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Anthropogenic Impacts on Riparian Forest Loss in East Tennessee: a GIS analysis

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To the Graduate Council:

I am submitting herewith a thesis written by Karen Burhenn entitled "Anthropogenic Impacts on Riparian Forest Loss in East Tennessee: a GIS analysis." 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 Ecology and Evolutionary Biology.

Carol P. Harden, Major Professor

We have read this thesis and recommend its acceptance:

Bruce Ralston, Jake Weltzin

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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and recommend its acceptance:

Bruce Ralston

Jake Weltzin

Accepted for the Council:

Dr. Anne Mayhew

Interim Vice Provost and
Dean of the Graduate School

(Original signatures are on file in the Graduate Student Services Office.)

Anthropogenic impacts on riparian forest loss in east Tennessee: a GIS analysis

A Thesis
Presented for the
Master of Science Degree
University of Tennessee, Knoxville

Karen Burhenn
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Abstract

Streamside, or riparian, areas are vital components of a healthy watershed system. Natural riparian areas perform multiple ecosystem functions including filtering sediments and pollutants from upland areas, stabilizing banks and floodplains, regulating stream temperatures, and providing habitat for many native and migratory species. In eastern Tennessee, natural riparian forests have declined by 40 to 60 percent (SAMAB 1996b). I examined the spatial distribution of humans and their land-cover changing activities in an effort to contribute to a better understanding of the loss of riparian forests in the eastern Tennessee region.

This research is centered in the Central Ridge and Valley ecoregion area of Tennessee, a landscape diverse in its physical characteristics, land usage, and human population density. Using Geographic Information Systems (GIS), I derived the human population, the proportion of each land use type, and the proportion of non-natural riparian area for each eleven-digit watershed study unit within the study area. I first used this information to investigate human population density as an indicator of overall human presence within each watershed unit and its relationship to the loss of riparian forests. I then looked more closely at possible land use causes of the loss of riparian forests in the Central Ridge and Valley ecoregion.

Eleven watershed-level land use variables were derived from the Multi-Resolution Landscape Characteristics (MRLC) dataset for consideration as possible indicators of riparian forest loss. These land use classifications include natural, high-density residential, low-density residential, commercial or industrial, croplands, pasture, mining, recreational grassy areas, and transitional. Watershed-level road density and riparian road density were also investigated in relation to riparian forest loss.

I tested the ability of population density to predict riparian forest loss, which resulted in a weak but highly significant positive relationship. Further research into specific land use classes showed over 85 percent of the variability in riparian forest loss was explained by four watershed-level land use proportion variables: pasture, low-density residential, croplands, and recreational grass. This study contributes to the understanding of anthropogenic effects on natural riparian systems and should prove useful in developing riparian protection and management strategies in the eastern United States.

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Chapter 1: Introduction

At the interface between flowing waters and terrestrial ecosystems lie unique areas called riparian zones. These dynamic open systems are characterized by a raised water table, alluvial soils, periodic flooding, the presence of obligate species, and high biodiversity (Malanson 1993). The high edge-to-area ratio and lateral flow of these areas allow for their high connectivity with other natural systems and processes (Naiman et al. 1993).

Riparian, or streamside, areas protect water quality and provide habitat both in the water and on land. Riparian vegetation stabilizes stream banks and land surfaces, controlling flood damage and erosion. Natural riparian systems protect water quality by buffering streams from pollutants in overland and ground water flow. In order for these beneficial buffer functions to occur, these areas must be maintained in a near natural state (Odum 1978, Omernik et al. 1981, Lowrance et al. 1984a, Hornbeck and Swank 1992).

Although riparian areas in East Tennessee are occasionally subjected to natural forces such as intensive flooding, fires, and shifting stream channels, these factors are not known to be occurring with sufficient frequency or intensity to dramatically alter the riparian landscape at the ecoregion level (see SAMAB 1996e). The most obvious driver of landscape change is human activity. Anthropogenic factors that alter the landscape and may affect riparian forest presence include population distribution, land use, and the presence of roads. This thesis examines the relationship between riparian forest loss in eastern Tennessee and patterns of anthropogenic influence. The location of this research is Central Ridge and Valley ecoregion, a Level II ecoregion contained within the Ridge and Valley physiographic province and more broadly within the Southern Appalachian Assessment (SAA) area. Level II ecoregions will be defined in Chapter 2.

Human population density may serve as a useful indicator of human impact within a specified area (Jones et al. 1997). Population growth leads to a rise in the value of developable lands as well as the intensity of development activities (Turner et al. 1996). In this thesis, I examine the relationship between human population density and riparian forest loss in the Central Ridge and Valley ecoregion. In mountainous landscapes, floodplain valleys are the most easily developed lands for roadbeds, homes, industry, and livestock and crop agriculture. Agricultural, urban, commercial, residential, and transportation development can result in dramatic loss of natural vegetation.

Identification of anthropogenic factors showing significant influences on the riparian forest systems in this region will allow for improved riparian forest management practices. Efforts to restore and manage riparian areas in the southeastern U.S. are often site-specific and may not restore the natural riparian functions within the dynamic stream system. In order to preserve the benefits of intact riparian forest systems, these areas need to be evaluated and managed at the watershed level. Such broad-scale ecosystem analysis can be effectively accomplished using Geographical Information Systems (GIS).

GIS presents an efficient tool for assessing watershed and regional scale data for environmental management (Perry et al. 1999). A GIS approach may be used to not only look at the present state of riparian areas, but to assess possible human and physical factors affecting current riparian forest conditions. In this thesis, I use GIS to quantify the relationship between the condition of riparian forests in eastern Tennessee and several human influence predictor variables, including population density, land use, and road proximity. By investigating these interactions, this research will contribute to an improved understanding of riparian systems in the utilized landscape.

Riparian Delineation

Riparian zones include stream bank, floodplain, and bottomland areas. The delineation of a riparian zone is difficult and methods differ among authors. Naiman et al. (1993) define the riparian corridor as extending from the stream channel out into the terrestrial vegetation as far as it is affected by flooding, high water table, or hydrophilic soils. The dimensions of this corridor depend on the specific stream and vegetation structure, hydrologic patterns, and geomorphic features of the area (Naiman et al. 1993). As part of the defined riparian zone, Naiman and Décamps (1997) include vegetation located beyond the direct influence of the riparian hydrologic regime that contributes organic matter or provides direct physical influences such as shading. Gregory et al. (1991) discuss an ecosystem perspective of riparian zones that encompasses the three-dimensional structure, interaction, and temporal change of hydrological and geomorphic processes, terrestrial plant succession, and aquatic ecosystems. Naiman and Décamps (1997) state that a riparian area may be defined by the area of nutrient or sediment contribution.

Riparian Buffers

Riparian areas naturally act as buffers between aquatic and terrestrial systems. Watershed management plans often attempt to retain this effect by delineating a riparian buffer zone to be maintained in a near-natural state. Vegetated riparian lands may be designated as buffer strips between developed lands and lateral water flows in order to protect water and habitat quality. The parameters of this buffer zone, also referred to as a streamside management area or riparian buffer strip, are highly variable. A buffer zone may be delineated by a set width, e.g., 90 meters, from the edge of a stream or other water body or as a variable range defined by local parameters.

According to Hornbeck and Swank (1992), the functional width of a riparian buffer zone depends on the specific site characteristics including slope, soil type, and climate. Soranno et al. (1996) found riparian areas to have dynamic critical widths that may vary annually and are strongly related to total precipitation. Haycock et al. (1993) suggest that riparian buffer width varies from 10 m to 150 m, depending on the groundwater flow path and the proximity of the water table to the soil surface. However, they also point out the political implications of setting a wide buffer zone. Wide buffer zones easily encroach on private lands, leading to property rights concerns, and can also include more area than is necessary to maintain drainage benefits. On the other hand, narrow buffers are unlikely to include the entire riparian floodplain and provide the benefits of an intact buffer. A riparian buffer zone may be defined using complex delineation methods that consider several factors such as slope, elevation, vegetation, and soil type. As this information is not often available over entire watersheds or ecoregions, the set width riparian buffer has become the standard method of riparian buffer zone delineation.

In 1978, Karr and Schlosser hypothesized that riparian buffers function best when maintained in a near-natural state, and highlighted the shortcomings of current management practices intended to protect water quality. They urged researchers to look more deeply into the specific ecosystem processes of the land-water interface and recommended development of specific Best Management Practices (BMPs) for riparian areas.

Riparian Function

Numerous studies have addressed the beneficial functions of riparian forests. Intact riparian forests alleviate damage and erosion due to flooding by inhibiting overland flow, slowing flood events, and stabilizing soil (Naiman et al. 1993). Large organic input from riparian forests decreases stream turbidity and velocity. Forest root systems stabilize banks preventing erosion, and riparian vegetation traps sediment in overland flow (Naiman and Décamps 1990, Malanson 1993).

Riparian vegetation provides habitat for a diversity of aquatic and terrestrial species. On land, riparian vegetation increases habitat heterogeneity, thereby allowing for increased plant and animal diversity (Malanson 1993). Continuous vegetated riparian areas have been shown to serve as effective movement corridors, providing many species with covered passage between forest fragments (Naiman et al. 1993). Shading from adjacent and overhanging riparian forests has been shown to reduce and regulate stream temperatures (Dolloff and Webster 2000). Riparian forests contribute woody debris and other organic matter to streams (Hemstrong 1989). This large organic input improves habitat heterogeneity and overall stream health by creating riffles, pools and shelters (Hemstrong 1989).

Schlosser and Karr (1981a) found that the loss of riparian vegetation in agricultural watersheds causes a significant seasonal shift in organic stream inputs, resulting in increased suspended sediment levels, stream turbidity, and bank erosion. Further research has found riparian forests to be excellent buffers, removing nutrients and sediment in ground water and overland flow (Perry et al. 1999). In agricultural watersheds, Peterjohn and Correll (1984) found nitrogen retention by riparian forests to be 89 percent compared to only 8 percent by cropland. Nitrogen reduction in riparian forests has been attributed to denitrification and vegetative uptake (Peterjohn and Correll 1984, Lowrance et al. 1984a). Water quality in agricultural areas is heavily dependent on the uptake and storage of nutrients via intact riparian forests (Lowrance et al. 1984a, Lowrance et al. 1984b). Riparian areas have been shown to act as filters, removing P, Ca, Mg, K, and Cl from upland runoff in agricultural watersheds (Lowrance et al. 1984a). Removal of riparian forests in agricultural watersheds thus increases stream nutrient loading and reduces water quality.

Riparian Decline

The extent of natural riparian systems has declined worldwide (Klopatek et al. 1979, Swift 1984). Riparian environments in the United States have not been excluded from such loss. Swift (1984) reported that the extent of natural riparian systems in the United States declined from 75 -100 million acres to 25-35 million acres in the last 300 years. The western United States has been the focus of much research on the loss of riparian areas (see Anderson et al. 1977, Gregory et al. 1991, Sorrano et al. 1996, Kauffman et al. 1997, and Hunter et al. 1999). However, declining natural riparian systems are found in the eastern United States as well. The EPA reports a 60 percent decline of bottomland hardwood forests in the southeastern U.S. over the last 200 years (EPA 2001). The Southern Appalachian Assessment (SAA) reported a loss of riparian forests ranging from 40 to 60 percent per county within the SAA area, which encompasses eastern Tennessee (SAMAB 1996b).

In eastern Tennessee, most riparian forest loss occurs on privately owned lands (SAMAB 1996e). These lands are subjected to a variety of human land uses including agricultural, commercial, residential, and urban development. The rich, level soils of east Tennessee's lowland floodplains support crop and livestock agriculture (SAMAB 1995e). Along with such development typically comes the construction of a vast network of roads. In the Central Ridge and Valleys ecoregion, many homes, businesses, and roads were built in floodplains, where the land was less difficult to develop (SAMAB 1995a). Although the topography of the region may have defined the areas in which homes, roads, and farms were built, the development and subsequent use of the land led to actual clearing of the riparian forests.

GIS in Riparian Research

Natural riparian areas are in decline and it follows that these ecosystem functions will be compromised. Identification of the sources of riparian alteration is essential in effectively protecting and managing riparian forests. One tool that is gaining popularity in ecological assessment and ecosystem management is Geographic Information Systems (GIS). GIS are integrated computer hardware and software systems capable of displaying, manipulating, and analyzing spatially referenced datasets. This technology is appropriate for ecosystem level management as it allows the user to efficiently look at interactions between various data layers on broad scales. Naiman et al. (1993) note that effective riparian management decisions must be made at the watershed level. They call for the development of GIS as management tools for assessing social, economic, and environmental considerations for management and policy decisions.

Several researchers have used GIS for riparian assessment and analysis, including Delong and Brusven (1991), Hunter et al. (1999), Russell et al. (1997), and Schuft et al. (1999). Research has used GIS to look into the processes by which riparian areas filter sediments and pollutants from water flowing from intensive land uses through riparian lands (Delong and Brusven 1991, Sorrano et al. 1996, Perry et al. 1999). Others have used GIS for delineation or classification of riparian areas (see Sheng et al. 1997, Fried et al. 1997, Narumalani et al. 1997, and Schuft et al. 1999).

Much of this research has focused on nutrient and sediment dynamics, but few studies have attempted to identify anthropogenic impacts on riparian forest condition. Turner et al. (1996) investigated land ownership in relation to land cover change in both the Olympic Peninsula, Washington and the southern Appalachian highlands of western

North Carolina. They used GIS to manipulate and analyze four land use classifications: coniferous forest, mixed forest, grassy cover, and unvegetated. They looked at six variables (ownership, elevation, slope, distance to market, distance to the nearest road, and population density) and made predictions concerning the relationships between these variables and land cover transitions such as forest to unvegetated and grass to forest. In the southern Appalachian area, Turner et al. (1996) found relationships relating slope with transitions from forest, and population density with a transition from forest to non-vegetated.

In an assessment of the Mid-Atlantic region, Jones et al. (1997) looked briefly at watershed forest presence in relation to several variables including population density, riparian forest presence, road density, and agricultural activity. They found spatial patterns relating population density, road density, and agriculture to the loss of watershed level forests.

