CHANGING PATTERNS OF LAND USE AND BASIN MORPHOMETRY: IMPACTS ON STREAM GEOMORPHOLOGY IN THE ILLINOIS RIVER BASIN NORTHWEST ARKANSAS 1941-2004
CHANGING PATTERNS OF LAND USE AND BASIN MORPHOMETRY:
IMPACTS ON STREAM GEOMORPHOLOGY
IN THE ILLINOIS RIVER BASIN
NORTHWEST ARKANSAS
1941-2004

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

By

JOHN V. WARD, B.S., M.S.
Central Washington University, 1999
Central Washington University, 2004

August 2007
University of Arkansas
ABSTRACT

Humans are altering land cover at unprecedented rates and scales. This paper investigates the relationship between changing patterns of land use, basin morphometry, and stream channel geomorphology in the Illinois River basin of northwest Arkansas during the years 1941-2004. An overview of the land use history of the Ozarks and the classification of land use time periods provided a temporal framework for investigations. Geographic information systems were utilized to integrate and analyze data from historical aerial photography and digital elevation models. The results show that land use land cover changes occur most intensely in basins containing lower gradient headwater reaches in proximity to urban centers, while the largest increase in channel change was found to be channel widening in the lower stream valleys along the main channel of the Illinois River. These findings indicate that channel change within the study area is a result of both decreased erosional resistance in valley bottom locations and increased upland land use related to urban development near headwater reaches. The results also highlight the importance of a basin scale system approach to land management.

Key Words: Land use, land cover, drainage basin morphometry, historical aerial photography, Illinois River, Northwest Arkansas, Ozarks
This dissertation is approved for
Recommendation to the
Graduate Council

Dissertation Director:

________________________________________________________________________
John Dixon, Ph.D.

Dissertation Committee:

________________________________________________________________________
Jason Tullis, Ph.D.

________________________________________________________________________
George Sabo, Ph.D.
DUPLICATION RELEASE

I hereby authorize the University of Arkansas Libraries to duplicate this dissertation when needed for research and/or scholarship.

Agreed ________________________________

Refused ________________________________
ACKNOWLEDGMENTS

Rarely are we alone in our endeavors. This dissertation could not have been completed without the contributions of the following folks. My sincere thanks to you all.

Dr. John Dixon
Dr. Jason Tullis
Dr. George Sabo
David Reed
Jan Dixon
Suzy Ward
Cassady
Madison
Jack
Sara
Jorja
# TABLE OF CONTENTS

List of Figures .............................................................................................................. viii
List of Tables ................................................................................................................. x

Introduction ..................................................................................................................... 1

Chapter 1. Historic Land Use Change in the Ozarks ....................................................... 3
Abstract ........................................................................................................................... 3
Introduction ....................................................................................................................... 4
Early Settlement (c. 1700 - c. 1870) .............................................................................. 7
  Historic Native Americans ......................................................................................... 7
  Early Exploration ....................................................................................................... 8
  Early Settlers .............................................................................................................. 9
  The Trail of Tears ..................................................................................................... 14
  The Civil War .......................................................................................................... 15
The Emergence of the New South (c. 1870 - c. 1920) ................................................. 16
  Post-War Change in the Ozarks ............................................................................... 16
  Railroads .................................................................................................................. 18
  Timber Resources .................................................................................................... 20
  Mineral Resources ................................................................................................... 22
  Ozark Landscapes Before and After 1880 ................................................................. 24
The Conservation Era (c. 1920 - c. 1960) ................................................................. 27
  The Effects of the Timber Boom ............................................................................. 27
  Farming ..................................................................................................................... 28
  Federal Land Acquisition ....................................................................................... 31
  Recreation and Tourism ......................................................................................... 32
The Modern Era (c. 1960 - Today) ............................................................................. 34
References ..................................................................................................................... 38
Figures ............................................................................................................................ 42
Tables .............................................................................................................................. 53

Chapter 2. Quantifying Basin Scale Land Use Land Cover Change Using Historical
Aerial Photography ........................................................................................................... 54
Abstract ....................................................................................................................... 54
Introduction ..................................................................................................................... 55
Study Area ..................................................................................................................... 56
  Historical Aerial Photography and Land Use Land Cover Change .................... 57
Methodology ................................................................................................................ 58
  Map Generalization ................................................................................................. 58
  Public Land Survey System ................................................................................. 61
  Land Use Land Cover Classes .............................................................................. 64
  Multidimensional Classification ............................................................................. 65
LIST OF FIGURES

Chapter 1

1. Location of the Ozarks................................................................. 42
2. Major physiographic provinces of the Ozarks............................... 43
3. Metropolitan areas in the Ozarks.................................................. 44
4. The Trail of Tears. ....................................................................... 45
5. Major Civil War battles in the Ozarks............................................. 46
6. Mining districts of the Ozarks........................................................ 47
7. National Forests and rivers of the Ozarks........................................ 48
8. Cattle population in select Missouri counties, 1850-2000. ............... 49
9. Ozark spas and mineral springs of late 19the century...................... 50
10. Major lakes of the Ozarks............................................................. 51
11. Retirement destination counties in the Ozarks............................... 52

Chapter 2

1. Study area and study units............................................................. 81
2. Location of study units and general study area topography.............. 82
3. Percent change forested land, 1941-1982...................................... 82
4. Percent change forested land, 1982-2004...................................... 83
5. Percent change forested land, 1941-2004...................................... 83
6. Percent change cleared land, 1941-1982...................................... 84
7. Percent change cleared land, 1982-2004...................................... 84
8. Percent change cleared land, 1941-2004...................................... 85
9. Percent change built land, 1941-1982.......................................... 85
10. Percent change built land, 1982-2004........................................... 86
11. Percent change built land, 1941-2004........................................... 86
12. Comparison of 2004 forested land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT) .......... 87
13. Regression plot for 2004 forested land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT) .......... 87
14. Comparison of 2004 cleared land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT) .......... 88
15. Regression plot for 2004 cleared land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT) .......... 88
16. Comparison of 2004 built land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT) .......... 89
17. Regression plot for 2004 built land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT) .......... 89
Chapter 3

1. Study area and study units ................................................................. 126
2. HUC-12 sub-basins and study units ..................................................... 127
3. Channel width measurement sites, Illinois sub-basin ............................. 128
4. Channel width measurement site, Clear Creek sub-basin ....................... 129
5. Comparison of channel width measurements in Illinois sub-basin ............. 130
6. Comparison of channel width measurements in Clear Creek sub-basin ...... 131
7. Land use land cover zones .................................................................... 132
8. Bankfull channel widths, Illinois sub-basin .......................................... 133
9. Bankfull channel widths, Clear Creek sub-basin ..................................... 134
LIST OF TABLES

Chapter 1

1. Land-use time periods ........................................................................................................... 53
2. Ten fastest growing metropolitan areas 1990-1998 ......................................................... 53

Chapter 3

1. Land-use time periods ......................................................................................................... 135
2. Basin morphometric variables ............................................................................................ 136
3. LULC change over time by study unit .................................................................................. 137
4. General trends in LULC change by study unit .................................................................... 138
5. Correlation between basin morphometric variables ....................................................... 139
6. Correlation between basin morphometrics, and LULC change .................................... 140
7. Correlation between LULC, basin morphometrics, and channel change .................... 141
8. LULC class percent change for all study units ................................................................. 142
INTRODUCTION

The purpose of this project is to investigate the relationship between changing patterns of land use, basin morphometry, and impacts on stream channel geomorphology in the Illinois River basin of northwest Arkansas during the years 1941-2004. The results of these investigations are being prepared for publication as a series of three papers, which together form this dissertation.

The first paper, “Historic Land Use Change in the Ozarks”, contains an overview of historic land use in the Ozarks from the 1700s to present. This paper also provides a classification of historic land use time periods in the region. These periods are: (1) Early Settlement (1700-1870), (2) the Emergence of the New South (1870-1920), (3) the Conservation Era (1920-1960), and (4) the Modern Era (1960-present). This classification provides a temporal framework for the project and describes general patterns of land use during each period.

The second paper, “Quantifying Basin Scale Land Use Land Cover Change Using Historical Aerial Photography”, describes a methodology for quantifying changes in land use land cover using historical aerial photography, the Public Land Survey System, a multi-dimensional map generalization classification technique, and geographic information systems. The technique is used to integrate and analyze data from historical aerial photography and digital elevation models, in order to map and quantify land use land cover within the study area during the years 1941, 1982, and 2004.

The third paper, “Relationships between Land Use Land Cover Change, Drainage Basin Morphometry, and Stream Channel Change in the Illinois River Basin Northwest Arkansas 1941-2004” utilizes statistical techniques to identify and quantify relationships
between land use land cover changes, drainage basin morphometric variables, and stream channel geomorphic change within the study area. Land use land cover data are analyzed to investigate changes in forest, cleared, and built land over time, during the periods 1941-1982, 1982-2004, and 1941-2004. Basin morphometric variables related to geomorphic and hydrologic change are measured and used to identify changes related to the morphology of the study area and stream channel widths are used to quantify changes in stream channels over time. Correlation analysis is then used to investigate the relationships between land use land cover, basin morphometry, and stream geomorphology.

This research can help land managers and land users to better understand how past human activity has impacted the environment, and offer the ability to project future trends in human activities and land use impacts. This in turn allows more informed decisions to be made about how we utilize the land around us.
CHAPTER 1. HISTORIC LAND USE CHANGE IN THE OZARKS

Abstract

European settlement of the Ozarks began in the early 1700’s and since that time the region has experienced a transformation with regard to land use practices and corresponding land cover patterns. In general, the land use history of the area can be divided into four time periods: (1) Early Settlement (1700-1870), (2) the Emergence of the New South (1870-1920), (3) the Conservation Era (1920-1960), and (4) the Modern Era (1960-present). Each of these time periods contains a set of characteristic land use practices, progressing from early valley-bottom land clearing to present day urban development. An understanding of the history of land use in the Ozarks provides the necessary background to investigate the impacts of human-environmental dynamics in the region.

Key Words: Ozarks, land use, environmental history, natural resources
INTRODUCTION

“We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect. There is no other way for land to survive the impact of mechanized man, nor for us to reap from it the ethical harvest it is capable, under science, of contributing to culture”. - Aldo Leopold (1949)

The Ozark Mountains are located in the south central United States, and are found in parts of Missouri, Arkansas, Oklahoma, and Kansas (Figure 1). The Ozark Mountains, together with the Ouachita Mountains to the south, constitute the Interior Highlands division of the central United States, and are a part of the larger Upland South region (Hudson 2002). The Ozarks are bounded by the Mississippi River to the northeast, the Gulf Coastal Plain to the southeast, and the Arkansas River to the south. The region extends slightly beyond the Missouri River to the north, while the western boundary generally follows the seam where Pennsylvania-age rocks overlap Mississippi-age rocks. The Ozarks stretch from the outskirts of St. Louis in the northeast to Tahlequah, OK in the southwest, and from near Batesville, AR in the southeast to well past Jefferson City, MO in the northwest. Covering approximately 40,000 square miles, the region has in general greater relief, steeper slopes, and older surface rocks than adjacent lands. Although they are often referred to as the Ozark Mountains, the Ozarks are, in fact, largely the product of uplift and erosion, and are thus better described from a geologic perspective as the Ozark Plateaus. The Ozarks consist of a structural uplift known as the Ozark dome, which is centered on the St. Francois Mountains, surrounded by a series of limestone plateaus (Figure 2). The general topography of the Ozark Plateaus consists of
receding frontal escarpments with plateau-like uplands on the backslopes (Thornbury 1965).

Most of the Ozarks are underlain by Paleozoic sedimentary rocks of Cambrian, Ordovician, Mississippian, and Pennsylvanian age (Rafferty 2001). The oldest rocks in the region can be found in the St. Francois Mountains, where the Pre-Cambrian igneous rocks of the Ozark dome have been eroded into a jagged topography.

Surrounding the dome is the Salem Plateau, consisting of Ordovician-aged limestones that have been dissected to form a rugged topography. Outside the Salem Plateau lies the Springfield Plateau, an area of relatively less-dissected Mississippian-aged rocks, thus having relatively less topographic relief (Payne 1951). The sedimentary rocks of both the Salem and Springfield Plateau formed at a time when water covered the Ozarks. Along the southern border of the Ozarks lies Boston Mountains, a north-thrusted strata consisting of younger Pennsylvanian-aged rocks consisting of sandstones, shales, and limestones. The Boston Mountains are an area of generally rugged topography.

Elevations throughout the Ozarks range from approximately 150 meters in the north along the Mississippi to greater than 720 meters in the Boston Mountains. Much of the Ozarks can be classified as a karst landscape. Over millions of years groundwater moving through cracks and crevices in the rocks has dissolved much of the limestone and dolomite, leaving the region with many springs, caves, sinkholes, and disappearing streams. Major rivers draining the Ozarks include the Osage, Gasconade, and Meramec in the north and west, and the White River and its tributaries in the south and east.

The Ozarks have both a mid-continental and a middle latitude location, each of which influences both daily and long-term patterns of temperature, precipitation, and
humidity in the region. In general, the Ozarks have a continental climate affected by prevailing east-moving systems, Gulf Coast moisture, and occasional incursions of the polar front. Mean annual temperatures in the region range from 60-65° F, with the uplands having an average temperature of 55° F. Mean annual precipitation ranges from 36 inches along the Missouri River to about 50 inches along the Arkansas River, with May and June generally receiving the most rainfall throughout the region. The growing season last almost 200 days (Hansen and Moneyhon 1999). However, it should be noted that Ozark climate is quite variable and very changeable throughout the year. In addition, microclimates persist throughout the region, with south and west facing slopes generally receiving more sunlight and thus having higher rates of evaporation (Rafferty 2001).

The Ozarks generally consist of average to poor soils, except in the river valleys where rich alluvial bottomland soils can often be found throughout the region. In the uplands, the soils have been derived from weathering of underlying rocks, and are dominated by the more resistant limestones and dolomites. These cherts also tend to mantle the lower slopes. This, along with their extensive distribution, makes these cherty-limestone soils the most abundant in the region. The northern and eastern border areas contain deep, fertile soils resulting from aeolian loess deposits (Rafferty 2001). Modern land cover in the Ozarks consists primarily of Oak-Hickory Forest with interspersed areas of woodland and grassland. Major agricultural areas occur to the southeast and north, in proximity to the Mississippi and Missouri Rivers, and to the south along the bordering Arkansas River Valley. Major metropolitan areas are found in St. Louis, Springfield, Joplin, and Columbia in Missouri; and Fayetteville-Springdale-Rogers and Fort Smith in Arkansas (Figure 3).
The history of land use in the Ozarks has been divided slightly different ways by different authors (for example: Jacobsen and Primm 1997, Rafferty 2001, Benac and Flader 2004). Adapted from the time periods used by Jacobsen and Primm (1997), this paper divides the past into four general periods of historic land use: (1) the Early Settlement Period, (3) The Emergence of the New South, (4) the Era of Conservation, and (5) the Modern Era (see Table 1).

**EARLY SETTLEMENT (c. 1700 – c. 1870)**

*Historic Native Americans*

The Ozarks were home to the Osage tribe when the first European explorers arrived in the region. These groups lived in villages along major streams of the Ozarks from the Arkansas River to the Missouri River. According to Osage origin legends, the tribe came from the central Mississippi River Valley and later moved into the Ozarks, where they would eventually make contact with European explorers (O’Brien and Wood 1998). Osage society was organized around kin-based clan units and involved elaborate social and political organization. They cultivated maize, squash, and pumpkins; gathered wild foods like roots, nuts, and berries; and fished in the rivers and creeks. The Osage utilized the Ozark uplands as hunting grounds for deer, elk, bear, and buffalo, along with smaller mammals such as turkey, rabbit, squirrel, quail, and opossum. During these hunting trips they occupied permanent camps to which they would return to hunt in the spring and summer (Sabo et al. 1990). As part of their resource acquisition activities, the Osage groups would periodically burn the forest. This provided better browse conditions
for hunting, allowed fruits and berries to flourish (Guyette, Dey, and Dey 1999), and also caused prairie conditions to spread eastward into the forest.

Starting around 1780, the massive migration of Native Americans pushed from the east by European settlers resulted in the migration of groups such as Cherokee, Shawnee, Delaware, and Kickapoo into the region. This influx of people, combined with drought conditions, led to an increase in fire frequency. During this time the forest was less dense than today, with open woodlands found on many ridgetops, along with more widespread savannahs (Guyette, Dey, and Dey. 1999).

Early Exploration

Spanish explorers led by Hernando de Soto first crossed the Mississippi River and entered the southern border area of the Ozarks region in 1541. They explored the region along the Mississippi and White Rivers, although the actual route(s) traveled by this group remains a topic of much debate (Hansen and Moneyhon 1999). Following the de Soto expedition, the French explorers Marquette and Joliet entered the eastern Ozarks region in 1673 during their explorations down the Mississippi River from Quebec to the mouth of the Arkansas River (Rafferty 2001). Soon others followed, including La Salle in 1682, and by the early 1700s trade had been established with the Osage, primarily involving pelts and guns. As more and more settlers began living in Osage lands, tensions between the groups increased, often resulting in conflict. In 1804-05, the Lewis and Clark expedition followed the Missouri River along the northern border of the Ozarks, on their journey to the Pacific Ocean (Goetzmann and Williams 1992).
Both Schoolcraft (Rafferty 1996) and Ladd (1991) describe the presettlement Ozarks uplands as a mosaic of grasslands, savannah, oak forest woodlands, and barrens. Schoolcraft also described dense timber on the valley slopes and densely wooded valley bottoms with some areas of grassland (Rafferty 1996). Presettlement prairie was found primarily along the western border of the Ozarks where prairie tended to be discrete units on rolling to level upland (Schroeder 1982). Archeological researchers in the Arkansas Ozarks have suggested that European settlers entered Ozark forests that had been modified by Native American land use activities over thousands of years (Sabo et al. 2004). Today, using these presettlement conditions as a baseline for the “natural” state of the Ozarks, land management practices such as controlled burning are serving to return some areas to these conditions. This burning also has the effect of improving wildlife habitat and increasing plant diversity (Guyette, Dey, and Dey 1999).

