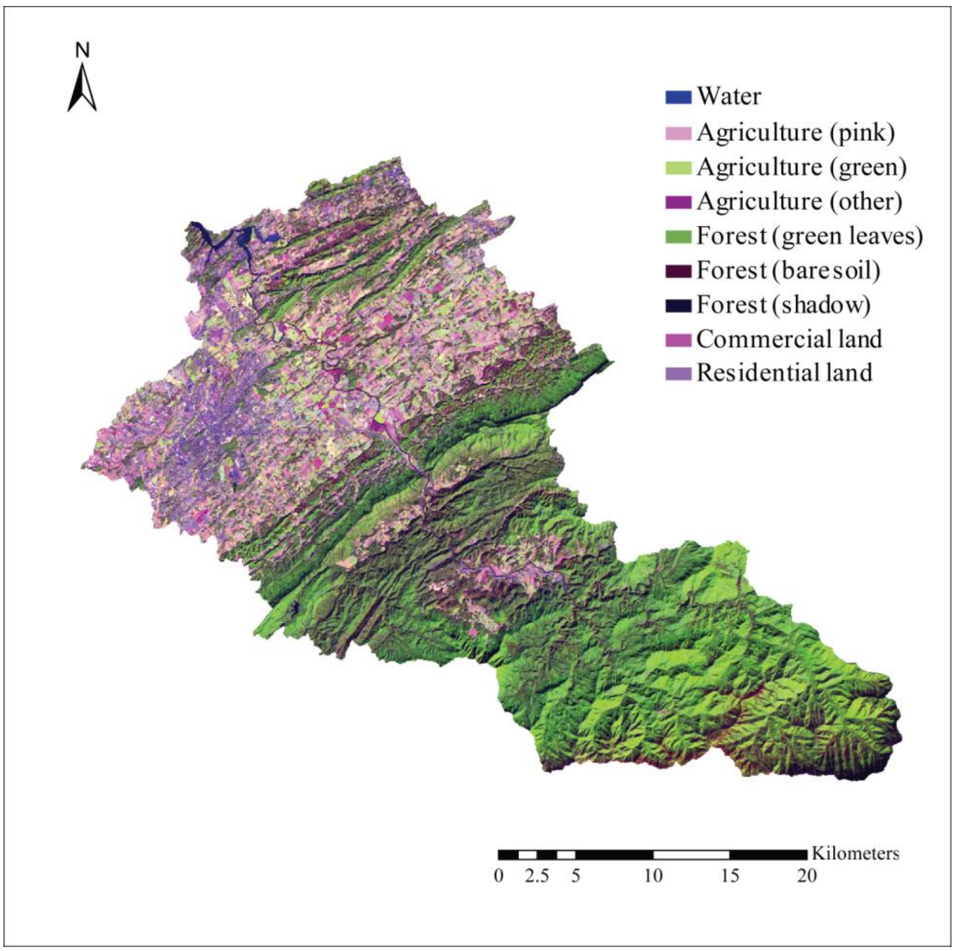

Fig. 2-3. The composition of band5, band4 and band3 of TM image 2010.

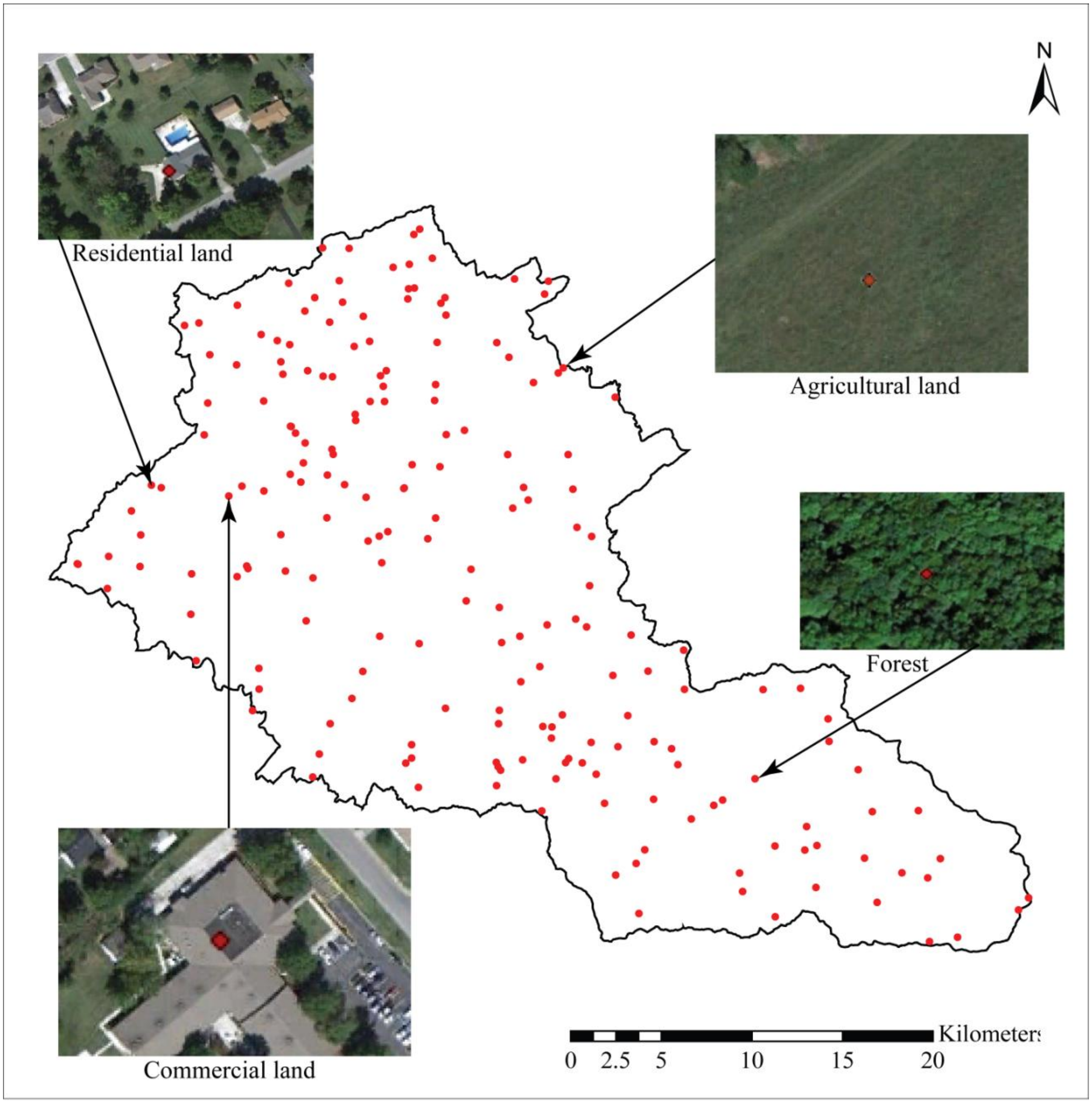

Fig. 2-4. Locations of the 200 points used to check classification accuracy of whole watershed.

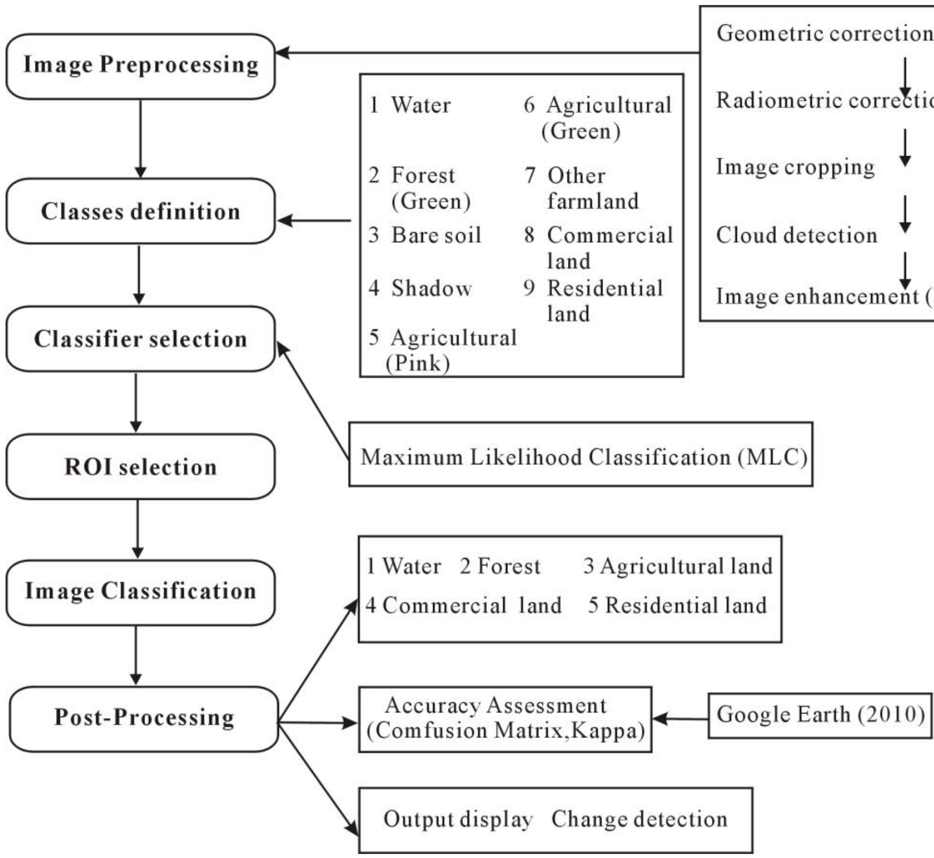

Fig. 2-5. The procedure of remote sensing classification. (ROI: regions of interest; PCA: principal component analysis)

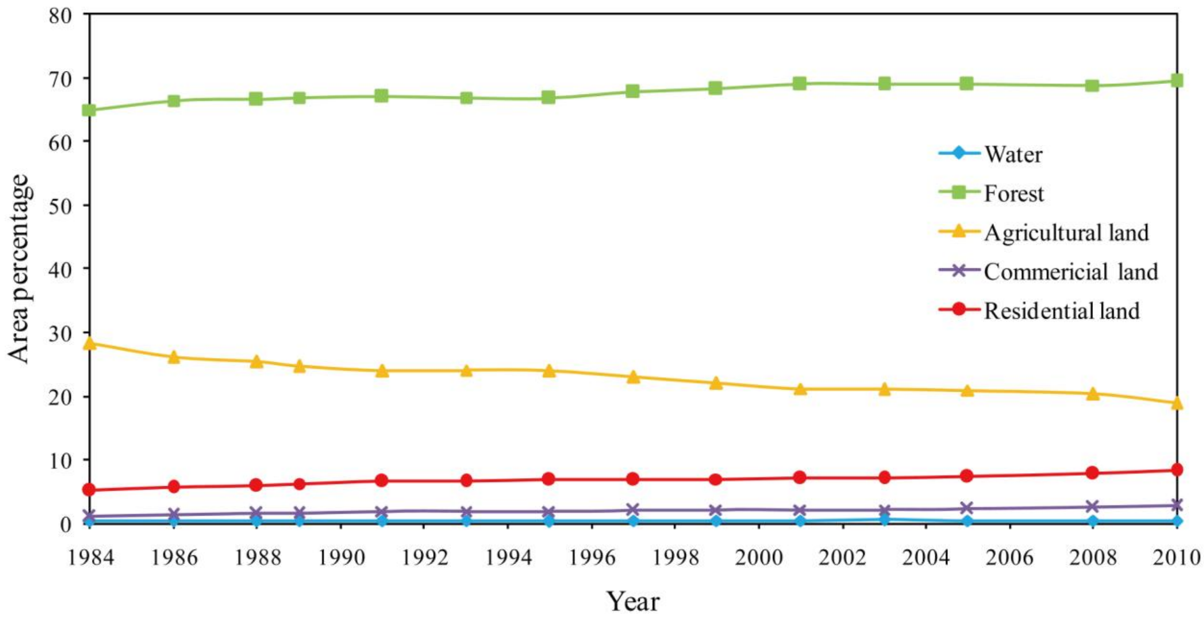

Fig. 2-6. Results of LULC change in the Little River Watershed from 1984 to 2010.

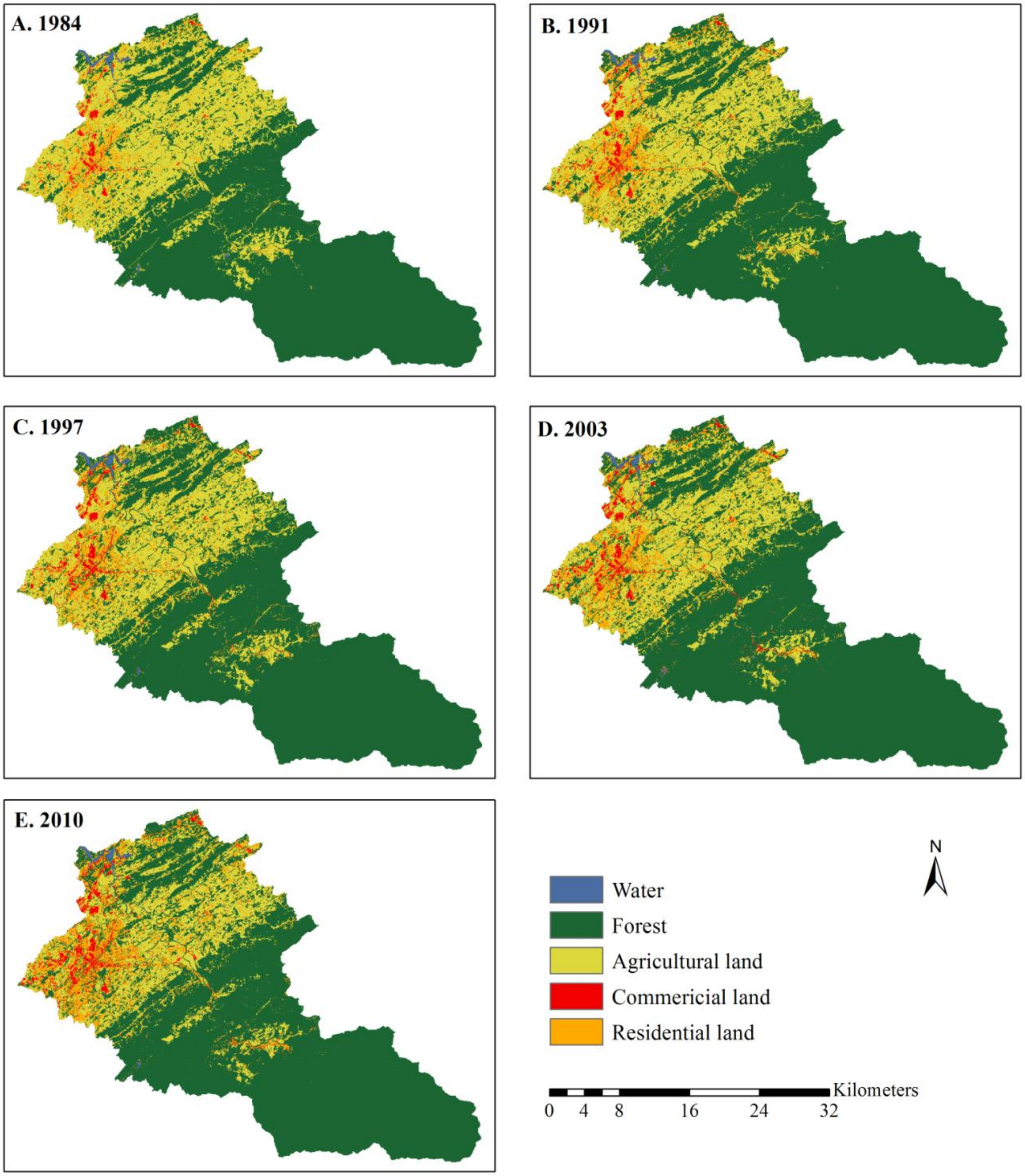

Fig. 2-7. (A) The LULC map of the watershed in 1984. (B) The LULC map of the watershed in 1991. (C) The LULC map of the watershed in 1997. (D) The LULC map of the watershed in 2003. (E) The LULC map of the watershed in 2010.

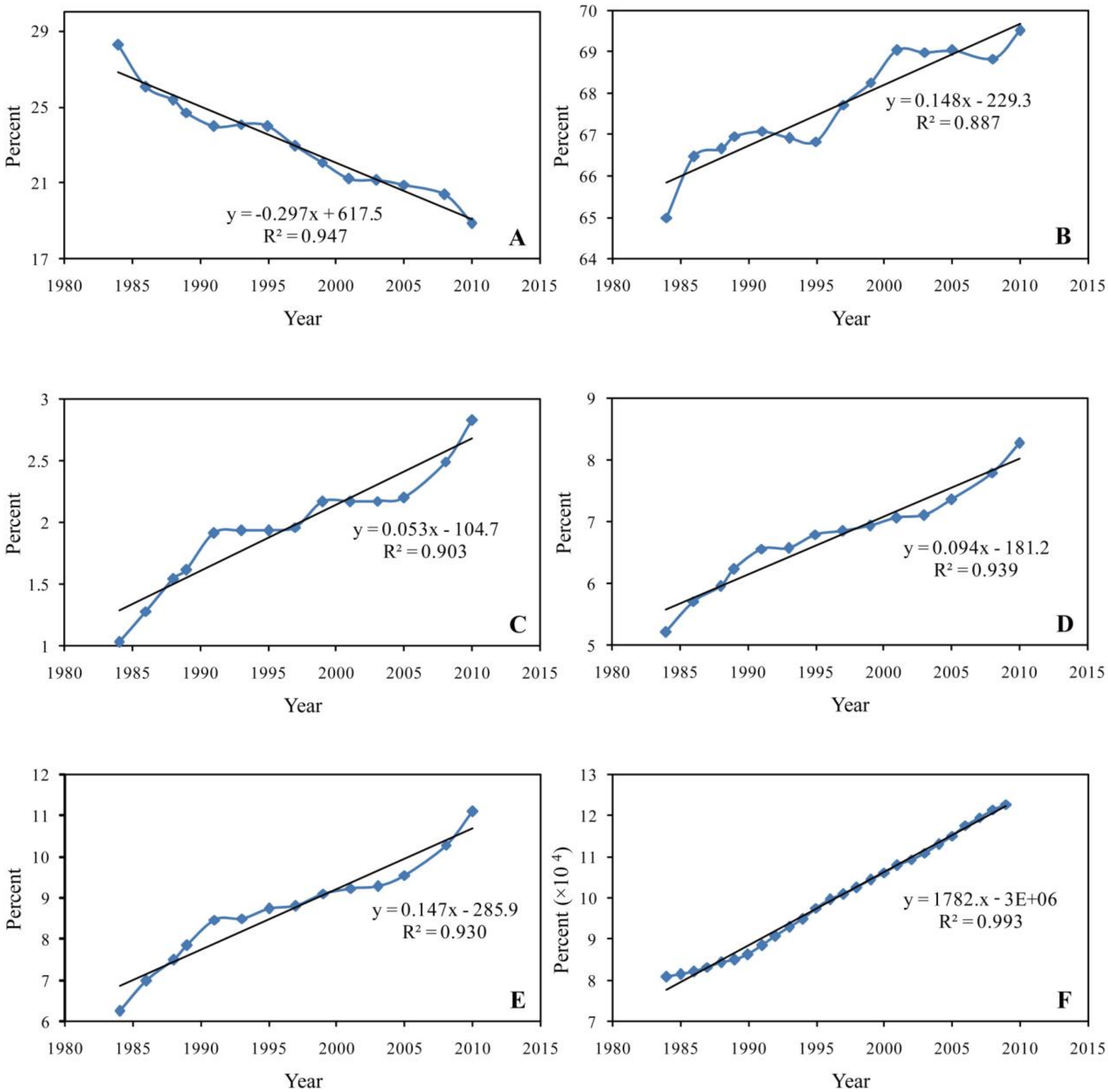

Fig. 2-8. (A) The change of Agricultural land. (B) The change of forest. (C) The change of commercial land. (D) The change of residential land. (E) The change of urban areas. (F) The change of Blount County population.