Like the work of Turner et al. (1996) and Jones et al. (1997), this thesis looks at population as an indicator of anthropogenic activity in the eastern United States. However, while the work of Turner et al. (1996) focused primarily on economic and physical factors affecting land cover within watersheds, I focus specifically on the relationship between watershed-level land use and riparian land cover patterns. Whereas the work of Jones et al. (1997) includes only a brief spatial overview of a wide variety of economic and ecological indicators in the Mid-Atlantic region, including general land uses and riparian forest patterns, my research involves a detailed investigation of the relationships between riparian forest loss and several defined land uses in eastern Tennessee. In this research, I also use finer classification of the land cover classes than were used in either study in order to avoid grouping land uses that may have varying effects.

Research Questions

The benefits offered by intact riparian forests have been established; nonetheless, the areal extent of riparian forests continues to decrease as anthropogenic activities place increasing pressure on these sensitive systems. Physical changes to stream hydrology, such as impoundments, channelization, and dredging, dramatically alter riparian regimes (Odum 1978, Naiman and Décamps 1997, Toner and Keddy 1997). However, human activities that influence riparian forest presence may extend well beyond flow modification projects. Humans convert natural landscapes for agriculture, residential, commercial, transportation, and recreational purposes. Such anthropogenic land use activities may play a key role in the rapid loss of natural riparian forests on private lands in eastern Tennessee.

In order to research different aspects of riparian forest loss and its relationship to anthropogenic activities, I posed the following questions:

1. What is the relationship between population density and riparian forest loss within each watershed?
2. When all land uses within each watershed are considered, which land uses are strongly associated with riparian forest loss?
3. Considering only non-natural land uses within each watershed, which of these most accurately predicts riparian forest loss?

4. Which land uses occur more densely in the riparian buffer area than in the watershed as a whole?

In order to address these questions, the potential consequences of population, land use, and road presence on the loss of riparian forests must be considered.

Population

Increasing human populations place ever growing pressure on natural resources (Naiman 1993, SAMAB 1996e). The Central Ridge and Valley ecoregion contains two major metropolitan areas, Knoxville and Chattanooga, as well as many small townships and farming communities. In the SAA area, 57 percent of the population lives in rural communities (SAMAB 1996d). The region is also characterized by moderate population growth of approximately 20 percent from 1980 to 1990 (SAMAB 1996e).

Jones et al. (1997) noted increased adverse effects of population density on riparian forest presence near heavily urbanized areas of the Mid-Atlantic region. In the Little Tennessee River Basin, Turner et al. (1996) claimed a positive effect of population density on the transition of forest to unvegetated land cover. However, east Tennessee's landscape is characterized by a complexity of non-natural land usages ranging from rural areas, with intensive agricultural practices, to urban areas, containing high-density residential development. Pasture, the most common non-natural land use in the study area, requires large, contiguous tracts of land for grazing and, in turn, primarily occurs in areas of low population density. Therefore, the relationship between human population density and land conversion may not necessarily be linear.

Land use

In this study, I will test whether the multiple land use activities in eastern Tennessee exhibit direct relationships to riparian forest loss. Land cover of the Ridge and Valley physiographic province, as classified in the MRLC taken in the early 1990's, is made up of approximately 60 percent forest cover, 30 percent pasturelands, 5 percent croplands, and 6 percent urbanized or barren (SAMAB 1996e). Land cover change is a function of land ownership and human land use; these influences will impact a variety of ecological processes (Hunsaker and Levine 1995, Turner et al. 1996). Land uses considered in this research include agricultural, residential, natural, commercial, and transportation.

Agriculture

Agricultural land uses in this area include pasture as well as cropland operations. Malanson (1993) directly attributes the loss of natural riparian forests, in part, to agricultural land practices. Riparian areas are often cultivated due to pressure to expand existing fields, despite the high environmental and economic costs of farming these areas (Lowrance et al. 1984a). In mountainous terrain, level fields along and within floodplains are attractive to farmers for their ease of development and management (Malanson 1993).

The rich alluvial soils of floodplain areas in this region are highly productive, barring flood damage (SAMAB 1996e). Following the construction of a series of river impoundments by the Tennessee Valley Authority in the mid 1900s, the floodplains of east Tennessee have become agriculturally successful and productive areas (TVA 1996).

During the early 1990s, in the SAA region, large commercial crop and livestock operations were most prevalent in valleys where such intensive agriculture is facilitated by the availability of substantial level tracts of land (SAMAB 1996d).

The SAA found a 2 percent decline in forest since 1975 and predicts this trend will continue through 2010 (SAMAB 1996e). This steady loss of forests in Appalachia is occurring on private lands, which are being converted for agricultural and other development uses (SAMAB 1996e). In a study of agricultural real estate trends in the United States, Derrick (1999) identified Tennessee as having the second highest increase, 39.55 percent, in per acre farm real estate value from 1994 to 1998 in the continental U.S. At the same time, the 1997 U.S. Census of Agriculture for Tennessee found a slight decrease in both the number of farms and the total acreage in farmland from 1992 to 1997 (U.S. Census, 2001). This conversion may be due, in part, to increasing economic value of farmland in the region. Because pasture is the predominant non-natural land use within the region, it is likely to be an important predictor of riparian forest loss in the study area.

Residential development

Residential development and property values often favor the aesthetic values offered by views of streams and other water bodies (TVA 1996). Therefore, I expect to find a significant, positive relationship between the extent of residential land use and loss of riparian forests. Residential land use will be divided into two classes as defined by the MRLC: high-density residential and low-density residential (see Appendix).

In most of eastern Tennessee, areas classified by the MRLC as high-density residential are relatively rare, particularly within riparian buffers. Only 23 of the 82 study watershed units contain pixels classified as high-density residential land use. However, their presence shows that riparian areas are not excluded from high-density residential development pressures. Land in areas of high population density is at a premium, and unless land is reserved as a park or wildlife habitat, few legal limitations exist in this region to exclude privately owned riparian areas from intensive development practices. Such intensive urban residential development attempts to maximize usable space, often by clearing any remaining forest structure to create room for housing structures and parking.

Low-density residential land use is found in all watersheds in the study area and includes suburban housing in smaller townships as well as what is commonly known as "urban sprawl." Low-density housing development is in a constant state of growth in most of east Tennessee (SAMAB 1996d) and accounts 6.9 percent of the non-natural land use within the study area. Riparian forest loss may be less detectable in areas of low-density housing, as such development is often less intensive and does not always cause detectable breaks in the canopy (Turner et al. 1996). I expect that low-density residential land use will be a positive predictor of riparian forest loss in this region.

Natural areas

The preservation or restoration of natural vegetation structure on private land may be considered a land use. Such areas still represent a value to the property owner, whether in real estate, timber, conservation easements, hunting grounds, or aesthetic lands. As the natural areas classification for this project includes all intact riparian forests and wetlands, I expect that the proportion of natural areas in a watershed will be negatively correlated to that of riparian forest loss. This prediction assumes that the riparian forest patterns are consistent with natural forest patterns throughout the watershed.

Recreational grasses

Grassy areas for recreation are typically parks, golf courses, or extensive commercial or residential lawns (see Appendix). Grassy recreational areas provide a land use in residential and commercial areas that can assist in maintaining the economic value of the adjacent properties by protecting sensitive lands, enhancing aesthetic appeal, controlling erosion, and creating recreational space (Lyons et al. 2000). It is useful to note that areas in this classification require consistent management and are not naturally occurring phenomena: a mown grass area within a watershed represents a specific land use decision (Lyons et al. 2000). These land uses are often features of a floodplain area. Grass lawns are often viewed as an improvement to the aesthetic value of the land, and a park or wide lawn can offer an unobstructed view of a nearby stream while providing some protection against bank erosion (Lyons et al. 2000). Another factor lies in the nature of the floodplain itself. It can be difficult or even illegal to maintain structures within the floodplain zone of a water body. The location of many managed parks is also related to the need to protect sensitive environmental systems from more intensive land uses without sacrificing the utilization of the land.

Commercial and industrial

Commercial and industrial facilities line the rivers of the Tennessee Valley. Their location is contingent not on the fertile soil, but rather on the access to water and the waterway. Riparian water law of the eastern U. S. gives the riparian landholder rights to the use of water from the adjacent water body. The Tennessee River is a major commercial route in the inter-coastal waterway system, serving a large portion of the southeastern U. S. However, for this work I research only the tributary streams of the study area and exclude major water bodies for reasons to be discussed in Chapter 3.

Within the defined riparian areas, the commercial and industrial classification represents only 1.29 percent of the land use. Large-scale industrial operations require significant tracts of lands and are often concentrated in industrial parks outside of cities. Commercial properties also tend to be concentrated, but more often within centers of population. Therefore, due to the locational and proximate needs of commercial and industrial operations, I expect to find a positive relationship between this land use classification and areas classified as riparian forest loss.

Other land uses

Lands classified as transitional account for 0.55 percent of the study area and are characterized by dynamic, sparse vegetation patterns (see Appendix). Transitional lands include areas subjected to clear-cutting, fire, flood, and other land cover disturbances resulting in patterns of gradual reestablishment of natural vegetation. Turner et al. (1996) found significant positive relationships between the area of land in transition from grass to forest and the independent variables of slope and distance to market. They also reported significant negative relationships between land in transition from grass to forest and the independent variables of elevation and population. However, since the areas classified as transitional represent a variety of land uses and only comprise a small percent of the study area, transitional areas are not expected to be important predictors of the extent of riparian forest loss in the region.

Mines occupy only a small percentage of the study area as well (0.10 percent). Mining can directly lead to the loss of forests through the clearing of the land and the subsequent pollution and acidification of adjacent lands. Although the influences of mining on forest and stream systems can be substantial, surface mining is unlikely to occur with sufficient frequency and pattern in the study area to show an association to riparian forest loss.

The barren classification was excluded from this analysis as it represents only 0.01 percent of the study area

Roads

Road proximity and density may affect riparian forests in three ways. First, roads allow easy access for development, logging, and recreational activities. Second, riparian forests may be lost through the construction and presence of roads in or near riparian areas. Third, the surface of a road creates an impervious surface that can cause increased quantity and velocity of overland flow during a storm event, thereby altering the natural riparian regime (Jones et al. 1997). Research in the Southern Appalachian highlands region by Turner et al. (1996) found forest loss to be more strongly influenced by locational factors, such as elevation and slope, than by proximity to roads. Wear and Flamm (1993), however, found distance to the nearest road positively and significantly influenced the likelihood that nearby forestlands had been disturbed. It should also be noted that within the narrow constraints of a riparian buffer, the presence of a road itself represents the unquestionable loss of vegetative habitat. Furthermore, because roads are vectors of human development, the alteration of the natural landscape may be attributed to not only the area taken by the roads themselves, but also to the additional land use changes facilitated by road presence (Wear and Flamm 1993). The proportion of pixels containing roads within the riparian buffer and the density of roads in the watershed as a whole are thus expected to affect the proportion of riparian forest loss in the study area.

Summary of the approach

To determine how riparian forest condition is affected by anthropogenic influences, I used a twofold approach. First, I use human population density, referred to as "POPDENS," as an indicator of overall human influence within a defined watershed study unit. The proportion of non-natural land use areas within the riparian areas of each watershed is used to represent a measure of riparian forest loss, or "RIPLOSS." To determine whether POPDENS is correlated with increasing RIPLOSS, I compare spatially explicit POPDENS with the RIPLOSS to identify the relationship between riparian forest condition and human presence.

In second part of this study, I look more specifically at land uses through which humans impact riparian forests. In this thesis, land use includes two categories of data: 1) land use classifications such as agricultural, residential, natural, and commercial/industrial; and 2) roads. These two types of land uses are separated because of the manner in which the data are stored in a GIS. The roads data are stored in vector format, or as lines, whereas the other land use data are stored in raster format, or as pixels.

I expect that watershed level land use, i.e., the proportions of each land use category in each watershed, will have a discernable and predictable influence on riparian forest absence. The land use categories are natural (“NATURAL”), high-density residential (“HDRES”), low-density residential (“LDRES”), croplands (“CROP”), pasture (“PASTURE”), commercial or industrial (“COMIND”), mining (“MINE”), recreational grass (“GRASS”), transitional (“TRANS”), and roads (“ROAD”). RIPROADS is an additional land use category representing the road density within the riparian buffer area of each watershed. These variables are further defined in Chapter 3.

Chapter 2: Study Area

This research is focused in the eastern portion of Tennessee, a forested temperate region of the United States. The study area has been selected because it represents a diversity of physical and anthropogenic influences that may be applicable over larger areas within the region. The general study area is constrained by the Central Ridge and Valleys ecoregion as defined by Omernik (1987). Aquatic ecoregions offer an appropriate spatial framework for ecosystem research and assessment as they represent zonal differences in soils, precipitation, topography, hydrology, and natural vegetation (Omernik and Bailey 1997).

Site selection

There are three categories of aquatic ecoregions as defined by Omernik and the U.S. Environmental Protection Agency. The most basic level, Level I, divides the continental United States into nine regions at the 1:750,000 scale. Level II is extended into thirty-two 1:250,000 scale categories with increased detail. The study area for this project is defined by the Central Ridge and Valleys ecoregion, a Level II ecoregion, extending from southwestern Virginia southward through most of eastern Tennessee. I chose this ecoregion to reduce variability due to radical ecosystem differences by constraining the study units.

Within this ecoregion, I chose to define the study units using USGS eleven-digit hydrological units, or watersheds. Watersheds provide an appropriate spatial structure for scientific analysis of the relationships between water quality, and environmental and human influences (Omernik and Bailey 1997). The use of watershed study units within a larger framework of ecoregions is recommended for ecological analysis (Omernik and Bailey 1997). The ecoregion encompasses numerous associated ecosystem components, while the watersheds serve as a spatial system for scientific research on the impacts of anthropogenic and environmental influences on water systems. I selected 82 study watershed units, all at least 80 percent within the Central Ridge and Valleys ecoregion, which comprise the final study area. The final study area (Figure 1) covers 13398.18 km^2 with a mean area of 163.39 km^2 per watershed.

Study area description

The diversified geography of east Tennessee offers a wide variety of land use practices and anthropogenic influences useful in researching anthropogenic activities that could affect the existence of riparian forests. The Central Ridge and Valleys ecoregion exhibits a diversity of physical characteristics. Folded, faulted valleys and ridges run parallel northeast to southwest with elevations ranging from 200 to 600 meters (McNab 1996). Strata consist of shale, sandstone, and limestone (SAMAB 1996e). The soils are primarily Udults with smaller percentages of Paleudults and Ochrepts (McNab 1996). Soil depth is variable, often deep in the limestone valleys and shallow in valleys underlain by shale (SAMAB 1998e). Sandstone ridge tops exhibit shallow soils, but where ridges are limestone or dolomite, soil and regolith may be tens of meters deep (pers. com. Harden).

