INVESTIGATING THE WILDLAND-URBAN INTERFACE AND POTENTIAL IMPACTS SURROUNDING GREAT SMOKY MOUNTAINS NATIONAL PARK

by

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(Under the Direction of Marguerite Madden)

ABSTRACT

The Great Smoky Mountains National Park (GRSM) which lies on the border between Tennessee and North Carolina is one of the largest and most biodiverse protected areas in the United States. The land in the periphery and surrounding the GRSM has experienced noticeable changes in land use in recent years. The areas bordering the park have seen a waning in agricultural uses and a continuous growth in development in tourism and recreation. This study focuses on using aerial imagery and geographic information systems (GIS) to map and visualize land use and land cover changes (LULC) in the Cobbly Nob community from 1977-2005 and analyze the wildland-urban interface (WUI) occurring at the study area using housing and population information from the US Census. It also aims to identify areas where human/environmental conflicts occur including areas where fire dependent vegetation and human development overlap.

INDEX WORDS: Wildland Urban Interface, Intermix, Interface, Table Mountain pine, Land use/land cover, Geographic Information Systems, Population, Housing units, Change analysis, Great Smoky Mountains National Park

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION, STUDY AREA, AND RESEARCH OBJECTIVES

Introduction

The wildland-urban interface (WUI) has gained considerable attention in the US due to increasing human-environmental conflicts in the areas where human structures are intermingled with undeveloped wildlands (Radeloff et al. 2005). Every year additional residential, commercial and industrial development occurs at the fringes of urban and rural centers adjacent to undeveloped and/or preserved lands that are considered to be wilderness areas. The need for urban expansion coupled with the desire of many people to "retreat" to wilderness areas for vacations, seasonal residence and retirement results in human encroachment into natural areas that are habitat to wild animal populations (particularly large mammal predators). Often these rugged areas are removed from community services and subject to natural ecosystem processes such as wildfire, landslides, floods, and avalanches. The consequence can be loss of human and domestic animal life due to wild animal attacks, property damage by wildlife, destruction of homes by wildfires, habitat fragmentation, introduction of exotic species, and an overall decline in biodiversity. Because of potential hazards and ecological impacts that occur in such volatile areas, understanding potential WUI risks on a local-scale is important for not only the safety of the human populations living there and the protection of cultural resources, but also the preservation of natural areas and conservation of shrinking wilderness suitable for sustaining wildlife and conserving endangered plant and animal populations.

The Great Smoky Mountains National Park (GRSM) which lies on the border between Tennessee and North Carolina, and the Foothills Parkway land set aside for the eventual construction of a northern entrance to GRSM are combined one of the largest and most biodiverse protected areas in the US. Located in the southeastern Blue Ridge Mountains and part of the larger Appalachian Mountain chain that stretches from Georgia to Maine, the park contains a variety of habitats that support numerous species of flora and fauna, some of which are endemic to GRSM. The GRSM, however, is being encroached upon by rapid development and growth of bordering urban centers due to increased tourism and interest in the area for seasonal vacation and retirement. Well known as one of the most bio-diverse regions of the world, the park's boundary is a volatile WUI in terms of wildfire, wildlife, and human conflicts.

The Foothills Parkway project was authorized by Congress in 1944 and remains Tennessee's oldest unfinished highway project. The construction was launched after it was decided that Blue Ridge Parkway was not going to pass through Tennessee. The original plan was to connect GRSM and the Shenandoah National Park. Through extensive lobbying and compromise the plan was approved; the Foothills Parkway was to cover 72 miles along the north side of GRSM and connect US-129 at Chilhowee Lake and I-40. Land has been set aside, however funding problems have stalled the Parkway since its commencement. In 2007, the NPS started conducting an environmental impact assessment and collecting public opinion regarding section 8B (connecting Cosby to Pittman Center via the crest of Webb Mountain 22.7 km (14.1 miles)) of the Foothills Parkway project (NPS 2008).

The land in the periphery surrounding the GRSM has experienced noticeable changes in land use over the years including a waning in agricultural uses and a continuous growth in tourism and recreation development (Carpenter 1982). A variety of land uses border GRSM including National Forest lands, year-round and vacation homesites, small towns, campgrounds, reservoirs and the tribal lands of the Eastern Band of the Cherokee Indians (EBCI). It is also closely located to the "gateway" communities of Gatlinburg, Tennessee and Cherokee, North Carolina (Shands 1979). In the counties surrounding the park, much of the land is purchased and owned by non-local residents who are interested in second vacation homes or real estate investment opportunities. Furthermore, the majority of recreational subdivisions and individual homes are located in areas that are steep in slope, have very few public services available to them, and few ordinances for development (Ambrose 1987).

The city of Gatlinburg lies approximately 1 km north of the GRSM northern border and is home to approximately 3,800 permanent residents. It offers tourist attractions such as skiing, amusement parks, aquariums, hotels, restaurants, shopping and many recreational activities which draw in locals and visitors alike. To the south of GRSM is the city of Cherokee, NC within the ECBI tribal lands. Developed on the floodplain of Oconaluftee River, approximately 8,092 members (2000 Census) of EBCI live in Cherokee and operate Harrah's Casino. Legalized gambling has attracted approximately 3.6 million visitors per year to Cherokee since it opened in 1997 (Harrah's Casino, personal communication, November 10, 2008). Vehicular traffic between Gatlinburg and Cherokee must travel on US 441 which crosses the center of the GRSM and over the highest mountain ridge, or spine, of the park at the North Carolina-Tennessee border. These "visitors" to the park can contribute to the 2006 statistic that the park grossed more than 9 million recreational visits, making it the most visited of the 57 National Parks in the nation, followed only by the Grand Canyon with 4.4 million (NPS 2008).

The GRSM covers an area of 2,032 square kilometers (785 square miles) in total area, 95 percent of which is forested. World renowned for its species diversity, the GRSM was declared an International Biosphere Reserve by the United Nations in 1976. The park is home to over 100 different species of trees, which is more than is found in any other North American National Park. With 95 percent of the park remaining forested and 25 percent of that being patches of old growth, it contains one of the largest remnants of virgin forest in North America (National Park Service 2008). One forest community that is unique to GRSM and found only at high elevations above 914 meters (3000 feet) is the Table Mountain pine (TMP) (*Pinus pungens*) community. Maintained once by natural fires, Table Mountain pine has serotinous cones that require high temperatures for the cones to open and seeds to be released. With long term fire suppression following designation of the area as a National Park, undergrowth of deciduous shrubs and seedlings thrived and out competed TMP growth. Recognizing the loss of these valuable pine communities and the need for periodic fires to kill successional deciduous species, release nutrients and create conditions for the (TMP) reproduction, the NPS developed a management strategy of controlled burning.

With the recent catastrophic wildfires in southern California, much debate has been spurred over National Park fire policies and the dangers associated with homes and businesses located within naturally fire prone areas. Much of the current research has focused on broad scale evaluation of the WUI at the national and state levels, but few fine scale studies have investigated local level conflicts of WUI. This study will attempt to do so using a combination of aerial photographs, remote sensing and geographic information systems (GIS) as geospatial tools that can be used to: 1) better understand the land use changes around protected areas such as GRSM and the Foothills Parkway; 2) model trends in cultural and natural resources impacted by WUI conflicts; and 3) quantify the number of people affected in the WUI by looking at housing information and population. This project will incorporate geospatial methods previously used in

WUI areas much broader in scale and apply them at the local scale. The resulting information can be used to rank critical areas within WUI and help local decision makers prevent future WUI conflicts at the local level.

Study Area

The Great Smoky Mountains National Park (GRSM), which covers about 2,032 square kilometers, was established in 1934 to protect the remaining portions of the Southern Appalachian forest threatened by logging and fire. The park has two main access points in Gatlinburg, Tennessee at the northern border and Cherokee, North Carolina at the southern border, with both cities located along US 441 that bisects the park (Figure 1.1) (NPS 2008).

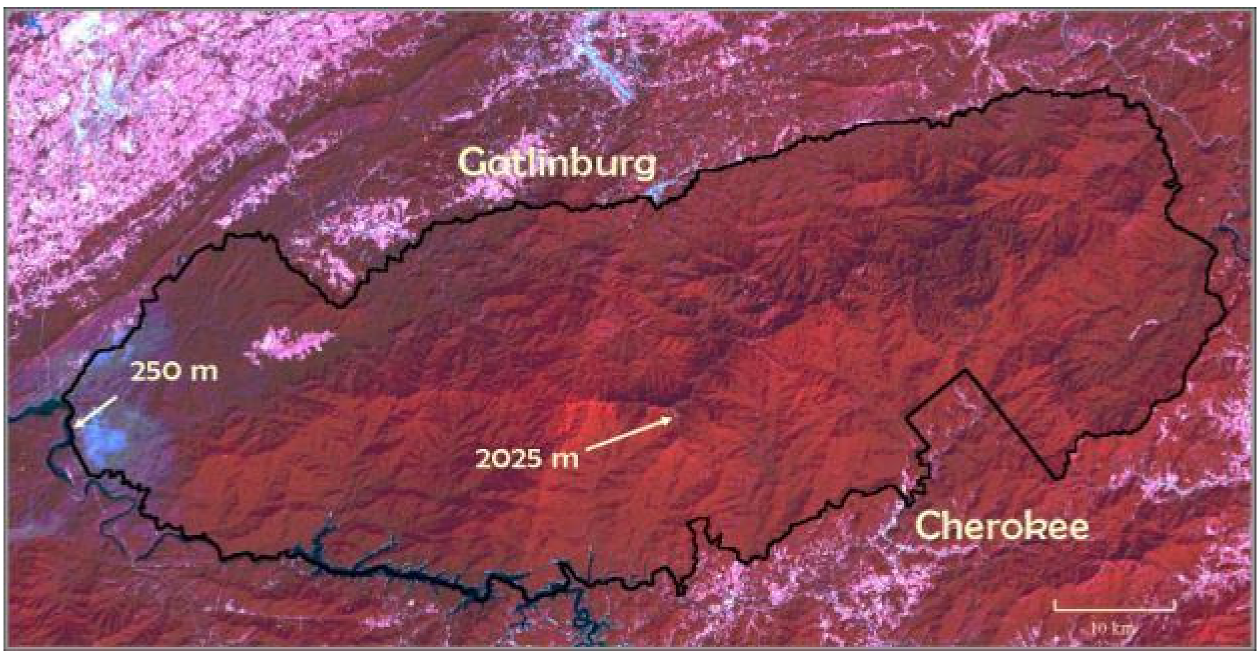


Figure 1.1- Great Smoky Mountain National Park.

This study will focus on an area 824 ha (2036.5 ac) in size within approximately two kilometers wide and five kilometers long strip adjacent to the northern boundary of the GRSM near Webb Mountain within the Foothills Parkway. Figure 1.2 illustrates the defined study region as the portion of land located enclosed by the Foothills Parkway and GRSM and is shaded in green. This study area provides a unique opportunity to examine land that is located between two areas of managed land, GRSM and Foothills Parkway, both of which are under the control of the NPS. The Foothills Parkway is a national parkway, which when completed will run parallel to GRSM and will connect US Route 129 with Interstate 40. Located in the WUI between GRSM and surrounding commercial, residential and agricultural land uses, the Foothills Parkway represents the volatile human-environmental conflict. Environmental advocates protest its construction and promote the preservation of one of the largest stands of remaining and rare TMP communities. Developers, on the other hand, support construction of the parkway for

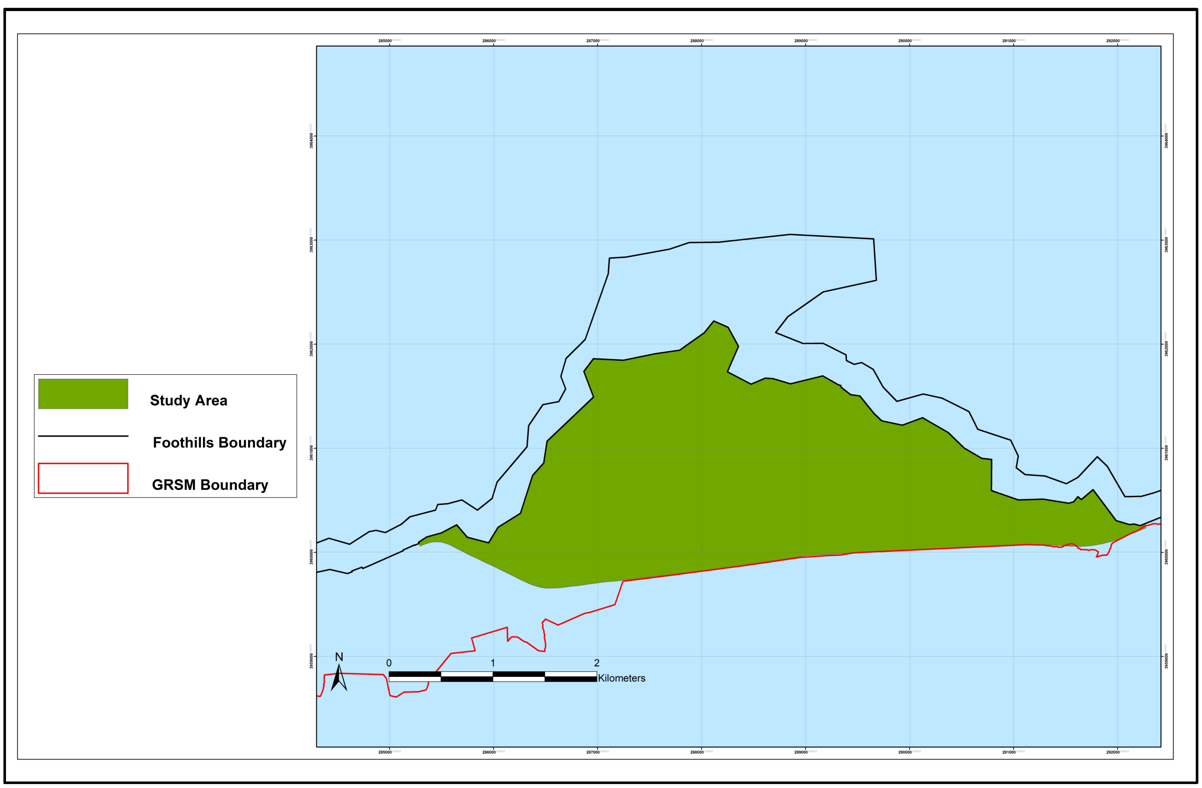


Figure 1.2- The defined study area is located between the Foothills Parkway and GRSM and is shaded in green.

improved access to the Gatlinburg area, economic benefits and increased tourism and recreational benefits. Some local residents and politicians see this as an unfulfilled promise of the federal government and yet another example of environmentalists imposing their agenda at the expense of the livelihoods of local citizens.

In anticipation of future completion of the Foothills Parkway and the potential of increased numbers of tourists to the Gatlinburg and surrounding areas, some development of services such as restaurants, hotels and vacation homes have been built along State Highway 129 parallel to the proposed route of the parkway. One such venture is the Cobbly Nob Cabin Rental Community and golf course.

Cobbly Nob, Tennessee is found in Sevier County adjacent to the northern border of the GRSM (Figure 1.3). Its convenient location to the park has made it an extremely popular tourist destination. The Cobbly Nob community is located on the Tennessee side of the GRSM. It covers a land area of 8.2 square kilometers and is surrounded by high ridges on all sides.

Figure 1.3- Location of Study Area (Google Earth 2008)

Gatlinburg, which is located approximately 10 miles to the west of this area, has a permanent population of less than 3,500 people (US Census 2002). However, it provides services for up to 60,000 additional people on peak tourist days that come to visit the Smoky Mountains (DECD 1991). As Gatlinburg has grown, the surrounding areas including the study area have been impacted by human development and construction. Figure 1.4 shows residential development along Webb Mountain adjacent to the Foothills Parkway.

Figure 1.4- Cabins located along Webb Mountain (Smokiesrental.com)

Great Smoky Mountains National Park has a moderate climate. Average annual temperature ranges from 15 to 20° C (59 to 68 º F) in July to 2 to 5° C (36 to 41 º F) in January, with the average number of frost-free days ranging from 170 to 180 (Della-Bianca 1990). Elevations that range in the park from 250 to 2025 meters above mean sea level greatly influence local microclimates and contribute to variations in habitat conditions. Consistent yearly rainfall amounts, coupled with high summer humidity, provide excellent growing conditions in the park. Annual rainfall varies from 139 centimeters in the valleys and up to 215 centimeters at some of the peaks (NPS 2008). Due to the high rates of evaporation and transpiration from the leaves of vast forests, there is often a blue haze from which the Smoky Mountains gets its name.

Recognizing the importance of the area, the United Nations has named GRSM an International Biosphere Reserve. Approximately 100 native tree species are currently growing in the park, which is more than is contained within any other North American National Park. There are over 1,570 species of flowering plants (10 percent are considered rare) and over 4,000 nonflowering plants. With 95 percent of the park remaining forested, it maintains one of largest blocks of deciduous, pine, and old growth forests in North America (NPS 2008). Discovering Life in America and GRSM National Park have conducted an All Taxa Biodiversity Inventory (ATBI) which aims to determine all species within the park. Currently, it is believed that only 12 percent (12,000) of the flora and fauna species have been documented. Scientists think there are potentially over 100,000 different organisms living in the park (NPS 2008).

Research Objectives

A study of WUI populations at risk that are adjacent to the biologically diverse GRSM and Foothills Parkway and with a rapidly growing urban, residential and recreational area requires the use of geospatial technologies including remote sensing and GIS. Historical aerial photographs available from local, state, and federal archives can provide invaluable information on the type, amount and spatial patterns of both development and natural resources within WUI areas. Geographic information systems can be used to compile geodatabases containing image and vector data sets and then perform spatial analyses such as overlay change analysis, risk modeling and spatial correspondence between population and land use/land (LULC) cover data. These techniques will be used to examine issues of risk conflicts and impacts within a critical area of WUI.

The overall objective of this project is to better understand the WUI in the areas surrounding National Parks, specifically the conflict of potential wildfires in close proximity to commercial, residential, and recreational activities located at the periphery of GRSM and Foothills Parkway. Results from the study will allow NPS and the US Forest Service to make informed decisions about prescribed burning management plans for fire dependent forest communities and resource allocation in the event of natural, arson, or escaped fires. Local governments will be better equipped to anticipate WUI issues in areas of existing development and plan future development to prevent WUI conflicts. The information from this study could be crucial to the protection of life, property, and natural resources.

Specific objectives for this study include the following.

a. Identify and quantify land use surrounding/along a portion of the northern border of the GRSM by examining two dates of historical aerial photographs (1977, 1997) and current aerial photographs (2006) and developing a WUI-tailored classification system specifically for the GRSM area to better understand WUI LULC change dynamics over time. Particular attention will be focused on an area extending from Gatlinburg, TN east to Webb Mountain located in the NPS Foothills Parkway adjacent to the northern boundary of GRSM.
b. Determine the GRSM WUI population at risk within the study areas based on the published Federal Register definitions, using two different methods: housing density and population density, related to potential impacts of wildfire related to fire dependent vegetation cover to better understand the WUI population, risk of wildfire and potential damage to personal property.
c. Compare the results between WUI population risk using housing density and population density as predictors for WUI areas by spatially highlighting areas of disagreement.
d. Identify areas of potential natural/human conflict in the GRSM/Foothills WUI including areas where fire dependent vegetation communities such as TMP and where development intersect.

CHAPTER 2

LITERATURE REVIEW

Severe wildfires that threaten people, homes, businesses and natural resources are a growing concern among federal and state agencies and local town and community governments. Subjected to decades of suppression in the past, wildfires are now considered part of a natural ecosystem and are significantly important in maintaining forest health and vitality, minimizing fuel load build-up, and maintaining species diversity. With increasing urban and suburban growth surrounding wild areas and reduced fire suppression, attention must be paid to wildfire impacts on the environment itself and the threat fire poses to human safety, especially in the critical WUI areas. In a survey of park managers nationwide, urban encroachment was the number one mentioned external threat to park natural resources (Hanson and Gryskiewicz 2003). Wildfire damage in the WUI can amount to hundreds of millions of dollars each year in the US (Mercer and Prestemon 2005). As a result, it has been difficult to convince the public that fire is a natural wildland process and an acceptable management tool. Forecasting potential conflicts and areas of greatest threat to wildfires will help resource managers balance requirements for the ecological health of the wilderness, while respecting the health and welfare of those living in adjacent urban environments.

History of Great Smoky Mountains National Park

The Great Smoky Mountains National Park (GRSM) lies on the border between Tennessee and North Carolina. It is one of the largest protected areas in the US and is part of the

National Park system. It is located in the Blue Ridge Mountains which is part of the larger Appalachian Mountain chain that stretches from Georgia to Maine.

The park was established in 1934 through a Congressional charter (Campbell 1960). It was placed under the control of the NPS with the hopes of recreating the success of parks that had already been established in the more Western areas of the United States. The project required the state and federal government to purchase over 6600 tracts of land from Indian reservation land, private homes and farms, mining areas, and several areas already held by mining companies. By purchasing these lands and creating a National Park, it led to the rearrangement of private land owners outside the park's boundaries (Ambrose 1987). From its beginning, the park was to be managed as a pristine public attraction where fire would play no role in its management (Pierce 2000).

The land surrounding the GRSM has experienced noticeable changes in land use over the years. The areas bordering the park have seen a waning in agricultural uses and a continuous growth in development in tourism and recreation (Carpenter 1982). The park land is adjacent to a variety of land uses including National Forest lands, vacation homesites, campgrounds, and reservoirs. It also located close to the "gateway" communities Gatlinburg, Tennessee and Cherokee, North Carolina (Shands 1979). In the counties surrounding the park, much of the land is purchased and owned by nonlocal residents who are interested in second vacation homes or real estate investment opportunities. Furthermore, the majority of recreational subdivisions and individual homes are located in areas that are steep in slope, have very few public services available to them, and few ordinances for development (Ambrose 1987).

Urban Development and Sprawl

At the beginning of settlement periods when the US was first colonized, the settlers were required to live near areas where natural resources were produced. As transportation improved, with the building of railroads and the invention of the personal automobile in the early 1900's, there was an increase in the transportation of goods which promoted settling along these transportation corridors and the consequent growth of towns and cities (Gude et al. 2006).

Up until the 1970's, employment opportunities in cities resulted in a steady flow of people from rural regions to more urbanized areas and cities (Herbers 1986). However, during the 1970's there was a shift and Americans started leaving the cities in great numbers to live in small towns and rural areas (Kloppenburg 1983). More recently, the development of information technology has given people the ability to telecommute to work and thereby live in more remote areas while maintaining inner city and suburban jobs (Gude et al. 2006; Platt 2006). This has led to many concerns about rapid land use change and conversion of wild to developed land around protected areas and National Parks. Many authors agree there are consistent qualities that are driving people to leave the city and develop in these more remote areas (Platt 2006; Radeloff et al. 2005; Gude et al. 2006; Ewert et al. 1993). According to Platt (2006), the drive for this "exurban" development includes both national scale trends and local characteristics. On the national scale, residential areas have become more sprawling and employment opportunities have moved from the city to suburbia and fringe cities. This, along with improved highway systems that bring rural areas within commuting distance of larger cities and telecommuting technology have expanded options for workers to live beyond city boundaries. Housing costs are also often lower in the peripheral regions, which provide further incentive to move out of cities.

