THE SPATIAL RELATIONSHIP BETWEEN EXURBAN DEVELOPMENT AND DESIGNATED WILDERNESS LANDS IN THE CONTIGUOUS UNITED STATES

by

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(Under the Direction of Gary T. Green and Nathan P. Nibbelink)

ABSTRACT

The National Wilderness Preservation System (NWPS) provides recreational opportunities and preserves historic and ecological values. Continual increases in low-density residential development in the contiguous United States pose a threat along the boundaries of public lands and uniquely valuable Wilderness areas. Development within and around protected lands can affect land management and landscape ecology by increasing forest and wildlife habitat fragmentation, reducing air and water quality, and decreasing recreational opportunities and access. Wilderness areas are particularly affected by exurban and rural sprawl, because land development is inconsistent with the nature of wilderness and its associated values. This research summarizes amenity migration factors within ten miles of the NWPS. Additionally, this study identifies NWPS units likely to experience exurban development in the near future based on land ownership, accessibility and natural amenity draws at the local level.

INDEX WORDS: Development, Exurban, Geographic Information Systems, Sprawl, Wilderness

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DEDICATION

I would like to dedicate this paper to my family: Charles, Kathy and Amy. Without their unwavering love and confirmation I would not have had the courage to follow my dreams. My parents sacrificed much to allow for my education and I am eternally grateful for the support they have provided throughout my life. I have a foundation for audacity and greatness because my father "loves me and he always will, no matter what." My mother's constant encouragement allowed me the freedom to do what I love. No matter the aspiration (including desires to become a nurse, horse trainer, forensic pathologist, veterinarian, biochemist, botanist, weatherwoman, mapmaker and finally, a park ranger), she has cheered me on toward my academic, personal and professional goals. There are many reasons I am thankful to have returned to the University of Georgia for my graduate career. One of the most prominent blessings is the stronger relationship I have enjoyed with my sister as a result of our mutual tenure in Athens. Our bond has blossomed from a largely genetic closeness to a true and deep friendship. Because of these three amazing people, I know that regardless of the economy or the unemployment rate, I am wealthy in all the ways that matter.

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CHAPTER I

Introduction

Public lands preserve historic and ecologic values while also providing unparalleled recreational opportunities (Cordell et al., 2005; Dilsaver, 1994; Harmon & Putney, 2003; Nash, 2001; National Park Service, n.d.; USDA Forest Service, 2008; USDI Bureau of Land Management, 2008; US Fish & Wildlife Service, n.d.). However, increases in low-density residential development in the United States (US) pose a threat along the boundaries of the nation's public lands (Stein et al., 2006). This threat not only affects national parks and forests, but also the uniquely valuable Wilderness areas[*] that compose the National Wilderness Preservation System (NWPS) (Cordell et al., 2005).

Though the terms "wildland" and "wilderness" are often used interchangeably to describe natural landscapes, Wilderness areas are a unique category of federal land protected through special legislation in the 1964 Wilderness Act. This legislation expressly prohibits human modification of the landscape. Although Wilderness areas are managed by one of four agencies (Bureau of Land Management [BLM], Fish and Wildlife Service [FWS], Forest Service [FS], National Park Service [NPS]), all Wilderness areas are part of the NWPS. These lands preserve inimitable research and recreational opportunities, provide sources of ecological and biological diversity, as well as oft-perceived aesthetic, existence, bequest and intrinsic values (Cordell et al., 2005; Hendee & Dawson, 2002).

[*] Capitalization of "Wilderness" denotes federally-designated units of the National Wilderness Preservation System in keeping with the current literature.

Development within and around protected lands can affect both the ecology and management of these ecosystems by increasing forest and wildlife habitat fragmentation and reducing air and water quality. Land ownership patterns may also affect recreational opportunities and access. Thus, housing density increases near Wilderness areas are incompatible with the characteristics and values of Wilderness and pose challenges for management of these areas (Cole, 2000; Hendee & Dawson, 2002).

This research seeks to identify NWPS units most at risk from exurban and rural housing density increases within ten miles of the Wilderness border. Targeting conservation efforts in exurban areas is often considered to be more cost-effective than in urban counterparts (Theobald, 2004), and research on rural residential development has the potential to positively affect public policy and planning design (Saving & Greenwood, 2002).

Statement of Purpose

Without current measures of land ownership in protective categories, housing density, modes of access and natural amenities near NWPS boundaries to identify areas of primary concern, land managers struggle to effectively plan for NWPS areas. Currently, the effects of changing rural and exurban land use on Wilderness lack definition and significant research (Cordell et al., 2005). Hence, research that analyzes spatial attributes, such as housing or road density, is necessary to identify Wilderness areas experiencing the greatest risk of development impacts. Furthermore, such research will aid land management agencies in helping to prevent conversion of these natural lands.

This study represents a collaboration between the University of Georgia and the USDA Forest Service Southern Research Station to fulfill an objective of the 2010 Renewable Resources Planning Act (RPA) Assessment. The purpose of this study is to obtain and analyze geographical and statistical data and develop approaches to describe the spatial relationship between designated areas within the NWPS and rural and exurban borderlands within ten miles of NWPS areas in the contiguous US. Through this analysis, a method will be suggested for effectively identifying those protected areas most at risk of development. This method will allow stakeholders to target locations where action is most necessary and improve strategies for conservation and protection (Theobald, 2003).

Research Goals & Objectives

Research Goals

This study will depict the relationship between areas in the NWPS and the geospatial pattern of rural and exurban development in the coterminous US so that stakeholders may make informed decisions regarding current and future management of NWPS areas. This proposed research includes three specific objectives: 1) to quantify factors associated with exurban sprawl and amenity migration on or near the periphery of Wilderness areas in the contiguous US; 2) to develop a standardized, repeatable, and updateable method for describing development pressures near NWPS lands through the creation of a risk assessment index; and 3) to rank selected NWPS areas by likelihood of borderland development.

Research Objective 1

To quantify factors associated with exurban sprawl and amenity migration near Wilderness areas in the continental US, several metrics were calculated: a) amount and percent of developable land on or near the periphery of Wilderness (non-federal land and other protected land); b) housing density (Census 2000) for Census block groups (CBGs) intersecting Wilderness areas and borderlands; c) accessibility of a Wilderness area using transportation infrastructure such as roads and airports; and d) presence of natural amenities (water features) within defined buffer distance. Analysis was performed on half, three and ten mile buffers of Wilderness to provide consistency with similar research (Cordell et al., 1990; Stein et al., 2005).

Research Objective 2

To develop a standardized, repeatable, and updateable method for describing development pressures around selected NWPS lands, several metrics known to influence likelihood of development were measured, standardized and combined to form an index describing relative risk of development adjacent to selected NWPS lands. Based on current literature, Wilderness areas experiencing the greatest likelihood of development are predicted to be positively correlated with short distances to urban areas, high road density, and the presence of nearby private land (Aldrich & Kusmin, 1997; Biehl, 1991; Deller et al., 2001; Garber-Yonts, 2004; Gude et al., 2006; Loeffler & Steineke, 2007). Additionally, due to the many disparate sources of geographic data and the manipulation required to calculate metrics associated with NWPS lands, the geographic database created for the purpose of this research should be of significant use for future studies of NWPS lands.

Research Objective 3

Using the index created from Objective 2, NWPS lands are ranked hierarchically in terms of relative risk of development. Since ranks may vary depending on buffer distance considered, the variation in ranks (inclusion of NWPS land in the top ten) will be reported for each buffer zone. Ranking methodology will a) assign a resampled index score to NWPS units for each metric known to affect likelihood of development; and b) categorize NWPS units by likelihood of exurban development (based on index score) and stratify by zero, zero to half, half to three, three to ten mile buffers, as well as a Landscape Level Assessment (LLA), of each Wilderness area.

CHAPTER II

Literature Review

History and Meaning of American Protected Lands

Though the term wilderness often challenges definition, for many it means the absence of civilization and is often regarded more as a state of mind than a physical truth (Cronon, 1995; Nash, 2001; Stankey, 1989). Wilderness denotes a place of solitude, and as such it has both a physical and psychological carrying capacity. The connotation of wilderness has varied greatly throughout history. Many Old World cultures associated wild lands with evil. For early settlers facing the hardships associated with wild land, wilderness was seen as an archenemy of civilization. Claiming divine right, settlers began modifying the land in hopes of eradicating wilderness in favor of pastoral or even urban settings (Nash, 2001).

Settlement trends in America have historically occurred in pulses originating from push-pull factors such as quality of environment, economic cycles and availability of resources (Goodrich, 1936; Ravenstein, 1885). Early America existed largely in the eastern US as immigrants primarily settled the Atlantic coast and inland near major waterways. The post-Revolutionary period brought diversification of crops; eventually poor forestry and agricultural practices result in exhausted and eroded soils until later experimentation in agrisciences led to deep plowing and fertilization as a means to rehabilitate the land. The onset of the Industrial Revolution saw an America comprised of small towns oriented toward subsistence agriculture while larger cities became trade centers (Merchant, 2005). Land ownership in the eastern US was, and still is, largely fragmented due to the history of settlement and land use in the region.

Land was only considered useful as potential areas of civilization and Westward expansion was celebrated as part of this mindset (Nash, 2001).

The War of 1812 opened up part of the West for settlement; some emigrants moved to the new territories while others relocated to cities. Throughout the nineteenth century, improvements in transportation such as steamboats and railroad cause increased resource extraction (Merchant, 2005). Additionally, the completion of railroads resulted in checkerboard land ownership patterns between federal and nonfederal entities that still exist today (Russell, 2006).

The western US drew pioneers extracting various forms of “gold;” yellow (gold ore) gold, white (water) gold, green (forest resources) gold, pink (salmon) gold and soft (fur) gold (Merchant, 2005). Some of the characteristics defining the pioneer spirit are captured in the idea of “Manifest Destiny,” the traditional belief that the earth and its resources should be subdued and used by man. In 1862, the Homestead Act brought ranchers to the Great Plains. Cattle ranching reigned for a time, but eventually led to overgrazing. Additionally, the widespread slaughter of bison occurred both as a means of oppressing Native Americans and to clear the open range for cattle. Thus, the stage was set for the Dust Bowl of the 1930s (Merchant, 2005). A scarcity of resources during the late 19th and early 20th century caused many Americans to recognize the need for additional resource conservation.

Origins of Conservation and Federal Land Managing Agencies

Romanticism first brought cultural acceptance to the natural ideal. Deism, Transcendentalism, landscape paintings and the recognition of wilderness “as a cultural and moral resource” during America’s search for its national identity eventually led to natural resource and wilderness appreciation (Nash, 2001, p. 67). The resulting endorsement for wilderness and protection of the American landscape gave way to a concern for preservation and the concept of setting aside public land emerged.

The first national park, Yellowstone, was “dedicated and set apart… for the benefit and enjoyment of the people” (Dilsaver, 1994, p. 28) in 1872 under President Ulysses S. Grant. The park was placed under the Department of Interior, planting the seeds for the NPS and sister agencies within the same department in later years. In 1916, the Organic Act officially created the Park Service. Today, NPS consists of 78 million acres in 391 Units, including 58 National Parks, as well as National Monuments, National Seashores, National Recreation Areas, National Battlefields and National Historic Parks (Gorte & Vincent, 2007). The NPS mission “preserves unimpaired the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations” (NPS, n.d.).

The origins of the National Forest System and the FS initiated around the 1870’s, largely due to several wildfires; in one case 1,500 people died, capturing the nation’s attention and support for forest reserves. The Division of Forestry was confirmed by an act of Congress in 1886 and was originally housed in the Department of the Interior. Once again, the Yellowstone region became home to conservation history; present-day Shoshone National Forest, originally Yellowstone Park Timber Reserve (est.1891) was the site of the first forest reserve. Congress used the Organic Administrative Act (1897) to clarify the purpose of the reserves stating “forest reserves were to be established only to secure favorable water-flow conditions and to furnish a continuous timber supply.” Gifford Pinchot was appointed Chief of the Division of Forestry in 1889. Under Pinchot’s direction, the forest reserves were transferred to the Department of Agriculture, becoming the Forest Service. Under this agency, the first wilderness area was set aside in 1924. Formal policies for wilderness areas were first issued as the L-20 regulations of 1929 and the U-Regulations of 1939.

Currently, the FS manages 192 million acres, overseeing 155 National Forests and 20 National Grasslands. The mission, to “sustain the health, diversity, and productivity of the Nation’s forests and grasslands to meet the needs of present and future generations” (USDA Forest Service, 2008), includes a variety of goals and objectives. The FS seeks to reduce risk of wildfire and invasive species, provide opportunities for outdoor recreation, assist in meeting the nation’s energy needs and improve the quality of watersheds.

Subsequent to the Dust Bowl, concerns ensued over open range in the West. The DOI was the first agency to institute grazing permits, and eventually FS established forage allotment as droughts and overgrazing wreaked havoc on the American West. In 1934 the Taylor Grazing Act was passed in Congress. Subsequently, all public lands not managed by NPS or FS were placed under the Grazing Service, which, in conjunction with the General Land Office, became the BLM in 1946. Because it is the largest federal landholding agency (258 million acres), it is not surprising that the management objectives of the BLM are the most varied. Programs administered by the BLM include mining, grazing, forestry practices including timber harvest, noxious weed eradication, wild horse and burro program, fish and wildlife conservation, recreation and protection of cultural and historic resources (USDI BLM, 2008).

The FWS was founded in 1940, to protect endemic and migratory flora and fauna. The FWS “mission is, working with others, to conserve, protect and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people (US FWS, n.d.).” The agency manages approximately 90 million acres as national wildlife refuges.

Origins of Wilderness Preservation

A dichotomy exists between the factions of conservation (sustainable use) and preservation (nature for nature's sake); though the goals of each cause are similar. The conservation movement, spearheaded by Aldo Leopold and Robert Marshall among others, experienced many milestones after the end of the Great Depression and WWII. The Wilderness Society was founded in 1935, and in the 1940s and 1950s many National Monuments were converted to National Parks, thereby increasing their protection. However, a rift exists between those who believe that "parks are for people" and those who reason that "parks are for nature and for people who like nature unmodified" (Nash, 2001, p. 327). In the midst of the Great Depression, considerable effort by the Civilian Conservation Corps created roads and other structures on many public lands. Subsequently, visitation to public lands increased rapidly between 1945 and 1960 as the interstate highway system made access more feasible and American affluence allowed more time and money for recreation and leisure (Sutter, 2002).

The concept of ecology, introduced by Eugene Odum and Aldo Leopold in the mid-20th century, denoted a shift from an anthropocentric point-of-view toward an understanding of nature as interrelated parts. The development of a "land ethic" as well as a "wilderness philosophy" lent repute to the wilderness defense. Recognition of wilderness' value in science and research provided justification for preservationists.

Congressional debates about American wild lands were often the result of increasing demands for water, especially in the arid American West. Ultimately, Alaska, known as America's "last frontier," was instrumental in highlighting the inherent value of wilderness as support was voiced from those who may never visit the state. The desire to assure a supply of wild and undeveloped land made favorable conditions for Wilderness. David Brower concludes, “the wilderness we have now is all…men will ever have” (Nash, 2001, p. 223). Howard Zahniser, Father of the Wilderness Act and director of the Wilderness Society, began his effort to convince Congress to support the establishment of Wilderness in 1955. Permanent protection of wild lands culminated with the passing of the 1964 Wilderness Act under President Johnson.

The 1964 Wilderness Act identified three agencies from which Wilderness may be created (FS, NPS and FWS). The Federal Land Policy and Management Act of 1976 added BLM to the list of NWPS managing agencies. Thus, the four largest federal landholding agencies are also the four Wilderness managing agencies. Though all are part of the NWPS, each agency has specific and unique management objectives. Additionally, the 1964 Act specifically prohibits the creation of a separate NWPS entity; instead each agency manages the Wilderness within its boundaries according to its respective laws and policies.

The NPS manages 43.5 million acres of Wilderness (40% of NWPS acreage) while FS oversees 32% of Wilderness land acreage (35.5 million acres). The FWS is the administrative agency for 20.7 million acres (19% of NWPS acreage) and BLM manages 7.8 million acres (7% of NWPS acreage). Approximately 33% of Americans (70 million citizens) visit a Wilderness area each year (Cordell et al., 2004).

Urbanization and Related Ecological Effects

Population Increase and Urbanization

American population surged between 1946 and 1960, with a national increase in urban population. Quality-of-life reform by middle and working class led to better infrastructure, and population and housing density increased on both ends of the rural-urban continuum. The trend of urban and suburban in-migration from 1940 - 1970 has seen a reversal in recent years, dubbed the “rural rebound” (O’Malley, 1994). At present, to accommodate an ever-increasing human population, housing density is projected to rise in many areas of the US, adding to the overall trend of urbanization (Cohen, 2003; Theobald, 2005).

A 34 percent increase in the amount of developed land experienced in the US between 1982 and 1997 is projected to be followed by a 79 percent increase by 2030, resulting in a doubling of the total developed land base (Alig et al., 2003). An overall trend of rapid development on natural lands is predicted in the near future. More than 44 million acres of private forests in the contiguous US are expected to undergo extensive housing density increase in the next quarter century, enough to substantially affect the borders of national forests and grasslands in America (Stein et al., 2005).

Though growth in nonmetropolitan counties often results in increased job opportunities, reductions in poverty, and support for better education and health programs, negative effects may also result from the economic stimulus (Hunter, Boardman & Saint Onge, 2005). These include greater land and housing costs, sprawl, and increased traffic congestion. Additionally, influx can stress public funds when demands for services and infrastructure exceed the generated tax revenues (USDA-ERS, 2007).

Negative Ecological Implications of Development

Increases in population, housing and road density comprise a marked effect on natural areas (Cordell & Overdevest, 2001), often with negative ecological implications. America's current proclivity for exurban and rural growth results in a "development footprint" that is unequal to population increase. Exurban and rural development disproportionately augments road density per housing unit and contributes to forest fragmentation (Hammer et al., 2003; Theobald, 2005). The effects of such low density development are expressed in both the ecology of the local system and human enjoyment of the landscape. Of primary concern are impacts resulting from development and subsequent fragmentation including critical wildlife habitat loss, a decline in biodiversity, introduction of invasive species, influences on air and water quality, alteration of nutrient flow, modification of migration patterns and risks associated with wildfire (Arnold & Gibbons, 1996; Debinski & Holt, 2000; Radeloff et al., 2005a; Riitters et al., 2002; Schueler, 1994). Additional effects include a decline in the manufacture of forest products and reduction of recreational opportunities (Stein et al., 2005).

When a parcel of wildland is developed, a concomitant increase in the amount of forest edge occurs, along with a decrease of forest cover and interior habitat size (Zipperer, 2005). Additionally, construction of roads and homes results in an increase in impervious surfaces and a subsequent increase in storm runoff which can result in permanent damage to stream biota (Arnold & Gibbons, 1996; Schueler, 1994). Habitat fragmentation and destruction are the origin of myriad conservation problems through the influence on social relationships and interaction among species, alteration of nutrient flow and modification of migration patterns (Belica & Nibbelink, 2006; Debinski & Holt, 2000).

The Wildland-Urban Interface (WUI) is defined as “the area where houses meet or intermingle with undeveloped wildland vegetation” and is also representative of development at the borders of protected lands and Wilderness. In the contiguous US, the WUI comprises almost ten percent of the land area, yet contains almost 40 percent of all houses (Radeloff et al., 2005b, p. 799). The distribution of low-density development causes disproportionately higher environmental conflicts than in concentrated urban areas on a per capita basis as houses and humans are spread across the landscape in a less sustainable manner (Radeloff et al., 2005b). Major WUI areas are often located in areas abundant in natural and recreational amenities.

Protected Lands and Development

Amenity Migration

Subsequent to current nonmetropolitan migration, many Americans are showing a preference for building both primary and secondary residences near rural or protected landscapes, illustrating the trend of amenity migration (Fuguitt & Beale, 1996; Johnson, 2002; Price, Moss & Williams, 1997). Areas historically influenced by amenity migration (coastal areas, mountains) are also categorized as classic examples of the wildland-urban interface (Moss, 2006; Radeloff et al., 2005b). Amenity migrants, those who seek permanent or temporary residence in areas rich in scenery or culture, often seek solace from an urban lifestyle on the periphery of wildlands and in favorable climates (Moss, 2006). This counter-migration has been described as depolarizing rural and urban, resulting in landscapes that offer characteristics of both country and city living (Hall & Muller, 2004).

A second home owner will generally visit a particular area, develop a place attachment, purchase a second or vacation home and potentially make this home their primary residence during retirement (Hall & Muller, 2004; Price et al., 1997; Williams & Van Patten, 1998). Access to areas becomes important not only as a draw for tourists, who visit the area prior to becoming an amenity migrant, but also for the second home owner when choosing to build a home (Kozak & Rimmington, 1999). Proximity to major highways, interstates, airports and various other transportation hubs increases the access to a region, and can positively affect both tourism and real estate development (Biehl, 1991; Garber-Yonts, 2004; Inskeep, 1988). Nonmetropolitan or rural areas proximal to airports show increases in rural development compared with rural areas that are not (Aldrich & Kusmin, 1997; Bingham & Mier, 1993). Additionally, climate, summer and winter seasonal activities and proximity to water sources suited for recreation increase the likelihood of quality-of-life fueled growth in a region (Deller et al., 2001; Duffy-Deno, 1998; Gude et al., 2006).

Proximity to protected areas, such as public or conservation lands often increase property values for nearby landowners in both rural and urban areas (Barnett, 1985; Cho, Bowker & Park, 2006; Do & Grudnitski, 1991; Doss & Taff 1996). In addition to tangible benefits, the presence of open space and public lands offer abstract environmental, economic and social benefits to local communities (Fausold & Liliholm, 1999, Harmon & Putney, 2003; Lewis, Hunt & Plantinga, 2001). However, amenity migrants wield a double-edged sword; their presence often leads to economic stimulation and improved infrastructure which can stress the exiting natural and social resources and raise the cost of living for long-term residents (Hunter et al., 2005; Loeffler & Steinicke, 2007).

The pressures of human development and private land ownership within the protected landscape add difficult and sensitive aspects to the duties of land managers. Fragmented land ownership patterns create a challenging issue for managers of public lands as they strive to protect natural and historic values and maintain access for recreation. The term “backcountry sprawl” describes the housing development increase within and near national forests and parks (Russell, 2006). The population growth between 1970 and 1988 near federal public land (23%) was more than double the average growth nationwide (11%) (Bailey, 1991).However, national forests and grasslands are not the only protected lands at risk from development along the borders; housing density will likely increase in and around Wilderness areas (Cordell & Overdevest, 2001; Duffy-Deno, 1998; Rudzitis & Johnson, 2000).

Wilderness and Development

An increase in use of public lands and especially Wilderness is a product of the intellectual revolution, advanced equipment, improved access through the transportation revolution, and the information revolution (Booth, 1999; Hendee & Dawson, 2002). Unfortunately, escalated use causes management issues and can destroy the wilderness experience through diminished solitude. Increases in visitation and use lead Nash (2001, p. xi) to conclude, “Wilderness was the basic ingredient of American culture… [and is now] in danger of being loved to death.” Additionally, impacts of borderland practices on Wilderness can be substantial, especially to wildlife, landscape ecology and wilderness experiences (Cole, 1994).