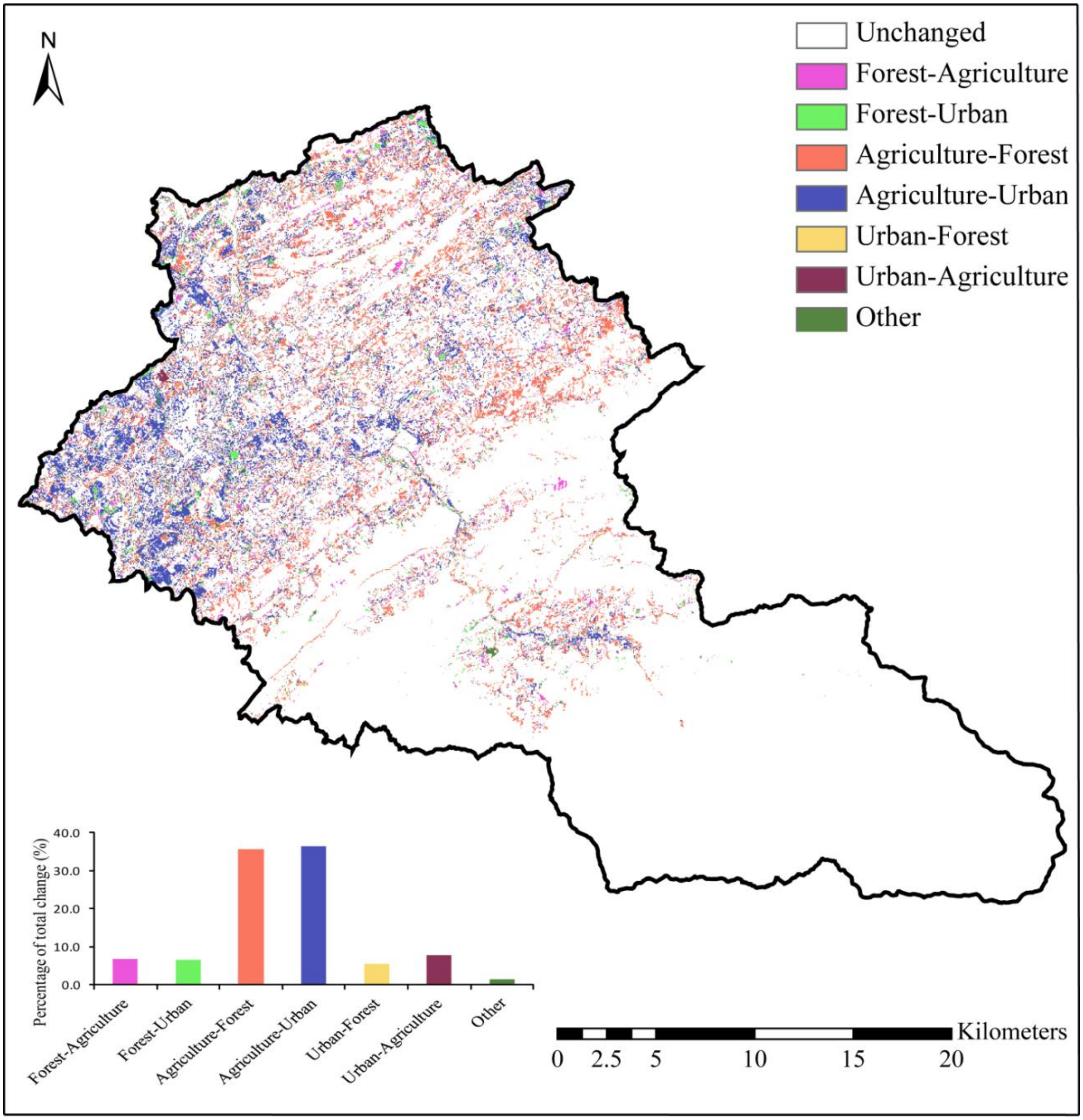

Fig. 2-9. Change detection of year 1984 and year 2010.

CHAPTER 3

LONG-TERM HYDROLOGICAL IMPACT OF LAND USE/LAND COVER CHANGE FROM 1984 TO 2010 IN THE LITTLE RIVER WATERSHED, TENNESSEE

This chapter is in preparation for submission to the journal *GISciences & Remote Sensing* by Chunhao Zhu and Yingkui Li.

My primary contribution to this paper include: (1) gathering data and reviewing literature, (2) processing experimental data, (3) design and conducting the experiments, (4) analyzing and interpretation of experimental data, (5) most of the writing.

Yingkui Li's contribution to this paper include: (1) identification of research objectives, (2) design the experiments, (3) revise writing.

Abstract

Accurately accessing the long-term impacts of land use/land cover (LULC) change on stream flow and water quality is important for land use planning and water resource management. Here, we present a case study from the Little River Watershed, Tennessee, a critical watershed supporting drinking water for >100,000 residents and recreational activities within and around the Great Smoky Mountains National Park (GSWMP). The long-term impacts of LULC change on stream flow and non-point source (NPS) pollution were quantified using the Soil and Water Assessment Tool (SWAT), a physically-based hydrological model, and a detailed LULC record with a roughly 2-year interval classified based on Landsat images from 1984 to 2010. The SWAT model was first calibrated and validated using observed stream flow data for 2010 and then simulated using different LULC patterns with the same, 1984-2010, climate record to quantify the long-term average hydrological impacts due to the LULC change. Results indicated just a 3% stream flow increase for the whole watershed from 1984 to 2010, but with a distinct spatial pattern. Almost no stream flow increase occurred in the upper portion of the watershed especially within the national park, whereas >10% stream flow increase was observed in the lower portion of the watershed, especially in areas close to cities. The increase in stream flow suggested a positive relationship with urban development, although the expansion of forest within the watershed mitigates the effect of urban development. Model simulation also suggested 34.6% decrease in sediment load and about a 10% decrease in nutrients (total nitrogen and phosphorus) decrease from 1984 to 2010, were closely related to the decrease in agricultural land. However, without calibration and validation, the simulation of the sediment load and nutrient

may be problematic because SWAT mainly simulates the static status of LULC patterns, while LULC transitional periods, such as construction phases, actually generate more sediment and nutrient loads. In addition, the simulation also does not account for sediment and nutrients generated from streams due to bank erosion.

Keywords: Land use/Land Cover (LULC), Little River Watershed, stream flow, NPS pollution, SWAT

3.1 Introduction

Land use/land cover (LULC) change has a significant hydrological impact on water quality and quantity such as surface runoff, groundwater, and non-point source (NPS) pollutions over a range of temporal and spatial scales (Bhaduri et al., 2000; Frumkin, 2002; Novotny & Olem, 1994; Rogers 1994; Weng, 2001). Expanded impervious surfaces, such as parking lots, roofs, sidewalks, and driveways, block the precipitation infiltrating into the groundwater and increase the total volume of surface runoff and the peak discharge of the stream flow. Excessively eroded sediment from agricultural land and construction sites also contributes to NPS pollution, which has become the leading cause of degraded water quality in the U.S. (Bhaduri et al., 2000). NPS pollution is difficult to regulate because such pollutants originate from diffuse rather than point sources (Ezzell et al., 2005). In addition, accumulated sediments and nutrients (such as nitrogen (N) and phosphorus (P)) in streams can adversely impact aquatic eco-systems and impair the use of water for industry, agriculture and drinking purposes (Issue in Ecology, 1998; USEPA, 2003; TDEC, 2006; USGS, 2011).

The hydrological impacts of LULC change are usually assessed by a modeling approach, and many associated models have been developed, such as EPA Storm Water Management Model (SWMM) (Huber et al., 1988; USEPA, 2011), Long-Term Hydrologic Impact Assessment (L-THIA) (Harbor, 1994), Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) and the United States Department of Agriculture (USDA) AGricultural Non-Point Source Pollution Model (AGNPS) (USDA, 2011). Among these models, SWAT has been widely used. For example, Wang et al. (2008) applied SWAT to simulate three land-use scenarios based on measured land use patterns to investigate stream flow variations in Northwest China. Ghaffari et al. (2009) quantified the hydrological response of land use change on surface runoff, groundwater flow, and stream flow based on SWAT simulation of three-year land-use patterns (1967, 1994, and 2007) in the Zanjanrood Basin in Northwest Iran. Conaghan (2010) used SWAT to compare stream flow and total sediment load between the current (2001) and developed future (2010) land use scenario in the Upper Neuse River Basin in North Carolina.

However, most previous studies assessed the hydrological impacts based on a few LULC maps (two or three scenarios). Few studies have integrated high-resolution temporal LULC maps derived from remote sensing (RS) classification with hydrologic modeling to evaluate the long-term hydrological impacts of the LULC change. A detailed LULC record would allow for an accurate assessment of the long-term hydrological consequences of LULC change and provide more quantified and useful information for decision makers in land use planning and water resource management. This paper provides a case study from the Little River Watershed, Tennessee, to assess the long-term impacts of LULC change on stream flow and NPS pollution from 1984 to 2010 using SWAT and a detailed LULC record classified using Landsat images.

3.2 Study Area

The Little River Watershed, Tennessee, is located around 35°44′N and 83°46′W with a drainage area of approximately 981 km^2 and ranges from 245 m to 2010 m above sea level. The watershed spans two ecoregions: the Blue Ridge and the Ridge and Valley (Harden et al., 2009; Foster, 2010; USEPA, 2011). The southeastern portion of the watershed is within the Blue Ridge Mountains with an area of about 517.1 km^2. The soil is deep and well-drained, with metamorphosed sedimentary bedrocks underneath. This portion of the watershed is mainly covered by the mixed forest with a world-renowned wondrous diversity of flora and fauna (Burley, 2008; U.S.NPS, 2011). The northwestern portion of the watershed lies primarily within the Ridge and Valley with an area of about 463.4 km^2. It is comprised of multiple layers of shale, limestone, fault lines, and dolomite (carbonate) bedrock, with fault lines and well developed karst topography (such as sink holes, depressions, and subterranean drainage systems) (King, 1964; Livingston, L. Richard and Mark Whited, personal communication). Agricultural land and urban areas are dominated in this portion. Agricultural land is mainly composed of hay and pasture for livestock and cultivated crops, such as corn, soybeans, and winter wheat (Dr. Erich

Henry, Director of Conservation, Blount County Government, personal communication; USDA, 2011). Urban areas include residential and commercial lands and are mainly distributed on the northwest corner of the watershed (Maryville and Alcoa in Blount County). The annual maximum and minimum temperatures were about 20.6 °C and 7.7°C, respectively, from 1966 to 2010. The average annual precipitation was about 1344 mm in lower elevations. Both temperature and precipitation vary significantly with the altitude (Shanks, 1954). Most precipitation events, such as showers and thunderstorms, were recorded in February, March, and July (U.S.NPS, 2010). More snow falls at higher elevation in the mountains from December to March.

The Little River (LR) is a scenic perennial stream about 96.6 km long and it is a northwest-flowing tributary of the Tennessee River (Hart, 2006; Burley, 2008) (Fig. 3-1).The water quality of the Little River varies within each portion of the river. The headwaters within the Great Smoky Mountains National Park (GSMNP) have outstanding water quality (USEPA, 2005). However, the lower portion of the stream flowing through urban areas such as Maryville and Alcoa has been affected by urban development. Some tributaries have experienced water quality degradation in recent years (Ezzell et al., 2005). As a result, the LRW was listed on the 2006 Targeted Watersheds Grants funded by United States Environmental Protection Agency (USEPA, 2005b; Harden et al., 2009).

3.3 Method

LULC Classification

A detailed LULC record has been composited from 1984 to 2010 in this watershed based on the Maximum Likelihood Classification (MLC) of Landsat TM/ETM+ images (Chapter 2). This record includes 14 years (1984, 1986, 1988, 1989, 1991, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2007, 2008, and 2010) of LULC maps in a roughly 2-year temporal interval (Fig. 3-2A). Five main classes were classified: water, commercial land, residential land, mixed forest, and agricultural land. The accuracy of the classification was assessed by comparing classified LULC classes in 2010 with their corresponding classes identified from Google Earth high-resolution imagery using a set of random points (representing “ground truth”). An overall accuracy of 89.7% and a kappa coefficient of 85.8%, were achieved suggesting that this record could be used to examine the spatial and temporal patterns of LULC change and assess the long-term hydrological impacts in this critical watershed.

SWAT

SWAT is a physically-based distributed hydrological model developed by the USDA-Agricultural Research Service (USDA-ARS) (Arnold et al., 1998; Neitsch et al., 2005; Arabi et al., 2007). It has been widely used to examine the hydrological impacts of LULC change on stream flow, sediment yield, and NPS pollution in various U.S. agencies (such as the EPA, NOAA, USDA), universities, and other global research institutes (Arnold et al., 1998; Fohrer et al., 2001; Gassman et al., 2007; Conaghan, 2010). SWAT operates with a wide range of scales with complex terrain features including varying soils, land use, and management conditions over a daily time-step. Different physical processes are simulated using corresponding models and parameters (Arnold et al., 1998; Neitsch et al., 1999; Weber et al., 2001; Setegn et al., 2010). The simulation of hydrological processes can be divided mainly into two phases, a land phase and a routing phase. The land phase controls the amount of water, sediments, nutrients, and pesticide loading to the main channel in each sub-watershed (Neitsch et al., 2005). The routing phase simulates the process of flows, sediment, and nutrient transported in the main channel to reach the outlet of the watershed. The hydrological cycle is simulated by SWAT based on the water balance equation.

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (2)$$

Where SW_t (mm) is the final soil water content, SW_0 (mm) is the initial soil water content, SW_0 (mm) is the initial soil water content, t (days) is the time, R_{day} (mm) is the amount of precipitation on day i, Q_{surf} (mm) is the amount of surface runoff on day i, E_a (mm) is the amount of evapotranspiration on day i, w_{seep} (mm) is the amount of water entering the vadose zone from the soil profile on day i, and Q_{gw} (mm) is the amount of return flow on day i (Neitsch et al., 2005). The major procedures in SWAT include watershed delineation, Hydrological Response Unit (HRU) analysis, weather data import, input parameters modification and input, and SWAT simulation.

SWAT requires a digital elevation model (DEM) to delineate the watershed, divide sub-watersheds, and calculate parameters for each sub-watershed such as slope and slope length (Jha et al., 2007). The 30-meter National Elevation Dataset (NED) DEM downloaded from USGS's National Map Seamless Server was used in this study to delineate the Little River Watershed into 31 sub-watersheds (Fig. 3-2B). The soil data was from the State Soil Geographic (STATSGO) Database downloaded from the Tennessee GIS Spatial Data Server (TNGIS) (Fig. 3-2C) (Appendix IV). Four meteorological stations close to the watershed including Gatlinburg 2 SW (403420), Knoxville Exp Station (404946), Knoxville McGhee Tyson Airport (404950), and Mt. Leconte (406328) (Table 3-1, Fig. 3-1) were used in SWAT simulation. Their daily precipitation and the maximum and minimum temperatures from 1984 to 2010 were downloaded from the National Climate Data Center (NCDC). The missing data in the precipitation and temperature records, as well as daily solar radiation, wind speed, and relative humidity, were generated automatically by SWAT (Jha et al., 2007). The stream flow data were collected from the USGS National Water Information System (NWIS) including two USGS stream gages, USGS 03498500 (Little River near Maryville) and USGS 03498850 (Little River above Alcoa), at the upper and lower portions of the watershed (Fig. 3-2D) (Table 3-2).

Model calibration and validation are necessary before using SWAT to simulate the stream flow and NPS pollution. The calibration and validation process includes a sensitivity analysis using the LH-OAT algorithm (Van Griensven et al., 2006; Wang et al., 2008; Setegn et al., 2009) to identify the most sensitive parameters such as the initial SCS CN II value (Cn2), the baseflow alpha factor (Alpha_Bf), the threshold water depth in the shallow aquifer for flow (Gwqmn), the soil evaporation compensation factor (Esco), the channel effective hydraulic conductivity (Ch_K2) representing surface runoff, groundwater, soil properties, and channel properties (Ghaffari et al., 2009) (Table 3-3). Nash-Sutcliffe efficiency (E_{ns}) and the regression coefficient (R^2) between the observed and simulated stream flow were used to assess the goodness of fit of SWAT in both calibration and validation. The Nash-Sutcliffe Efficiency (E_{ns}) was defined as (Nash & Sutcliffe, 1970):

$$E_{ns} = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2} \tag{3}$$

Where n is the number of observations during the simulated period, O_i is the observed value at each time step i, P_i is the predicted value at each time step i, $\overline{O}$ is the average observed value over the simulation period. E_{ns} indicates how well the plot of observed and predicted value fits the 1:1 line (Santhi et al., 2001). The value of 1.0 of E_{ns} represents a perfect match of model simulation while the value of 0 or below means the prediction result is unacceptable (Moriasi et al., 2007). The parameters with the most influence on stream flow were repeatedly adjusted until E_{ns} was >0.5 and R^2 was >0.6, which are the minimum acceptable calibration values suggested by some studies (Santhi et al., 2001).

Evaluation of the Long-term hydrological impacts of LULC change

After calibrating and validation, SWAT was run from 1984 to 2010 for each LULC map as the input to simulate stream flow and NPS pollution. The simulated output for year 1984 was used as the baseline to examine stream flow and NPS pollution variations in other years' LULC scenarios. The ratio of change can be calculated using the simulated value for a certain year to divide the simulated value of 1984 for each sub-watershed. The results were displayed using ArcGIS to illustrate the spatial pattern of stream flow and NPS pollution variations due to the LULC change and quantify the long term impacts of LULC change on stream flow and NPS pollution. Environmental sensitive areas at each sub-watershed corresponding to LULC change can be identified for further discussion.

3.4 Results

SWAT calibration and validation

We conducted the calibration and validation for two USGS stream gage stations (USGS 03498500 and USGS 03498850) from the upper and lower stream sections respectively. The reason to choose these two stations for the calibration and validation is because the upper portion of the watershed is dominated by forest, whereas the lower portion is mainly agricultural and urban. We used SWAT to simulate daily stream flow from January 1, 2009 to March 15, 2010 based on the land use map of 2010. The period from January 1 to October 9, 2009, was treated as a “warm up” period to stabilize the model. Simulated and observed stream flow data from October 10, 2009, to December 31, 2009, were used for calibration, and data from January 1 to March 15, 2010, were used for validation.

At the upper stream station (USGS 03498500), the summed simulated and observed stream flows during the calibration period were 28.68 and 29.14 cm, respectively. The best calibration we can achieve is E_{ns} of 0.847 and R^2 of 0.855. The total simulated and observed stream flows during the validation period were 24.81 and 26.15 cm, respectively, with an E_{ns} of 0.728, and R^2 of 0.733, indicating a good validation (Table 3-4, Fig. 3-3A, B, Appendix V-A, B). At the lower stream station (USGS 03498850), the total simulated and observed stream flows during the calibration period were 31.06 and 31.43 cm, respectively. We also achieved a good calibration with an E_{ns} of 0.838 and R^2 of 0.852. The total simulated and observed stream flows during the validation period were 27.94 and 29.03 cm, respectively with an E_{ns} of 0.712 and R^2 of 0.713, also suggesting a satisfactory validation (Table 3-4, Fig. 3-3C, D, Appendix V-C, D). The high E_{ns} and R^2 values in both the calibration and validation periods indicated that the SWAT with calibrated parameters can be used to simulate the stream flow of the watershed and quantify the long-term hydrological impacts of LULC change.

LULC change and its impact on stream flow

As discussed in Chapter 2, the Little River Watershed experienced obvious LULC change from 1984 to 2010. The increase in urban areas mainly occurred around the cities of Maryville and Alcoa due to the population growth in Blount County. Residential and commercial lands increased from 5.2% and 1.0% in 1984 to 8.3% and 2.8% in 2010, respectively. In contrast, agricultural land decreased from 28.3% in 1984 to 18.9% in 2010. Forest increased from 65.0% to 69.5% in this period due to the protection effort of the Great Smoky Mountain National Park, as well as the natural replacement of abandoned agricultural land by forest.

SWAT simulation suggested a total 3% stream flow increase from 1984 to 2010 for the whole watershed. The increase was relatively consistent through the whole period, except that it was more stable in 1991-1995 and rapid in 1984-1986 and 2008-2010 (Fig. 3-4A, Appendix VI). Bar charts in Fig. 3-5 illustrate a distinct spatial pattern of the stream flow increase rate for each sub-watershed in different years. Stream flows from sub-watersheds located within the GSMNP were relatively stable in 1984-2010, whereas >10% stream flow increase occurred at sub-watersheds around the cities of Maryville and Alcoa. Moderate stream flow increase (0.4 - 5.3%) also occurred in the middle and lower portions of the watershed where agricultural lands were converted to urban areas.

Regression analysis between stream flow and the percentage of urban areas from different years demonstrated a strong and positive relationship (R^2 =0.94, $P < 0.001$) (Fig. 3-6A). Although urban areas only account for a small percentage of the watershed (<12%), and a slight increase of forest may mitigate the streamflow increase effect, the stream flow increase in this watershed seems mainly driven by the expansion of urban areas, especially in the lower portion of the watershed.

Impacts on NPS pollutions

SWAT simulation also indicated considerable changes in NPS pollution from 1984 to 2010 due to the LULC change. Although modeled sediment load in 1989, 1993, and 2003, nitrogen in 1995, and phosphorus in 1991, 1995, and 2003 increased slightly, the overall trend of sediment, nitrogen, and phosphorus loads decreased from 1984 to 2010 (Appendix VII, VIII and IX). Using the simulation results of 1984 as the baseline, from 1984 to 2010, the sediment, nitrogen, and phosphorus loads decreased 34.59%, 10.35%, and 10.0%, respectively (Fig. 3-4B, C, and D). Spatially, the decrease in sediment, nitrogen, and phosphorus loads mainly occurred in the middle and lower portions of the watershed where agricultural lands were replaced by urban and forest (Fig. 3-7). Positive relationships ($R^2 > 0.9$, $P <0.001$) were obtained between each pollution load and the percentage of agricultural land from different years (Fig. 3-6B, C and D). Therefore, the decrease in agricultural land is probably related to the reduction of NPS pollution.

3.5 Discussion

SWAT simulation indicated that the overall stream flow increase was mainly driven by urban expansion especially in the lower portion of the Little River Watershed around the cities of Maryville and Alcoa. On the other hand, the slight increase in forest due to protection efforts of the Great Smoky Mountain National Park and the natural replacement of abandoned agricultural land appears to mitigate the increase effect of urban expansion. Therefore, the overall streamflow of the whole watershed only increased by a small amount (3%). SWAT simulation also suggested that decrease in NPS pollution is closely associated with the decrease in agricultural land. This decrease appears consistent with the report from TVA (2003) based on modeling results, which concluded that reductions in Total Suspended Solids (TSS), Total Nitrogen (TN), and Total Phosphorous (TP) loads from agriculture exceeded increases from urban areas. However, we hesitate to draw this as a firm conclusion because we did not perform the calibration and validation for NPS pollution due to a lack of observed data.