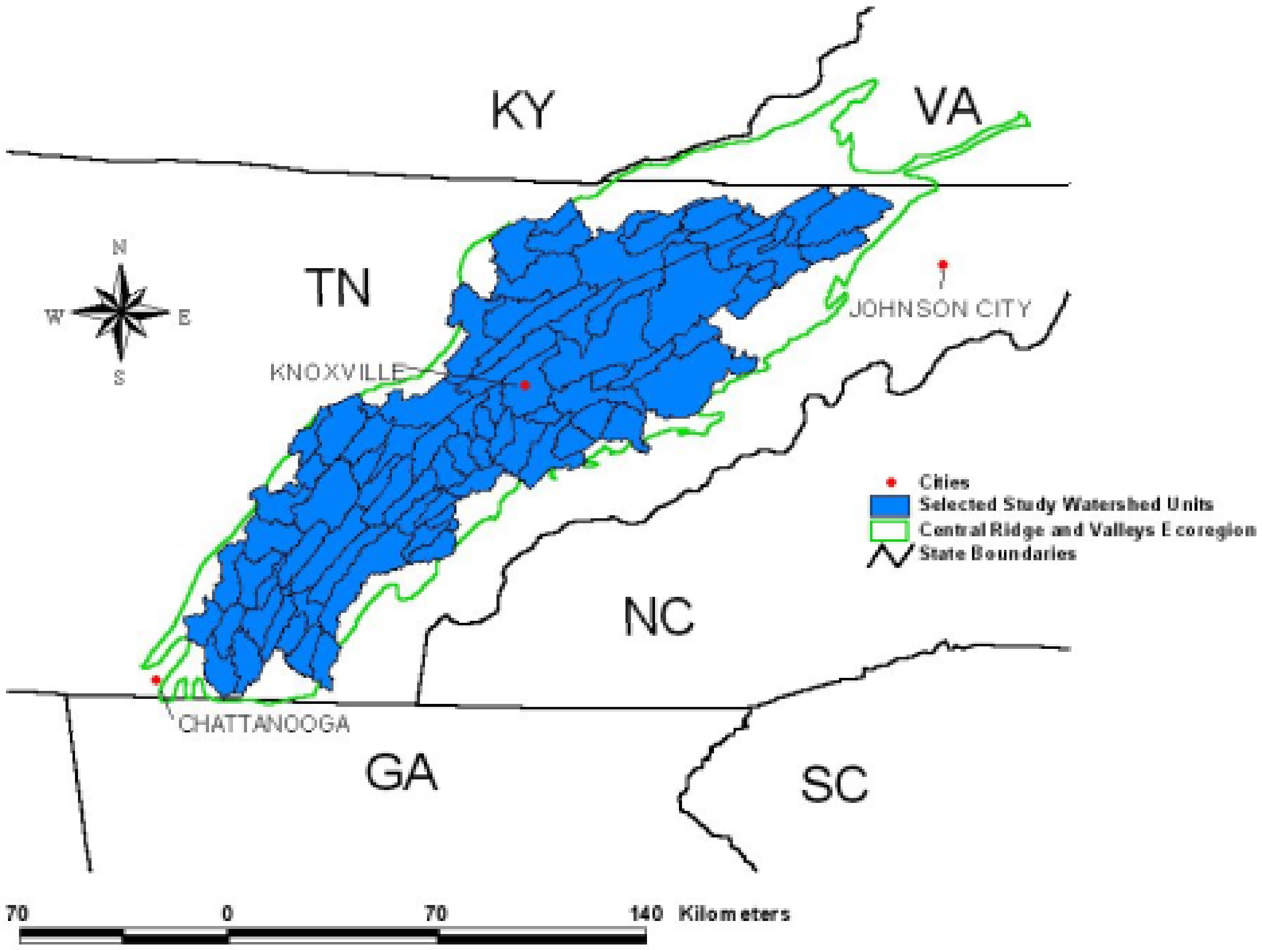

Figure 1: Study watershed units within the Central Ridge and Valleys ecoregion

Average annual precipitation ranges from 910 to 1400 mm (McNab 1996). The trellis-type drainage is composed of a high density of small to medium perennial streams contributing to higher flow perennial rivers, including the Tennessee, the Holston, the Little Tennessee, and the Clinch. The vegetation of the ecoregion is primarily Appalachian oak forest, although roughly 40 percent of the forest has been cleared for agricultural and urban land uses (SAMAB 1996e). The pre-European vegetation of the area consisted of over 92 percent forest species including oak, chestnut, and pine (Braun 1950).

Most counties within the Central Ridge and Valley physiographic province have experienced steady population growth over the last several decades. In 1990, population density in the Southern Appalachian Assessment Area (SAA) ranged from 4.4 to 1558.1 persons per km^2, with Knox and Hamilton counties having the highest densities (SAMAB 1996d). My study area contains 78 cities, as well as many rural farming communities. The notable physical and demographic variability of this region creates an excellent test area for ecological analysis of human impacts at a regional scale.

Land ownership in the study area is only 0.7 percent federal and 1 percent state owned, consisting primarily of private land holdings (98 percent). Previous research in this region has shown significantly more forest loss on private lands than in publicly managed areas (Wear and Flamm 1993, SAMAB 1996e, Turner et al. 1996). The entire study area for this project falls within the boundaries of the SAA area. Approximately 84 percent of the riparian lands in the SAA area are in private ownership (SAMAB 1996e). In the SAA database from 1996, these private lands had the least percentage of intact riparian forests – approximately 60 percent compared to more than 90 percent on each category of public lands (SAMAB 1996e).

Another study, in the Little Tennessee River Basin of western North Carolina, looked at land cover by ownership within part of the SAA area holdings (Turner et al. 1996). It found that land ownership had a significant effect on forest presence, with private lands having less forested area and more small forest patches than public holdings (Wear and Flamm 1993, Turner et al. 1996). Researching an area of predominately private-owned land allows for focus on the relationship between private land management practices and riparian forest condition. The management of public holdings tends to be more regulated, with specific efforts made to protect riparian environments (Wear and Flamm 1993).

Chapter 3: Methods

Study Area

I used several different datasets to research riparian condition in the Central Ridge and Valleys ecoregion. I obtained the data from varying sources, each representing the best available source of such geographic information. I acquired, re-projected, and manipulated coverages for land cover, Omernik's ecoregions, streams, states, counties, roads, and census block group data.

The projection for all coverages in this project is Albers Conical Equal-Area Projection with the datum of NAD83 employing the GRS1980 ellipsoid. The units used are meters. The locally appropriate standard parallels are 34° 00' and 38° 00' with a central meridian of 82° 00' and the latitude of the origin at 33° 00'. I chose this projection because it is considered appropriate for small regions as well as for the conterminous United States (ESRI 1997). The area calculations in this projection are accurate and there is minimal distortion of shape and distance. I used Environmental Systems Research Institute (ESRI®) ARC/INFO 8 GIS software to manipulate and analyze the various data layers.

Study area definition

After the coverages were acquired, the next step was to define the study area. The definition of the study area was based on two sets of data: Omernik's ecoregions and eleven-digit watersheds. A coverage of the Omernik and EPA's Level II 1:250,000 scale ecoregions was downloaded from the USGS website (<http://www.usgs.gov>). I used Omernik's Level II ecoregions to isolate the study area, capturing the Central Ridge and Valleys ecoregion and utilizing it to clip the other data layers. Clipping out the specific area of interest conserved memory space and processing time. I obtained the eleven-digit watersheds (Hydrological Unit Code, or HUC) from the Tennessee Valley Authority (TVA). The 1:100,000 scale eleven-digit HUCs served as the units of study.

Study area delineation

The selected ecoregion contains 162 watersheds units; however, not all of these watershed units are wholly within this ecoregion. Therefore, I excluded watersheds with less than 80 percent presence within the selected ecoregion. Watershed units with obvious political rather than hydrologic boundaries, such as state lines, were also excluded. The few watersheds remaining within the state of Virginia were removed, because they were non-contiguous with the remaining study units. The final study area contains 82 watershed units (see Figure 1).

Data acquisition and manipulation

Population Data

I obtained block group level human population data for 1995 from the United States Census (<http://www.census.gov>). I also downloaded 1995 shape files of the block groups for the study area from ESRI (<http://www.esri.com>). I joined the data to the block group shape files to create a block group level coverage of human population.

Using ArcInfo, I spatially joined the census block groups with the HUC coverage to create coverage with both HUC and block group information. Based on the area, I calculated the proportion of each block group within each HUC, and then multiplied this value by the block group level population value. The results, summed by watershed, gave the total number of persons per HUC. I divided this variable by the watershed area to produce population density per HUC, "POPDENS."

Land Use Data

I used FTP to extract the land cover data from the United States Geological Service (USGS) web site (USGS 2001). This land cover raster coverage, known as the Multi Resolution Land Cover (MRLC), was originally built from 30 meter Landsat 5 Thermal Mapping (TM) data from the early 1990s as a part of the National Land Cover Data (NLCD) project. The land cover classification encompasses 32 natural and non-natural land cover classes that delineate various land uses including deciduous forest, pasturelands, high-density housing, and mines. It should be noted that pasture areas, as defined in this study and in the MRLC, include livestock lands as well as hay fields. Similarly, croplands include fields currently in use as well as those that are in rotation or are fallow. The classifications used in the MRLC are detailed in the Appendix.

I reclassified the MRLC land cover data into a land use coverage containing representative land uses within the study area (Table 1). MRLC categories that were not present within the study region were excluded from the reclassification. The resulting land use coverage included the following 11 classes: low-density residential, high-density

Table 1. Variables used in this study

Variable Description	Raw Data Source	Percent of total area	Percent of total riparian area	Representative Variable in Analysis
Population density	U.S. Census	-	-	POPDENS
Low-density residential	MRLC land cover class 21	2.14	1.99	LDRES
High-density residential	MRLC land cover class 22	0.38	0.36	HDRES
Commercial, industrial	MRLC land cover class 23	1.20	1.29	COMIND
Barren	MRLC land cover class 31	0.01	0.01	BARE
Mines	MRLC land cover class 32	0.10	0.10	MINE
Transitional	MRLC land cover class 33	0.55	0.22	TRANS
Pasture	MRLC land cover class 81	21.33	25.31	PASTURE
Row crops	MRLC land cover class 82	4.19	4.99	CROP
Urban/ recreational grass	MRLC land cover class 85	1.19	1.12	GRASS
Natural areas	MRLC land cover classes 41, 42, 43, 91, and 92	64.52	64.21	NATURAL
Other	MRLC land cover classes 0 and 11	4.40	0.40	OTHER
Road density	SAA dataset	6.39	-	ROAD
Riparian road density	SAA dataset	-	9.13	RIPROAD

residential, commercial and/or industrial, barren, mines, transitional, recreational grasses, row crops, pasture, natural areas, and other. Figure 2 spatially depicts the 11 land use classes used in this study.

The non-natural land uses categories I used include low-density residential, high density residential, commercial and/or industrial, mines, transitional, recreational grasses, row crops, and pasture. In the natural category, I combined deciduous, evergreen, and mixed forest groups, as well as the wetland group. Intact forests and wetlands are grouped together into the "natural" category because they are considered to be the natural state for riparian areas in this region of the United States. Grouping natural land uses distinguishes them from the non-natural land use classes. This distinction is important to my research design, as I am interested in the change from natural to non-natural land uses. The classification "other" includes pixels identified as water or null data. I excluded the "water" class as it does not constitute a non-natural land use nor does it represent natural forest or watershed land areas.

I acquired the 1:100,000 scale River Reach RF3 stream coverage from TVA. This dataset is also available for this area from the Southern Appalachian Man and the Biosphere (SAMAB) project at <http://www.samab.org/>. I clipped this dataset to produce a stream coverage of the study area. The National Hydrologic Database (NHD) stream spatial dataset is available from the USGS at <http://nhd.usgs.gov/>. I downloaded, appended, and re-projected both datasets to produce an updated stream coverage for the study area. I compared the two data sources using 'change' in ARC/INFO. Very few differences existed. The NHD data include connections between