Wilderness areas are particularly affected by exurban and rural sprawl, because land development is inconsistent with the nature of wilderness and its associated values (Cordell et al., 2005). Without current measures of housing density near NWPS boundaries and landscape level land cover change to identify areas of primary concern, land managers cannot effectively plan for NWPS areas. Conservation efforts directed toward preserving biodiversity at the landscape level should address both rural and exurban development (Radeloff et al., 2005a). By merging Census and land ownership data with known factors affecting development, this study will provide a method for ascertaining which Wilderness areas are most at risk for borderland development in the near future, thus targeting locations where action is most necessary and improving strategies for conservation and protection (Theobald, 2003). Because only a small percentage of the contiguous US is designated Wilderness, today’s management decisions and human utilization carry substantial and possibly irreversible consequences for the future of these public lands.

CHAPTER III

Methodology

Study Area

The NWPS is currently comprised of 704 federally designated Wilderness areas (Wilderness Institute, 2008). Wilderness areas are created from existing federal lands and managed by one or more of the four Wilderness managing agencies. At present, the contiguous US contains 652 individual units of the NWPS, totaling nearly 107.5 million acres (Appendix A, Figure 1). For the purposes of this research, only units in the contiguous US were evaluated due to consistencies in available geographic data. Zones of half, three and ten mile buffers surrounding NWPS lands were considered in this analysis. Calculation of metrics likely to influence development pressures in these zones serves two purposes: a) comparisons with other work, as the same buffer distances were used in *Forests on the Edge* and research on the Recreation Opportunity Spectrum (Cordell et al., 1990; Stein et al., 2005; Stein et al., 2006) to characterize development pressures adjacent to National Forest and other public lands and b) provision of information at multiple scales to evaluate changes in development pressure.

Data Sources

Geographic data (ESRI shapefile format) were acquired from National Atlas, US Census Bureau, US Department of Agriculture, US Department of the Interior and the US Geological Survey and imported to a Geographic Information System (GIS) (National Atlas, 2005; National Atlas, 2006; US Census Bureau, 2001). A list of data layers and sources is located in Table 1.

Table 1. *Data Layers Utilized in the Research*

Data Layer	Data Source
National Wilderness Preservation System of the United States	National Atlas
Federal Lands of the United States	National Atlas
Surface Management Areas of USDA Forest Service & Bureau of Land Management	Bureau of Land Management National Integrated Land System
National Park Service Current Administrative Boundaries (excludes inholdings)	National Park Service Natural Resource and GIS Metadata and Data Store
Indian Lands of the United States	National Atlas
Streams and Water bodies of the United States	National Atlas
2000 Census Block Group Boundaries for the Contiguous United States	US Census Bureau
State Boundaries of the United States	National Atlas
Major Roads of the United States	Environmental Systems Research Institute
Canada Base Map	Environmental Systems Research Institute
Protected Areas of Canada	Environmental Systems Research Institute
Mexico Base Map	Environmental Systems Research Institute

Coordinate systems for each shapefile were all projected in ArcCatalog (ESRI, Redlands, CA) to an Albers Equal Area Conic Projection for the contiguous United States using the North American Datum (1983). The resolution of the shapefiles varies between sources and the finest-scale data for each metric was used in the final analysis. Geographic data (boundary files) exist for Wilderness areas greater than 640 acres and designated prior to 2004; a total of 600 NWPS units. A shapefile containing Wilderness areas designated since 2004 is necessary to complete an up-to-date analysis. The logistical complexity of a fine-scale analysis of all NWPS lands is outside of the scope of this project. Additionally, current GIS data for Alaska, Hawaii and US territories is at too coarse a resolution, thus this study focuses only on the continental US.

Census Geography

Census geography divides land into bounded areas based on population size and political boundaries thereby categorizing every person or household in the US into legal, administrative and statistical tabulation units (US Census Bureau, 1994; US Census Bureau, 2001). Census geography hierarchy begins at the national level, and then subdivides an area in the country into regions, divisions, States (or statistical equivalent), counties (or statistically equivalent entity), Census tracts, Census block groups (CBG), and Census blocks (Appendix A, Figure 2). The smallest unit for which the Census Bureau releases the majority of statistical information is the CBG. A CBG usually includes between 600 and 3,000 people, with an optimum average population of 1,500 people. The total number of houses and the total population are reported for each CBG, and then subdivided by various demographics (e.g., age, gender, etc.). An exclusive code exists for each CBG by stringing together a sequence of the unique codes denoting the higher units of the Census geography hierarchy.

The smallest unit for which the Census Bureau tabulates real data, rather than a sample, is the Census block. The US is comprised of 8.2 million Census blocks, and an average of 39 blocks composes one block group. However, in keeping with the current literature and due to the complexity of working at the block level, this research chose the block group level as the appropriate scale for analysis (Aplet, Thomson & Wilbert, 2000; Brown et al., 2005; Theobald, 2001).

Analysis

Metrics Affecting Likelihood of Development

Quantification of the potential for amenity migration and subsequent housing density increases near Wilderness in the continental US includes a) calculation of area and percentage of developable land within zero, half, three and ten mile distances of NWPS lands b) determination of year 2000 housing density for CBGs intersecting zero, half, three and ten mile distances of NWPS boundaries; c) estimation of the "remoteness" of each NWPS unit using transportation infrastructure; and d) inclusion of the presence of natural amenities such as water features. For this study, it was assumed that presence of designated Wilderness and public lands is a draw for inmigrants (Cordell et al., 2005; Cordell & Overdevest, 2001; Duffy-Deno, 1998; Rudzitis & Johnson, 2000); however, the likelihood of development is not equal across the system. Additional factors, such as accessibility, amount of land available for development, historical conversion of natural lands to development will allow for stratification of NWPS areas more or less likely to experience borderland development in the near future. Several buffer distances were chosen to mimic the approach used in the *Forests on the Edge* (2005) study, which was based on the fundamental assumption that impacts to public lands and natural resources vary depending on the distance of development from the borders and the scale of analysis (Radeloff et al., 2005b; Stein et al., 2005; Stein et al., 2006). Administrators must take into account the scale at which development is occurring on the landscape to properly manage for resource responsibilities such as protection of wildlife habitat, recreational opportunities or fire risk mitigation. Additionally, the half and three mile distances have been employed in recreation opportunity spectrum research (Cordell et al., 1990). Analysis was performed on individual Wilderness areas (within the borders), and buffers ranging from zero to half, half to three, and three to ten miles from the borders of each Wilderness area. These buffers represent straight-line distance from the NWPS border and are analogous to a radius, except that NWPS areas are irregularly shaped (Appendix A, Figure 3). An additional buffer zone was analyzed consisting of all land within ten miles of NWPS boundaries, including the Wilderness, and is denoted as the LLA. Wilderness areas experiencing the greatest likelihood of development are predicted to be positively related to exurban housing densities, the presence of nearby private land and short distances to roads and metropolitan areas. Table 2 lists each metric, along with the range of values and method of calculation.

Table 2. *Metrics Affecting Likelihood of Development.*

Metric	Unit	Calculation Method
Non-Protected Land Tier 1	%	((Area of Buffer - Area of Land Protected by BLM, FS, FWS or NPS)/Area of Buffer)*100
Non-Protected Land Tier 2	%	((Area of Buffer - Area of Land Protected by any entity)/Area of Buffer)*100
Housing Density	units/ sq mi	Housing Units/Total Land Area for Buffer
Mean Distance to Roads	mi	Distance to Nearest Road for 30 m Cell
Enplanements for Airports Within 50 Miles	Persons	Sum of Number of Boarded Passengers for All Airports Intersecting a 50 Mile Buffer of NWPS
Presence of Water Features	sq mi	Area of all Lakes, Reservoirs or Oceans Within Each Buffer Zone

Land Ownership

Land ownership plays a substantial role in the likelihood of development of a particular parcel. Public lands are generally excluded from commercial development or housing density increases. Areas this study excludes from potential development include all water features and land owned by BLM, FS, FWS or NPS (Appendix A, Figure 4). A second tier of protection includes land owned by the Department of Defense (DOD), the Department of Energy (DOE), Tennessee Valley Authority (TVA), Bureau of Reclamation (BOR), state and local parks, tribal lands and protected areas of Canada (Appendix A, Figure 5). Surface ownership files including information regarding inholdings were used for representation of BLM and FS land holdings. However, the remaining agencies have geographic data for the administrative boundaries only; thus, the actual amount of developable land is likely underestimated. Geographic data for protected areas in Canada was incorporated for Wilderness areas at the US-Canada border. However, such information is not yet available for Mexico, thus the nine NWPS areas whose buffers intersect the southern US border may reflect larger amounts of developable land than are actually present. A mask is a dataset made for the purpose of analyzing data within a specific extent; in this study the mask is a feature that represents all undevelopable areas of the contiguous US based on public or protected status and the presence of water features. Two masks were created (in ESRI shapefile format), the first comprised of water features and land managed by BLM, FS, FWS or NPS. The second mask included water features and all public or protected lands for which data was available. The masks were erased from each buffer zone, designating remaining parcels as protected or non-protected within each buffer distance. This process was applied to both first tier (land protected by Wilderness managing agencies) and second tier (land protected by any federal, state, local or tribal entity) protection levels. Thus, the amount and percent of non-federal land for each protection category within each buffer distance was calculated.

Census Data

Housing density. The housing density for each CBG was calculated by dividing the total number of housing units by the amount of land in square miles (Appendix A, Figure 6). Urban and suburban housing densities are represented by 64 or more units per square mile. Exurban housing densities exist where 16-64 units per square mile are present; while rural areas contain less than 16 units per square mile (Stein et al., 2006; Theobald, 2005). A database of NWPS units that intersect CBGs at urban and exurban housing densities was created in ArcGIS (ESRI, 2008) by assigning urban, exurban and rural housing density categories to each CBG in the contiguous US. Census block groups intersecting each NWPS buffer zone were analyzed.

Accessibility

The probability of development is increased with existing infrastructure and access (Biehl, 1991; Inskeep, 1988; Lepczyk et al., 2007). Proximity to roads and airports is expected to identify Wilderness areas with high accessibility, or low remoteness.

Distance to Roads. Roads facilitate access for visitors, who may develop an attachment to the Wilderness area, as well as construction crews. For those amenity migrants that purchase second homes within driving distance of their primary residence, roads will serve as their principal mode of access. An individual road rarely exists as a separate entity in the transportation network; it must connect with an existing road to be considered useful. Thus, distance to the nearest road offers a rough estimate of likelihood of development of a given area. A road dataset (ESRI, 2002) was clipped to a 20 mile buffer of each NWPS unit to ensure correct calculation of distance to nearest road for all roads within a ten mile buffer. The straight line distance was calculated using Spatial Analyst tools in ArcGIS for all 30 m cells within the 20 mile buffer (Appendix A, Figure 7). The resulting raster dataset was summarized using Zonal Statistics for the zero, zero to half, half to three, three to ten and LLA buffers of each NWPS unit. For each Wilderness area and each buffer distance, the mean distance to nearest road is reported. In general, as distance to nearest road increases, road density decreases and the Wilderness Area is considered more remote.

Access to Airports. Airports provide access to areas unreachable or remote by car. Additionally, due to the fact that most hub airports are located in metropolitan areas, proximity to airports may serve as a surrogate for proximity to urban areas in some cases. Airports that intersect a 50 mile buffer of the NWPS (Aldrich & Kusmin, 1997) were selected (Appendix A, Figure 8). Rather than use discrete data (number of airports), the availability of continuous data (number of enplanements) was utilized to improve the index. Each airport has an expected sphere of influence relative to its hub size. Because a large number of airports existed with few enplanements and a few large airports were included with extremely high numbers of enplanements, the data was highly skewed and required a power transformation of the total number of enplanements (boarded passengers) in order to normalize the data and produce a useful continuous index. Implementation of a Box-Cox transformation (Box & Cox, 1964) using a lambda of 0, successfully transformed the data to a distribution approaching normality.

Presence of Natural Amenities

Access to water bodies for recreational use has been shown to positively affect growth in rural areas (Aldrich & Kusmin, 1997; McGranahan, 1999; Nord & Cromartie, 1997). Presence of a bay, estuary, lake, reservoir or ocean within each buffer distance will increase the likelihood of development. Calculation of a continuous metric to account for the draw associated with water features proved problematic. Consideration was given to percent of each buffer distance that water features represent, however, this metric is misleading as higher percentages of water in each buffer may decrease the likelihood of development due to lack of an available land base. Additionally, utilization of the area of the actual water body that each NWPS unit intersects was considered. However, this method introduced problems for Wilderness areas that intersect only a small fraction of a large body of water, such as an ocean or Great Lake. Therefore, the area of the portion of water features intersecting each buffer zone is reported and is expected to be generally related to the amount of waterfront property in the buffer distance.

Ranking Methodology

Calculation of metrics for an individual NWPS unit is useful in gaining insight into the development threats facing a particular Wilderness. However, comparison across the System was necessary in order to determine which Wilderness areas were most likely to experience housing density increases at their borders. Fulfillment of Research Objective 2 required the creation of an index that combined the standardized ranking for each unit based on the relative values for each metric. This study assumed that the risk of development will increase as the presence of private land, accessibility by airports and the presence of water features increases, and as the distance to the nearest road decreases. Because data for housing density projections is currently unavailable, the Census data could only be used to stratify Wilderness areas in the next step.

After summarizing data for all NWPS units in the contiguous United States, a subset of units were chosen to address Objectives 2 & 3 (calculation of development risk index and relative ranking). Wilderness areas intersecting areas already at urban densities or those with essentially no developable land within the LLA, are unlikely to experience exurban development pressure. Removing these units from consideration in the final index prevents some biases in the interpretation of some of the criteria. For instance, at Great Swamp Wilderness just outside of New York City, it is nearly impossible for exurban development to occur as the Census block groups surrounding the Wilderness are already at urban densities. Likewise, road density is largely assumed to be a positive indicator of development risk due to increased access, however at the highest levels, an area may be saturated and no new development would be expected to occur.

Elimination procedure

First, Wilderness areas that are 95% surrounded by federal land or water within the LLA were eliminated on the assumption that housing density will not increase on lands owned by BLM, FS, FWS or NPS. Next, NWPS units that intersect only rural CBGs within the LLA were eliminated because this study focuses on exurban development. Additionally, Wilderness areas that intersected CBGs at urban housing densities were eliminated as urban housing densities were treated as being at carrying capacity for the purposes of this research. The remaining Wilderness areas are ranked based on four criteria; percent of land protected by Wilderness managing agencies and other federal, tribal, state or local entities; distance to the nearest road;

area of water features within each buffer distance; and the transformed value of the sum of enplanements for airports within 50 miles of the NWPS unit.

Resampling

Each criterion was normalized to a zero to one scale, assigning a zero to the minimum value in the range and a one to the maximum value for each metric in each buffer distance. Additionally, for each metric a zero indicates the least likely to contribute to development, whereas a value of one indicates a higher propensity for housing density increase. Thus, if a metric was inversely related to development risk, it was inverted.

For example, development risk increases with a decrease in the distance to the nearest road. This metric was inverted such that an increase (closer to one) indicated Wilderness units that are increasingly closer to roads on average. The index is built on a local level, meaning that the resampled value is scaled to the range of values for each metric in each buffer distance.

For instance, rather than scaling the land ownership metric based on a 0-100% scale, if the largest value for non-protected land is 25% and the lowest value is 5%, the metrics will be resampled so that 5% is equal to zero and 25% is equal to one. Thus, the resampled value = (continuous value - minimum value)/(range of values) for each metric when that metric exhibits a positive linear relationship with development.

For the mean distance to roads metric, the opposite is true. In this case, as the mean distance to roads increases, development likelihood is expected to decrease. Therefore, to capture this inverse relationship the resampled value is subtracted from one. Additionally, to avoid confounding the results, land ownership was divided into two categories: percentage of land within each buffer distance not owned by the four Wilderness managing agencies and percentage of non-federally owned land that receives additional protection through other agencies. To achieve this, the percent of land not protected by any agency (essentially equal to private land) was subtracted from the percent of land not owned by the four Wilderness managing agencies to yield the percent of land in each buffer that is protected by agencies other than the BLM, FS, FWS, and NPS. This figure was then divided by the percent of land not owned by the four Wilderness managing agencies and multiplied by 100. The final result is the percent of non-federal land within each buffer that enjoys additional protection through other entities.

The formulas and values used to calculate the resampled index scores are listed in Table 3. It should be noted that by utilizing this particular scaled resampling approach, the index may only be used to compare Wilderness areas within the same buffer distance.

Table 3. *Formulas and Values Used to Calculate Resampled Index Scores for Each Metric in Each Buffer.*

$RI_{T1} = (T1 - minimum_{T1})/(range_{T1})$
$RI_{T2} = 1 - (T2 - minimum_{T2})/(range_{T2})$
$RI_{W} = (W - minimum_{W})/(range_{W})$
$RI_{RD} = 1 - (RD - minimum_{RD})/(range_{RD})$
$RI_{A} = (A - minimum_{A})/(range_{A})$
RI = Resampled index score
T1 = Value for percent of land not protected by Tier 1 agencies
T2 = Percent of land that receives additional protection from Tier 2 agencies
W = Area of water features
RD = Mean distance to the nearest road
A = Transformed number of enplanements for airports within 50 miles

Creation of Index

Current literature does not quantify the degree to which each metric contributes to the likelihood of development. Thus, this index assumes that each metric affects development equally. The resampled values for each metric were averaged, resulting in an index score that compares NWPS units within each buffer distance. The formula for the comprehensive index (CI) score is: $CI = [(RI_{T1} + RI_{T2} + RI_{W} + RI_{RD} + RI_{A})/5]$. A rank value was assigned to each Wilderness based on the scores for the index. A rank of one indicates the Wilderness area experiencing the greatest average propensity for development based on the index compared with the other seventy NWPS units for the same buffer.

Ranking

Using the comprehensive index score, Wilderness area were rank ordered for each buffer zone. This method assigns each Wilderness area a rank that denotes its risk of exurban development relative to other units in the same buffer. A rank of one indicates the Wilderness area experiencing the greatest average propensity for development based on the index compared with the other NWPS units for the same buffer. This rank ordering provides an assessment of risk at the individual scales. In this manner, it was simple enough to create a list of the Wilderness areas facing the highest risk of development for each independent buffer zone, merely by selecting those units that ranked highest in each zone. However, deciding upon a list of the Wilderness areas facing the greatest overall development risk was difficult.

A multitude of methods exist for determining overall rank, each with various strengths and weaknesses. The simplest method for determining rank that transcends all buffers was to calculate the weighted-average of the rank for each Wilderness in each buffer zone distance. However, inclusion of the ranking of NWPS areas facing development within their borders was problematic due to uncertainty created by the resolution of the Wilderness boundary data and the small relative risk when compared with lands outside the Wilderness boundary. Thus, the overall ranking focuses on borderland development only. Additionally, the landscape level assessment was excluded from the weighted-average ranking because it would have confounded the data through redundancy. The final ranking was determined by taking the comprehensive index score rank that the Wilderness was assigned for each of the zero to half, half to three and three to ten mile buffer zones, multiplying that ranking by the distance of the total (ten mile) buffer that the given buffer zone represents, and dividing by the number of zones included in the analysis. The formula for the weighted mean rank is: $[(Rank_{0\text{-}0.5}*0.05 + Rank_{0.5\text{-}3}*0.25 + Rank_{3\text{-}10}*0.7)/$ number of buffer zones$]$. A lower score indicated a higher propensity for development.

CHAPTER IV

Results

Research Objective 1

Quantification of factors associated with exurban sprawl and amenity migration near Wilderness areas in the contiguous US included several metrics for each NWPS unit in each buffer zone. These metrics were: a) amount and percent of developable land (for both tiers of protection); b) housing density for 2000 CBGs; c) accessibility of Wilderness based on presence of roads and airports; and d) presence of water features.

Wilderness and Land Ownership

Land unprotected by federal Wilderness managing agencies. The amount and percent of the area within Wilderness boundaries and each buffer zone is water or is not managed by BLM, USFS, FWS or NPS was calculated. Because the amount of land was primarily a function of NWPS unit size, only percentages will be discussed. The range of values, as well as the average and median value, for the percentage of land within each buffer zone that is not protected by the Wilderness managing agencies is located in Table 3. Only three Wilderness areas experienced 100% protection of the land within ten miles of their borders: Farallon Wilderness, Isle Royale Wilderness and Jumbo Springs Wilderness. Of these, Farallon and Isle Royale were completely surrounded by water; their protection is a function of separation from the mainland, not federal land ownership. The ten Wilderness areas experiencing the highest and lowest percentages of land managed by Wilderness managing agencies within the LLA are listed in Appendix B.

Table 4. *Percent of Land Not Managed by Wilderness Managing Agencies Within Each Buffer Zone.*

Buffer Distance

	NWPS	0 - 0.5 Mile	0.5 - 3 Miles	3 - 10 Miles	10 Miles
Minimum (%)	0.00	0.00	0.00	0.00	0.00
Maximum (%)	51.37	98.88	100.00	99.86	96.43
Average (%)	2.03	19.45	28.95	41.10	35.97
Median (%)	0.37	11.62	24.38	39.13	32.69

Figure 9 (Appendix C) illustrates the frequency of NWPS units by percentage of unprotected (by Wilderness managing agencies) land within each buffer. Note that the majority of Wilderness areas (71.5% of NWPS) experiences more than 50% protection by Wilderness managing agencies for land within ten miles of the Wilderness boundary. However, for zones closest to the Wilderness boundary (zero, zero to half mile buffer, etc.), the vast majority of NWPS units experience very little unprotected land within the buffer zone. For the larger buffer zones (half to three miles, three to ten miles, LLA), the percent of unprotected land is more equally distributed. The general trend illustrated by this histogram shows that as distance from the Wilderness border increases, the percent of non-protected land increases when comparing the metric at multiple scales. This trend is repeated for frequency distributions for every metric except enplanements, which were transformed, thus figures containing histograms for each metric are omitted as the pattern remains the same. Generally speaking, the potential for development increases in a straight-line distance moving from the Wilderness boundary. This means that the highest percentages of unprotected land (for both tiers), the highest housing

densities, and the shortest mean distance to roads exist in the buffer zones farthest from Wilderness.

Land unprotected by public ownership at federal, state and local scales. The data was analyzed a second time, excluding land owned by BOR, DOD, DOE, BLM, FS, FWS, NPS, TVA, state and local parks (for which vector data is available), tribal lands and all water features from each buffer. The range of values, as well as the average and median value, for the percentage of land within each buffer zone that is not protected by the any federal, state, local or tribal entity, is located in Table 4. The ten Wilderness areas experiencing the highest and lowest percentages of land managed by any agency within the LLA is located in Appendix B.