Simulated results of NPS pollution may also be problematic because of the limitations in SWAT and our simulation strategy. In this work, we simply used SWAT to simulate NPS pollution for different LULC scenarios of different years without the consideration of LULC transitional periods, such as construction phases of urban development. However, sediment and nutrient loads are mainly generated during construction phases and would be significantly reduced once the construction is completed. For example, several studies indicated that construction can increase the soil erosion rate up to 4,000 times more than the preconstruction rates (McClintock & Harbor, 1995; Harbor, 1999). From the model perspective, SWAT incorporated a Modified Universal Soil Loss Equation (MUSLE) to estimate sediment load generated from the watershed. However, it does not account for sediment generated from the streams (Neitsch et al., 2005). Stream bank erosion may provide a large contribution to total sediment budget but it is very difficult to estimate accurately. Recent studies by Harden et al. (2009, 2010) in the Little River pointed out the importance of bank erosion and the need to include it in total sediment load estimates. In addition, as a consequence of continuous urban expansion, the increase in stream flow and flash flooding may accelerate bank erosion and carry more sediment and nutrients into the streams. Therefore, SWAT simulations would more likely underestimate NPS pollution loads, especially the sediment component.

The LULC record may also introduce uncertainties in SWAT simulations. In particular, the LULC record used in this study does not differentiate cropland and grassland (pasture and hay fields) and SWAT treated them together as one LULC class (agricultural land). However, this treatment may introduce uncertainties because cropland and grassland may have different hydrological impacts especially on NPS pollution. Further studies to differentiate these two LULC classes would improve the simulation results.

3.6 Conclusions

In this paper, SWAT was applied to examine the long-term hydrological impact of LULC change in the Little River Watershed using a detailed LULC record with a roughly 2-year interval classified based on Landsat images from 1984 to 2010. The model was first calibrated and validated using observed stream flow data in 2010 and then simulated using different LULC scenarios in 1984-2010 to quantify the long-term hydrological impacts due to the LULC change. Model simulation results indicated just a 3% stream flow increase for the whole watershed from 1984 to 2010, but with a distinct spatial pattern. Almost no stream flow increase occurs in the upper portion of the watershed especially within the national park, whereas >10% stream flow increase was observed in the lower portion of the watershed, especially in areas close to cities. The increase in stream flow is probably driven by urban expansion, but the slight increase of forest mitigates the increase effect of urban development. SWAT simulations also suggested 34.6% sediment and about 10% nutrient (nitrogen and phosphorus) decrease from 1984 to 2010, seems closely related to the decrease in agricultural land. However, without calibration and validation, the simulation of the sediment load and nutrient may be problematic because SWAT mainly simulates the static status of LULC patterns, but LULC transitional periods, such as construction phases, actually generate more sediment and nutrient loads. In addition, the simulation also does not account sediment and nutrients generated from streams due to the bank erosion.

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Table 3-1
Four NCDC weather stations used in the SWAT model.

Stations	Name	Latitude	Longitude	Elevation	In service	County
403420	Gatlinburg 2 SW	35°41'N	83°32'W	443.2m	01 Aug 1948 to Present	Sevier
404946	Knoxville Exp Station	35°53'N	83°57'W	253.0m	01 Jan 1949 to Present	Knox
404950	Knoxville Mcghee Tyson Airport	35°49'N	83°59'W	293.2m	01 Jan 1893 to Present	Blount
406328	Mt Leconte	35°39'N	83°26'W	1979.1m	01 Jul 1987 to Present	Sevier

Table 3-2
Two USGS stream sites within the Little River Watershed.

Hydrologic Unit	Latitude	Longitude	Elevation (m)	Drainage (km^2)	Period	Cooperation
03498500	35°47'07.93"	83°53'04.93"	261	696.71	1951-Present	Maryville, TVA[a]
03498850	35°48'31.52"	83°55'36.03"	251	777	1986- Present	Alcoa

[a] TVA: Tennessee Valley Authority.

Table 3-3

List of top 5 parameters in sensitivity analysis and calibrated value for SWAT calibration.

Parameter	Description	Rank [a]	Rank [b]	Default	Lower Bound	Upper Bound	Method	Location	Calibrated value
Cn2(Forest)	Initial SCS CN II value	1st	2nd	36-79	-25%	25%	Multiplying initial parameter by value (%)	Management (.mgt)	27-59.25
Cn2(Agricultural land)				49-84					36.75-63
Alpha_Bf	Baseflow alpha factor (days)	2nd	1st	0.048	0	1	Replacement of initial parameter by value	Groundwater (.gw)	0.75
Gwqmn	Threshold water depth in the shallow aquifer for flow(mm)	3rd	3rd	0	0	1000	Replacement of initial parameter by value	Groundwater (.gw)	0
Esco	Soil evaporation compensation factor	4th	4th	0.95	0	1	Replacement of initial parameter by value	General data(.bsn)	0.3
Ch_K2	Channel effective hydraulic conductivity (mm/hr)	5th	5th	0	0	150	Replacement of initial parameter by value	Routing (.rte)	130

[a] rank for sensitivity analysis at USGS 03498500. [b] rank for sensitivity analysis at USGS 03498850.

Table 3-4

Daily calibration/validation results of two USGS stations.

Stations	Period	Simulated Mean (m^3/s)	Observed Mean (m^3/s)	E_{ns}	R^2	Re (%)
USGS 03498500	Calibration	28.68	29.14	0.847	0.856	1.56
	Validation	24.81	26.15	0.728	0.734	5.12
USGS 03498850	Calibration	31.06	31.43	0.838	0.852	1.19
	Validation	27.94	29.03	0.712	0.714	3.76

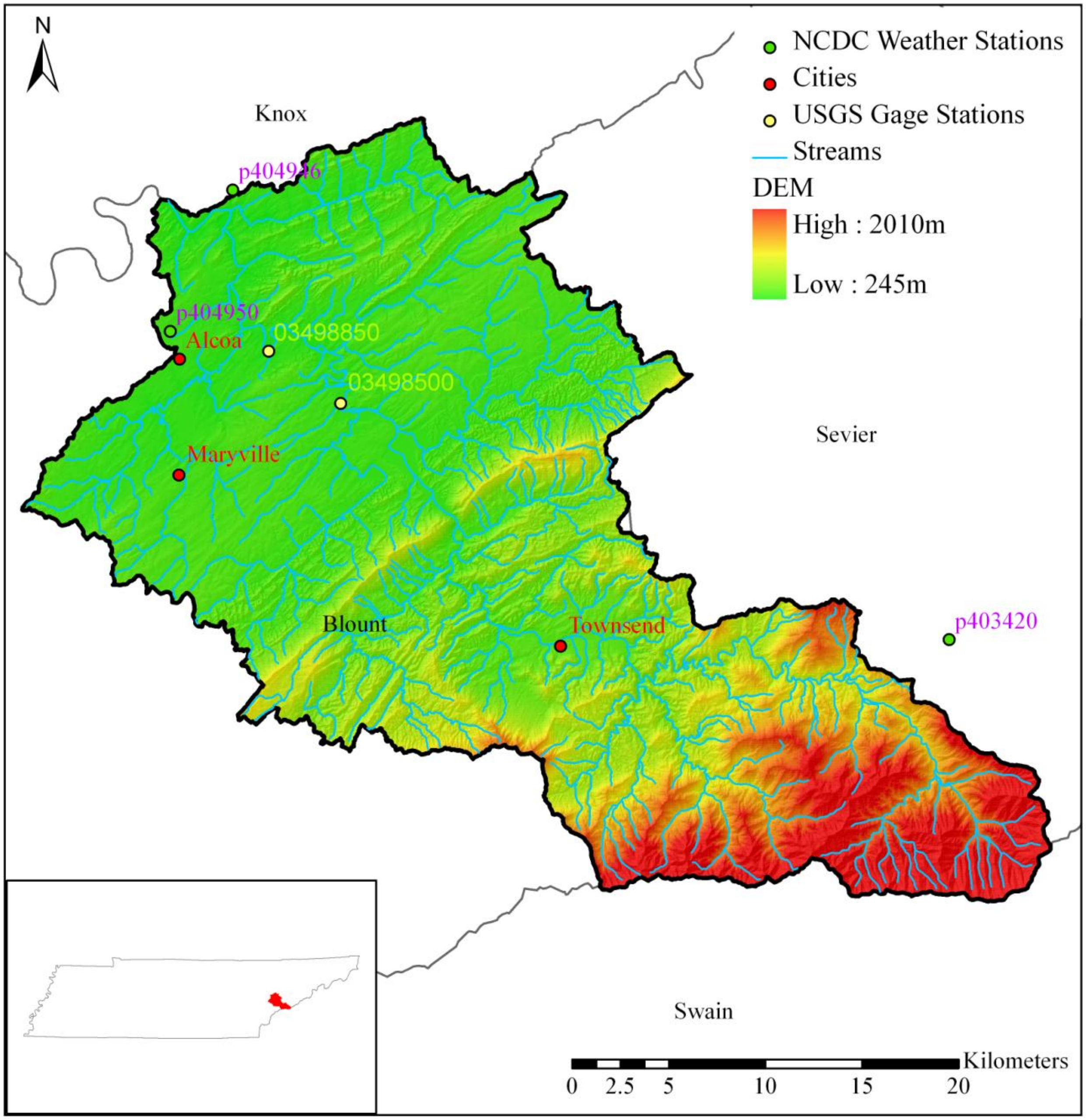

Fig. 3-1. Location of the Little River Watershed in Eastern Tennessee.

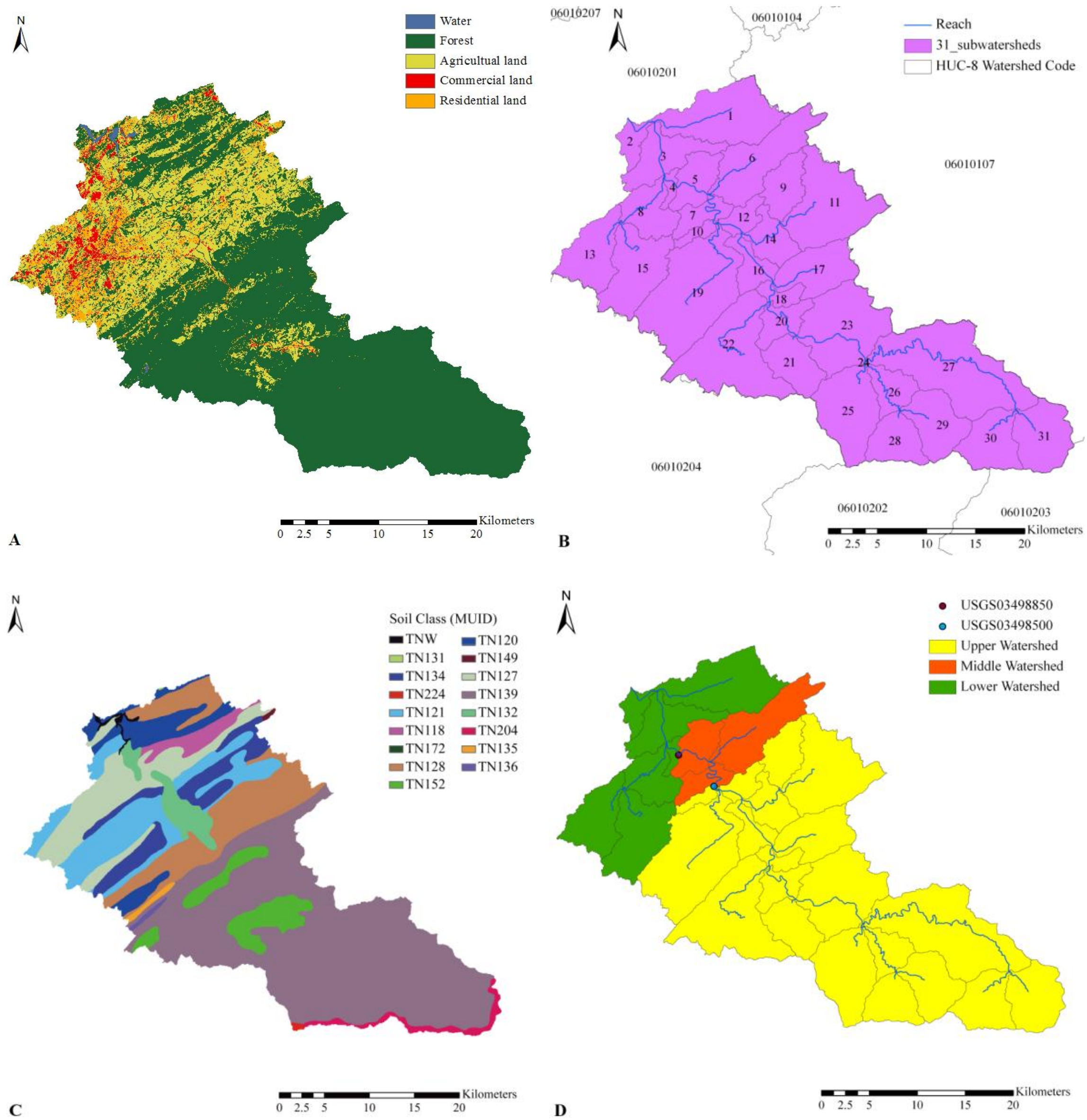

Fig. 3-2. (A) LULC classification of year 2010. (B) 31 Sub-Watersheds after Watershed Delineation. (C) State soil distribution for the Little River Watershed (STATSGO). (D) Upper, Middle and Lower portion of the Watershed.

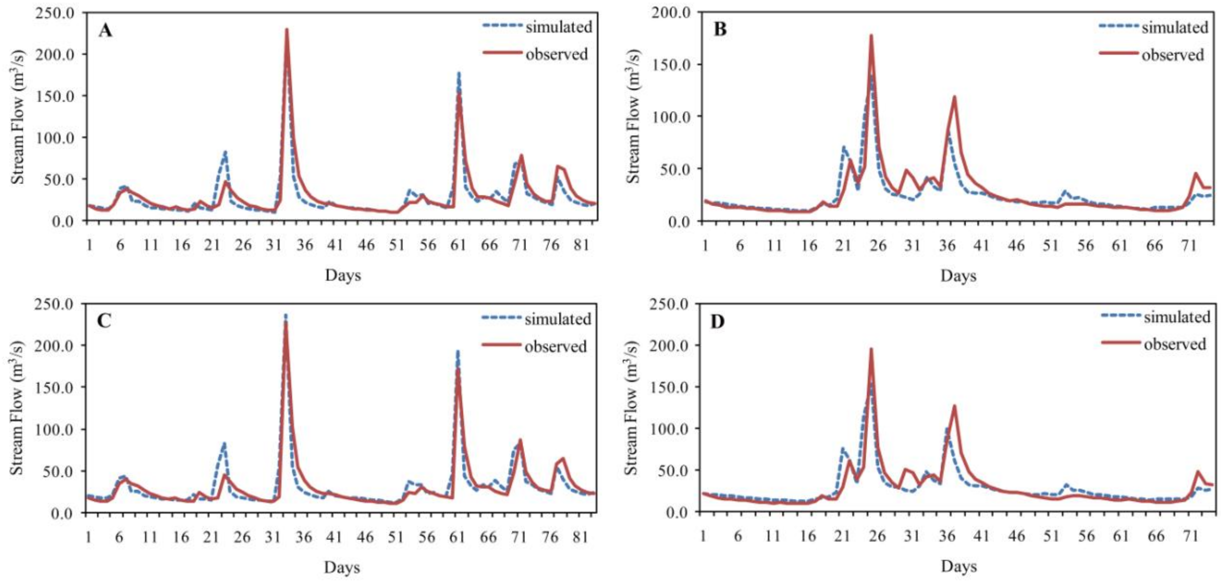

Fig. 3-3. (A) Comparison between simulated and observed stream flow in daily calibration for USGS 03498500. (B) Comparison between simulated and observed stream flow in daily validation USGS 03498500. (C) Comparison between simulated and observed stream flow in daily calibration for USGS 03498850. (D) Comparison between simulated and observed stream flow in daily validation for USGS 03498850.

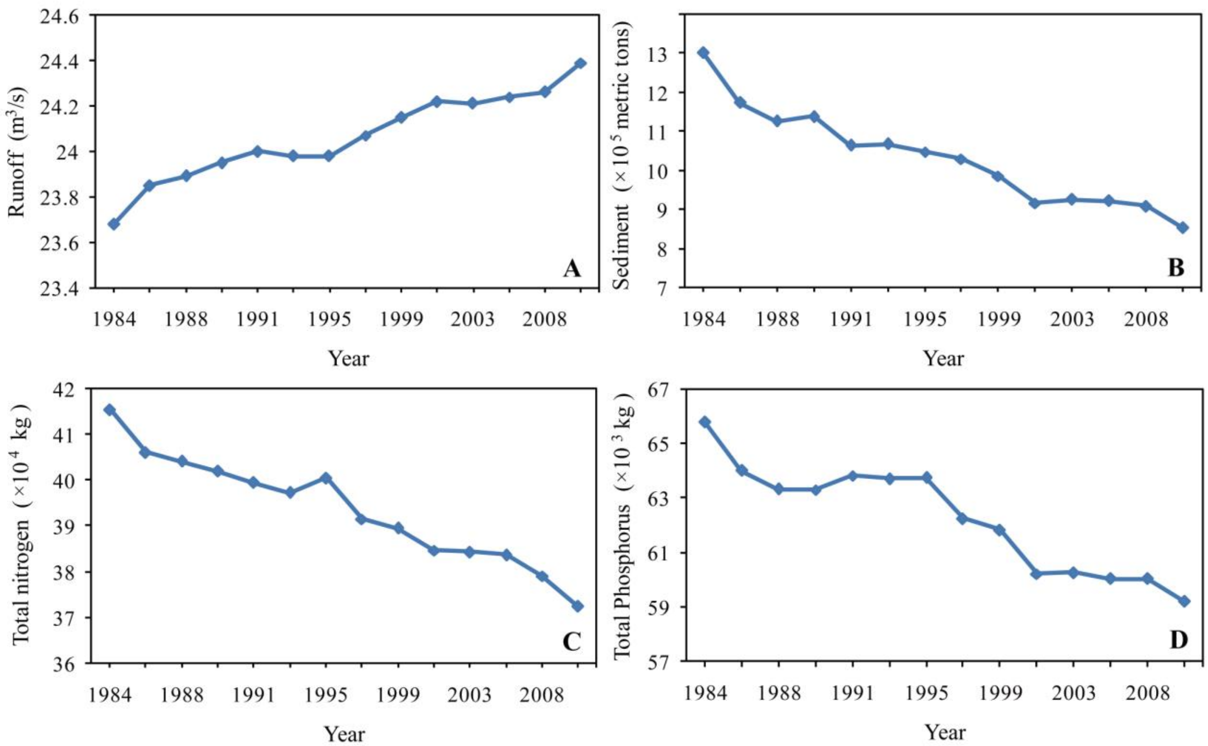

Fig. 3-4. (A) Stream flow modeled by SWAT of 14 years. (B) Sediment yield modeled by SWAT of 14 years. (C) Total nitrogen modeled by SWAT of 14 years. (D) Total phosphorus modeled by SWAT of 14 years.

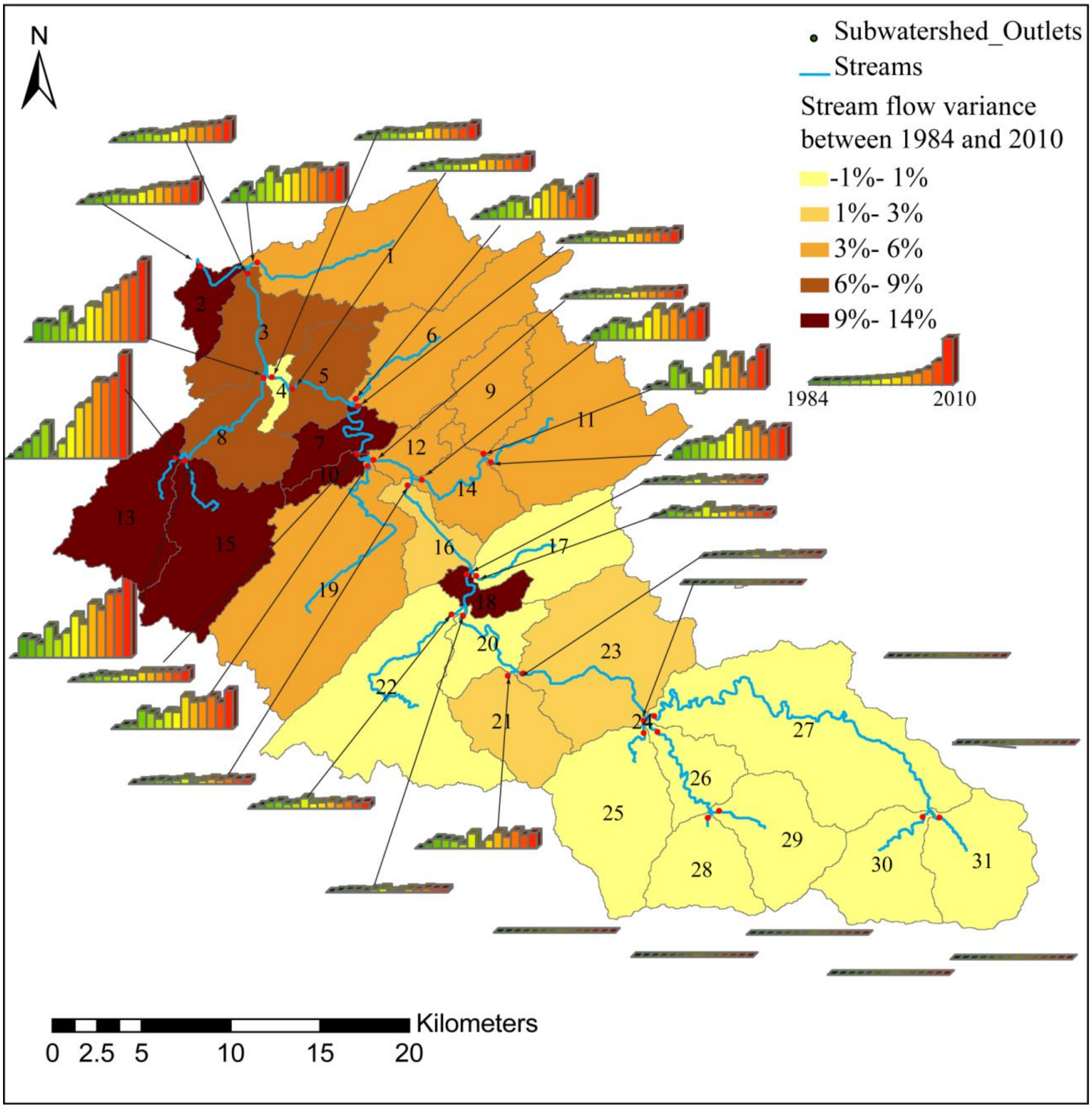

Fig. 3-5. Stream flow change rate of 14 years and comparison of year 1984 and 2010 at each sub-watershed outlet.