Local characteristics are just as important in exurban development. Platt (2006) and others agree that housing demands are growing near wild and protected areas. People want to move near recreational amenities such ski resorts, forests, lakes and seashores that are often adjacent to protected areas (Radeloff et al. 2005). Homebuyers in this growing sector desire western ranch and lodge style homes, homes with larger lots, and vacation homes. Wealthy young professionals, people in the service industry and retirees make up the majority of the growing population who are moving into the WUI (Ewert et al. 1993). Patterns of rural human settlement are thus characterized by three stages: 1) natural resource constraints, 2) transportation expansion, and 3) pursuit of natural amenities (Gude et al. 2006).

Population growth in rural areas is projected to continue into the future (Figure 2.1). Between the years of 1982 and 1992, approximately 53,823.2 km^2 (13.3 million acres) of rural land in the US was converted to urban use (Macie and Hermansen 2002). The South accounted for approximately half of the change with 26,304.6 km^2 (6.5 million acres) of the total converted area, which was the most of any region in the US. Tennessee alone has seen a 62.7 percent increase in its population from 3,567,089 in 1960 to 5,689,283 in 2000 (US Census 2002). This growth will occur in areas where forest land is still available and plentiful, thus causing pressure and demands on the land including development, recreation, and road building. The Southern Wildland-Urban Interface Assessment was compiled by the Southern Wildland-Urban Interface Council (an interagency group consisting of representatives from the US Forest Service; Southern Group of State Foresters; universities; the Cooperative Extension Service, Southern Region; and nonprofit organizations) in 2002 to confront the many interface issues specifically facing the southern US. It identifies “population hot spots” where it is thought that these population pressures will be the greatest, and included in this is the Southern Appalachians (Figure 2.1) (Macie and Hermansen 2002).

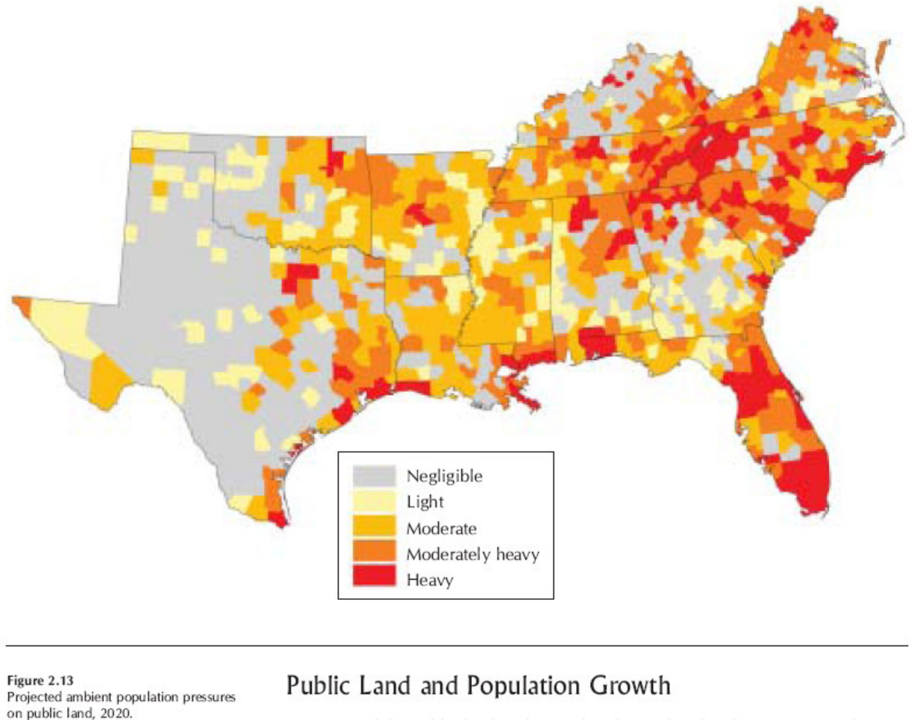


Figure 2.1- This map indicates areas of population growth and pressure adjacent to public land in the Southern US with heavy growth centered on the GRSM study area (Macie and Hermansen 2002).

Changes in the economy and tax policies in the South have impacted land use change, particularly in the WUI. The economy that was once based on agriculture and natural resources has seen a shift to service, industry, and computer manufacturing sectors. Since 1978, approximately 4 out of every 10 jobs gained in the US has been in the South (Hermansen et al. 2004). This has led to migration and relocation to the region and, in turn, fueling the growth of urban development. Land use policies have also provided incentives to develop rural areas. The US Federal Government established and subsidized the creation of the National Interstate

Highway system, and thus cleared the way for huge tracts of rural land to be developed (Hermansen et al. 2004).

Wildland-Urban Interface

The wildland-urban interface (WUI) is defined as the area where houses or other development intermingle with undeveloped wildland vegetation (Radeloff et al. 2005). Threats to people and property within the WUI often result from wildfires that escape from preserved wildlands (Cohen 2000). In 2000, the WUI in the continental US included 719,156 km^2 of land (which accounted for about 9 percent of the total land area), but most surprisingly, it was comprised of 44.8 million housing units (Stewart et al. 2005). This translates to 39 percent of all houses in the US. These areas are extensive in the eastern US where population densities are generally higher than those in the West. All 48 states contain some form of WUI, yet the eastern US, specifically northern Florida, the coastal areas in the Northeast, and the Southern Appalachians are the most affected (Radeloff et al. 2005).

Classic Interface WUI

There are three types of WUIs that are described as classic interface, the isolated intermix, and the WUI island. The classic interface has the largest number of people living in it and it is most closely related to urban sprawl where new development, especially subdivisions, intrudes into public and private wildlands (Macie and Hermansen 2002). As depicted in Figure 2.2, the classic interface consists of fully urban land use directly adjacent to wildlands with clear and abrupt boundaries between the two land uses. This type of WUI can often create a false sense of security among residents due to the paved streets, fire hydrants, and green lawns of the living space within the urban portion of the WUI and the perception of being distanced from the wildlands. The greatest structural loss due to fire has occurred in the classic interface and this is expected to continue into the future (Davis 1987).

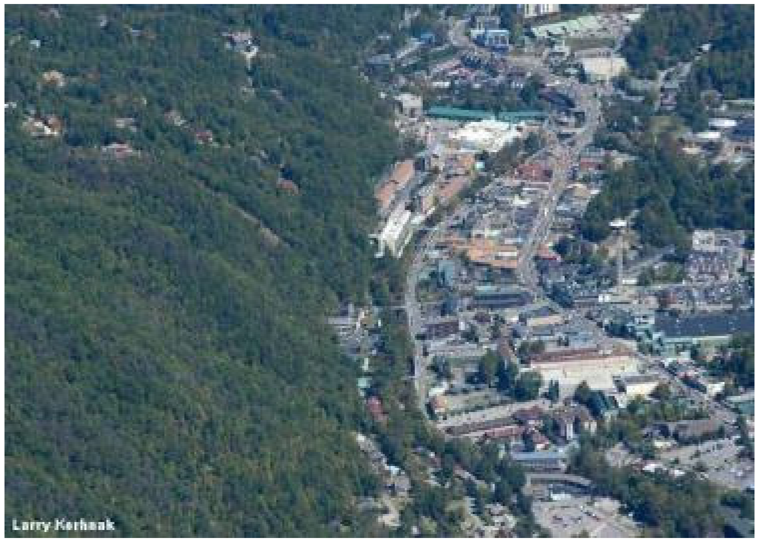


Figure 2.2- Classic interface where urban land use is directly adjacent to wildlands (Larry Korhnak 2002).

Isolated Intermix WUI

The isolated intermix WUI is defined as single home dwellings and medium size subdivisions that are surrounded by large amounts of vegetation in remote areas (Figure 2.3) (Macie and Hermansen 2002). These are usually summer homes, ranches, or recreation rental homes that are scattered throughout the wildland region. Population growth in the Blue Ride Ridge Mountains of Virginia grew rapidly between the years 1979 and 1984 and the number of isolated homes that became vulnerable to wildfire increased 400 percent (Davis 1987). Davis (1987) defines the typical residents in the isolated WUI as commuters, retirees, the poor and successful corporate executives. This has created a unique blend of residents where there is a mix of wealthy, educated and informed individuals as well as poor and uninformed permanent residents with traditional views on fire suppression. Areas like these are difficult to protect for the reason that large wildland areas may be susceptible to burning and the homes may be spread out and hard to reach.

Figure 2.3- Isolated intermix WUI where scattered homes are intermixed with wilderness (Larry Korhnak Center 2003).

Homes scattered throughout wildland forest, shrubland and prairie also amplify the potential for wildfires by concentrating the number one cause of the wildland fires, which is humans. Downed power lines, arson, sparks from vehicles and abandoned campfires are just some of the ignition sources found in these isolated areas that are not found in areas devoid of human presence (Walsh 2007).

WUI Island

Lastly, the WUI island as shown in Figure 2.4 is described as areas of undeveloped land that are surrounded by and imbedded in an urban setting. They are "islands" of undeveloped land in a sea of development (Davis 1990). The areas of "natural" vegetation often remain as public or private protected open space or land deemed undevelopable or too expensive to develop for various reasons such as topography or wetlands (Macie and Hermansen 2002). City parks are often surrounded by businesses and homes in an attempt to maintain a sense of contact with nature (Davis 1987).

Figure 2.4- WUI island of relative wilderness embedded in urban development (Larry Korhnak 2003).

Kamp and Sampson (2003) reported Tennessee as having the 10th highest WUI interface population in the US. Stewart et al. (2005) found that in 1990, approximately 24,697.8 km² (6,102,963 acres) (46.6 percent of total land area) in Tennessee could be found in the WUI, containing 940,693 housing units. By the year 2000, the area had grown to 31,655.74 km² (7,822,304 acres) (50.6 percent of total land area) and included 1,234,338 housing units.

Fire

Fire, as a natural process, has been a difficult concept for people to grasp over the years and controversy exists about the best way to manage fires. Wildfires in the US often damage structures and landscaping in the WUI worth up to hundreds of millions of dollars each year (Mercer and Prestemon 2005). More land has been affected by wildfires in recent years than in any period since the 1960's. In 2004, for example, more than 32,374.85 km² (8 million acres) of

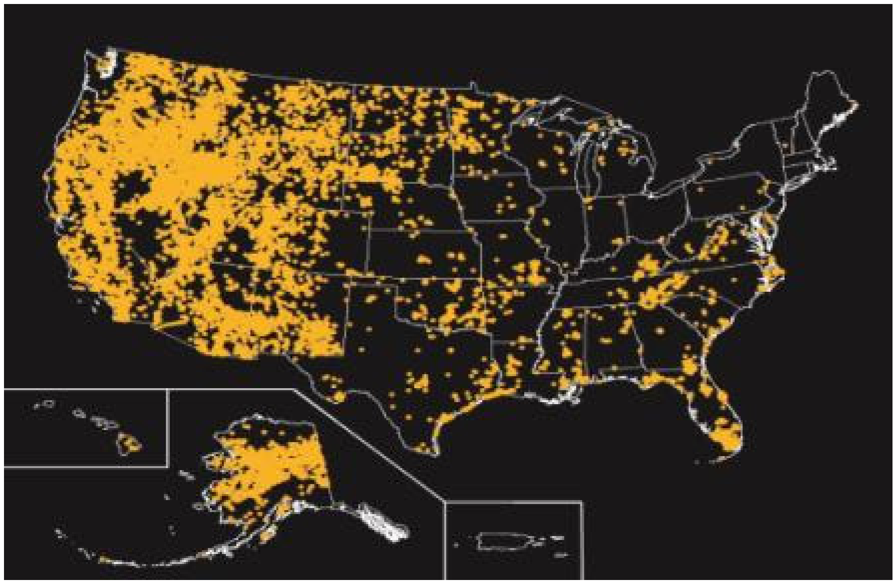


Figure 2.5- Location of wildfires greater than 250 acres from 1980-2003 (USGS 2006).

land was burned by over 40 wildfires across the US (Figure 2.5, USGS-Fact Sheet 2006). As a result, it has been difficult to convince the public that fire is an acceptable wildfire management tool and fires, both prescribed and natural, should be allowed to burn natural landscapes.

There are both natural and anthropogenic origins of wildfires. In a study conducted by Barden (1974), lightning was found to be the cause of ignition for only 15 percent of the fires in GRSM between the years 1940-1969. In a more recent study, the NPS found that approximately 10 percent of the fires are caused by lightning ignitions and the rest could be attributed to human origin (NPS 1997). While both types of fires produced the same mean size of consumed area, lightning fires were more commonly found on ridge tops, while anthropogenic fires were found in areas of lower slope (Barden 1974). In a study conducted by Cardille et al. (2001) in the northern Great Lakes region, it was found that areas with higher human population density and activity were often positively associated with fire occurrence and counts. Higher housing density contributed to considerably higher rates of human related wildland fire ignitions. This association between wildfires and human activities raises concern within the WUI since the majority of fires ignited are at lower elevations where many commercial structures and houses are located. While single home fires can cause partial or complete destruction of a home, wildland fires can cause total destruction of hundreds of homes (Cohen 2000). Haight et al. (2004) found fire occurrence is strongly correlated to human access especially in areas with higher road and population densities. This, along with fire suppression and the absence of regular fire cycles that would maintain low fuel loads, raises the likelihood that a catastrophic broad-scale fire will result. Growing numbers of people in the WUI increases the chances devastating fires will be ignited (Irwin 1987). With the threat of a growing WUI and the large number of fires started by human action, there is a need for information and tools to assess urban expansion in wilderness areas (Keeley et al. 2004).

Fire History and Management in GRSM

Much of the landscape seen today in GRSM and the Foothills Parkway is a direct result of fire and human influence. The first known instance of human settlement in the park was approximately 8,000 years ago with prehistoric Native Americans migrating throughout the area as hunter gatherers who used fire as a tool to clear land and drive game (Van Lear and Waldrop 1989; Pierce 2000). Europeans settlers in the 18th century also used fire as a tool to shape and improve the slopes and ridges where they grazed livestock. This practice was commonly referred to as “greening the grass”, which facilitated the growth of grasses and removed underbrush that hindered the livestock’s’ movement (Pierce 2000).

For most of GRSM's history since its establishment in 1934, a strict suppression policy was in effect to extinguish all forest fires within the Park boundary. More recently, research has supported the premise that many plant and animal communities are dependent on occasional fires. Twelve fire dependent plant and animal species are indigenous to the Park including Table Mountain pine (*Pinus pungens*) and the Red-cockaded Woodpecker (*Picoides borealis*). Consequently, the NPS has adopted fire management policies that promote the use of prescribed burns and allowing wildland fires to burn in order to facilitate healthy ecosystems. These policies enable the forest to return to the conditions present previous to European settlement (NPS 2008).

The GRSM is divided into three levels of fire suppression zones (Figure 2.6). Zone I, or the full suppression zone, is located along the park boundary and includes historical and developed areas. Within the 40,054 ha (98,975 acres) of Zone I, 3,827 ha (9,457 acres) are located beyond the Park's boundary and include the Foothills Parkway. Zone II is the conditional zone and contains 37,761 ha (93,309 acres) of land where fires may or may not be suppressed depending on the location and circumstances of the fire. This is the buffer between Zones I and III where fires can burn if there is no threat to Zone I. Zone III is the prescribed and natural fire zone that contains the most land within the park, 132,731 ha (327,985 acres). Here, fires are allowed to burn if they stay within certain boundaries and are not a threat for leaving the zone within 48 hours (NPS 1997). The Cobbly Nob study area is located between the two suppression zones along the border of the park and the boundary of the Foothills Parkway.

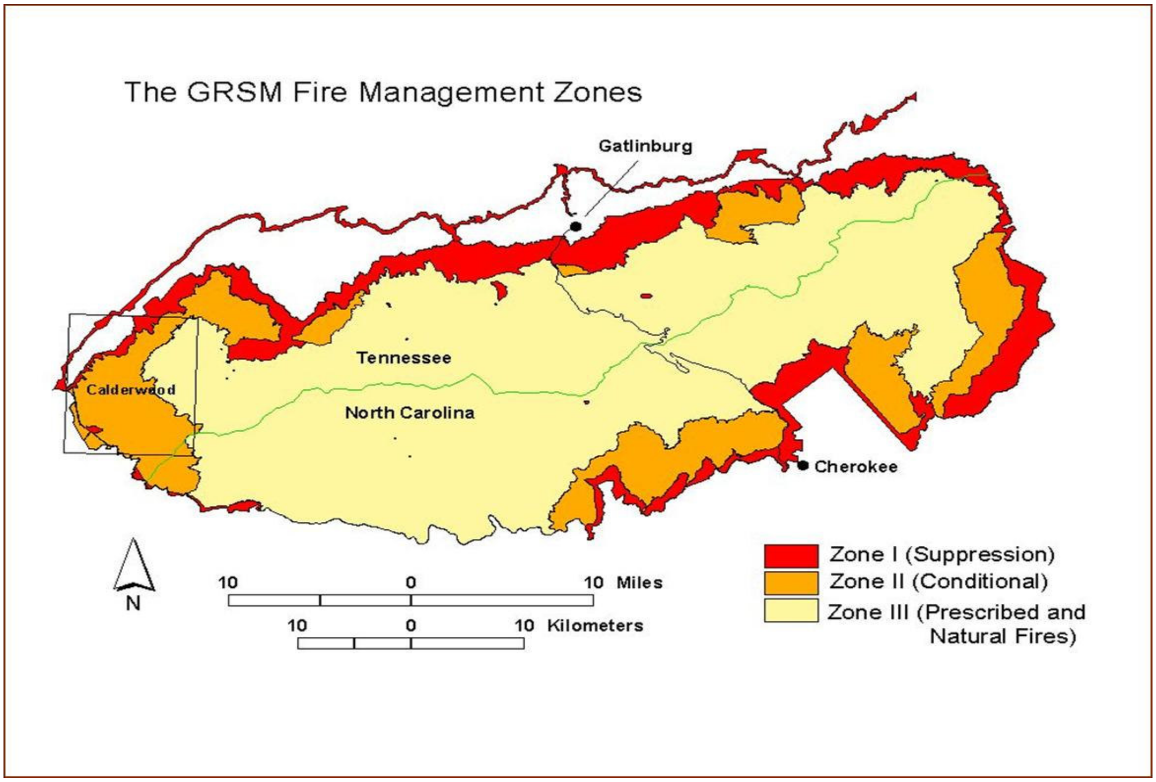


Figure 2.6- The GRSM fire management zones (NPS 1997).

Table Mountain Pine

Table Mountain pine is a pine species that is endemic to the Southern Appalachian region (Figure 2.7a). This pine is found in small, dense, unevenly distributed stands throughout its range, which extends from Pennsylvania through the Appalachian Mountains to eastern Tennessee and northern Georgia (Della-Bianca 1990).

Table Mountain pine has medium to thick bark, serotinous cones, self-pruning limbs, a deep rooting habit, and is pitch producing and shade intolerant, all of which are characteristics of trees adapted to repeated occurrences of surface fires (Della-Bianca 1990; Sutherland et al. 1995; Keeley and Zedler 1998). Only during a fire will the serotinous cones open and release its seeds to reestablish and maintain the population (Figure 2.7b). This species of pine is, therefore, dependent on lightning ignited and human induced fire in order to reproduce. With the historical practices of fire suppression, many of the Table Mountain pine stands have not been exposed to fires hot enough to open the cones. Since the establishment of the GRSM, these fire suppression management policies have hindered the stability of the Table Mountain pine communities and, in turn, allowed hardwood species to invade and become the dominant vegetation (Turrill 1998; Williams 1998).

Figure 2.7- Table Mountain pine (a) and Table Mountain pine cone (b) (Natural Sciences 2008).

Table Mountain pine is a secondary pioneer species that can establish itself quickly on sites that have been disturbed, especially due to fire. Therefore, this tree plays a major role in the regeneration of mountain forests after major fire occurrences (Zobel 1969; Williams and Johnson 1990). The NPS indicates that many of the Table Mountain pine stands in GRSM are failing to reproduce based on past fire control practices (NPS 2008). Therefore, it is expected that natural fires allowed to burn and prescribed burning of Table Mountain pine stands in GRSM and the Foothills Parkway will continue in the future. Development trends in the area between GRSM and the Foothills Parkway create conditions of conflict and increase risk in the WUI of this study area. Remote sensing data such as current and historical aerial photographs, existing vegetation databases and census information can be combined in GIS risk models to assist resource managers and local planners to minimize deaths, injury and property damage in the WUI.

WUI Studies Using Geographic Information Systems (GIS)

Several previous studies have used geographic information systems (GIS) to better analyze WUI conflicts. In a study by Radeloff et al. (2005), an inventory of the WUI across the US was conducted in order to assess the magnitude of this national issue and facilitate future scientific inquiries. They used GIS to examine the medium resolution (50-m pixel) vegetation cover USGS National Land Cover Data Set (NLCD) combined with housing density information from the U.S. Census. The Federal Register's definitions of WUI provided spatial criteria to visually evaluate areas of the country experiencing WUI conflicts and rank areas at greatest risk. They were able to create WUI maps for the entire US, regions of the US and individual states (Figure 2.8).

Haight et al. (2004) took a similar approach, but narrowed the study area in scope to a small portion of Michigan. Like the previous study, GIS assessment of NLCD land use and land cover (LULC) data sets identified the WUI within the study area. However, information on the historical fire regimes was included. By adding areas classified by fire rotation cycles to the study, the authors felt they could more accurately assess areas likely to burn based on burn classes and fire frequencies. This same approach also was used in a larger study performed by Hammer et al. (2007). Census data, the NLCD, and fire regime classes were overlaid in a GIS to examine WUI risk in California, Oregon, and Washington.