Early Settlers

The location of the Ozarks at the “funnel opening” of the Ohio-Mississippi River immigration routes, along with the area’s imposing topography, played a major role in the settlement and development of the region. Situated adjacent to St. Louis, the “gateway to the west”, the Ozarks represented the first major unsettled lands west of the Mississippi. Yet, its rugged topography acted to deflect the main flow of immigrants to the bordering river routes along the Mississippi, Missouri, and Arkansas Rivers, leaving the Ozarks relatively unsettled as immigrants moved around the Ozarks to other available lands. This period of early settlement corresponds to the “Old Ozarks Frontier” settlement phase described by Rafferty (2001).
The first European settlers in the Ozark region were French Creoles, who entered the region from settlements on the Great Lakes, drawn by a quest for furs and minerals. By 1703 the French had a permanent settlement at Kaskaskia and by the 1740s settlements were established west of the Mississippi in the Ste. Genevieve District. Natural resources were abundant in the area, providing for the rapid and successful settlement by both Europeans and Americans. The availability of good soils was of great importance to early settlers. In fact, the spatial correlation between areas of alluvial, loessial, and limestone soils and lands claimed in 1804 is nearly perfect, reflecting not only the importance of soil quality to these settlers, but also demonstrating the usefulness in soils maps in predicting settlement patterns (Schroeder 2002).

To this day, some towns and rivers in the eastern Ozarks retain their French name, a legacy of early French Creole settlement. These settlements were strategically located on the banks of the Mississippi, which served as the main link between French settlements on the Great Lakes on those in Louisiana. In addition, these early settlements were located in the general area where the Ohio, Missouri, Illinois, and Wisconsin rivers joined the Mississippi, providing access to the continental interior (Sauer 1920). Many of these early French settlers were engaged in activities such as trading, farming, mining, or salt making (Rafferty 2001). The presence of lead mines and the use of salt springs are both described as early as 1700 (Sauer 1920).

In 1770 Spain took possession of the Ozark region, an area referred to at the time as Upper Louisiana. Since few Spanish actually came to settle in the region, this ownership amounted to relatively weak governance by a few administrators and soldiers (Schroeder 2002). Driven by their fear of British attack, the Spanish had lured American
settlers to the area with attractive land grants. The Spanish were bombarded with petitions for these grants, mostly for areas of fertile soil and mineral occurrence. Following the United States purchase of the Louisiana territory in 1803, a law allowing settlers to reclaim lands impacted by the New Madrid earthquakes of 1811 and 1812 injected more controversy into land ownership in the newly settled areas (Rafferty 2001).

Other immigrants soon followed the early French settlers. Many of these early settlers of the Ozarks interior had immigrated from Kentucky, Tennessee, Virginia, and North Carolina, and traced their kin from the upland South to Scotland (Benac and Flader 2004) and Northern Ireland. Their choice of land to settle was in large part driven by their culture, which provided them with models for how to settle the landscape in kinship networks, how to organize their farms, and how to react to the many other decisions they would face (Schroeder 2002). These people were thus drawn to landscapes and climates that resembled those from which they had originally immigrated to the New World. The settlement patterns reflected this, and were such that the Scotch-Irish headed into the rugged interior wilderness, the Germans settled to the north along the Missouri River or to the Great Plains to the west, and the Scandinavians passed through the temperate Ozarks continuing north to colder climates in what would become Wisconsin, Minnesota and the Dakotas (Rafferty 1982).

The early settlement of the Ozarks was primarily composed of small farms or hamlets, located along stream routes. Major stream valleys such as the Neosho and White Rivers basins were settled first (Sauer 1920), followed by smaller tributary valleys. Upland areas were usually settled later, due to lack of permanent water sources. By 1799, however, settlers began to live in the uplands, where they found areas of weathered
limestone-derived soils well suited to growing corn and wheat (Rafferty 2001). By 1811 the frontier had been extended 60 miles west of the Mississippi River (Sauer 1920).

From 1814 to 1850, the population of Missouri rose from 26,000 to 682,000 people (Stevens 1991). During this period, these exponential increases in the population of European settlers correspond to an increase in fire frequency from (Guyette, Dey, and Dey 1999). These early Ozark inhabitants would burn the forest each spring to improve livestock forage and reduce ticks and snakes (Jacobsen and Primm 1997). Guyette, Stambaugh, and Dey (2003) classify the fire regime at this time as an “ignition dependent stage”, during which fire frequency increases as human population and potential fire ignition increases. During this period, living both geographically and culturally isolated from the outside world, early settlers developed a subsistence lifestyle based on making a living from the natural world around them. Forests served as a commons, where they could find game, fruits, nuts, and herbs, and also provided firewood and timber.

As settlement increased, they cleared small plots in the valley bottoms for growing wheat, corn, and oats. Being the most productive agricultural land, the thick deciduous forest of the valley bottoms was plowed, logged, and pastured, lowering the erosional resistance of stream banks by altering land cover (Jacobsen and Primm 1997). The conversion of prairie and forest to cropland in the Ozarks followed that of the eastern woodlands by about a century (Knox 2002). Livestock grazed the valley slopes and uplands, probably having substantial effects on runoff and soil erosion in areas where groups of livestock were concentrated. However, written accounts do not specifically refer to upland erosion related to land use activities (Jacobsen and Primm 1997). In fact, the history of the region provides little evidence of concern for environmental
degradation, although on occasion a few people did speak out regarding the environmental impacts of timber harvest, burning, soil use, and lead washing (Schroeder 2002). During the later part of the Early Settlement Period, the incidence of wildfires decreased due to suppression by settlers based on safety concerns driven by increasing population densities (Guyette and McGinnes 1982, Guyette, Stambaugh, and Dey 2003), resulting in an increase in woodland with woody undergrowth (Jacobsen and Primm 1997). It is estimated that there was also a moderate decrease in riparian erosional resistance during this time (Rafferty 2001).

Settlement of the Ozarks eventually moved to the interior in pursuit of mining interests, and finally spread across the whole region by 1850. The original attraction of mining was the promise of gold, silver, and copper. While these were probably never found, the early miners did find lead, zinc, and iron ore (Blanc, Caldwell, and Hawks 1998). Another draw for early settlers moving into the interior was the growing reputation of the limestone-derived soils.

Settlement of the interior Springfield Plain region was much slower than that of the eastern and northern Ozark border areas. This was due to a lack of navigable streams, the rugged topography of the interior hills, the relative isolation this caused for settlers, and a lack of resources compared with the border regions. In addition, the much narrower valleys of the interior offered less potential for agriculture. The exceptions in terms of resources were minerals and timber, which were found in abundance throughout the interior. Eventually though, large numbers of settlers were drawn to the interior, first to the lead districts in St. Francois and Washington Counties (Rafferty 2001). By the 1820s scattered settlements were established in the interior, centered around sawmills,
saltpeter mines, and iron making. In 1850 the western Ozarks began to be settled, driven by the discovery of lead in southwestern Missouri. This discovery aroused such interest that a project was begun to construct a railroad into the area, although by the start of the Civil War it was only completed as far as west as Rolla (Sauer 1920).

Settlement of the interior also generally followed the pattern of the largest river valleys being settled first, followed by the smaller tributary valleys, and finally the uplands. Early on the farmers found the limestone-soil basins were well suited to agriculture, and these lands were the first to be occupied and organized into communities (Schroeder 2002). Often, an entire valley or hollow would be taken up by an extended family. As the interior Ozarks began to be settled, streams such as the Osage River became navigable routes. Overland routes into the interior began along the Missouri River at Boonville and Jefferson City. In addition, other overland routes utilized upland divides. Most significant among these was the route from St. Louis to Fayetteville by way of Rolla, Springfield, and Bentonville. This route would later be followed by the St. Louis-San Francisco Railroad, U.S. Highway 66, and Interstate 44 (Rafferty 2001).

*The Trail of Tears*

The Osage had relinquished most of their Ozark lands in the Treaty of Fort Clark (1808). By 1825, the United States government threatened to remove the remaining Osage and other tribes from the Ozark region by force, eventually persuading most of them to move to western Oklahoma following the Cherokee Treaty of 1828. In 1837 and 1838 other Native American tribes, including the Cherokee and Delaware, were rounded
up from their eastern homelands and moved by force across the Ozarks to reservations in Oklahoma. This forced migration became known as the Trail of Tears (Figure 4).

Several different routes were actually used to cross the Ozarks. The main trail entered the Ozarks via Cape Girardeau, crossing through Rolla and Springfield and then heading south to Monet before reaching Fort Gibson, OK. Other routes headed southwest from Cape Girardeau towards Batesville, AR, crossing northern Arkansas via Fayetteville and also continued south to Little Rock and turned west up the Arkansas River Valley to Fort Smith on the way to the reservations. An estimated 18,000 Native Americans started the trip. Approximately 4,000 died along the way.

Those that survived the journey would reside on reservations that had been established in Oklahoma (Rafferty 2001). By the beginning of the Civil War, the Ozarks were almost entirely populated by European settlers, outside the boundaries of the northeastern Oklahoma reservations. This movement of Native Americans across the Ozarks and onto reservations in northeast Oklahoma marked the beginning of the end of the Ozarks Early Settlement period.

_The Civil War_

The Civil War battles that took place in southern Missouri and northern Arkansas made it one of the bloodiest regions of the war (Steele and Cottrell 2003). Feuding between Missouri and Arkansas slaveholders and Kansas abolitionists had started as early as 1855, resulting in violence along the Kansas-Missouri state line, and continued up until the start of the war in 1861. As many early settlers in the Ozarks had migrated from southern states, they maintained their loyalties to the Confederacy, yet many Union
sympathizers also lived in the region (Steel and Cottrell 2003). In addition, many Cherokee, Choctaw, Chickasaw, Seminole, and Creek took up arms on both sides. Thus, the spring of 1861 found the Ozarks a divided land, much like the rest of the country, and although Arkansas succeeded from the Union many people living in the Ozarks remained loyal to the Federal government. As a border state Missouri, and therefore much of the Ozarks, was disputed territory, especially due to its strategic location with regards to control of the vital Mississippi River travel route. By the summer of 1861 much of Missouri was a battlefield (Steele and Cottrell 2003), while other fighting took place in Arkansas, Oklahoma, and Kansas (Figure 5). By 1865, the formal surrender of Confederate troops had taken place, the Civil War had officially come to an end. The scars it left across the country were slow to heal, and the Ozarks would continue to see its share of war-related feuds for decades to come (Steele and Cottrell 2003).

Following the Civil War, the former Confederacy entered a period of national development, referred to as the “New South”. It would mark the beginning of the next period in Ozarks history and bring to the region a time of enormous change to both the cultural and natural landscape.

THE EMERGENCE OF THE NEW SOUTH (c. 1870 – c. 1920)

Post-War Change in the Ozarks

Following the Civil War, a period of internal changes and industrial development began throughout the southeastern United States. This included the formation of new state governments, an influx of northern investors, the encouragement of railroad building, the development of sharecropping, and efforts to improve the educational
system (Dougan 1994). Referred to by historians as the New South, this was a time of government and corporate collaboration in an effort to integrate the South into the changing national economy (Stevens 1991). The emergence of the New South had a lasting effect on the Ozarks. It was during this time period that post-war economic development brought to the region new railroads, mineral and timber exploitation, manufacturing plants, and an influx of immigrants, many of who came from northern states. In addition, the late 19th century saw the appearance of social institutions in the Ozarks, such as public schools, newspapers, town bands, and debating societies (Pitcathley 1987). This was a time of political change for the states that include the Ozarks, although it was the political voices in the Missouri and Arkansas River Valleys that shaped the destiny of the region, rather than the residents of the Ozarks themselves (Rafferty 2001). However, despite the growing cultural and economic complexity of life, the people managed to maintained their traditional values and way of life (Dougan 1994).

This period initially saw economic troubles plague the region as many counties were heavily in debt due to public improvements needed following the war. In addition, the western Ozarks remained an area of unrest during this time, as the conflicts and lawlessness of the war lingered. Yet despite the problems the war had left in the region, changes in communication and transportation following the war, as well as the investments of eastern capitalists, served to transform both the cultural and natural landscape of the Ozarks. It was also during this period that both electricity and the telephone arrived in the Ozarks (Rafferty 2001). But the strongest forces of change may have been the arrival of the railroad and the lingering frontier attitude towards natural resources that prevailed in the region. These combined forces are reflected by the fact
that this period has been designated by names such as the “Era of Exploitation” (Benac and Flader 2004), and the “Timber Boom Period” (Jacobsen and Primm 1997).

**Railroads**

The period following the Civil War was a time of railroad construction and all the elements of modernity that follow (Rafferty 2001). Railroads played an important role in the economic, cultural, and environmental change that occurred in the Ozarks during this time. They not only opened new areas formerly inaccessible to settlers but also provided increased mobility to populations; connected formerly isolated communities to new goods, services, and ideas (Gates 1932); provided access to mineral and timber resources; and supplied and distributed products from farms (Rafferty 2001). Being the commercial center of Missouri, St. Louis was the focal point of early rail building, and the place from which railroads would eventually lead to the southeast, southwest, and northwest. It was there, in 1851, that the Pacific Railroad began construction of the first railway in both Missouri and the Ozarks, built through the assistance of both state subsidies and a federal land grant. By the following year the rails had reached Cheltenham, and by 1856 reached Jefferson City. By 1861 the Pacific was extended to Sedalia and its southwest branch ran to Rolla. The Civil War temporarily interrupted plans to reach mineral resources near Springfield and open that area to settlers (Rafferty 2001), but that was soon to change following the war.

The Hannibal and St. Joseph Railroad ran parallel to the north of the Pacific Railroad, and was completed in 1859, covering 207 miles. Being in an area less settled than the Pacific, the Hannibal and Joseph line received 611,323 acres in land grants,
while the Pacific received 125,000. Due to its location, the Hannibal and St. Joseph attracted investors interested in joining it to existing lines, including the Michigan Central and Illinois Central railroads, creating a rail system through Michigan, Indiana, Illinois, and Missouri and onward to the west (Gates 1932). Smaller rail lines included the North Missouri running from St. Louis to St. Charles, and the St. Louis and Iron Mountain heading southwest from St. Louis. In addition, the Mississippi River and Bonne Terre Railroad was built to haul lead ore from St. Francis County to a smelter at Herculeum on the Mississippi River (Rafferty 2001).

During the Civil War years railroad construction decreased in the Ozarks. Yet, despite the conflict between the states, the Pacific Railroad was completed in 1865, demonstrating the importance of this line to the future of the Ozarks. During this time the interior Ozarks were relatively untouched by rail construction, and consequently grew more slowly than other regions of Missouri. At the same time, the areas of the state where rail construction took place increased in population so much that by 1870 Missouri had the fifth largest population in the country. This population increase was primarily in rural areas, helping lift Missouri to the status of one of the greatest agricultural states of the time (Gates 1932).

In addition to the railroads built in Missouri, several lines were soon constructed in the more rugged regions of the northern Arkansas Ozarks, breaking down many of the states natural geographic barriers. These railroads included the Missouri and North Arkansas Railroad that connected Joplin, Missouri with Helena, Arkansas on the banks of the Mississippi River. Originally built to service the resort town of Eureka Springs, it would also be utilized to transport crossties and lumber. Several lumber mills were built
along the line, and by the 1880s the lumber industry had a strong foothold in Arkansas. During this time many communities were developed as sawmill towns (Shaddox 1989). In addition to the Missouri and North Arkansas, the St. Louis and San Francisco line built a branch from Missouri through northwest Arkansas to Fort Smith (Hansen and Moneyhon 1999). Other rail lines in the Arkansas Ozarks included the Arkansas and Oklahoma Railroad and the Monte Re Railroad (Rafferty 2001). By the end of the 19th century, railroad investors throughout the United States began to realize they could not operate all the railroads that had been constructed at a profit. This ultimately led to the consolidation of some smaller railroads, and the abandonment of lines that ran parallel to competing lines as well as short spur lines built to serve cities or mining and timber towns. Many of the latter were simply abandoned once the mineral or timber resources in the area were depleted (Rafferty 2001).

Timber Resources

During the New South Period many settlers came to the Ozark seeking jobs in the forests and mills (Jacobsen and Primm 1997). It was during this time that large timber companies moved into the Ozarks to harvest pine and oak, thanks in large part to the penetration of railroads into the region (Benac and Flader 2004). This new method of transportation, along with the introduction of steam-powered mills, resulted in increased lumber production in the Ozarks. While water-powered sawmills had produced tens of thousands of board feet per year, the new steam-powered mills produced tens of millions of board feet annually (Stevens 1991). Only in recent times has saw log production in the Ozarks reached comparable levels to the timber harvest during this time.
The railroads also brought with them commercial agriculture, corporate mining and lumbering, and urbanization (Rafferty 2001). However, not all the trappings of modernity came to the Ozarks with the railways. Due to resistance by the resident subsistence-based populations to both corporate and government efforts to bring industrial productivity to the region, governmental conservation efforts ultimately developed later than in other areas (Benac and Flander 2004). During this time the distribution of timber harvest was controlled for the most part by the distribution of timber resources and the location of railroad routes. The distribution of these resources and infrastructure, along with the low cost of extraction, resulted in a concentration of timber harvesting activities in southeast Missouri (Stevens 1991). During this time fire frequency decreased, due to fragmentation of potential fire fuel (Guyette, Stambaugh, and Dey 2003), but at the same time the slash left over from logging operations served as fuel for some major wildfires ignited by farmers attempting to convert forest into pasture (Guyette, Dey, and Dey 1999). Also during this time there was an increase in cattle and hog populations, along with a slight increase in both upland and valley slope sediment yield, and a decrease in valley bottom erosional resistance (Rafferty 2001).

Cutting of the forests on a large scale started in the 1880s, encouraged by railroad developers. As the rails were built railroad construction camps became logging camps, and sawmills were built at these locations. There was also a rapid expansion of mills and factories making products from the timber, such as crossties, shingles, boxes, doors, furniture. By 1909 Arkansas was the fifth largest lumber producer in the nation, and timber-related industries employed over half the state’s non-farm workforce.
Until the 1920s harvesting in the Ozarks can be classified as “cut and run”, with timber crews removing the best timber and moving on, while greatly impacting the forests in the process. The best timber was gone by 1920s and facing hard times some companies began emphasizing conservation of existing forests and redevelopment of cutover areas. This ultimately allowed the timber industry to continue as one of the most important economic activities in Arkansas. In 1977, for example, eighteen million acres of forestland were being worked and producing almost forty-nine million board feet of lumber (Hanson and Moneyhon 1999). The impact of the Timber Boom on Ozark forests is demonstrated by the results of a study on the age distribution of Oak forests in north-central Arkansas. The findings of this dendrochronological study show all four stands sampled originated between 1900 and 1930, the result of timber harvest and/or wildfire near the end of the New South Period (Soucy, Heitman, and Spetich 2004). Overall, the exploitation of timber resources during this time resulted in a depleted resource base and an increased population in the Ozarks. By the end of this time period, there was enough concern about the state of the Ozark forests that the region would see the beginning of government forest management and conservation through the creation of national forests throughout the region (Rafferty 2001).