Table 5. *Percent of Land Not Protected by Any Agency Within Each Buffer Zone.*

Buffer Distance

	NWPS	0 - 0.5 Miles	0.5 - 3 Miles	3 - 10 Miles	10 Miles
Minimum (%)	0.00	0.00	0.00	0.00	0.00
Maximum (%)	51.37	98.88	100.00	98.43	95.39
Average (%)	1.70	15.83	24.27	35.52	31.03
Median (%)	0.20	7.63	18.76	33.10	27.33

Wilderness and Census Data

Census block groups from the year 2000 intersecting each NWPS buffer were analyzed. In many instances, different portions of the same block group intersect more than one Wilderness area buffer; however, an individual block group was considered only once in this analysis regardless of overlap. For reference, average housing density for CBGs in the contiguous US is

2,397.43 units per square mile with a maximum density of 158,362.57 units per square mile. The average population density is 5,842.50 persons per square mile with a maximum of 332,787.16. The median densities for these metrics was not readily available nationwide. The minimum, maximum, average and median values for housing density and population density for CBGs intersecting each buffer distance zone are located in Tables 5 and 6.

Table 6. *Housing Density Values for Census Block Groups Intersecting Each Buffer Zone.*

Buffer Distance

	NWPS	0 - 0.5 Miles	0.5 - 3 Miles	3 - 10 Miles	10 Miles
Minimum (units/sq mi)	0.00	0.00	0.00	0.00	0.00
Maximum (units/sq mi)	1,743.59	3,488.92	7,582.42	30,520.83	30,520.83
Average (units/sq mi)	23.89	65.42	792.14	1,158.04	1,161.18
Median (units/sq mi)	3.63	5.02	28.53	439.62	458.84

Table 7. *Population Density Values for Census Block Groups Intersecting Each Buffer Zone.*

Buffer Distance

	NWPS	0 - 0.5 Miles	0.5 - 3 Miles	3 - 10 Miles	10 Miles
Minimum (person/sq mi)	0.00	0.00	0.00	0.00	0.00
Maximum (person/sq mi)	4,203.70	6,242.05	21,757.86	76,180.36	76,180.36
Average (person/sq mi)	44.49	130.60	792.14	2,944.02	2,949.03
Median (person/sq mi)	5.73	9.16	28.53	1,016.52	1,048.90

National Wilderness Preservation System lands. Of the 600 NWPS units in the contiguous US for which geographic data is available, only 488 are completely surrounded by land in the rural housing density category. Thirty-nine Wilderness areas contain part of a CBG at urban housing densities while 99 NWPS units intersect with CBGs at exurban housing densities. Twenty-six Wilderness areas intersect with both urban and exurban CBGs. Of 1,139 CBGs intersecting a Wilderness area boundary, 70 were at urban housing densities, and 142 block groups are at exurban housing density. The remaining 927 block groups were below the rural housing density threshold.

National Wilderness Preservation System lands buffered zero to one half mile. For the zero to half mile buffer of NWPS, only 448 units were completely surrounded by land in the rural housing density category. Fifty-seven Wilderness areas buffered by zero to one half mile contain part of a CBG at urban housing densities while 138 NWPS units intersect with CBGs at exurban housing densities. However, 43 Wilderness areas intersect with both urban and exurban CBGs for the specified buffer distance. Of 1,424 CBGs intersecting a zero to half mile buffer of Wilderness area boundaries, 165 were at urban housing densities, and 217 block groups were at exurban housing density. The remaining 1,042 block groups were below the rural housing density threshold.

National Wilderness Preservation System lands buffered one half to three miles. Three hundred eighty-one NWPS units buffered one half to three miles were completely surrounded by land in the rural housing density category. One hundred twenty-three Wilderness areas contain part of a CBG at urban housing densities while 214 NWPS units intersect with CBGs at exurban housing densities. However, 118 Wilderness areas intersect with both urban and exurban CBGs. Of 2,742 CBGs intersecting a half to three mile buffer of Wilderness area boundaries, 904 were at urban housing densities, and 461 block groups were at exurban housing density. The remaining 1,377 block groups were below the rural housing density threshold.

National Wilderness Preservation System lands buffered three to ten miles. An analysis of NWPS units buffered three to ten miles yields 250 units completely surrounded by land in the rural housing density category. Three hundred twenty-four Wilderness areas contain part of a CBG at urban housing densities while 364 NWPS units intersect with CBGs at exurban housing densities. However, 338 Wilderness areas intersect with both urban and exurban CBGs. Of 10,897 CBGs intersecting a three to ten mile buffer of Wilderness area boundaries, 7,196 were at urban housing densities, and 1,383 block groups were at exurban housing density. The remaining 2,318 block groups were below the rural housing density threshold.

Landscape Level Assessment of the National Wilderness Preservation System. Of the 600 NWPS units in the contiguous US for which geographic data was available, only 250 were completely surrounded by land in the rural housing density category. Three hundred twenty-four Wilderness areas contain part of a CBG at urban housing densities while 364 NWPS units intersect with CBGs at exurban housing densities. However, 338 Wilderness areas intersect with both urban and exurban CBGs. Analysis was repeated for the 11,165 CBGs intersecting the LLA of NWPS lands. Of these block groups, 7,424 were at urban housing density, 1,409 at exurban density and 2,332 at rural housing density. The ten NWPS units experiencing the highest and lowest average housing densities for CBGs intersecting the LLA is located in Appendix B.

Wilderness and Distance to Roads

The distance to the nearest road was calculated for cells within the borderlands of Wilderness. Distance to the nearest road is considered a more appropriate metric for calculating human disturbance than road density, and also allows comparison with several related studies (Beier et al., 2008; Ritters & Wickham, 2002). Generally, a farther distance to the nearest road signifies a lower the road density of a given area. Less roads mean less access, and thus less likelihood of development.

The mean distance to nearest road (based on 30 m resolution) was reported for each NWPS unit for each buffer distance. Though roads are expressly prohibited within Wilderness areas, some roads do transect NWPS administrative boundaries. Additionally, roads form the boundary line for many NWPS units. Table 7 lists the average, median and range of values for the mean distance to roads for cells within each buffer distance zone.

Table 8. *Mean Distance to Nearest Road for Each Buffer Zone.*

Buffer Distance

	NWPS	0 - 0.5 Miles	0.5 - 3 Miles	3 – 10 Miles	10 Miles
Minimum (mi)	0.14	0.09	0.07	0.06	0.06
Maximum (mi)	16.85	16.93	16.47	14.03	14.67
Average (mi)	1.28	0.75	0.74	0.81	0.81
Median (mi)	0.93	0.47	0.48	0.49	0.51

The minimum mean distance of travel to reach the nearest road was shortest in Cumberland Island Wilderness. In each of the buffer zones outside of NWPS boundaries, Great Swamp National Wildlife Refuge Wilderness had the smallest mean distance to the nearest road, while Farallon Wilderness area had the largest. The ten NWPS units experiencing the highest and lowest mean distances to the nearest road for the LLA are located in Appendix B.

Wilderness and Access to Airports

The number of international and regional/municipal airports within a 50 mile buffer of NWPS units was calculated as regional growth is shown to correlate with the presence of passenger service airports (Aldrich & Kusmin, 1997). Only 99 Wilderness areas lack any passenger service airports within 50 miles of their borders. The median number of airports within a 50 mile buffer of NWPS units is two; in most instances there are more regional and municipal airports within the buffer than there are international airports.

The sum of the enplanements for airports within 50 miles of NWPS boundaries was calculated. For those NWPS units containing airports in this buffer, the sum of total boarded passengers ranged from 109 for Wildernesses near Bishop, CA to more than 37 million for NWPS units in southern California serviced by Los Angeles International in combination with various regional airports. The average number of enplanements was 2.25 million within a 50 mile buffer of NWPS and the median was almost 59,000 passengers. The ten largest airports (in terms of passenger service) within 50 miles of a Wilderness, each with more than 13 million enplanements per year, provide easy access to 58 NWPS areas (Table 19, Appendix B).

Wilderness and Natural Amenities

Presence of water features raises property values and increases likelihood of development due to the aesthetic and recreational values afforded by bays, estuaries, lakes, reservoirs and oceans. Seventy-eight Wilderness areas intersect a water feature, 23 of which intersect an ocean. In the zero to half mile buffer, the number of Wildernesses intersecting water features increases to 112, with 26 intersecting the ocean. For the half to three mile buffer, 193 NWPS units include all or part of a water feature and 30 include the coastline. Three hundred seventeen Wilderness areas contain water features (46 of which are an ocean) in the three to ten mile buffer of their borders. For the LLA of NWPS units, 329 Wilderness areas include portions of a water feature, again with 46 of those Wilderness areas including an ocean. For provision of a continuous variable, the area of water features within each buffer distance was calculated.

Table 9. *Area of Water Features Within Each Buffer Zone.*

	Buffer Distance				
	NWPS	0 - 0.5 Miles	0.5 - 3 Miles	3 - 10 Miles	10 Miles
Minimum (sq mi)	0.00	0.00	0.00	0.00	0.00
Maximum (sq mi)	883.21	82.17	346.64	1,639.33	2,361.23
Average (sq mi)	2.10	0.98	5.86	28.65	37.56
Median (sq mi)	0.00	0.00	0.00	0.41	0.84

Coastal Wilderness areas had much higher amounts of water features within the buffer distances. Within NWPS boundaries the amount of Wilderness that is water is highest within the administrative boundaries of Marjory Stoneman Douglas Wilderness in the Everglades. For buffer zones outside NWPS borders, coastal areas such as Isle Royale Wilderness, Farallon Wilderness, and Oregon Island Wilderness ranked highest. In reality, these Wilderness areas are some of the least likely to face development as they are removed from the mainland and lack a developable land base. These NWPS units are perfect examples of the need to apply selection criteria to the list of Wilderness areas considered and ranked by likelihood of development in the near future.

Research Objective 2

Development of a standardized, repeatable, and updateable method for describing development pressures around selected NWPS lands began with the elimination of areas less likely to experience development based on amount of developable land and current housing densities. Seventy-one Wilderness areas met the selection criteria for further analysis. These NWPS units are less than 95% protected by federal land and contain at least one CBG at exurban density, but no CBGs at urban densities within the LLA.

The frequency distributions for each metric for the 71 selected Wilderness areas are located in Figures 10 through 13 in Appendix C. Due to the fact that the chosen Wilderness areas are located in or near exurban areas, the average values for each metric trend more toward a higher likelihood of development than the system as a whole. This means that, on average, when compared with the system-wide values discussed in the analysis of Research Objective 1, the selected NWPS units exhibit higher percentages of developable land and shorter distances to the nearest road, coupled with moderate amounts of water features and relatively good access to airports.

Figure 10 (Appendix C) illustrates the amount of developable land within the specified buffer distance zones of Wilderness. The two tiers of protection exhibit the same trends when compared at multiple scales, denoting that the additional protection enjoyed by the second tier agencies does not represent a substantial portion of the buffer zone.

The buffer zones including Wilderness boundaries exhibit the lowest amounts of developable land, with most Wilderness areas experiencing less than 20% non-protected lands within half a mile of their borders. The three to ten mile buffer exhibits the highest percentages of non-protected land, with a sharp rise around 50% non-protected. Figure 11 (Appendix C) illustrates the distribution of raw data values for the mean distance to the nearest road for NWPS areas within each buffer zone.

Based on the data for the selected Wilderness areas, no clear relationship exists between mean distance to the nearest road and distance from the NWPS boundary. However, using the resampled index, the mean distance to the nearest road for a given Wilderness area relative to the mean distance to the nearest road for all selected NWPS units is calculable. The same premise holds true for the index scores for developable land and the area of water features.

The frequency distribution for the area of water within buffer zones of selected NWPS units (Figure 12, Appendix C) illustrates that many Wilderness areas have a small amount of water within their buffer zones, but very few have large reserves of water features. As with the other metrics, the data was resampled to calculate the development risk relative to values for each metric within each buffer distance.

The raw data values of the chosen metrics known to influence the likelihood of development were standardized and combined to form an index describing relative risk of development adjacent to NWPS lands. Based on a zero to one scale for each metric (zero being the lowest value present for each metric in each buffer, and one being the highest value), Wilderness areas were ranked based on the highest percentages of developable land, the shortest mean distance to roads, the highest accessibility to passenger service airports and the largest reserves of water features. Then each Wilderness area was assigned a total index score based on an average of the index scores assigned for each of the metrics.

The histograms of the total index score (Figure 13, Appendix C) allow administrators to understand where the top ten highest scores fit into the distribution of index scores across the selected NWPS areas. In some cases, the top four or five stand out well above the rest, while the next several highest ranked, though included in the top ten, have index scores in a bracket that includes many units. In these cases, it may become important to inspect Wilderness areas that rank lower than the top ten, as they face similar threats of development.

Research Objective 3

The NWPS lands meeting selection criteria were ranked hierarchically in terms of relative risk of development. Ranking methodology assigned a resampled index score to NWPS units for each metric known to affect likelihood of development. These scores were used to categorize NWPS units by likelihood of exurban development and then stratify by each zone: land within the NWPS unit and zero to half, half to three, three to ten mile buffers as well as the LLA of each Wilderness area.

Several Wilderness areas rank in the top ten for more than one buffer zone. Kisatchie Hills Wilderness, Hells Canyon Wilderness and Table Rock Wilderness are listed in the top ten rankings for each of the five buffer distances. Juniper Dunes, Swanquarter, Ishi, and Glacier View Wilderness Areas ranked in the top ten for four of the five buffer distances. The Wilderness areas with the ten highest average scores for resampled metrics are reported for each buffer distance in Appendix D.

Deciding upon a list of the top ten Wilderness areas facing borderland development was difficult. The method used in this research calculated the weighted-average of the rank for each Wilderness in each buffer zone distance. The weighted mean rank indicates those Wilderness Areas facing the highest risk of borderland development based on a weighted average of the relative ranking for the Wilderness at multiple scales (Table 10). Vector analyses and GIS images of each of the top ten Wilderness areas listed in Table 10 are located in Appendix E.

Table 10. *The Top Ten Wilderness Areas Facing Borderland Development Based on a Weighted Average of the Relative Ranking for the Wilderness at Multiple Scales.*

Name	Agency	State	0 - 0.5 Rank	0.5 - 3 Rank	3 - 10 Rank	Weighted Mean Rank Score	Weighted Mean Rank
Juniper Dunes Wilderness	BLM	WA	10	2	1	0.5667	1
Hells Canyon Wilderness	BLM	AZ	1	4	2	0.8167	2
Swanquarter Wilderness	FWS	NC	4	3	3	1.0167	3
Table Rock Wilderness	BLM	OR	3	1	7	1.7667	4
Mingo Wilderness	FWS	MO	17	5	5	1.8667	5
Ishi Wilderness	FS	CA	9	11	4	2.0000	6
Kisatchie Hills Wilderness	FS	LA	5	10	6	2.3167	7
Glacier View Wilderness	FS	WA	12	6	10	3.0333	8
Mountain Lakes Wilderness	FS	OR	13	12	9	3.3167	9
Soldier Creek Wilderness	FS	NE	6	8	11	3.3333	10

CHAPTER V

Results and Conclusions

Wilderness and Land Ownership

Though the majority of NWPS units experience less than 35% non-protected land within ten miles of their border, those with private borderlands may experience housing density increases as Americans search for natural areas to build primary, second, vacation and retirement residences. In cases where percentage of non-protected land exceeds 75%, the Wilderness areas are essentially islands of BLM, FS, FWS or NPS land within a privately owned landscape. Hypothetically, some form of development can occur right up to the edges of these NWPS units. Identification of NWPS units with such stores of unprotected land is the first step in protecting areas where additional easements and acquisition may be necessary.

A second tier of protection where housing density increase is unlikely includes land owned by the various federal, state, local or tribal entities as well as protected areas of Canada. Though residential development is often prohibited on these lands, preservation of Wilderness characteristics is not promoted by these agencies and other forms of development (e.g. hydroelectric projects, nuclear facilities, etc.). However, these lands do represent areas where housing density increases are unlikely and the addition of the second tier of development improved the accuracy of the index. Ideally, the protection layers would be subdivided into three or more protection categories to further clarify acceptable or permissible land use occurring on neighboring lands. Information on conservation easements may also be included as geographic data becomes readily available.

Wilderness and Census Data

Both the average and median values for population and housing density for CBGs intersecting each Wilderness buffer increases as the distance from the NWPS border increases. The average housing density for all Wilderness buffers is much lower than the national average per CBG. In fact the highest housing density experienced for CBGs intersecting NWPS lands (1,743.59 units/sq mi) is still much less than the housing density average (2,397.43 units/sq mi) for the contiguous US. However, at the landscape level, housing densities exceeding 30,000 units per square mile exist in CBGs intersecting a ten mile buffer of Wilderness. In light of the nature and values of Wilderness, housing density of such magnitude seems to diminish the purpose and objectives of the NWPS.

Because the presence of homes can drastically affect the ecological and aesthetic integrity of a landscape, knowledge of housing density is important (Radeloff et al., 2005a; Radeloff et al., 2005b; Stein et al., 2005). This research provides an assessment of the 2000 housing and population densities for the NWPS and lands within ten miles of its borders. Future studies may use the baseline data available through this study as a starting point for modeling housing density increases and forecasting development.

Wilderness and Roads

Roads were, for the most part, absent from within the boundaries of many Wilderness areas. However, when analyzed within the borderland zones, roads were pervasive in the buffers of most NWPS units. These roads provide access for visitors, as well as commercial and residential development. In fact, only within the boundaries of one mainland NWPS unit, Teton Wilderness, does the maximum distance to the nearest road exceed 20 miles.

Ritters & Wickham (2003) measured the proportion of land located within several distances (between 127-5176 m) of the nearest road and determined that regions that experience more than 60% of total land area within 382 m of the nearest road may risk the greatest ecological impacts from roads. For the ten mile buffer of NWPS, 89 Wilderness areas have a mean distance to the nearest road below 382 m; nine Wilderness areas experience a mean distance to the nearest road below this value within their borders. Overall, only three percent of the land base in America is located more than 5,176 m from the nearest road (Ritters & Wickham, 2003). Surprisingly, only 209 Wilderness areas (35% of NWPS) contain any parcel (at 30 m resolution) that exceeds 5,176 meters to the nearest road. When averaged within the buffer, the mean distance to the nearest road does not exceed 5,176 m for any Wilderness area in any buffer zone. The NWPS, a category of land that expressly prohibits roads, was expected to greatly exceed the national average for the farthest distances to the nearest road. However, the data indicates that lands within the boundaries of the NWPS are only slightly farther from the nearest road than in comparison with the contiguous US.

When planning for a Wilderness area, consideration should be given to the spatial distribution of these roads on a local level. Additionally, future consideration of the size and traffic capacity of the road may improve this index. Datasets that contains the most up-to-date road network, including unimproved roads, will assist in painting a clearer picture of the accessibility of the NWPS. Although utilizing the mean distance to the nearest road for a large buffer may generalize the road network by averaging roads across a large area, this metric is useful in determining patterns of access.

Wilderness and Airports

The NWPS is, overall, quite accessible by air travel; 501 Wilderness areas have at least one passenger service airport within 50 miles of their borders. Certainly the hub size, number of connecting flights and price of travel will affect access for visitors and homeowners to these Wilderness areas. The decision to use enplanements within a 50 mile buffer, rather than the number of airports allowed for calculation of a continuous variable that reflects the greater influence exerted by larger airports. However, the presence of large passenger service airports may not accurately reflect the amount of visitation a particular Wilderness experiences. Additional research may allow estimation of the influence that airports exert on Wilderness visitation and the potential for development.

Wilderness and Natural Amenities

Inclusion of the affect natural amenities exert on amenity migration allowed for a better estimation of areas with draws in addition to public land designation. While water is certainly not the only natural amenity attracting visitors or settlers to natural areas, it is a strong attractor nationwide (Deller et al., 2001; Gude et al., 2006). Also, data was readily available for hydrologic features in the US. An inclusive study may also include information on climate, cultural resources, seasonal recreational opportunities, topography, and land value (Aldrich & Kusmin, 1997; Deller et al., 2001; Kozak & Rimmington, 1999). However, information such as presence of ski resorts or the number of heating and cooling days per year, while critical for certain areas, would confound a national study such as this one, due to regional variation. Essentially, though presence of ski areas would enhance the development risk for a parcel of land near Wilderness in areas such as the Rocky Mountain West, this metric is not useful for determining relative risk because many Wilderness units are not proximal to ski amenities.

Ranking

This research represents a national analysis of development risk to Wilderness. Based on available geographic data, the study identified metrics that could be incorporated at the national level; however, certain excluded metrics may be important to improving the index, especially at a local or regional scale. The ranking methodology employed in this research compared Wilderness areas within the same buffer distance based on the range of values for each metric within that buffer distance. Consideration was given to the creation of a global index, however, problems arose in the delineation of maximum values for each metric. Additionally, as the purpose of this study was to rank NWPS units on the likelihood of development, the local model is purported to more accurately capture the processes affecting development within each buffer distance. Ultimately, this index requires slight modification to compare additional NWPS units or to compare across spatial and temporal scales.

Certain patterns may exist for Wilderness areas experiencing a relatively high risk of development. Interestingly enough, five of the top ten (Table 9) Wilderness areas are located in the West Coast region, an area highlighted for characterizing the wildland-urban interface (Radeloff et al., 2005b). Future research may quantify threshold values for each metric that prove useful in determining the risk of future housing density increase.

The methods used in this research provided a starting point for identifying areas with relative high or low risk at various scales. However, knowledge of the methodology is important before translating the assigned rank or index score into tangible conservation goals.

Applicability of the Index

Currently, the implications of rural and exurban land use on Wilderness lack definition and significant research. The findings presented in this paper may aid land management agencies and stakeholders in preventing conversion of these natural lands. Future research may quantify threshold values for each metric that prove useful in determining the risk of future housing density increase. Ultimately, this index requires slight modification to compare additional NWPS units or to compare across spatial and temporal scales. Inclusion of other disciplines, such as principles of landscape ecology, is also encouraged. This includes the ability to link or connect Wilderness areas with other critical habitat to promote corridors for wildlife as well as consideration of the existing structure of the landscape (Hudson, 1993). Identification of stakeholders in land preservation, such as Non-government organizations, and State and local governments, as well as programs such as the Conservation Reserve Program will increase the ability to plan for and execute landscape level protection of the NWPS (Johnson & Maxwell, 2001). Non-profit organizations such as The Nature Conservancy, Sierra Club or the Campaign for America's Wilderness may find this paper of use in prioritizing lands for conservation or acquisition of lands adjoining Wilderness.

While the index developed herein has limitations, it represents a strong starting point, containing measured attributes supported by the literature as elements nationally influencing exurban development patterns. The data and analyses provided by this research are the first step in understanding of the development risks facing the National Wilderness Preservation System. The baseline data acquired from this study is helpful for Wilderness planning. Wilderness managers are encouraged to use data produced in this research, in conjunction with local scale data, (such as infrastructure, land values or zoning restrictions) to fully understand development pressures facing a given NWPS unit. A subset of the data provided through this research can be easily analyzed to produce an analysis of risk of development to NWPS by agency, geographic region, ecoregion, etc. based on the needs of local, state or federal agencies.