While these studies demonstrate the need for WUI risk assessment in the U.S. and the benefit of GIS capabilities for combining spatial data sets on LULC, population data and fire regimes, they were all conducted at state, regional and national levels. Local planners and park managers of wilderness areas require more specific information on WUI boundaries, urban development trends and vegetation details on plant communities dependent on fire. These issues will be addressed for the GRSM-Foothills Parkway study area of Tennessee.

a)

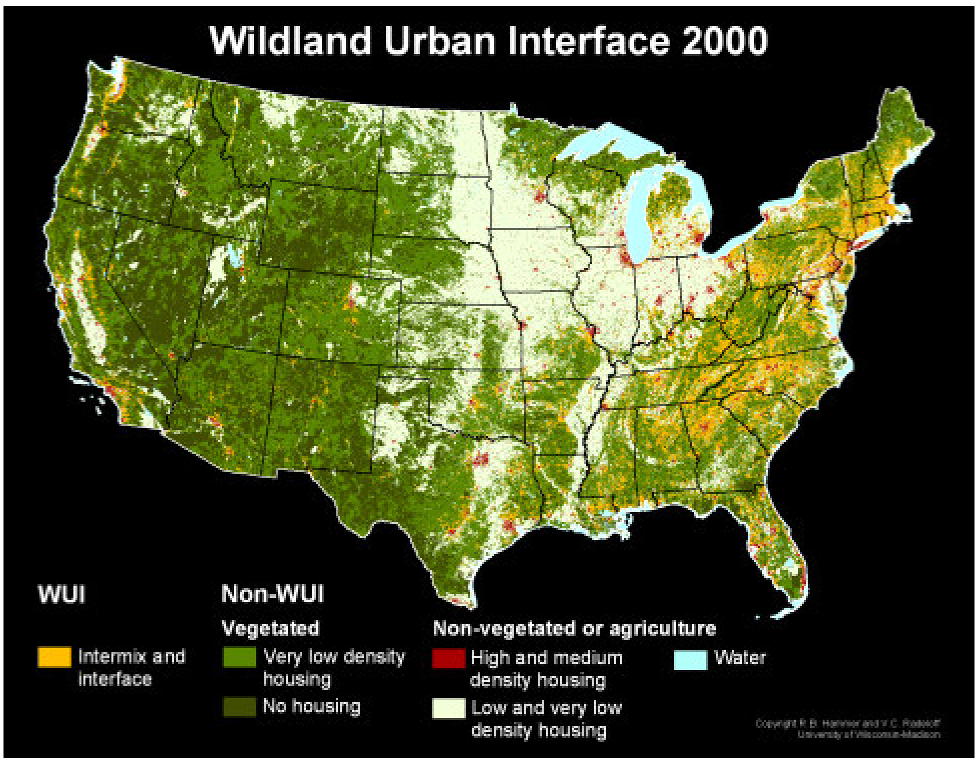
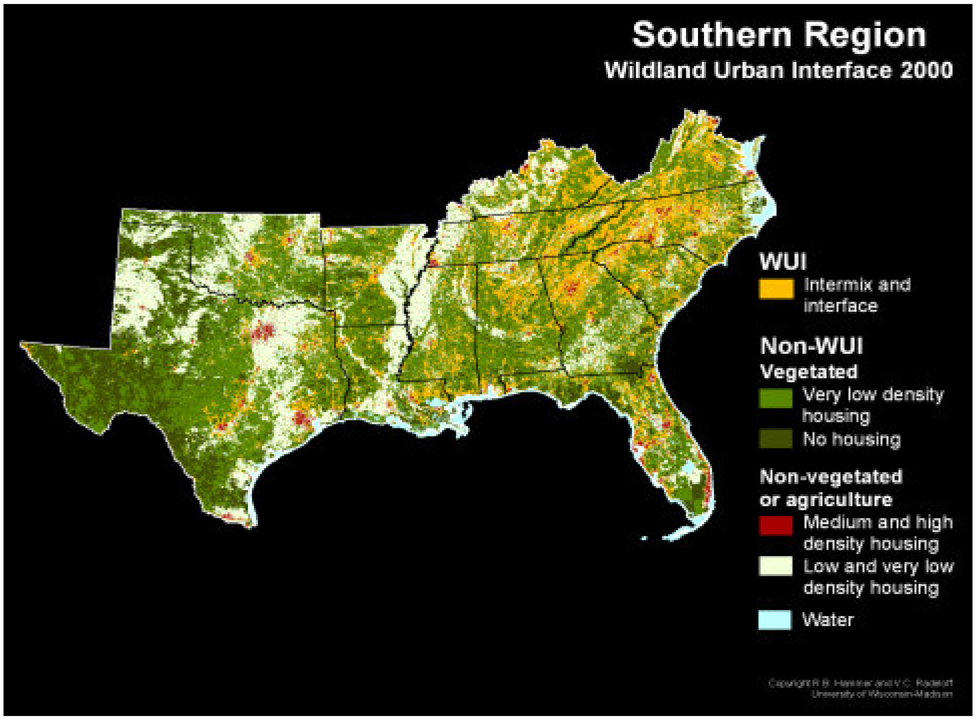


Figure 2.8- WUI in a) United States (Radeloff et al. 2005).

b)



c)

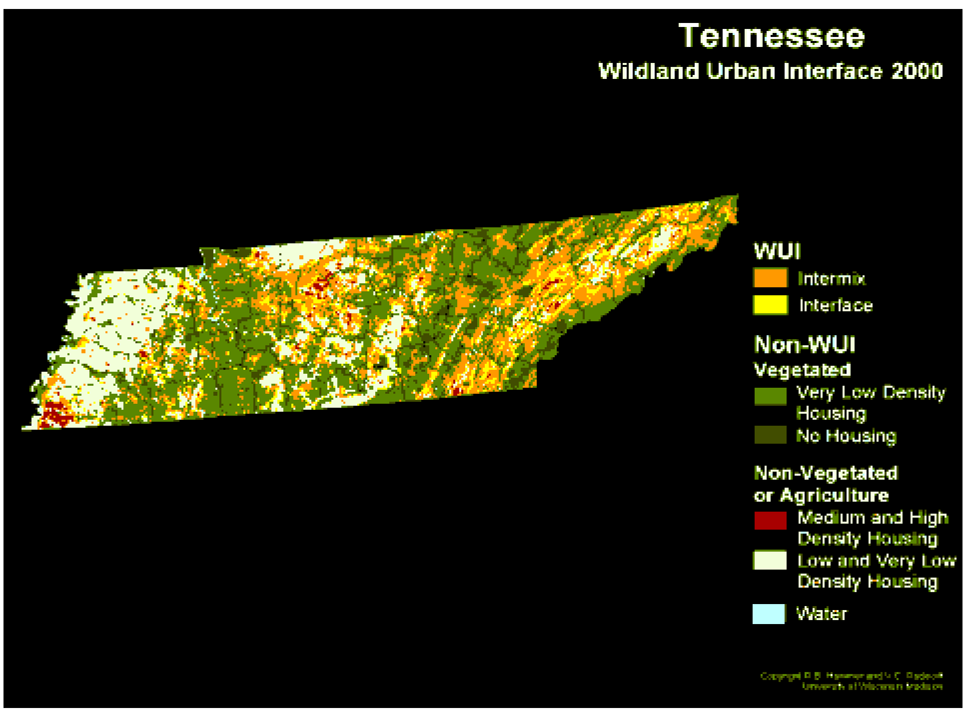


Figure 2.8- WUI in b) Southern Region, and c) Tennessee (Radeloff et al. 2005).

CHAPTER 3

DATA AND METHODOLOGY

The current project is aimed at assessing threats and developing management recommendations to reduce wildfire risk within the WUI surrounding the NPS wildlands at the GRSM border and Foothills Parkway at the Cobbly Nob community. It will also identify trends in development and land use/land cover (LULC) changes over time within the WUI and compare differences in mapping human risk by using WUI population estimates and housing estimates.

Data Sources

In order to visualize and interpret land use trends over time in the study area and assess risks to the WUI current conditions, information on past and current LULC is needed. This information is available through the use of historical aerial photographs, dating back to 1977 from the Tennessee Valley Authority (TVA). These 1:24000-scale black and white paper prints were scanned at 1000 dots per inch (dpi) and the resulting raster images were rectified to the Universal Transverse Mercator (UTM) Zone 17 ground coordinate system tied to the North American Datum of 1983 (NAD83) (Table 3.1). The other sources included USGS Digital Orthophoto Quarter Quadrangles (DOQQs) for 1997 and National Agriculture Imagery Program (NAIP) for 2006 (Figure 3.3). The 1997 DOQQ and 2006 NAIP also were projected in UTM Zone 17 in NAD83.

Table 3.1- Aerial photo date, source and associated parameters.

Date	Source	Resolution	Scale	Film Type
2006	USDA/NAIP	1 meter	N/A	True Color
1997	USGS/DOQQ	1 meter	Based on 1: 40,000 photos	BW
1977	TVA	Scanned at 0.61 m pixels	1:24,000	BW

Population numbers and housing densities for the study area are available through the most current US Census Bureau 2000 Census (Figure 3.4). The housing and population numbers are reported at the block-level, the smallest reporting unit provided the by US Census and defined as an area of land bounded by clearly demarcated features such as roads, streams, and railroad tracks, as well as political boundaries such as county lines and property lines (Haight et al. 2004). Census blocks can vary in size from very large (e.g., 574 ha or 1418 ac) in less populated areas to very small (e.g., 2.8 ha or 6 ac) in cities.

A community-level vegetation database of two major NPS wildland areas, GRSM and the Foothills Parkway, were created by the Center of Remote Sensing and Mapping Science (CRMS), Department of Geography, at the University of Georgia (Jordan 2002, Welch et al. 2002, Madden et al. 2004) (Figure 3.5). The vegetation was mapped by manual interpretation of orthorectified large scale color infrared (CIR) aerial photographs using a combination of Global Positioning System (GPS), softcopy photogrammetry and GIS, along with the USGS digital elevation model (DEM) to construct a vector-based vegetation database of the parks. The GRSM database was mapped from 1997-1998 photos and an accuracy assessment was conducted by NPS (Jenkins 2007). The overall accuracy of this vegetation database is over 80 percent. The Foothills Parkway was mapped by CRMS from 2005 CIR air photos acquired at 1:16,000 scale by Air Photographic, Inc. under contract by CRMS.. These data provided information on current vegetation conditions in the area classified according to the National Vegetation Classification (NVC) System to the association, or plant community, level following methods used to map the vegetation communities of the GRSM (Welch et al. 2002, Madden et al. 2004). Specific information on Table Mountain pine stands was extracted from the vegetation database to spatially assess the proximity of this fire dependent forest community on the population of the GRSM-Foothills Parkway study area.

Rectification of Historical Aerial Photographs

Historical aerial photographs dated March, 1977 of the GRSM-Foothills Parkway study area were obtained from the Tennessee Valley Authority (TVA) for a fee of $58 per photo. Three 1:24000-scale photos in black-and-white format were required to cover the study area (Figure 3.1). Photos were scanned at 1000 dpi by TVA resulting in digital images of 0.61 m pixel size. Before any land use classification could be performed with the 1977 air photos, georectification was required to correct distortions and displacements inherent in the photographs and the raw digital images. The photogrammetric process of georectification uses ground control points that link locations on the aerial image with the same locations on a base map or an image of a known ground coordinate system, in this case a 1997 USGS DOQQ of 1-meter resolution and horizontal accuracy of +/- 3 meters (Figure 3.2). This process is used when developing GIS databases for GIS modeling, extracting accurate distance and area measurements, and overlaying images with vector data. The common map coordinate system for both images is UTM Zone 17 tied to the NAD 83.

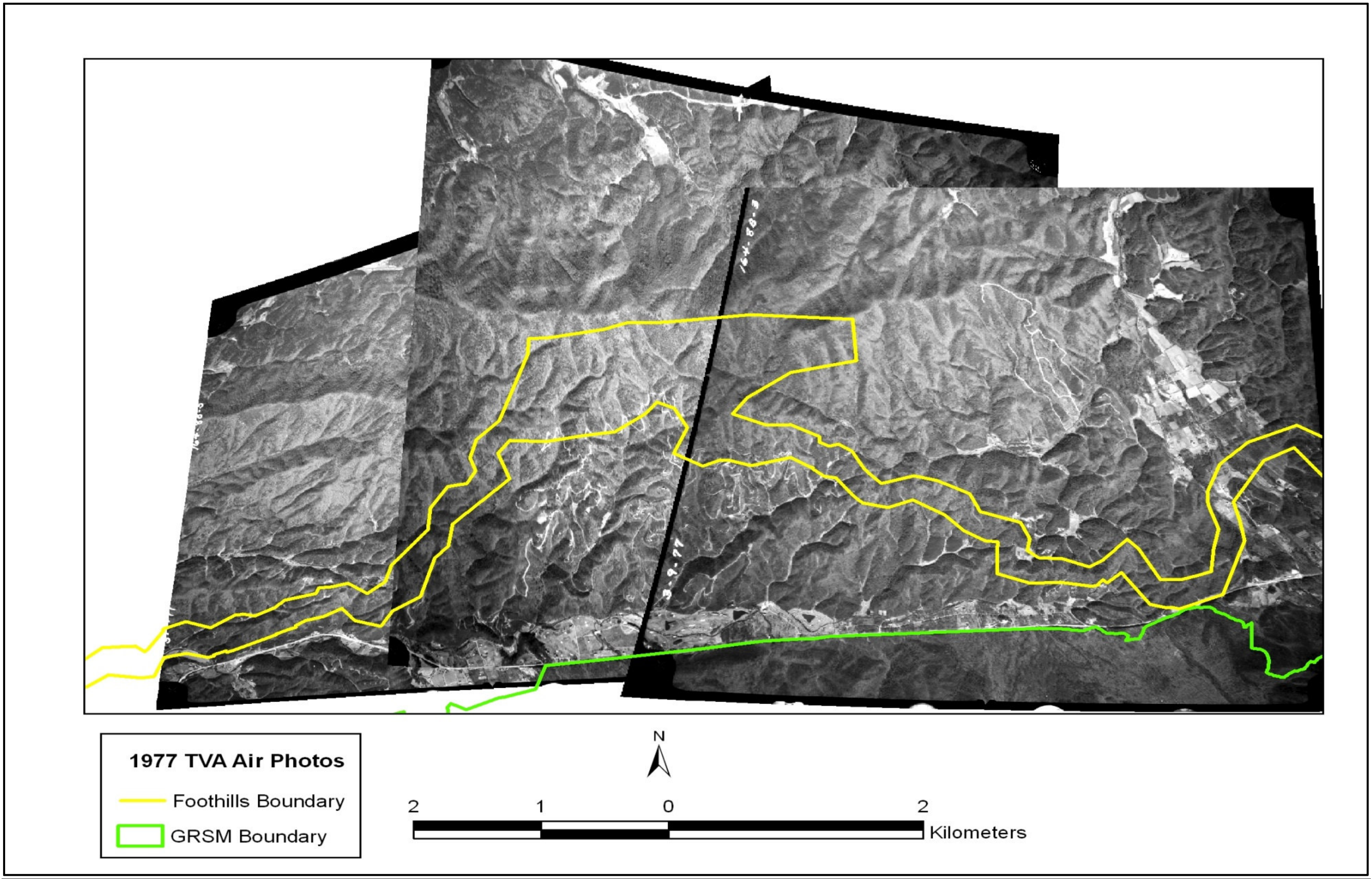


Figure 3.1- Black and white 1977 aerial photographs of GRSM-Foothills Parkway study area acquired at 1:24,000-scale by the Tennessee Valley Authority (TVA).

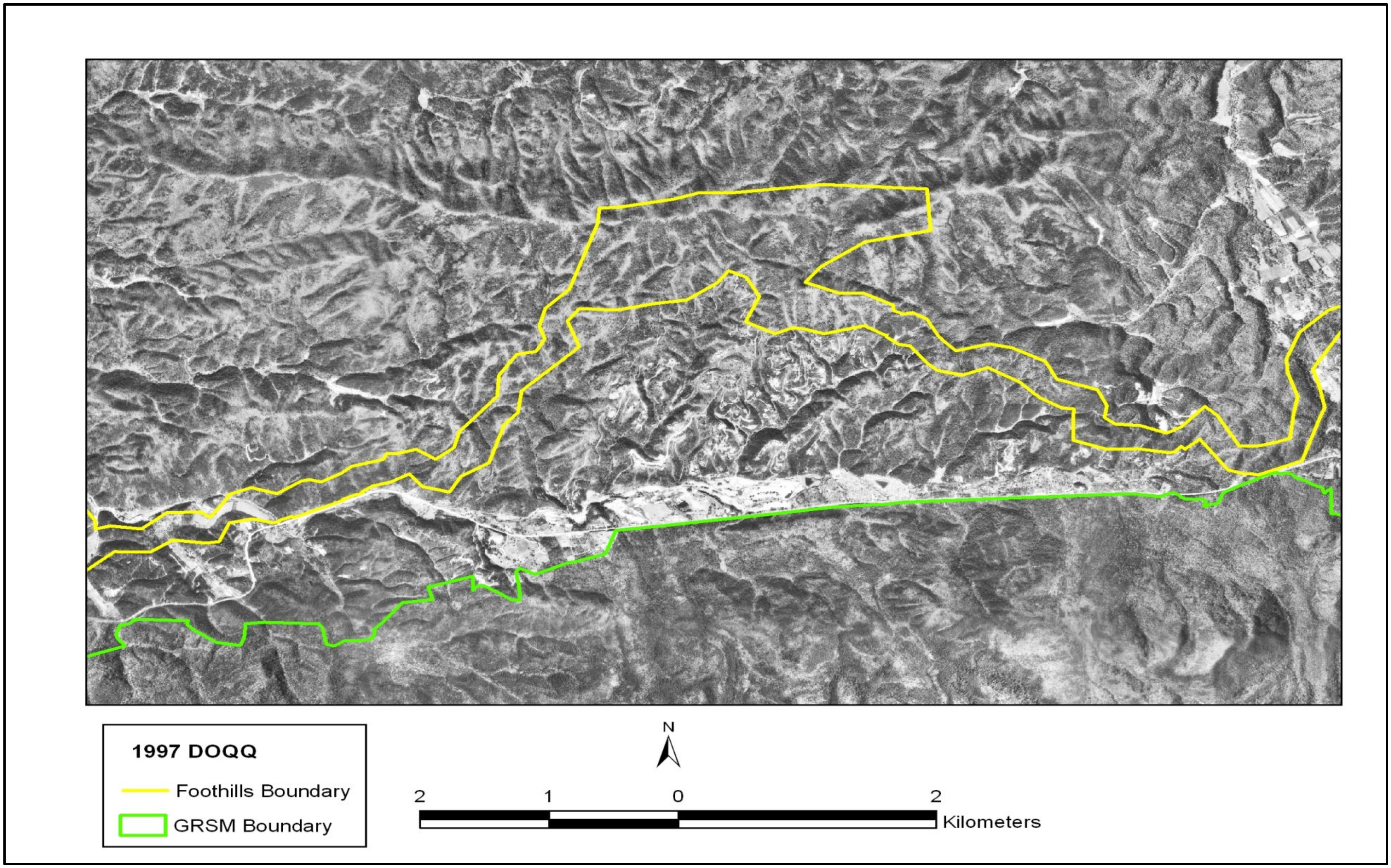


Figure 3.2- Black and white 1997 USGS Digital Orthophoto Quarter Quadrangle (DOQQ) of the GRSM-Foothills Parkway study area based on USGS National Aerial Photography Program (NAPP) aerial photographs acquired at 1:40,000-scale.

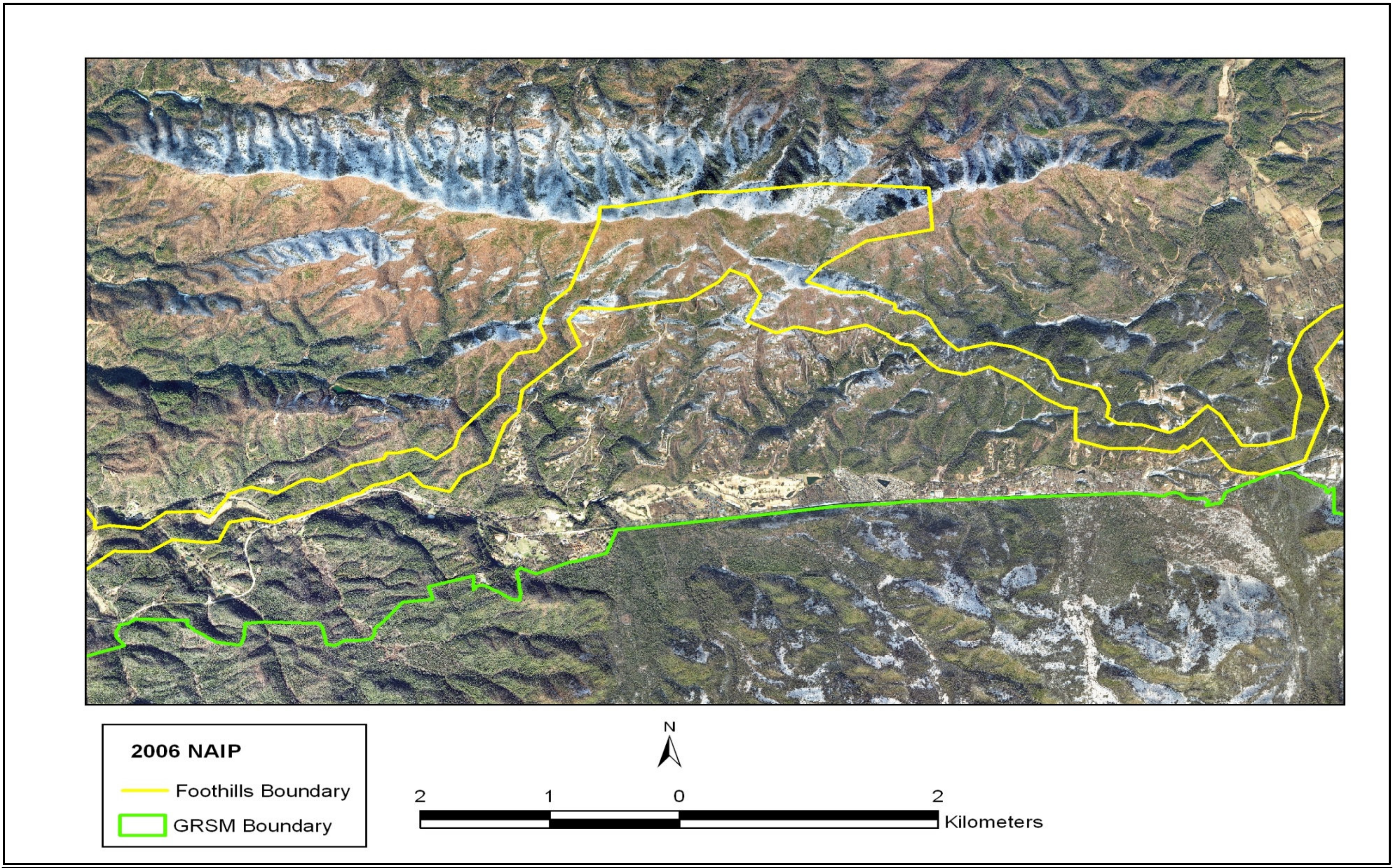


Figure 3.3- True color 2006 NAIP aerial imagery of the GRSM-Foothills Parkway study area aquired 1-meter resolution from the United States Department of Agriculture.