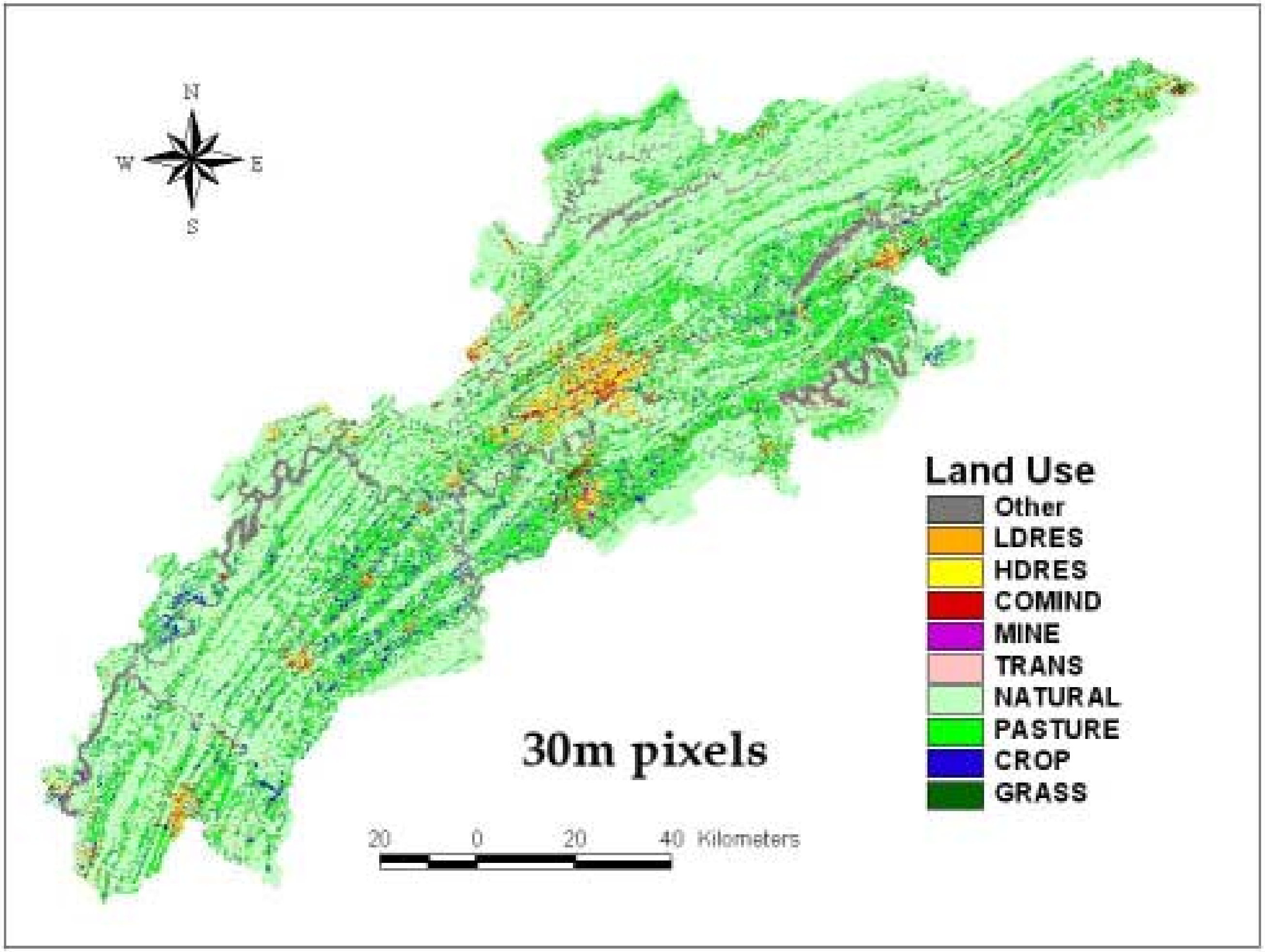

Figure 2. Land use classification

previously fragmented data and contain several new streams. However, there are some obvious errors in these data such as quadrangle boundaries represented as streams in a few cases. Therefore, I decided to use the RF3 dataset for the stream information. The original RF3 stream data contain stream, rivers, lakes, and reservoir features. Because the study area has been defined by watersheds that drain to streams rather than by flooded river valleys, I excluded non-stream features, notably reservoirs, from the river reach dataset.

The National Wetlands Inventory (NWI) is available through the U.S. Fish and Service website (<http://www.fws.gov>). This dataset had already been incorporated into the MRLC land cover dataset. I reclassified wetland classes from the MRLC into a new grid representing wetland presence. I used the wetlands coverage to identify wetlands that are adjacent to streams, as buffers around such wetlands also constitute riparian areas. I joined the land cover data with the study area stream data to create a combined coverage that included adjacent wetland areas. I then converted this coverage to a raster coverage representing all stream and wetlands areas to be buffered.

I created a riparian buffer of 90 m on each side of all streams and adjacent wetlands in the raster coverage. The use of a set riparian buffer width is the standard approach for GIS riparian buffer delineation (Haycock et al. 1993, Barling and Moore 1994). The 90 m scale is appropriate, as the size of the feature studied, e.g., the riparian area, should be two to five times larger than the spatial feature of interest, e.g., the 30 m land coverage, in order to account for scale and resulting potential for error (O’Neill et al. 1996). The 90 m-wide buffer area served as the “riparian area” in the analysis. As the stream and wetland coverage had been rasterized to 30 m pixels prior to the calculation of the buffers, the distance from the original vector feature ranges from 90 to 104 m. Therefore, the minimum width of the riparian area is 210 m. The riparian buffer and its associated land cover classifications are represented in Figure 3. The horizontal error associated with a 1:100,000-scale line coverage is 50.6 m (USGS 2001). The buffer distance on either side of the feature is greater than this error.

I calculated the proportion of each land use present within each watershed (Eq. 1).

Equation 1:

$$\text{Proportion of total area} = \frac{\text{Total number of pixels in specific land use classification}}{\text{Total number of pixels in the watershed}} \tag{1}$$

Thus, the numerical representation of each land use variable in each watershed unit is a dimensionless value indicating the proportion of the area of the watershed it occupied in the early 1990s. To numerically represent the absence of riparian forest, I performed a similar calculation at the riparian level within each watershed. I calculated the proportion of riparian area in forested, non-forested, and other condition within each eleven-digit watershed. I defined RIPLOSS, a new variable, as the proportion of riparian buffer area in non-natural, non-water land uses (Eq. 2). Figure 4 maps RIPLOSS by watershed unit.

Equation 2:

$$\text{RIPLOSS} = \frac{\text{Total number of non-natural land use pixels in riparian area}}{\text{Total number of pixels in the riparian area}} \tag{2}$$

Sewee Creek Watershed, Meigs County, TN

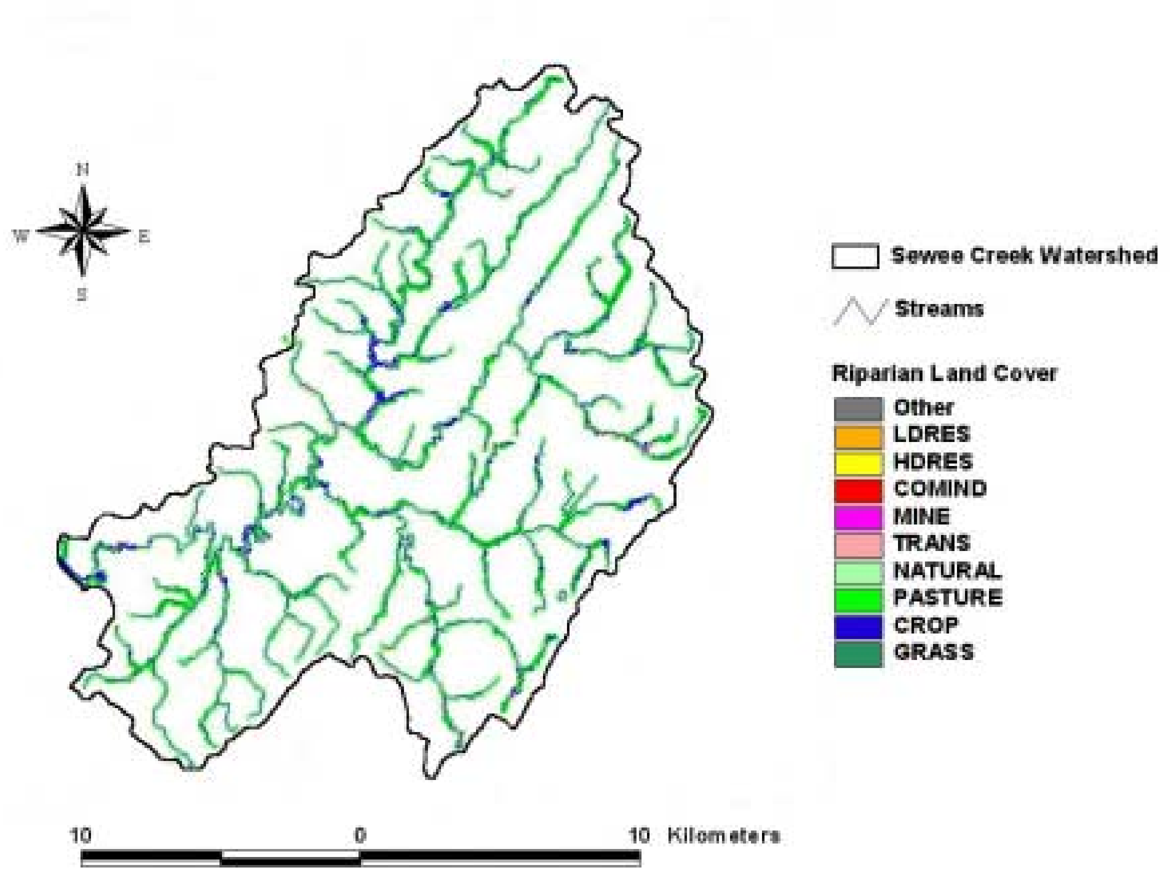

Figure 3. Example of the defined riparian buffer area and associated land cover classification

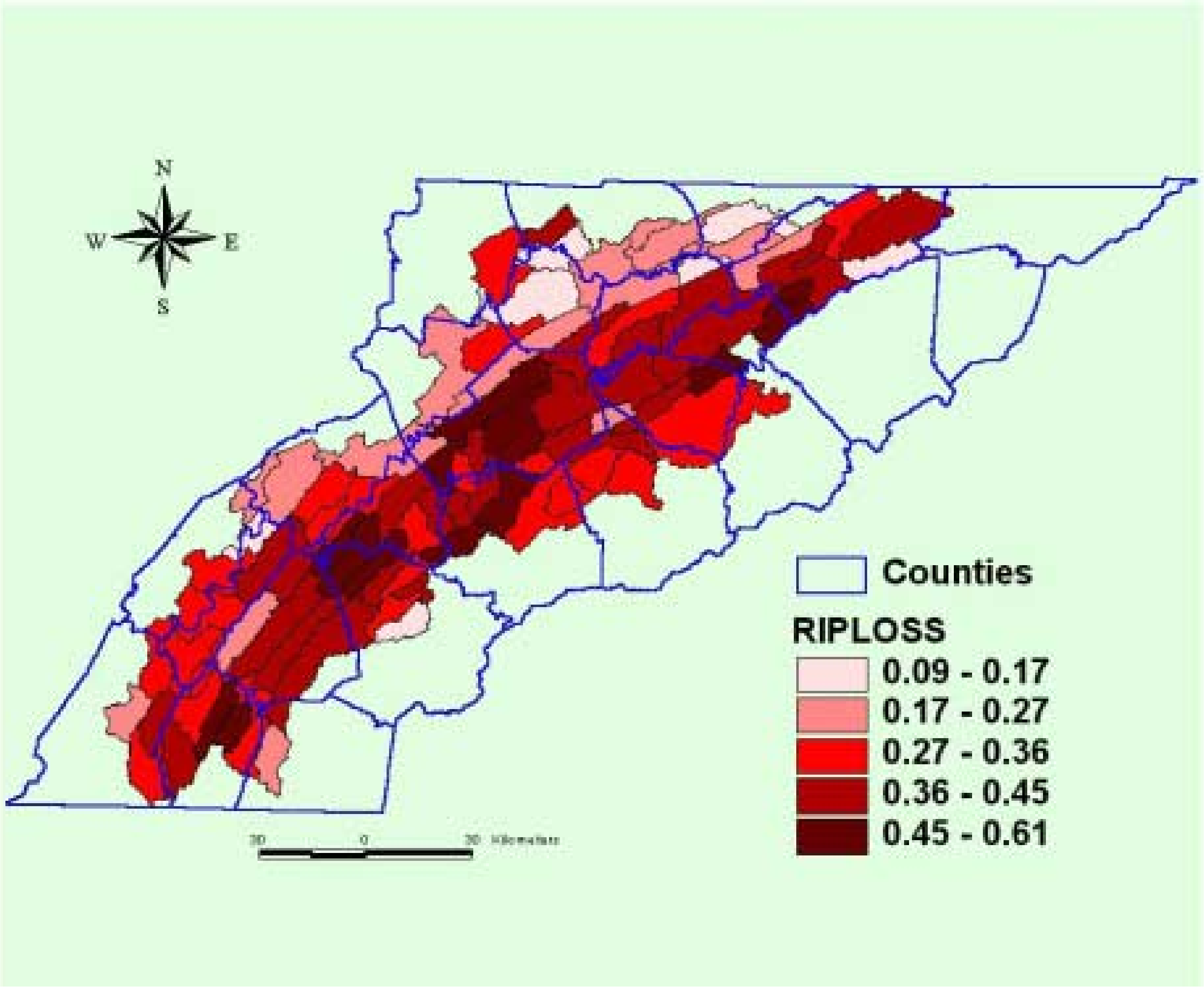

Figure 4. The spatial distribution of RIPLOSS by watershed unit .

Road Data

I derived the road data from the Southern Appalachian Man and the Biosphere (SAMAB) dataset. Although more up to date road coverages were available, I used this dataset because it is most closely associated with the early 1990s time period of the land cover dataset. To simplify the SAA road data, I merged four road class coverages into a single large road coverage for the entire study area. I converted these vector data to raster and reclassified them into a road presence grid. Then, I calculated road density, ROAD, as the total number of pixels that contain road divided by the total number of pixels in the watershed unit (Eq. 3).

Equation 3:

$$\text{ROAD} = \frac{\text{Total \# of pixels containing a road}}{\text{Total \# of pixels in watershed}} \tag{3}$$

I similarly calculated road density in the riparian areas, RIPROAD (Eq. 4).

Equation 4:

$$\text{RIPROAD} = \frac{\text{Total \# of pixels containing a road in riparian buffer area}}{\text{Total \# of pixels in riparian buffer area}} \tag{4}$$

Other Data

Detailed United States county and state boundaries for Tennessee were available as polygons within the ESRI® ArcView data files. I clipped the counties coverage using the study area layer in order to capture all counties within the study area. Then I matched the projection of these datasets to that of the land cover data. The use of state and county boundary coverages aids in the identification and visualization of the datasets and results.

Analysis

The aforementioned datasets were used to approach the predictions posed in Chapter 1 within a Geographic Information System (GIS). I used ESRI® ARC/INFO software to analyze the GIS datasets. For statistical data analysis beyond the scope of ARC/INFO 8, I used Microsoft Excel and SPSS statistical software package. I derived 12 variables from the GIS data: POPDENS, NATURAL, LDRES, HDRES, COMIND, PASTURE, CROP, MINE, TRANS, GRASS, ROADS, and RIPROADS.

Population data regression

POPDENS was entered into a backward stepwise linear regression analysis with RIPLOSS as the dependent variable. The criteria for the model was $p = 0.05$ to enter the regression and $p = 0.10$ to remain in the model.