By merging Census data with spatial patterns of development, this and other studies can provide a method for ascertaining which protected areas are most at risk, thus targeting locations where action is most necessary and improving strategies for conservation and protection (Saving & Greenwood, 2002; Theobald, 2003). This study has described the relationship between areas in the NWPS and the spatial pattern of exurban development in the contiguous United States, and identified Wilderness areas most likely to be at relative risk from development on adjacent lands. The data and analyses provided by this research are the gateway to understanding external risks facing the NWPS. Furthermore, an understanding of the implications of private land development on the surrounding protected landscape is necessary in order to preserve the natural resource values afforded by American public lands. Hopefully the findings presented in this research will contribute to a broader dialog that also considers other elements essential to conservation planning, in an effort to protect the unique values afforded by American public lands.

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APPENDIX A

Geographic Data and Sources

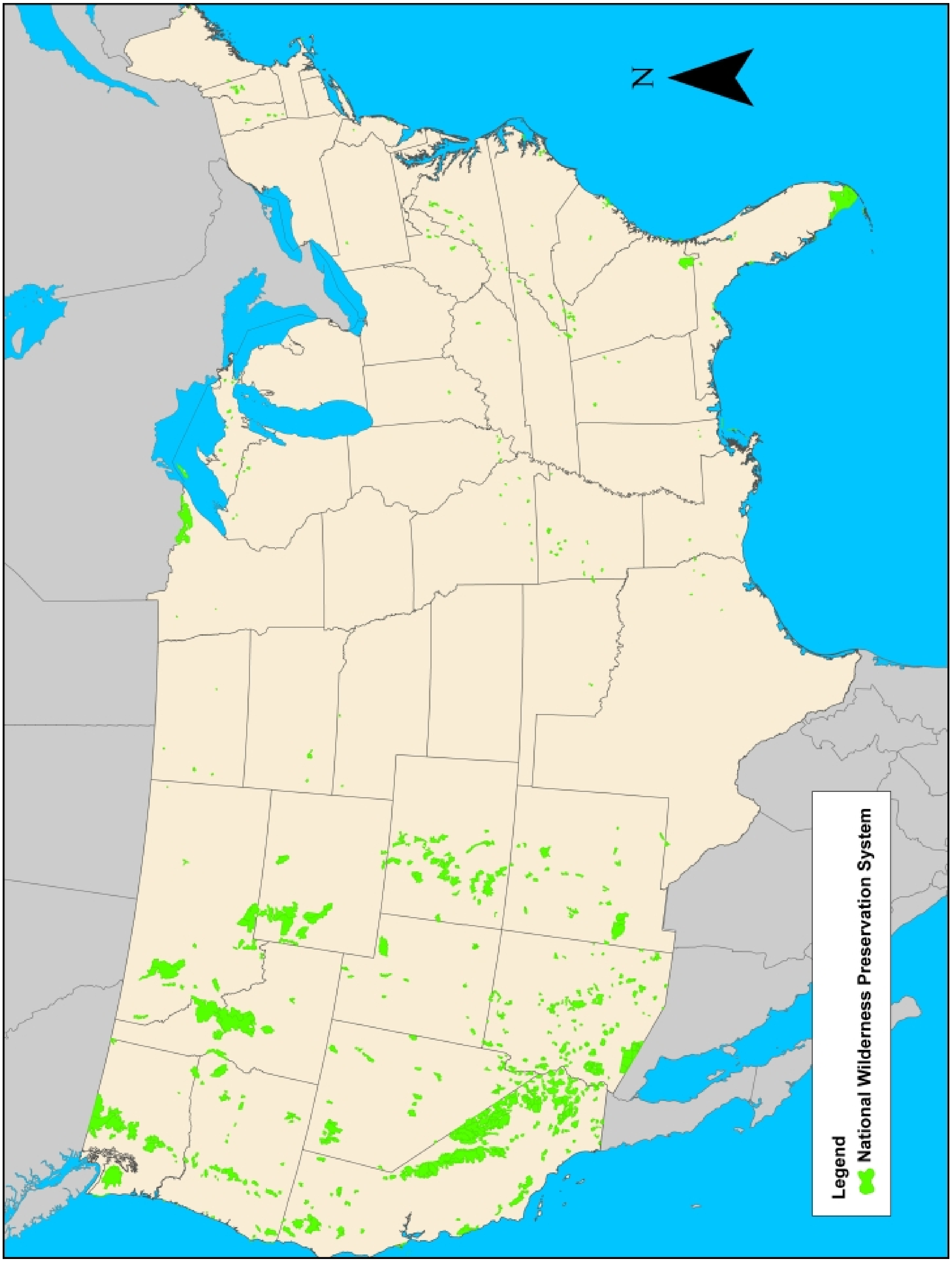

Figure 1. National Wilderness Preservation System Units in the Contiguous United States.

Figure 2. Census Geography Hierarchy.

Note. From “Census Geography” by the United States Census Bureau, 2005, American Fact Finder, Washington, D.C. © 2005 US Census Bureau. Reprinted with permission.

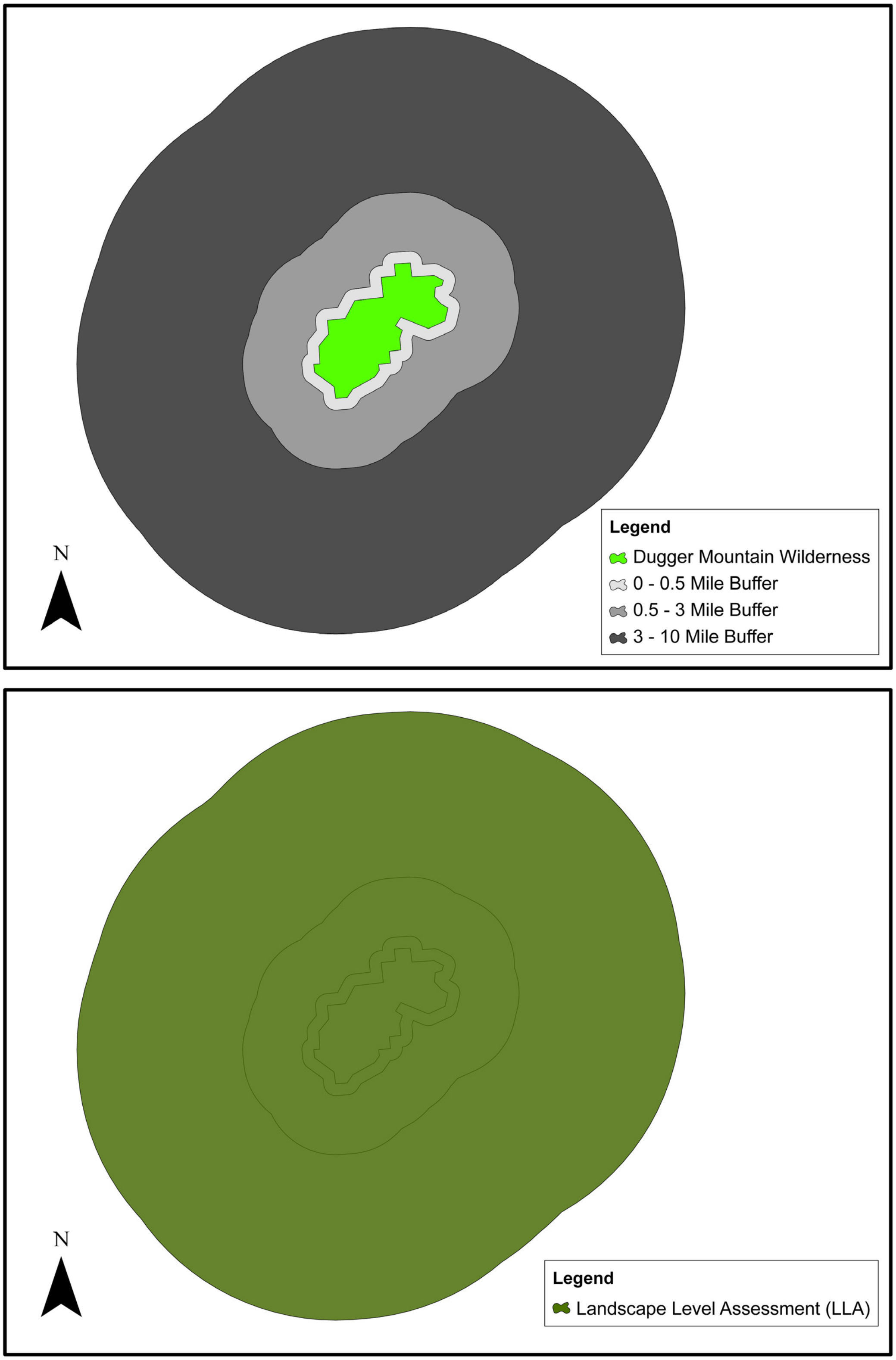

Figure 3. Example of Buffers Around a National Wilderness Preservation System Unit.

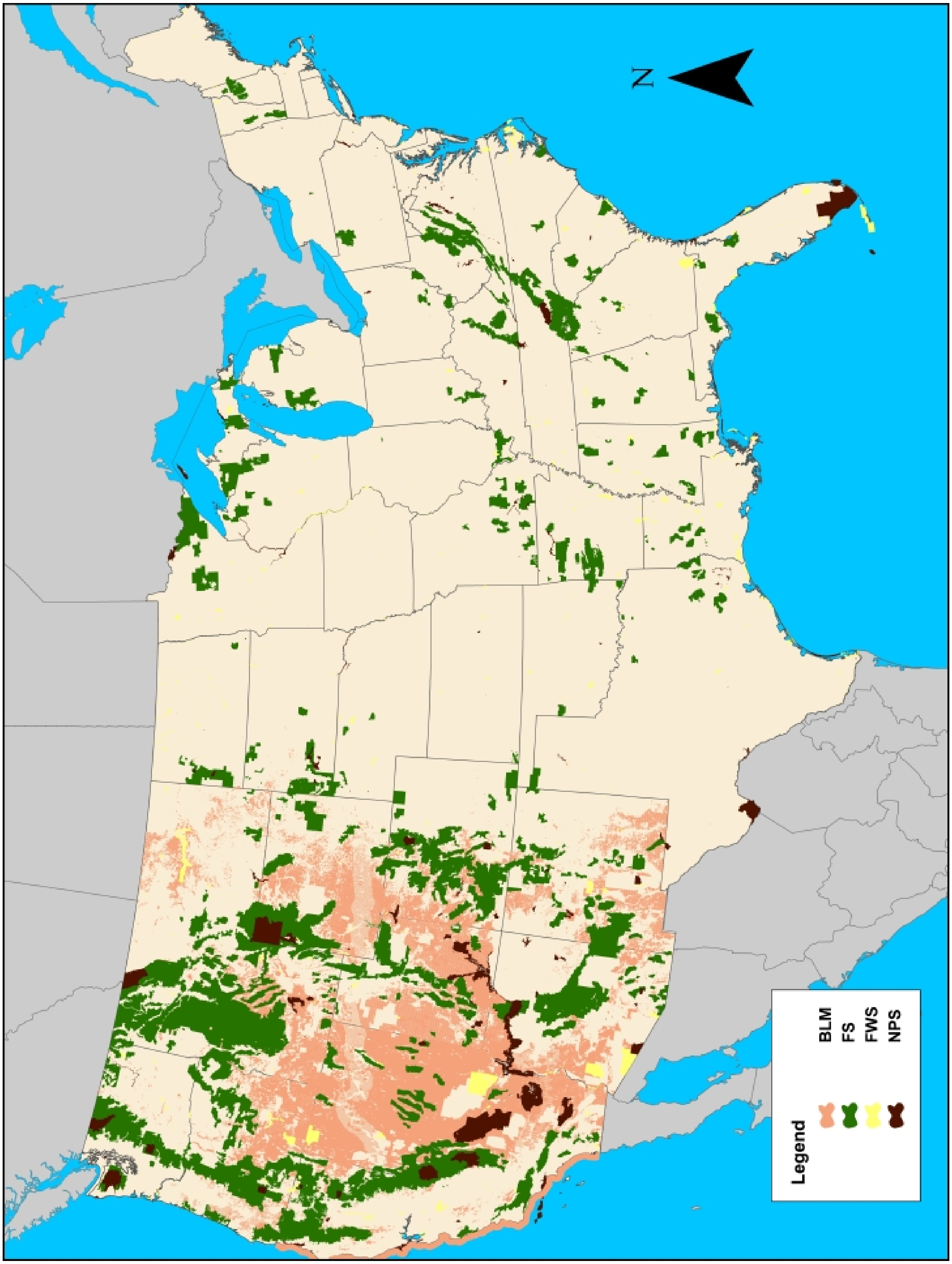

Figure 4. Lands Owned by Wilderness Managing Agencies in the Contiguous United States.

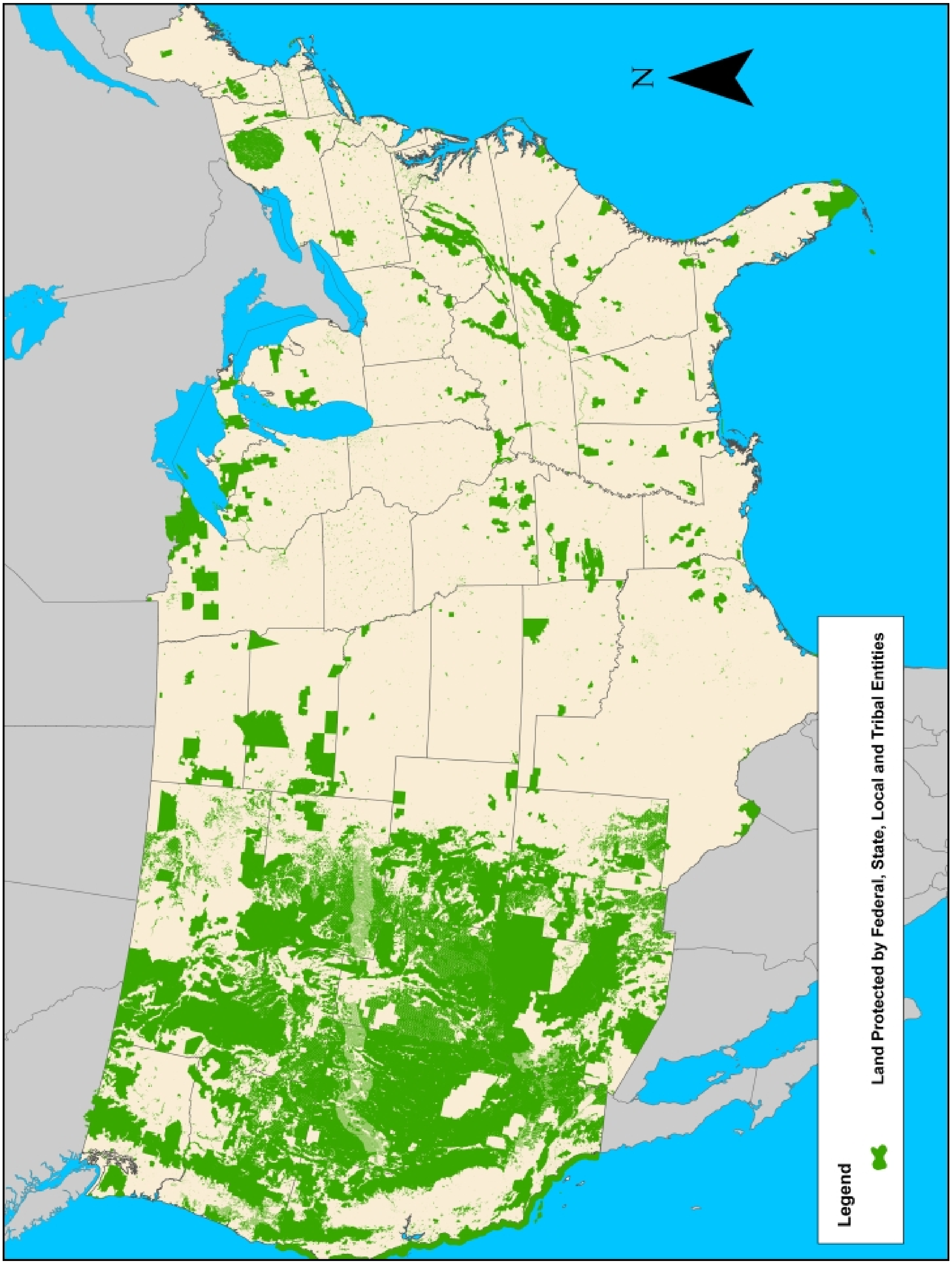

Figure 5. Land Owned by Federal, State, Local or Tribal Entities in the Contiguous United States

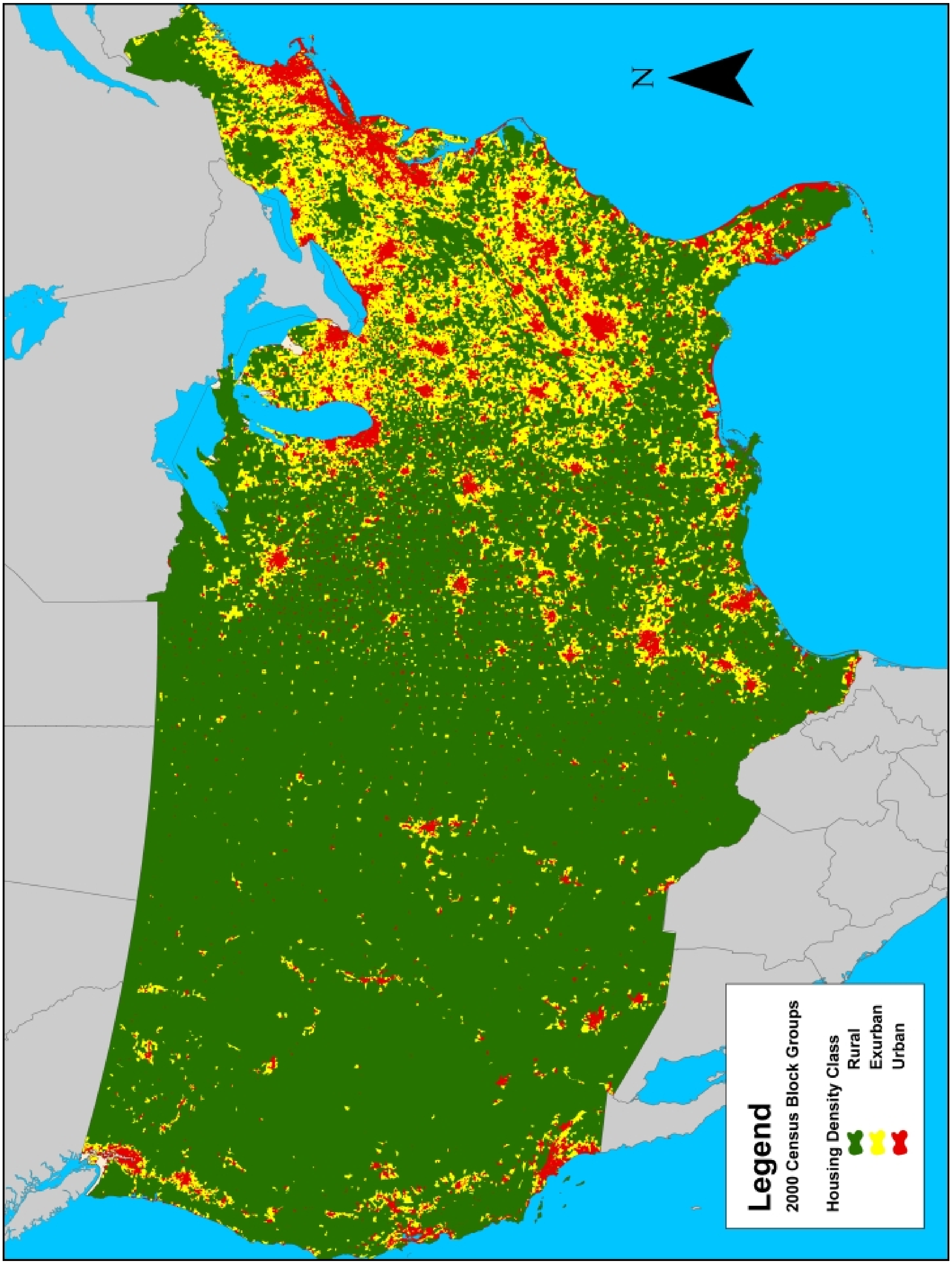

Figure 6. 2000 Census Block Groups of the Contiguous United States by Housing Density Class.

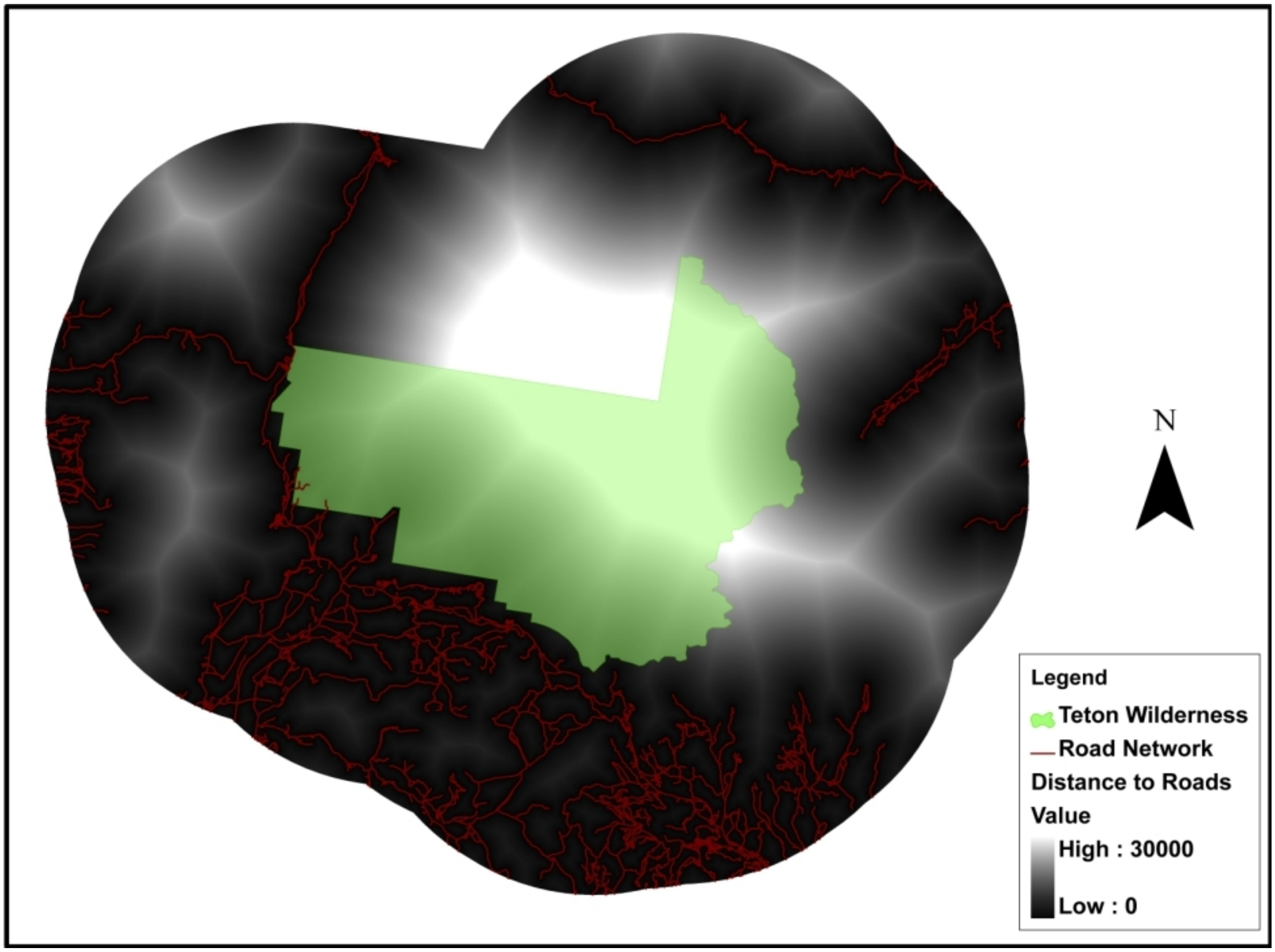

Figure 7. Example of Distance to Nearest Road Calculation.