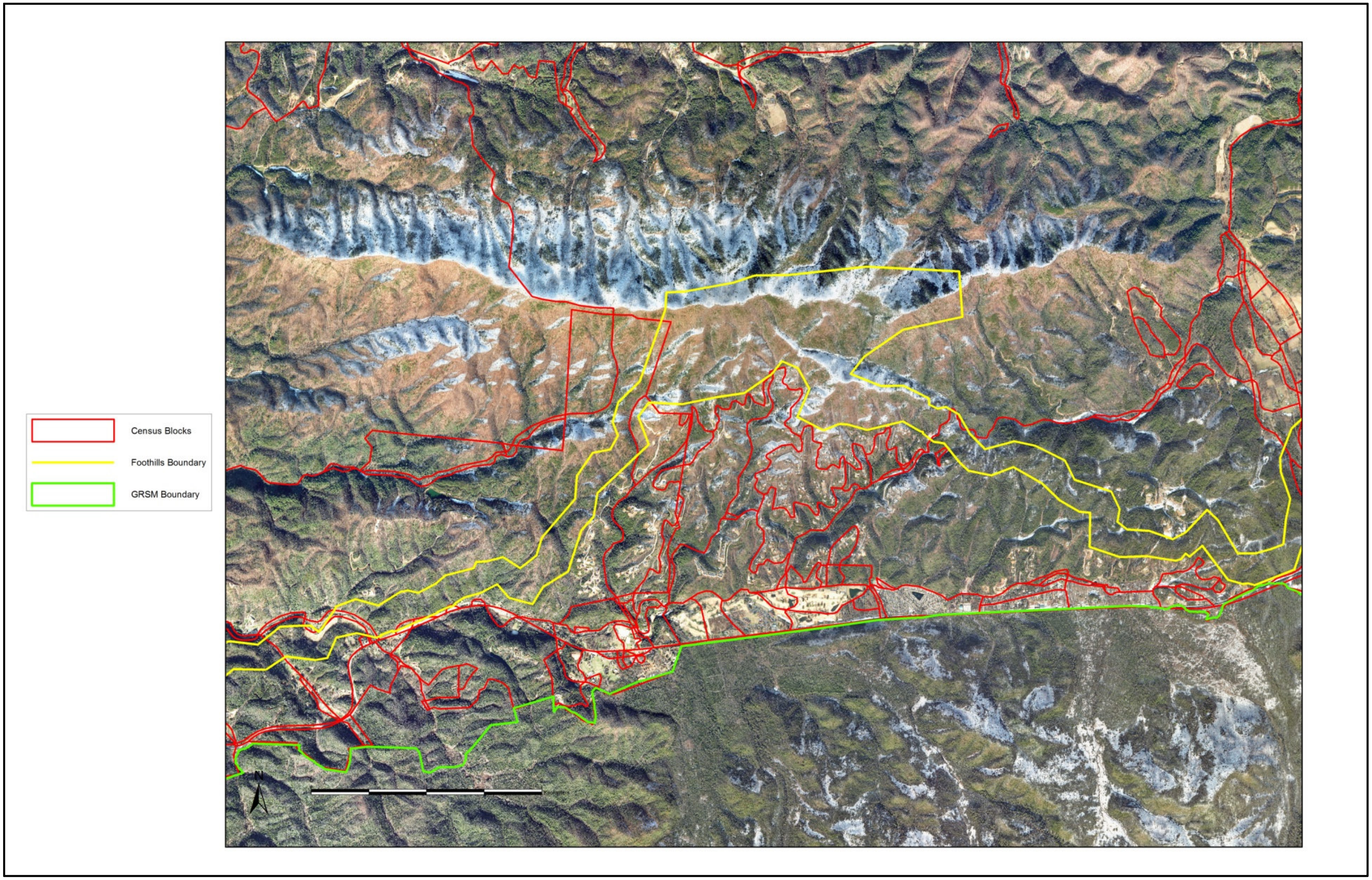


Figure 3.4- The 2000 US Census Blocks for the GRSM-Foothills Parkway study area.

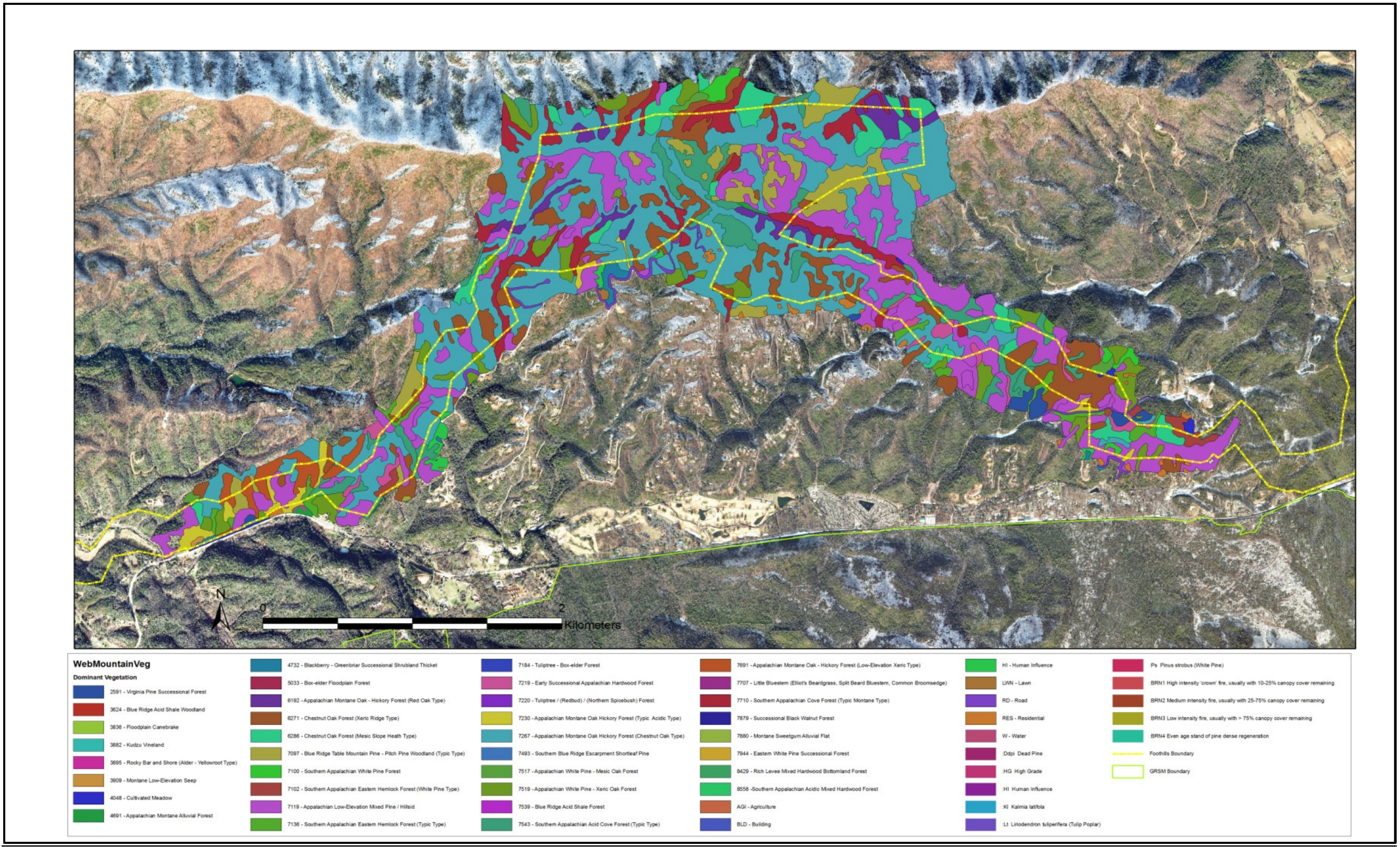


Figure 3.5- Vegetation of the NPS Foothills Parkway adjacent to the GRSM-Foothills Parkway study area mapped by the Center for Remote Sensing and Mapping Science (CRMS), Department of Geography, University of Georgia for ARCADIS, Inc. Vegetation associations follow the National Vegetation Classification System.

Georectification was conducted using ERDAS Imagine. The 1977 digital aerial images and 1997 DOQQ were loaded into Imagine and a second order polynomial geometric model was selected. Six common ground control points were located on each 1977 image and the corresponding 1997 reference image at well defined areas such as road intersections, golf course features, buildings, etc. Transformation coefficients were computed and each image was subsequently transformed and resampled using the nearest neighbor resampling procedure. The root mean square error (RMSE) for each image was +/- 1.2, 1.0 and 1.2 m.

The 1997 images used in this project were obtained from the Georgia GIS Clearinghouse (https://gis1.state.ga.us/) as a free download. Created by the USGS from 1:40,000-scale black-and-white aerial photographs from the USGS National Aerial Photography Program (NAPP), the digital orthophoto quarter quadrangle (DOQQ) images are provided at 1-meter pixel resolution and meet National Digital Aerial Standards with horizontal accuracy of +/- 3 meter. The 2006 images were obtained through the United States Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP) which acquires the images during the agricultural growing seasons in the continental US. The NAIP image was acquired with 1-meter ground sample distance (GSD) with a horizontal accuracy that matches within 5 meters of a reference ortho image. It was obtained as a compressed county mosaic (CCM). Each NAIP photo attempts to comply with the 10% cloud cover per quarter quad tile, weather conditions permitting.

Historical Land Use/Land Cover Classification and Interpretation

This section will discuss the development of an historical and current LULC database for the GRSM-Foothills Parkway study area. A customized WUI-LULC classification scheme created for the three dates, 1977, 1997, and 2006 also will be presented.

WUI LULC Classification System

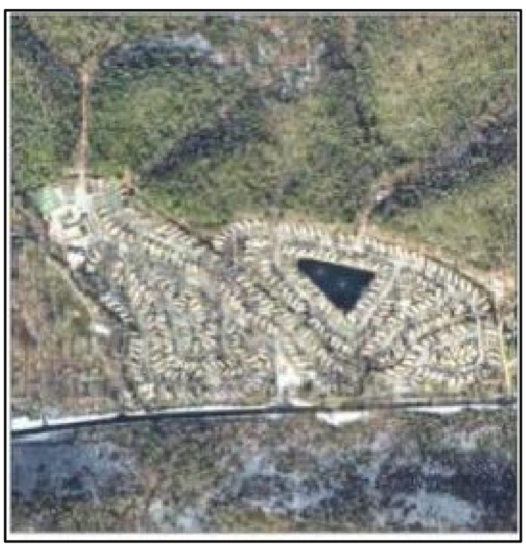
A WUI LULC classification system developed for use in assessing LULC within WUI zones was based on the "USGS R. Anderson Land Use and Land Cover Classification System for Use with Remote Sensor Data" (Anderson et al. 1976). This historical classification system was developed to create an up-to-date and standardized overview LULC that can be used by Federal and State agencies that allows uniform categorization from data obtained from satellite and aircraft remote sensors. Housing density classes were added to the Anderson system at Level IV to accommodate manually interpreted land uses that can be related to human population density and potential impacts of fire in the study area (Table 3.2, Figure 3.6). The rest of the urban land was classified as commercial, industrial, transportation, or mixed commercial/residential urban classes. Wildland vegetation was classified: mixed forest and transitional. The wildland vegetation classifications did not include urban grass and orchards since these areas are clearly not "wild".

Table 3.2- Anderson Land Use Classification

Anderson Land Use Class Number and Abbreviation			Description
1111	HDSF	High Density Single Family	Equal or greater than 3 houses per acre.
1112	MDSF	Medium Density Single Family	Equal or greater than 1 house per 5 acres and less than 3 houses per acre.
1113	LDSF	Low Density Single Family	Equal or greater than 1 house per 40 acres and less than 1 house per 5 acres.
1121	HDMF	High Density Multi-Family	Equal or greater than 3 multi-family units per acre.
117	HDMU	High Density Mixed Urban Commercial/Residential	Equal or greater than 3 mixed structures per acre.
118	MDMU	Medium Density Mixed Urban Commercial/Residential	Equal or greater than 1 commercial/residential structure per 5 acres and less than 3 mixed structures per acre.
12	CS	Commercial and Services	Structures and infrastructures predominantly used for the sale of products and services. Ex. Office buildings, shopping centers, business districts.
14	T	Transportation	Major transportation corridors, highways, airports, rail facilities.
18	REC	Recreational	Areas used for sports and entertainment. E.g., Golf courses, ski resorts, stadiums.
43	MF	Mixed Forest Land	Includes forest areas where evergreen and deciduous tree are mixed
76	TRAN	Transitional	Areas which are in transition from one land use activity to another. E.g., Mixed Forest to Residential.

a)

b)



c)

d)

Figure 3.6- Examples of housing density classes a) Low Density Single Family; b) Medium Density Single Family; c) High Density Single Family; d) High Density Multiple Family (NAIP 2006).

LULC Database Compilation

Interpretation for the three dates was performed using a heads up digitizing approach in which the image was displayed on-screen and LULC was manually interpreted and delineated in ArcMap. The image area extending from the northern boundary of GRSM to the southern boundary of the Foothills Parkway land was interpreted. The entire study area was located within the 2.4-kilometer buffer of wildland vegetation that was established by the Federal Register as the estimated distance fire brands can be carried to ignite a roof of a house (USDI and USDA 1995). Digital images of each date of 1977, 1997, and 2006, were manually interpreted in ArcGIS 9.2 and land use polygons were delineated and attributed according to the classification scheme listed in Table 3.2 (Figures 3.7-3.9).

LULC Changes

Several spatio-temporal datasets showing changes in LULC were created for each combination of individual years to produce intermediate and overall LULC change layers: 1977-1997, 1997-2006, and 1977-2006 (Figures 3.10 -3.12). This change process was completed in ArcGIS 9.2 using the Spatial Analysis tool, Union, which allows the user to calculate the combination of the two polygon layers. Polygons from each of the layers are divided at the intersection of change and saved in the change output layer. The resulting changed polygons were assigned change classes (e.g., MF-MDSF) to identify the land use in the first and second date, respectively. Color-coding the change attribute classes revealed what portions of the study area had changed and what type of change had occurred. Oranges and reds were selected to highlight areas where Mixed Forest was lost and housing infrastructure had developed. Polygons shaded cream experienced no change during that particular time period.

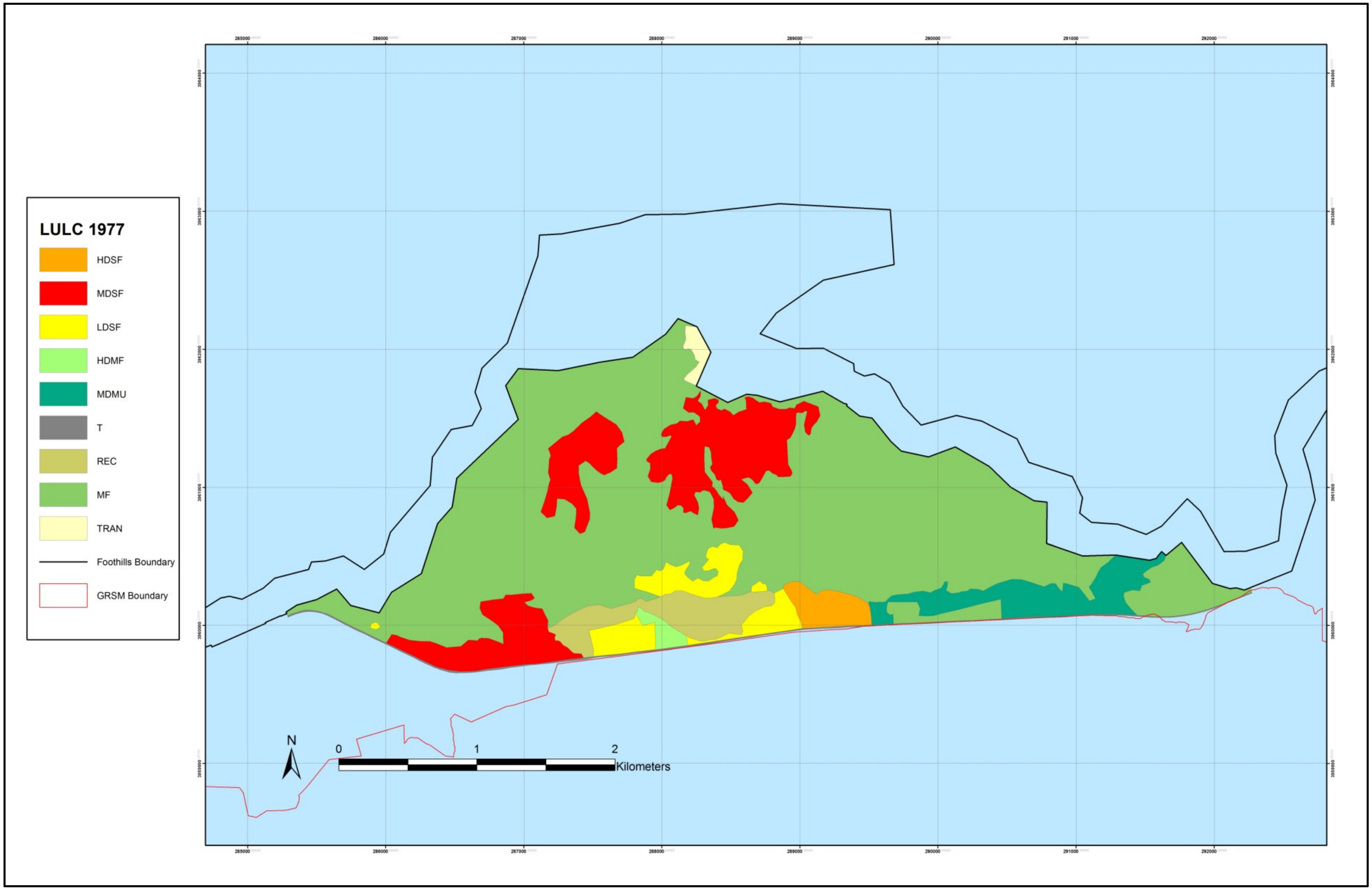


Figure 3.7- Land use classifications for GRSM-Foothills Parkway study area for the 1977 time period.

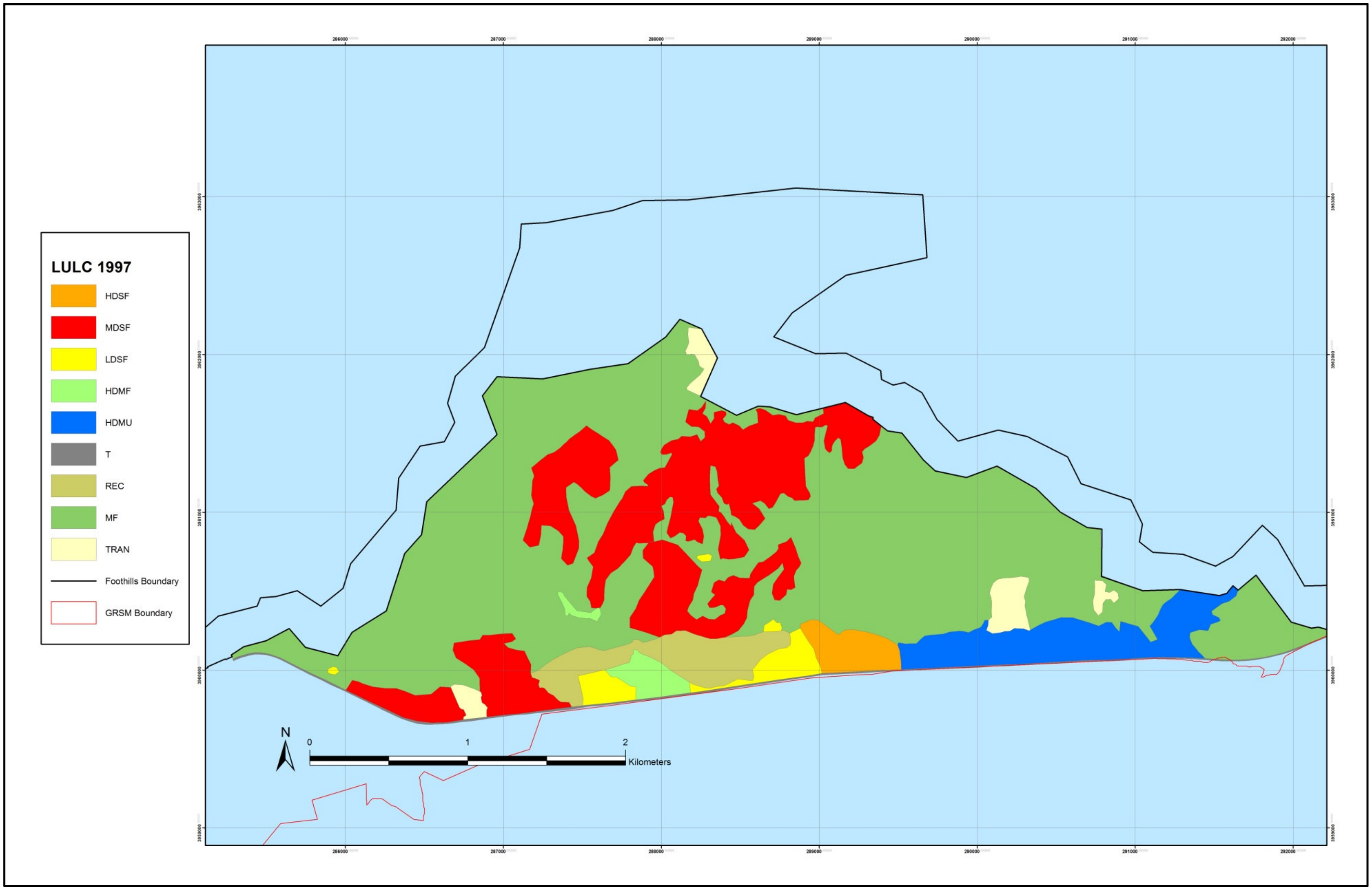


Figure 3.8- Land use classifications for GRSM-Foothills Parkway study area for the 1997 time period.