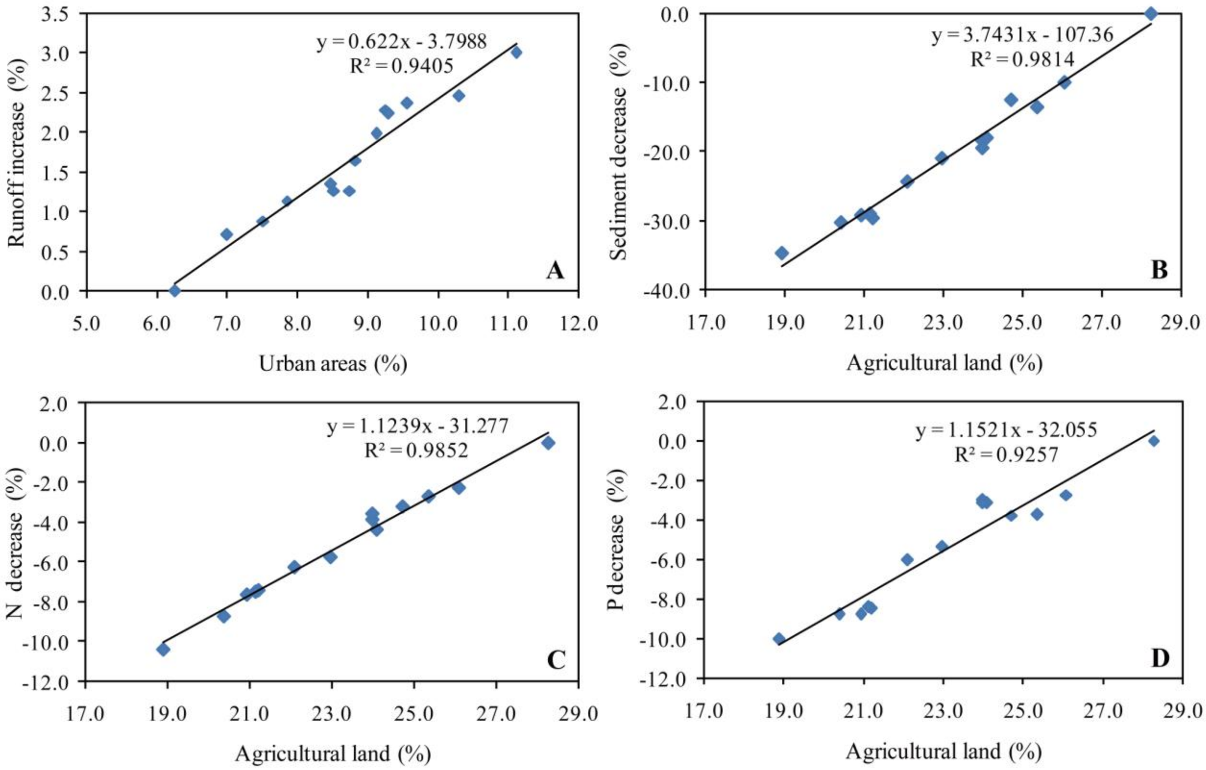

Fig. 3-6. (A) Relationship between stream flow increase and the percentage of urban areas. (B) Relationship between sediment yield decrease and the percentage of agricultural land. (C) Relationship between total nitrogen decrease and the percentage of agricultural land. (D) Relationship between total phosphorus decrease and the percentage of agricultural land.

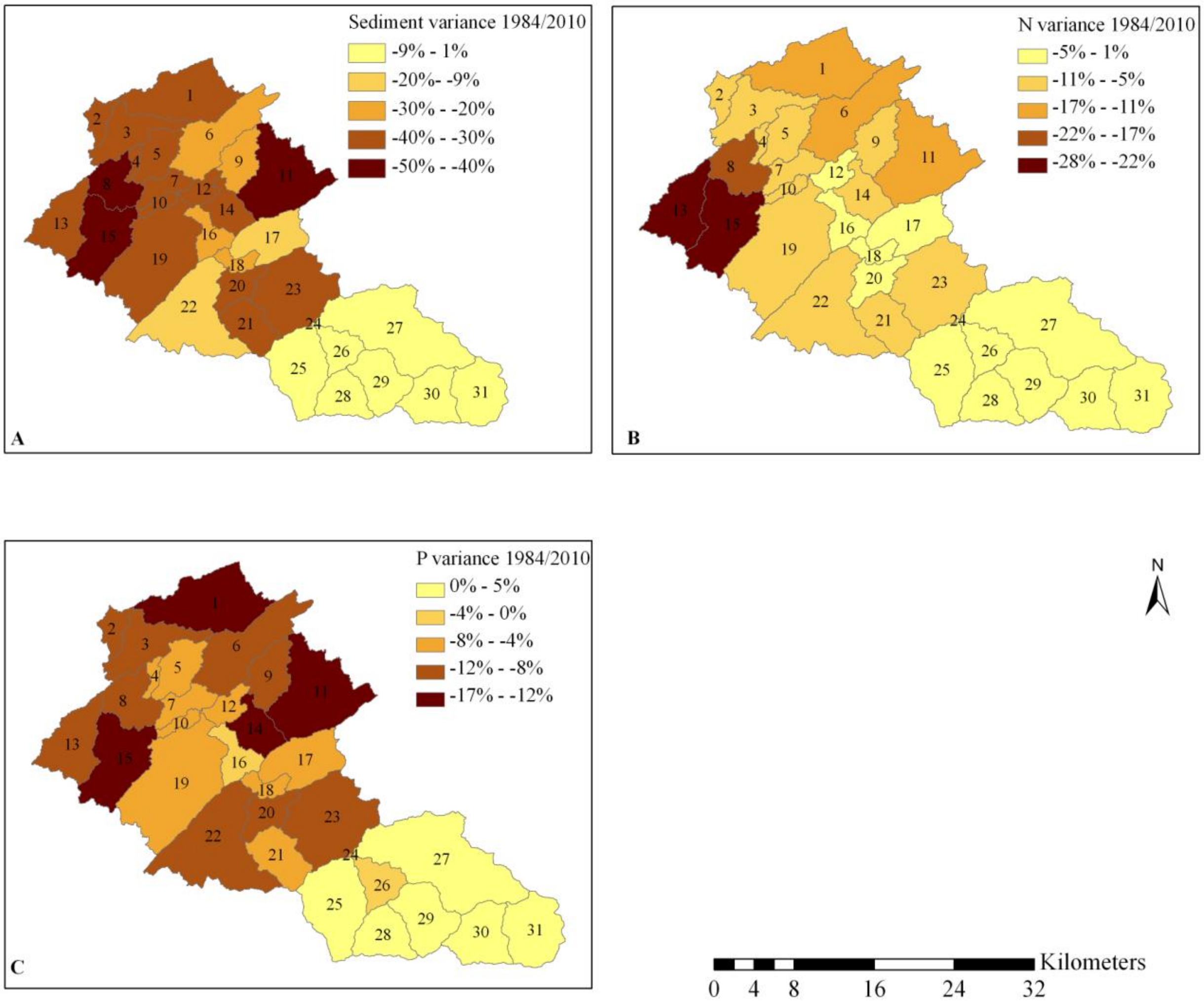

Fig. 3-7. (A) Comparison of sediment yield between year 1984 and 2010. (B) Comparison of total nitrogen (N) between year 1984 and 2010. (C) Comparison of total phosphorus (P) between year 1984 and 2010.

CHAPTER 4

SUMMARY AND CONCLUSIONS

4.1 Major Findings and Conclusions

The main goal of this thesis was to examine the long-term hydrological impact of land use/land cover (LULC) change from 1984 to 2010 in the Little River Watershed, Tennessee, and address two main limitations in previous studies: 1) the lack of detailed LULC records to detect LULC change; and 2) the lack of integration between hydrological modeling and remote sensing based LULC classification in assessing the long-term hydrological impacts of the LULC change.

First, free accessibility of Landsat images provides a reliable data source with which to examine the detailed LULC change and assess its long-term hydrological impact. For the Little River Watershed, this thesis composited a long-term detailed LULC record from 1984 to 2010 with a roughly 2-year time interval and examined the spatial and temporal patterns of LULC change in this watershed. The LULC classes for each year were classified based on the Maximum Likelihood Classification of Landsat TM/ETM+ images. The accuracy of the classification was assessed by comparing classified LULC classes with their corresponding classes identified from Google Earth high resolution imagery (representing "ground truth"). An overall accuracy of 89.7% and a kappa coefficient of 85.8% were achieved for the classification of 2010. Change detection of classified LULC maps indicated that urban areas (residential and commercial lands) and forest increased in 1984-2010 from 6.3 to 11.1% and from 65.0 to 69.5%, respectively. In contrast, agricultural land decreased from 28.3 to 18.9%. The increase in urban areas is consistent with the population increase in the watershed in recent decades, and the increase in forest is probably due to the natural conversion of abandoned agricultural land. This is the first detailed long-term LULC record in this critical watershed and would provide valuable information for local land use planning and management. In addition, this thesis also demonstrated that Google Earth high resolution imagery can be used as a reliable and proficient way to obtain "ground truth" information for the accuracy assessment of remote sensing classification. The Google Earth-based accuracy assessment method designed in this thesis has the potential to be used in other studies to assess the classification accuracy.

Second, this research developed an integrated approach for combining hydrological modeling with remote sensing classification to assess the long-term impacts of LULC change on stream flow and NPS pollution. In particular, the SWAT model, calibrated and validated using observed stream flow data in 2010, was integrated with the detailed LULC record classified using Landsat images to simulate the long-term hydrological impacts. Simulation results indicated an overall 3% stream flow increase for the whole watershed in 1984-2010, but with a distinct spatial pattern. Almost no stream flow increase occurred in the upper portion of the watershed especially within the national park due to the protection effort of the Great Smoky Mountains National Park, whereas >10% stream flow increase was observed in the lower portion of the watershed, especially in areas closed to cities. The increase in stream flow is probably caused by urban development, but the expansion of forest within the watershed might mitigate the effect of urban development. Model simulation also suggested 34.6% sediment load and about 10% nutrient (nitrogen and phosphorus) decrease in 1984-2010, possibly due to the decrease in agricultural land. Even though the simulation results of NPS pollution are probably problematic due to the lack of model calibration and validation, these findings and conclusions can provide useful information to assist decision making efforts of land use planning and water resource management. In addition, the integrated approach developed in this study can also be applied to other watersheds, particularly those that have experienced rapid LULC change.

4.2 Limitations

Even though significant efforts have been made to complete this study, several limitations still exist.

Remote sensing classification and LULC data

As discussed in Chapter 3, grouping grassland and cropland as one agricultural land class may introduce uncertainties in the SWAT simulation. One possible way to classify these two types is to utilize additional Landsat images of different seasons. Since grass and row crops have different growth periods, incorporating different season images may be able to classify these two LULC classes and improve the simulation results (Ralston, 2004). Another possible way is to use other classification algorithms such as Decision Tree. This Decision Tree algorithm recursively partitions the whole dataset into smaller datasets using different criteria until every single class is separated. It is organized using a tree structure and each branch has its own criterion. The Normalized Difference Vegetation Index (NDVI) or Normalized Difference Water Index (NDWI) may be used to differentiate grassland and cropland based on their different water contents.

Another challenge in LULC classification is urban areas, particularly residential land, due to the spatial resolution of the images. The resolution of Landsat TM/ETM+ images used in this study is 30 meters. At this resolution, some urban classes, especially residential land, are composed of a variety of ground surface features. Therefore, the spectral characteristics of these urban areas are mixed and more complex than homogeneous land use types such as water and forest. The spectral complexity of urban areas results in confusion between anthropogenic (roads, roofs, etc.) and natural materials (vegetation, bare soil, etc.), causing mis-classification and low classification accuracy (Herold et al., 2003). Using high-resolution imagery with spatial resolutions of 1 m or higher, such as IKNOS or QuickBird images, may improve the classification accuracy of urban areas (Jensen, 2005). Objective Oriented (OO) classification is commonly used and has a distinct advantage for classifying high resolution imagery because of the consideration of both object spatial context and spectral characteristics (Arroyo et al., 2006).

With the continuous development of high spatial and temporal resolution LULC products, the USDA Cropland Data Layer (CDL) can be used as a potential data resource for further studies, especially in rural regions. Now, all historical "agricultural specific" CDL products developed by the National Agricultural Statistics Service (NASS) are freely open to the public and include detailed annual classifications of agriculture and other land-use types back to 1997 (NASS, 2011). However, this research did not use this dataset because the spatial resolution of this product in this region before 2007 is too coarse for accurate SWAT simulations (based on visual interpretation).

SWAT modeling

During the calibration and validation of the SWAT model, stream flow variations were observed at two gaging stations from April to early October to have a weak response to precipitation events (Appendix X). We initially thought it is because of the irrigation activities. However, local experts said that no significant irrigation activities occurred in this period (Erich Henry, Director of Conservation, Blount County Government, personal email communication, April 2011). Further discussion indicated that a potential reason for water loss during this period was because of the karst topography. As we mentioned earlier, the bedrock in eastern Tennessee is mainly comprised of shale, limestone, and dolomite with well developed fault lines (Appendix XI) and karst topography, such as sink holes, closed depressions, caves, and subterranean drainage systems, are typical (USGS, 2011). Therefore, during winter months, water tables are relatively high and underground drainage systems are usually filled. In summer months, water tables are low and surface runoff may flow underground through caves and sinkholes, causing the weak response to precipitation events (Livingston L. Richard, Resource Soil Scientist for East Tennessee; Mark Whited, Executive Director, Little River Watershed Association, personal email communication).

In SWAT simulation, enough precipitation data with good quality are very important. This research used four weather stations with continuous weather records from 1984 to 2010. Only one station (COOP ID: 404950) is located within the watershed and all other stations are outside of the watershed. Other weather stations located within the watershed are available but had not been in service since 1962. Precipitation data from these four stations may not be able to provide an accurate representation for the whole watershed with large elevation variations. Therefore, limited weather data with its uneven spatial distribution may introduce uncertainties in the simulation.

As mentioned in Chapter 3, this thesis did not perform the calibration and validation for NPS pollution. The reason is due to the challenges in gathering water quality data in this watershed. The water quality data are widely distributed in EPA STORET (both the Legacy system and Modern system) and the USGS National Water Information System (NWIS) database. Part of the data are also stored by the Tennessee Department of Environment and Conservation (TDEC) (Contact Person: Linda Cartwright, Biologist, Division of Water Pollution Control, TDEC) and TVA. However, data from different sources are different in format and quality. Unclear identifications and mismatches among different data sources and poor documentation of these data make it is difficult to reorganize, reformat, and standardize the data (Burley, 2008; Thomas E. Burley, Texas Water Science Center, USGS, personal communication, 2010).

4.3 Suggestions for Future Research

This thesis focused on the application of remote sensing classification and hydrological modeling, so the modeling results can be used for land use planning and water resource management. However, this thesis did not investigate the response of the community or land owners to the LULC change and its related hydrological impacts. In this regard, one potential area of future research is to investigate the response of the community or land owners to gain a comprehensive understanding of the impacts of LULC change on water resources and how it influences the decision making of organizations, governments, and agencies at various levels to improve water quality.

I also plan to conduct some additional research in the Little River Watershed in the future. As part of initial research efforts, I completed an application for permission from the Institutional Review Board (IRB) to address three main questions related to LULC change and water quality degradation around Maryville and Alcoa: 1) By conducting a scalar analysis to examine power and cooperation relations in environmental organizations, more specifically, focusing on two main organizations as representatives (one at the federal/state level, and the other at the local level) to explore how organizations at different scales work together to mitigate water quality degradation due to LULC change, particularly in regard to urbanization; 2) In what ways can local organizations increase their decision-making influence and ability to affect government or agency policy making efforts at the top level by investigating their current policies and future plans? And 3) How to balance the relationship between the rapid urban development pressures stemming from rapid population growth in this region and water quality protection for urban planning departments. I have also obtained permission from the Executive Director of the Little River Watershed Association, Mark Whited, to volunteer for future activities and attended two seasonal meetings of the Little River Water Quality Forum (LRWQ) in March 2011 and June 2011. In these two meetings, many different local, state, and federal government agencies, community organizations, colleges, and universities met to discuss the current condition of this watershed and further cooperation. I already gathered some information through email communication with some experts in this watershed and by talking with local residents.

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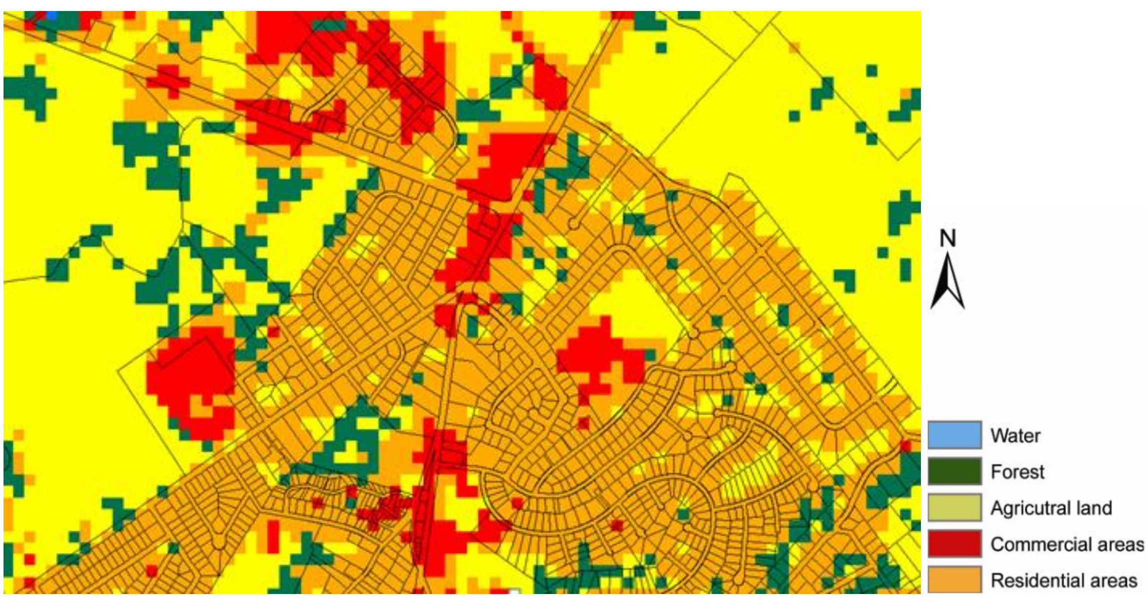
APPENDIX

Appendix I: LULC change from 1984 to 2010

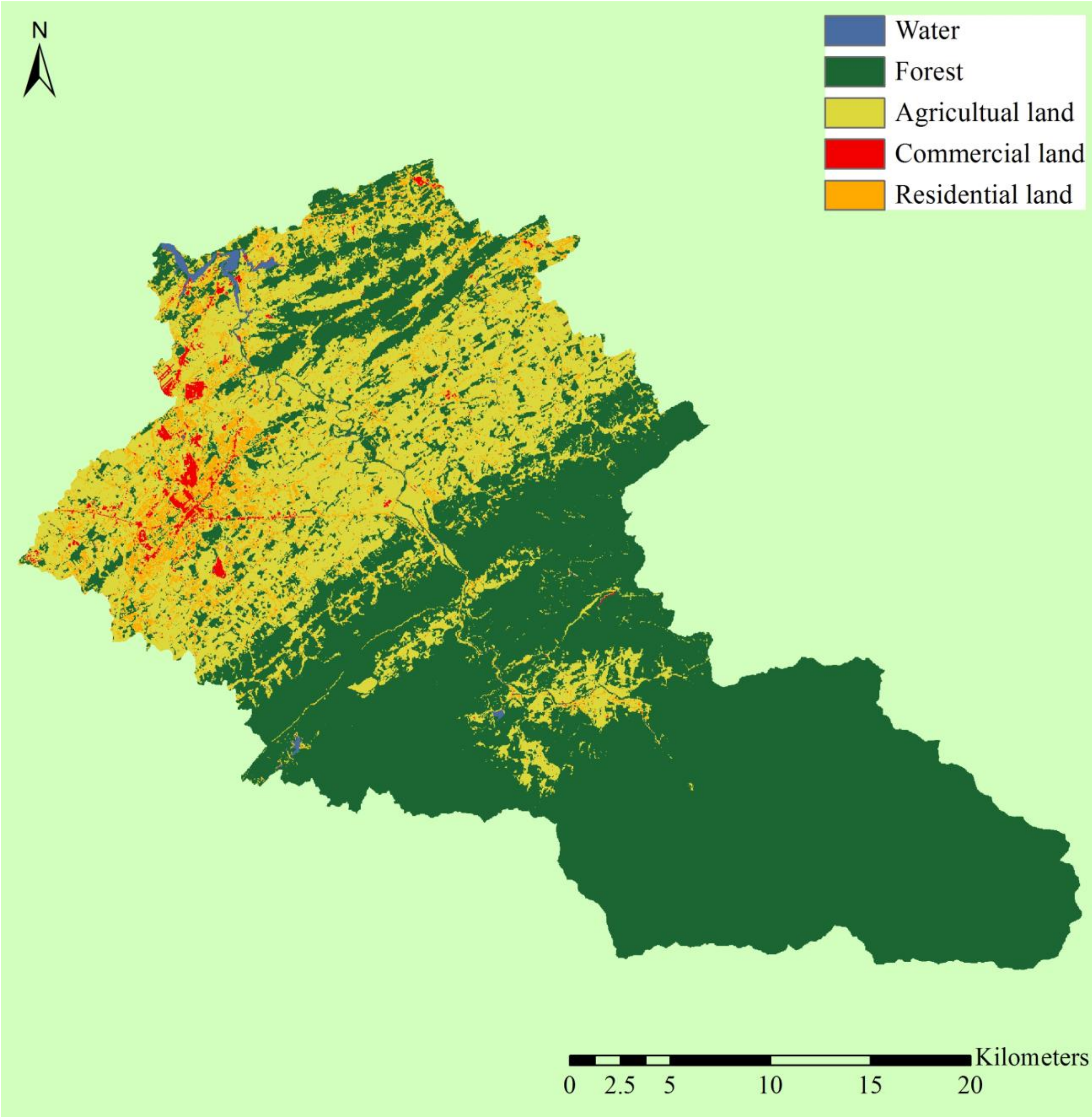
LULC	1984	1986	1988	1988	1991	1993	1995	1997	1999	2001	2003	2005	2008	2010
Water	0.5	0.4	0.5	0.5	0.4	0.5	0.4	0.5	0.5	0.5	0.6	0.5	0.5	0.5
Forest	65.0	66.5	66.7	67.0	67.1	67.0	66.8	67.7	68.3	69.1	69.0	69.0	68.8	69.5
Agricultural	28.3	26.1	25.4	24.7	24.0	24.1	24.0	23.0	22.1	21.2	21.1	20.9	20.4	18.9
Commercial	1.0	1.3	1.6	1.6	1.9	1.9	1.9	2.0	2.2	2.2	2.2	2.2	2.5	2.8
Residential	5.2	5.7	6.0	6.2	6.6	6.6	6.8	6.9	7.0	7.1	7.1	7.4	7.8	8.3
Urban[a]	6.3	7.0	7.5	7.9	8.5	8.5	8.7	8.8	9.1	9.3	9.3	9.6	10.3	11.1

[a] Urban areas include commercial and residential areas.