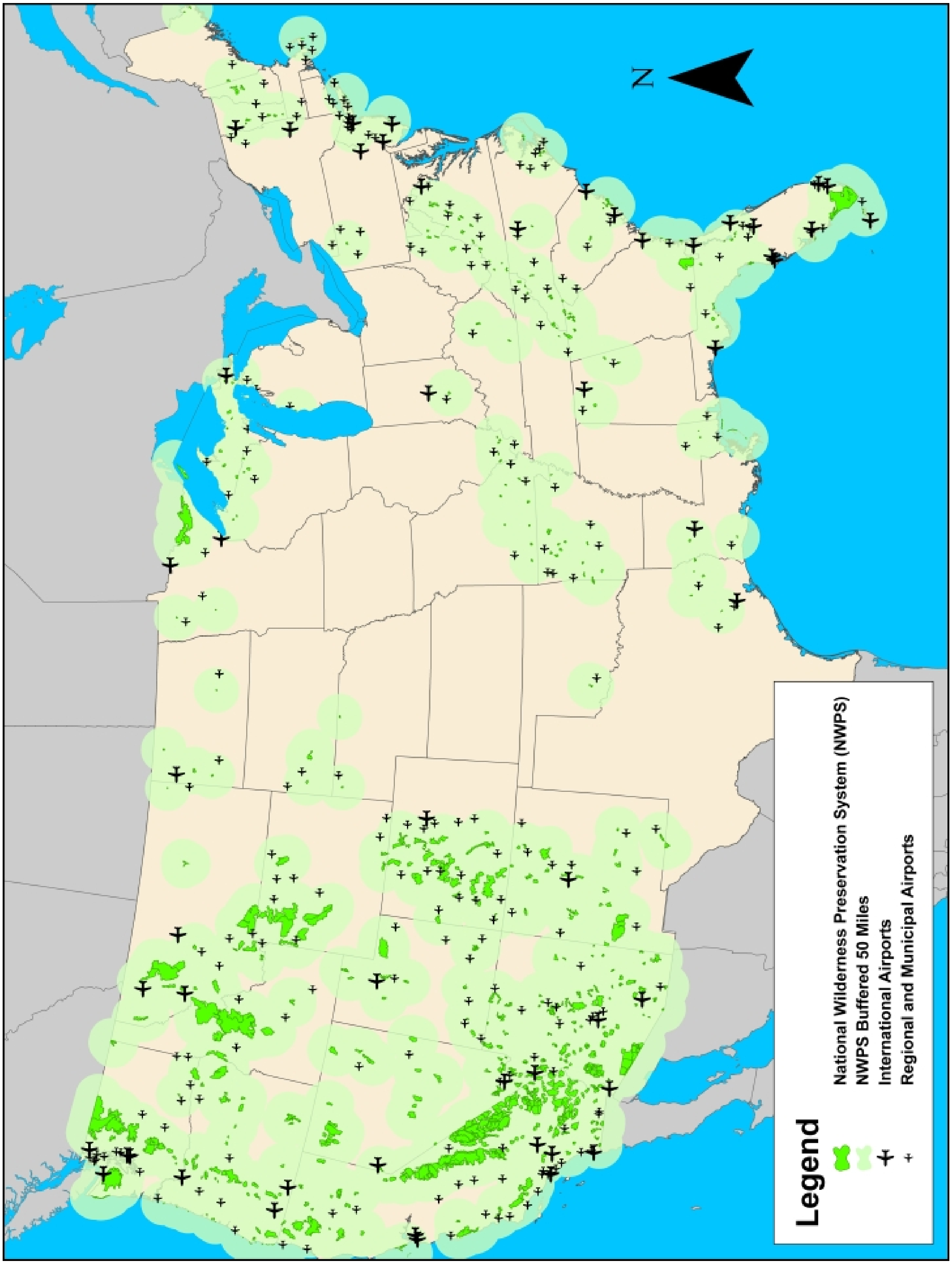

Figure 8. Airports Within 50 Miles of Wilderness.

APPENDIX B

Summary of National Analyses

Table 11. *The Ten Wilderness Areas With the Lowest Percentages of Land Not Managed by the Four Wilderness Managing Agencies Within the Landscape Level Assessment*

Name	Agency	State	Percent Not Protected (%)
Farallon Wilderness	FWS	CA	0.00
Isle Royale Wilderness	NPS	MI	0.00
Jumbo Springs Wilderness	BLM	NV	0.00
South Jackson Mountains Wilderness	BLM	NV	0.28
Grand Wash Cliffs Wilderness	BLM	AZ	0.28
Pine Mountain Wilderness	FS	AZ	0.35
Waldo Lake Wilderness	FS	OR	0.40
Calico Mountains Wilderness	BLM	NV	0.58
Frank Church-River of No Return Wilderness	BLM/FS	ID	0.58
South McCullough Wilderness	BLM	NV	0.66

Table 12. *The Ten Wilderness Areas With the Highest Percentages of Land Not Managed by the Four Wilderness Managing Agencies Within the Landscape Level Assessment*

Name	Agency	State	Percent Not Protected (%)
Lostwood Wilderness	FWS	ND	90.43
Pinnacles Wilderness	NPS	CA	92.17
Congaree National Park Wilderness	NPS	SC	93.25
McCormick Wilderness	FS	MI	93.32
Birkhead Mountains Wilderness	FS	NC	93.80
Fort Niobrara Wilderness	FWS	NE	93.85
Big Lake Wilderness	FWS	AR	95.28
Chase Lake Wilderness	FWS	ND	95.39
Coyote Mountains Wilderness	BLM	AZ	96.16
Great Swamp National Wildlife Refuge Wilderness	FWS	NJ	96.44

Table 13. *The Ten Wilderness Areas With the Lowest Percentages of Non-Protected Land Ownership Within the Landscape Level Assessment*

Name	Agency	State	Percent Not Protected (%)
Farallon Wilderness	FWS	CA	0.00
Jumbo Springs Wilderness	BLM	NV	0.00
Isle Royale Wilderness	NPS	MI	0.00
Jimbilnan Wilderness	NPS	NV	0.07
Lime Canyon Wilderness	BLM	NV	0.14
South Jackson Mountains Wilderness	BLM	NV	0.28
Grand Wash Cliffs Wilderness	BLM	AZ	0.28
Bear Wallow Wilderness	FS	AZ	0.29
Pine Mountain Wilderness	FS	AZ	0.35

Table 14. *The Ten Wilderness Areas With the Highest Percentages of Non-Protected Land Ownership Within the Landscape Level Assessment*

Name	Agency	State	Percent Not Protected (%)
McCormick Wilderness	FS	MI	85.86
Soldier Creek Wilderness	FS	NE	87.13
Juniper Dunes Wilderness	BLM	WA	88.82
Lostwood Wilderness	FWS	ND	90.43
Great Swamp National Wildlife Refuge Wilderness	FWS	NJ	91.09
Pinnacles Wilderness	NPS	CA	92.10
Congaree National Park Wilderness	NPS	SC	92.87
Birkhead Mountains Wilderness	FS	NC	93.24
Big Lake Wilderness	FWS	AR	93.81
Chase Lake Wilderness	FWS	ND	95.39

Table 15. *The Ten Wilderness Areas With the Lowest Weighted-Average Housing Density for Census Block Groups Intersecting the Landscape Level Assessment*

Name	Agency	State	Average Housing Density (units/mi^2)
Farallon Wilderness	FWS	CA	0.0000
Breton Wilderness	FWS	LA	0.0125
Cabeza Prieta Wilderness	FWS	AZ	0.0203
Piute Mountains Wilderness	BLM	CA	0.0273
Old Woman Mountains Wilderness	BLM	CA	0.0315
Clipper Mountain Wilderness	BLM	CA	0.0518
High Rock Canyon Wilderness	BLM	NV	0.0529
Cadiz Dunes Wilderness	BLM	CA	0.0539
Little High Rock Canyon Wilderness	BLM	NV	0.0559
Trilobite Wilderness	BLM	CA	0.0582

Table 16. *The Ten Wilderness Areas With the Highest Weighted-Average Housing Density for Census Block Groups Intersecting the Landscape Level Assessment*

Name	Agency	State	Average Housing Density (units/mi^2)
Brigantine Wilderness	FWS	NJ	268.1113
Cucamonga Wilderness	FS	CA	286.6084
Pusch Ridge Wilderness	FS	AZ	321.2895
Otay Mountain Wilderness	BLM	CA	338.6187
Twin Peaks Wilderness	FS	UT	422.2316
Monomoy Wilderness	FWS	MA	424.1718
Fire Island Wilderness	NPS	NY	452.6808
Mount Olympus Wilderness	FS	UT	477.8987
J.N. "Ding" Darling Wilderness	FWS	FL	535.9228
Great Swamp National Wildlife Refuge Wilderness	FWS	NJ	825.2822

Table 17. *The Ten Wilderness Areas With the Lowest Mean Distance to the Nearest Road for the Landscape Level Assessment*

Name	Agency	State	Mean Distance to Nearest Road (mi)
Great Swamp National Wildlife Refuge Wilderness	FWS	NJ	0.0623
Bay Creek Wilderness	FS	IL	0.1175
Crab Orchard Wilderness	FWS	IL	0.1267
Cucamonga Wilderness	FS	CA	0.1314
Brasstown Wilderness	FS	GA	0.1321
Glacier View Wilderness	FS	WA	0.1409
Gee Creek Wilderness	FS	TN	0.1456
Saint Mary's Wilderness	FS	VA	0.1503
Bull of the Woods Wilderness	FS	OR	0.1574
Clearwater Wilderness	FS	WA	0.1575

Table 18. *The Ten Wilderness Areas With the Highest Mean Distance to the Nearest Road for the Landscape Level Assessment*

Name	Agency	State	Mean Distance to Nearest Road (mi)
Marjory Stoneman Douglas Wilderness	NPS	FL	4.8391
Cummins Creek Wilderness	FS	OR	5.0710
Teton Wilderness	FS	WY	5.2108
Cape Romain Wilderness	FWS	SC	5.5863
Cedar Keys Wilderness	FWS	FL	5.7204
Mount Adams Wilderness	FS	WA	7.8309
Gulf Islands Wilderness	NPS	MS	8.3201
Isle Royale Wilderness	NPS	MI	10.3384
Breton Wilderness	FWS	LA	13.0395
Farallon Wilderness	FWS	CA	14.6673

Table 19. *The Ten Largest Airports Within 50 Miles of the National Wilderness Preservation System and Associated Wilderness Areas*

Airport	Enplanements	Wilderness Areas Within 50 Miles
Los Angeles International	26239584	Cucamonga Wilderness
		San Gabriel Wilderness
		Sespe Wilderness
		Sheep Mountain Wilderness
Phoenix Sky Harbor International	18252853	Castle Creek Wilderness
		Four Peaks Wilderness
		Hells Canyon Wilderness AZ
		Mazatzal Wilderness
		North Maricopa Mountains Wilderness
		Sierra Estrella Wilderness
		South Maricopa Mountains Wilderness
		Superstition Wilderness
		Table Top Wilderness
		Woolsey Peak Wilderness
Denver International	17969754	Indian Peaks Wilderness
		James Peak Wilderness
		Mount Evans Wilderness
Mc Carran International	17097738	Arrow Canyon Wilderness
		Black Canyon Wilderness

Airport	Enplanements	Wilderness Areas Within 50 Miles
Mc Carran International (cont.)	17097738	Eldorado Wilderness
		Ireteba Wilderness
		Jimbilnan Wilderness
		Kingston Range Wilderness
		La Madre Mountain Wilderness
		Lime Canyon Wilderness
		Mesquite Wilderness
		Mojave Wilderness
		Mount Wilson Wilderness
		Mt. Charleston Wilderness
		Muddy Mountains Wilderness
		Nellis Wash Wilderness
		Nopah Range Wilderness
		North McCullough Wilderness
		North Mesquite Mountains Wilderness
		Pahrump Valley Wilderness
		Pinto Valley Wilderness
		Rainbow Mountain Wilderness
		South McCullough Wilderness
		Stateline Wilderness
		Wee Thump Joshua Tree Wilderness
Houston Intercontinental	16134684	Little Lake Creek Wilderness

Airport	Enplanements	Wilderness Areas Within 50 Miles
Newark International	14628708	Great Swamp National Wildlife Refuge Wilderness
Miami International	14198321	Marjory Stoneman Douglas Wilderness
San Francisco International	14079173	Farallon Wilderness
		Phillip Burton Wilderness
Orlando International	13375162	Alexander Springs Wilderness
		Billies Bay Wilderness
		Lake Woodruff Wilderness
Seattle - Tacoma International	13109153	Alpine Lakes Wilderness
		Clearwater Wilderness
		Colonel Bob Wilderness
		Glacier View Wilderness
		Mount Rainier Wilderness
		Mount Skokomish Wilderness
		Norse Peak Wilderness
		Olympic Wilderness
		The Brothers Wilderness

APPENDIX C

Frequency Distributions of Values of Metrics

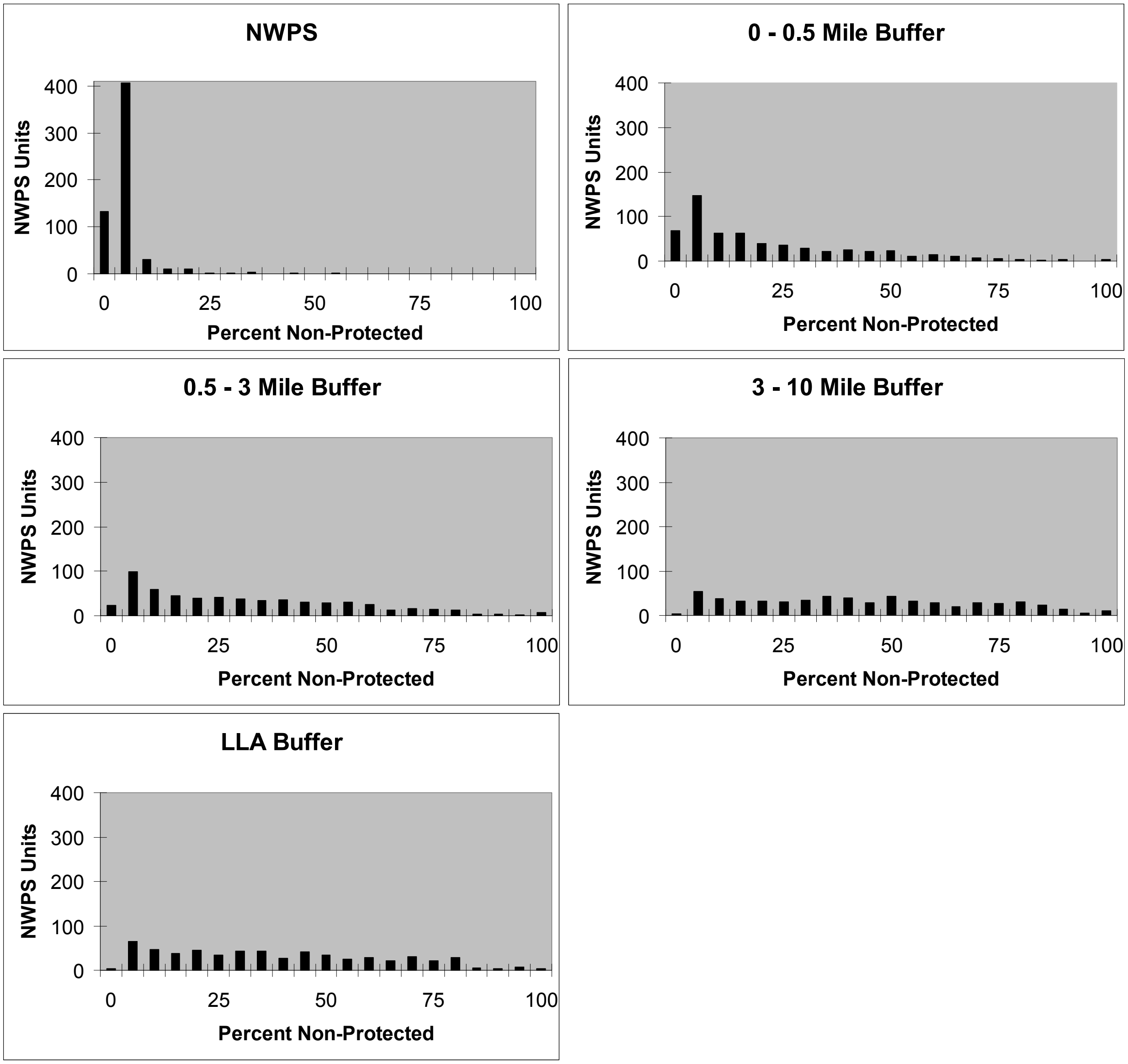

Figure 9. Frequency Distributions for Wilderness Based on Percent of Land Not Managed by the Four Wilderness Managing Agencies for Each Buffer Zone.

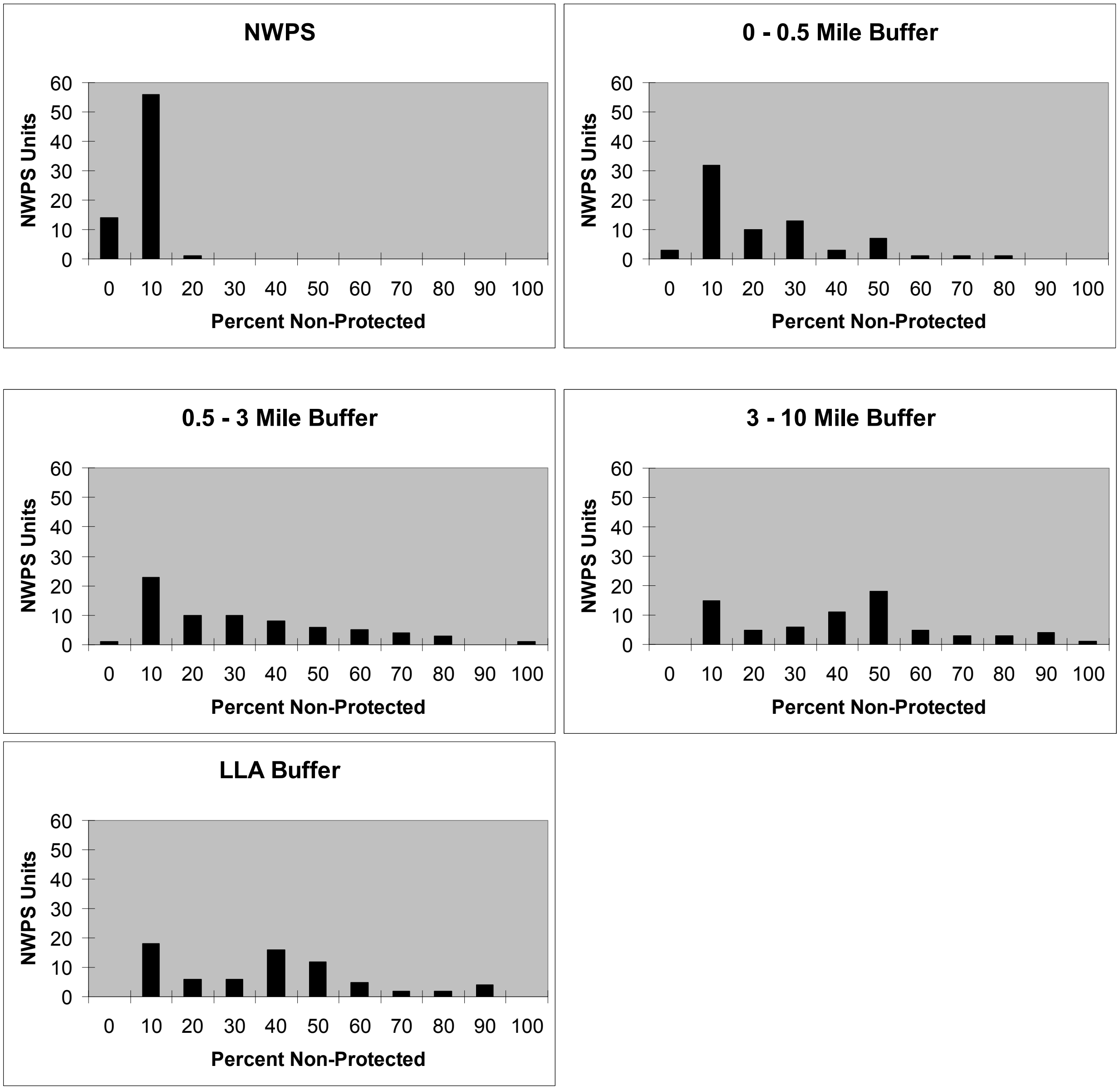

Figure 10. Frequency Distribution of Percent of Land Not Protected by Any Agency for Each Buffer Zone of Selected Wilderness Areas.