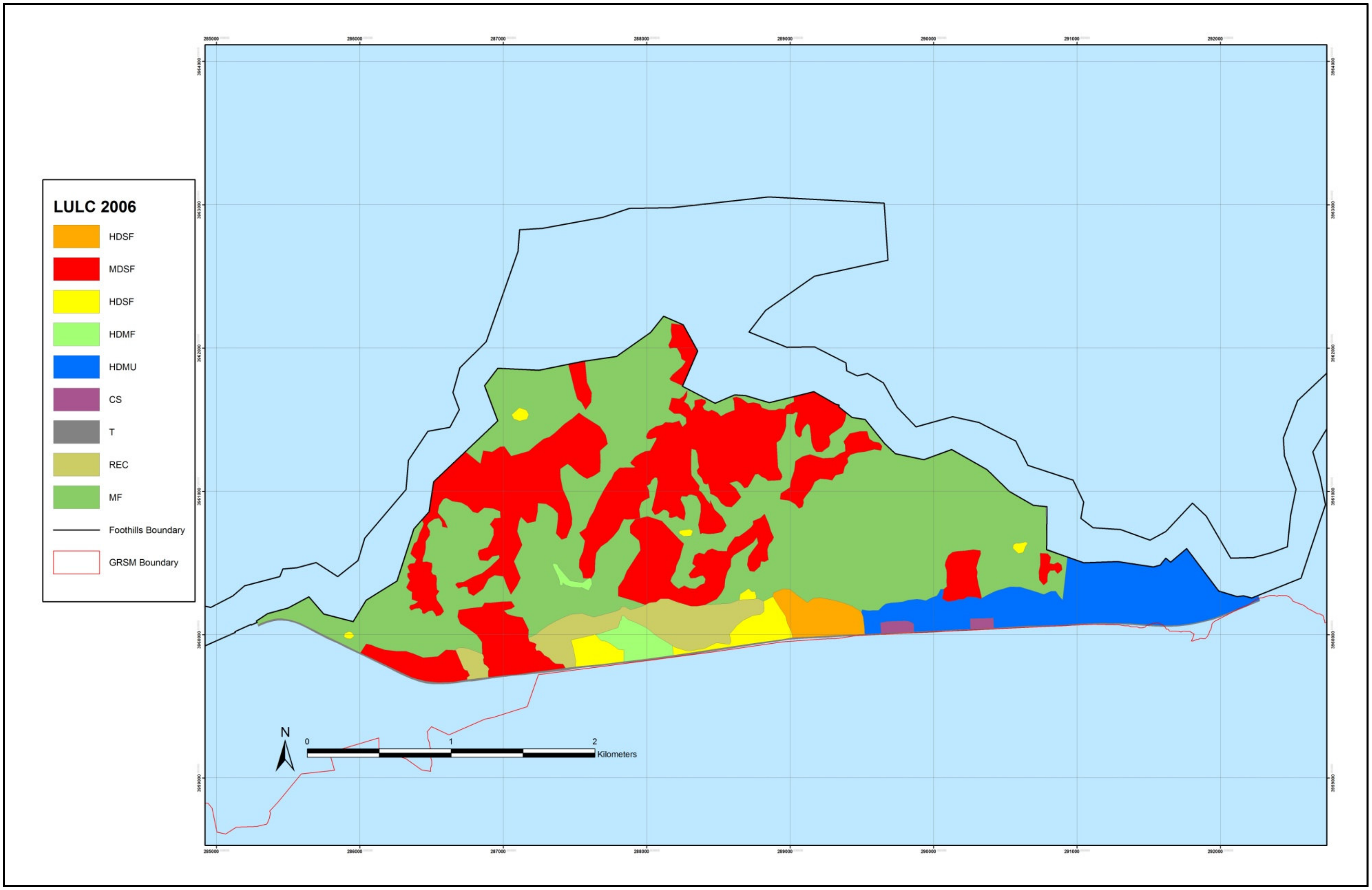


Figure 3.9- Land use classifications for GRSM-Foothills Parkway study area for the 2006 time period.

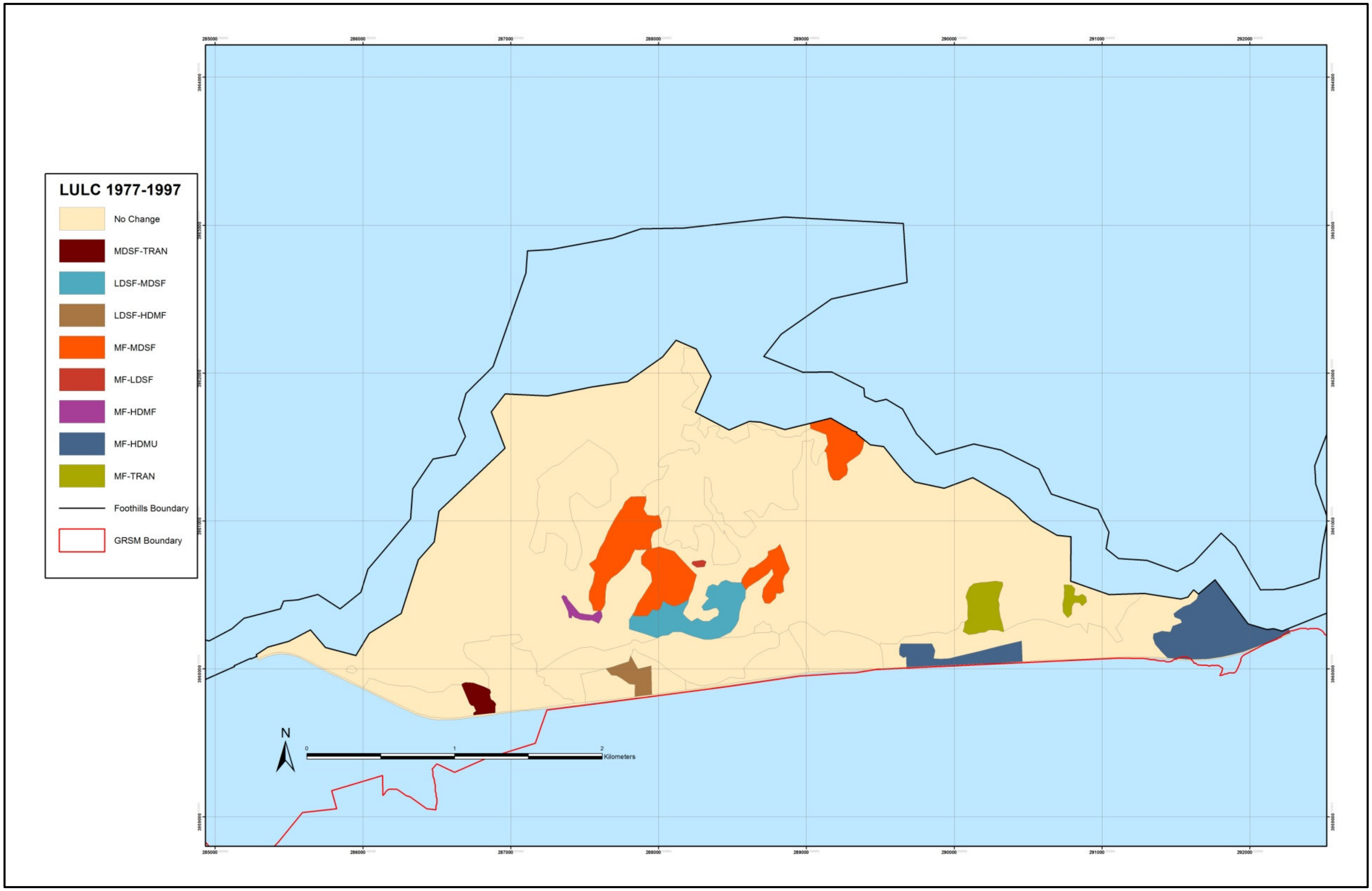


Figure 3.10- Location and type of LULC change experienced in the GRSM-Foothills Parkway study area between 1977-1997.

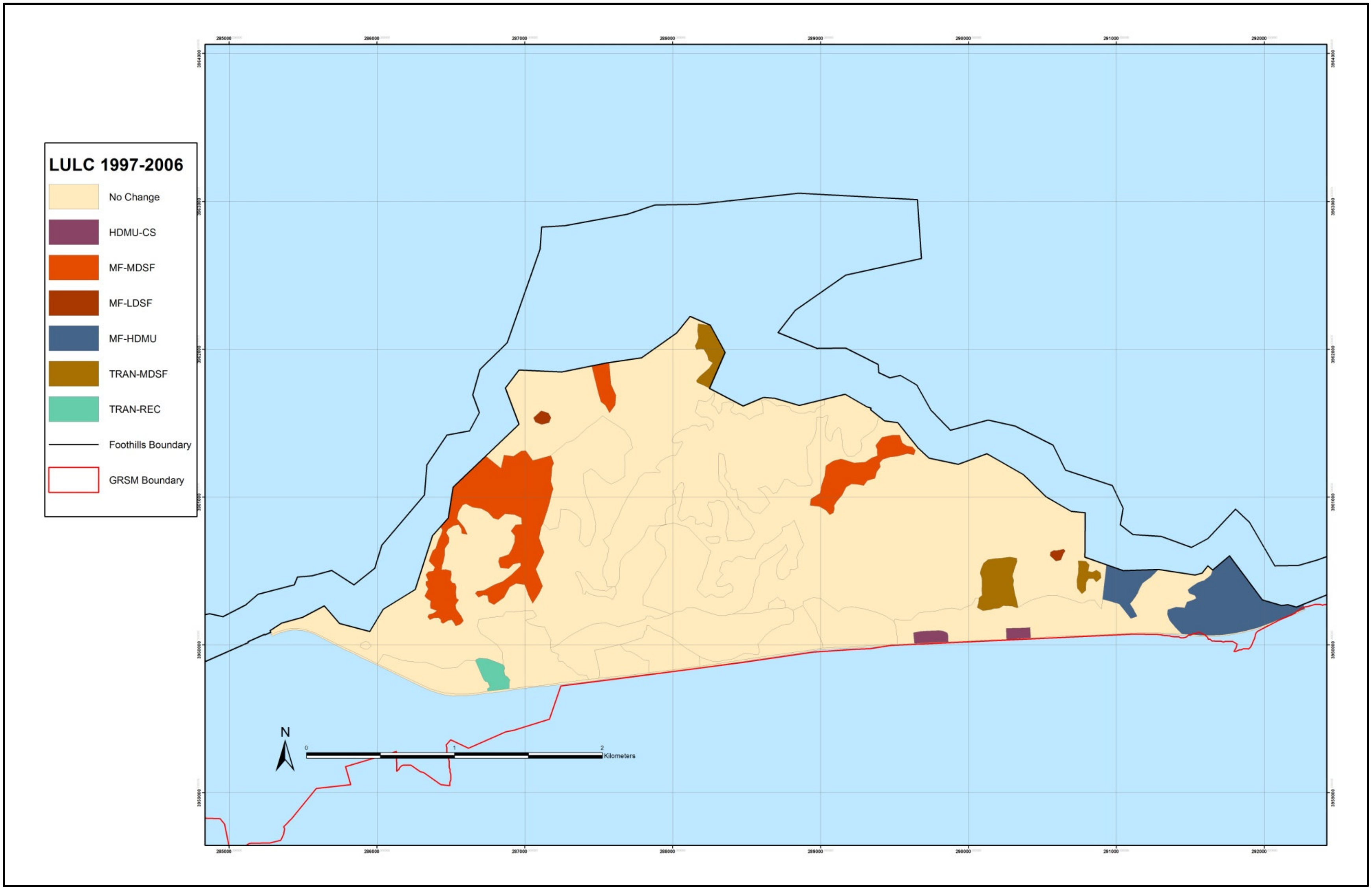


Figure 3.11- Location and type of LULC change experienced in the GRSM-Foothills Parkway study area between 1997-2006.

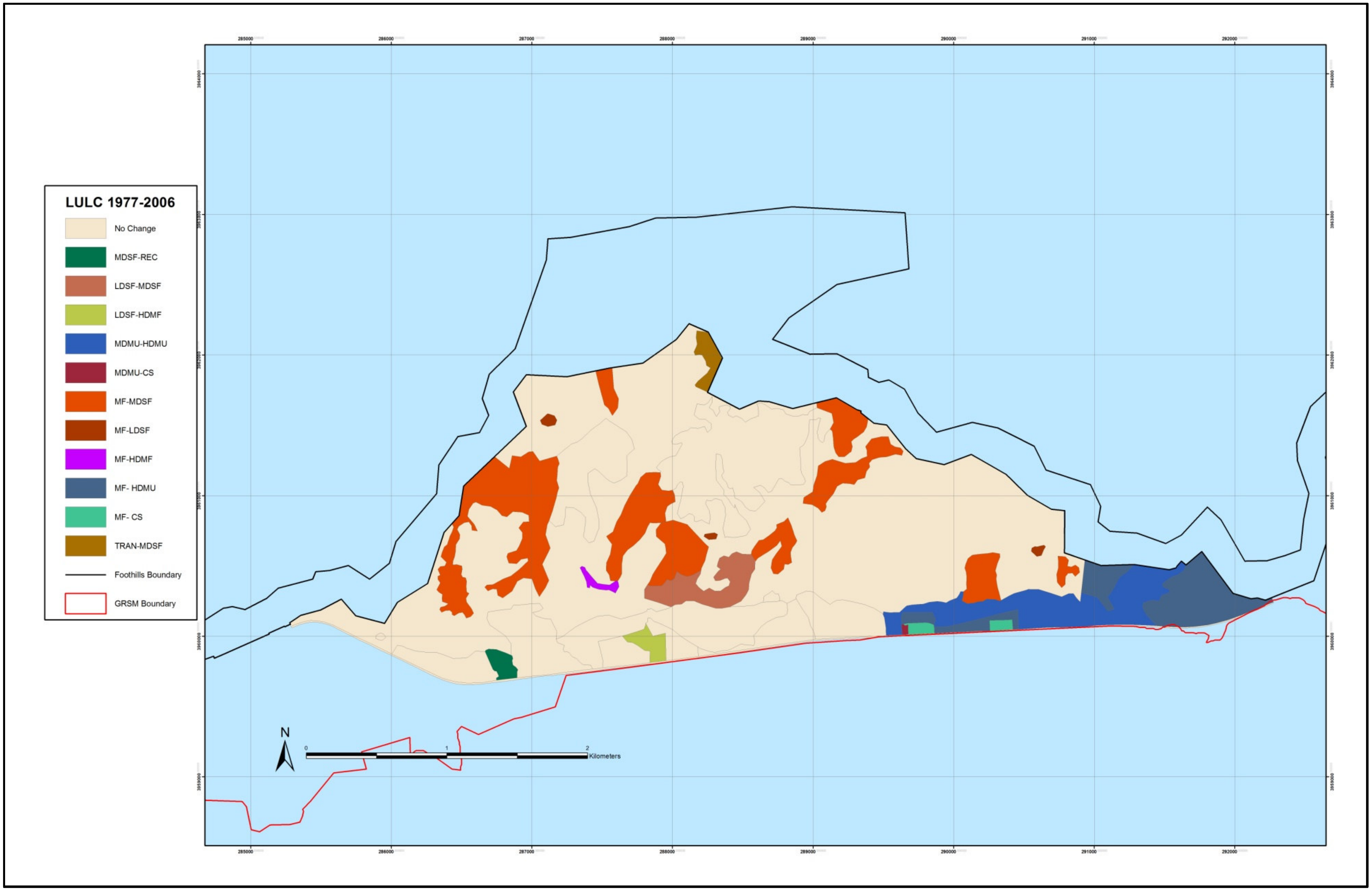


Figure 3.12- Location and type of overall LULC change experienced in the GRSM-Foothills Parkway study area between 1977-2006.

Wildland-Urban Interface

The Federal Register defines the WUI as an area that contains at least 6.17 housing units/km² (1 house/40 acres) that are located within 2.4 km of a wild area and at least 5 km² in size (USDA and USDI 1995). For the purposes of this investigation, the entire area is considered to be within the defined WUI area since it falls within the 2.4 km buffer distance of an area that is heavily vegetated and is larger than 5 km². Housing density was evaluated on a US Census block level to determine WUI type. Interface WUI areas are defined as having a minimum of 1 housing unit per Census Block and less than 50 percent of the Block covered by vegetation, not including the area covered by water. The intermix WUI has a minimum of 1 housing unit per Census Block with greater than 50 percent of the area being covered with wildland vegetation. There were no island WUI areas in the study area.

The information provided by the US 2000 Census also allowed the opportunity to map the different types of housing density present in the area. Total housing units, owner occupied, renter occupied and vacant are all important in visualizing areas of higher WUI risk based on permanent and temporary occupancy (Figures 3.13-3.14).

a)

b)

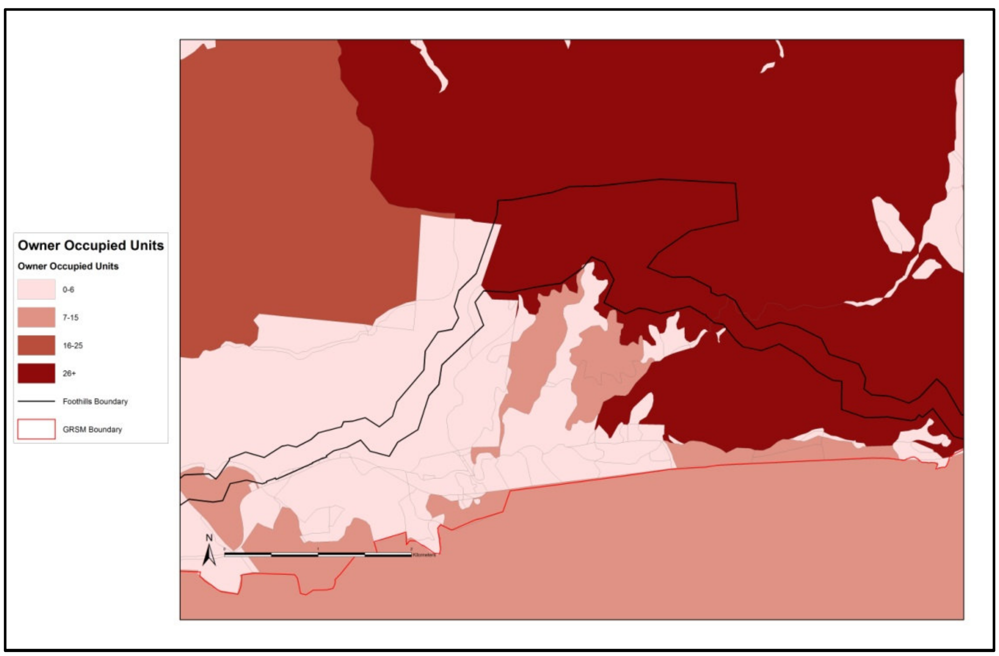
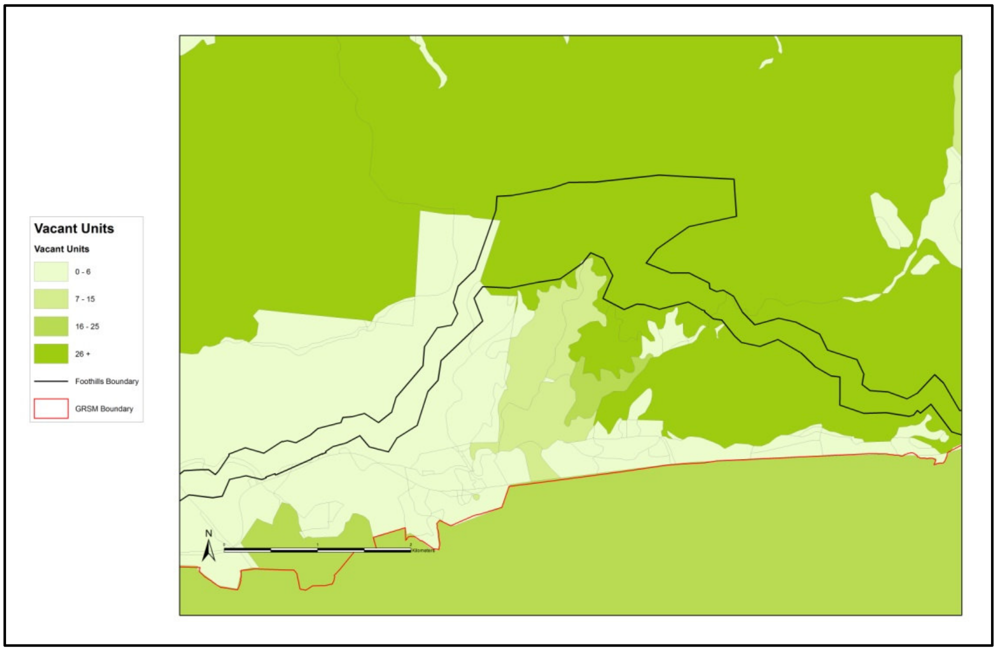


Figure 3.13- Distribution of a) total housing units and b) owner occupied units in GRSM-Foothills Parkway study area using US 2000 Census information.

a)



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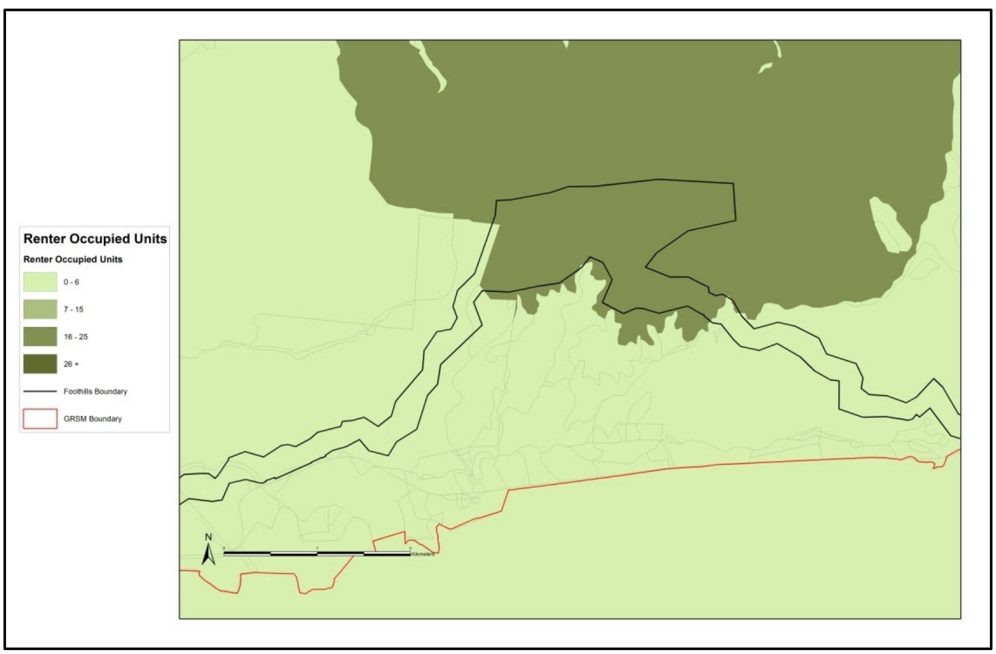


Figure 3.14- Distribution of a) vacant units and b) renter occupied units in GRSM-Foothills Parkway study area using 2000 US Census information.

The population estimation within the GRSM-Foothills Parkway study area was carried out in the same manner using population totals from the US 2000 Census (Figure 3.15). Since it can be assumed if there is a human presence in a Census Block there will also be a corresponding housing unit count, this will be the minimum requirement for the WUI definition. Interface areas are defined as Census Blocks containing a minimum of 1 person and less than 50 percent wildland vegetation. The intermix is represented by a minimum of 1 person per Census Block and greater than 50 percent vegetation.