Mineral Resources

In addition to the timber industry, the construction of railroads spurred development of mineral resources in the Ozarks, creating what is today one of the major mining regions in the United States (Rafferty 2001). The main mining districts in the Ozarks include the Tri-State Lead-Zinc District (encompassing parts of southwest
Missouri, northeast Oklahoma, and southeast Kansas); the Central Lead-Zinc District Missouri; the North Arkansas Lead-Zinc District, and the Mineral Area (including the Lead Belt) in southeast Missouri (Figure 6).

Interest in mining the Ozarks had begun during the early exploration of the region, with lead had been sought in the region since the early 1700s (Pitcaithley 1987). Government expeditions into the Ozarks in both 1818 (Rafferty 1996) and in 1834 (Featherstonhaugh 1835) noted lead deposits in northern Arkansas and southern Missouri. Following the Civil War mining activity increased in the Ozarks, and included the formation of the Arkansas Geological Survey. The first state geologists of Arkansas traveled the state during 1857-60 and reported the presence of small lead mining operations along the Buffalo River. During the war these mines would be utilized by Confederate troops for supplying lead munitions. It was not until the 1870s, however, that large-scale mining was introduced into northern Arkansas (Pitcaithley 1987).

In Missouri, the St. Joseph Lead Company developed major operation at Bonne Terre in the St. Francis Mountains during the middle of the 19th century. The mine was worked for over ninety years and grew from 964 acres in 1864 to 13,000 in 1892. Many similar frontier mining towns would soon grow into modern communities (Stevens 1991).

Soon, however, interest in lead began to decrease as the focus of mining operations shifted to zinc concentrations in the Ozarks. In fact, by 1920 the Tri-State Lead-Zinc District was the largest producer of zinc in the country. Mining in this area led to its principal city, Joplin, becoming one of the most important railroad centers in Missouri (Sauer 1920). Although smaller zinc operations had been around since the 1850s, it was the discovery of a large deposit on Rush Creek in north-central Arkansas.
and the subsequent organization of the Morning Star Company in 1891 that would mark the beginning of large-scale zinc mining in the Ozarks. By 1900, hampered by a lack of transportation infrastructure, the Boston Mountain area would be surrounded by railroads, yet lack reliable transportation routes into the interior. By 1909, however, a railroad was constructed across the mountains, and new towns grew along its route (Pitcaithley 1987). Mining in the Rush Creek area would continue until 1962 (Rafferty 2001).

In addition to lead and zinc, the Ozarks produced clay, limestone, granite, barite, iron ore, Tripoli, copper, silver, and coal. In general, while much of the profits from mining area taken out of the region, the presence of these activities did contribute to the construction of good roads and railroads and create markets for local agricultural products and other merchants (Sauer 1920). By the end of the 19th century, railroad, timber, and mining developments in the Ozarks led to an unprecedented prosperity across parts of the region. This was a time of town growth and the replacement of a largely barter system that remained in parts of the region with money-based commerce. These developments and the new technologies that arrived with them came to co-exist with the frontier culture of the Ozarks (Stevens 1991).

Ozark Landscapes Before and After 1880

During the first half of the 20th century it was thought the non-prairie areas of the Ozarks were dense forest (Braun 1950). Using notes from early 19th century surveyors, it has since been shown that much of the non-prairie area of the Missouri Ozarks was in fact open woodland or barrens (Beilmann and Brenner 1951). One early observer described the Springfield Plateau between the White River and Bentonville in northwest
Arkansas as consisting of barrens interspersed with prairie (Owen 1858). Other more recent research has supported the open woodland/barren view, and gone on to stress the role of fire in maintaining this type of environment (Ladd 1991, Guyette and Spetich 2003). It is important to note that most of the research on historic environmental conditions in the Ozarks has focused on the part of the region within Missouri, and while the models constructed may apply to the Arkansas (and Oklahoma) Ozarks, there may indeed be differences. Being that the Boston Mountain subdivision of the Ozarks does not extend into Missouri, there may be both physiographic and biological differences between the Boston Mountains area and the Ozark Highlands (Foti 2004).

While much historic vegetation remains in the Ozark Highlands, changes since early settlement are a result of a complex and spatially diverse set of disturbances. These include fire suppression, logging, controlled burning, cultivation, flood control, grazing and urban development (Jacobsen and Primm 1997, U.S. Department of Agriculture, Forest Service 1997). These activities have resulted in decreased erosional resistance and increased sedimentation in Ozark streams (Jacobsen and Primm 1997), thus altering the geomorphology of the Ozarks.

It is the presence of chert that contributes in large part to the character of the streams in the Ozarks. Containing probably more chert than any similar area, the Ozarks possess chert in ranges from small nodules to large beds. A typical stream channel in the region is floored with a thick bed of chert fragments. Since this chert floor is more resistant than the margins of the bed, streams show a tendency for lateral erosion, producing a bed of prodigious width, and likely accounting for the relatively great width of Ozark valley floors, as well as the nature of the meandering habits of even rapidly
flowing Ozark streams (Sauer 1920). Viewed in light of land use activities and land cover changes described by Jacobsen and Primm (1997), it makes sense that valley-bottom activities that decrease erosional resistance and in turn increase sedimentation would serve to exacerbate the lateral erosion of Ozark streams, and thus cause temporal changes in stream gravel inputs coming from valley storage, directly related to these anthropogenic activities.

Overall, while the early settlement of the Ozarks likely created decreased erosional resistance due to bottomland clearing, this would have been countered by upland fire suppression, which would have decreased annual runoff. During the Timber Boom Period, increased erosion likely had a much greater impact on channel disturbance and geomorphology, not from hillslope erosion, but rather from continued clearing of bottomland and riparian zone road building. This is supported by evidence of stream disturbance during this time, and observations that increased gravel in Ozark streams has come from small stream valleys rather than from the hillslopes. This bottomland disturbance increased as grazing, crop production, and transportation uses grew following the Timber Boom Period (Jacobsen and Primm 1997).

One reason that has been used to explain the patterns of land use in the Ozarks is the fact that combination of geographic and political reasons resulted in the frontier way of life surviving longer in parts of the Ozarks than in other places (Dougan 1994). It has been suggested that the attitudes and institutions inherited from the frontier settlers are in fact the cause of the depletion of natural resources during this period. The abundance of resources during earlier times acted to repress the development of a conservation ethic and perpetuate the beliefs that (1) all land was suitable for agriculture, (2) forests did not
require management and would take care of themselves, and (3) government regulation was unnecessary for the sustainability of resources (Hammar 1935). In addition, it has been suggested that the frontier traditions of subsistence hunting, gathering and farming, as well as a strong adherence to the belief that government should not involve itself in private affairs, led to a resistance to governmental and corporate efforts to bring modernization and industrial productivity to the Ozarks. These attitudes would continue to create resistance to government conservation efforts during the following time period, even as the federal government became the largest landowner in the Ozarks with the creation of its national forests (Benac and Flader 2004), beginning with the creation of the Ozarks National Forest in 1908.

THE CONSERVATION ERA (c. 1920 – c. 1960)

The Effects of the Timber Boom

The timber boom of the New South period in the Ozarks resulted in both a greatly depleted resource base and a greatly increased population. While the decline of the timber industry in the early 20th century led to an emigration of many people from the Ozarks, the population still remained greater than it had been before the Timber Boom period, and this population generally worked to re-establish their lives free from outside interference (Benac and Flader 2004). This population, in order to sustain itself, added additional strain to the natural resources in the region. During this time many of the larger land holdings that had been cutover during the Timber Boom were subdivided and sold off as farms. This acted to initially increase the overall population in areas formerly under timber harvest, while at the same time decreasing the general population outside
the timber areas. Drawn by the potential for growing crops like tomatoes and strawberries on the cleared ridgetops, these farmers soon found that demand for their new products declined, as more conveniently located areas came into production for these same crops. After initially attempting to replace these crops with corn and wheat on the ridgetops, and finding this to also prove unsuccessful, many farmers shifted their emphasis to the raising of livestock. This led in turn to open-range grazing on cutover lands, and the burning of re-growth timber to improve forage conditions for livestock. Overall, these activities had the effect of delaying timber restoration in the former timber harvest areas (Rafferty 2001), while increasing the erosion potential (Jacobsen and Primm 1997).

This period has been classified as having a “culturally dependent” stage in the overall fire regime. As such, culture serves as the primary limit on fire frequency (Guyette, Stambaugh, and Dey 2003), as well as the primary agent with regard to intentional burning. It is estimated that during this time there was a moderate increase in upland and valley slope sediment yield and a substantial decrease in valley bottom riparian erosional resistance (Rafferty 2001). This is due in no small part to the land use activities taking place in these areas.

**Farming**

Mixed farming in the Ozarks had started around 1870, primarily in the river valleys and on the Springfield Plateau. Prior to this time agricultural activities consisted mostly of subsistence-based farming, as well as livestock farming. The latter was the
only commercially viable farming activity since the animals could be driven to markets to the north and south. The transition from subsistence and livestock farming to general farming took place rather quickly, however, as the introduction of railroad transportation following the Civil War allowed livestock, as well as crops such as wheat and corn, to be transported to market (Rafferty 2001).

Throughout the Ozarks, and across the South in general, farming had been devastated by both the Civil War and the period of Reconstruction that followed. As the people of the South began to rebuild their lives, many families kept a few hens and a rooster to supply eggs for consumption, but in general poultry husbandry was considered a supplementary farming activity. An exception to this, however, was in northwest Arkansas, where, since the late 19th century, Washington and Benton Counties had gained a reputation as a sort of agricultural oasis, having well-watered, fertile soil and a temperate climate. Farmers in the area grew apples and vegetables, and by the early 20th century had over four and a half million apple trees (Strausberg 1995). In was here, at the Arkansas Agricultural Experiment Station and the University of Arkansas that the modern poultry industry in the Ozarks had its beginnings.

During this time, the railroads, seeking to increase rail traffic, began allowing refrigerated cars to transport slaughtered chickens, supplementing the trucking-dominated transport of live birds. Utilizing the railroads, chickens from northwest Arkansas were transported to places such as Chicago, New York, Boston, and Philadelphia. Also during this time, the apple industry was suffering from insect and worm infestation, drought, and a severe freeze. As the problems grew, farmers increasingly turned to poultry as an alternate pursuit. In addition, the rise of the poultry industry in northwest Arkansas
attracted the attention of people outside the area, who themselves realized the economic opportunity at hand. The outcome of this was the development of a chicken hatchery business in Missouri, which supplied growers with both feed and eggs, as well as a trucking industry to transport the birds to markets in Tulsa, Kansas City, St. Louis, Springfield, and Chicago. By 1950, Arkansas had become the third largest broiler chicken producer in the country, and by 1960 was second only to Georgia in poultry production (Strausberg 1995). The rise of the poultry industry in the Ozarks had created a wealth of fertilizer available for agricultural use, and has thus led to an increase in agricultural land use in areas formerly less-than-suitable for such activities.

Since around 1920, an increase in clearing has taken place in these marginal areas in order to cultivate crops. Along with this has come accelerated erosion. At the same time, the valley bottoms have experienced a much longer period of land use, involving settlement, clearing, farming, and grazing. The removal of riparian vegetation in these areas has likely led to bank instability and increased erosion (Jacobsen and Primm 1997). These bottomland areas would have likely been prone to erosion, due to the combination of recent and past land use activities. Free-range grazing, crop production, and the construction of transportation routes during the New South Period and the Era of Conservation have accelerated stream disturbance in these areas. Oral accounts of historic land use describe livestock eating away the vegetation of gravel bars and clearing bottomland pasture of woody understory growth. In addition, these accounts describe the congregation of livestock along the riverbanks, where they would come to drink and sleep (Jacobsen and Primm 1997). The cumulative effect of land use over time has likely led to an overall increase in valley bottom erosion during the 20th century.
**Federal Land Acquisition**

By the end of World War I, the federal government became the Ozarks’ largest landholder and biggest employer (Rafferty 2001), establishing both national forests and national parks within the region (Figure 7). This began in 1908, when President Theodore Roosevelt created the Ozark National Forest in Arkansas (Shaddox 1989). On March 6 of that year, President Roosevelt set aside close to one million acres of public land, creating the first area of protected hardwood timber in the country (Strausberg and Hough 1997, Smith 2004). In 1933, the Mark Twain National Forest was created in Missouri, covering approximately one and a half million acres. The National Forest lands in the Ozarks are made up of several non-contiguous districts, and comprise approximately twenty percent of the Ozark uplands (Rafferty 2001). In addition, the Civilian Conservation Corps created first extensive system of all weather roads in the backcountry of Boston and Ouachita Mountains (Smith 1986), as well as constructing facilities at other recreation site such as Lake Wedington and Devil’s Den State Park. Like many national forests, those in the Ozarks contain much private land within their borders, usually in cleared valleys and along upland roads, with the Forest Service owning most of the more rugged areas. In all areas, the designation and purchase of lands for public ownership has led to population decreases (Rafferty 2001).

In the late 1930s, the U.S. Forest Service and rural fire protection organizations developed fire suppression programs to protect lives, timber, homes, buildings and other rural improvements (Guyette, Dey, and Dey 1999). Prior to that time, landowners had burned some timbered areas on an average of about once every three years. In the Mark
Twain National Forest lands alone, an average of about 280,000 acres were burned per year before the conversion to public lands. Within ten years of federal ownership that average had dropped to about 8,000 per year (Rafferty 2001).

These public lands have played an important part in the recovery of wildlife species including deer, bear, and turkey, which had greatly diminished in numbers prior to public land creation in the Ozarks (USDA Forest Service 1997). In addition, the creation of public lands has brought with it an increased awareness of the importance of conservation as well as the institution in some areas of riparian buffer zones, leading to an increase in riparian vegetation and, in some areas at least, a decrease in livestock congregation and erosion along the streams (Jacobsen and Primm 1997).

Generally speaking, the biggest change with regard to land use in the Ozarks since the beginning of the century has been the conservation and land management practices of Federal and State agencies associated with the creation of national and state public lands. This has led to a recovery of riparian woodland areas and some increase in channel stability during recent years. Along with this have come more intensified logging and agriculture on private lands, and an increase in cattle populations and grazing density (Figure 8). These trends are evidenced by increases in both livestock populations and lumber production, and have the potential to continue the historic stream disturbance pattern by increasing runoff and sediment supply.

Recreation and Tourism

The Ozarks contain abundant high quality resources in terms of recreation and tourism, having picturesque rural landscapes, hardwood forests, clear streams, and a
generally mild climate (Rafferty 2001). The location, landscape, and generally rural nature of the Ozarks region make it ideal for both recreation and tourism. The Ozark-Ouachita region is the only major upland area in the mid-South west of the Mississippi River, and is located within a day’s drive of Little Rock, Tulsa, St. Louis, Kansas City, Memphis, Des Moines, Omaha, Dallas, Oklahoma City, and Chicago (Figure 1). Today, approximately 57 million people live within this draw area (USDA Forest Service 1999).

Hunting and fishing have long been popular in the Ozarks. The abundance of game animals such as deer, turkey, rabbit, quail, squirrel, and fish continue to make these early subsistence activities popular recreational past times. It was not until the early 20th century, however, that federal and state government managed to establish their presence in the Ozarks. The creation of National Forests and Parks in the Ozarks marked the beginning of the tourism industry that exists today.

In addition to outdoor recreation, the mineral springs of the Ozarks have been used since the Civil War to treat a variety of diseases and maladies (Rafferty 2001). Among the notable resort destinations that were developed for such activities were Eureka Springs, Siloam Springs, Ravenden Springs, and Heber Springs (Figure 9).

Another reason people come to the Ozarks is the generally rural nature of the region. By the 1930s the relatively isolated lifestyle of areas like the Buffalo River would were being sought after as people returned to the Ozarks to elude the nation’s economic troubles (Pitcaithley 1987). Starting at that time, folks from out of town came to fish the rivers on johnboats, and by the 1950s, canoeing became popular. Among the most popular destinations were the Current, Meramec, Gasconade, and White Rivers. By the 1960s the construction of better roads and the widespread use of the automobile have
opened most Ozark streams to recreational activities. In addition, the relatively mild currents of Ozark streams make them ideal for family recreation, as well as novice paddlers. Along with this has come the development of canoe rental businesses to serve both locals and visitors from surrounding states (Rafferty 2001). Today, it is estimated that 1.5 million canoeists, campers, fishermen, hikers, hunters, and horseback riders pass through the small Missouri town of Eminence each year, heading for recreational opportunities on the Ozarks Scenic Riverways (Attoun 2002).

In addition to the recreational potential of natural waterways in the Ozarks, the construction of large reservoirs and the accompanying infrastructure development has served to draw recreationists from across the country, while also impacting stream disturbance and geomorphology. However, by the late 1960s widespread opposition to dam building due to concerns for the environment led to cancellation of several dam projects, including those on the Meramec, James, and Buffalo Rivers (Rafferty 2001).

**THE MODERN ERA (1960 – TODAY)**

From a cultural perspective, the Ozarks have remained primarily a rural region, consisting of a mostly white, protestant population. The area possesses a relatively stable social system, where traditional lifestyles, reluctance to change, and a distinctive cultural landscape persist (Rafferty 2001). While this is not unique to the Ozarks, they are to a large degree indicative of the culture and lifestyle of the rural American South. Overall, the population of the Ozarks has continued to increase since the Civil War. While the region did see somewhat of a stabilized population during the first half of the 20th century, the second half of the century has seen a population boom. Between 1960 and
1998 the population of the Ozarks rose from about 1.4 million people to about 2.5 million people, an increase of 81%. During the same time period the population of the nation as a whole rose 50% (Rafferty 2001).

More than half this growth in the Ozarks was the result of migration, while an excess of births over deaths accounts for the remainder. In fact, from 1960 to 1998 only four Ozark counties actually decreased in population (Rafferty 2001). The growth in the Ozarks has been centered in certain parts of the region, such as the lake districts and around the larger towns. Along with this population growth has been a migration of the rural population into the towns (Dougan 1994). Starting in the 1960s, a growing industrialization has been taking place northwest Arkansas, driven in part by the growth of companies such as Wal-Mart and Tyson Foods. This has created a need for workers in the area (Rafferty 2001). In addition, while the population of the city of St. Louis actually decreased from 1960 to 1998, the growth of St. Louis suburbs has led to population increased in the northeast Ozark region. In fact, much of the population growth in the region is the result of urban sprawl as development continues along the urban-rural interface. In addition, the growth of small towns and subdivisions near large lakes such as the Lake of the Ozarks, Table Rock Lake, Bull Shoals Lake, Beaver Lake, and Lake of the Cherokees has contributed population increases (Figure 10).