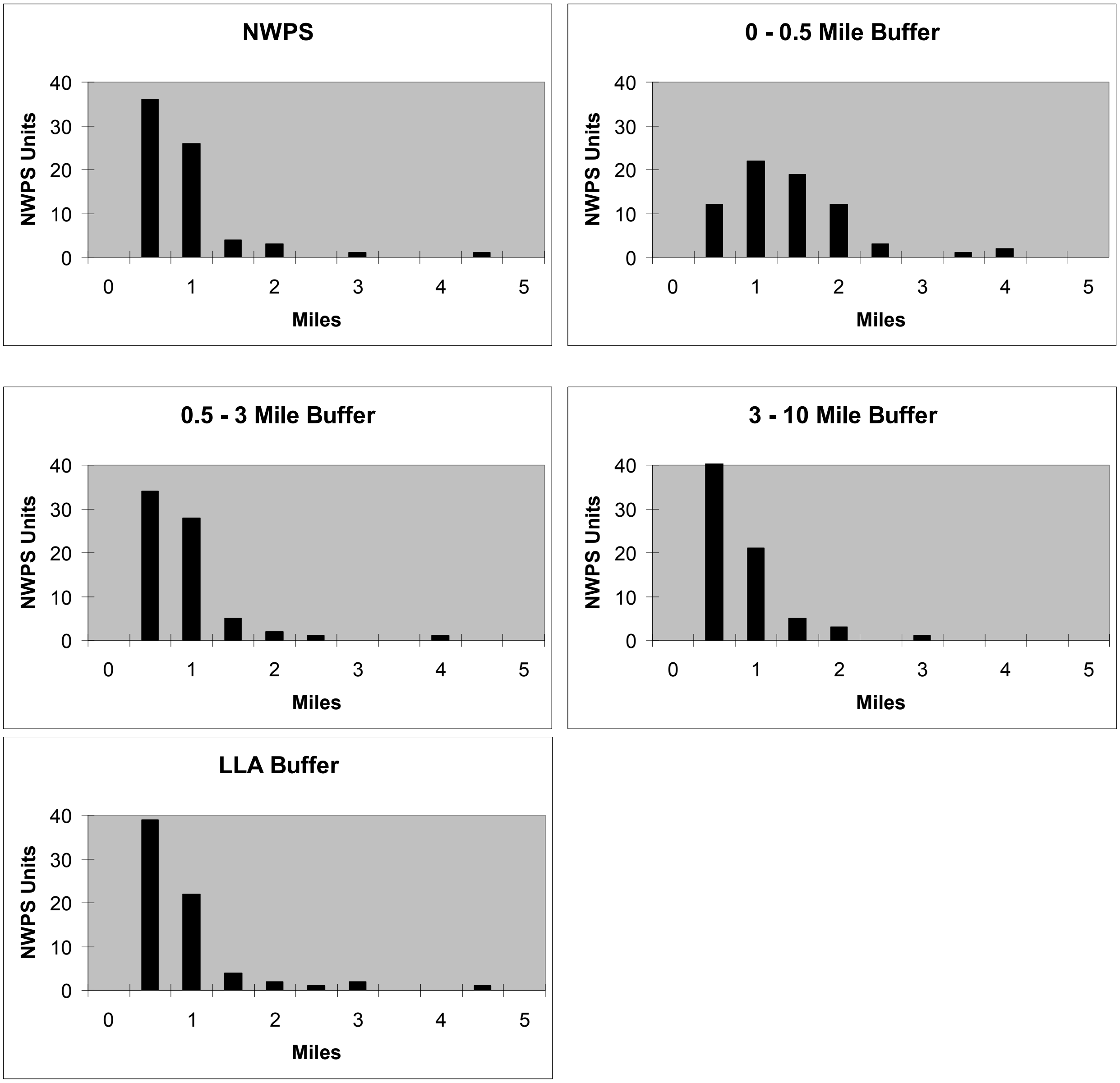

Figure 11. Frequency Distribution of Mean Distance to the Nearest Road for Each Buffer Zone of Selected Wilderness Areas.

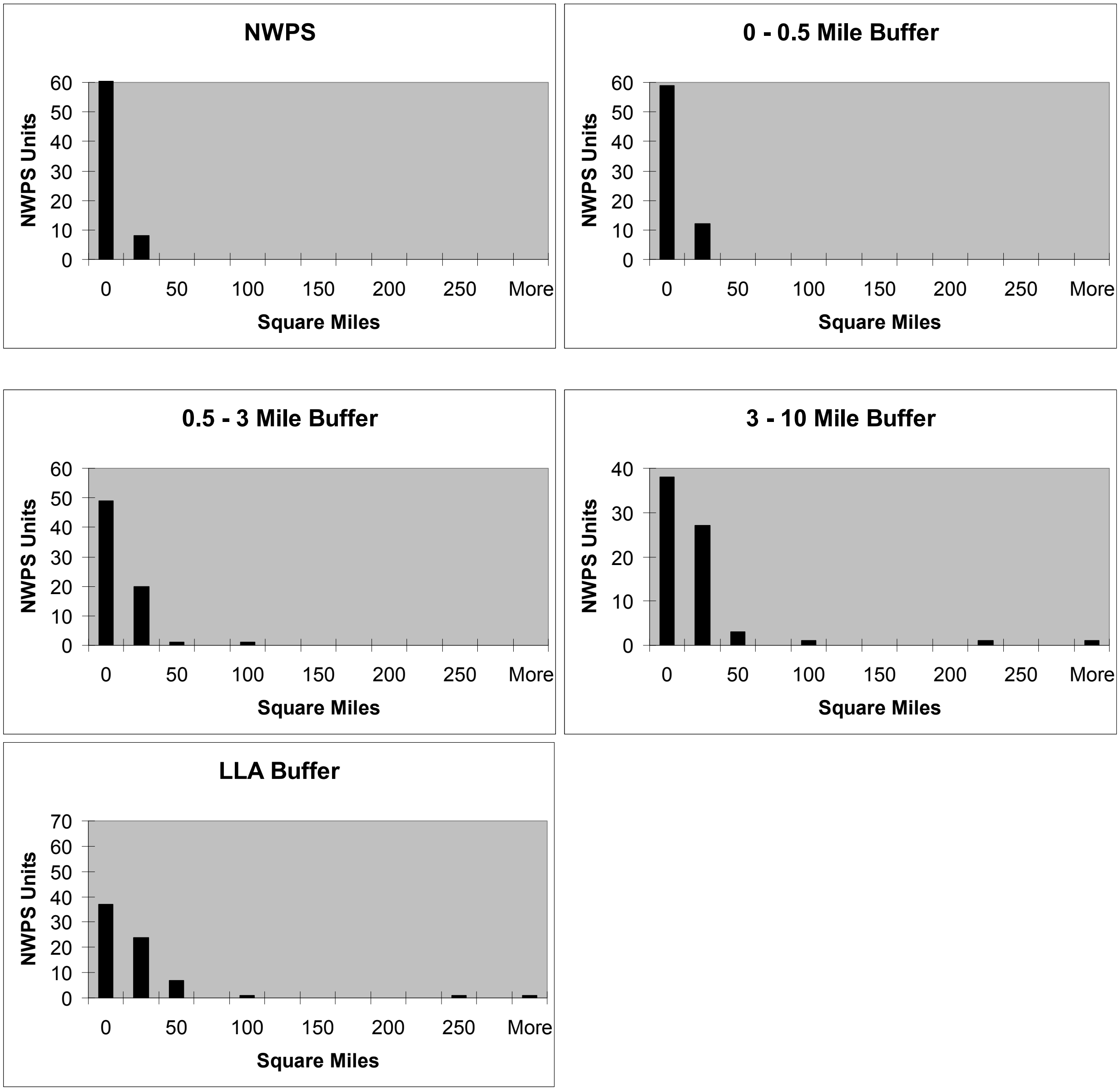

Figure 12. Frequency Distribution of the Area of Water Features for Each Buffer Zone of Selected Wilderness Areas.

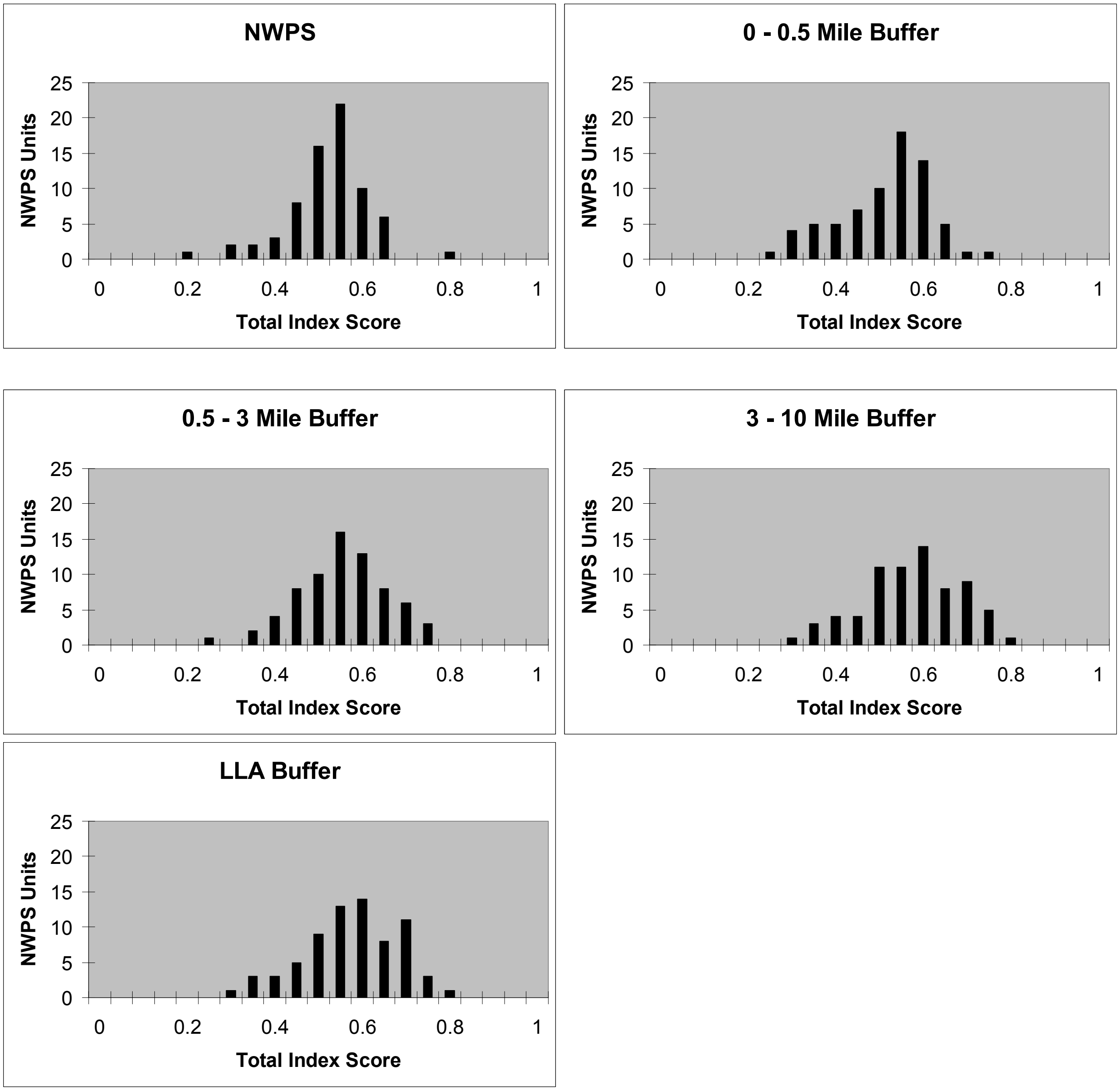

Figure 13. Frequency Distribution of Total Index Score for Each Buffer Distance of Selected Wilderness Areas.

APPENDIX D

Summary of Ranked Analyses

Table 20. *Top Ten Ranked Wilderness Areas for the National Wilderness Preservation System Boundaries*

Name	Agency	State	Rank
Sylvania Wilderness	FS	MI	1
Kisatchie Hills Wilderness	FS	LA	2
Big Island Lake Wilderness	FS	MI	3
Ishi Wilderness	FS	CA	4
Glacier View Wilderness	FS	WA	5
Hells Canyon Wilderness	BLM	AZ	6
Table Rock Wilderness	BLM	OR	7
North Maricopa Mountains Wilderness	BLM	AZ	8
Menagerie Wilderness	FS	OR	9
Upper Kiamichi River Wilderness	FS	OK	10

Table 21. *Top Ten Ranked Wilderness Areas for the Zero to One Half Mile Buffer of the National Wilderness Preservation System*

Name	Agency	State	Rank
Hells Canyon Wilderness	BLM	AZ	1
Blackbeard Island Wilderness	FWS	GA	2
Table Rock Wilderness	BLM	OR	3
Swanquarter Wilderness	FWS	NC	4
Kisatchie Hills Wilderness	FS	LA	5
Soldier Creek Wilderness	FS	NE	6
Black Mountain Wilderness	BLM	CA	7
Sylvania Wilderness	FS	MI	8
Ishi Wilderness	FS	CA	9
Juniper Dunes Wilderness	BLM	WA	10

Table 22. *Top Ten Ranked Wilderness Areas for the One Half to Three Mile Buffer of the National Wilderness Preservation System*

Name	Agency	State	Rank
Table Rock Wilderness	BLM	OR	1
Juniper Dunes Wilderness	BLM	WA	2
Swanquarter Wilderness	FWS	NC	3
Hells Canyon Wilderness	BLM	AZ	4
Mingo Wilderness	FWS	MO	5
Glacier View Wilderness	FS	WA	6
Sylvania Wilderness	FS	MI	7
Soldier Creek Wilderness	FS	NE	8
Blackbeard Island Wilderness	FWS	GA	9
Kisatchie Hills Wilderness	FS	LA	10

Table 23. *Top Ten Ranked Wilderness Areas for the Three to Ten Mile Buffer of the National Wilderness Preservation System*

Name	Agency	State	Rank
Juniper Dunes Wilderness	BLM	WA	1
Hells Canyon Wilderness	BLM	AZ	2
Swanquarter Wilderness	FWS	NC	3
Ishi Wilderness	FS	CA	4
Mingo Wilderness	FWS	MO	5
Kisatchie Hills Wilderness	FS	LA	6
Table Rock Wilderness	BLM	OR	7
Mill Creek Wilderness	FS	OR	8
Mountain Lakes Wilderness	FS	OR	9
Glacier View Wilderness	FS	WA	10

Table 24. *Top Ten Ranked Wilderness Areas for the Landscape Level Assessment of the National Wilderness Preservation System*

Name	Agency	State	Rank
Juniper Dunes Wilderness	BLM	WA	1
Swanquarter Wilderness	FWS	NC	2
Hells Canyon Wilderness	BLM	AZ	3
Table Rock Wilderness	BLM	OR	4
Mingo Wilderness	FWS	MO	5
Glacier View Wilderness	FS	WA	6
Kisatchie Hills Wilderness	FS	LA	7
Ishi Wilderness	FS	CA	8
Soldier Creek Wilderness	FS	NE	9
Mountain Lakes Wilderness	FS	OR	10

APPENDIX E

Vector analyses and Geographic Information System Images

Figure 14. Juniper Dunes Wilderness Area.

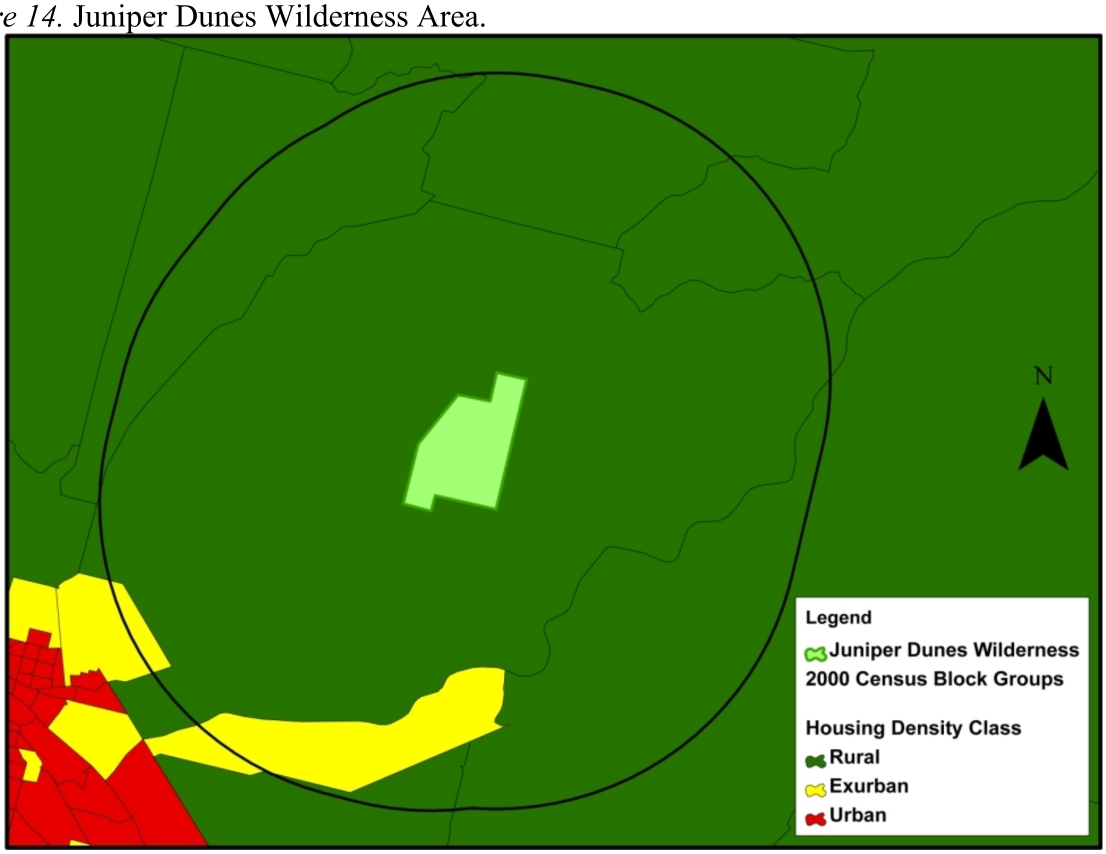

Figure 15. Census Block Groups Near Juniper Dunes Wilderness.

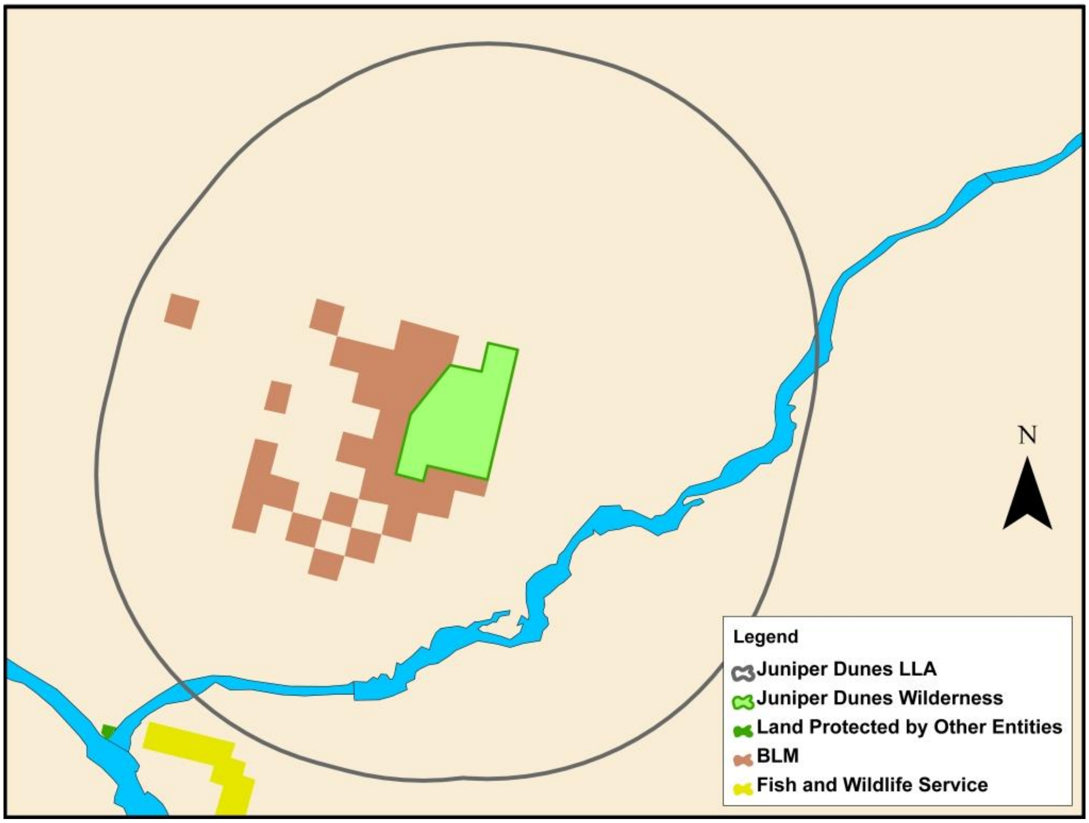

Figure 16. Land Ownership Near Juniper Dunes Wilderness.

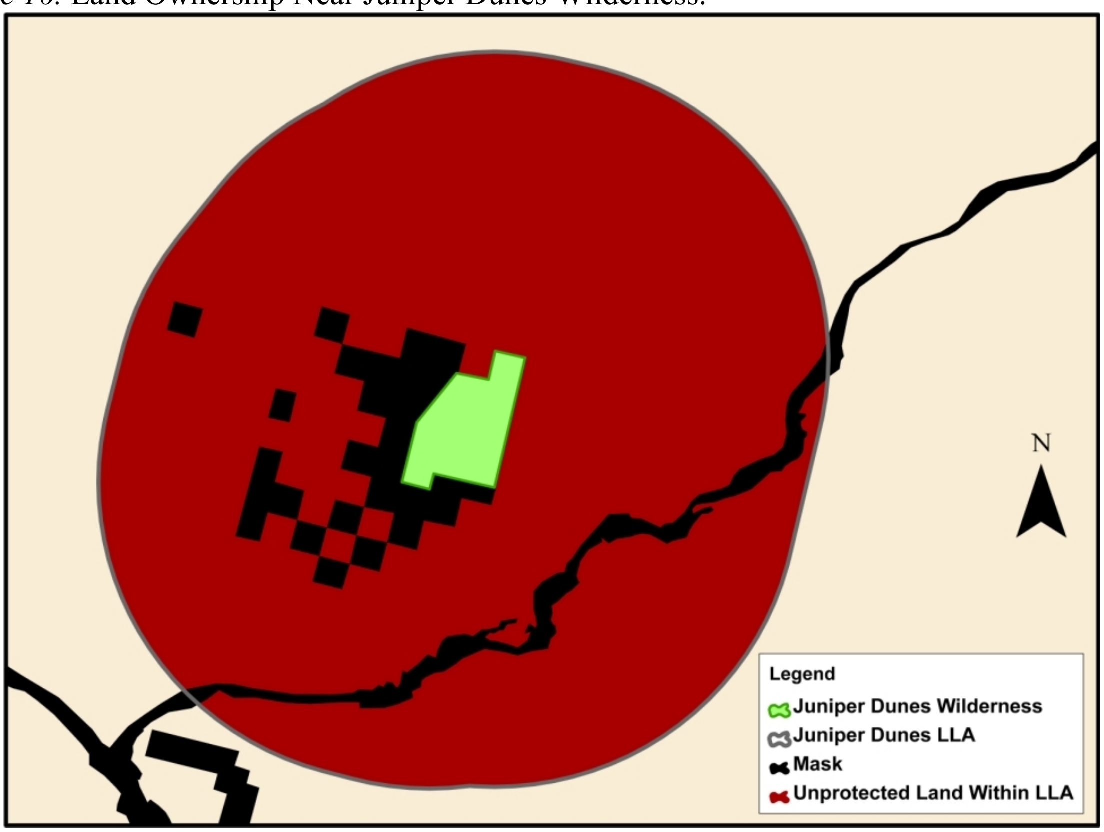

Figure 17. Protected Land Near Juniper Dunes Wilderness.