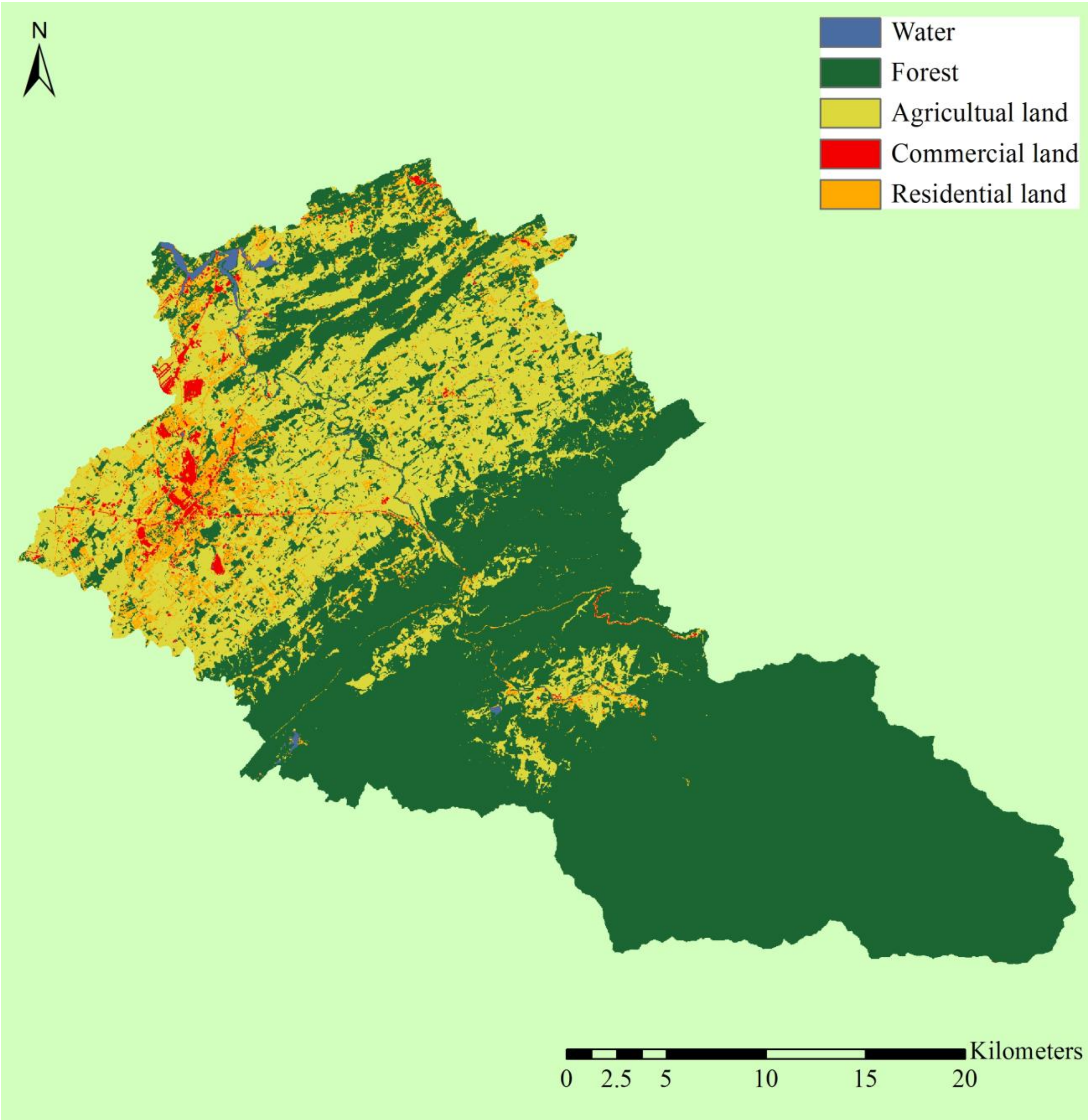
Appendix II: the LULC map of one residential area in 2008 overlaying with 2008 land parcel data from KUB(Knoxville Utilities Board)



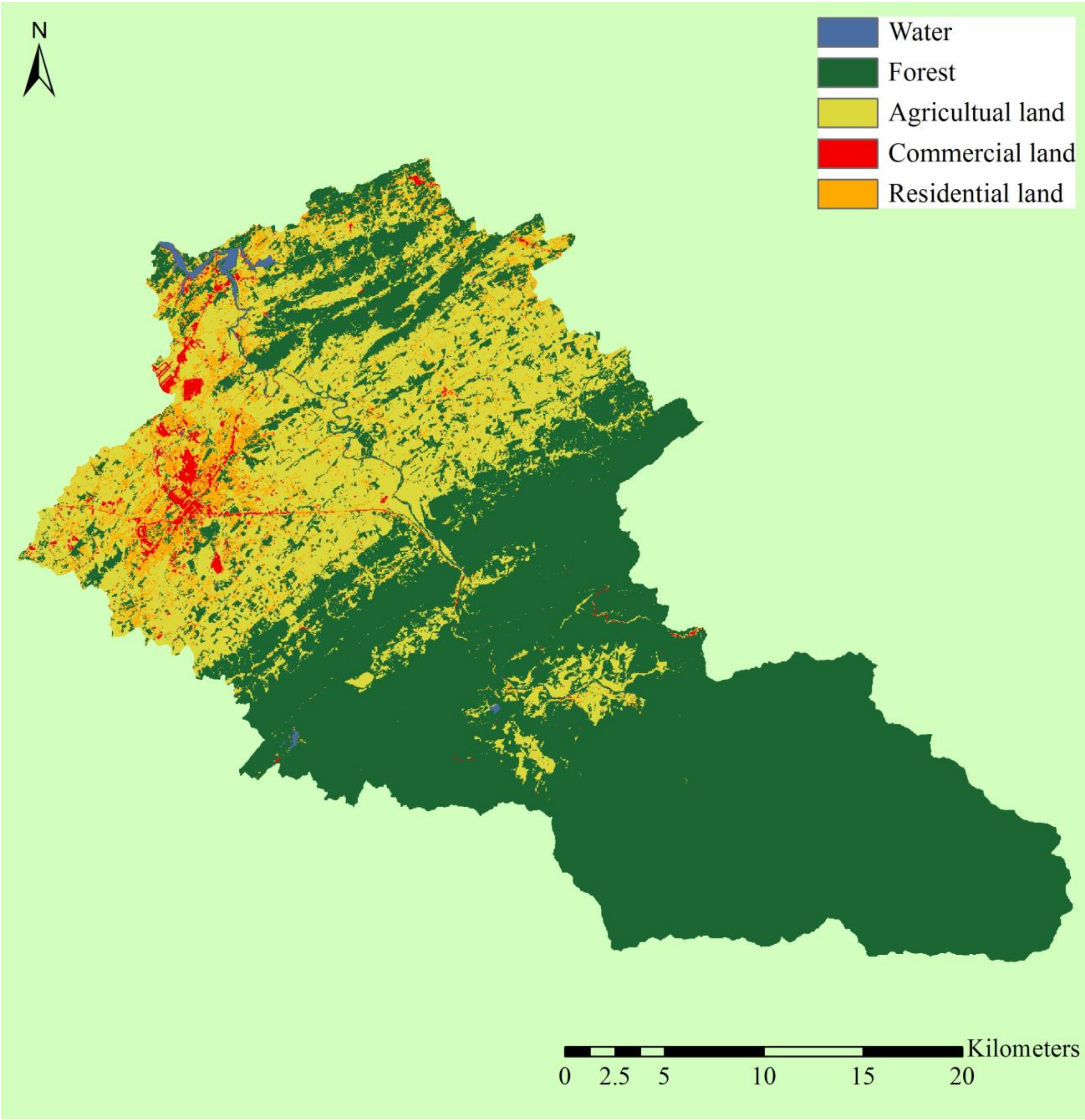
Appendix III: 14 years remote sensing classification results



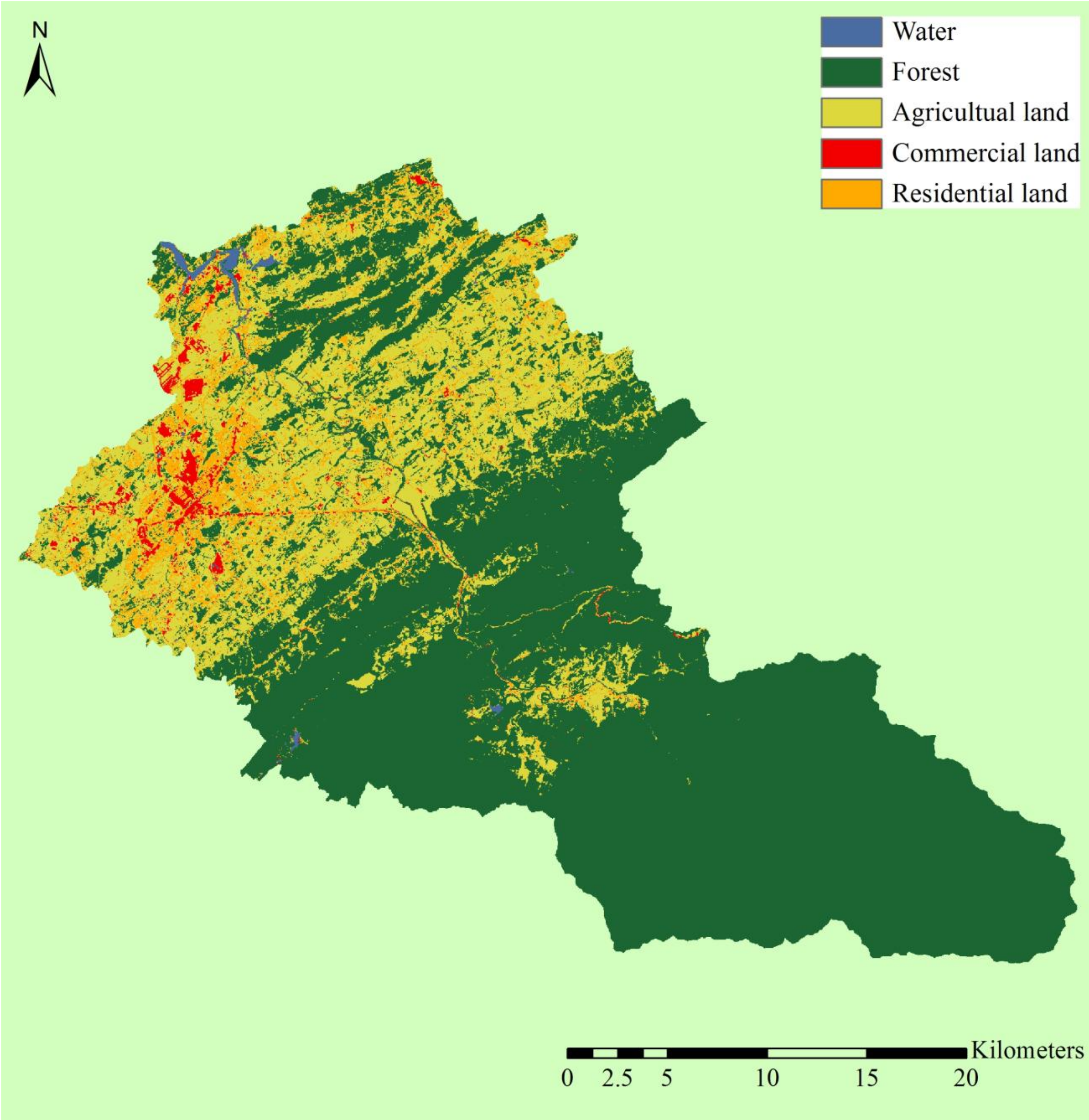
Remote sensing classification of year 1984.



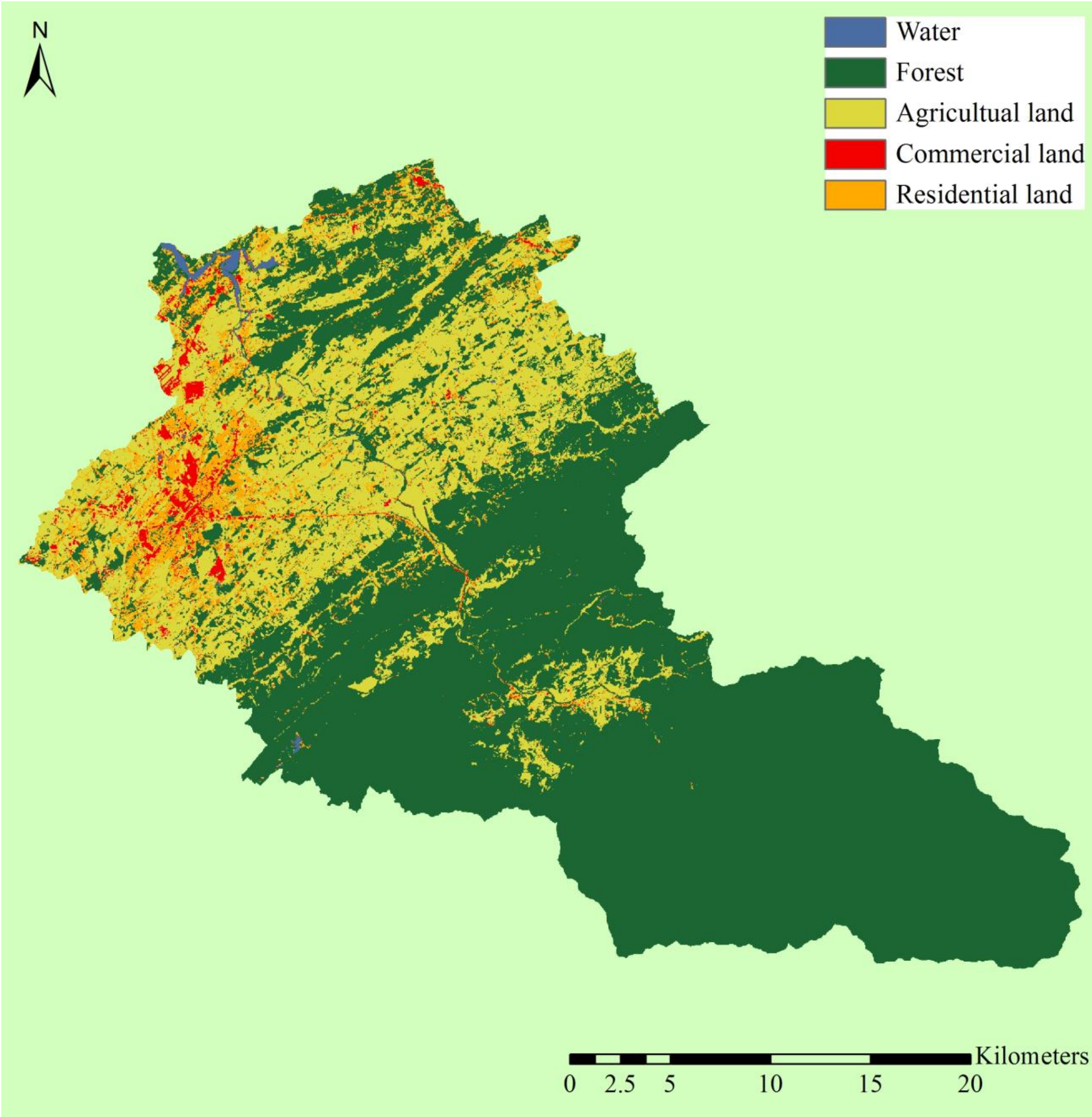
Remote sensing classification of year 1986.



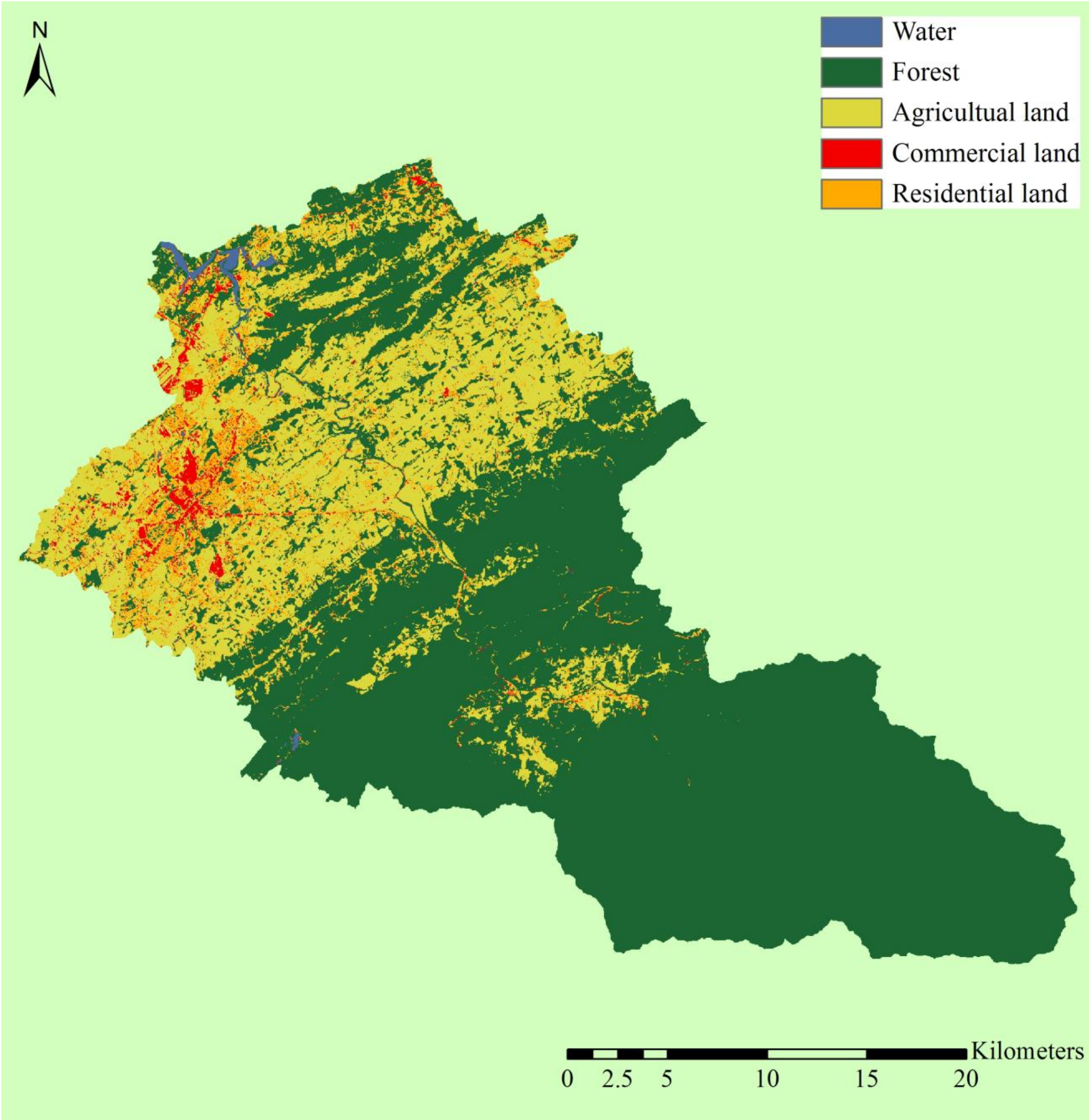
Remote sensing classification of year 1988.