With the abundance of recreational opportunities found throughout the Ozarks, it is interesting to note that from 1970 to 1996, metropolitan counties containing national forest lands grew 20%, while metropolitan counties without national forest lands grew only 7% (USDA Forest Service 1999). This is likely the result of both the draw of these rural recreational lands as well as the continuing development of the rural-urban interface.
surrounding these metropolitan areas. Another factor behind the population growth is that during this time period retirement destinations have become quite popular in the region (Figure 11). Starting in the 1950s, retirees have been coming to the Ozarks, drawn by the regions four seasons, mild winters, and abundant sunshine (Dougan 1994). In general, these retirement destination counties are located in the central Ozarks. These counties include Benton, Camden, Hickory, Morgan, Ozark, Polk, Stone, and Taney Counties in Missouri; Baxter, Cleburne, Marion, Stone, and Van Buren Counties in Arkansas; and Delaware County in Oklahoma (USDA Forest Service. 1999). The Ozarks have also experienced a new ethnic diversity during the second half of the 20th century. Immigrants from Mexico, China, and Vietnam have been part of the population expansion in the region (Rafferty 2001).

Along with the population boom in the Ozarks has come a concern over the environmental impacts of the growth and development the region has seen. Efforts to address these concerns began with the creation of public lands in the region, and the attempts by forestry officials at the time to end the annual practice of burning the woods. Since that time, the growing population has continued to put a strain on the general environment, and particularly on the natural resources being used in the area. The environmental movement in the region has included efforts by concerned citizens to rebuild wildlife populations through the institution of hunting and fishing seasons, to stop the building of dams and preserve free-flowing streams, to control the disposal of hazardous wastes, and to reduce clear-cutting in the forests (Dougan 1994). Local environmental groups such as the Ozark Society have been formed to organize such efforts and play an important role in the conservation of the Ozarks natural resources.
Since the 1960s the Ozarks have seen major, rapid changes driven by population growth and development. This has had a particular impact in northwest Arkansas, where the Fayetteville-Springdale-Rogers metropolitan area (Figure 2) has been one of the fastest growing metropolitan areas in the United States (Table 2).

The population growth in the Ozarks has been accompanied by rapid development in order to create the housing, infrastructure, and amenities needed to serve the expanding population. The land use patterns resulting from this development bring with them corresponding patterns of land cover change, along with corresponding changes to the landscape and the streams. In order to understand the historical geography of land use in the Ozarks and to better anticipate potential future environmental dynamics, it is important to investigate the impacts that human have had on the environment of the region, and to search for manifestations of these impacts within the environment that can provide variables with which anthropogenic-induced environmental change can be described over time.
REFERENCES


Owen, D. D. 1858. First report of a geological reconnaissance of the northern counties of Arkansas made during the years 1857 and 1858. Johnson and Yerkes, Little Rock, AR.


Strausberg, S. F. 1995. *From hills and hollers: rise of the poultry industry in Arkansas.* Arkansas Agricultural Experiment Station, University of Arkansas, Fayetteville.


Figure 1. Location of the Ozarks
Figure 2. Major physiographic provinces of the Ozarks
Figure 3. Metropolitan areas in the Ozarks
Figure 4. The Trail of Tears
Figure 5. Major Civil War battles in the Ozarks
Figure 6. Mining districts of the Ozarks
Figure 7. National Forests and rivers of the Ozarks
Figure 8. Cattle population in select Missouri counties, 1850-2000
(Source: Missouri Agricultural Statistic Service)
Figure 9. Ozark spas and mineral springs of late 19th century
Figure 10. Major lakes of the Ozarks
Figure 11. Retirement destination counties in the Ozarks
(Adapted from USDA Forest Service. 1999)
Table 1. Land use time periods

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Approximate Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Settlement</td>
<td>1700 – 1870</td>
</tr>
<tr>
<td>The Emergence of the</td>
<td>1870 - 1920</td>
</tr>
<tr>
<td>New South</td>
<td></td>
</tr>
<tr>
<td>The Conservation Era</td>
<td>1920 – 1960</td>
</tr>
<tr>
<td>Modern Era</td>
<td>1960 – present</td>
</tr>
</tbody>
</table>

Table 2. Ten fastest-growing metropolitan areas 1990-1998
(U.S. Bureau of Census 1999)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Metropolitan Area</th>
<th>Population</th>
<th>Increase</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Las Vegas, Nevada-Arizona</td>
<td>1,321,546</td>
<td>468,900</td>
<td>55.0</td>
</tr>
<tr>
<td>2</td>
<td>Laredo, Texas</td>
<td>188,166</td>
<td>54,927</td>
<td>41.2</td>
</tr>
<tr>
<td>3</td>
<td>McAllen-Edinburg-Mission, Texas</td>
<td>522,204</td>
<td>138,659</td>
<td>36.2</td>
</tr>
<tr>
<td>4</td>
<td>Boise City, Idaho</td>
<td>395,953</td>
<td>100,102</td>
<td>33.8</td>
</tr>
<tr>
<td>5</td>
<td>Naples, Florida</td>
<td>199,436</td>
<td>47,337</td>
<td>31.1</td>
</tr>
<tr>
<td>6</td>
<td>Phoenix-Mesa, Arizona</td>
<td>2,931,004</td>
<td>692,506</td>
<td>30.9</td>
</tr>
<tr>
<td>7</td>
<td>Austin-San Marcos, Texas</td>
<td>1,105,909</td>
<td>259,682</td>
<td>30.7</td>
</tr>
<tr>
<td>8</td>
<td>Fayetteville-Springdale-Rogers, Arkansas</td>
<td>272,616</td>
<td>61,708</td>
<td>29.3</td>
</tr>
<tr>
<td>9</td>
<td>Wilmington, North Carolina</td>
<td>218,248</td>
<td>46,979</td>
<td>27.4</td>
</tr>
<tr>
<td>10</td>
<td>Provo-Orem, Utah</td>
<td>335,635</td>
<td>72,045</td>
<td>27.3</td>
</tr>
</tbody>
</table>
CHAPTER 2. QUANTIFYING BASIN-SCALE LAND USE LAND COVER CHANGE USING HISTORICAL AERIAL PHOTOGRAPHY

Abstract

Historical aerial photography provides a valuable source of data for studying temporal changes in land use and land cover (LULC). While satellite imagery has in large part replaced air photos in recent LULC investigations, historical aerial photography dates back to the middle of the 19th century, and widespread coverage exists for a time period approximately twice as long as available satellite data, thus providing a source of data for studies of longer term landscape changes. This paper presents a public land system survey (PLSS)-based multi-dimensional map generalization technique for classifying and quantifying basin-scale LULC change using historical aerial photography, geographic information systems (GIS), and the American Planning Association (APA) Land-Based Classification System (LBCS). The study area consists of twelve sub-basins of the Illinois River in Northwest Arkansas. Aerial photographs from 1941, 1982, and 2004 were used to quantify changes in LULC over time. Results show an increase in development at the urban-rural interface, and reforestation of federally managed public lands. The results of the 2004 LULC quantification were found to have high correlation with the same general LULC classes quantified using satellite imagery from the same year, offering a means of evaluating the accuracy of the results.

Key Words: land change science, land use land cover, map generalization, Public Land Survey System, historical aerial photography
INTRODUCTION

“In a variety of ways the drainage basin has formed a framework for human activity”. – C. T. Smith (1969)

Land use is the pattern of human exploitation of the land with regard to the opportunities and constraints present in the landscape, relative to the abilities of humans to access and exploit natural resources. It is a function of culture, settlement patterns, and environmental characteristics (Meinig 1968), and has been defined as human activity on the land that is related to the land (Clawson and Stewart 1965). The impact of land use activities affects many parts of the earth’s natural system, including climate, hydrology, biodiversity, and the sustainability of lands (Land use Land Cover Change Group 2004), with changes happening most rapidly at the urban-rural interface (Johnson and Beale 1995). Due to the major impact that land use activities have on the landscape, it is important to understand and reconstruct the distribution and history of land use patterns and land cover change across the landscape, in order to gain insight into the complex processes and responses within the landscape, and to inform projections of future trends in human activities and land use land cover (LULC) change (Climate Change Science Program and the Subcommittee on Global Change Research 2003). It is through a better understanding of how land use activities impact land cover and geomorphology that people can better understand the effects of anthropogenic activities with regard to ecological impacts such as habitat destruction and wildfire risk. This, along with a better understanding of the biophysical changes that have occurred in a region, provides a starting point for identifying research needs, establishing conservation goals, and targeting ecological restoration efforts (Black et al 2004).
This type of historical-ecological investigation relies on three general potential sources of data: (1) written documentation (including historical maps and photographs), (2) sedimentary records, and (3) traces of anthropogenic land use left on the landscape (Russell 1997). The focus of this study is on the former, specifically, the development of a Public Land Survey System (PLSS)-based multi-dimensional map generalization methodology for classifying and quantifying basin-scale LULC change using historical aerial photography, geographic information systems (GIS), and the American Planning Association (APA) Land-Based Classification System (LBCS).

Study Area

The study area is located in the Illinois River basin of Northwest Arkansas (Figure 1). The entire study area is approximately 142 km², and is situated between Fayetteville, Springdale, and Siloam Springs. For the purpose of examining the spatial distribution LULC change, the study area has been divided into twelve sub-basins, hereafter referred to as study units. These study units were delineated using automated GIS scripts and a digital elevation model of the area.

The study area is located on the periphery of the Fayetteville-Springdale-Rogers metropolitan area making it an ideal area for studying changes at the urban-rural interface (Johnson and Beale 1995). It is underlain by the Mississippian-age Boone formation, providing relatively uniform lithology for all study units. Other morphometric characteristics of the study area are being examined in another stage of the overall project.
Historical Aerial Photography and Land Use Land Cover Change

The use of historical aerial photography to quantify LULC change can be traced to the mid-1940s when Francis Marschner, working as a cartographer for the U.S. Department of Agriculture, used air photos from the previous decade to map major land uses in the United States (Marschner 1950, Anderson 1967, Anderson et al. 1976). By the 1970s, the federal government of the United States began making efforts to gain an overview of LULC patterns across the country, which required a standardized classification system. This resulted in the development of the widely used Anderson (1967) classification system. This system was designed specifically for use with aerial photography and is still in use today (Anderson et al. 1976), along with an updated LULC classification system designed by the Federal Geographic Data Committee (FGDC 2006).

Today, satellite imagery has widely replaced aerial photography for use in the mapping and quantification of LULC change. However, the availability of satellite imagery only allows an examination of LULC changes over the past thirty years or so, limiting the ability to understand changes over the longer periods of time. In addition, with a minimum pixel size of about 80 square meter, satellite data are of limited use in quantifying many changes that might be detected at a smaller spatial scale. Other sources of historic land use information are therefore crucial for understanding present and future human-environmental dynamics with respect to longer-term patterns of change (Foster 1992). In order to examine change over longer periods of time, historical aerial photography and maps must be used, since they show the landscape as it existed, or was represented, prior to the time period of satellite imagery (Campbell 2001). Often only disparate data sources are available, requiring data to be brought to the same level of
resolution for comparison and change detection. This can be accomplished through map generalization techniques (Turner 1990; Petit and Lambin 2001; Franklin, Hansen, and Stenhouse 2002; Franklin, Montgomery, and Stenhouse. 2005).

For the current study, aerial photographs from the years 1941, 1982, and 2004 were utilized to map and quantify LULC in the study area. Hard copy photos from 1941 and 1982 were scanned and georeferenced for integration into a GIS prior to LULC classification.

METHODOLOGY

Map Generalization

Map generalization involves simplifying the detail of a map to a resolution appropriate for a given purpose, for either display or analytical purposes (International Cartographic Association 1973, Müller 1991, Goodchild et al. 1991, Painho 1995), and is present in all forms of digital cartography and data collection (João 1998). Map generalization involves representing a portion of the real world with decreasing detail, while maximizing information with respect to a given application. The process may involve the modification of the shape, size, and/or number of map features (ICA 1973), and acts to modify one or more of three types of map information: the geometric, semantic, and topologic aspects of objects contained in a map (Li and Huang 2002, Dettori and Puppo 1996). Operations for generalizing spatial data are fundamental to GIS with regard to scale change, information reduction, and thematic emphasis (Weibel and Dutton 1999).
While advances have been made in automating map generalization, it remains a difficult process, due in large part to its subjective and intuitive nature. Due to this, the process of using map generalization algorithms often incorporates human control through a knowledge-based systems component (Weibel 1991, Beard 1991), which has been termed “amplified intelligence” (Weibel and Buttenfield 1988). However, user input in map generalization remains, as it was described 100 years ago, the place where art enters into map making (Eckert 1908).

A theoretical framework has been outlined for map generalization as it applies to geographic information systems (McMaster and Shea 1992). This framework contains three objectives with regard to generalization: (1) philosophical objectives (i.e. why you generalize), (2) cartometric evaluation (i.e. when you generalize), and (3) spatial and attribute transformation (i.e. how you generalize). Three specific methods of map generalization have been identified for the latter objective, two for data and one for graphics (Weibel 1992; Grünreich, Powitz, and Schmidt 1992; Müller et al. 1995; Peng, Tempfli, and Molenar 1996; Weibel and Dutton 1999; Cheng and Li 2006). The first of these is object generalization, or the degree of generalization represented in a database. This type of generalization applies to the development and implementation of the deductive model to be used for data collection (i.e. sampling methods). This may be done in order to build a database model with appropriate content and resolution for a specific application; to minimize expenditure of time, space, and money; and/or to increase data robustness (i.e. create a lean, clean database) (Weibel and Dutton 1999). The second type is model generalization (i.e. database generalization), or the derivation of a reduced database from a source database. This is done in order to derive secondary
data from a multi-purpose database (Weibel and Dutton 1999). Finally, the most commonly applied method is cartographic generalization (i.e. visualization) or the derivation of a graphic product from a source database. This can also, in the absence of corresponding model generalization, allow for database manipulation independent of cartographic representation (Müller et al. 1995). However, this type of map generalization is usually done in order to optimize data display for visual communication (Weibel and Dutton 1999).

Two basic strategies exist for employing cartographic map generalization (Cheng and Li 2006): (1) geometry-based generalization, where geometric resolution is the driving factor in the process, and adjacent objects can belong to the same class, (2) theme-based generalization, where adjacent objects belonging to the same class are aggregated to form larger spatial units with the same thematic characteristics. This results in no adjacent objects belonging to the same class. Regardless of the strategy employed, actual map generalization operations generally consist of five kinds of procedures: (1) simplification, (2) omission, (3) fusion, (4) displacement, or (5) exaggeration (McMaster and Shea 1992, Weibel and Dutton 1999, Bolstad 2005). The results of map generalization can be evaluated in terms of one of more of the following criteria: (1) accuracy, (2) precision, (3) resolution, (4) consistency, and (5) completeness (Sukhov 1970; Müller 1991; Müller et al. 1995; Pairrho 1995; João 1995; Veregin and Hargitai 1995; João 1998; Li and Huang 2002; Li and Choi 2002; Hupy et al. 2004; Cheng and Li 2006).

Although map generalization is most often thought of as it applies to the amount of information contained in cartographic products derived from a dataset, map
generalization is also a technique that can be applied to one or more sets of data, in order
to bring data sets of disparate resolution to a similar resolution in order to allow more
reliable quantification and analysis of differences in these data sets. When developing a
methodology for investigating LULC change, one must consider whether the goal of such
study is concerned with knowing where change is occurring (i.e. mapping the changes),
or quantifying how much change in occurring (i.e. area estimates), or both (Woodcock
and Ozdogan 2004). The latter can be accomplished through a combination of
cartographic and model generalization. An application of this type of analytical map
generalization is the integration of temporally discrete data sets in order to allow
integration of data for change detection purposes (Petit and Lambin 2001).

This study is concerned with developing an efficient, flexible, and standardized
methodology for using historical aerial photography to measuring the amount of basin-
scale LULC change that is occurring within a study area over a given period of time.
This is accomplished through the utilization map generalization, along with a multi-
dimensional LULC classification scheme, applied within the spatial framework of the
PLSS.

Public Land Survey System

Originally conceived by Thomas Jefferson, the PLSS was created by the Land
Ordinance of 1785, an act of Congress with the goal of raising money through the sale of
land in the territory west of the original 13 colonies. Since this area was largely
unmapped, the act established the PLSS as a means of organizing these lands politically.
The PLSS establishes a land-based grid system whereby the land is divided into square
townships, six miles per side. Townships are subdivided into 36 one square mile
sections, each of which could be further divided by quartering repeatedly until reaching a
size suitable for sale. Approximately 75% of the United States has been subdivided using
land cover change are directly related to property ownership and control (Meyer 1995).

The PLSS has been used in previous investigations related to LULC
quantification, usually as a unit of aggregation or a sampling device (Stier 2000, He et al.
2000, Han 2002, VanLooy and Martin 2006). However, random sampling is not ideal for
LULC studies since LULC change is not randomly distributed (Skole et al. 1997). The
PLSS does serve as the basis of Natural Resources Conservation Service (NRCS) land
use sampling design (NRCS 2006) and has been advocated as a structural basis for the
storing of spatial information for local government GIS land use databases (Huxhold,
Fowler, and Parr 2004). The PLSS also offers a spatial framework for conducting multi-
scale classification of LULC, as well as a convenient framework for comparing results of
studies at different spatial scales by utilizing the PLSS for data aggregation.

Unlike more specific ownership boundaries (i.e. parcel boundaries), PLSS
boundaries do not change over time (Han 2002). In areas where it applies, the PLSS
remains the basis for most land ownership and transfers today, and the official procedures
for its utilization are provided for in the Manual of Instructions for the Survey of the
Public Lands of the United States, 1973 (U.S. Department of Interior 2006). In addition,
each section of the PLSS has its own unique land use history since its creation, which can
be investigated in perpetuity. These characteristics make the PLSS a common framework
for ownership, control, and land use history, and thus, in areas where it is used, it is the
most fundamental model for the spatial organization, mapping, and quantification of land use as it relates to landscape change. In addition, the PLSS provides a scalable spatial framework for mapping and quantifying LULC at multiple resolutions.

While the PLSS has much to offer as a LULC spatial framework, it has not been widely utilized, perhaps due to certain limitations and problems associated with it. These problems include the presence of original survey errors, non-standard sections, accuracy issues related to the scale of digitized PLSS layers, and the fact that it is not a projected grid system resulting in offset when used in GIS with other projected grid systems (DeMers 2005, Warwick 2006). However, despite these issues, the precision of the PLSS is dividing the landscape into spatial units based on land use history tied to ownership, and thus control, is unequaled in terms of a standard mapping unit that is directly tied to land use boundaries, and the availability of the PLSS as a commonly-used GIS layers provides for standardization of its application, despite the inherent spatial errors associated with it. The PLSS also provides a spatial framework for a hierarchically structured multi-purpose database with scale-dependent layers, allowing for retrieval of data and production of maps at user-specified scales. This type of “pseudo-scale-independent” database (Jones and Abraham 1986) provides many of the same benefits and flexibility as a truly scale-independent format (Müller 1991, João 1998).