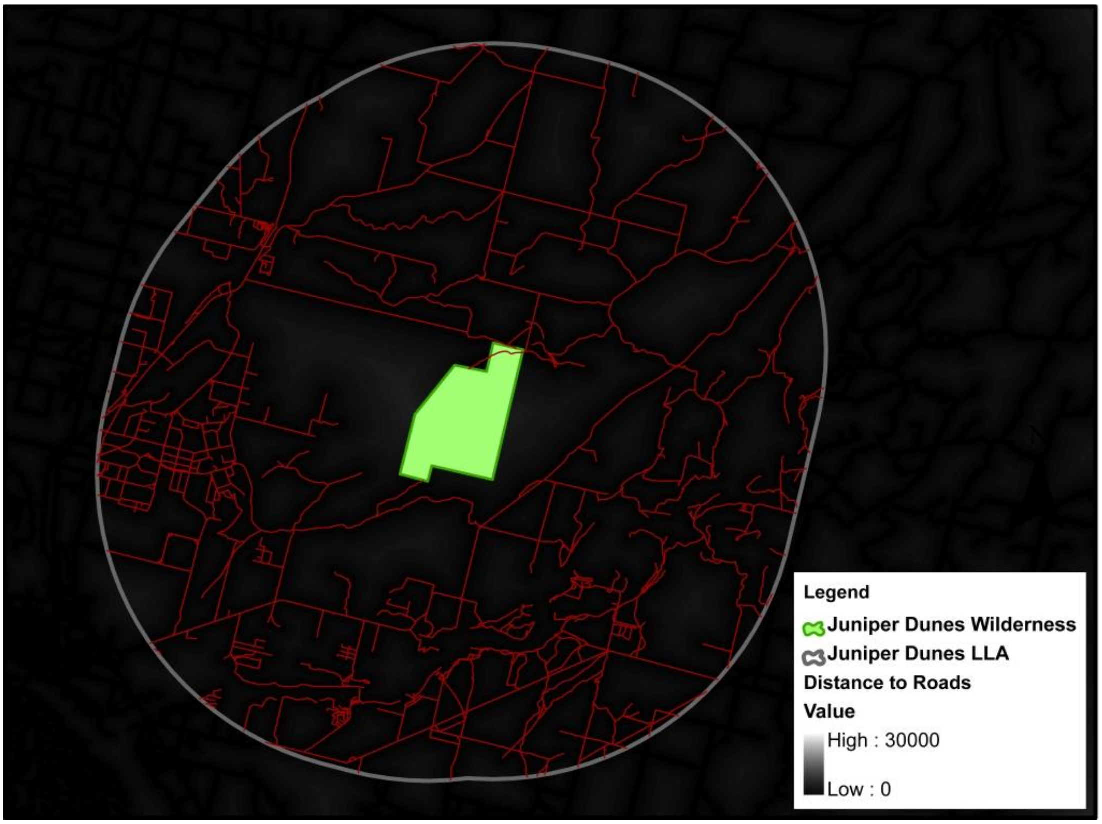

Figure 18. Distance to Nearest Road for Land Near Juniper Dunes Wilderness.

Figure 19. Airports Within 50 Miles of Juniper Dunes Wilderness.

Figure 20. Swanquarter Wilderness Area.

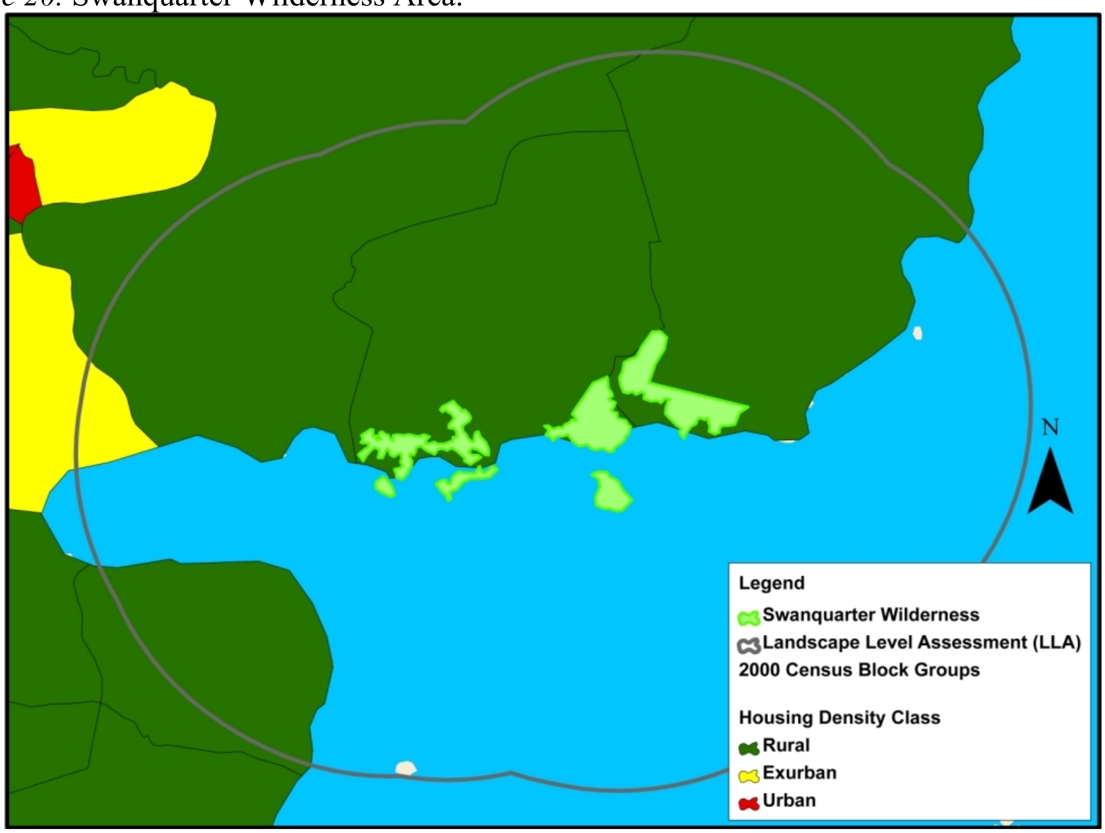

Figure 21. Census Block Groups Near Swanquarter Wilderness.

Figure 22. Land Ownership Near Swanquarter Wilderness.

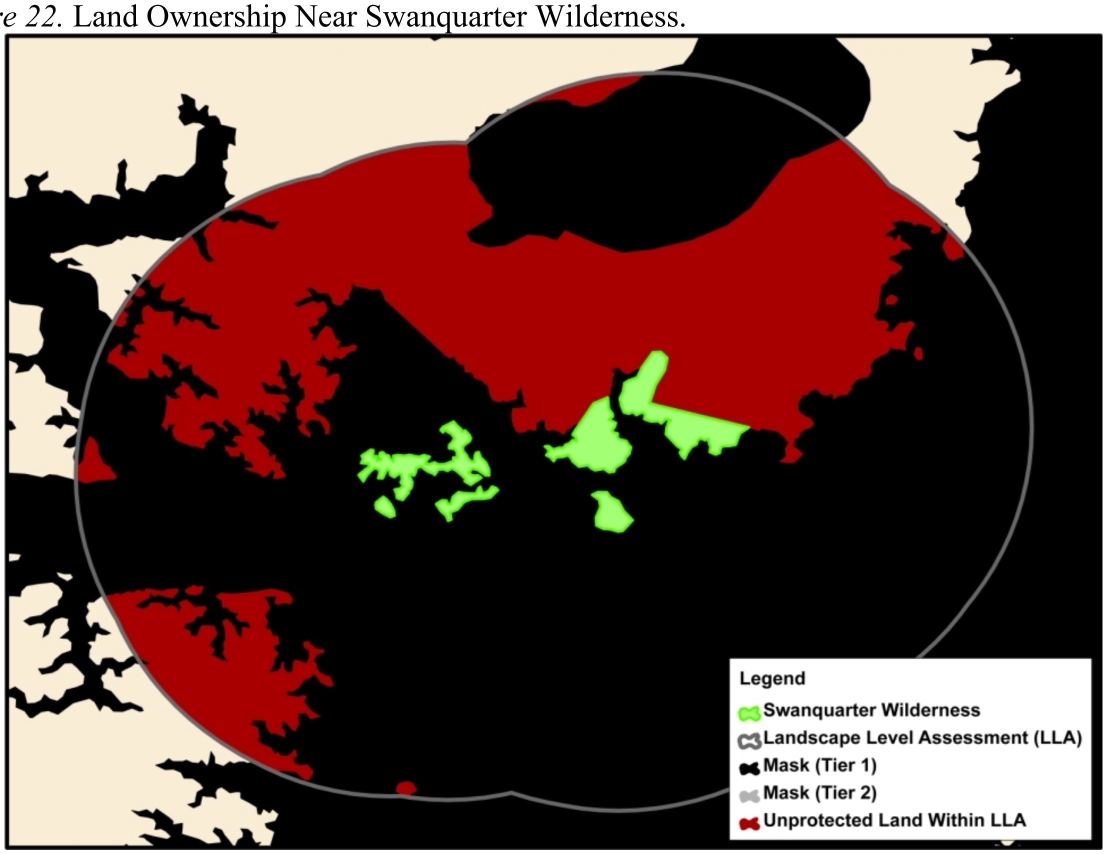

Figure 23. Protected Land Near Swanquarter Wilderness.

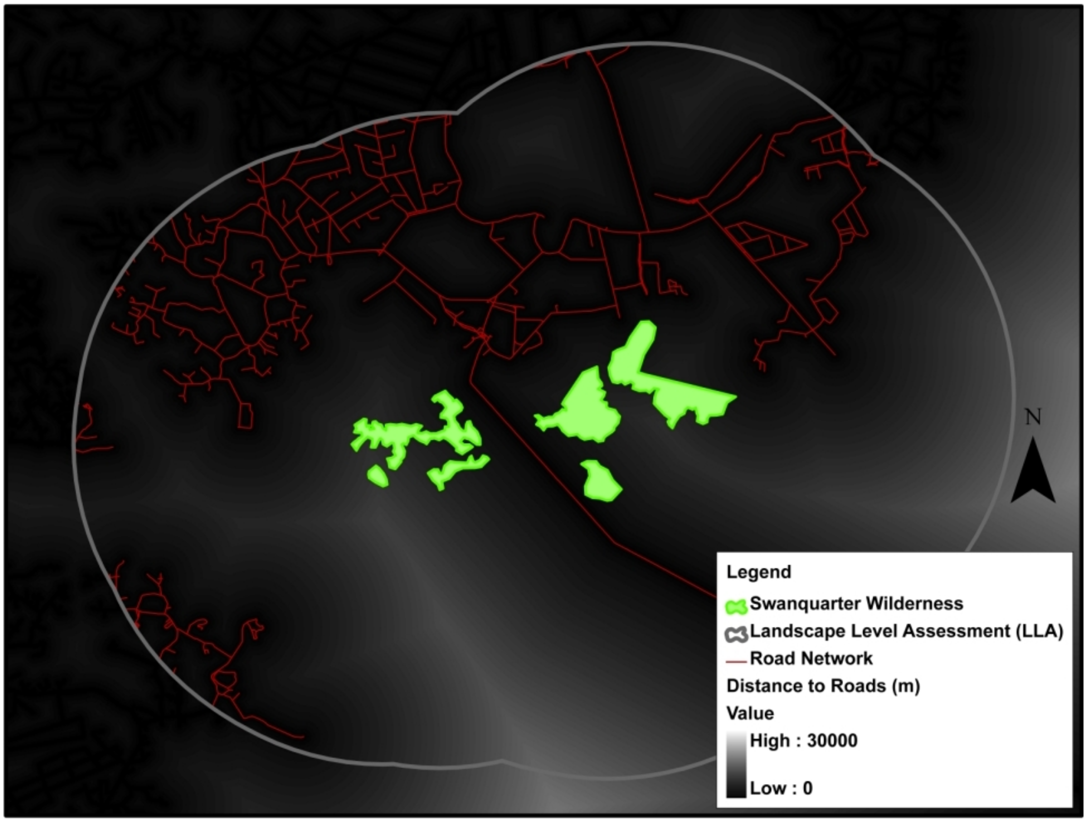

Figure 24. Distance to Nearest Road for Land Near Swanquarter Wilderness.

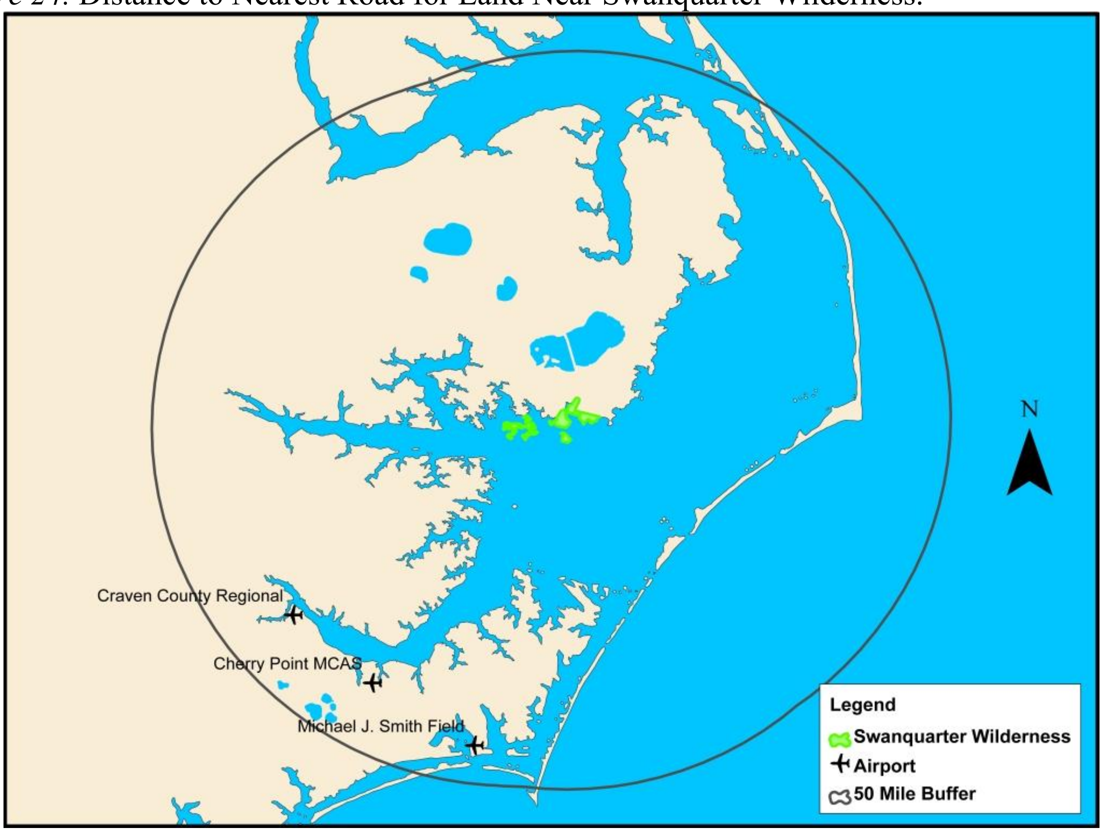

Figure 25. Airports Within 50 Miles of Swanquarter Wilderness.

Figure 26. Hells Canyon Wilderness Area.

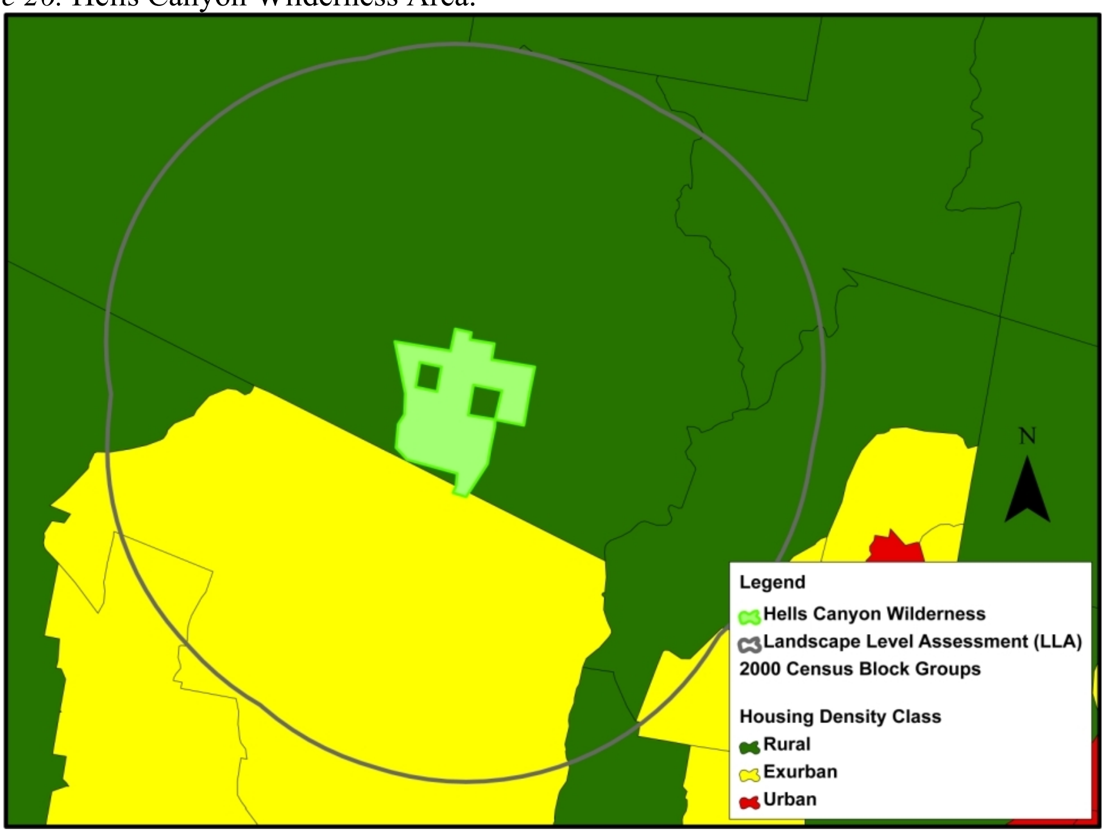

Figure 27. Census Block Groups Near Hells Canyon Wilderness.

Figure 28. Land Ownership Near Hells Canyon Wilderness.

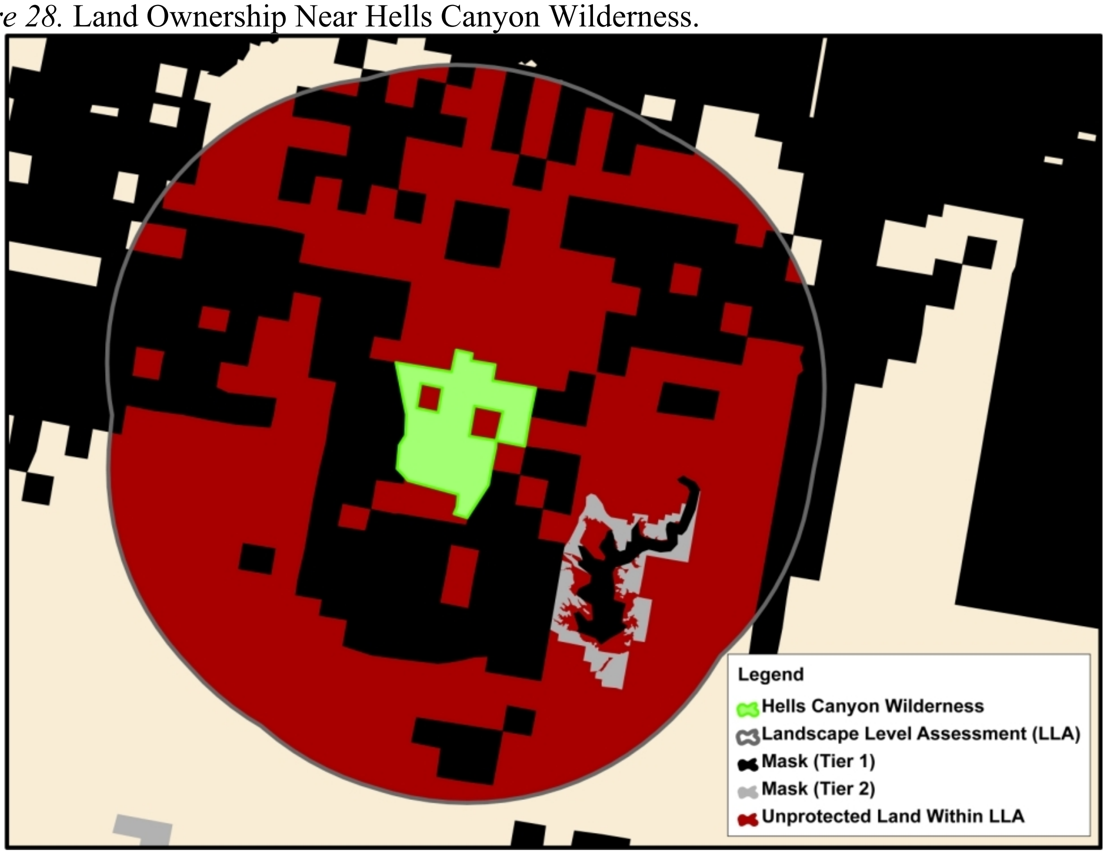

Figure 29. Protected Land Near Hells Canyon Wilderness.