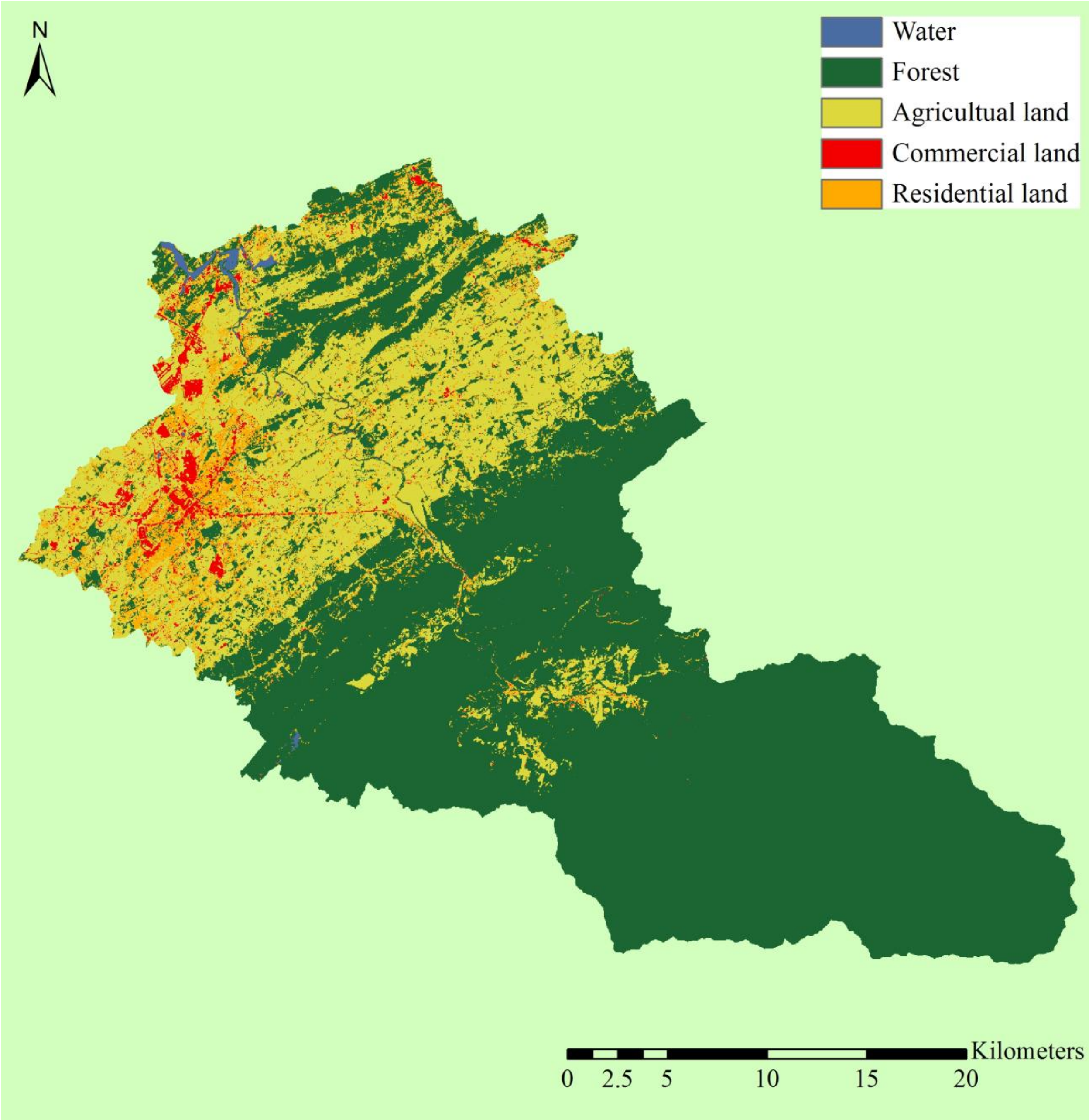
Remote sensing classification of year 1989.



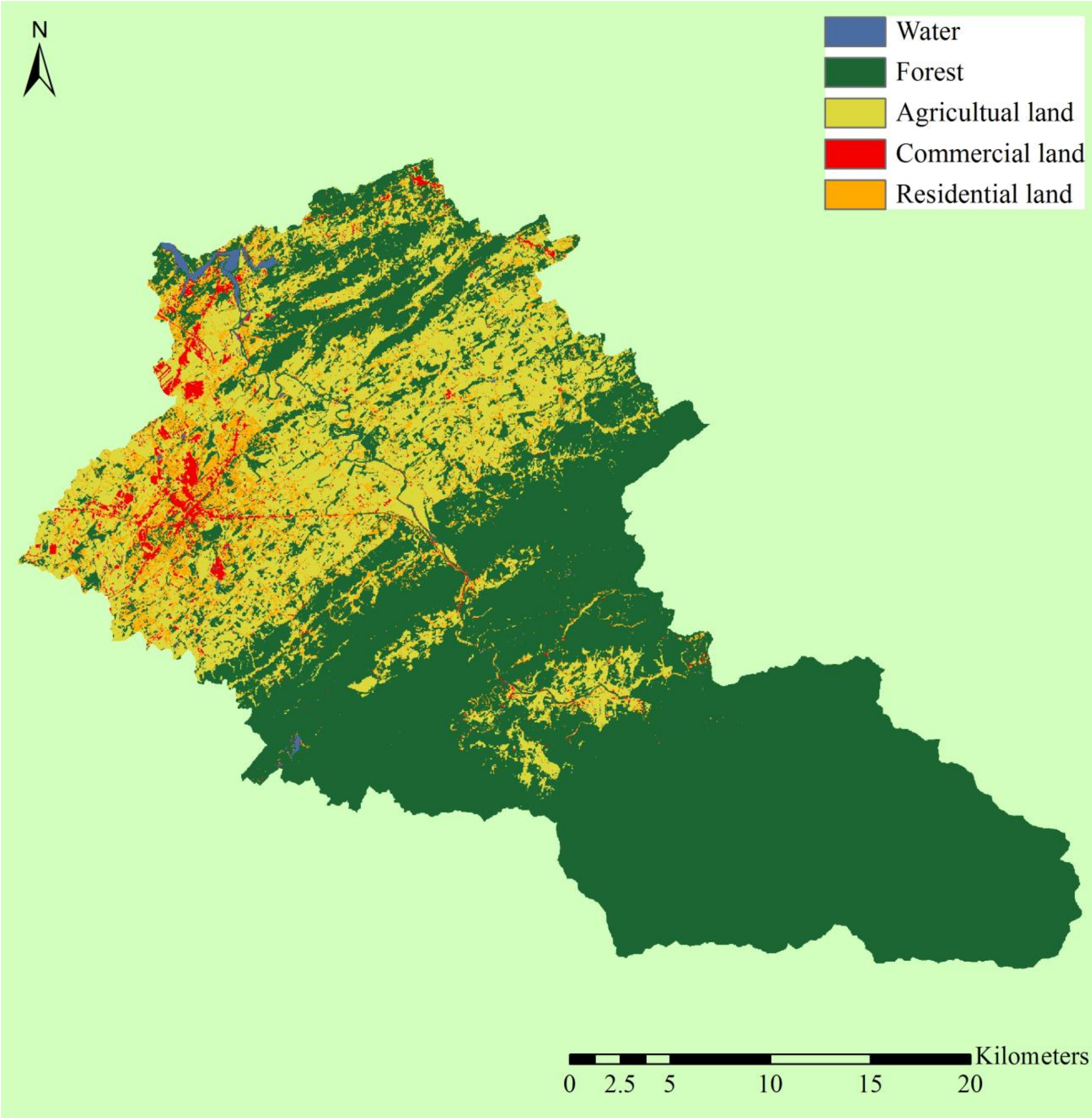
Remote sensing classification of year 1991.



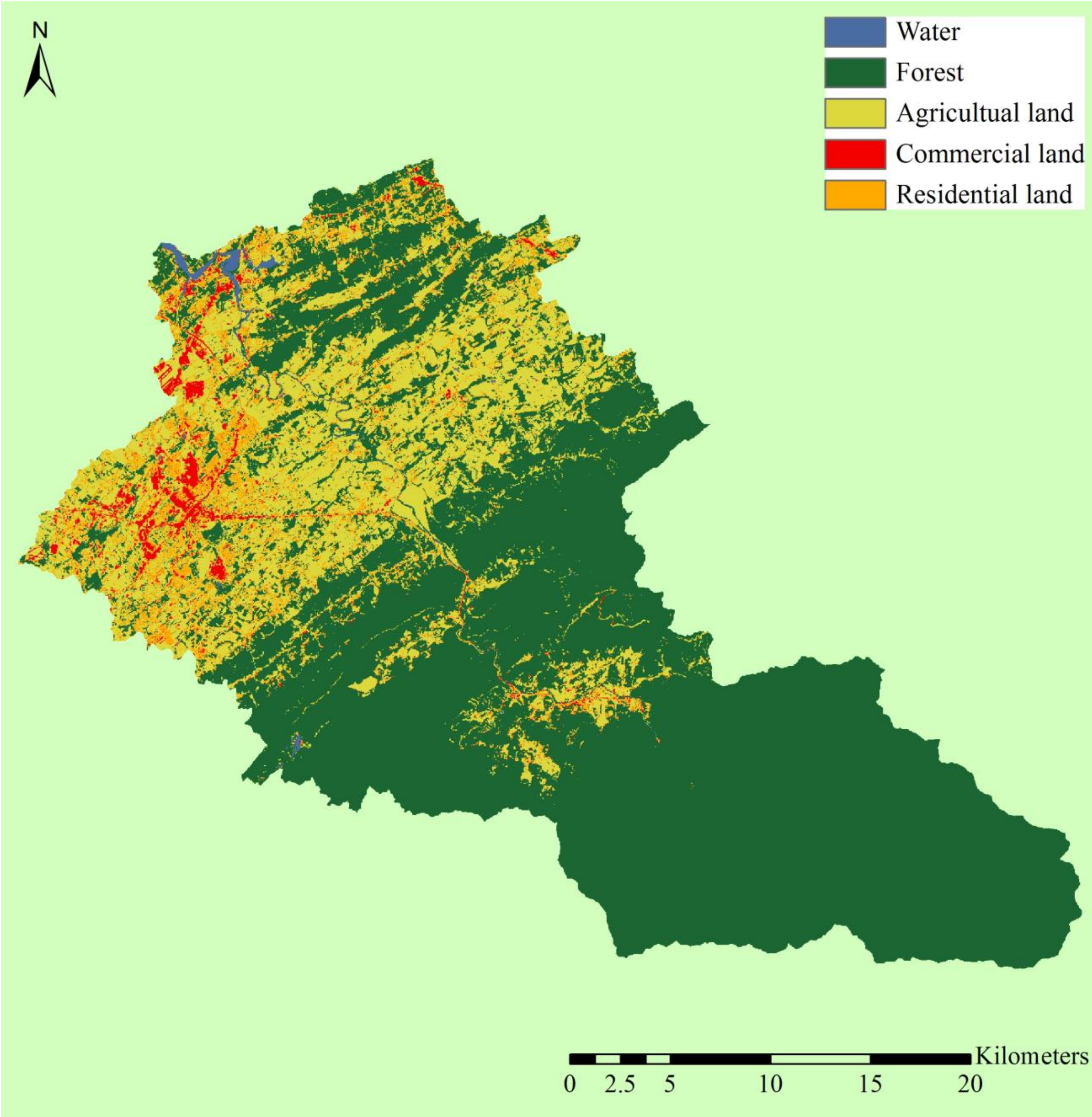
Remote sensing classification of year 1993.



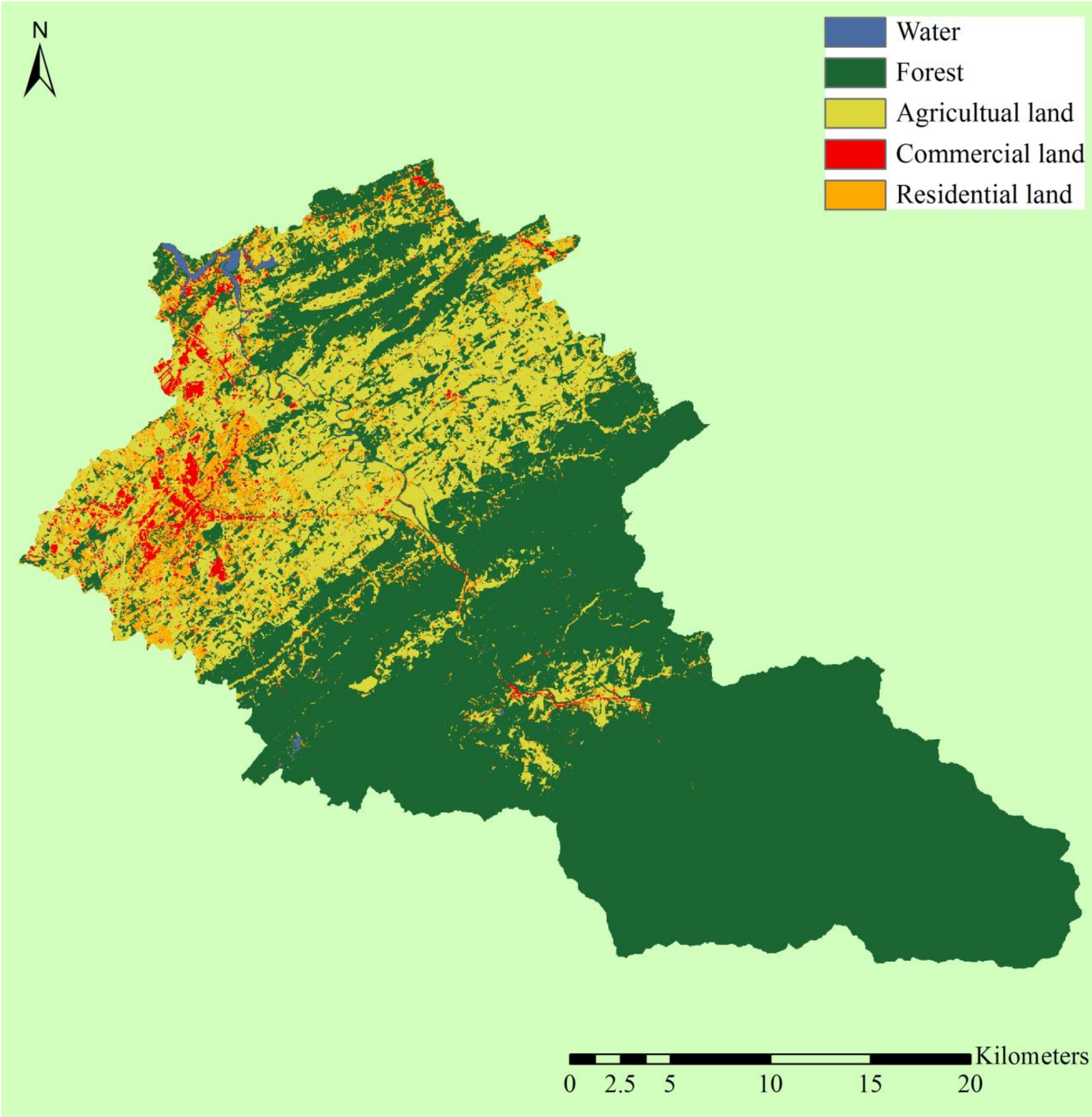
Remote sensing classification of year 1995.



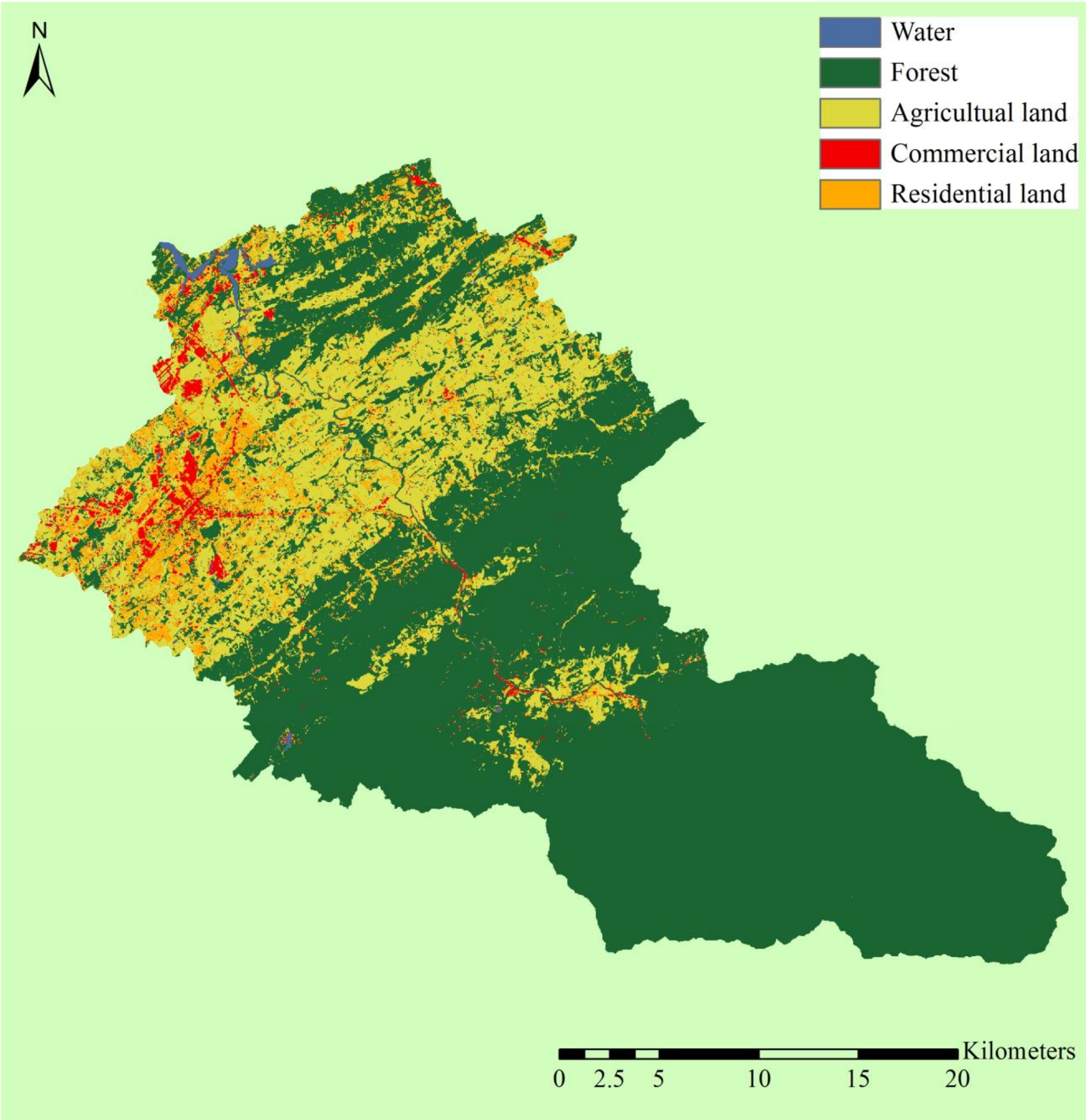
Remote sensing classification of year 1997.



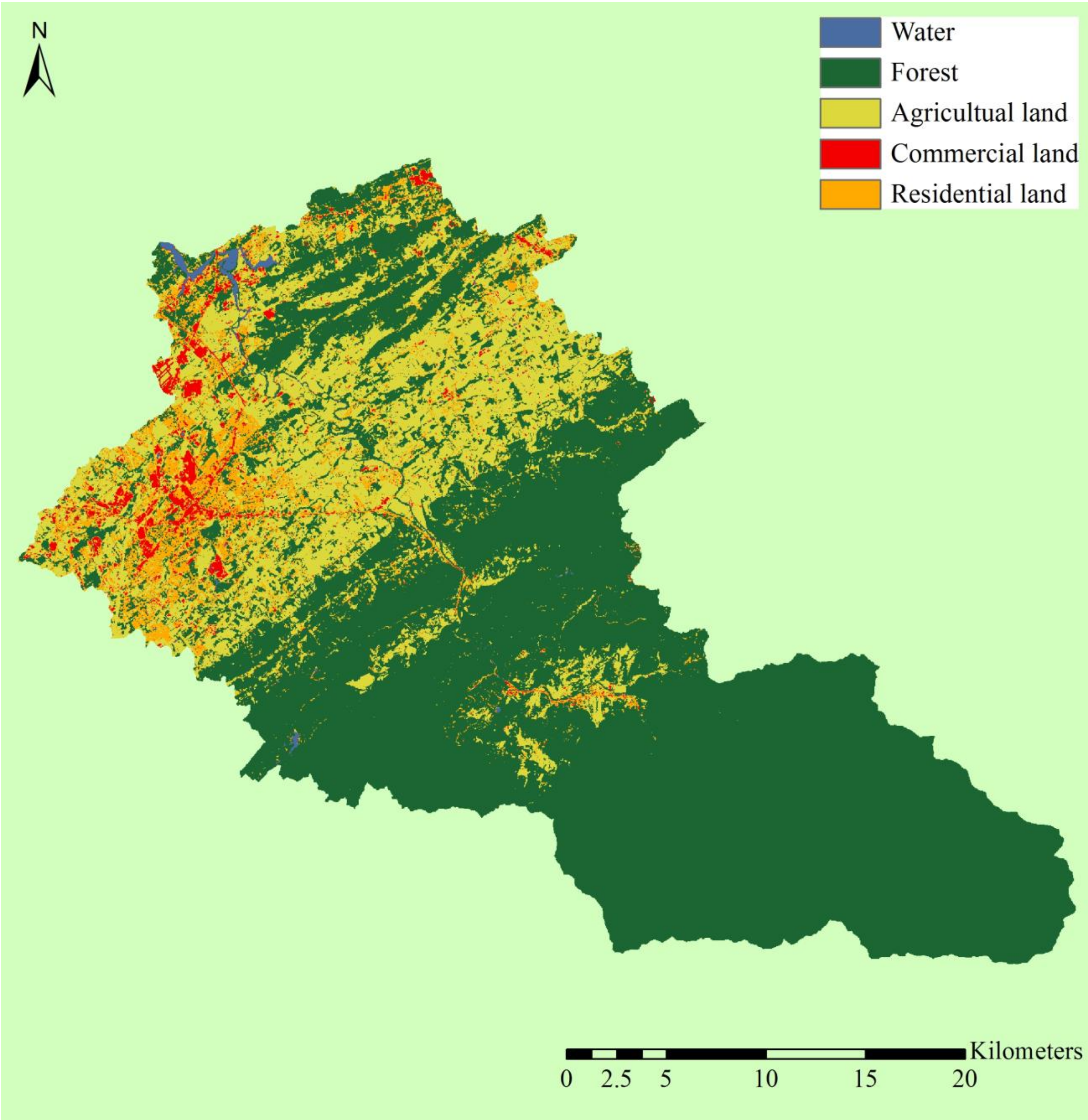
Remote sensing classification of year 1999.