For this study, the PLSS quarter section was selected as the minimum mapping unit (MMU) for the visual classification of LULC change. In order to more accurately visually estimate the percent coverage of LULC types within each section, the sections were subdivided into “quarter-quarter-quarter” (hereafter QQQ) sections, each covering approximately 10 acres. During the process of LULC classification the sixteen resulting
sections found within each quarter (Q) section served as a basis for estimating percent coverage of each LULC type within each MMU. Thus, for each LULC type, each section was classified as containing from one to sixteen sections, regardless of where the LULC type was located within the section. This technique allows for more accurate estimation, by allowing spatially discrete area of a certain LULC type to be aggregated visually for total areal coverage within the section. Since each mapping unit contained 160 acres, divided into sixteen sections, the resulting number was then multiplied by a factor of ten to derive total acreage covered by a specific LULC type within each quarter section. Totals from all sections whose center was contained within a study unit were then summed and divided by the total acreage of each study unit in order to estimate total percent coverage for each LULC type within each study unit. This methodology has the benefit that it can be utilized using any PLSS scale as a MMU, providing a flexible spatial framework that offers standardization, the capability of being tailored to a scale appropriate to a specific study, and allows aggregation of results for comparison of results with other studies.

Land Use Land Cover Classes

Land cover constitutes what is on the land, both in terms of vegetation and human constructions (Burley 1961, Cihlar and Jansen 2001). There is much overlap in the classification of land use and land cover, with certain types of land uses being associated with types of land cover. Much land cover is, in fact, the visible evidence of land use (Campbell 1987). Aerial photography, or any other remotely sensed imagery, is not capable of recording activity, but does record the resulting surface characteristics, and
thus it is through land cover mapping that interpretations regarding land use activities are made (Anderson et al. 1976).

Since the 1970s, LULC classification systems used with remotely sensed data have involved the traditional \textit{a priori} hierarchical type focused on land cover (e.g. Anderson et al. 1976, CEC 1993, Thompson 1996, FGDC 2006), as well as the more recent “dichotomous, modular hierarchical” type that incorporated \textit{a posteriori} elements in order to allow flexibility for wider geographic application within a standardized framework (e.g. Di Gregorio 1996. Di Gregorio and Jansen 2000). In addition, classification systems have been developed that focused on mapping land use based on the strength of relationships with existing land cover map classes (Cihlar and Jansen 2001). However, a ubiquitous limitation contained within these systems is the fact that each MMU must be assigned a single (i.e. one dimensional) value, regardless of horizontal and/or vertical spatial heterogeneity in LULC types related to the investigation within each mapping unit. The solution to this is most often related to changing the size of the MMU, or through the use of variable-size mapping units (Di Gregorio and Jansen 2000). However, the limitation of one-dimensional classification acts to exclude inventory and quantification of multiple uses occurring on a single piece of land (Anderson et al. 1976, Cihlar and Jansen 2001), and for this reason is not utilized in this study.

\textit{Multi-Dimensional Classification}

An alternative approach is the Land-Based Classification System (LBCS) used by the American Planning Association (APA), which employs a multi-dimensional approach.
to LULC mapping (APA 2006). This classification system utilizes five general top-level classes or dimensions of land use, each independent of the others, providing for precise control over classification. The five top-level dimensions used in this system are (1) activity, (2) function, (3) structure, (4) development character, and (5) ownership. Activity refers to the actual observable use of the land, function refers to the type of establishment present, structure refers to the type of buildings present, development character refers to the overall physical development of the land, and ownership refers to use rights (APA 2006). Within each of these dimensions, multiple class levels exist, providing for a flexible and scalable classification system.

This methodology allows for the quantification of multiple uses within a single mapping unit by mapping each type or “dimension” of LULC separately. For example, land that is forested is mapped independently of land that is built. The result is that the same mapping unit may be classified as forested and built if it indeed contains both LULC types. This essentially shifts the focus of the classification and quantification process from how much of the total land has a majority of a certain LULC class, to how many MMUs contain a certain LULC class, based on a threshold of inclusion, and regardless of other LULC classes existing within the same MMU. As with any hierarchical classification system, the LBCS allows for expanding and contracting of classes for specific applications, while conforming to the same implementation methodology. It also allows for cross-scale comparisons by aggregation and generalization of one set of results for comparison with another classified at a different level of LBCS dimensional classes, and affords users the application of subsets of the
classification system tied to specific research or management driven purposes, while working within the same classification system.

Although the LBCS was developed for use by planners working with parcel-level data, non-parcel-based applications are also appropriate (APA 2006). This study utilizes the APA LBCS within the spatial framework of the PLSS, as described above. In addition, this study is part of a larger project investigating relationships between LULC, drainage basin morphology, and stream channel geomorphology. As such, a subset of LBCS classes that are related to landscape geomorphic change have been utilized. For the purposes of this study these classes have been renamed (1) forested, (2) cleared, and (3) built. The flexibility of tailoring the dimensions to the purpose of the application is another benefit of multidimensional classification.

*Visual Estimation of Land Use Land Cover*

LULC classification is often done digitally with satellite imagery. Since historical aerial photography lacks the spectral reflectance available in satellite imagery, visual classification is the most common method of classification (Magilligan and Stamp 1997; Mid-Atlantic RESAC 2003; Evans 2005; Franklin, Montgomery; and Stenhouse 2005; Loveland and Acevedo 2006; Kirk 2006; Plieninger 2006; Galster 2006). This study utilizes what essentially amounts to a visual fuzzy logic approach to pattern recognition and classification. In a fuzzy set an element can be assigned to a class based on degrees of membership, from 0% to 100% (Nedeljkovic 2004). The utilization of two levels of the PLSS division, one as an MMU and one as a framework for visual coverage estimates, provides a relatively quick and efficient method for estimating LULC class
membership, while maintaining a spatial framework related directly to land ownership, land control, and land use.

For the purposes of the larger project of which this investigation is a part, a generalized LULC classification has been utilized, as a means of quantifying general LULC changes through time that are potentially related to potential stream channel geomorphic change. A close approximation of this general classification scheme has been used in previous LULC studies in the Ozarks (Panfil and Jacobson 2001), as well as other studies related to general LULC classes (Magilligan and Stamp 1997, Mid-Atlantic RESAC 2003, Evans 2005, Loveland and Acevedo 2006, Kirk 2006, Plieninger 2006, Galster 2006), albeit not in a multidimensional framework. These classes follow the general pattern of land cover change that has occurred in much of the eastern half of the United States since European settlement.

RESULTS

The PLSS-based multi-dimensional map generalization technique described above resulted in both the mapping and quantification of three general LULC types: (1) forested, (2) cleared, and (3) built. The data were collected from historical aerial photography from the years 1941, 1982, and 2004, in order to examine LULC change over time. The results are summarized as a series of maps, showing both the location and quantity of LULC types as they changed between time periods in each of twelve study units (Figure 2). The maps include change that occurred from 1941-1982, 1982-2004, and total change from 1941-2004.
Forested Land

During the time period 1941-1982, the largest increase in forested land occurred in study units 7 (16%) and 10 (11%) (Figure 3). The only other area to show an increase was study unit 9 (4%). All other study units experienced a loss in forested lands, with the largest losses occurring in study units 5 (-13%) and 8 (-9%). No increase in forested land greater than 3% occurred during the 1982-2004 time period. Study units showing a slight increase in forested land during this period include study units 2 (3%), 3 (3%), 7 (2%), 8 (2%), 9 (3%), and 11 (1%) (Figure 4). Overall, the greatest increase in forested land during the entire 1941-2004 was located in the Illinois River main channel stream valley (Figure 5). Study units 7 (18%), 10 (11%), and 9 (7%) contained the largest increases. Visual examination of the aerial photographs reveals a concentration of reforestation along tributary stream valley bottoms. This increase appears to be related to reforestation of tributary stream valleys within federally managed lands of the Ozark National Forest west of the Illinois River, as well as private land-owner action to the east.

Cleared Land

During the 1941-1982 time period a majority of the study units (67%) experienced an increase in cleared land (Figure 6). This included study units 5 (12%), 8 (8%), 2 (5%), 11 (4%), 1 (3%), 12, (3%), 3 (1%), and (1%). As expected, cleared land decreased in study units 7, 9, and 10 since these units experience and increase in forested land during this time. No change was documented in study unit 6. During the second time period, 1982-2004, only two study units experienced an increase in cleared land, study unit 4 (7%), and study unit 1 (4%) (Figure 7). No change in the amount of cleared
land was documented in study units 10 and 12 during this period. All other study units experienced a decrease in cleared land, including study unit 2 (-13%), 3 (-8%), 6 (-5%), 9 (-3%), 5 (-3%), 7 (-2%), 8 (-2%), and 11 (-2%). Overall, during the sixty-four year time period that was examined (1941-2004), 50% of the study units experienced an overall increase in cleared land (Figure 8). This increase was concentrated in the central portion of the study area. Study units 4 (8%) and 5 (8%) saw the largest increase, while study units 1 (7%) and 8 (6%) were not far behind. In addition, study units 12 (3%) and 11 (2%) saw small increases in cleared land coverage.

Built Land

During the time period 1941-1982, study units 6 (5%), 11 (4%), 8 (3%), 2 (2%), and 5 (1%) experienced an increase in built land (Figure 9). No change was documented for study units 1, 3, 4, 7, 9, 10, and 12. The increase was concentrated in eastern and north-central regions of the study area. The second time period, 1982-2004 saw a similar spatial patterning. An increase in built land was experienced, but to a lesser degree than the previous time period. Study units 6 (4%), 2 (3%), 5 (1%), 8 (1%), and 11 (1%) (Figure 10). No change was documented for study units 3, 4, 7, 9, 10, and 12, as was the case during the earlier time period examined. Overall, the increase in developed land was concentrated in the areas with closest proximity to the Springdale and Fayetteville city limits, indicating LULC changes occurring at the urban-rural interface (Figure 11). Study units 6 (9%), and 11 (5%) saw the biggest increases, with study units 2 (4%), 3 (4%), and 5 (2%) also experiencing an increase in built land. Study units 9
(1%) and 12 (1%) both experienced a minimal increase when examined over the total time period, while study units 1, 3, 4, 7, and 10 saw no change.

_Evaluating the Technique_

In order to evaluate the accuracy of the PLSS based LULC change quantification and mapping technique described above, the results of the 2004 LULC change using this technique were compared to 2004 LULC data derived from Landsat TM 5 scenes available from the State of Arkansas (http://www.geostor.arkansas.gov). LULC classes for the satellite derived data (hereafter SAT) were aggregated to 3 general classes (forested, cleared, and built) for comparison and class coverage was calculated as a percentage of total area within each study unit. Regression analysis was then run to determine the degree of correlation between the results of the SAT data and the PLSS technique. Forested land (Figure 12 and 13) showed the highest degree of accuracy, with cleared land (Figure 14 and 15) yielding similar results. Built land (Figure 16 and 17) show slightly less correlation, most likely do to differences in resolution. The high correlation for all data classes indicates the accuracy of this technique, at least in this initial application.

**CONCLUSIONS**

Historical aerial photography provides a source of information for LULC research that has been underutilized. This paper describes a map generalization methodology for quantifying LULC data using historical aerial photography. The method involves the utilization of both a standardized spatial reference, the PLSS, and a standardized LULC
classification system and methodology, the APA LBCS. Both of these provide a nested, hierarchical framework that can be utilized to provide multi-scale LULC data. The results of generalized basin-scale LULC were compared to LULC quantification from satellite imagery for 12 basins in Northwest Arkansas. This comparison showed very similar results and suggests the PLSS-based map generalization technique has the potential to provide insights into LULC change over the time period for which historical aerial photography is currently available. Provided these results hold up to further scrutiny and testing, this would basically double the time period for which similar change detection studies can currently be done utilizing satellite imagery.

One of the goals of the geographic information systems (GIS) community is the realization of scale-independent GIS. The ability to maintain a single database of scale-free data, from which different scale maps could be produced by assigning a scale suitable for a specific purpose and then generalizing the data in real time databases. The benefits of scale-independent GIS would be to provide reduced storage needs, the production of flexible scale-dependent output from a multi-purpose database, reduce cost, and provide consistency and integrity between various scale outputs (Beard 1987, Müller 1991, João 1998). Due the areal nature of LULC and remotely sensed imagery, absolute scale-independence has limited if no practical utility. The use of both the PLSS and the APA LBCS provide a spatial and classification scheme capable of providing multi-scale resolution of both space and level of classification for GIS for land use data, which represents a major step towards the development of truly scale-independent LULC databases, and would offer to a large degree the benefits of a scale-independent database.
These results of this study are part of a larger project examining relationships between patterns of land use change, basin morphometry, and stream channel change within the study area. The measured changes in LULC, along with measurements of basin morphology, and stream channel change are begin statistically analyzed in an effort to explain the potential impacts of LULC changes with regard to stream channel geomorphology within the same study area.
REFERENCES


Climate Change Science Program and Subcommittee on Global Change Research. 2003.


York: Oxford University Press.


Marschner, F. J. 1950. Major land uses in the United States. [map, scale 1:5,000,000]


Peng, W., K. Tempfli, and M. Molenar. 1996. Automated generalization in a GIS


Figure 1. Study area and study units
Figure 2. Location of study units and general study area topography

Figure 3. Percent change forested land, 1941-1982
Figure 4. Percent change forested land, 1982-2004

Figure 5. Percent change forested land, 1941-2004
Figure 6. Percent change cleared land, 1941-1982

Figure 7. Percent change cleared land, 1982-2004
Figure 8. Percent change cleared land, 1941-2004

Figure 9. Percent change built land, 1941-1982
Figure 10. Percent coverage built land, 1982-2004

Figure 11. Percent coverage built land, 1941-2004
Figure 12. Comparison of 2004 forested land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT)

Figure 13. Regression plot for 2004 forested land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT)

\[ R = 0.98, \quad R^2 = 0.97 \]
Figure 14. Comparison of 2004 cleared land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT)

Figure 15. Regression plot for 2004 cleared land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT)

\[ R = 0.96, R^2 = 0.93 \]
Figure 16. Comparison of 2004 built land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT)

Figure 17. Regression plot for 2004 built land as a percentage of area for each study unit by PLSS method and satellite image classification (SAT)

\[ R = 0.75, \quad R^2 = 0.57 \]
Abstract

This paper investigates the relationship between changing patterns of land use, basin morphometry, and stream channel geomorphology in the Illinois River basin of northwest Arkansas during the years 1941-2004. Geographic information systems (GIS) were utilized to integrate and analyze data from historical aerial photography and digital elevation models. The results show that land use land cover changes occur most intensely in basins containing lower gradient headwater reaches in proximity to urban centers, while the largest increase in channel change was found to be channel widening in the lower stream valleys along the main channel of the Illinois River. These findings indicate that channel change within the study area is a result of both decreased erosional resistance in valley bottom locations and increased upland land use related to urban development near headwater reaches. These findings also highlight the importance of a basin scale system approach to land management.

*Key Words: Land use, land cover, drainage basin, morphometry, stream channel change, Ozarks, Illinois River, Northwest Arkansas*
INTRODUCTION

“With the disappearance of the forest, all is changed”. – George Perkins Marsh (1864)

Humans are altering land cover at unprecedented rates and scales (National Resource Council 2002), and the resulting changes to the natural landscape have been described as the most significant agents of global change (Skole et al. 1997). The impact of land use activities, along with corresponding land cover change, affects many parts of the earth’s system, including hydrology, biogeography, and geomorphology. Geographic science seeks to understand the human-environmental dynamics that result in landscape change, in terms of type, magnitude, and location. This understanding requires the integration of social, natural, and geographic information sciences (Rindfuss et al. 2004, Gutman et al. 2004).

This paper investigates the relationship between changing patterns of land use, basin morphometry, and stream channel geomorphology in the Illinois River basin of northwest Arkansas during the years 1941-2004. Geographic Information Systems (GIS) were utilized to integrate and analyze data from historical aerial photography and digital elevation models. The results of this study add to the body of knowledge provided by previous land use and geomorphology related studies in the Ozarks (Sauer 1920; Bretz 1965; Saucier 1984; Pugh 1992; Jacobsen and Gran 1999; Jacobsen and Primm 1997; Jacobsen, Femmer, and McKenney 2001; Panfil and Jacobsen 2001; Pavlowsky 2004).

Previous Land Use Investigations in the Ozarks

Historic land use activities have altered the geomorphology of streams across the United States, including the Ozarks region. Activities such as agriculture, logging,
mining, and development have caused rivers to experience aggradation by the addition of substantial quantities of gravel, accelerated channel migration and avulsion, and growth of gravel point bars (Knox 2002; Jacobsen, Femmer, and McKenney 2001; Pavlowsky 2004), in turn altering runoff, sediment supply, and stream bank resistance, thereby creating stream channel disturbance (Jacobsen and Primm 1997).

Sauer (1920) first commented on the relationship between land use and changes in stream geomorphology in the Ozarks when he suggested that upland land use had led to increased gravels in Ozark streams. This relationship has been used more recently as an explanation for stream aggradation and channel instability in the Ozarks (Panfil and Jacobsen 2001, Jacobsen and Gran 1999, Jacobsen and Primm 1997, Pugh 1992), and has previously been examined through the interpretation of oral accounts, historic documents, land use statistics, and historic photography, as well as archeological and stratigraphic studies, for the Current River basin in Missouri, (Jacobsen and Primm 1997); through the use of gauging station records, stratigraphic analysis, and historical aerial photography in the Little Piney Creek basin, Missouri (Pugh 1992); and through the statistical analysis of basin and segment scale data including measures of morphometric variables (such as slope, relief, and drainage area) geology, land use, channel geometry, substrate, and gravel bar area for the Current River basin in Missouri and the Buffalo River basin in Arkansas (Panfil and Jacobsen 2001, Jacobsen and Gran 1999). In general, these studies conclude that while both temporal and spatial variability are common in Ozarks streams, land use activities have resulted in stream disturbance characterized by aggradation, point bar growth, migration, and avulsion (Jacobsen and Primm 1997, Pugh 1992).
In the Ozarks of south-central United States, historical land use can be generally divided into four time periods (Ward 2007b): (1) Early Settlement Period, (3) Emergence of the New South (4) Conservation Era, and (5) Modern Era (Table 1).