Correlations

I created a correlation matrix with each land use and road variable used in the analyses and calculated both the significance (2-tailed) and Pearson’s product-moment correlation coefficient. I tested these variables for significance using Bonferroni's correction. This method corrects for potential capitalization of a Type 1 error that can be caused by the input of a larger number of variables. The Bonferroni method reduces the alpha level of each individual test to ensure that the overall risk remained 0.01 (Elston and Johnson 1994). I used an alpha value of 0.0004 to identify significant correlations between variables. For analysis of residuals, I calculated the proportion of each land use within the riparian area (Eq. 3)

Equation 5:

$$\text{Proportion of riparian area} = \frac{\text{Total number of land use pixels in riparian area}}{\text{Total number of pixels in the riparian area}} \tag{5}$$

Land cover data regressions

An equation of the form presented in Equation 6 was tested for the regression model:

Equation 6:

$$\hat{Y}_i = a+b_iX_i+...+ b_nX_n+\varepsilon \tag{6}$$

$\hat{Y}$	predicted (fitted) Y
X	independent variable
a	Y-intercept
b	partial regression coefficients
i	positive integer 1 through n
ε	error

Into the first backward stepwise linear regression analysis, I entered RIPLOSS as the dependent variable and NATURAL, LDRES, HDRES, COMIND, PASTURE, CROP, MINE, TRANS, GRASS, ROADS, and RIPROADS as independent variables. The tolerance of the model was set at $p = 0.05$ to enter the regression and $p = 0.10$ to remain in the model.

The second stepwise linear regression analysis addresses the relationship between the dependent variable, RIPLOSS, and alteration of the landscape for various non-natural land use activities. The same variables were entered as in the first stepwise linear regression with the exception of NATURAL. The tolerances remained the same as in the first model. I calculated the normalized residuals for the second regression model and tested these values for normality and outliers. I selected all study units with outlying residual values (values > 1.5 or < -1.5) and examined their spatial relationships to all available variables available including POPDENS, the proportion of each land use within each watershed, and the proportion of each land use within each riparian area.

Difference t-test

A t-test was used to evaluate the differences in means of the various land uses within the watershed with those of the riparian area alone. I compared the relative areal extent of each land use within entire watersheds to that within riparian areas alone, by testing the significance of the mean differences between the proportions of the variables (NATURAL, LDRES, HDRES, COMIND, PASTURE, CROP, MINE, TRANS, GRASS, and ROADS) at the watershed and riparian levels. For each land use variable tested, the proportional land use difference was calculated using equation 7.

Equation 7:

$$\text{Proportional Land Use Difference} = \frac{\text{\# of pixels of land use in watershed}}{\text{Total \# of pixels in watershed}} - \frac{\text{\# of pixels of land use in riparian area}}{\text{Total \# of pixels in riparian area}} \quad (7)$$

For each land use variable, I performed a one-sample t-test to compare the mean of the proportion of area occupied by that land use in the watersheds to that in the respective riparian areas alone. Each variable was tested for significance using an alpha value calculated with Bonferroni's correction for of 10 variables with an initial alpha of 0.01. Using a strict Bonferroni alpha value of 0.001, I was able to bring the overall alpha level back to 0.01.

Chapter 4: Results

RIPLOSS (Figure 3) exhibits visible spatial patterns in relation to several of the variables investigated in this study including POPDENS, PASTURE, LDRES, CROP, and GRASS. Each variable is discussed below within the context of the applicable statistical testing results.

Population Regression

Figure 5 shows the distribution of POPDENS by watershed. Population density had a positive association with riparian forest loss ($r^2 = 0.141$, beta = 0.375, Pr > F = 0.001, 81 d.f.) in the study area watersheds. Although the relationship between RIPLOSS and POPDENS was significant, the low r^2 value indicates that the variability in POPDENS accounts for only 14 percent of the variability in RIPLOSS within the study watersheds. The regression model is shown in equation 8.

Equation 8:

$$Y_1 = 0.312 + 0.375(X_1) \tag{8}$$

Y_1 RIPLOSS
X_1 Population Density (persons/sq. mi.)

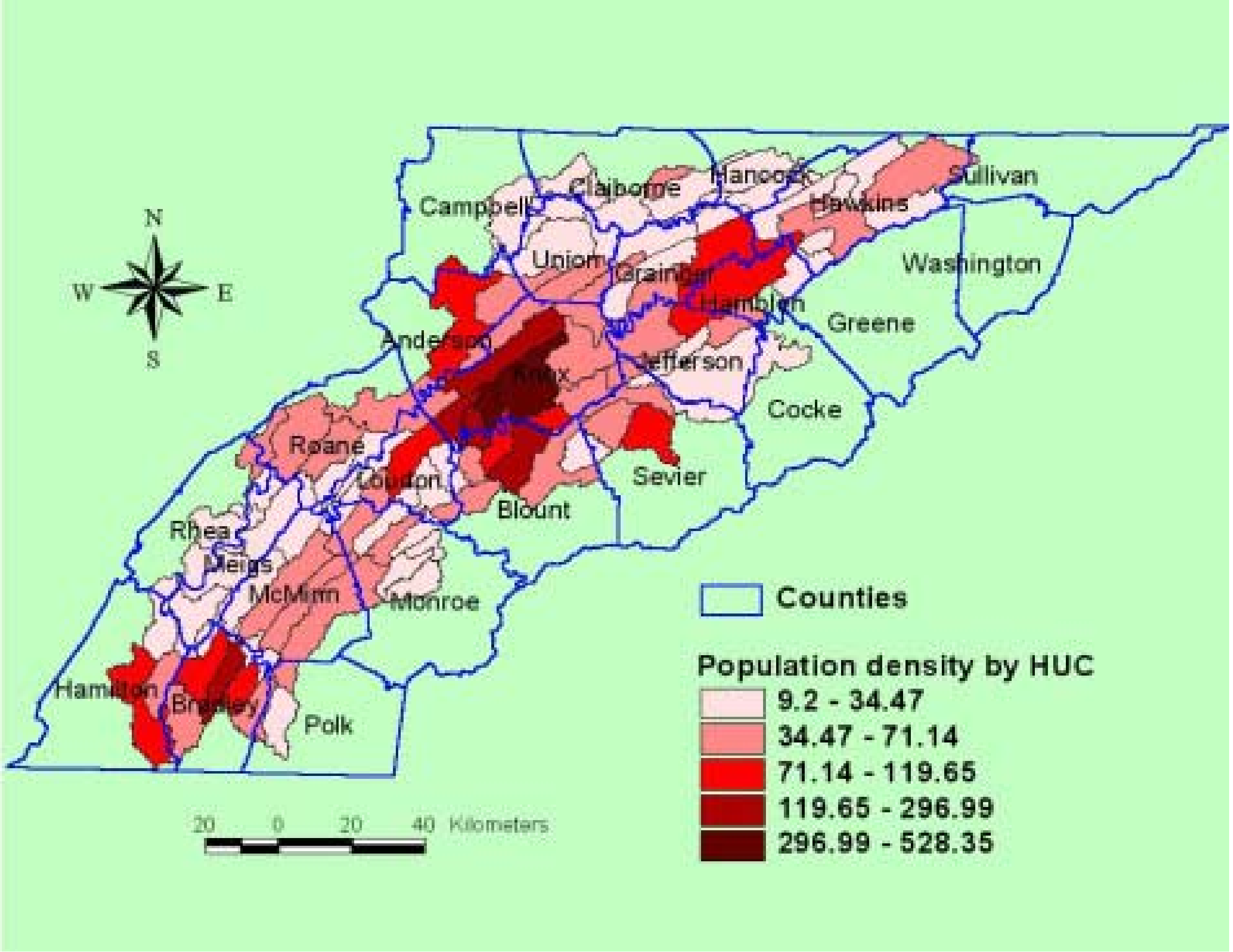

Figure 5. The spatial distribution of POPDENS by watershed unit.

Stepwise linear regressions

The expressions for the estimated regression lines for each of the response variables are shown in equations 9 and 10:

Equation 9:

$$Y_1 = 0.286 - 0.207(X_2) + 0.610(X_3) + 2.910(X_4) + 0.860(X_5) + 1.226(X_6) \quad (9)$$

Equation 10:

$$Y_1 = 9.905E^{-02} + 0.722(X_3) + 0.997(X_7) + 1.229(X_5) + 1.405(X_6) \quad (10)$$

Y_1	RIPLOSS
X_2	NATURAL
X_3	PASTURE
X_4	HDRES
X_5	CROP
X_6	GRASS
X_7	LDRES

The above equations for each test are further discussed in the sections below.

Stepwise linear regression for all land uses

The five independent variables that entered the regression equation accounted for over 85 percent of the predicted variability in RIPLOSS (Table 2). NATURAL was the first variable to enter the model (R^2 = 74.8 percent, beta = -0.867) and shows a negative correlation with RIPLOSS, with all other variables constant. LDRES, COMIND, MINE, TRANS, ROADS, and RIPROADS were not retained in the optimal model. The correlation matrix for all variables allowed to enter into the regression is shown in Table 3.

Table 2. Results of step-wise linear regression for all land use variables

(expressed as a proportion of area of watershed unit)

Dependent = RIPLOSS

Model	**Predictors**	**Beta**	**Adjusted R^2**
1	NATURAL	-.867	.748
2	NATURAL, PASTURE	-.652 .320	.802
3	NATURAL, PASTURE, HDRES	-.397 .545 .282	.842
4	NATURAL, PASTURE, HDRES, CROP	-.320 .488 .310 .149	.848
5	NATURAL, PASTURE, HDRES, CROP, GRASS	-.221 .501 .252 .199 149	.855

Table 3. Variable Correlations – Pearson's product-moment correlation coefficient

n = 82	**RIPLOSS**	**LDRES**	**HDRES**	**COMIND**	**MINE**	**PASTURE**	**CROP**	**NATURAL**	**GRASS**	**TRANS**	**ROAD**	**RIPROAD**
RIPLOSS	1	.345	.323	.436 (**)	0.119	.758 (**)	.721 (**)	-.867 (**)	.458 (**)	-0.09	.425 (**)	0.048
LDRES	.345	1	.950 (**)	.935 (**)	0.191	-0.173	-0.065	-.425 (**)	.777 (**)	-0.091	.921 (**)	.687 (**)
HDRES	.323	.950 (**)	1	.908 (**)	0.149	-0.191	-0.077	-.368	.682 (**)	-0.057	.940 (**)	.754 (**)
COMIND	.436 (**)	.935 (**)	.908 (**)	1	.287	-0.053	0.001	-.519 (**)	.852 (**)	-0.099	.945 (**)	.693 (**)
MINE	0.119	0.191	0.149	.287	1	0	0.009	-0.17	.320	-0.025	.224	0.117
PASTURE	.758 (**)	-0.173	-0.191	-0.053	0.00	1	.763 (**)	-.672 (**)	0.03	-0.14	-0.039	-.325
CROP	.721 (**)	-0.065	-0.077	0.001	0.009	.763 (**)	1	-.698 (**)	0.035	0.01	-0.003	-.332
NATURAL	-.867 (**)	-.425 (**)	-.368	-.519 (**)	-0.17	-.672 (**)	-.698 (**)	1	-.520 (**)	0.074	-.469 (**)	-0.076
GRASS	.458 (**)	.777 (**)	.682 (**)	.852 (**)	.320	0.03	0.035	-.520 (**)	1	-0.133	.802 (**)	.524 (**)
TRANS	-0.09	-0.091	-0.057	-0.099	-0.025	-0.14	0.01	0.074	-0.133	1	-0.113	-0.114
ROAD	.921 (**)	.940 (**)	.945 (**)	.224	-0.039	-0.003	-.469 (**)	-.439 (**)	.802 (**)	-0.113	1	.750 (**)
RIPROAD	.687 (**)	.754 (**)	.693 (**)	0.117	-.325	-.332	-0.076	-0.057	.524 (**)	-0.114	.750 (**)	1

(** = significant: Bonferroni alpha < 0.0008, p < 0.01)

Table 4. Results of step-wise linear regression using only non-natural land uses

Dependent = RIPLOSS

Model	Predictors	Beta	Adjusted R^2
1	PASTURE	.758	.569
2	PASTURE, LDRES,	.843 .491	.803
3	PASTURE, LDRES, CROP	.636 .472 .267	.831
4	PASTURE, LDRES, CROP, GRASS	.594 .333 .284 .171	.840

Stepwise linear regression for only non-natural land uses

When considering only the non-natural land use variables, PASTURE dominated the models, predicting 56.9 percent of the riparian forest loss (Table 4). The four variables that remained in the regression were positively correlated with RIPLOSS. HDRES, COMIND, MINE, TRANS, ROADS, and RIPROADS were not retained in the optimal model. Figures 6-9 depict the spatial distributions of PASTURE, LDRES, CROP, and GRASS over the 82 study watershed units.

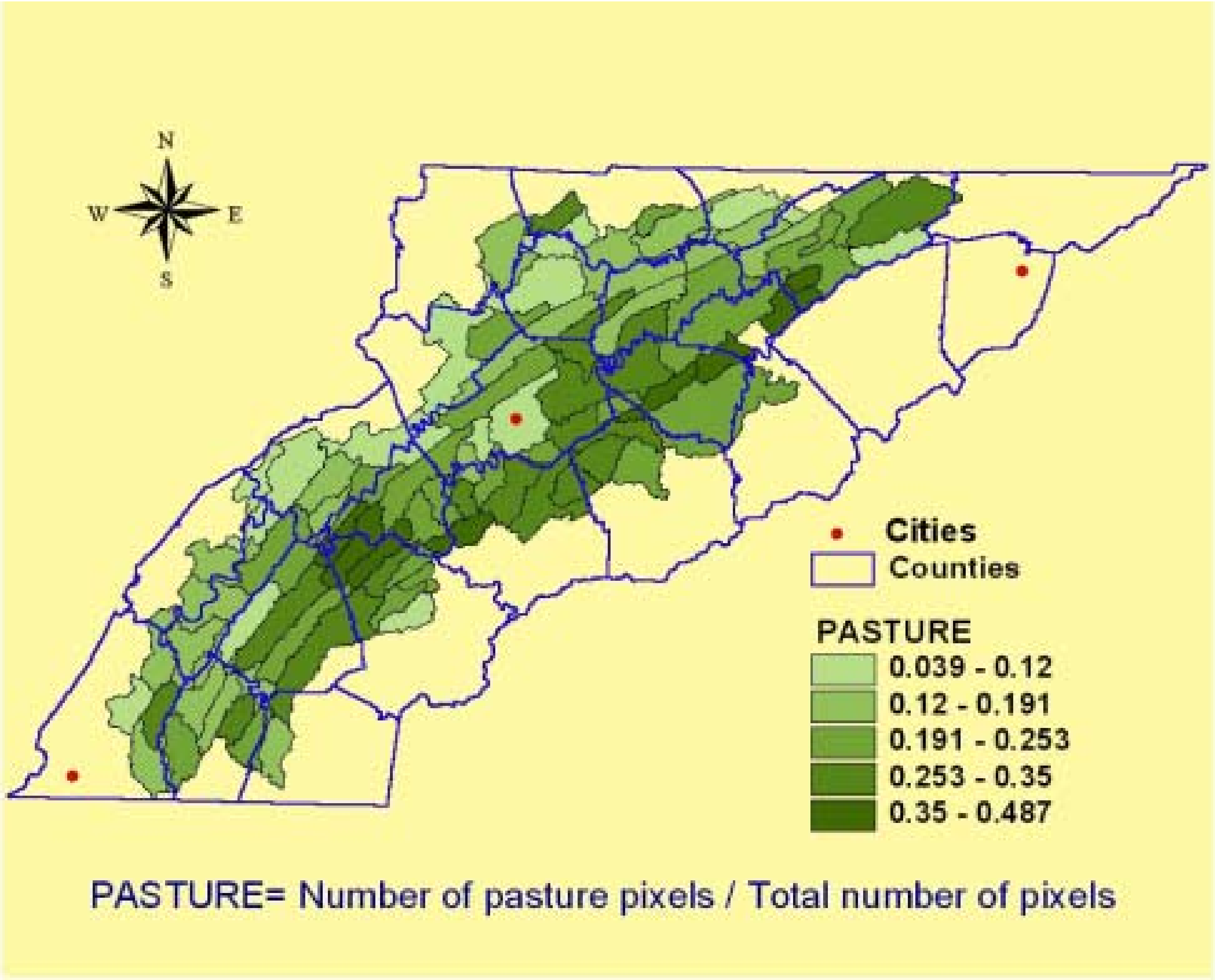

Figure 6. The spatial distribution of PASTURE by watershed unit.