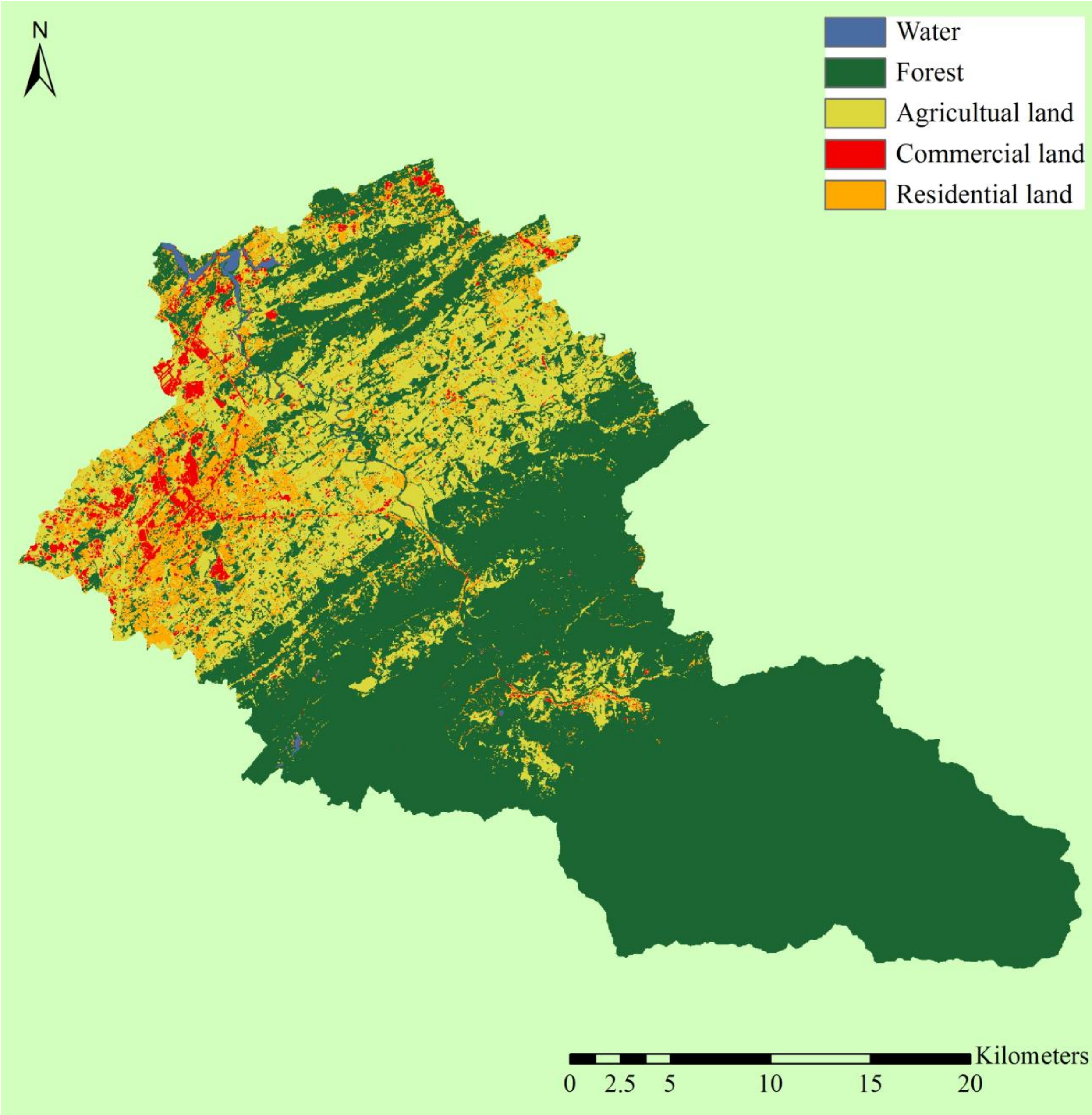
Remote sensing classification of year 2001.



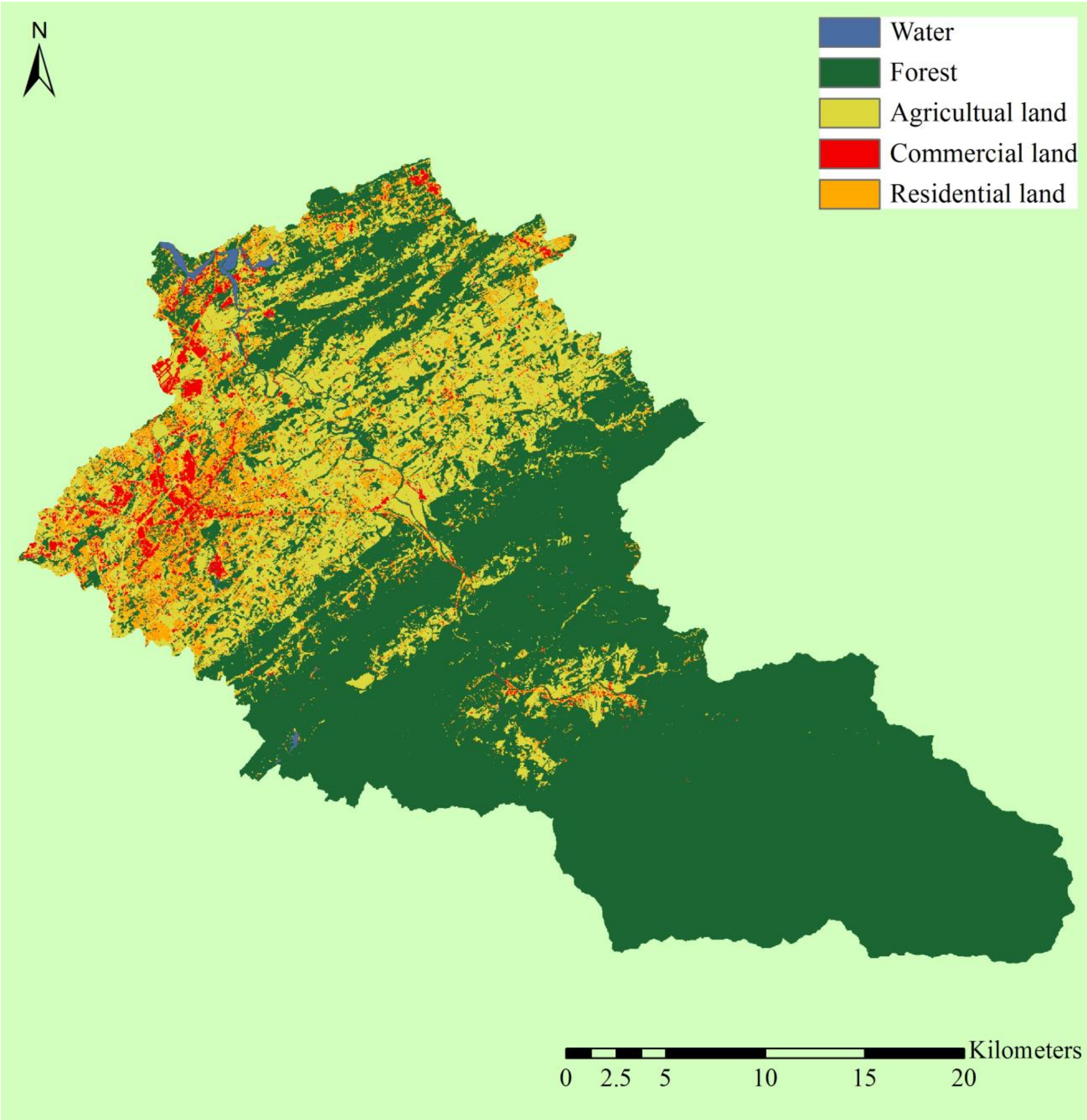
Remote sensing classification of year 2003.



Remote sensing classification of year 2005.



Remote sensing classification of year 2008.



Remote sensing classification of year 2010.

Appendix IV: Report from SWAT

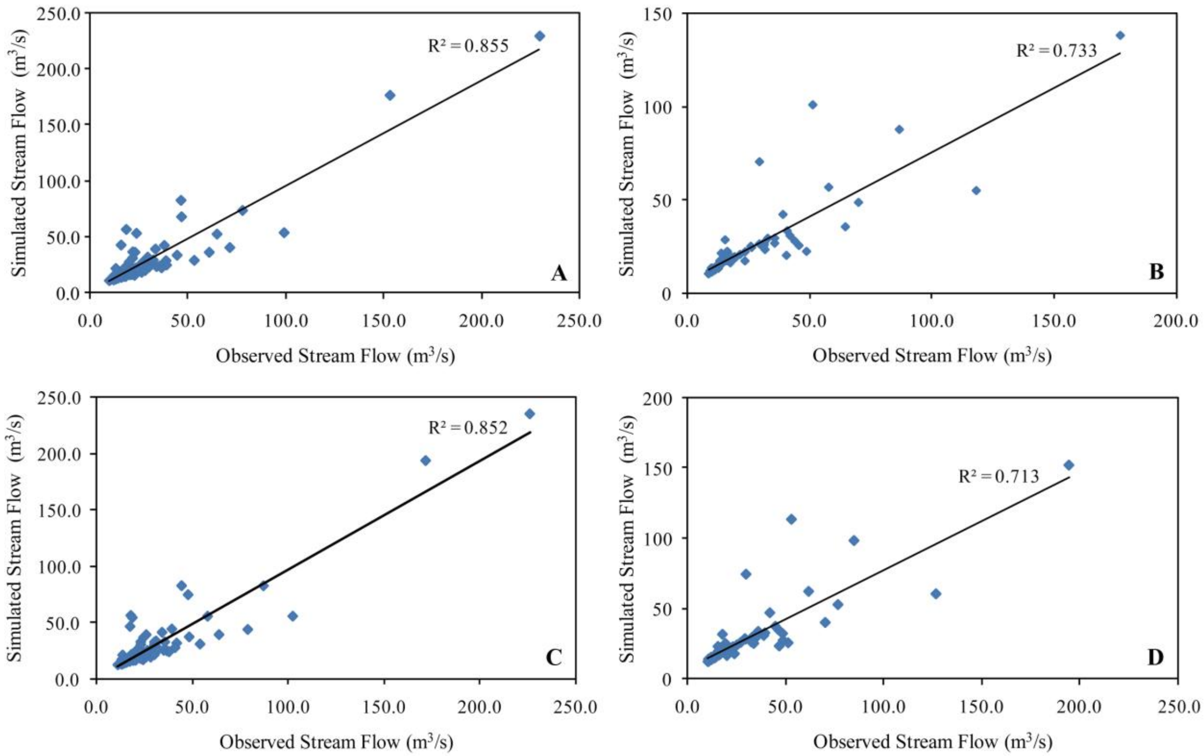
Detailed LANDUSE/SOIL/SLOPE distribution SWAT model class Date: 9/4/2011 12:00:00 AM Time: 17:57:56.6150000

	Area [ha]	Area [acres]
Watershed	97193.5400	240170.0971

Number of Subbasins: 31

	Area [ha]	Area [acres]	%Wat.Area
LANDUSE:			
Water --> WATR	435.4200	1075.9447	0.45
Forest-Mixed --> FRST	67636.3215	167132.7322	69.59
Winter Pasture --> WPAS	18398.4313	45463.4437	18.93
Commercial --> UCOM	2730.7253	6747.7587	2.81
Residential --> URBN	7992.6419	19750.2178	8.22
SOILS:			
TN118	1866.4141	4612.0025	1.92
TN120	4656.7053	11506.9517	4.79
TN121	10088.8968	24930.1685	10.38
TN127	8808.3089	21765.7717	9.06
TN128	11809.0962	29180.8671	12.15
TN131	11.2845	27.8845	0.01
TN132	2912.4861		
TN134	5370.6910	13271.2461	5.53
TN135	356.5092	880.9521	0.37
TN136	243.3419	601.3101	0.25
TN139	44050.6124	108851.2657	45.32
TN149	87.3339	215.8064	0.09
TN152	4942.4447	12213.0280	5.09
TN172	1.2091	2.9876	0.00
TN204	1546.4585	3821.3763	1.59
TN224	100.1901	247.5748	0.10
TNW	341.5573	844.0051	0.35
SLOPE:			
0-18.32	46099.0291	113913.0059	47.43
18.32-40.79	26037.7881	64340.6764	26.79
40.79-68.59	17852.8666	44115.3260	18.37
68.59-9999	7203.8562	17801.0888	7.41

Appendix V: Coefficient (R^2) and Regression for simulated and observed stream flow



(A) R^2 for simulated and observed stream flow in daily calibration for USGS 03498500. (B) R^2 for simulated and observed stream flow in daily validation for USGS 03498500. (C) R^2 for simulated and observed stream flow in daily calibration for USGS 03498850. (D) R^2 for simulated and observed stream flow in daily validation for USGS 03498850.

Appendix VI: Simulated Streamflow of 14 years at each sub-watershed outlet

ID	1984	1986	1988	1989	1991	1993	1995	1997	1999	2001	2003	2005	2008	2010
1	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
2	23.7	23.9	23.9	24.0	24.0	24.0	24.0	24.1	24.2	24.2	24.2	24.2	24.3	24.4
3	22.1	22.2	22.3	22.4	22.4	22.3	22.4	22.4	22.5	22.6	22.6	22.6	22.6	22.7
4	19.6	19.7	19.8	19.8	19.8	19.8	19.8	19.8	19.9	19.9	19.9	19.9	20.0	20.0
5	19.6	19.7	19.7	19.8	19.7	19.7	19.8	19.8	19.9	19.9	19.9	19.9	19.9	19.9
6	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
7	18.1	18.2	18.2	18.3	18.3	18.3	18.3	18.3	18.4	18.4	18.4	18.4	18.4	18.4
8	1.8	1.8	1.8	1.8	1.9	1.8	1.8	1.9	1.9	1.9	1.9	1.9	2.0	2.0
9	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
10	17.9	18.0	18.0	18.1	18.0	18.0	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.2
11	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
12	16.2	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.4	16.4	16.4	16.4	16.4	16.4
13	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
14	2.1	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
15	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9
16	13.9	13.9	14.0	14.0	14.0	14.0	14.0	13.9	14.0	14.0	14.0	14.0	14.0	14.0
17	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
18	12.9	12.9	13.0	13.0	13.0	13.0	13.0	12.9	13.0	13.0	13.0	13.0	13.0	13.0
19	1.6	1.6	1.6	1.7	1.6	1.6	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.7
20	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
21	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
22	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
23	10.2	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
24	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
25	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
26	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
27	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
28	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
29	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
30	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
31	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7

Unit: m^3/s (cubic meter per second).

Appendix VII: Simulated Sediment yield of 14 years at each sub-watershed outlet

ID	1984	1986	1988	1989	1991	1993	1995	1997	1999	2001	2003	2005	2008	2010
1	1.5E+05	1.4E+05	1.3E+05	1.4E+05	1.2E+05	1.1E+05	1.2E+05	1.1E+05	1.1E+05	9.3E+04	9.4E+04	9.9E+04	1.0E+05	9.3E+04
2	1.3E+06	1.2E+06	1.1E+06	1.1E+06	1.1E+06	1.1E+06	1.0E+06	1.0E+06	9.9E+05	9.2E+05	9.3E+05	9.2E+05	9.1E+05	8.5E+05
3	1.2E+06	1.0E+06	1.0E+06	1.0E+06	9.6E+05	9.7E+05	9.4E+05	9.3E+05	8.8E+05	8.3E+05	8.4E+05	8.3E+05	8.2E+05	7.7E+05
4	9.4E+05	8.5E+05	8.2E+05	8.0E+05	7.8E+05	7.7E+05	7.4E+05	7.6E+05	7.0E+05	6.7E+05	6.8E+05	6.9E+05	6.7E+05	6.5E+05
5	9.4E+05	8.5E+05	8.2E+05	8.0E+05	7.8E+05	7.7E+05	7.5E+05	7.6E+05	7.0E+05	6.8E+05	6.8E+05	6.9E+05	6.8E+05	6.5E+05
6	1.7E+05	1.7E+05	1.6E+05	1.6E+05	1.5E+05	1.5E+05	1.6E+05	1.5E+05	1.4E+05	1.4E+05	1.4E+05	1.5E+05	1.4E+05	1.3E+05
7	7.3E+05	6.5E+05	6.2E+05	6.1E+05	6.0E+05	5.9E+05	5.5E+05	5.8E+05	5.3E+05	5.1E+05	5.1E+05	5.1E+05	5.1E+05	4.9E+05
8	2.0E+05	1.8E+05	1.8E+05	1.9E+05	1.7E+05	1.9E+05	1.8E+05	1.7E+05	1.7E+05	1.5E+05	1.5E+05	1.4E+05	1.3E+05	1.2E+05
9	6.7E+04	6.7E+04	6.5E+04	6.1E+04	6.1E+04	6.5E+04	6.5E+04	6.2E+04	5.5E+04	5.9E+04	5.5E+04	6.2E+04	5.8E+04	5.4E+04
10	7.2E+05	6.4E+05	6.1E+05	6.0E+05	5.9E+05	5.8E+05	5.3E+05	5.7E+05	5.2E+05	5.0E+05	4.9E+05	5.0E+05	5.0E+05	4.8E+05
11	2.2E+05	1.9E+05	1.6E+05	1.7E+05	1.6E+05	1.5E+05	1.4E+05	1.4E+05	1.1E+05	1.2E+05	1.1E+05	1.2E+05	1.2E+05	1.2E+05
12	5.4E+05	4.6E+05	4.4E+05	4.4E+05	4.3E+05	4.2E+05	3.8E+05	4.1E+05	3.9E+05	3.6E+05	3.5E+05	3.7E+05	3.6E+05	3.6E+05
13	8.7E+04	8.5E+04	8.0E+04	8.3E+04	7.3E+04	9.0E+04	8.3E+04	8.1E+04	7.3E+04	6.9E+04	6.4E+04	6.2E+04	6.2E+04	5.4E+04
14	3.1E+05	2.7E+05	2.5E+05	2.5E+05	2.4E+05	2.4E+05	2.2E+05	2.2E+05	1.9E+05	1.9E+05	1.8E+05	2.0E+05	1.9E+05	1.9E+05
15	8.7E+04	7.7E+04	7.8E+04	8.0E+04	6.9E+04	7.8E+04	7.1E+04	6.6E+04	6.9E+04	5.7E+04	6.1E+04	5.2E+04	4.8E+04	4.3E+04
16	2.2E+05	1.7E+05	1.7E+05	1.8E+05	1.8E+05	1.6E+05	1.5E+05	1.7E+05	1.8E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05
17	2.0E+04	1.7E+04	1.6E+04	1.6E+04	1.6E+04	1.6E+04	1.5E+04	1.6E+04	1.6E+04	1.6E+04	1.6E+04	1.6E+04	1.6E+04	1.8E+04
18	1.8E+05	1.4E+05	1.3E+05	1.4E+05	1.5E+05	1.3E+05	1.2E+05	1.4E+05	1.5E+05	1.2E+05	1.3E+05	1.2E+05	1.2E+05	1.3E+05
19	1.7E+05	1.6E+05	1.6E+05	1.5E+05	1.5E+05	1.5E+05	1.4E+05	1.5E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.2E+05
20	1.3E+05	9.8E+04	8.9E+04	1.0E+05	1.0E+05	8.8E+04	7.9E+04	1.0E+05	1.1E+05	8.1E+04	8.4E+04	7.5E+04	7.9E+04	8.2E+04
21	2.0E+04	1.6E+04	1.4E+04	1.5E+04	1.5E+04	1.8E+04	1.4E+04	2.1E+04	2.1E+04	1.2E+04	1.4E+04	1.1E+04	1.4E+04	1.2E+04
22	4.8E+04	4.2E+04	4.0E+04	4.0E+04	4.2E+04	4.0E+04	3.7E+04	4.0E+04	4.2E+04	3.9E+04	4.1E+04	3.9E+04	4.1E+04	4.1E+04
23	9.3E+04	7.2E+04	6.6E+04	7.4E+04	7.7E+04	6.2E+04	5.7E+04	7.1E+04	7.5E+04	6.1E+04	6.1E+04	5.5E+04	5.6E+04	5.9E+04
24	9.4E+03	9.0E+03	9.0E+03	9.1E+03	9.1E+03	9.0E+03	9.0E+03	9.0E+03	9.0E+03	9.0E+03	9.0E+03	9.0E+03	9.0E+03	9.0E+03
25	3.5E+03	3.5E+03	3.5E+03	3.5E+03	3.5E+03	3.5E+03	3.5E+03	3.5E+03	3.5E+03	3.5E+03	3.5E+03	3.5E+03	3.5E+03	3.5E+03
26	5.8E+03	5.5E+03	5.5E+03	5.6E+03	5.5E+03	5.5E+03	5.5E+03	5.5E+03	5.5E+03	5.5E+03	5.5E+03	5.5E+03	5.5E+03	5.5E+03
27	2.0E+04	2.0E+04	2.0E+04	2.0E+04	2.0E+04	2.0E+04	2.0E+04	2.0E+04	2.0E+04	2.0E+04	2.0E+04	2.0E+04	2.0E+04	2.0E+04
28	2.0E+03	2.0E+03	2.0E+03	2.0E+03	2.0E+03	2.0E+03	2.0E+03	2.0E+03	2.0E+03	2.0E+03	2.0E+03	2.0E+03	2.0E+03	2.0E+03
29	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03
30	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03
31	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04

Unit: Ton.