Jacobsen and Primm (1997) pointed out that valley bottoms have the longest history of disturbance since they were the first to be settled and cleared for farming. This has resulted in a loss of riparian vegetation and decreased erosional resistance. They suggested that the impacts of upland timber harvest were relatively minor compared to the impacts of valley bottom clearing and the corresponding reduction in erosional resistance that resulted. They concluded that headward erosion and extension of the channel network may have resulted, leading to increased flow and sediment transport in the channel network, increased flood peaks downstream, and removal of gravel from storage in first and second order valleys. They state that their hypothesis was supported by (1) lack of other source areas for gravel and (2) observations by interviewees that gravels aggrading Ozark streams came from the small stream valleys rather than the slopes (Jacobsen and Primm 1997). This conclusion is also generally supported by investigations of recent geomorphic development at Little Piney Creek in Phelps County, southwest of Rolla (Pugh 1992). This study included gauging station measurements to examine the timing and frequency of flooding, as well as changes in channel morphology and bed elevation. In addition, it utilized historic aerial photography to examine land use and channel change through time. Based on the results, Pugh suggested a wave of post-settlement alluvial deposition, induced by upland land use activity. However, he was quick to point out that the short period of stream gage records for the stream meant he could not rule out climate change, rather than anthropogenic activity, as the cause. Thus,
Pugh concluded that stream disturbance along the Little Piney Creek was a result of a complex interaction between land use change and climate change (Pugh 1992).

In an earlier study conducted in the Current River basin, Saucier (1984) also noted a post-European settlement wave of gravel, and concluded that gravel entering the fluvial system from valley bottom clearing was insignificant compared to gravel resulting from upland erosion. He suggested that small tributaries of the Current River were the primary storage location for gravel eroded from the uplands. He went on to say that during the last 100-150 years reworking of the floodplain has occurred at a rate estimated to have required five to ten thousand years without this influx of gravel. These conclusions are quite interesting in light of what Jacobsen and Primm (1997) found, in that while the location and nature of land use activities resulting in gravel influx is different (valley bottom clearing vs. upland clearing), the source of the gravel is generally agreed to be the uplands. The question of whether the gravel is coming from the timber harvest on the hillslopes or from valley bottom clearing resulting in headward erosion, migration and release of gravel from storage in first and second order valleys remains unanswered, except through oral-historical accounts. While both studies discuss small tributary valley gravel storage and release, neither offers quantitative evidence for this source. The primary objective of this study is to attempt to resolve this conflict.

Study Area

The study area is located in the Illinois River basin of Northwest Arkansas between Fayetteville, Springdale, and Siloam Springs (Figure 1). The study area is located on the periphery of the core of the Fayetteville-Springdale-Rogers metropolitan
area, one of the faster growing metropolitan areas in terms of percent population growth. This makes it an ideal area for studying changes at the urban-rural interface, an area highly susceptible to impact by land use activities (Johnson and Beale 1995). The area is almost entirely located in Washington County, with only slight areas on the north and west spanning into Benton County. The entire study area is underlain by the Mississippian-age Boone limestone formation, providing relatively uniform lithology for all study units, and thus geology is not considered as a basin morphometric variable in this study.

The study area is approximately 142 km$^2$ and has been divided into twelve sub-basins, hereafter referred to as study units (Figures 1 and 2). These study units were delineated by using automated GIS scripts and the 2004 LIDAR 25-foot digital elevation model (DEM) of the area to subdivide the 2006 12-digit hydrologic unit (HUC-12) GIS layer produced by the U. S. Natural Resources Conservation Service into smaller sub-basins. The study area encompasses three HUC 12 sub-basins (Figure 2), hereafter referred to as the Illinois sub-basin, Clear Creek sub-basin, and Wildcat Creek sub-basin.

METHODS

*Historical Aerial Photography*

Historical black and white aerial photography was available in hard copy format in the special collections department of the University of Arkansas libraries. This data source provided a record of land use land cover (LULC) and stream channel dating back approximately 65 years. University of Arkansas library staff provided a digitized set of available photographs covering the study area for the years 1941 and 1982. Photographs
were scanned at 600 dpi on a 9 x 9 inch scanner, providing digital data with a resolution and spatial scale used in other recent studies involving digitization and analysis of historical aerial photographs (Galster 2006, Plieninger 2006, Mount et al. 2002, Laliberte et al. 2001). Aerial photographs from 2004 were already available in digital format and were used as a base map for georeferencing of the two older series. For each image, nine to sixteen control points were used. This was a higher number than the five to six control point used in some recent studies (Galster 2006, VanLooy and Martin 2006), and within the range of the nine to twenty-five used in other studies (Gurnell 1997, Stier 2000, Urban and Rhoads 2003, Plieninger 2006). The location of control points focused was on identifying and utilizing roads, outcrops, and property edge forest boundaries present in all three photo time periods. First order polynomial transformation was used in georeferencing, with an average root mean square (RMS) error of approximately twelve, the target RMS used in a previous study of historic stream channel change (Galster 2006).

_Land Use Land Cover_

A Public Lands Survey System (PLSS)-based map generalization technique was developed in order to classify and quantify LULC change using GIS and has been described in detail by Ward (2007a). In general, the technique involves the use of general LULC classes. A PLSS quarter section layer created from existing digital PLSS section layer was utilized as a spatial framework and provided a minimum mapping unit (MMU) for LULC quantification. The results were subsequently aggregated by study unit for correlation analysis.
Generalized LULC classification followed a multidimensional approach used in the American Planning Association (APA) Land-Based Classification System (LBCS). Percent coverage for each class was estimated independent of other classes, and utilized a quarter-quarter-quarter (Q³) section layer as a visual framework for estimates of land cover measures within each MMU. A total of six LULC classes were utilized: forested (F), cleared (C), built (B), transportation (T), developed without buildings (N), and developing (D). Percent coverage for classes was quantified for each time period: 1941, 1982, and 2004. For the purposes of analysis percent change was then calculated for 1941-1982, 1982-2004, and 1941-2004. This LULC classification is an expansion of the three general LULC classes (forested, agricultural-open, and developed) used by Galster (2006). Ultimately, only forested, cleared, and developed LULC classes were used in the analysis of relations between LULC and stream channel change. In this analysis the LULC methodology described above accounted for 99% of the total basin area when a 12-digit hydrologic unit code (HUC-12) sub-basins were used for data aggregation and results were compared to GIS-derived area measures at the same spatial scale. The actual margin of error in accounting for areal coverage ranged from 1-4%.

**Basin Morphometry**

The drainage basin is the fundamental geomorphic unit (Chorley 1969; Leopold, Wolman, and Miller 1964), providing a clearly defined physical unit for studying fluvial forms and processes (Knighton 1998). The idea of the drainage basin as a framework for geographic study can be traced at least as far back as the mid-18th century (Buache 1756), and continues to provide a suitable framework for geomorphic studies.
Morphometry is the measurement and analysis of the earth’s surface and its landforms, including the characteristics of rivers and drainage basins (Clarke 1966). Repeatable, quantitative measurements of drainage basin form are required for both describing and comparing drainage basins (Mark 1975), for understanding form-form and form-process relationships within basins (Leopold, Wolman, and Miller 1964; Gregory and Walling 1973), and for relating LULC change and stream channel change to basin morphometry.

Basin scale morphometric analysis is vital to understanding stream channel changes because the size, shape, relief, and drainage density of a drainage basin are directly related to fluvial geomorphic processes due to the influence of each on the quantity and rate of both water and sediment yields (Gregory and Walling 1973). A total of ten basin morphometric measures were obtained for the each of the study units within the study area (Figure 2), each having been used either independently, or as part of one or more indices, to quantify the relative morphometry of drainage basins. These variables were area, shape, elevation range, mean slope, bluff area, mean elevation, drainage density, channel sinuosity, mean roughness, and distance to urban center. In addition, measures of variation (standard deviation) of heat loss and percent of public land area were included for each basin, for a total of twelve basin-scale variables. These variables, and their relationship to understanding stream channel changes, are described below.

The relative area of a basin affects both the amount of discharge and the available sediment, and thus strongly influences processes and resulting forms within a drainage basin. Drainage basin size represents a fundamental measure of the differences between drainage basins and must be utilized to assure comparisons account for spatial scale.
Differences in basin size and shape influence both water and sediment yield (Gregory and Walling 1973), and therefore represent important morphometric variables. For the purposes of this study, basin shape is measured as a ratio of basin length squared to basin area.

Smith (1935) and Huggins (1935) both introduced the concept of relative relief of a drainage basin in the same year. This measure represents the difference in elevation extremes with each study unit. Since basin size varies often a relief ratio is used, based on measures such as length, perimeter, and area (Mark 1975). Relative relief is an important measure of basin morphometry because sediment yield has been related to both basin relief and size (Schumm 1954, 1963; Maner 1958), using various shape and relief indices (Selby 1985). For the purposes of this study, relative relief is measured as the elevation range, or the highest elevation minus the lowest elevation within a given basin.

Slope has been cited as the most important aspect of surface form since surfaces are entirely composed of slopes and because slope angles control the gravitation force available for geomorphic work (Evans 1972, Statham 1977). Slope is both a result of past and present geomorphic processes, and an influence on future geomorphic processes (Schumm 1956, Ahnert 1972). While slope measurements vary widely with regard to spatial scale, mean slope has been shown to be much less sensitive than other measures (Gerrard and Robinson 1971), and is a useful as a measure of the relationship between vertical and horizontal spatial scale within a basin (Mark 1975). Mean slope has been used as a measure of relative slope among the study units.

Roughness is the irregularity of topographic surface, and represents the distribution of mass within the vertical range of topography (Mark 1975). There is no
single way to measure roughness (Stone and Dugundji 1965), as one area may be relatively rougher due to several factors (e.g. surface wavelength, amplitude, and/or irregular ridge spacing). For the purposes of this study, roughness has been measured as the ratio of surface area to planimetric area within each study unit, as described by Jenness (2004).

Horton (1932, 1945) was the first to use drainage density in geomorphologic studies. Drainage density is equal to total stream length divided by basin area and is an indicator of relation between climate, vegetation, rock resistance, and soil resistance. Sinuosity is the ratio of channel length to valley length and represents the deviation of the river channel from a straight form. Schumm (1969) discussed sinuosity as one dimension of river response to changes in discharge and sediment load, and thus this variable was measured to investigate relationships with LULC change within the study area.

Bluff area was measured for each study unit as the total area having a slope of >30° divided by the total study unit area. Previous studies of Ozark streams have suggested a relationship between this measure and stream channel geomorphology (Saucier 1984, Jacobson 1995, McKenney 1997, Panfil and Jacobson 2001).

Mean elevation is a variable that can be used in hypsometric analysis, which is the measurement of the relationship between altitude and area (Clarke 1966). As it relates elevation to basin area, it has been cited as a measure of the degree of dissection of a landscape (Evans, 1972), and can be used to represent the relative extent to which a basin has been eroded (Clarke 1966). Pike and Wilson (1971) have shown that the elevation-relief ratio of Wood and Snell (1960), (mean elevation – minimum elevation)/(maximum elevation – minimum elevation), is mathematically comparable to the hypsometric
integral utilized by Strahler (1952). This measure represents the proportion of total basin height as a function of the proportion of total basin area and reveals how much of the basin occurs within a given elevation range, and provides an indication of the volume of the original basin that remains unweathered.

Five of the variables were the same as those used by Panfil and Jacobson (2001) in their study of the Buffalo and Current River systems of the Ozarks. These variables were area, shape, elevation range, mean slope, and bluff area. The use of these variables provides the opportunity to compare results across the Ozarks and helps contribute to the overall understanding of the region. In addition to these variables, mean elevation was used to measure relative topographic location within the study area, drainage density and sinuosity were measured to explore their potential as indicators of stream channel changes other than channel widening; and mean roughness, heat load, and distance to urban center were measured to explore their potential as indicators of differential land use activity related to topography. Public land percentage per study unit was measured to examine its potential as an indicator of differential land use related to land management and land use restrictions. All basin morphometry calculations and analyses were done using GIS technology, a LIDAR 25-foot resolution Digital Elevation Model, and other GIS data layers. All data utilized were available through the State of Arkansas (http://www.geostor.arkansas.gov).

The basin represents the most basic unit for study of physical processes of hydrology, and for the management of land and water resources (Chorley 1969, Newson 1992). As such, all measures of basin morphometry and LULC change have been aggregated to each study unit for analysis. Analysis at the sub-basin study unit scale
provided for an examination of differential LULC within the study area and within each HUC-12 study unit, and provided for correlation analysis with basin morphometric variables and stream channel width.

**Stream Channels**

Studies of river channel change using aerial photography can be traced from the 1970s (Lewin and Manton 1975; Lewin and Weir 1977), to more recent studies (Lane et al. 1994, 1998; Panfil and Jacobson 2001). These studies in general either replace time with space, examining channel change at different locations, or cover relatively short (e.g. decadal) periods of time. Studies involving longer temporal sequences of aerial photographs are less common (Gurnell 1997; Galster 2006), but provide an opportunity to examine the impacts of land use change over longer time periods (Urban and Rhoads 2003, Galster 2006). For this study, historical aerial photographs from the years 1941, 1982, and 2004 were utilized to measure changes in stream channel geomorphology over time. It is important to note that when using aerial photographs acquired in different years changes in discharge and water level must be considered. As a result, channel width at bankfull stage (hereafter all channel width measurement references refer to bankfull channel width) has been proposed as the most reliable method for comparing changes over time, (Laliberte et al. 2001) and is utilized in this study. Bankfull has been defined as the location on the stream bank where a stream changes from flowing in its channel to overflowing its banks (Rosgen 1996). Bankfull is also defined as the discharge stage at which channel maintenance is the most effective, and which results in the creation of average morphologic characteristics for a given channel (Dunne and
Leopold 1978). For the purposes of measuring bankfull channel width for this study, bankfull is defined as a break in slope above which an increase in depth is accompanied by a disproportionately large increase in width (Osterkamp and Hedman 1982, Mount et al. 2003). In addition for accounting for changes in water level, rates of change quantified from temporal sequences of aerials must show that the amount of change measured is greater than the spatial error involved (Mount et al. 2003; Downward, Gurnell, and Brookes 1994). Scanning and georeferencing of historical aerial photography resulted in a resolution of approximately 0.35 meters. Considering the RMS of twelve, the resulting margin of error was approximately four meters.

The PLSS grid was once again used as a spatial framework for sampling channel width changes, and has been previously used by VanLooy and Martin (2006) and Schumm and Lichty (1963). However, while these studies have relied on the location of township boundaries for locating sample sites, for the current investigations PLSS quarter (Q) section grid was utilized to spatially distribute site locations. Due to riparian tree cover and poor visibility in some areas of the aerial photography, visual inspection was relied upon to choose site locations with areas of visible banks in each of the three temporal periods for which photos were available. Following methods used elsewhere (Mount et al. 2003, Galster 2006, VanLooy and Martin 2006) channel width measures were taken in areas having clear banks, at 90° angles to the river channel, and were spaced to ensure independence. In order to minimize effects of edge distortion on accuracy, when photos overlapped measurements were taken on the photo where the area being measured was closest to the center (Galster 2006). A total of 15 sites were chosen for channel width measurements in the Illinois sub-basin for an average of 0.9 sites/km
along the approximately 17.6 km main stream channel within this sub-basin (Figure 3). A total of 11 sites were chosen for channel width measurements in the Clear Creek sub-basin for an average of 0.6 sites/km along the approximately 19.4 km main stream channel within this sub-basin (Figure 4).

Channel width sampling for temporal change was done at a higher site/km rate than 0.3 sites/km used in a recent study (VanLooy and Martin 2006) and was comparable to 0.6 sites/km rate used in previous investigations (Schumm and Lichty 1963). Changes in channel width were quantified and analyzed by taking repeated measurements at each site and comparing temporal measures using a paired T-test (Galster 2006, VanLooy and Martin 2006). Following the methodology used in other studies of channel width change (Galster 2006), each width measurement was repeated ten times and a T-test was run on the means of the repeated measurements for each year to determine the statistical significance of any differences in stream width at a 95% confidence level (Earickson and Harlin 1994).

Statistical Analysis

An exploratory data analysis (Tukey 1977) approach was utilized for all data analysis, utilizing correlation analysis to identify relationships between variables measuring LULC change, basin morphology, and stream channel planform geomorphology. Correlation coefficients were significant at the 95% confidence level. This statistical technique has previously been employed in a study of Ozark human-environmental dynamics (Panfil and Jacobson 2001).
RESULTS

Land Use Land Cover Change

LULC change was calculated as percent change for each LULC class within each study unit (Tables 3 and 4). Forested land increased the most in the valley bottoms within the Illinois sub-basin (study units 7, 9, and 10), with the majority of the increase in all three basin occurring during the 1941-1982 time period. The biggest decrease in forested land was located in study units 1, 5, 6, and 8. Cleared land increased the most in study area 1, 4, 5, and 8. The biggest increase occurring in the latter two study units during the 1941-1982 time period. The largest decreases in cleared land were found in study units 2, 3, 7, 9, and 10. The most increase in built land was located in study units 6 and 11. No study unit experienced a decrease in built land. With the exception of an 8% increase in developed land without buildings in study unit 5 during 1982-2004, and a 6% increase in developing land in study unit 2 during 1982-2004, all increases in LULC classes involving the classes transportation, developed land without buildings, and developing land were measured at $\leq 1\%$. Such small change suggests an adjustment of spatial scale is necessary to examine more fully the impact of these types of LULC change.

Among the twelve study units the biggest impact was found in study unit 2 (four out of six classes changed), and 6 (four out of six classes changed), while no LULC change was found in study unit 1, 4, 12, and little overall change in study units 3 and 7. The study units showing the biggest change (2 and 6) were also located closest to urban centers (Figure 2), supporting the idea that the impact of LULC is occurring most rapidly in the urban-rural interface area.
Correlation analysis was conducted to better understand relationships amongst basin morphometric variables. All correlations are with respect to the 95% confidence level (Table 5). Elevation range was found to have a positive correlation with mean slope, bluff area, mean roughness, distance to urban center, standard deviation of heat load, and public lands. Mean slope had a positive correlation with elevation range, mean roughness and standard deviation of heat load, and a negative correlation with mean elevation. Distance to urban had a positive correlation with elevation range, bluff area, mean roughness, public lands, and standard deviation of heat load. Mean elevation had a negative correlation with mean roughness, heat load, and mean slope. In addition to elevation range, mean elevation, and distance to urban center, standard deviation of heat load was found to have a correlation with bluff area and mean roughness. No correlation was found between any of the measured variables and area, shape, drainage density, and stream sinuosity.