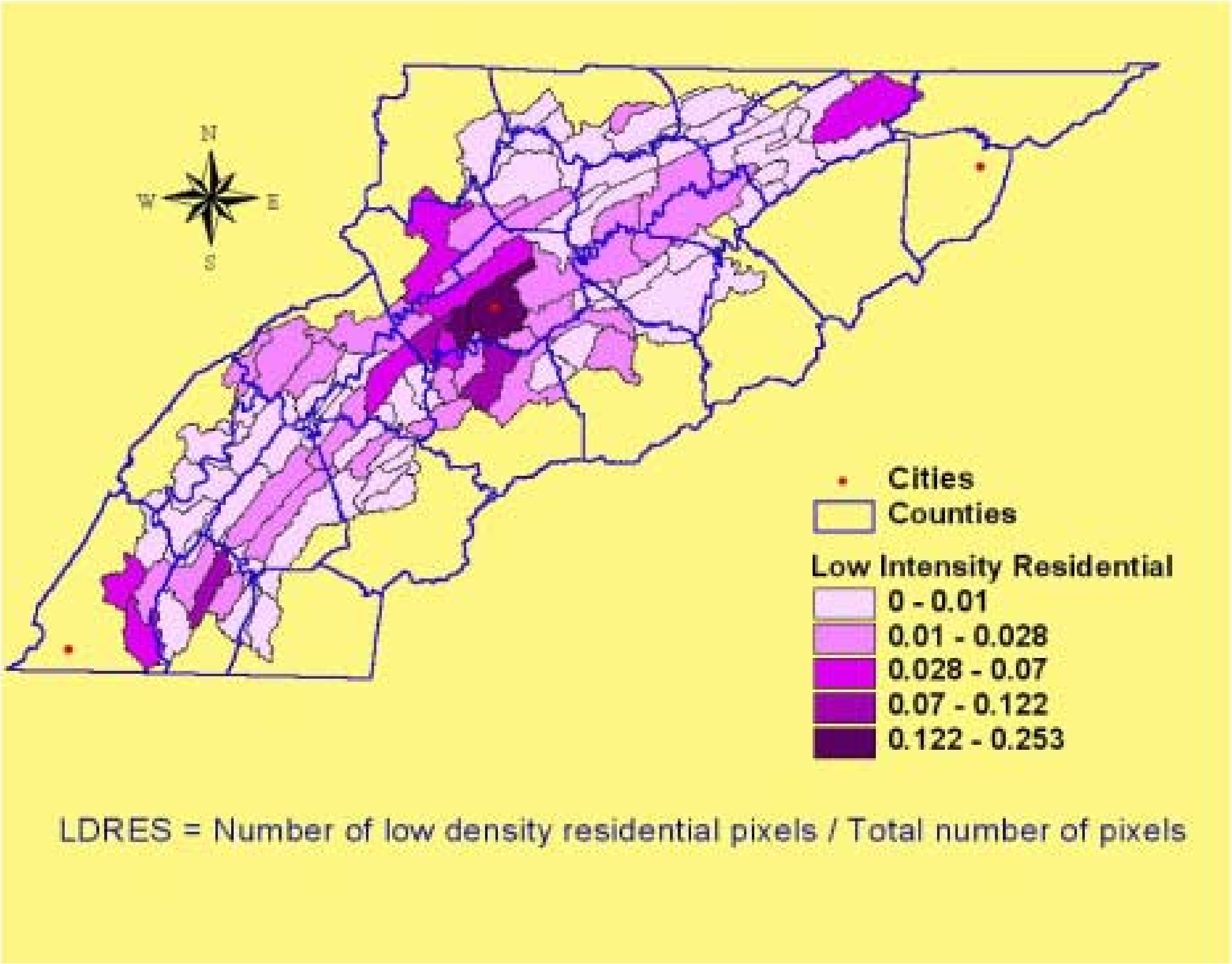

Figure 7. The spatial distribution of LDRES by watershed unit

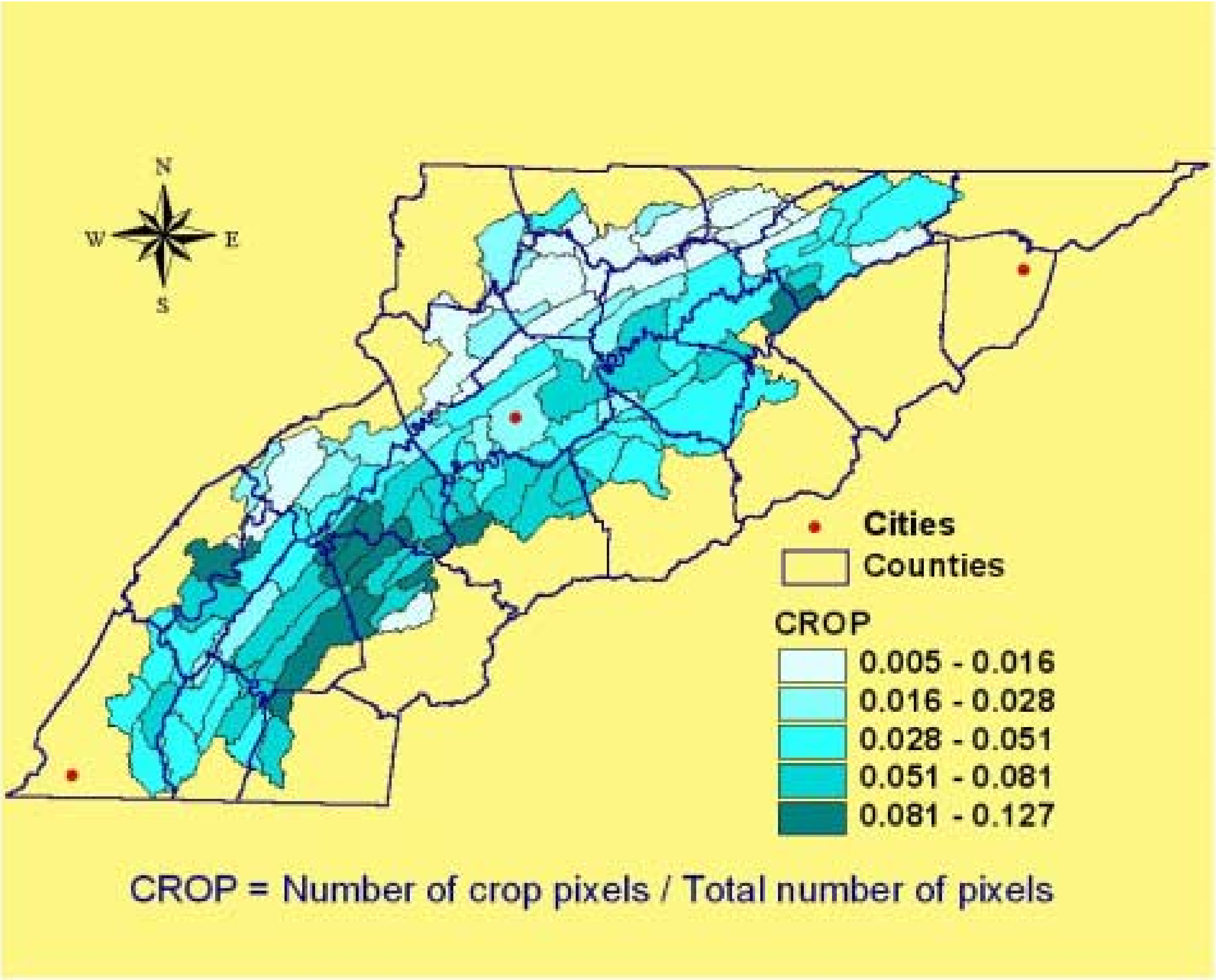

Figure 8. The spatial distribution of CROP by watershed unit.

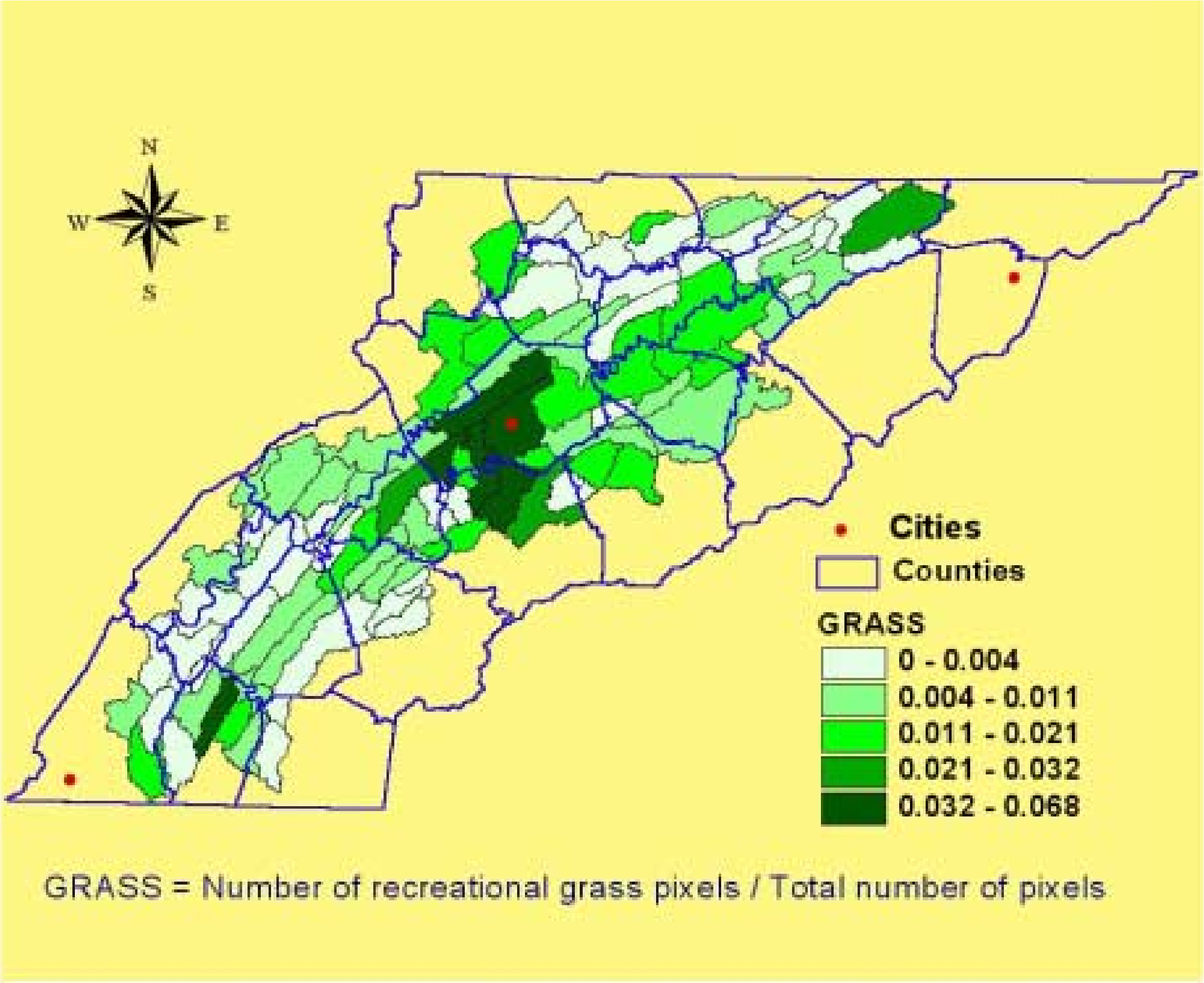

Figure 9. The spatial distribution of GRASS by watershed unit.

Residual testing

The residuals from the second step-wise multiple linear regression model showed a spatial relationship to the difference in the proportion of pasture between the riparian and watershed areas. Positive residual values > 1.5 showed a relationship with very low pasture difference values. Conversely, negative residual values occurred in watersheds with extremely high pasture difference values. The watersheds with outlier residuals from the second stepwise multiple linear regression model are depicted in Figure 10.

Difference between watershed and riparian area proportions

For each land use variable, a one-sample t-test was performed to compare the mean of the proportion of each land use in the watersheds to that in the respective riparian areas alone (Table 5 and 6). Highly significant relationships with negative t values were found for PASTURE, CROP, and ROAD. These results indicated that the mean percentage each of these land usages was higher in the riparian area than in the watershed area as a whole. TRANS was highly significant with a positive t value, indicating less area in transitional land use in the riparian buffer area than within the watershed as a whole. However, the four significant variables have minimal mean differences indicating only a slight but significant change in the land use between riparian and watershed levels.