Appendix VIII: Simulated Total nitrogen of 14 years at each sub-watershed outlet

ID	1984	1986	1988	1989	1991	1993	1995	1997	1999	2001	2003	2005	2008	2010
1	4.9E+04	4.7E+04	4.6E+04	4.7E+04	4.5E+04	4.2E+04	4.4E+04	4.3E+04	4.3E+04	4.2E+04	4.2E+04	4.3E+04	4.3E+04	4.1E+04
2	4.2E+05	4.1E+05	4.0E+05	4.0E+05	4.0E+05	4.0E+05	4.0E+05	3.9E+05	3.9E+05	3.8E+05	3.8E+05	3.8E+05	3.8E+05	3.7E+05
3	3.9E+05	3.8E+05	3.8E+05	3.8E+05	3.8E+05	3.8E+05	3.8E+05	3.7E+05	3.7E+05	3.6E+05	3.6E+05	3.6E+05	3.6E+05	3.5E+05
4	3.0E+05	3.0E+05	3.0E+05	3.0E+05	3.0E+05	3.0E+05	3.0E+05	2.9E+05	2.9E+05	2.9E+05	2.9E+05	2.9E+05	2.9E+05	2.8E+05
5	3.2E+05	3.2E+05	3.2E+05	3.2E+05	3.2E+05	3.2E+05	3.2E+05	3.1E+05	3.1E+05	3.1E+05	3.1E+05	3.1E+05	3.1E+05	3.0E+05
6	5.3E+04	5.2E+04	5.1E+04	5.1E+04	5.1E+04	5.0E+04	5.2E+04	5.0E+04	4.9E+04	4.8E+04	4.8E+04	5.0E+04	4.8E+04	4.7E+04
7	2.7E+05	2.7E+05	2.7E+05	2.6E+05	2.7E+05	2.7E+05	2.6E+05	2.6E+05	2.6E+05	2.6E+05	2.6E+05	2.6E+05	2.6E+05	2.5E+05
8	8.2E+04	7.8E+04	7.8E+04	7.8E+04	7.6E+04	8.0E+04	7.9E+04	7.5E+04	7.6E+04	7.3E+04	7.2E+04	7.0E+04	6.9E+04	6.6E+04
9	2.8E+04	2.8E+04	2.8E+04	2.6E+04	2.7E+04	2.8E+04	2.8E+04	2.7E+04	2.6E+04	2.6E+04	2.5E+04	2.7E+04	2.6E+04	2.5E+04
10	2.7E+05	2.7E+05	2.7E+05	2.6E+05	2.7E+05	2.7E+05	2.6E+05	2.6E+05	2.6E+05	2.6E+05	2.6E+05	2.6E+05	2.6E+05	2.6E+05
11	4.7E+04	4.5E+04	4.3E+04	4.3E+04	4.3E+04	4.3E+04	4.2E+04	4.1E+04	3.9E+04	4.1E+04	4.0E+04	4.2E+04	4.0E+04	4.0E+04
12	2.2E+05	2.2E+05	2.1E+05	2.1E+05	2.2E+05	2.2E+05	2.1E+05	2.1E+05	2.1E+05	2.1E+05	2.1E+05	2.1E+05	2.1E+05	2.1E+05
13	3.3E+04	3.3E+04	3.2E+04	3.2E+04	3.1E+04	3.3E+04	3.2E+04	3.1E+04	2.9E+04	2.9E+04	2.8E+04	2.8E+04	2.7E+04	2.5E+04
14	7.7E+04	7.6E+04	7.4E+04	7.3E+04	7.4E+04	7.4E+04	7.4E+04	7.2E+04	6.9E+04	7.1E+04	6.9E+04	7.2E+04	7.0E+04	7.0E+04
15	4.0E+04	3.7E+04	3.8E+04	3.8E+04	3.6E+04	3.8E+04	3.6E+04	3.5E+04	3.6E+04	3.3E+04	3.3E+04	3.1E+04	3.0E+04	2.9E+04
16	1.4E+05	1.4E+05	1.4E+05	1.4E+05	1.4E+05	1.4E+05	1.4E+05	1.4E+05	1.4E+05	1.4E+05	1.4E+05	1.4E+05	1.4E+05	1.4E+05
17	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.0E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04
18	1.2E+05	1.2E+05	1.1E+05	1.1E+05	1.2E+05	1.1E+05	1.1E+05	1.2E+05	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.1E+05
19	7.0E+04	7.0E+04	7.0E+04	6.6E+04	6.8E+04	6.9E+04	6.6E+04	6.7E+04	6.4E+04	6.5E+04	6.5E+04	6.5E+04	6.6E+04	6.3E+04
20	9.5E+04	9.4E+04	9.3E+04	9.3E+04	9.4E+04	9.3E+04	9.1E+04	9.4E+04	9.2E+04	9.1E+04	9.2E+04	9.0E+04	9.1E+04	9.1E+04
21	1.5E+04	1.4E+04	1.4E+04	1.4E+04	1.5E+04	1.5E+04	1.4E+04	1.5E+04	1.4E+04	1.4E+04	1.4E+04	1.3E+04	1.4E+04	1.4E+04
22	2.3E+04	2.2E+04	2.2E+04	2.1E+04	2.2E+04	2.2E+04	2.0E+04	2.2E+04	2.1E+04	2.1E+04	2.2E+04	2.1E+04	2.2E+04	2.1E+04
23	8.2E+04	8.1E+04	8.0E+04	8.0E+04	8.0E+04	7.9E+04	7.8E+04	8.0E+04	7.8E+04	7.7E+04	7.8E+04	7.6E+04	7.8E+04	7.7E+04
24	1.8E+04	1.8E+04	1.7E+04	1.8E+04	1.8E+04	1.8E+04	1.8E+04	1.7E+04	1.8E+04	1.8E+04	1.7E+04	1.7E+04	1.7E+04	1.7E+04
25	5.8E+03	5.8E+03	5.8E+03	5.8E+03	5.8E+03	5.8E+03	5.8E+03	5.8E+03	5.8E+03	5.8E+03	5.8E+03	5.8E+03	5.8E+03	5.8E+03
26	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04
27	3.3E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04
28	3.9E+03	3.9E+03	3.9E+03	3.9E+03	3.9E+03	3.9E+03	3.9E+03	3.9E+03	3.9E+03	3.9E+03	3.9E+03	3.9E+03	3.9E+03	3.9E+03
29	4.3E+03	4.3E+03	4.3E+03	4.4E+03	4.3E+03	4.3E+03	4.3E+03	4.3E+03	4.3E+03	4.3E+03	4.3E+03	4.3E+03	4.3E+03	4.3E+03
30	5.7E+03	5.7E+03	5.7E+03	5.7E+03	5.7E+03	5.7E+03	5.7E+03	5.7E+03	5.7E+03	5.7E+03	5.8E+03	5.7E+03	5.7E+03	5.7E+03
31	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04	1.2E+04

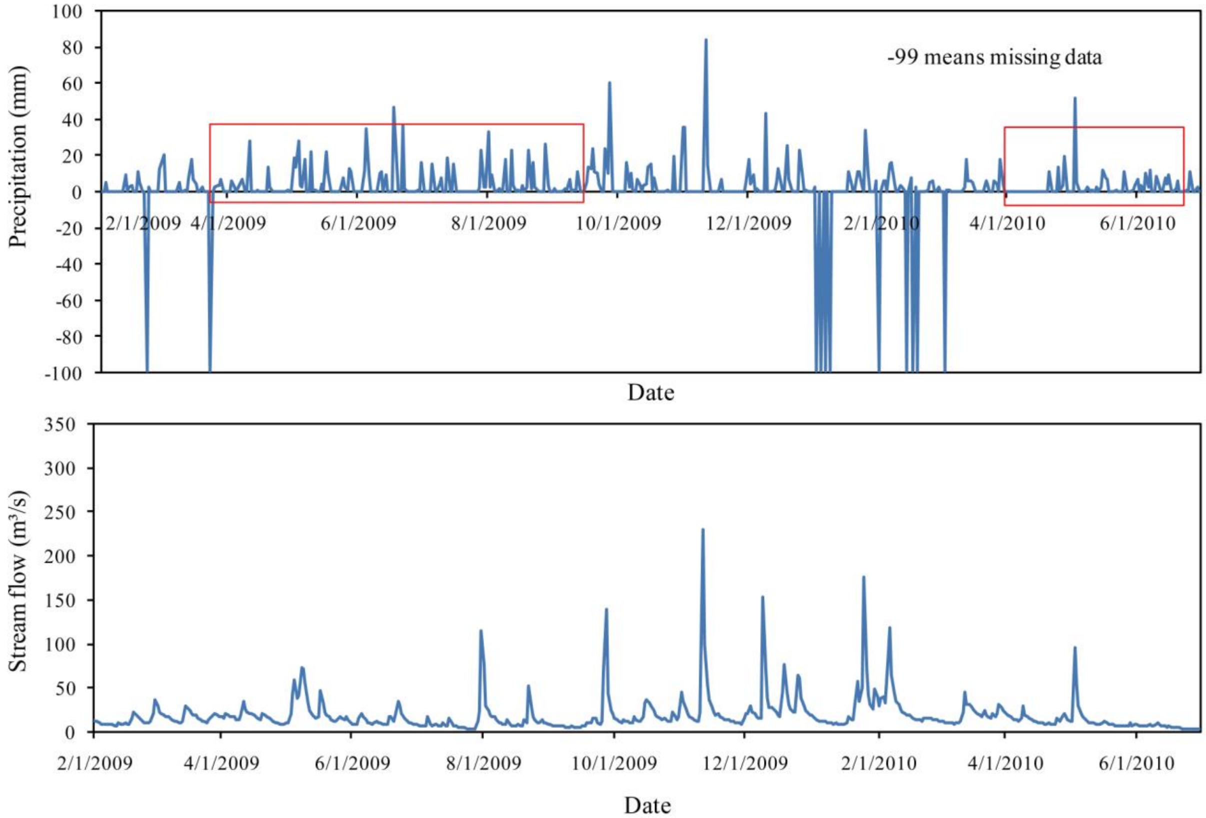
Unit: Kg.

Appendix IX: Simulated Total phosphorous of 14 years at each sub-watershed outlet

ID	1984	1986	1988	1989	1991	1993	1995	1997	1999	2001	2003	2005	2008	2010
1	5.0E+03	4.7E+03	4.6E+03	4.8E+03	4.6E+03	4.2E+03	4.5E+03	4.2E+03	4.3E+03	4.1E+03	4.1E+03	4.3E+03	4.3E+03	4.2E+03
2	6.6E+04	6.4E+04	6.3E+04	6.3E+04	6.4E+04	6.4E+04	6.4E+04	6.2E+04	6.2E+04	6.0E+04	6.0E+04	6.0E+04	6.0E+04	5.9E+04
3	6.0E+04	5.8E+04	5.8E+04	5.7E+04	5.8E+04	5.8E+04	5.8E+04	5.7E+04	5.6E+04	5.5E+04	5.5E+04	5.5E+04	5.5E+04	5.4E+04
4	4.5E+04	4.4E+04	4.3E+04	4.3E+04	4.4E+04	4.4E+04	4.4E+04	4.3E+04	4.3E+04	4.2E+04	4.2E+04	4.2E+04	4.2E+04	4.1E+04
5	4.4E+04	4.4E+04	4.3E+04	4.3E+04	4.4E+04	4.4E+04	4.3E+04	4.3E+04	4.2E+04	4.1E+04	4.1E+04	4.1E+04	4.1E+04	4.1E+04
6	6.5E+03	6.3E+03	6.3E+03	6.3E+03	6.2E+03	6.2E+03	6.6E+03	6.1E+03	6.0E+03	5.8E+03	6.0E+03	6.2E+03	5.9E+03	5.8E+03
7	3.5E+04	3.4E+04	3.3E+04	3.3E+04	3.4E+04	3.4E+04	3.3E+04	3.4E+04	3.3E+04	3.2E+04	3.2E+04	3.2E+04	3.2E+04	3.2E+04
8	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.0E+04	1.0E+04	1.0E+04	1.0E+04	9.9E+03
9	3.6E+03	3.5E+03	3.6E+03	3.4E+03	3.5E+03	3.6E+03	3.7E+03	3.4E+03	3.3E+03	3.4E+03	3.3E+03	3.5E+03	3.4E+03	3.3E+03
10	3.3E+04	3.2E+04	3.1E+04	3.1E+04	3.2E+04	3.3E+04	3.1E+04	3.2E+04	3.1E+04	3.0E+04	3.0E+04	3.0E+04	3.1E+04	3.1E+04
11	5.8E+03	5.5E+03	5.3E+03	5.3E+03	5.3E+03	5.4E+03	5.2E+03	5.0E+03	4.6E+03	4.9E+03	4.7E+03	5.1E+03	4.9E+03	4.9E+03
12	2.5E+04	2.5E+04	2.3E+04	2.4E+04	2.4E+04	2.5E+04	2.4E+04	2.4E+04	2.4E+04	2.3E+04	2.3E+04	2.3E+04	2.3E+04	2.3E+04
13	4.6E+03	4.6E+03	4.6E+03	4.5E+03	4.5E+03	4.8E+03	4.7E+03	4.6E+03	4.4E+03	4.4E+03	4.2E+03	4.3E+03	4.4E+03	4.2E+03
14	9.7E+03	9.3E+03	9.1E+03	9.0E+03	9.0E+03	9.3E+03	9.1E+03	8.9E+03	8.3E+03	8.5E+03	8.3E+03	8.7E+03	8.5E+03	8.5E+03
15	5.8E+03	5.7E+03	5.8E+03	5.7E+03	5.6E+03	5.8E+03	5.7E+03	5.4E+03	5.6E+03	5.3E+03	5.3E+03	5.1E+03	5.1E+03	5.0E+03
16	1.3E+04	1.3E+04	1.2E+04	1.3E+04	1.3E+04	1.3E+04	1.2E+04	1.4E+04	1.3E+04	1.3E+04	1.3E+04	1.2E+04	1.3E+04	1.3E+04
17	1.1E+03	1.0E+03	9.2E+02	9.6E+02	9.9E+02	9.7E+02	8.7E+02	1.0E+03	9.6E+02	9.7E+02	9.9E+02	9.7E+02	1.0E+03	1.0E+03
18	1.0E+04	1.0E+04	9.1E+03	9.6E+03	9.9E+03	9.9E+03	8.9E+03	1.0E+04	1.0E+04	9.3E+03	9.5E+03	8.8E+03	9.4E+03	9.4E+03
19	7.1E+03	7.1E+03	7.0E+03	6.7E+03	7.0E+03	7.2E+03	6.8E+03	6.9E+03	6.6E+03	6.7E+03	6.6E+03	6.5E+03	6.7E+03	6.5E+03
20	7.5E+03	7.5E+03	6.8E+03	7.2E+03	7.2E+03	7.4E+03	6.6E+03	7.5E+03	7.4E+03	6.9E+03	7.0E+03	6.5E+03	6.9E+03	6.9E+03
21	1.4E+03	1.4E+03	1.3E+03	1.4E+03	1.4E+03	1.6E+03	1.3E+03	1.5E+03	1.5E+03	1.3E+03	1.4E+03	1.3E+03	1.4E+03	1.3E+03
22	2.1E+03	2.0E+03	1.9E+03	1.9E+03	2.0E+03	2.0E+03	1.7E+03	2.0E+03	2.0E+03	1.9E+03	1.9E+03	1.8E+03	1.9E+03	1.9E+03
23	5.9E+03	6.0E+03	5.4E+03	5.6E+03	5.6E+03	5.6E+03	5.2E+03	5.8E+03	5.7E+03	5.3E+03	5.3E+03	5.0E+03	5.4E+03	5.4E+03
24	1.1E+03	1.1E+03	1.0E+03	1.1E+03	1.1E+03	1.1E+03	1.1E+03	1.0E+03	1.1E+03	1.1E+03	9.9E+02	1.0E+03	1.0E+03	1.0E+03
25	3.7E+02	3.9E+02	3.8E+02	4.0E+02	3.9E+02	4.0E+02	3.7E+02	3.7E+02	3.7E+02	3.7E+02	3.7E+02	3.8E+02	3.7E+02	3.7E+02
26	6.3E+02	6.3E+02	6.1E+02	6.4E+02	6.3E+02	6.3E+02	6.1E+02	5.7E+02	6.2E+02	6.2E+02	5.7E+02	5.7E+02	5.7E+02	6.2E+02
27	1.7E+03	1.7E+03	1.6E+03	1.7E+03	1.6E+03	1.7E+03	1.7E+03	1.7E+03	1.7E+03	1.6E+03	1.6E+03	1.6E+03	1.7E+03	1.7E+03
28	2.3E+02	2.3E+02	2.3E+02	2.3E+02	2.3E+02	2.3E+02	2.3E+02	2.3E+02	2.3E+02	2.3E+02	2.3E+02	2.3E+02	2.3E+02	2.3E+02
29	2.4E+02	2.4E+02	2.4E+02	2.5E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02
30	2.5E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02
31	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03

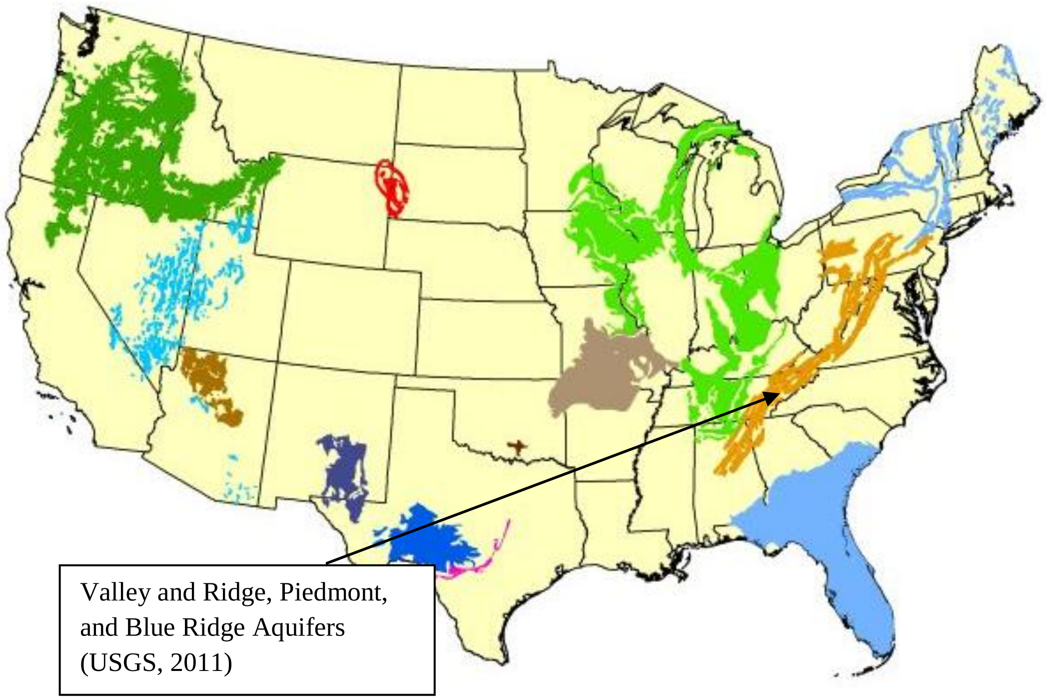
Unit: Kg.

Appendix X: Comparison of precipitation and stream flow record from 2009.1 – 2010.6



(A) Precipitation data at NCDC weather station 403420 from 2009.1 – 2010.6. (B) Stream flow data at USGS 03498500 from 2009.1 – 2010.6.

Appendix XI: Karst Aquifers of the United States



VITA

Chunhao Zhu was born on March 15, 1985. He grew up in Beijing, China, and lived there for 18 years. He graduated with a Bachelor of Science degree in Geographic Information System (GIS) and a Bachelor of Economics degree in International Economy and Trade from Wuhan University in China in 2007. He graduated with a Master's degree in Cartography and Geographic Information System from Wuhan University in China in 2009. It is a great honor in his life to study in the Department of Geography at the University of Tennessee, Knoxville and graduate with a Master of Science degree. This is the first time that Chunhao has studied in the U.S independently, to pursue his biggest dream in life. It is also a great honor for Chunhao to meet Dr. Yingkui Li, one of the best advisors in Chunhao's life track. Chunhao has so many dreams in his life. Chunhao is committed to the environment, education, and charity as three most important goals in his life. He also dreams of travel around the world and facilitating cultural exchange in the world.