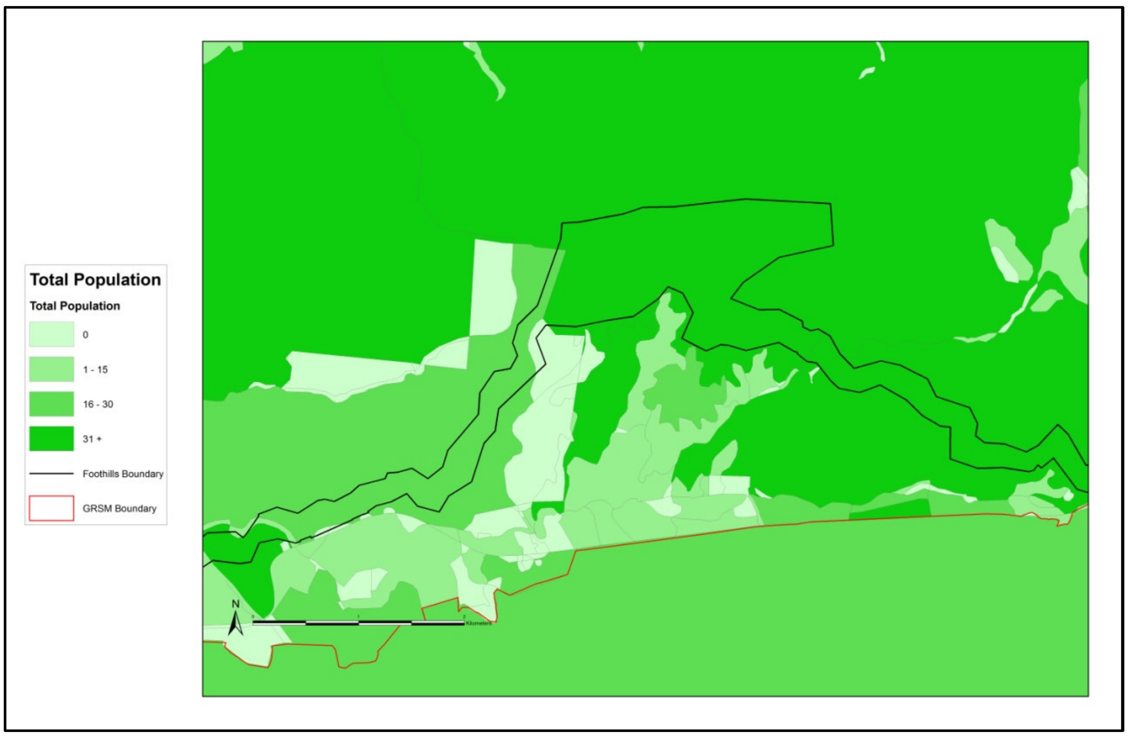


Figure 3.15- Distribution of total population in GRSM-Foothills Parkway study area using 2000 US Census information.

Table Mountain Pine and Risk Assessment

Current relationships between WUI human activities and the natural environment, specifically the fire dependent Table Mountain pine (TMP) community, were examined. The current vegetation conditions within the Foothills Parkway were mapped by CRMS with funding by ARCADIS Inc. An internal accuracy assessment indicated the identification of TMP was at least 80 percent accurate. The locations of the TMP stands were selected from the GRSM NPS vegetation database of the Foothills Parkway. This provided current distribution information for the fire dependent species, TMP (Figure 3.16). Areas of concern were determined based on where the existence of this community intersected with the GRSM-Foothills Parkway WUI.

Risk and Buffers

The TMP polygons were buffered in a multiple ring buffer analysis using ArcGIS 9.2. They were buffered in concentric zones at 500, 1000, 2000, and 2400 meters to denote risk at the different distances (Table 3.3). The maximum distance of 2400 meters was chosen because this was the estimated distance a fire brand could travel to a roof of a house. Once the buffers were placed around the TMP stands, the relative risk to housing units and population could be addressed.

Table 3.3- Relative risk of WUI areas to wildfire.

Risk	**Distance to TMP stands**
Very High Risk	≤ 500 m
High Risk	>500 - ≤ 1000 m
Medium Risk	>1000 - ≤ 2000 m
Low Risk	>2000 - ≤ 2400 m
Very Low Risk	> 2400 m

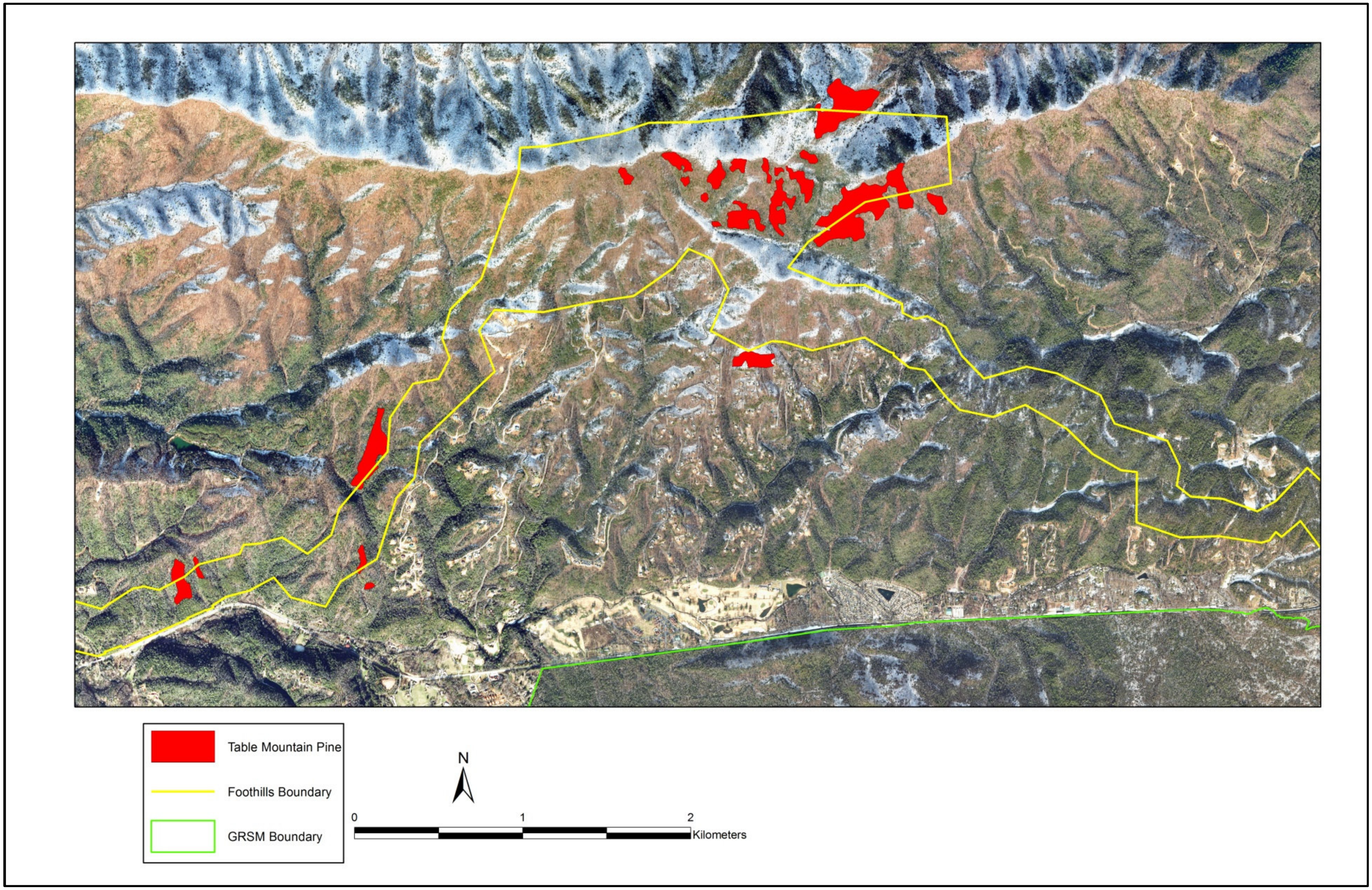


Figure 3.16- Location of Table Mountain pine stands in Foothills Parkway boundary.

CHAPTER 4

RESULTS AND DISCUSSION

The results of this thesis include: 1) LULC data sets for the GRSM-Foothills Parkway study area for three dates (1977, 1997 and 2006); 2) land use change data sets for 1977 to 1997, 1997 to 2006 and 1977 to 2006; and 3) local scale analysis of the population at risk relative to trends in LULC within the WUI surrounding the GRSM. A number of maps, graphs, and charts have been created from these data and will be evaluated in this chapter. It is anticipated that the LULC maps can be used by land planners for steering development decisions. The WUI information can guide land managers, as well as rescue workers, to critical areas of need if a wildland fire were to occur in the area.

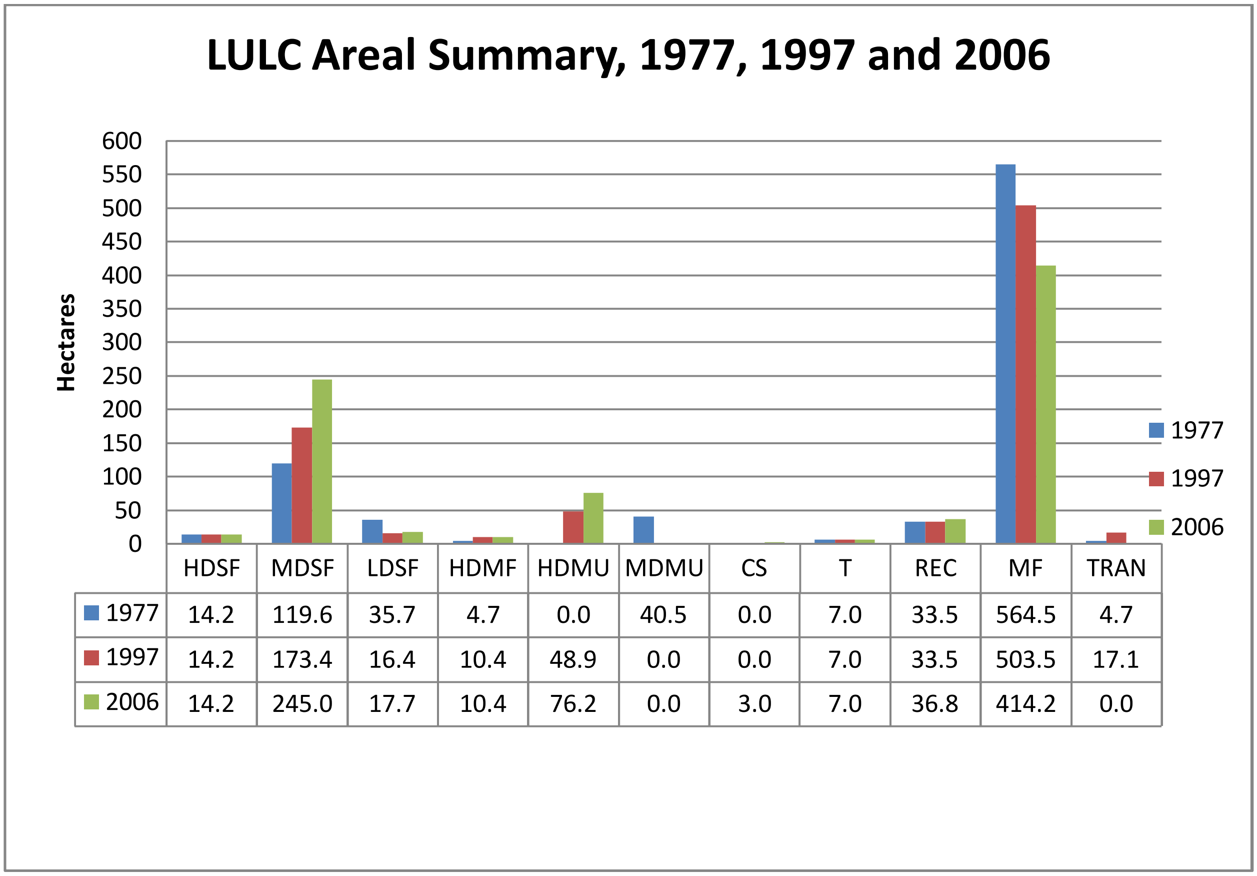
Historical LULC Summary Statistics, Maps and Analysis

Summary statistics for the area of each LULC class for the three years of investigation are presented in Table 4.1. The total area for the study area is 824 ha (2036.5 ac). Figure 4.4 depicts the total number of hectares for each of the LULC categories and each of the three study dates. Although Mixed Forest remained the category with the largest areal coverage throughout all three dates, this class experienced greatest amount of decline between 1977 and 2006. Over 18 percent (151.1 ha) of the area classified as mixed forest was lost in the 29-year period. Several of the land use classes remained the same through all three dates, including Transportation (T) and High Density Single Family (HDSF). Other classes were present in one or two dates, but did not remain through all three. Included in this observation was Transition (TRAN) present in only 1977 and 1997, Medium Density Mixed Urban/Commercial (MDMU)

Table 4.1- Area summary (in hectares) for land use 1977-2006

LULC Class		Polygon Total	1977 Area (ha)	1977 Percent Area	Polygon Total	1997 Area (ha)	1997 Percent Area	Polygon Total	2006 Area (ha)	2006 Percent Area
1111	HDSF	1	14.21	1.7	1	14.2	1.7	1	14.2	1.7
1112	MDSF	3	119.64	14.5	5	173.4	21.0	10	245.0	29.7
1113	LDSF	5	35.75	4.3	5	16.4	2.0	7	17.7	2.1
1121	HDMF	1	4.70	0.6	2	10.4	1.3	2	10.4	1.3
117	HDMU	0	0.00	0.0	1	48.9	5.9	1	76.2	9.2
118	MDMU	1	40.45	4.9	0	0.0	0.0	0	0.0	0.0
12	CS	0	0.00	0.0	0	0.0	0.0	2	3.0	0.4
14	T	1	7.04	0.9	1	7.1	0.9	1	7.1	0.9
18	REC	1	33.52	4.1	1	33.5	4.1	2	36.8	4.5
43	MF	3	564.45	68.5	2	503.5	61.1	1	414.2	50.2
76	TRAN	1	4.66	0.6	4	17.1	2.1	0	0.0	0.0

only in 1977, High Density Mixed Urban/Commercial (HDMU) in 1997 and 2006, and Commercial and Services (CS) which appeared in 2006 alone.



	HDSF	MDSF	LDSF	HDMF	HDMU	MDMU	CS	T	REC	MF	TRAN
1977	14.2	119.6	35.7	4.7	0.0	40.5	0.0	7.0	33.5	564.5	4.7
1997	14.2	173.4	16.4	10.4	48.9	0.0	0.0	7.0	33.5	503.5	17.1
2006	14.2	245.0	17.7	10.4	76.2	0.0	3.0	7.0	36.8	414.2	0.0

Figure 4.1- Histogram of land use for 1977-2006 (in hectares)

The most profound change in LULC between 1977and 2006 was the gain in Medium Density Single Family (MDSF) and loss of Mixed Forest (MF). A total of 150 ha (371 ac) or 18 percent of forest land was lost. In contrast, Medium Density Single Family gained 125 ha (310 ac) and accounted for 15 percent of the land use in 2006. Further research and data from the US Census can be used to provide more insight into the rate of housing development and urban growth on a decadal basis. Past housing growth rates and trends are often times good foundations for forecasting future development (Hammer et al. 2004).

LULC Change Maps

Combining the different LULC datasets from each of the years using GIS overlay analysis allowed visualization of the different changes, examination the combination of changes that took place, and quantification the increases and decreases in LULC classes throughout the study area and over the three date study period. Historic LULC change maps were created for each of the transition dates: 1977 to 1997, 1997 to 2006, and 1977 to 2006 (Figures 4.2-4, Tables 4.2-4.4). These maps highlight the areas that are most susceptible to change and indicate what types of change have occurred over the 29-year period.

In the 20 years between1977-1997 the study area had a combined LULC change of 107.7 ha (266 ac). The majority of change was in the Mixed Forest (MF) loss category. Of the total 107.7 ha of LULC change during this time period, Mixed Forest made up 78 percent (84.8 ha) of the total loss with Medium Density Single Family (56.7 ha) and High Density Mixed Urban (32.2 ha) gaining the most area.

Although the next study period, 1997-2006, was considerably shorter and covered a time span of 9 years, the study area experienced more change than during the first observation period. In the 9 years between the two dates, 110.2 ha (272.2 ac) experienced LULC change. This suggests that the rate of change and development became more rapid in the late 1990's and on into the early 2000's. Mixed Forest saw a decline in total area, losing 90.2 ha (222.8 ac). Of the total Mixed Forest loss, the majority was lost to Medium Density Single Family (58.5 ha) and High Density Mixed Urban (30.4 ha). Commercial and Services (CS) had an area gain of 3 ha between the years 1997-2006, which could also suggest new businesses, shopping and increased development for the area.

The most dramatic change in LULC occurred over the entire study period from 1977 to 2006. The land use with the most consistent category of loss was Mixed Forest. In each of the intermediate change periods and in the overall change period, this group made up the majority of land lost. Mixed Forest classifications totaled almost 567 ha (1400 ac) (68.5 percent of study area) in 1977 (Table 4.2). Yet, by 2006 it had been reduced to only 414 ha (1023 ac) and represented only 50 percent of the total area. In conjunction with the forest lost, the area covered by Medium Density Single Family (MDSF) saw the largest gain. It accrued 125 ha (310 ac) over the 29-year time period. In 1977, it accounted for 119 ha (295 ac) or14.5 percent of the study area and by 2007 it had doubled in size to 245 ha (605 ac) or 30 percent of the study area.

Another notable trend was in the Transition (TRAN) land category. It 1977 it only accounted for approximately 4.5 ha (11 ac) of land, in 1997 that amount had increased to 17 ha (42 ac), and by 2006 those areas in transition had been converted to various land uses throughout the study area.

The majority of LULC change occurred in the center of the study area and along the main road that runs along the park border. These areas are becoming more built up with people living in more dense housing and new people continuing to build new homes in formerly forested areas. These types of land conversion show trends of losing natural areas and gaining human influenced areas. Figures 4.2-4.4 further reveal what types of changes the area is experiencing and where the change is occurring.