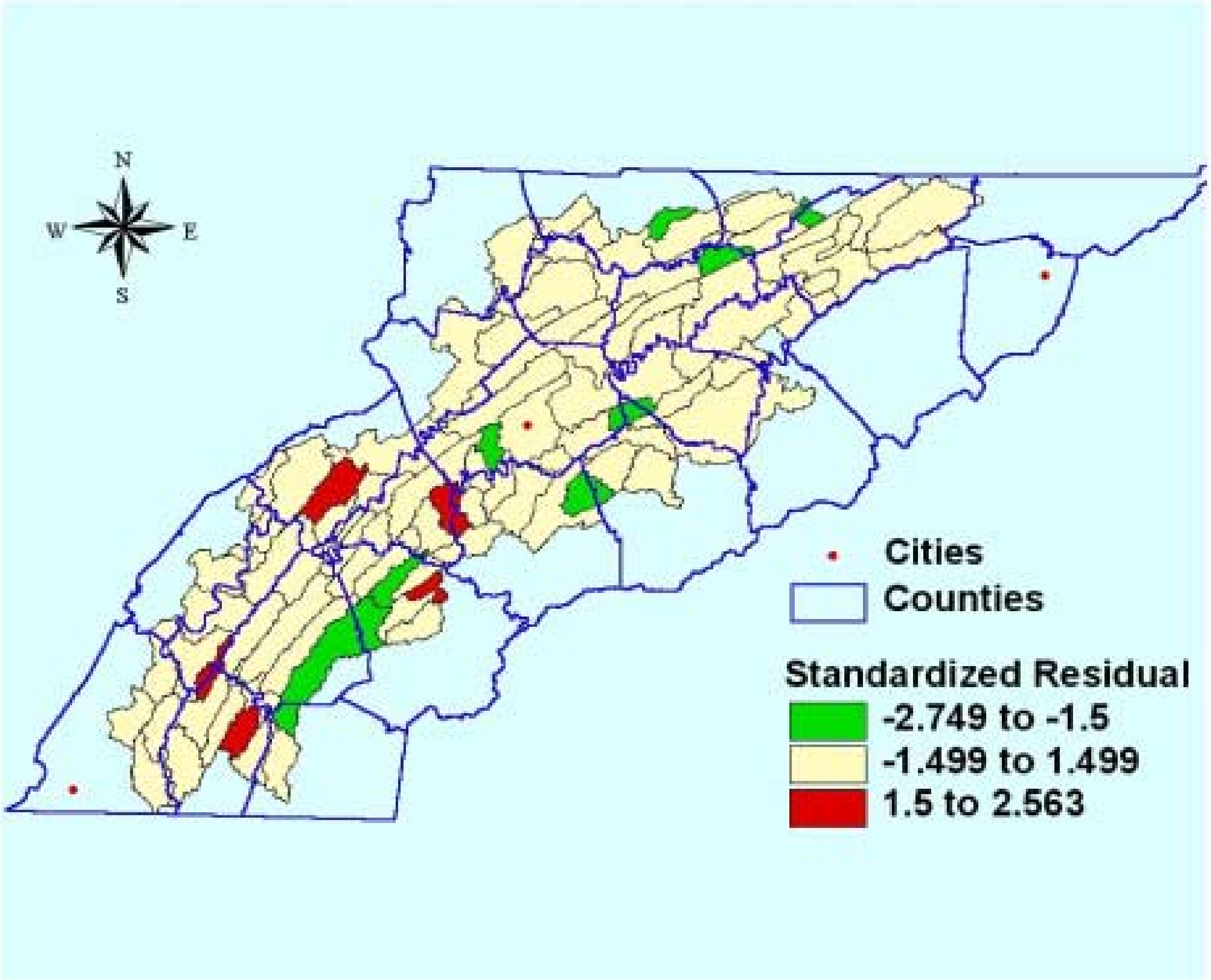

Figure 10. Stepwise multiple linear regression residuals

Table 5. One-sample statistics

Comparison of land use proportions within entire watershed versus

those within riparian area only

Variable (n=82)	Mean	Std. Deviation	Std. Error Mean
LDRES	8.956E-04	7.519E-03	8.303E-04
HDRES	1.649E-04	2.263E-03	2.499E-04
COMIND	-1.2352E-03	7.257E-03	8.014E-04
MINE	1.869E-04	1.947E-03	2.150E-04
TRANS	1.768E-03	4.445E-03	4.909E-04
NATURAL	-2.6237E-03	6.474E-02	7.150E-03
PASTURE	-2.9608E-02	4.438E-02	4.901E-03
CROP	-5.9592E-03	1.207E-02	1.333E-03
GRASS	3.804E-04	4.885E-03	5.394E-04
ROAD	-2.7333E-02	1.872E-02	2.068E-03

Table 6. One-sample t-test

Comparison of land use proportions within entire watershed versus those within riparian area only

Landuse: Proportional difference from whole watershed to riparian buffer area	Test Value = 0 df = 81 * = significant Bonferonni alpha < 0.001, p < 0.01	
	t	Sig. (2-tailed)
Low Density Residential	1.079	.284
High Density Residential	.660	.511
Commercial/Industrial	-1.541	.127
Mines	.869	.387
Transitional	3.602	.001*
Natural Areas	-.367	.715
Pasture	-6.041	.000*
Cropland	-4.470	.000*
Grass	.705	.483
Roads	-13.218	.000*

Chapter 5: Discussion

Effects of population on RIPLOSS

While the relationship between population density and proportion of riparian forest loss was highly significant, the percent of variance in RIPLOSS explained by the POPDENS was quite low. The influence of population density on riparian forest loss was discernable but exhibits a low predictive ability.

Although RIPLOSS (Figure 4) was relatively high in watersheds characterized by the highest population densities (Figure 5), it was similarly high in some watersheds with low population densities, hence the low r^2. Dense human populations place increasing pressure on riparian areas for residential, commercial, and transportation development. However, riparian areas remain common locations for crop and livestock agricultural activities. Agricultural areas, characterized by dispersed population densities, account for most of the non-natural land use area in this region.   The results of the t-test for differences in agricultural area between watersheds and riparian areas alone demonstrate that these land uses are also slightly more common in the riparian buffer area than throughout the watershed (Table 6).

The weak, positive relationship between RIPLOSS and POPDENS supports results by Jones et al. (1997) that found inverse relationships between population density and riparian forest presence in proximity to heavily urbanized areas in the Mid-Atlantic region. Human population density, used in the present study as an indicator of human presence, does not explain the actual activities that lead to the decrease of riparian forest area. In further consideration of the alteration of the landscape, it is important to look at human land use activities in each watershed as they relate to the loss of the riparian forests.

Effects of land use on RIPLOSS

Natural Areas

The proportion of natural areas within each watershed proved to be the strongest predictor of RIPLOSS in this study (Table 2). The presence of natural areas is highly negatively correlated with RIPLOSS (r = -0.867). Further query into the dominance of the natural areas variable leads to the question of what determines the distribution of natural areas in watersheds. Turner et al. (1996) found a highly significant negative relationship between watershed level forest loss and slope on private lands in the Little Tennessee River Basin area. In areas of less slope, land use development has greater economic feasibility. In steep areas, it is more difficult to harvest forests, build roads, and develop properties. This physical factor may account for much of the floodplain development patterns witnessed in the often steep-sloped Ridge and Valley ecoregion.

NATURAL accounted for most of the explanatory power of the first model (Table 2). Since NATURAL and RIPLOSS are so strongly correlated, controlling NATURAL in the stepwise linear regression allows for analysis of the actual developmental land usages that influence RIPLOSS. Therefore, the second stepwise linear regression offers more insight into the issue of riparian forest alteration.

Agricultural land uses

In the modified stepwise linear regression (Table 4), PASTURE accounted for 57 percent, of the variability seen in RIPLOSS, holding all other variables constant. Croplands also contributed to the final regression model, adding a predictive ability of just 0.09 percent. Hence, the variability of both of the agricultural variables contributes positively to the explanation of the observed proportion of riparian forest loss.

Some explanation may lie in the development patterns of the region and the economic value of the land. Pasture is the predominant non-natural land use in the region, extending over 21 percent of the study area (see Table 1). According to the classification, croplands comprise another 4 percent. In this topographically diverse landscape, pasture and croplands are commonly found in the valley floodplain areas. Historically, many roads were first built along streambeds, providing people easy access for harvest of the floodplain forests and development of the relatively level land (SAMAB 1996d). The rich alluvial soils of the bottomland riparian areas proved to be some of the best available lands for agricultural development (SAMAB 1996e). Today, agricultural practices still have a strong presence in riparian areas of the Central Ridge and Valley ecoregion (see Figures 6 and 8).

Economic pressures often drive farmers to utilize every available surface of their properties for agricultural production, making a riparian buffer strip a costly sacrifice of usable land (Malanson 1993, NRCS 1999). In agricultural riparian areas, the farmer must choose between a riparian conservation buffer and valuable additional crop or fodder producing land. That Tennessee had the second highest increase in farm real estate value in the continental U.S. between 1994 to 1998 (Derrick 1999) highlights the economic pressure on Tennessee farmers.

The dominance of agriculture, while not surprising, is a key element in the management of local riparian systems. There is a correlation between CROP and PASTURE (see Table 3, $r = 0.763$, $p<0.01$), and the combination of the variance of these agricultural land uses predicts over 80 percent of the variability found in RIPLOSS. Both categories of agricultural areas can alter water and habitat quality within watersheds. Croplands can produce runoff containing fertilizer and pesticide and often contribute silt to adjacent stream systems (Schlosser and Karr 1978). Natural riparian areas adjacent to upland crop agriculture fields have been shown to effectively ameliorate these sources of non-point source pollution (Schlosser and Karr 1978, Peterjohn and Correll 1984, Lowrance et al. 1984a). Agricultural livestock practices have been shown to contribute significant quantities of silt, nitrogen, phosphate, and bacterial contaminants to nearby streams. Agricultural non-point source pollution can be decreased by strategic use of riparian buffers. Lowrance et al. (1984a and 1984b) documents effective buffering of livestock agriculture non-source pollution by natural riparian forests in the southeastern United States.

The t-test (Table 6) shows significantly higher mean proportions of pixels classified as pasture and as croplands in the riparian areas when compared to those of the entire watershed area. Fertile floodplain valleys are ideal areas for producing agricultural products, particularly in a region with considerable relief. The primary agricultural cash crop in eastern Tennessee is tobacco (SAMAB 1996d), which is frequently grown in relatively narrow fields proximate to creeks and rivers of the study area (pers. obs.). Much research has demonstrated that agricultural operations in riparian and upland areas are major sources of non-point source pollution.

Investigation of the outlying residuals shows that in some watersheds characterized by an extreme positive difference in pasture percentage, RIPLOSS is significantly over-predicted (see Figure 11). In Figure 11, a positive pasture difference value indicates a greater proportion of pasture in the watershed as a whole than in the riparian area alone. Were the model to be used to predict the variability of RIPLOSS in east Tennessee based on measurements of PASTURE, LDRES, CROP, and GRASS, in some watersheds the proportionate loss of riparian forests could be significantly less than predicted.

The opposite effect, under-prediction of RIPLOSS, is seen where a greater proportion of pasture is found in the riparian area compared to the watershed area as a whole. One scenario in which a watershed would have less riparian forest than the model predicts would be found in a watershed with steep, forested slopes that make farming in areas other than the floodplain difficult or economically unfeasible. In such a case, agricultural and developmental land usage would be concentrated in the floodplain area. In managing for specific riparian functions such as water quality, erosion control, or available habitat, the under-estimation of RIPLOSS could skew one's understanding of management needs. This problem highlights the need for knowledge of the spatial distribution of riparian forests within the watershed.

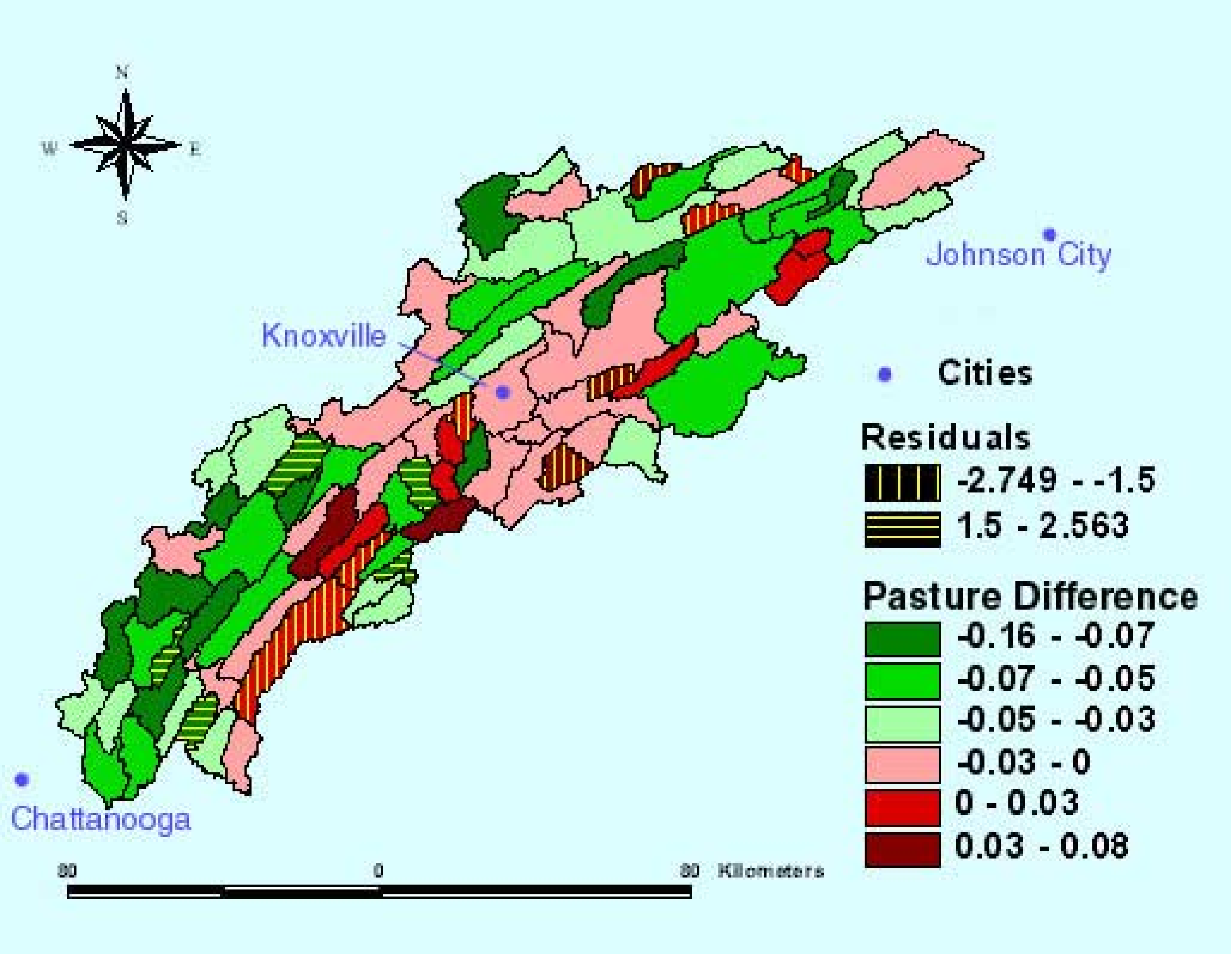

Figure 11: Spatial comparison of the residual outliers with PASTURE differences (Eq. 7) by watershed unit

Residential and Recreational

When only the non-natural land variables were entered into the regression, LDRES land use appeared as a strong predictor of riparian forest loss (Table 4). Pearson's correlation coefficient between HDRES and LDRES is 0.950 (Table 3, p<0.01). The significant correlation between these two residential land uses could account for the suppression of low-density residential in the first stepwise linear regression analysis, which included natural areas. Natural areas were negatively correlated with LDRES (r=-.425, p<0.01).