Taken as a whole, these results can be summarized with a general statement that higher areas are flatter, have less public land, receive more consistent solar radiation, and are closer to urban centers. Also, there is greater topographic variation as distance increases from urban centers in the study area. These results support the findings of previous Ozark land use studies which found correlations between relief, slope, and bluff area, as well as relations between relief and land use (Panfil and Jacobson 2001).
Correlation analysis was also employed to identify bivariate relationships between basin morphometric and LULC change variables. Each of the basin morphometric variables for the twelve study units were used to measure correlation with percent change for all six LULC classes during each time interval (1941-1982, 1982-2004, 1941-2004). As no quantifiable change was measured for developing land during 1941-1982, results from that period are not presented, resulting in seventeen LULC change classes.

Results of correlation analysis between basin morphometric variables and LULC classes are summarized below (Table 6). No correlation was found between the forested class and any basin morphometric variables. The only significant correlation associated with cleared land was between increased cleared land during 1982-2004 as distance to urban centers increased. While difficult to interpret, these findings could suggest a zone of land clearing beyond the urban-rural interface related to the beginnings of additional urban sprawl. By far the most significant correlations were associated with the built class. Positive correlations were found between built land and mean elevation during all time periods, and negative correlations were found between built land and mean slope, mean roughness, standard deviation of head load for all time periods. In addition, negative correlations were found between built land and distance to urban centers for 1982-2004 and 1941-2004, and between built land and elevation range in 1941-1982. The 95% confidence level was used for all analyses. It should be noted, however, that the majority of these correlations were also significant at the 99% level. This analysis would seem to indicate a general trend of increased building on flatter, lower gradient uplands in the headwater reaches, within close proximity to urban centers.
The only significant correlation between transportation and basin morphometric variable was with basin area during the periods 1941-1982. Correlations between developing lands without buildings were only found during the 1941-1982 period. These included mean slope, mean elevation, mean roughness, and standard deviation of heat load. All were negative correlations except mean elevation. A negative correlation was also found between developing land and distance to urban centers for the time periods 1982-2004 and 1941-2004. While the results of LULC change for transportation, developed without buildings, and developing lands did indicate some change over time, this change was significantly different that that measured for the forested, cleared, and built classes. There is little doubt that changes of these types are occurring, and it is likely that more significant change can be detected if the resolution of the spatial framework used for measure change were decreased. Due to the relatively low level of change measured, these LULC classes were not incorporated into the correlation analysis involving stream channel change.

Stream Channel Change

Stream channel widths were measured to track channel changes over time. The results of a t-test conducted on the repeated stream channel width measurements from each time period for all sites within both the Illinois (Figure 5) and Clear Creek (Figure 6) sub-basins showed the channel widths were not significantly related between time periods at the 95%, as well as the 99%, confidence level. Therefore all the changes in channel width during 1941-1982, 1982-2004, and 1941-2004 are interpreted as being
significantly different over time, indicating a measurable level of channel width change has occurred throughout the study area.

**Land Use Land Cover, Basin Morphometry, and Stream Channel Change**

Correlation analysis was utilized to examine relationships between changes in stream channels over time and both basin morphometric variables and LULC change (Table 7). Once again a 95% confidence level was used as an indicator of significant correlation. Overall, the highest correlation was found to exist between stream channel width change and distance to urban centers. This correlation was also significant during the time period 1941-1982. Positive correlations were also found between channel change during the entire 1941-2004 time period and elevation range, mean slope, and mean roughness, as well as land clearing during 1982-2004 time period. Negative correlations were found between overall channel change and built land during both the 1982-2004 and 1941-2004 time periods. Channel change during the 1982-2004 period was positively correlated with mean slope and cleared land, and negatively correlated with mean elevation and built land during the same time period. Channel change during the time period 1941-2004 was also correlated with elevation range, distance to urban centers, and percent coverage of public lands.

One interesting pattern that emerged from this analysis was the high correlation between 1941-1982 channel change and public lands (0.878), and the subsequent lack of correlation between 1982-2004 channel change and public lands (0.079). One interpretation of this would be that the observed tributary reforestation during time period the 1982-2004, which is related to management practices on public lands, is serving as a
stabilizing driver of channel change during the latter time period due to the increased resistance of riparian areas.

Scale and Differential Landscape Sensitivity

Finally, an examination of LULC class change over time for both the 12 study units and the 2 HUC-12 study units reveals the role that scale plays in investigations of landscape change at different scales (Thomas 2001). At the HUC-12 scale rates of LULC change range from -0.4 to +0.5, while at the 12 study unit scale rates of change range from -0.17 to +0.18, far more indicative of landscape impacts. These results suggest that apparent patterns of LULC change are dependent upon the scale of investigation and that a complete understanding of LULC change requires multi-scale investigations.

DISCUSSION

Changes in LULC patterns have been shown to impact stream channel geomorphology by increasing peak discharge (Leopold 1968, Hollis 1975), altering sediment load (Wolman 1967; Dawdy 1967; Trimble 1997; Pizzuto, Hession, and McBride 2000; Kondolf, Piegay, and Landon 2002), and subsequently increasing bank width (Hammer 1972; Leopold 1973; Morisawa and LaFlure 1979; Arnold, Boison, and Patton 1982; Galster 2006). In addition, one important study has shown a decrease in channel width as a result of changes in LULC (Clark and Wilcox 2000). However, despite major advances in understanding human-environmental dynamics, the magnitude of anthropogenic influences on geomorphic processes remains illusive from a quantitative perspective (Urban and Rhoads 2003). Investigations into relationships between LULC,
basin morphometry, and stream channel changes provide an opportunity to gain insight into the complex feedback mechanisms and underlying processes involved through an examination of form-related changes over time. Historical aerial photography offers an invaluable snapshot of landscape forms at varying points in time, allowing for quantitative comparison of temporally disparate landforms.

Land Use Land Cover Patterns

An examination of the overall LULC change reveals three general zones of LULC (Tables 3 and 8). Moving away from the urban centers of Fayetteville and Springdale (Figure 7), the first area can be called urban-rural 1 and includes study units 2, 6, 11. This zone is generally defined by the overall change in built land during 1941-2004 and represents the common urban-rural interface. This is the peri-urban zone of suburban and commercial development related to urban sprawl that surrounds many urban centers. The patterns that resulted from mapping changes in LULC classes (Ward 2007a) reveal a second zone of land use that can be called urban-rural 2. This zone is composed of study units 1, 4 5, 8, 11 and is indicated by overall change in cleared land during 1941-2004. Finally, beyond the immediate LULC impacts of development and land clearing is the rural zone. This zone is made up of study units 7, 9, 10, 12 and can be defined by the overall change in forested land during 1941-2004. This pattern of LULC zoning suggests proximity to urban-center as a primary driver of LULC change within the study area. Furthermore, the positive correlations between channel change and distance to urban centers, and channel change and land clearing during 1982-2004, when considered along with the negative correlation between channel change and built land, suggests the biggest
impact to stream channels are found in the valley bottom lands experiencing the most clearing within the urban-rural 2 zone.

**Stream Channel Change**

Bankfull width changes have been shown to result from increased sediment supply to stream channels (Roberts and Church 1986, Knighton 1988, Madej and Ozaki 1996). The results demonstrate widening is indeed occurring within the study area, and thus supports previous investigations regarding increased gravel input occurring during historic times in the Ozark streams (Saucier 1984, Pugh 1992, Jacobson and Primm 1997). The stream channel width measurements show that each peak in the channel width measurements corresponds to a disturbed reach (Figures 8 and 9), supporting the idea that Ozark streams are composed of relatively straight, stable reaches alternating with disturbed reaches containing large gravel bars (Panfil and Jacobson 2001).

**Correlation Analyses**

An examination of the results of the correlation analyses reveals several patterns and relationships. Terrain indicators, such as mean elevation, mean slope, and mean roughness were all significantly related to LULC and channel change measures. In terms of topography and land use, the study area was found to contain generally more relief as distance increases away from urban centers, as indicated by the positive correlation with elevation range, bluff area, and mean roughness. Of particular interest were the correlations found between channel change and distance to urban centers, and channel change and percent public land, as these factors have not been measured in previous
studies of Ozark human-environmental dynamics. The relationships identify these as drivers of landscape change, and indicate (1) the relatively rural nature of the study area as distance increases from urban centers, (2) the influence of land management practices on landscape stability in areas of public ownership, and (3) the increased land use activity occurring on private lands within the urban-rural 1 and urban-rural 2 interfaces.

Overall, LULC changes were found to occur most intensely in basins containing lower gradient headwater reaches in proximity to urban centers. This activity has been found to result in unstable banks in other upstream urban areas of the Ozarks (Nickolotsky, Miller, and Pavlowsky 2004), and can thus be described as a driver of landscape change within the study area. In addition, patterns of developing land and land clearing were found to be centered between urban-rural 1 and rural areas, and have been called the urban-rural 2 zone. This zone is undergoing increased land use activity related to expansion of the urban-rural interface.

The largest increase in channel change was found to be in the lower stream valleys along the main channel of the Illinois River, in areas with the longest land use history, which has subsequently led to decreased erosional resistance (Jacobson and Primm 1997). One interesting result was the lack of correlation between channel change and bluff area. Previously suggested as a potential sediment source, the lack of correlation suggests that bluffs are either not a major source of in-channel sediments when compared to valley gravel in storage or not detectable at the scales used in this study. Overall, the efficacy (Hooke 1994) of LUCL change has resulted in stream channel disturbance in the study area. The geomorphological effectiveness (Wolman and
Gerson 1978) of anthropogenic activity has without doubt produced long-lasting changes in the landscape, resulting in stream aggradation and widening within the study area.

**Gravel Storage**

Many streams today cannot be said to exist in a long term equilibrium state due to alluvial and colluvial storage within their basins. While previous studies have suggested the release of sediment from valley storage as the source of gravel aggradation in Ozark streams (Saucier 1984, Jacobson and Primm 1997), these studies have focused on first and second order stream valleys as the primary gravel source. The results of this study would suggest that higher order stream valleys are also significant contributor to increased stream gravels in the Ozarks.

It has previously been suggested that changing patterns of land use lead to an increase in stream transport ability, leading to alluvial deposits being dissected and migrating (Trimble 1975). More specifically, it has been show that valley bottom storage due to early settlement agriculture is being reworked today in some areas (Trimble 1976, 1983). A potentially major contributor to this is gravel mining, which has a long history in the Ozarks (Brown and Lyttle 1992). Since the majority of streams in the Ozarks can be classified as having alluvial gravel riffle and pool channel form and have relatively predictable geometry, removal of substrate from activities such as gravel mining probably has a greater impact than they would is other types of streams (Brussock, Brown, and Dixon 1985). The effects of in-stream gravel mining on northwest Arkansas stream habitats has previously been examined at Crooked Creek and Kings River, as well as the Arkansas portion of the Illinois River (Brown and Lyttle 1992). This assessment found
that mining significantly impacts the quality of stream ecosystems and alters channel form through increased sedimentation rates, reduction in ripples, and formation of larger, shallower pools downstream, all resulting in decreased habitat quality. In addition, Saucier (1984) noted that re-vegetation of floodplains has resulted in the deposition of large quantities of gravel on the floodplains, placing them in long-term storage. Subsequent floodplain land uses such as clearing for agriculture and grazing have the potential to release these gravels from storage. Gravel mining effects have also been tested at Sylamore Creek in Arkansas utilizing an experimental gravel removal project. Results of this study showed an immediate impact on stream geomorphology in the form of accelerated erosion and downstream deposition of sediment and gravel, as well as formation of a second channel where only a single channel formerly existed (Arkansas Department of Environmental Quality 2004). In California, James (1989, 1991) found that mining activities have resulted in sustained sediment storage within the basin, and that stream channel morphology continues to respond to this mining activity 100 years after the majority of such activities ceased. These findings have significance in the Ozarks with regard to the potential for mining activities to increase the quantity of sediment in storage, as well as the temporal scale at which streams can potentially respond to mining. Both of these factors ultimately have an influence on channel stability, geomorphology, flood frequency, and habitat conditions.

Without exception, all lines of evidence point to reworking of gravels from valley storage as the primary source of aggradation in Ozark streams. However, the true spatial and temporal scale of gravel storage and release is difficult to discern. Preconditioning of the stream valleys involving underfit streams (Dury 1964a, 1964b, 1965, 1983), along
with valley bottom gravel storage, valley bottom land use, and changes in riparian land cover can be used as a theoretical model to explain much of the patterns of geomorphic change within the study area. Differential landscape sensitivity (Thomas 2001) factors can be related to geomorphic conditions in which underfit streams are currently eroding gravel and other sediment from valley bottom storage, while gravels stored in first and second order valleys are currently being eroded due to headwater erosion resulting from upstream controls and land clearing related to. It is, therefore, most likely that the Illinois River basin contains both an older source of gravel in the form of large amounts of valley bottom sediment that is being reworked in stream channels, along with a second, more recent wave of gravel within the channel that is being released from upper valley storage. Both of these sources of gravel are currently increasing as the result of ongoing historical land use activities.

CONCLUSIONS

The investigation of correlations between LULC, basin morphometry, and stream channel change offers valuable insight into the complex interrelatedness of human-environmental dynamics. While correlation does not necessarily provide direct insight into causation (Earickson and Harlin 1994), the examination of relationships between LULC, basin morphometry, and stream channel change does reveal the presence of relationships between quantifiable variables for each. By supporting these relationships with explanatory process-based theory, models of the linkages between environmental processes, both natural and anthropogenic, and their resulting landscape forms can be constructed. While the actual magnitude of such linkages will likely remain illusive due
to spatial and temporal variability in the underlying processes, the explanatory nature of such models, when infused with an examination of the historical trajectory of environmental drivers, provides a framework within which a better understanding of related processes, resulting forms, and ranges of change can be investigated and applied in both the study and the management of fluvial environments, and with regard to the identification of thresholds at which different environmental drivers dominate processes (Bracken and Wainwright 2006). Such understanding provides both a spatial and temporal context for correlations between process and form, and an insight into historical conditions that create a dynamic range for fluvial conditions. An historical human–environmental perspective offers land managers a dynamic model for fluvial behavior within a margin of error, rather than a fixed equilibrium baseline. This allows environmental dynamics to play an increasingly more important role in both geomorphic investigations and land management practices.
REFERENCES


Arkansas Department of Environmental Quality. 2004. *Instream Gravel Mining in South Sylamore Creek.* Technical Services Division-Ecology Section.  
http://www.ozarksociety.net/Revised%20InstreamSouthSylamoreCreek-1.pdf (last accessed 20 July 2007).


Jacobson, R. B. 1995. Spatial controls on patterns of land use induced stream disturbance at the drainage basin scale – an example from gravel bed stream of the Ozark Plateaus, Missouri. *Geophysical Monography* 89. American Geophysical Union. 219-239.


Figure 1. Study area and study units
Figure 2. HUC-12 sub-basins and study units
Figure 3. Channel width measurement sites, Illinois sub-basin
Figure 4. Channel width measurement site, Clear Creek sub-basin
Figure 5. Comparison of stream channel width measurements in Illinois sub-basin
Figure 6. Comparison of channel width measurements in Clear Creek sub-basin
Figure 7. Land use land cover zones
Figure 8. Bankfull channel widths, Illinois sub-basin (upstream to left)
Figure 9. Bankfull channel widths, Clear Creek sub-basin (upstream to left)
Table 1. Land use time periods

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Approximate Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Settlement</td>
<td>1700 – 1870</td>
</tr>
<tr>
<td>The Emergence of the New South</td>
<td>1870 - 1920</td>
</tr>
<tr>
<td>The Conservation Era</td>
<td>1920 – 1960</td>
</tr>
<tr>
<td>Modern Era</td>
<td>1960 – present</td>
</tr>
</tbody>
</table>
Table 2. Basin morphometric variables

<table>
<thead>
<tr>
<th>Basin Variable</th>
<th>Definition</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Total area (km²) in each study unit</td>
<td>LIDAR Digital Elevation Model 25-foot resolution (DEM)</td>
</tr>
<tr>
<td>Shape</td>
<td>Drainage basin shape factor, basin length²/basin area (km²/km²)</td>
<td>DEM</td>
</tr>
<tr>
<td>Elevation Range</td>
<td>Difference between highest and lowest elevation values (m) within each study unit</td>
<td>DEM</td>
</tr>
<tr>
<td>Mean Slope</td>
<td>Average slope for all cells within each study unit</td>
<td>DEM</td>
</tr>
<tr>
<td>Bluff Area</td>
<td>Total area of all cells with slope &gt;30° in each study unit divided by total area in each study unit (km²/km²)</td>
<td>DEM</td>
</tr>
<tr>
<td>Mean Elevation</td>
<td>Average elevation for all cells within each study unit</td>
<td>DEM</td>
</tr>
<tr>
<td>Drainage Density</td>
<td>Total length of streams in each study unit divided by total area of each study unit (km/km²)</td>
<td>USGS 100K Streams, DEM</td>
</tr>
<tr>
<td>Sinuosity</td>
<td>Total length of main channel stream divided by total stream valley length (km/km)</td>
<td>USGS 100K Streams, DEM</td>
</tr>
<tr>
<td>Mean Roughness</td>
<td>Total surface area divided by planimetric area for each study unit</td>
<td>DEM (Jenness 2004)</td>
</tr>
<tr>
<td>Distance to Urban Center</td>
<td>Minimum distance from study unit centroid to point location for either Springdale or Fayetteville, AR</td>
<td>Populated places and study unit centroid, calculated using GIS</td>
</tr>
<tr>
<td>Standard Deviation of Heat Load</td>
<td>Standard deviation of heat loss values for each study unit</td>
<td>DEM (McCune and Keon 2002)</td>
</tr>
<tr>
<td>Public Lands</td>
<td>Total area of public lands divided to total area for each study unit</td>
<td>Federal lands and study units</td>
</tr>
</tbody>
</table>
Table 3. LULC change over time by study unit