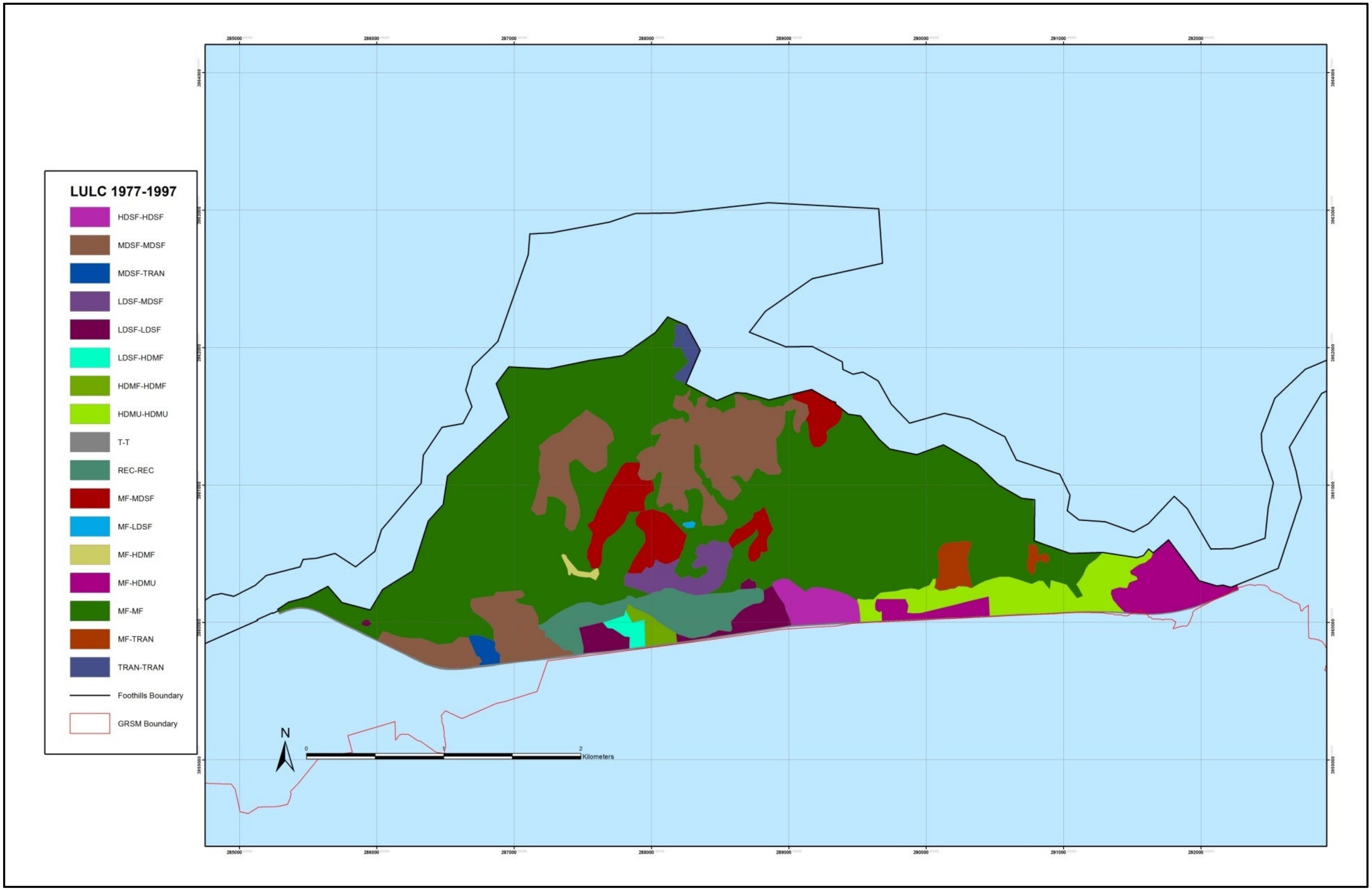


Figure 4.2- LULC change from 1977-1997

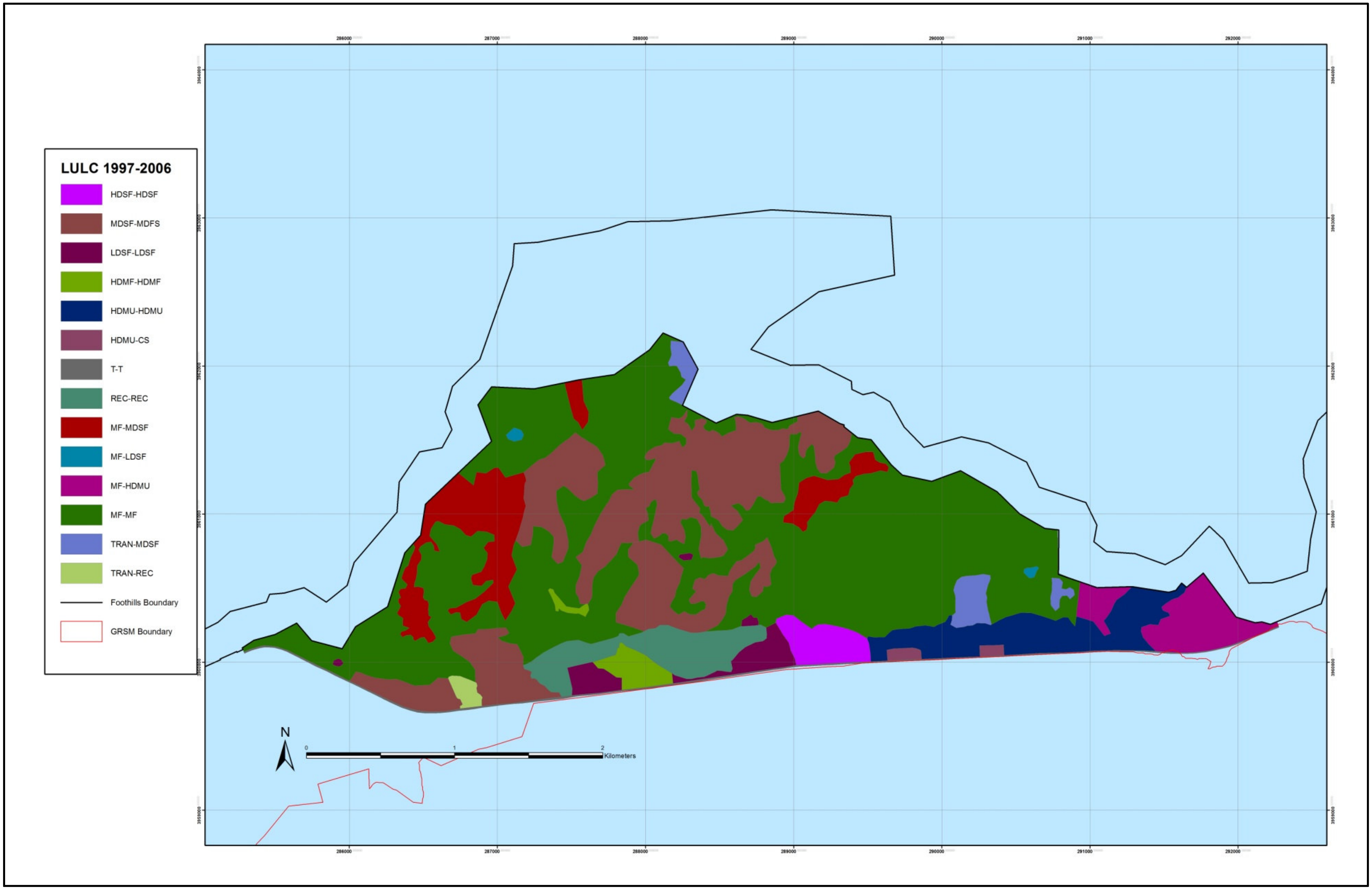


Figure 4.3- LULC change from 1997-2006

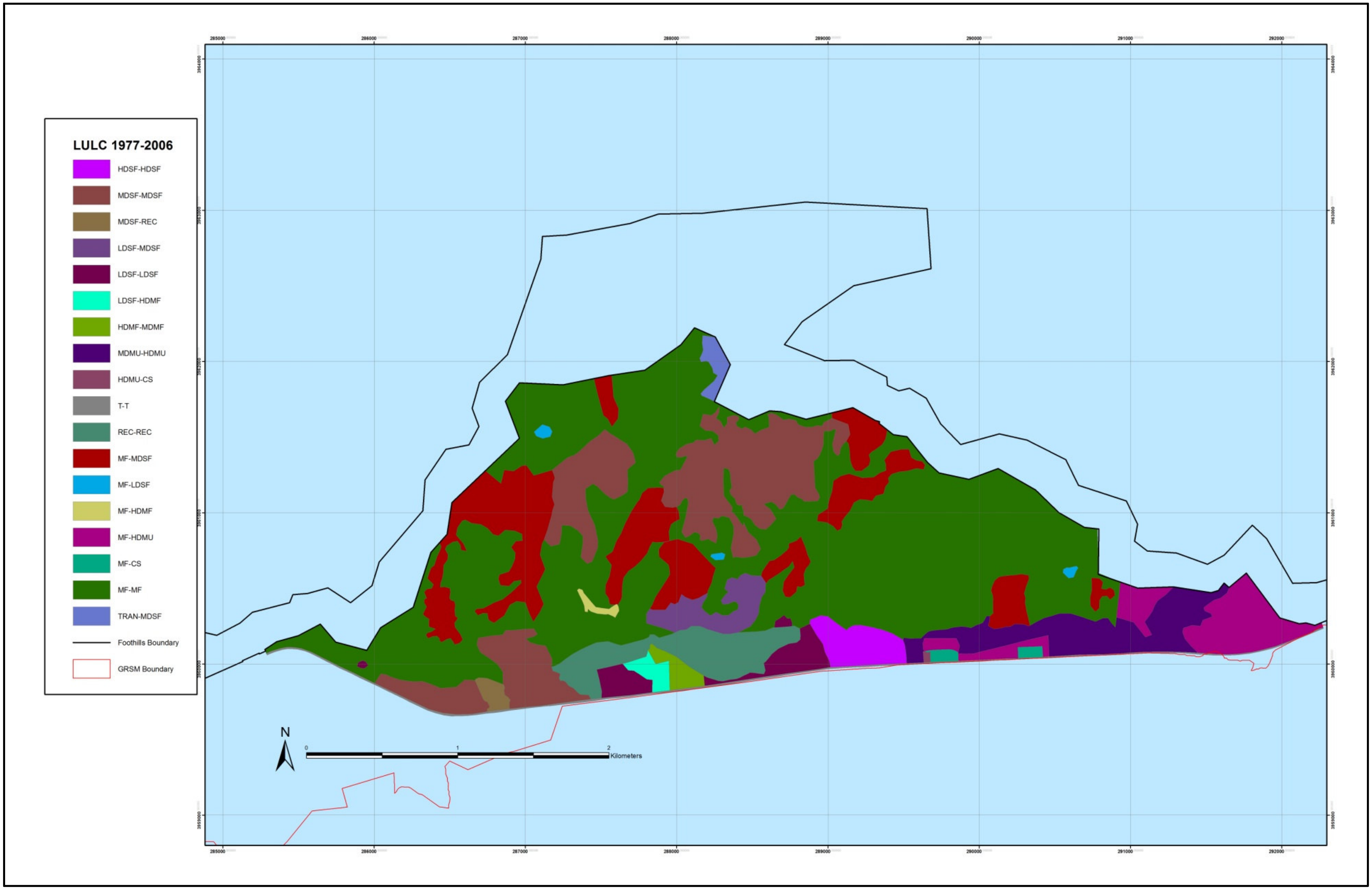


Figure 4.4- LULC change from 1977-2006

Table 4.2- Land use change matrix 1977-1997 (in hectares)

		1997											
	LU-Code	**HDSF**	**MDSF**	**LDSF**	**HDMF**	**HDMU**	**MDMU**	**CS**	**T**	**REC**	**MF**	**TRAN**	**Area Loss**
1977	**HDSF**												
	MDSF											3.2	3.2
	LDSF		15.6		4.1								19.7
	HDMF												
	HDMU												
	MDMU												
	CS												
	T												
	REC												
	MF		41.1	0.4	1.6	32.2						9.5	84.8
	TRAN												
	Area Gain		56.7	0.4	5.7	32.2						12.7	**107.7**

Table 4.3- Land use change matrix 1997-2006 (in hectares)

		2006											
	LU-Code	**HDSF**	**MDSF**	**LDSF**	**HDMF**	**HDMU**	**MDMU**	**CS**	**T**	**REC**	**MF**	**TRAN**	**Area Loss**
1997	**HDSF**												
	MDSF												
	LDSF												
	HDMF												
	HDMU							3.0					3.0
	MDMU												
	CS												
	T												
	REC												
	MF		58.5	1.3		30.4							90.2
	TRAN		13.8							3.2			17.0
	Area Gain		72.3	1.3		30.4		3.0		3.2			**110.2**

Table 4.4- Land use change matrix 1977-2006 (in hectares)

		2006											
	LU-Code	**HDSF**	**MDSF**	**LDSF**	**HDMF**	**HDMU**	**MDMU**	**CS**	**T**	**REC**	**MF**	**TRAN**	**Area Loss**
1977	**HDSF**												
	MDSF									3.2			3.2
	LDSF		15.6		4.1								19.7
	HDMF												
	HDMU												0
	MDMU					40.2		0.3					
	CS												
	T												
	REC												
	MF		109.1	1.6	1.6	36.1		2.6					151
	TRAN		4.4										4.4
	Area Gain		129.1	1.6	5.7	76.3		2.9		3.2			**178.3**

Population Relative to the WUI

The WUI type was identified by two methods using data from the 2000 US Census: 1) by density of housing units; and 2) by population density. The WUI were further classified as either interface or intermix depending on density criteria described in Chapter 3.

Across the study area, the WUI covers a majority of the US Census blocks. The total housing WUI, defined by any Census block having a minimum of one housing unit, covered approximately 17,480 ha (43,193 ac). This number is substantially larger than the true size of the study area because the study area includes several Census blocks that extend beyond the defined boundary of the study (Figure 4.5). Thus, the total size of the WUI area is not reflective of the true defined study area.

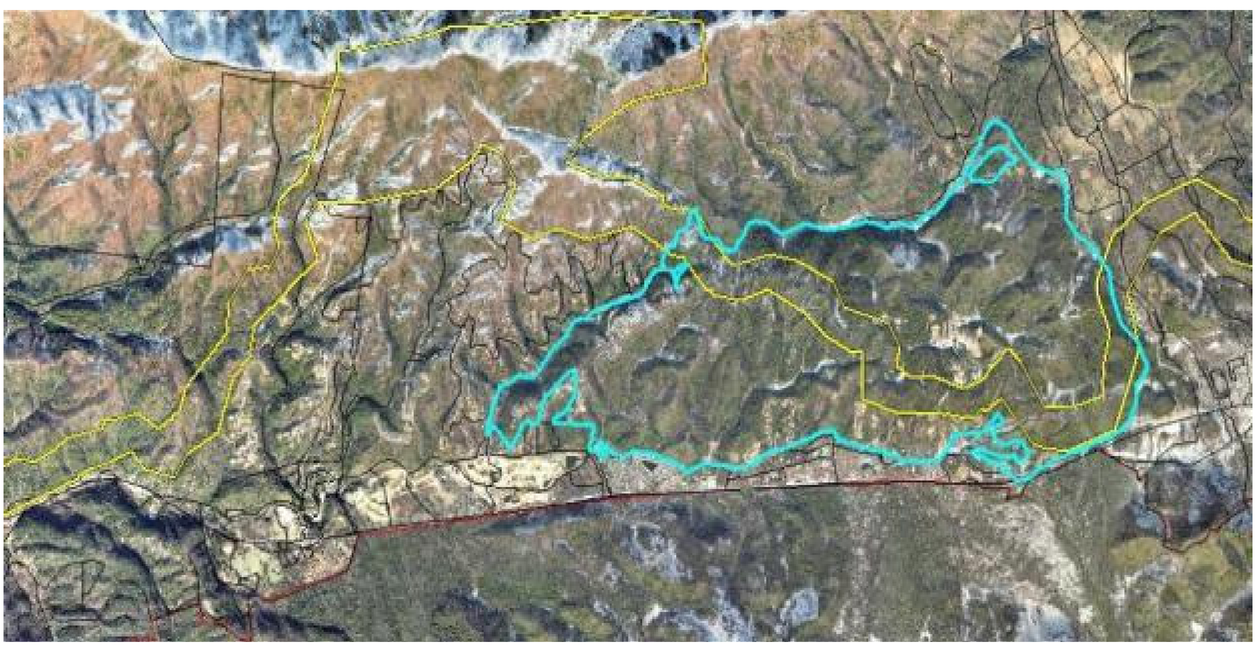


Figure 4.5- Example of a Census block extending beyond boundary of defined study area.

Regarding the WUI area defined by housing information (i.e., housing WUI), the area of interface WUI accounted for 201 ha (496 ac) or 1.1 percent of the WUI area and 24 percent of the total study area (Table 4.5 and Figure 4.6). This WUI class included 167 housing units and 287 people. It is interesting to note that approximately 43 percent of the housing units in WUI interface area were either vacant or occupied by renters in 2000. The WUI intermix contained the majority of the land, 17,286 ha (42,697 ac), and contained 597 housing units and 662 people. Within this WUI category, 56 percent of the housing units were either vacant or renter occupied

Nearly all of the Census blocks defined as interface were located along the major transportation route East Highway TN-73, which follows the borders along the GRSM boundary (Figure 4.7). The intermix areas were dispersed throughout the rest of the study area and continued into the adjacent land. This is particularly interesting because of the high topography, remoteness and access in case of fire. There is a dramatic increase of risk.

The total area for land classified as non WUI in the housing study was 142 ha (351 ac) and contained 41 polygons. This translated into 17 percent of the study area, leaving the rest, 83 percent, to be classified as WUI. Most of non-WUI was located in the western section of the study area and to some extent along the park border.

Table 4.5- Housing WUI totals for interface, intermix and total WUI.

Housing WUI							
	Hectares	**Acres**	**Population**	**Total Housing Units**	**Vacant**	**Owner Occupied**	**Renter Occupied**
Interface Total	201	496	287	167	48	95	24
Intermix Total	17286	42697	662	597	313	228	56
WUI Total	17487	43193	949	764	361	323	80

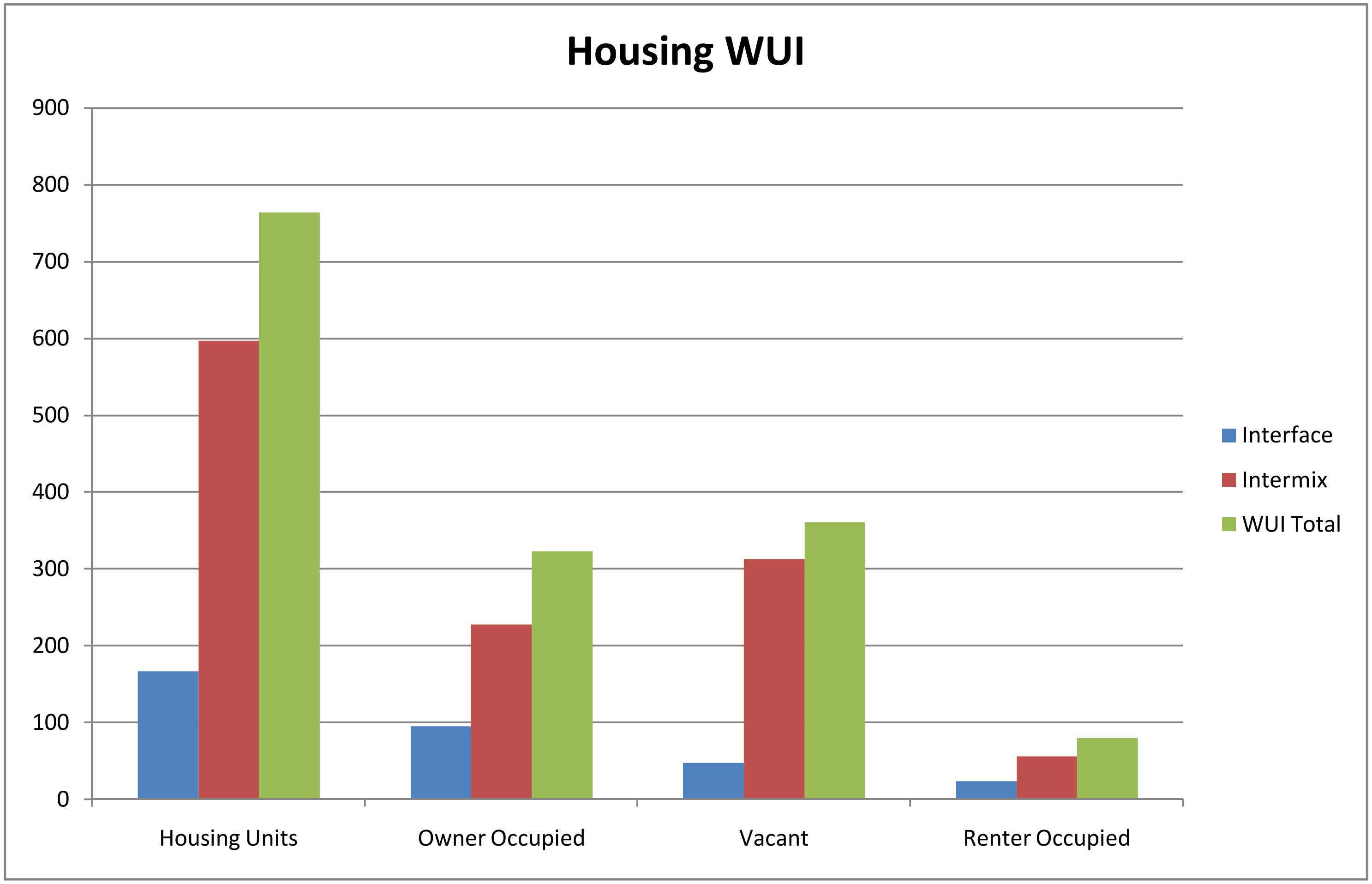


Figure 4.6- Histogram of total number of housing units found in each of the housing WUI classifications.

Figure 4.7- Housing WUI classification in GRSM-Foothills Parkway study area using 2000 US Census data.

Population WUI yielded similar numbers for interface and intermix (Table 4.6 and Figure 4.8). Total area for population WUI was 17,417 ha (43,021 ac), roughly 68 ha (170 ac) less than for Housing WUI. Land classified as interface in the Population WUI represented 174 ha (429.8 ac) or .99 percent of WUI area and 21 percent of total study area. The interface consisted of 164 housing units and 285 people. Intermix blocks of the Population WUI retained the majority of the housing units with 578 total and 661 people. Vacant and renter occupied made up 43 percent and 53 percent, respectively of interface and intermix WUI. Land not affected by WUI totaled 180 ha in 46 polygons. Non-WUI made up 22 percent of the total area, therefore, WUI area accounted for 78 percent of the total study area. Figure 4.9 depicts population WUI in the GRSM-Foothills Parkway study area.

Table 4.6- Population WUI totals for interface, intermix and total WUI.

Population WUI							
	Hectares	**Acres**	**Population**	**Total Housing Units**	**Vacant**	**Owner Occupied**	**Renter Occupied**
Interface Total	174	430	285	164	47	93	24
Intermix Total	17243	42590	661	578	295	228	55
WUI Total	17417	43021	946	742	342	321	79

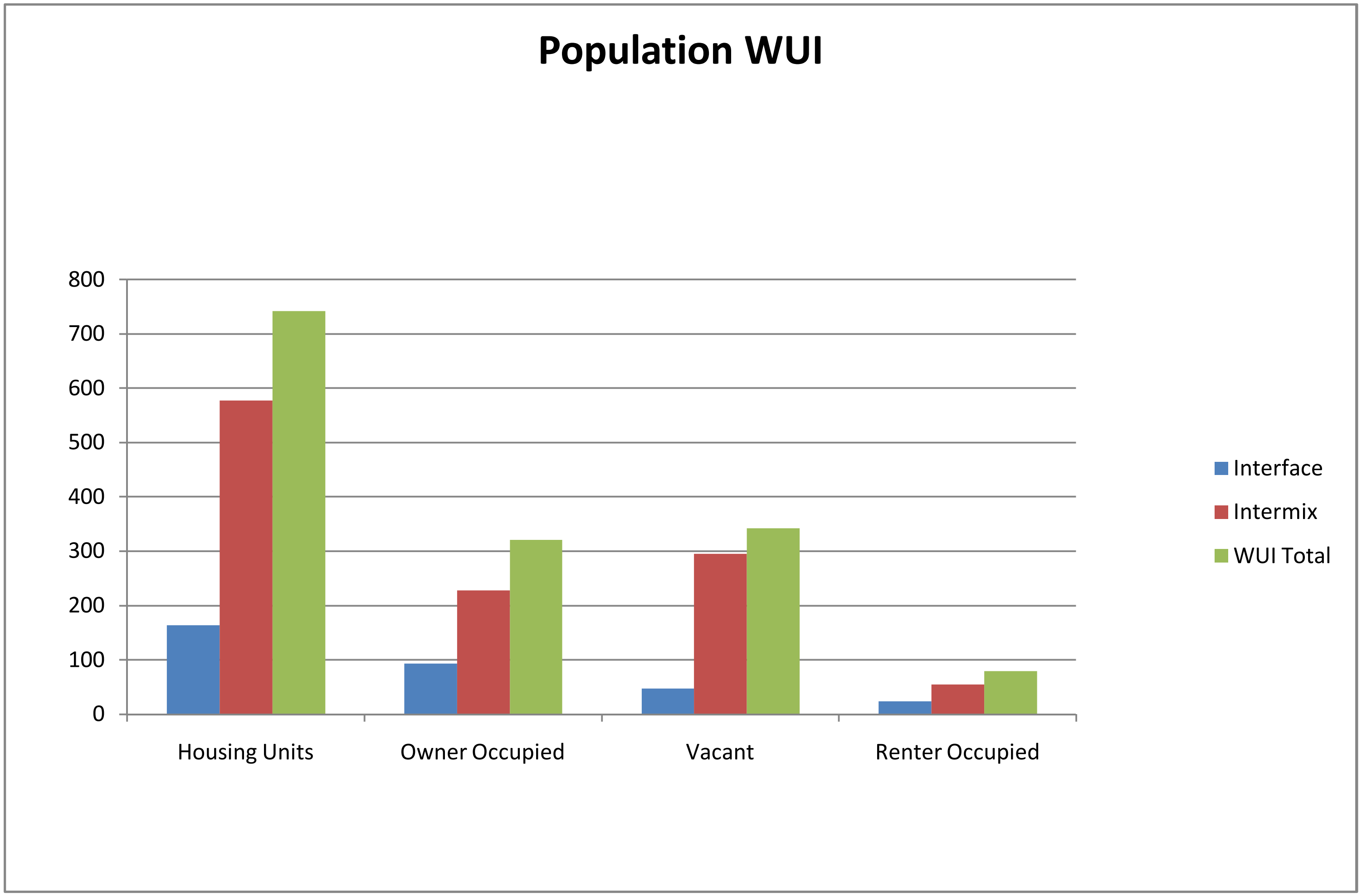


Figure 4.8- Histogram of total number of housing units found in each of the population WUI classifications.