Economic variables probably also play a role in explaining the significance of low-density residential expansion near the streams. Low-density residential development in riparian areas may often be a product of nearby urban sprawl (see Figure 7). As low-density housing encroaches on farms established on attractive but inexpensive riparian lands, the value of the land as a residential property may quickly exceed the value of the agricultural activities conducted on the property.

GRASS only accounted for 0.9% of the noted pattern of riparian forest loss in the model used. Nonetheless, the relationship between GRASS and RIPLOSS was strong enough for it to remain within the stepwise regression model. A study by the Natural Resources Conservation Service (NRCS 1999) found that 88 percent of riparian buffer areas on participant farms consisted of managed, grassy waterways. If this mown grass buffer spanned a width of at least 30m, it could appear in the grassy areas classification and would increase the percentage of this land use affecting the riparian forest loss variable. The aesthetic and economic appeal of a managed lawn may be closely related to the interest in locating such an area near aesthetically attractive features such as streams.

Difference in land usage

It is interesting that TRANS, or the proportion of watershed area classified as transitional, within the whole watershed is significantly higher than that within the riparian buffer area. This finding is probably the result of increased land abandonment outside of the riparian buffer (see Klopatek et al. 1979), and may reflect a higher value for agricultural or other developmental land uses within the floodplain relative to properties beyond the riparian areas. Riparian areas often represent highly fertile, easily accessible areas with relatively flat terrain, which may be reflected in the demand for such parcels for land development. Transitional areas may also represent areas previously subjected to intensive logging or mining activities that are now in a gradual state of recovery (see Appendix). Logging and mining practices are discouraged, but seldom illegal, in riparian areas of Tennessee.

However, the t-test results (Table 6) do indicate that riparian areas do not show patterns of any obvious riparian development restrictions. Had strict riparian forest buffer zones been implemented, either by incentive or law, throughout the study area, we would expect to see a significant change in the mean value for proportion natural between riparian and watershed areas. In such a case, the riparian areas should contain primarily riparian forest while the watershed areas outside of the riparian buffer would show significantly increased agricultural, residential, and other developmental land usage patterns.

Accuracy of data

An accuracy assessment is available for the Multi Resolution Land Cover (MRLC) land cover dataset (Roth et al. 1999). This assessment was performed by the United States Environmental Protection Agency (US EPA) on a portion of the MRLC data available for the eastern United States using sample point analysis. The results showed an overall region-wide accuracy of almost 85 percent considering baseline comparison, registration factors, sub-classification factors, and class definition factors (Roth et al. 1999). Inaccuracies were mostly attributed to confusion among land uses of the same type, i.e. evergreen forest inaccurately classified as deciduous or mixed forest. Another primary source of error in the MRLC dataset was the classification of wetlands as forest types. For anthropogenically-altered land uses, the misclassification was less common. Roth et al. (1999) attribute this reduction in error to the heterogeneity of the developed landscape, which appears with clear boundaries in the imagery and allows for more accurate land use identification. In this thesis, because I combined forest and wetland categories into one group, the classification of one natural land use as another does not affect the grouped variable, nor does it change the calculations of non-natural land uses. The MRLC dataset is the finest scale, most accurate public land cover data currently available for the study area.

Chapter 6: Conclusion

This watershed-scale investigation into predictors of riparian forest loss addresses several important issues. Traditional ecosystem management approaches, which often focus purely on biophysical aspects of ecosystem change, can fail to consider other explanatory variables such as social, political, or economic factors (Turner et al. 1996). The interconnectedness of land uses, natural forests, economic, and physical attributes of the landscape is evident. Riparian areas are often converted to alternative uses because of the increasing economic returns over maintaining the natural riparian system (Schmidt 1991). This study shows that portions of riparian forests in these 25 counties in eastern Tennessee have been replaced by human land uses such as pasturelands, residential development, croplands, and grassy recreational areas. All non-natural land uses combined comprised 31 percent of the study area. The four determining land uses, PASTURE, LDRES, CROP, and GRASS, together made up almost 29 percent of the land use in the study area. Other studies have shown forest presence to be related to slope, elevation, and land ownership (Turner 1996, Wear and Flamm 1993). The results of this study reinforce the concept that, in order to effectively evaluate a riparian system, one must consider land usage and management practices as well as topographical factors.

Riparian forests have been shown to remove, detain, and alter pollutants from overland and subsurface flow. However, the varying effects of intensive land uses adjacent to these riparian buffers require careful consideration. High-density residential areas, although sparsely distributed and not a significant predictor of riparian forest loss in eastern Tennessee when natural areas are excluded from the analysis, can be disproportionate sources of both non-point and point-source pollution (Murphy and Phillips 1989) and must not be overlooked when managing riparian systems.

Furthermore, riparian forest presence does not imply that the buffering capabilities of the riparian area can equally compensate for the pollution effects of various adjacent land uses. Even non-point source runoff from intensive land use practices, such as mining, can overwhelm the buffering capabilities of a riparian forest and requires specific management practices. Protecting riparian areas is just one method of protecting water quality. The buffering properties and the buffer width needed to control runoff pollution must be evaluated in context of adjacent upland land usage, slope, and vegetation type.

In this research, the use of GIS allowed me to investigate land use pattern in relation to riparian forest loss within the Central Ridge and Valleys ecoregion. The results of this study point to two main categories of land use explaining the absence of natural riparian forests in these 82 eastern Tennessee watersheds: (1) community development activities, such as low-density residential and grassy recreational areas, and (2) agricultural activities, particularly pasture and croplands. Residential and agricultural land uses are not significantly correlated with each other implying that these variables are acting with relative independence.

The land use classes that were included in the final regression model include PASTURE, CROP, LDRES, and GRASS. These land uses specifically share the need for intense and frequent management of vegetation. On agricultural lands, riparian vegetation, as cash crop or fodder for livestock, is produced as a managed commodity. In such scenarios, the landowner receives direct seasonal compensation for managing the riparian vegetation. For these owners, the loss of land for conservation will have a direct and measurable effect on the success of their business.

In the LDRES and GRASS land uses, the vegetation is managed primarily to enhance the aesthetic and economic values of the property. The landowner receives little or no direct compensation for managing the riparian portions of the property. Parks offer primarily aesthetic value, but when located in proximity to residential property, they add to the value of adjacent properties. Golf courses require costly intensive land management in order to maintain their essential aesthetic quality. On these lands, the landowner is willing to provide the labor, time, and cost of maintaining the riparian vegetation in exchange for heightened property values and aesthetic quality. These landowners may be willing to consider reestablishing and maintaining attractive natural riparian vegetation once they are introduced to the many values of such management.

On the other hand, in the agricultural land use scenarios, the farmer would have to sacrifice valuable productive lands, labor, and subsequent income in order to maintain a unprofitable riparian buffer strip. This buffer area would be unlikely to contribute much to the book value of an agricultural field unless a conservation easement or incentive program was in place to compensate the farmer for his sacrifice. In this situation, a combination of land management education and conservation assistance would be needed to promote natural riparian buffer restoration and management.

A continuance of this research could involve studying temporal changes in riparian land use and land cover to identify a relationship between changing land use practices and the re-establishment or continued loss or natural riparian buffers. Another beneficial riparian study would involve the assessment of water quality in relation to riparian and upland land usage as part of an economic assessment of the true cost of non-natural riparian land usage at the watershed level.

The establishment and management of riparian buffers in areas of intensive upland land use, notably pasture and crop areas, would offer considerable water quality and public benefit. Based on the results of this investigation, I recommend that broad scale efforts to restore or manage riparian forests in eastern Tennessee focus on agriculturally productive riparian land usage and property enhancing riparian land uses such as residential and recreational development. Steps to protect existing riparian forests would include regulation of urban expansion onto natural riparian buffer areas and incentive programs that encourage farmers to restore and maintain riparian areas. The protection of public waters from pollutants such as N, P, and silt is possible through effective riparian buffer management at the watershed level (Schlosser and Karr 1981a, Lowrance et al. 1984a.) GIS can be an effective tool in evaluating watershed level impacts on riparian forests. This type of GIS analysis, then, provides an essential step in the effective management of riparian areas and the protection of our dynamic stream systems.

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Appendix

MRLC land cover classification

Land cover classification
23-Class National Land Cover Data Key:
(from National Landcover Data readme file…)

NLCD Land Cover Classification System Key - Rev. July 20, 1999

Water
- 11 Open Water
- 12 Perennial Ice/Snow

Developed
- 21 Low Intensity Residential
- 22 High Intensity Residential
- 23 Commercial/Industrial/Transportation

Barren
- 31 Bare Rock/Sand/Clay
- 32 Quarries/Strip Mines/Gravel Pits
- 33 Transitional

Forested Upland
- 41 Deciduous Forest
- 42 Evergreen Forest
- 43 Mixed Forest

Shrubland
- 51 Shrubland

Non-natural Woody
- 61 Orchards/Vineyards/Other

Herbaceous Upland
- 71 Grasslands/Herbaceous

Herbaceous Planted/Cultivated
- 81 Pasture/Hay
- 82 Row Crops
- 83 Small Grains
- 84 Fallow
- 85 Urban/Recreational Grasses

Wetlands
- 91 Woody Wetlands

92 Emergent Herbaceous Wetlands

NLCD Land Cover Classification System Land Cover Class Definitions

Water - All areas of open water or permanent ice/snow cover.

11. Open Water - All areas of open water; typically 25 percent or greater cover of water (per pixel).

12. Perennial Ice/Snow - All areas characterized by year-long cover of ice and/or snow.

Developed - Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc).

21. Low Intensity Residential - Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.

22. High Intensity Residential - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to100 percent of the cover.

23. Commercial/Industrial/Transportation - Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential.

Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.

31. Bare Rock/Sand/Clay - Perennially barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, beaches, and other accumulations of earthen material.

32. Quarries/Strip Mines/Gravel Pits - Areas of extractive mining activities with significant surface expression.

33. Transitional - Areas of sparse vegetative cover (less than 25 percent of

cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clearcuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.).

Forested Upland - Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.

41. Deciduous Forest - Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.

42. Evergreen Forest - Areas dominated by trees where 75 percent or more of the tree species maintain their leaves all year. Canopy is never without green foliage.

43. Mixed Forest - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.

Shrubland - Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

51. Shrubland - Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms.

Non-natural Woody - Areas dominated by non-natural woody vegetation; non-natural woody vegetative canopy accounts for 25-100 percent of the cover. The non-natural woody classification is subject to the availability of sufficient ancillary data to differentiate non-natural woody vegetation from natural woody vegetation.

61. Orchards/Vineyards/Other - Orchards, vineyards, and other areas planted or maintained for the production of fruits, nuts, berries, or ornamentals.

Herbaceous Upland - Upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.

71. Grasslands/Herbaceous - Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing.

Planted/Cultivated - Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.

81. Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.

82. Row Crops - Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.

83. Small Grains - Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.

84. Fallow - Areas used for the production of crops that are temporarily barren or with sparse vegetative cover as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.

85. Urban/Recreational Grasses - Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.

Wetlands - Areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al.

91. Woody Wetlands - Areas where forest or shrubland vegetation accounts for 25-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.

92. Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for 75-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.

Vita

Karen Elizabeth Burhenn was born in Chattanooga, TN. The daughter of a philosophy professor and a registered nurse, she developed an unexpected interest in nature and animals. Karen graduated from Girls' Preparatory School in Chattanooga in 1990. She entered at the University of Tennessee the same year. There she received a Bachelor of Science degree in Biology with a concentration in Ecology in 1994. She was soon thereafter employed under the Environmental Remediation group of the Environmental Sciences Division at the Oak Ridge National Lab for three years.

Karen returned to the University of Tennessee to pursue a Master of Science in Ecology and Evolutionary Biology. While contemplating a thesis topic, Karen was introduced to the powers of Geographic Information Systems (GIS). While completing the course requirements of her department, Karen began taking GIS courses in the Geography department and developing this thesis. She was employed for one semester as a GIS graduate student researcher by the Community Health Research Group under the guidance of Bruce Ralston. She then accepted another internship position with the Tennessee Valley Authority (TVA) in Norris, TN. She was soon offered and accepted a contractor position with the River Operations group at TVA in downtown Knoxville.

In December of 2000, Karen was offered a position with Q Systems, Inc. in Oak Ridge, TN as a GIS Applications Programmer. She is currently employed there where she works on development and implementation of the Oak Ridge Environmental Information System (OREIS).

Karen has one sister, Lauren, who is currently living in Austria with her Austrian husband, Oliver. Karen is planning a wedding of her own for August 2001 to Douglas Velliquette, a computer network security officer at the Federal building in Oak Ridge, TN.

Karen completed her Master of Science degree in 2001. She will continue to pursue GIS work in ecological and environmental conservation.