<table>
<thead>
<tr>
<th>Study Unit</th>
<th>F4182</th>
<th>F8204</th>
<th>F4104</th>
<th>C4182</th>
<th>C8204</th>
<th>C4104</th>
<th>B4182</th>
<th>B8204</th>
<th>B4104</th>
<th>T4182</th>
<th>T8204</th>
<th>T4104</th>
<th>N4182</th>
<th>N8204</th>
<th>N4104</th>
<th>D4182</th>
<th>D8204</th>
<th>D4104</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.03</td>
<td>-0.05</td>
<td>-0.07</td>
<td>0.03</td>
<td>0.04</td>
<td>0.07</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>-0.07</td>
<td>0.03</td>
<td>-0.04</td>
<td>0.05</td>
<td>-0.13</td>
<td>-0.08</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>-0.01</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>-0.08</td>
<td>-0.07</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>-0.03</td>
<td>-0.01</td>
<td>-0.04</td>
<td>0.01</td>
<td>0.07</td>
<td>0.08</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>-0.13</td>
<td>-0.04</td>
<td>-0.17</td>
<td>0.12</td>
<td>-0.03</td>
<td>0.08</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.08</td>
<td>0.08</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>-0.05</td>
<td>-0.01</td>
<td>-0.06</td>
<td>0.00</td>
<td>-0.05</td>
<td>-0.05</td>
<td>0.05</td>
<td>0.04</td>
<td>0.09</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>7</td>
<td>0.16</td>
<td>0.02</td>
<td>0.18</td>
<td>-0.12</td>
<td>-0.02</td>
<td>-0.14</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>-0.09</td>
<td>0.02</td>
<td>-0.07</td>
<td>0.08</td>
<td>-0.02</td>
<td>0.06</td>
<td>0.03</td>
<td>0.01</td>
<td>0.04</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>9</td>
<td>0.04</td>
<td>0.03</td>
<td>0.07</td>
<td>-0.04</td>
<td>-0.03</td>
<td>-0.07</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>0.11</td>
<td>0.00</td>
<td>0.11</td>
<td>-0.11</td>
<td>0.00</td>
<td>-0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>11</td>
<td>-0.06</td>
<td>0.01</td>
<td>-0.05</td>
<td>0.04</td>
<td>-0.02</td>
<td>0.02</td>
<td>0.04</td>
<td>0.01</td>
<td>0.05</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>12</td>
<td>-0.01</td>
<td>0.00</td>
<td>-0.02</td>
<td>0.03</td>
<td>0.00</td>
<td>0.03</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 4. General trends in LULC change by study unit

<table>
<thead>
<tr>
<th>Study Unit</th>
<th>Forest Cleared</th>
<th>Built</th>
<th>Transportation Developed, No Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>3</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>6</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>7</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>+</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>9</td>
<td>+</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>10</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5. Correlation between basin morphometric variables

<table>
<thead>
<tr>
<th></th>
<th>Area</th>
<th>Shape</th>
<th>Elev Range</th>
<th>μ Slope</th>
<th>Bluff Area</th>
<th>μ Elev</th>
<th>Density</th>
<th>Sinu</th>
<th>μ Rough</th>
<th>Durban</th>
<th>s.d. HL</th>
<th>PubL%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape</td>
<td>-0.004</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elev Range</td>
<td>-0.021</td>
<td>-0.506</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>μ Slope</td>
<td>-0.303</td>
<td>-0.064</td>
<td></td>
<td>0.607</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bluff Area</td>
<td>-0.295</td>
<td>-0.355</td>
<td>0.704</td>
<td></td>
<td>0.423</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>μ Elev</td>
<td>0.499</td>
<td>-0.301</td>
<td>0.043</td>
<td>-0.630</td>
<td>-0.269</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>-0.011</td>
<td>0.149</td>
<td>0.140</td>
<td>0.289</td>
<td>0.378</td>
<td>-0.419</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinu</td>
<td>0.507</td>
<td>-0.105</td>
<td>0.127</td>
<td>-0.026</td>
<td>-0.031</td>
<td>0.140</td>
<td>-0.008</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>μ Rough</td>
<td>-0.339</td>
<td>-0.149</td>
<td>0.665</td>
<td>0.986</td>
<td>0.527</td>
<td>-0.611</td>
<td>0.246</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durban</td>
<td>-0.446</td>
<td>-0.355</td>
<td>0.679</td>
<td>0.975</td>
<td>0.583</td>
<td>-0.644</td>
<td>0.291</td>
<td>-0.104</td>
<td>0.983</td>
<td>0.641</td>
<td></td>
<td></td>
</tr>
<tr>
<td>s.d. HL</td>
<td>-0.395</td>
<td>-0.126</td>
<td>0.672</td>
<td>0.975</td>
<td>0.583</td>
<td>-0.644</td>
<td>0.291</td>
<td>-0.104</td>
<td>0.983</td>
<td>0.641</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PubL%</td>
<td>-0.084</td>
<td>-0.387</td>
<td>0.803</td>
<td>0.394</td>
<td>0.557</td>
<td>-0.002</td>
<td>0.139</td>
<td>0.124</td>
<td>0.446</td>
<td>0.770</td>
<td>0.458</td>
<td></td>
</tr>
</tbody>
</table>

Key: Elev = elevation, Sinu = sinuosity, Rough = roughness, Durban = distance to urban center, s.d. HL = standard deviation of heat load, PubL% = percentage of public land
Table 6. Correlation between basin morphometrics and LULC change

<table>
<thead>
<tr>
<th></th>
<th>Area</th>
<th>Shape</th>
<th>Elev Range</th>
<th>μ Slope</th>
<th>Bluff Area</th>
<th>μ Elev</th>
<th>Density</th>
<th>Sinu</th>
<th>μ Rough</th>
<th>Durban</th>
<th>s.d. HL</th>
<th>PubL%</th>
</tr>
</thead>
<tbody>
<tr>
<td>F4182</td>
<td>-0.233</td>
<td>0.192</td>
<td>0.249</td>
<td>0.543</td>
<td>0.220</td>
<td>-0.327</td>
<td>0.437</td>
<td>0.139</td>
<td>0.531</td>
<td>0.396</td>
<td>0.489</td>
<td>0.036</td>
</tr>
<tr>
<td>F8204</td>
<td>0.031</td>
<td>-0.042</td>
<td>-0.276</td>
<td>-0.141</td>
<td>-0.512</td>
<td>0.150</td>
<td>-0.217</td>
<td>0.498</td>
<td>-0.173</td>
<td>-0.319</td>
<td>-0.244</td>
<td>-0.333</td>
</tr>
<tr>
<td>F4104</td>
<td>-0.197</td>
<td>0.158</td>
<td>0.144</td>
<td>0.440</td>
<td>0.055</td>
<td>-0.248</td>
<td>0.327</td>
<td>0.257</td>
<td>0.421</td>
<td>0.263</td>
<td>0.365</td>
<td>-0.058</td>
</tr>
<tr>
<td>C4182</td>
<td>0.035</td>
<td>-0.241</td>
<td>-0.193</td>
<td>-0.441</td>
<td>-0.183</td>
<td>0.234</td>
<td>-0.456</td>
<td>-0.290</td>
<td>-0.431</td>
<td>-0.278</td>
<td>-0.371</td>
<td>0.045</td>
</tr>
<tr>
<td>C8204</td>
<td>-0.047</td>
<td>-0.319</td>
<td>0.299</td>
<td>0.395</td>
<td>0.480</td>
<td>-0.270</td>
<td>0.214</td>
<td>-0.247</td>
<td>0.455</td>
<td>0.575</td>
<td>0.424</td>
<td>0.246</td>
</tr>
<tr>
<td>C4104</td>
<td>-0.001</td>
<td>-0.414</td>
<td>0.031</td>
<td>-0.118</td>
<td>0.158</td>
<td>0.023</td>
<td>-0.248</td>
<td>-0.408</td>
<td>-0.070</td>
<td>0.140</td>
<td>-0.039</td>
<td>0.199</td>
</tr>
<tr>
<td>B4182</td>
<td>0.445</td>
<td>0.158</td>
<td>-0.583</td>
<td>-0.930</td>
<td>-0.466</td>
<td>0.636</td>
<td>-0.274</td>
<td>0.094</td>
<td>-0.915</td>
<td>-0.517</td>
<td>-0.948</td>
<td>-0.391</td>
</tr>
<tr>
<td>B8204</td>
<td>0.496</td>
<td>0.240</td>
<td>-0.379</td>
<td>-0.738</td>
<td>-0.470</td>
<td>0.714</td>
<td>-0.290</td>
<td>0.193</td>
<td>-0.762</td>
<td>-0.706</td>
<td>-0.779</td>
<td>-0.383</td>
</tr>
<tr>
<td>B4104</td>
<td>0.492</td>
<td>0.203</td>
<td>-0.526</td>
<td>-0.897</td>
<td>-0.493</td>
<td>0.705</td>
<td>-0.296</td>
<td>0.143</td>
<td>-0.898</td>
<td>-0.628</td>
<td>-0.926</td>
<td>-0.409</td>
</tr>
<tr>
<td>T4182</td>
<td>0.652</td>
<td>0.207</td>
<td>-0.054</td>
<td>-0.178</td>
<td>-0.068</td>
<td>0.349</td>
<td>-0.278</td>
<td>0.442</td>
<td>-0.160</td>
<td>-0.418</td>
<td>-0.223</td>
<td>-0.318</td>
</tr>
<tr>
<td>T8204</td>
<td>-0.003</td>
<td>0.420</td>
<td>-0.150</td>
<td>-0.053</td>
<td>-0.152</td>
<td>-0.199</td>
<td>-0.009</td>
<td>-0.104</td>
<td>-0.089</td>
<td>-0.047</td>
<td>-0.066</td>
<td>0.219</td>
</tr>
<tr>
<td>T4104</td>
<td>0.234</td>
<td>0.481</td>
<td>-0.164</td>
<td>-0.116</td>
<td>-0.171</td>
<td>-0.065</td>
<td>-0.110</td>
<td>0.060</td>
<td>-0.144</td>
<td>-0.198</td>
<td>-0.145</td>
<td>0.096</td>
</tr>
<tr>
<td>N4182</td>
<td>0.435</td>
<td>0.258</td>
<td>-0.390</td>
<td>-0.704</td>
<td>-0.363</td>
<td>0.712</td>
<td>-0.392</td>
<td>0.166</td>
<td>-0.699</td>
<td>-0.569</td>
<td>-0.737</td>
<td>-0.394</td>
</tr>
<tr>
<td>N8204</td>
<td>-0.149</td>
<td>0.389</td>
<td>-0.133</td>
<td>0.025</td>
<td>-0.105</td>
<td>-0.322</td>
<td>-0.068</td>
<td>-0.168</td>
<td>-0.004</td>
<td>0.073</td>
<td>0.031</td>
<td>0.293</td>
</tr>
<tr>
<td>N4104</td>
<td>-0.073</td>
<td>0.436</td>
<td>-0.202</td>
<td>-0.099</td>
<td>-0.169</td>
<td>-0.198</td>
<td>-0.137</td>
<td>-0.140</td>
<td>-0.127</td>
<td>-0.027</td>
<td>-0.098</td>
<td>0.224</td>
</tr>
<tr>
<td>D8204</td>
<td>0.062</td>
<td>-0.009</td>
<td>-0.159</td>
<td>-0.299</td>
<td>-0.284</td>
<td>0.369</td>
<td>-0.018</td>
<td>0.087</td>
<td>-0.349</td>
<td>-0.579</td>
<td>-0.328</td>
<td>-0.323</td>
</tr>
<tr>
<td>D4104</td>
<td>0.062</td>
<td>-0.009</td>
<td>-0.159</td>
<td>-0.299</td>
<td>-0.284</td>
<td>0.369</td>
<td>-0.018</td>
<td>0.087</td>
<td>-0.349</td>
<td>-0.579</td>
<td>-0.328</td>
<td>-0.323</td>
</tr>
</tbody>
</table>

Key: F = forested, C = cleared, B = built, T = transportation, N = developed with no buildings, D = developing, 1941-1982, 1982-2004, Elev = elevation, Sinu = sinuosity, Rough = roughness, Durban = distance to urban center, s.d. HL = standard deviation of heat load, PubL% = percentage of public land
Table 7. Correlations between LULC, basin morphometry, and channel change

<table>
<thead>
<tr>
<th></th>
<th>$\mu_{CW4182}$</th>
<th>$\mu_{CW8204}$</th>
<th>$\mu_{CW4104}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>F4182</td>
<td>0.371</td>
<td>0.478</td>
<td>0.351</td>
</tr>
<tr>
<td>F8204</td>
<td>-0.364</td>
<td>-0.512</td>
<td>-0.567</td>
</tr>
<tr>
<td>F4104</td>
<td>0.176</td>
<td>0.209</td>
<td>0.075</td>
</tr>
<tr>
<td>C4182</td>
<td>-0.111</td>
<td>-0.399</td>
<td>-0.117</td>
</tr>
<tr>
<td>C8204</td>
<td>0.559</td>
<td><strong>0.813</strong></td>
<td><strong>0.797</strong></td>
</tr>
<tr>
<td>C4104</td>
<td>0.418</td>
<td>0.448</td>
<td>0.623</td>
</tr>
<tr>
<td>B4182</td>
<td>-0.553</td>
<td>-0.595</td>
<td>-0.656</td>
</tr>
<tr>
<td>B8204</td>
<td>-0.636</td>
<td><strong>-0.738</strong></td>
<td><strong>-0.767</strong></td>
</tr>
<tr>
<td>B4104</td>
<td>-0.604</td>
<td>-0.676</td>
<td><strong>-0.723</strong></td>
</tr>
<tr>
<td>ElevRng</td>
<td><strong>0.850</strong></td>
<td>0.136</td>
<td>0.763</td>
</tr>
<tr>
<td>$\mu$ Slope</td>
<td>0.602</td>
<td><strong>0.722</strong></td>
<td><strong>0.759</strong></td>
</tr>
<tr>
<td>Bluff Area</td>
<td>0.511</td>
<td>0.512</td>
<td>0.656</td>
</tr>
<tr>
<td>$\mu$ Elev</td>
<td>-0.064</td>
<td><strong>-0.756</strong></td>
<td>-0.318</td>
</tr>
<tr>
<td>$\mu$ Rough</td>
<td>0.611</td>
<td>0.692</td>
<td><strong>0.777</strong></td>
</tr>
<tr>
<td>Durban</td>
<td><strong>0.834</strong></td>
<td>0.443</td>
<td><strong>0.837</strong></td>
</tr>
<tr>
<td>PubL%</td>
<td><strong>0.878</strong></td>
<td>0.079</td>
<td>0.695</td>
</tr>
</tbody>
</table>

Key: CW – channel width, F = forested, C = cleared, B = built,
4182 = 1941-1982, 8204 = 1982-2004, 4104 = 1941-2004,
Elev = elevation, Rng = range, Rough – roughness,
Durban = distance to urban center, PubL% =
Percentage of public land
Table 8. LULC class percent change for all study units

<table>
<thead>
<tr>
<th>Study Unit</th>
<th>F4182</th>
<th>F8204</th>
<th>F4104</th>
<th>C4182</th>
<th>C8204</th>
<th>C4104</th>
<th>B4182</th>
<th>B8204</th>
<th>B4104</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.03</td>
<td>-0.05</td>
<td>-0.07</td>
<td>0.03</td>
<td>0.04</td>
<td>0.07</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>-0.07</td>
<td>0.03</td>
<td>-0.04</td>
<td>0.05</td>
<td>-0.13</td>
<td>-0.08</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>3</td>
<td>-0.01</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>-0.08</td>
<td>-0.07</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>-0.03</td>
<td>-0.01</td>
<td>-0.04</td>
<td>0.01</td>
<td>0.07</td>
<td>0.08</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>-0.13</td>
<td>-0.04</td>
<td>-0.17</td>
<td>0.12</td>
<td>-0.03</td>
<td>0.08</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>6</td>
<td>-0.05</td>
<td>-0.01</td>
<td>-0.06</td>
<td>0.00</td>
<td>-0.05</td>
<td>-0.05</td>
<td>0.05</td>
<td>0.04</td>
<td>0.09</td>
</tr>
<tr>
<td>7</td>
<td>0.16</td>
<td>0.02</td>
<td>0.18</td>
<td>-0.12</td>
<td>-0.02</td>
<td>-0.14</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>-0.09</td>
<td>0.02</td>
<td>-0.07</td>
<td>0.08</td>
<td>-0.02</td>
<td>0.06</td>
<td>0.03</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>9</td>
<td>0.04</td>
<td>0.03</td>
<td>0.07</td>
<td>-0.04</td>
<td>-0.03</td>
<td>-0.07</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>10</td>
<td>0.11</td>
<td>0.00</td>
<td>0.11</td>
<td>-0.11</td>
<td>0.00</td>
<td>-0.11</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>11</td>
<td>-0.06</td>
<td>0.01</td>
<td>-0.05</td>
<td>0.04</td>
<td>-0.02</td>
<td>0.02</td>
<td>0.04</td>
<td>0.01</td>
<td>0.05</td>
</tr>
<tr>
<td>12</td>
<td>-0.01</td>
<td>0.00</td>
<td>-0.02</td>
<td>0.03</td>
<td>0.00</td>
<td>0.03</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Illinois

<table>
<thead>
<tr>
<th>Study Unit</th>
<th>F4182</th>
<th>F8204</th>
<th>F4104</th>
<th>C4182</th>
<th>C8204</th>
<th>C4104</th>
<th>B4182</th>
<th>B8204</th>
<th>B4104</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois</td>
<td>0.04</td>
<td>0.00</td>
<td>0.05</td>
<td>-0.04</td>
<td>0.00</td>
<td>-0.04</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Clear</td>
<td>-0.04</td>
<td>0.01</td>
<td>-0.03</td>
<td>0.01</td>
<td>-0.04</td>
<td>-0.04</td>
<td>0.02</td>
<td>0.02</td>
<td>0.04</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Humans are altering the land at unprecedented rates. Through the use of historic aerial photography, past LULC and stream geomorphic changes can be examined and analyzed in order to better understand the past and to predict the potential impact of future land use activities. This study involves the investigation of historic land-use in the Ozarks, the creation of a temporal framework for historic land-use in the region, the development of a PLSS-based map generalization technique for quantifying LULC change over time using historical aerial photography, and the analysis of relationships between LULC changes, basin morphometry, and stream channel geomorphology.

The results of the LULC quantification and analysis indicate an increase in development at the urban-rural interface, and an increase in reforestation of federally managed public lands. The results of the 2004 LULC quantification were found to have high correlation with the same general LULC classes quantified using satellite imagery from the same year. Although further application is need these initial results seem to indicate the utility of the PLSS-based map generalization technique with regard to quantifying LULC changes using historical aerial photography. This technique also has the potential to be applied in remote sensing applications.

The statistical analysis of correlation between LULC, basin morphometric variables, and stream channel widths shows that LULC changes occur most intensely in basins containing lower gradient headwater reaches in proximity to urban centers, while the largest increase in channel change was found to be channel widening in the lower stream valleys along the main channel of the Illinois River. These findings suggest that channel change within the study area is a result of both decreased erosional resistance in
valley bottom locations and increased upland land use related to urban development near headwater reaches.

Due to the major impact that anthropogenic activities have on the landscape, it is important to understand and reconstruct the distribution and history of land use patterns and land cover change. This type of study provides insight into the complex processes and responses within the landscape, and helps land managers and land users to project future trends in human activities and land use impacts. It is through a better understanding of how human activity impacts the land that people can better understand the effects of ecological impacts with regard to the land, as well as its human and non-human inhabitants. This understanding in turn provides a starting point for informing land use decisions, establishing conservation goals, and targeting ecological restoration efforts.