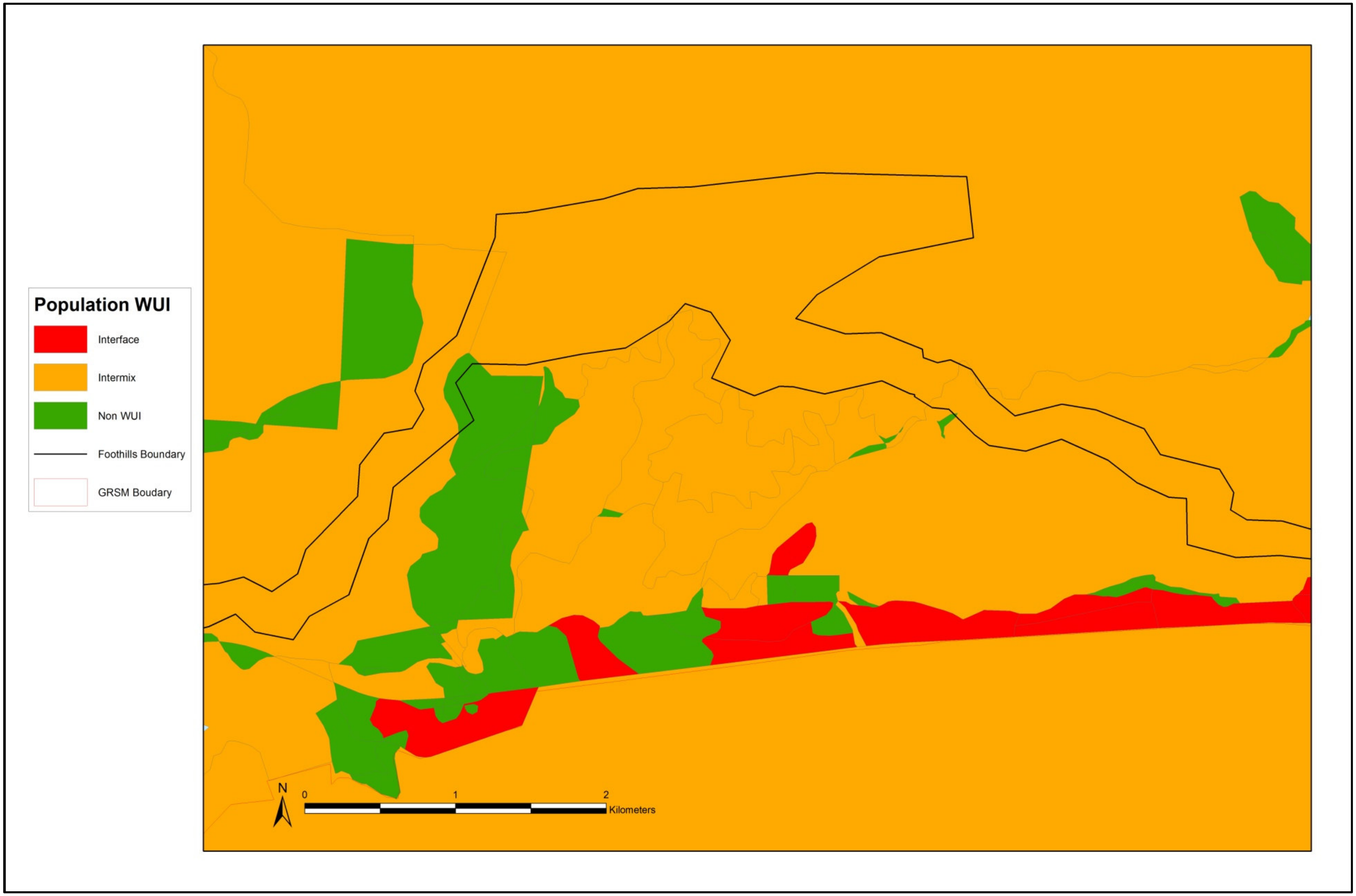


Figure 4.9- Population WUI classification in GRSM-Foothills Parkway study area using 2000 US Census data.

Based on the summary statistics and maps for WUI in the GRSM-Foothills Parkway study area, it may be inferred that there is no significant difference in overall WUI using either US Census housing information or population data in the chosen study area. A strong linear relationship exists between housing and population (Figure 4.10). Each observation on the graph represents the total population and total number of housing units according to the 2000 US Census in each of the individual Census blocks in the study area. Housing and population generally have a strong correlation to one another because the greater the number of people living in an area, the greater the number of housing units that are required. In tourist destinations, however, this relationship can change. Often times there will be more housing units than permanent population present. Therefore, it was important for this study to examine and determine if there was a significant difference in results between the two methods.

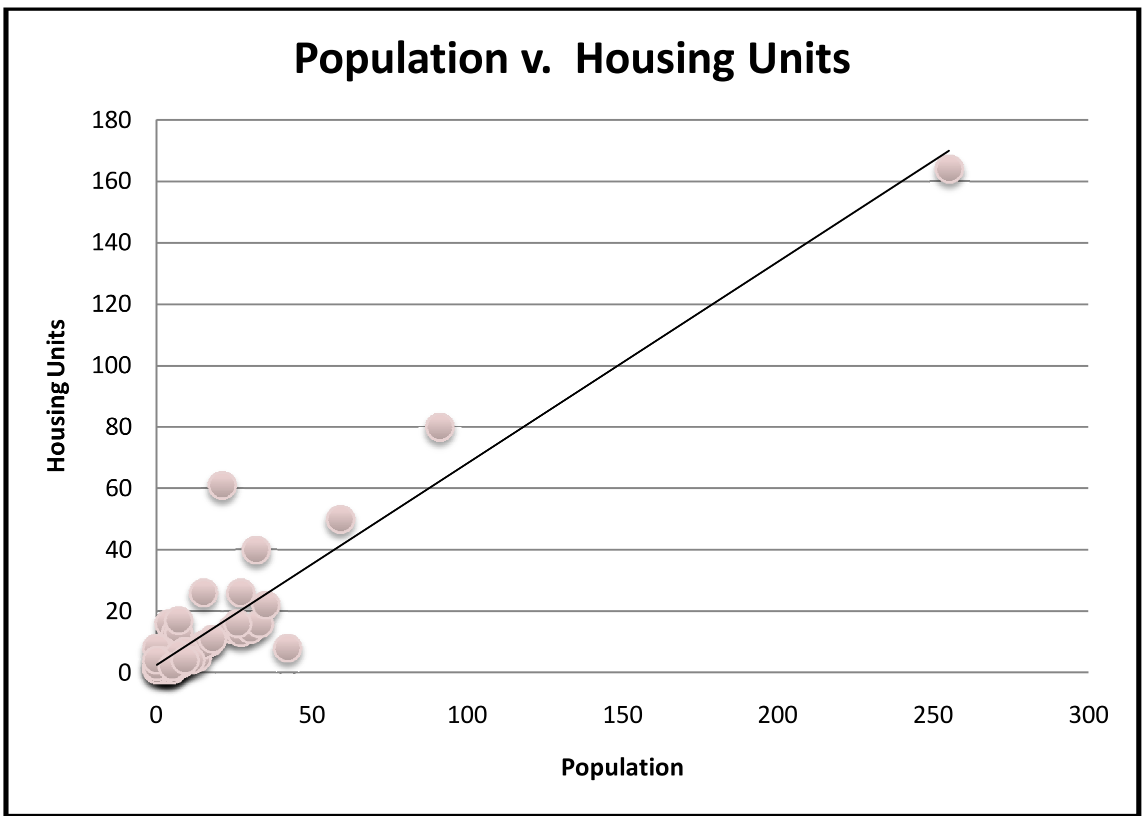


Figure 4.10- Relationship between total population and total number of housing units based on 2000 US Census information.

In looking at both housing WUI and population WUI, some consistencies were found. The interface WUI always had a higher count in the owner occupancy category. Both Housing and Population WUI maintained around a 56 percent owner occupancy rate, while vacant units made up 28 percent and renters were only 15 percent. Contrary to this, over half (53 percent) of the housing units were classified as vacant in intermix blocks. Owner occupied units dropped to 38 percent and renter occupied units were at 9 percent. This could suggest that many of the homes located in the intermix areas are not primary residences and could be vacation or second homes.

When examining the WUI regions, a noteworthy observation emerges. While looking at vegetation cover for Census blocks, there were blocks that were defined as having zero population and zero housing units. However, the 2006 NAIP photo revealed noticeable development in those blocks since the 2000 US Census data were collected. Since the Census data in some areas do not reflect true current conditions, it can be assumed that there is now more WUI than was estimated in 2000. Specifically, this was manifested in the western portion of the study area where many of the Census blocks had been identified as non-WUI.

It is important to realize that while this study yielded comparable results using population and housing to define the WUI, each method can point to different disaster management strategies with respect to where monetary, human, and physical resources are needed. For example, mapping total housing units is a good tool for identifying where the most structural loss may occur in the event of a WUI wildfire. Population totals, on the other hand, would be useful to determine where the most human life may be in jeopardy and identify areas of human risk. A future study could update the WUI by counting housing units with current imagery or using housing growth rates to better estimate the number of housing units at risk instead of waiting for the next decadal Census.

Table Mountain Pine Risk Assessment

The Table Mountain pine (TMP) species is fire dependent, yet the majority of the TMP communities lie within the NPS suppression zone. There are 22 individual polygons (or stands) of the TMP community identified in the CRMS-NPS Foothills Parkway 2005 vegetation database. Total area for the TMP class was 38 ha (93.4 ac). The highest concentrations of TMP communities were located in the most Northern section of the study area within the Foothills Parkway boundaries.

The multiple buffer ring analysis revealed that nearly the entire study area is contained within the 2,400 meter buffered area around TMP stands (Figure 4.11). The significance of the buffer distances is the maximum 2,400-m ring represents the maximum distance a fire brand can travel to the roof of a house. Nearly, the entire study area fell within the buffered distances for being at risk to fire for the TMP communities. The total area considered to be susceptible to potential wildfire risk is 5,060.7 ha. Forty-four percent of that total is classified as Medium Risk to wildfire while 36 percent was determined to be of High and Very High Risk to wildfires (Table 4.7). The High and Very High Risk areas tend to be related to high relief and remote access and therefore compound the risk of living in these isolated locations. The last 20 percent of remaining land was classified as Low Risk.

It is also important to note that a portion of GRSM falls within these areas of relative risk to wildfire. The large amounts of vegetation present around the border of the park are within the designated parameters to be susceptible to fire brands.

This model is also significant because it reveals a large amount of land vulnerable to wildfire risk lies outside the study area boundary. There is both risk of wildfires in the Parks spreading to the surrounding community in the WUI and risk of a fire in WUI spreading to National Park land. Further research in areas beyond the Foothills Parkway boundary may be necessary to further address human development in and around fire dependent species.

Table 4.7- Areal statistics for WUI areas at risk for wildfire in GRSM-Foothills Parkway study area.

Risk	**Distance to TMP Communities**	**Perimeter (meters)**	**Total Area (hectares)**	**Percent of Total Risk Area**
Very High Risk	≤ 500 m	17,849.3	819.1	16.2
High Risk	>500 - ≤ 1000 m	21,853.9	995	19.7
Medium Risk	>1000 - ≤ 2000 m	24,596.5	2216	43.8
Low Risk	>2000 - ≤ 2400 m	26,972.8	1029.9	20.4

Figures 4.12 and 4.13 illustrate the Census blocks that hold the highest number of people and housing units overlaps with TMP communities and, therefore, are associated with very high risk of fire. This area is classified as intermix, which denotes that at least 50 percent of the area is covered in wildland vegetation. Much of the new development is occurring in intermix areas and is encroaching on species that need wildfire to maintain ecological health. Continuing the trend of building that was reflected in the LULC change analysis would only further the risk of structural damage and harm to residents from fires in TMP communities within the WUI. Future studies could attempt to provide specific geospatial and quantitative data for local resources managers and insurance companies to make changes and prevent damage caused by wildfires.

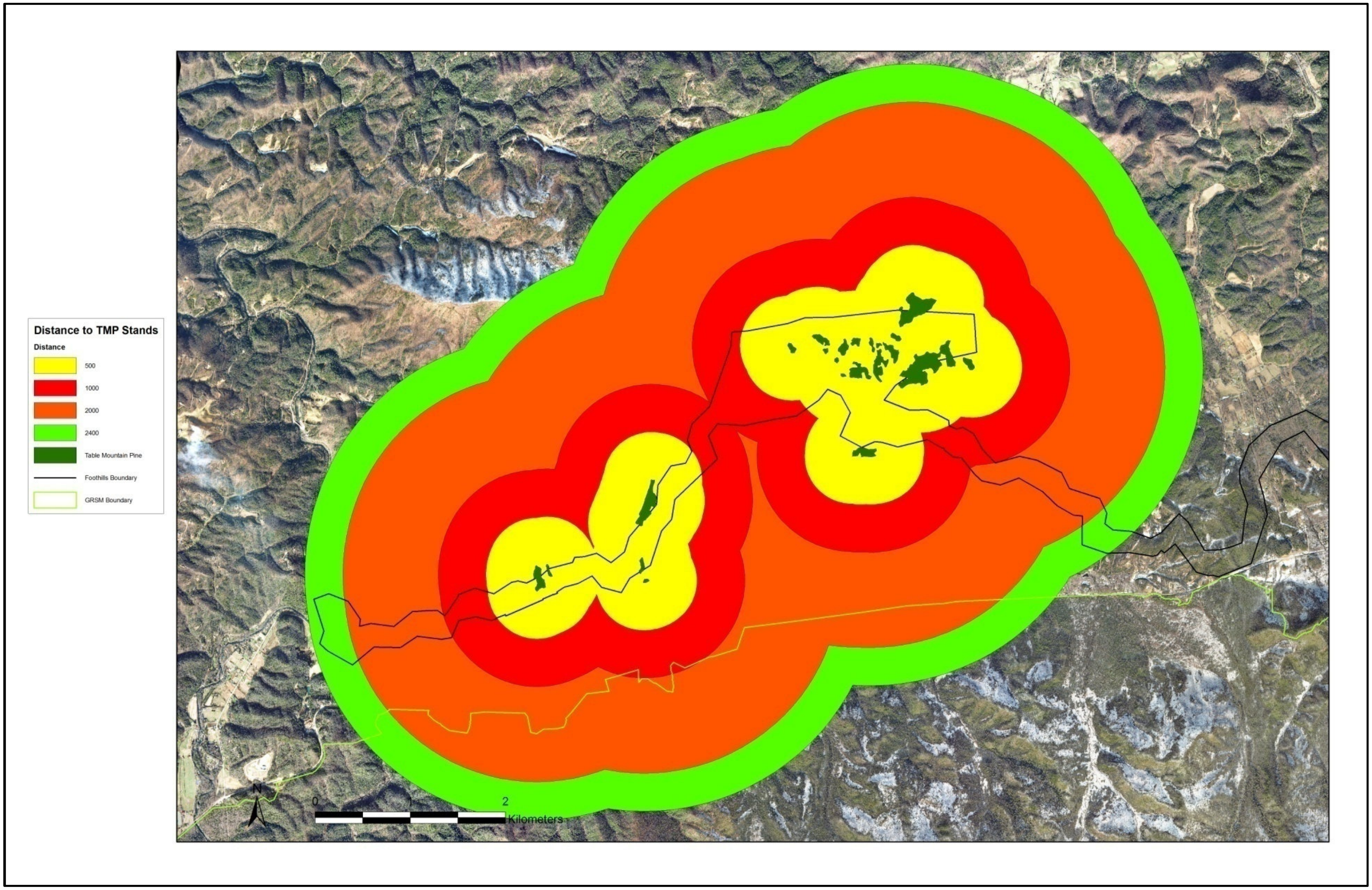


Figure 4.11- Relative risk of fire defined by distance to TMP stands based on risk levels and based on Federal Register definitions.

Figure 4.12- Distribution of population and TMP stands throughout GRSM-Foothills Parkway study area, highlighting the Census blocks with the highest population overlap boundary with the Table Mountain pine communities.

Figure 4.13- Distribution of total housing units and TMP stands throughout GRSM-Foothills Parkway study area, highlighting the Census blocks with the highest population overlap boundary with the Table Mountain pine communities.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Lands that are controlled and managed by NPS are becoming progressively influenced by human and environment interactions. National Parks cannot be conceptualized as discrete parcels of land that are removed from the landscape; they also are vital components of the landscape and connected to surrounding ecosystems. The lands just beyond National Park borders are often desirable for residential, recreational and commercial development, which creates a wildland urban interface (WUI) with inherent risks and conflicts associated with the close proximity of wilderness and human inhabitants. The goal of this study was to provide an assessment of land use and land cover (LULC) change dynamics surrounding Great Smoky Mountains National Park (GRSM) and the Foothills Parkway, highlight areas classified as WUI and identify possible areas of concern within the GRSM-Foothills Parkway WUI due to risk of wildfires. To achieve this, several geospatial databases were created: 1) a spatio-temporal LULC database for the Cobbly Nob community located within the GRSM-Foothills Parkway WUI; 2) two different maps classifying WUI using population and housing density; and 3) a relative risk to wildfire map based on the location of fire dependent Table Mountain pine (TMP) communities.

The information for the LULC database was collected primarily through the interpretation of 1977 historical aerial photographs acquired by TVA, 1997 USGS DOQQ, and 2006 USDA NAIP digital images. The 1977 scanned aerial photographs were rectified and referenced to the Universal Transverse Mercator (UTM) coordinate system (UTM Zone 17 in NAD83) using ERDAS Imagine and ground control from the USGS DOQQ. The three dates of imagery were classified using the USGS Anderson Land Use Classification System. A Level 2 classification system was used for all LULC with the exception of housing information which was classified to Level IV for a more detailed assessment. There were a total of 11 different classes identified. Three LULC data sets/maps were created for 1977, 1997 and 2006 by manual interpretation and on-screen digitizing in ArcGIS. Overlay GIS functions were then used to generate change maps from the LULC information including 1977-1997, 1997-2006, and overall change 1977-2006. These data highlighted areas that were experiencing change (i.e., where changes were occurring in the landscape) and provided quantitative information on what type of change (i.e., what old class was changed to what new class) was occurring. Area statistics were computed and summarized.

Next, using information from the US Census, the WUI within the GRSM-Foothills Parkway study area was identified using population and housing data associated with 96 2000 US Census blocks and mapped. A minimum of one housing unit per block and two people per block was the established threshold. Intermix WUI was defined as having more than 50 percent wild vegetation per block and interface WUI included areas with less than 50 percent vegetation. This information, coupled with housing and population counts, allowed a visual representation of areas affected by WUI, as well as the type of WUI to identify relative risk to property and human safety. Two maps were then created that depict WUI type and non-WUI areas based on population and housing, respectively.

The final goal of the project was to create a relative risk map related to the location of TMP communities in the GRSM-Foothills Parkway study area and assess wildland fire potential in areas classified as WUI. The assessment was performed in ArcGIS using a multiple ring buffer analysis. Risk for fire was determined based on designated distances (500, 1000, 2000, and 2400 meters) from the TMP communities. The designated distances represented levels of risk (very high risk, high risk, medium risk, low risk, and very low risk). Development of this relative risk to wildfire model was adapted from Federal Register definitions. The results of this map show the widespread fire potential within the study area.

After concluding the study, several LULC trends were consistent with each of the three time periods examined. Mixed Forest was consistently the class that lost the most area, 151 ha total. Medium Density Single Family and High Density Mixed Urban gained the most land area over the 29-year study period, 129 ha and 76 ha respectively.

Population and housing information Housing WUI covered approximately 17,480 ha (43,193 ac) of the study area. The total area for population WUI yielded similar results with 17,419 ha (43,021 ac) being affected. The majority of land in both population and housing WUI was classified as intermix; housing intermix WUI contained 17,286 ha and population intermix WUI contained slightly less with 17,243 ha. Interface WUI comprised considerably less of the study area and accounted for only 174 ha in housing interface WUI and 210 ha in population interface WUI.

Nearly the entire study area fell within the boundaries of potential wildfire risk due to firebrands. Total area considered to be susceptible to potential wildfire risk is 5,060.7 ha.
The fire risk model estimated that 819 ha of the study area were classified to be at Very High Risk to wildfires relative to their proximity to the fire dependent species Table Mountain pine.

These results are significant because it reveals that the majority of people and structures are located in intermix areas, which are defined as single homes or small subdivisions surrounded by large amounts of vegetation in remote areas and high relief. This has the potential to present obstacles for emergency services and their ability to get to remote locations and adequately provide protection from wildfire risk.

Future Applications

A potential application of this study is for other small remote and bedroom communities located near wilderness areas to utilize this methodology to gain a general knowledge of their relative risk of areas within WUIs to wildfire. To-date, most studies of risk in WUI areas have been conducted on a relatively small scale (i.e., broad area) with the minimum mapping unit (mmu) or finest scale of analysis at the county level. This study is unique because it makes use of publically available data to spatially assess problems of risk in WUI areas on a larger scale, providing more detailed and precise information for local land managers and city planners for the areas in which they are most interested.

Further research should be devoted to making this type of investigation accessible to communities and areas near and around National Parks, particularly communities that are experiencing rapid vacation and retirement home development. Using the WUI analysis procedures developed here, local planners and the managers of wilderness lands could identify areas that are defined by Chou (1991) as "critical zones". Critical zones occur where: 1) the zone is classified as high fire risk; and 2) the zone includes valuable property, natural resources, endangered species, or human inhabitants. With the aid of GIS, increasingly available and current remote sensing imagery and the local knowledge of natural and human resources and areas at risk for fire, critical zones could be better refined and managed to minimize loss of property and lives while preserving wilderness resources.

Wildfires are considered natural disasters that most people believe to be out of their control in terms of prevention or protection of their home and property. However, if homeowners can use WUI locational information and identify their homes or property at risk to potential wildfires, then they can use recommendations suggested by Cohen (2000) to minimize their risk.

He states given a wildfire, the "home ignition zone" is, the zone that determines potential for home ignition and includes the home and the land surrounding it within 100-200 feet. Using this information, along with the WUI assessment, residents can make major changes to their homes including: 1) replacing a flammable roof; 2) removal of firewood piles, dead leaves, conifer needles, dead grass, etc.; and 3) mechanical thinning to remove fuels.

Other variables including fuel loads, housing values, and transportation networks may be important layers to include in the next step of evaluating the WUI for land managers and other involved parties such as insurance companies. Each of these factors could be weighted and incorporated into a model to better assess risk. For example, high risk categories could include large fuel loads, homes > $100,000, and > 2 miles from county maintained roads. Insurance companies may be able to use this type of information to establish policies and regulate deductibles and pricing.

Conclusions

Given the increased urban sprawl and development of recent years within areas considered WUIs, it is imperative for land managers, wildland managers and fire fighters to know where the most important areas to protect are located. The methodology presented in this thesis established a spatially detailed approach for characterizing risk in a rapidly developing WUI that is located in close proximity to National Park lands that contain fire dependent plant communities. The final contributions of this study include LULC change databases, two WUI maps representing both population and housing, and a relative risk map based on the distance relationship between human development and a fire dependent plant community (TMP) and summary statistics quantifying relative risk. Remote sensing and GIS techniques provide the tools to best assess this growing spatial problem and address ways in which potential conflicts between resource preservation and economic growth can be mitigated. The geospatial sources used are widely available and the methods easily reproduced for similar studies in other areas. The approach presented here allows for user manipulation of analysis criteria and input data sets to target site-specific locations. The information obtained from the created GIS databases also can be utilized by a number of different stakeholders including urban planners, natural resource managers, NPS employees, wildland fire fighter, land managers, insurance companies, home owners, and real estate developers.

In conclusion, development in and around wilderness areas such as National Parks should be a carefully thought-out process. Management decisions should raise concerns for not only the safety and integrity of humans and their buildings and homes, but also for the natural integrity of the ecosystems within which they are entering. Building at the interface of urban and wild lands must be done wisely in order to protect lives and protect ever diminishing wilderness resources.

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