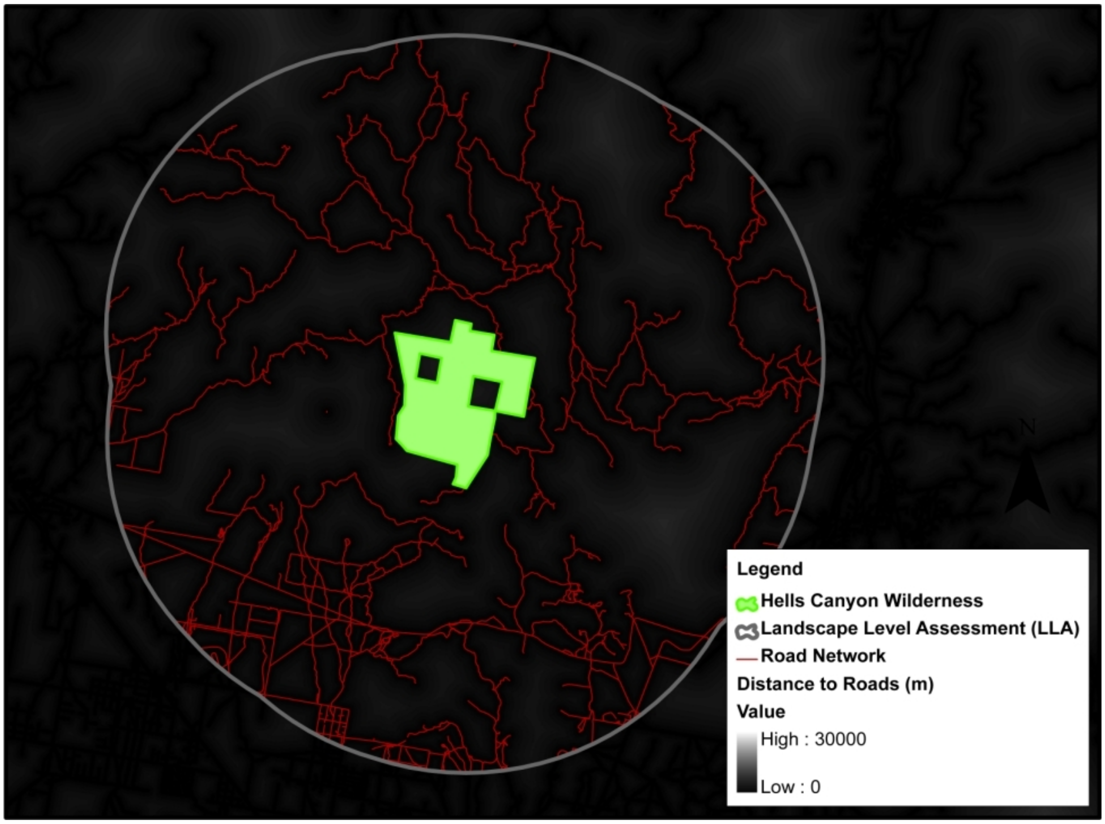

Figure 30. Distance to Nearest Road for Land Near Hells Canyon Wilderness.

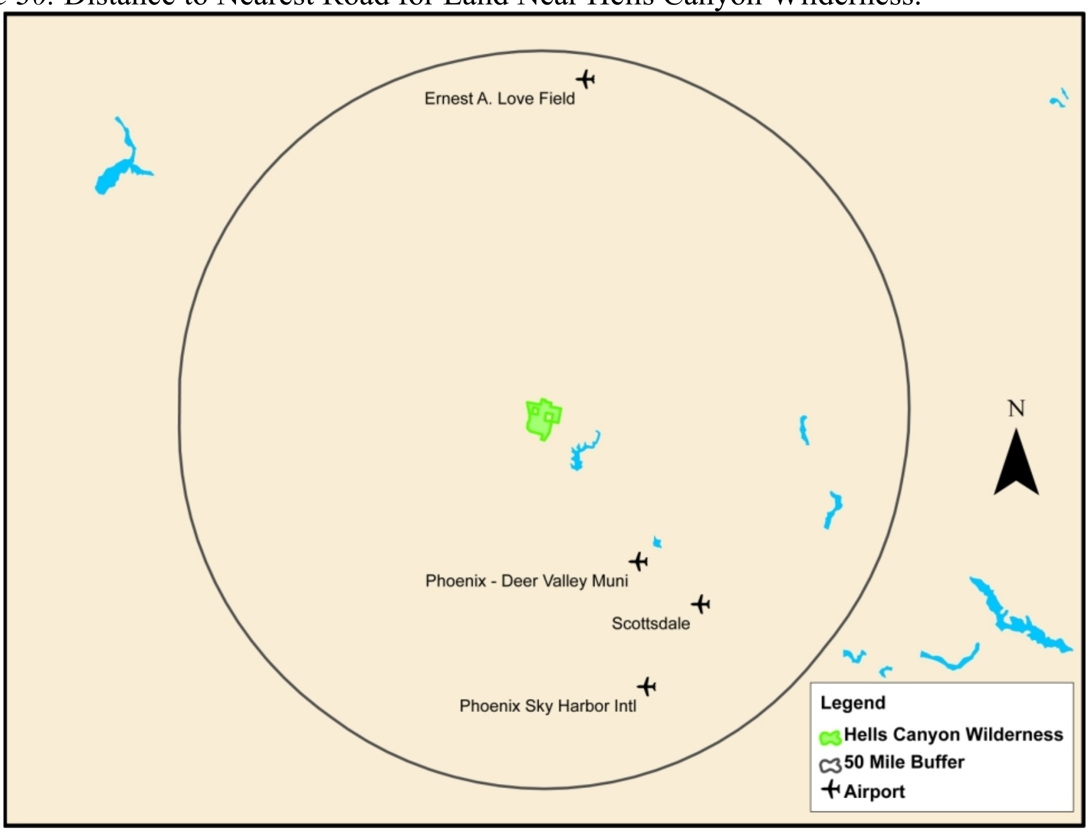

Figure 31. Airports Within 50 Miles of Hells Canyon Wilderness.

Figure 32. Table Rock Wilderness Area.

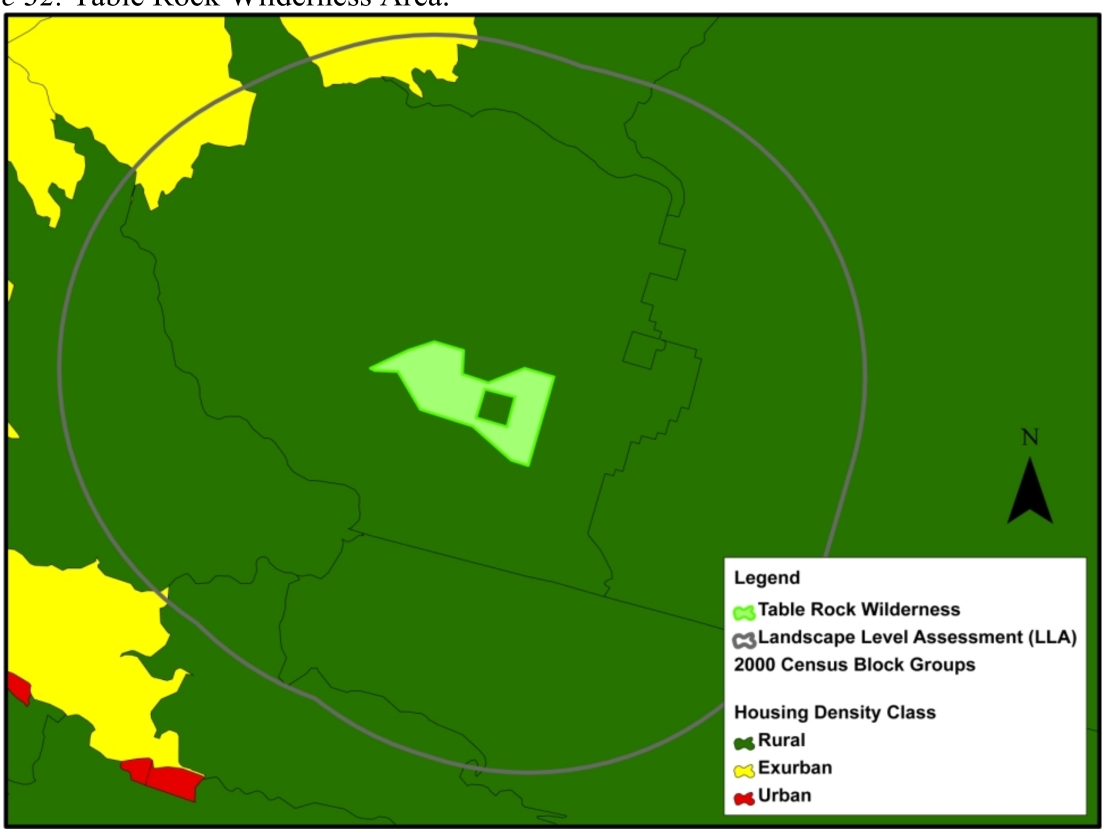

Figure 33. Census Block Groups Near Table Rock Wilderness.

Figure 34. Land Ownership Near Table Rock Wilderness.

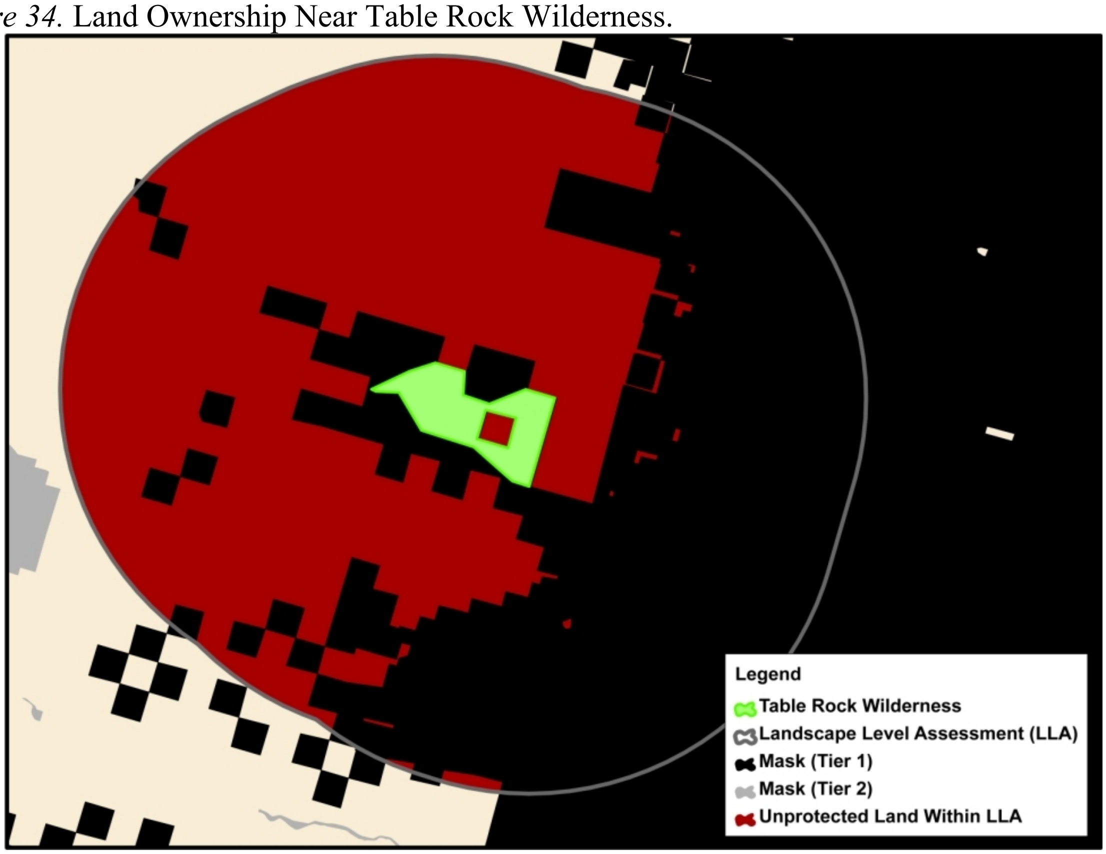

Figure 35. Protected Land Near Table Rock Wilderness.

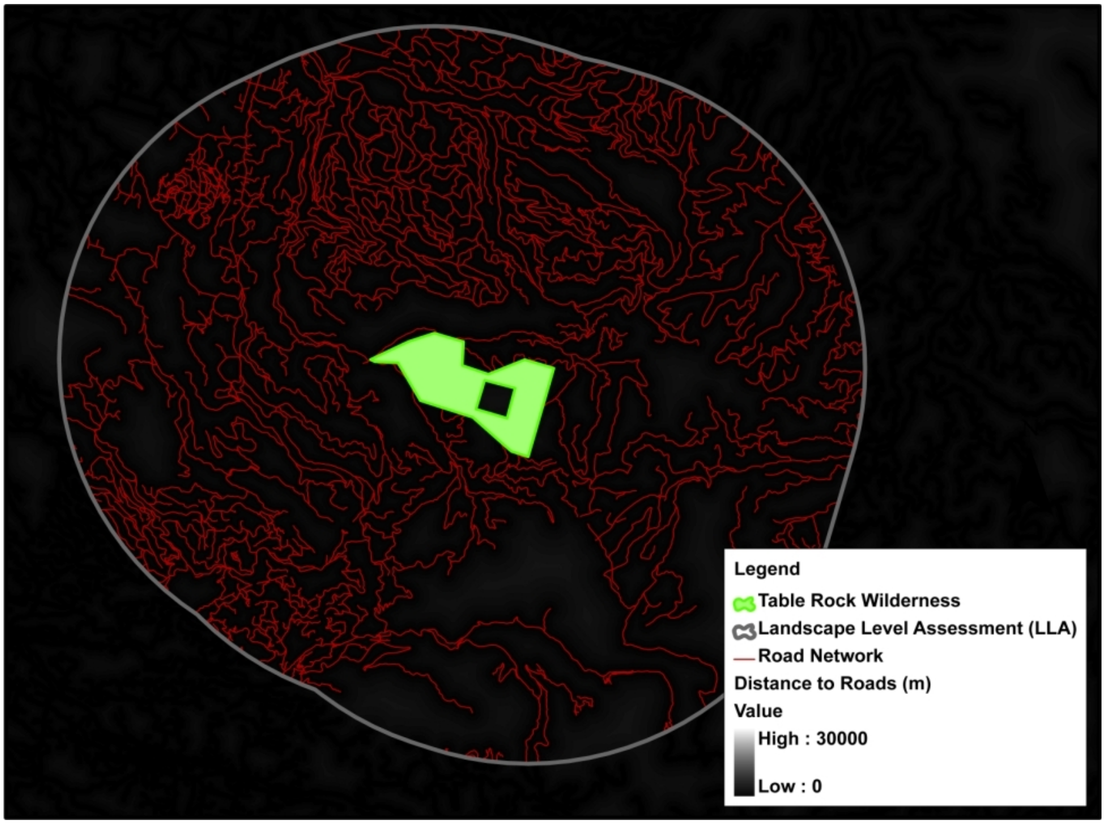

Figure 36. Distance to Nearest Road for Land Near Table Rock Wilderness.

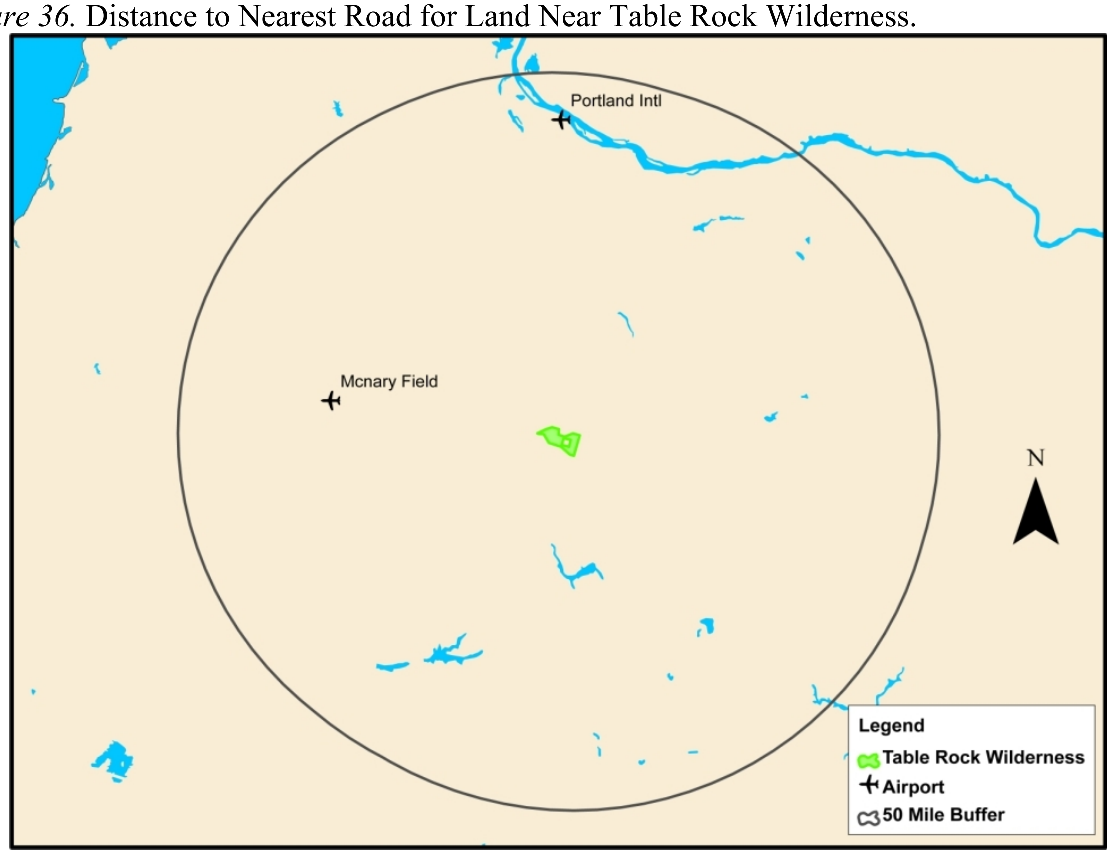

Figure 37. Airports Within 50 Miles of Table Rock Wilderness.

Figure 38. Mingo Wilderness Area.

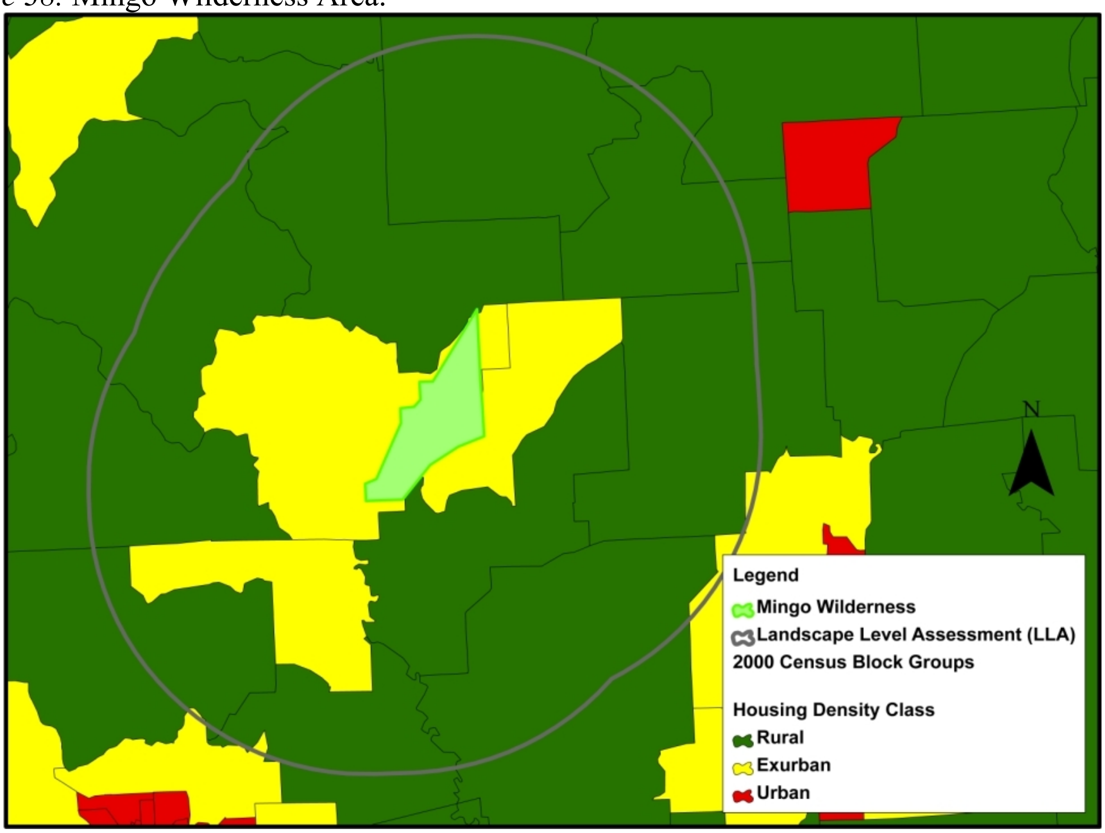

Figure 39. Census Block Groups Near Mingo Wilderness.

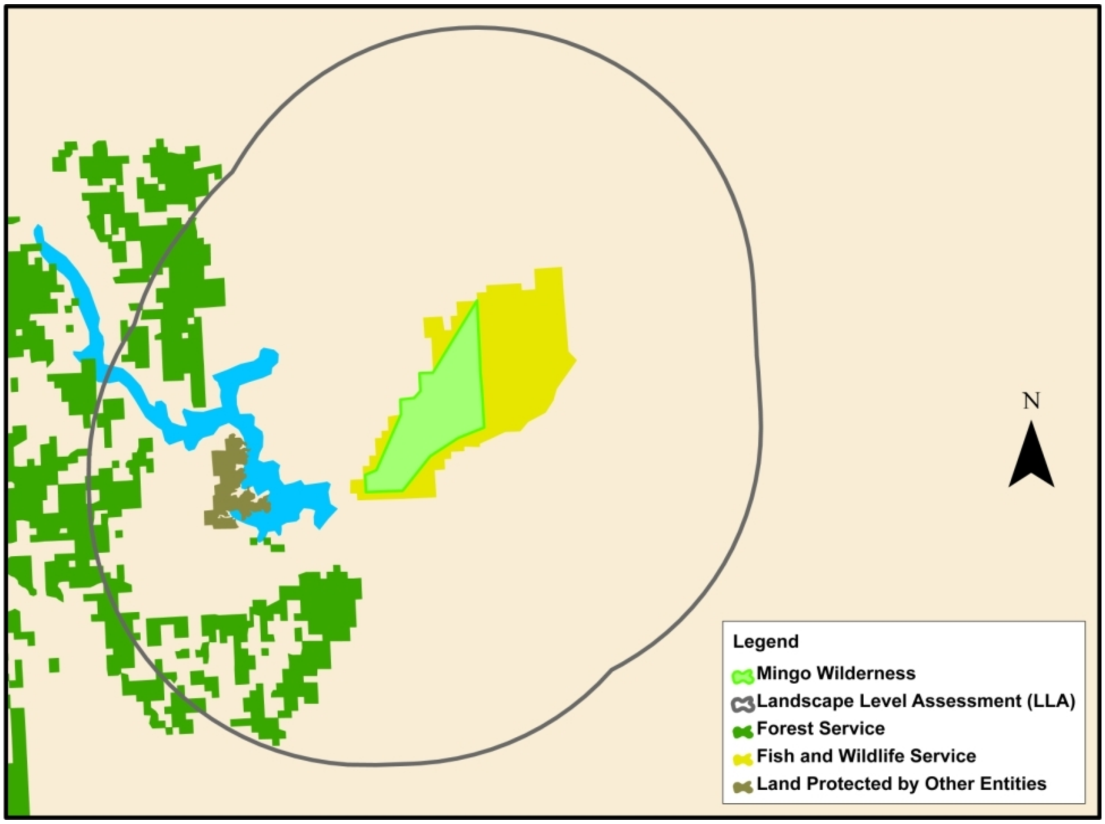

Figure 40. Land Ownership Near Mingo Wilderness.

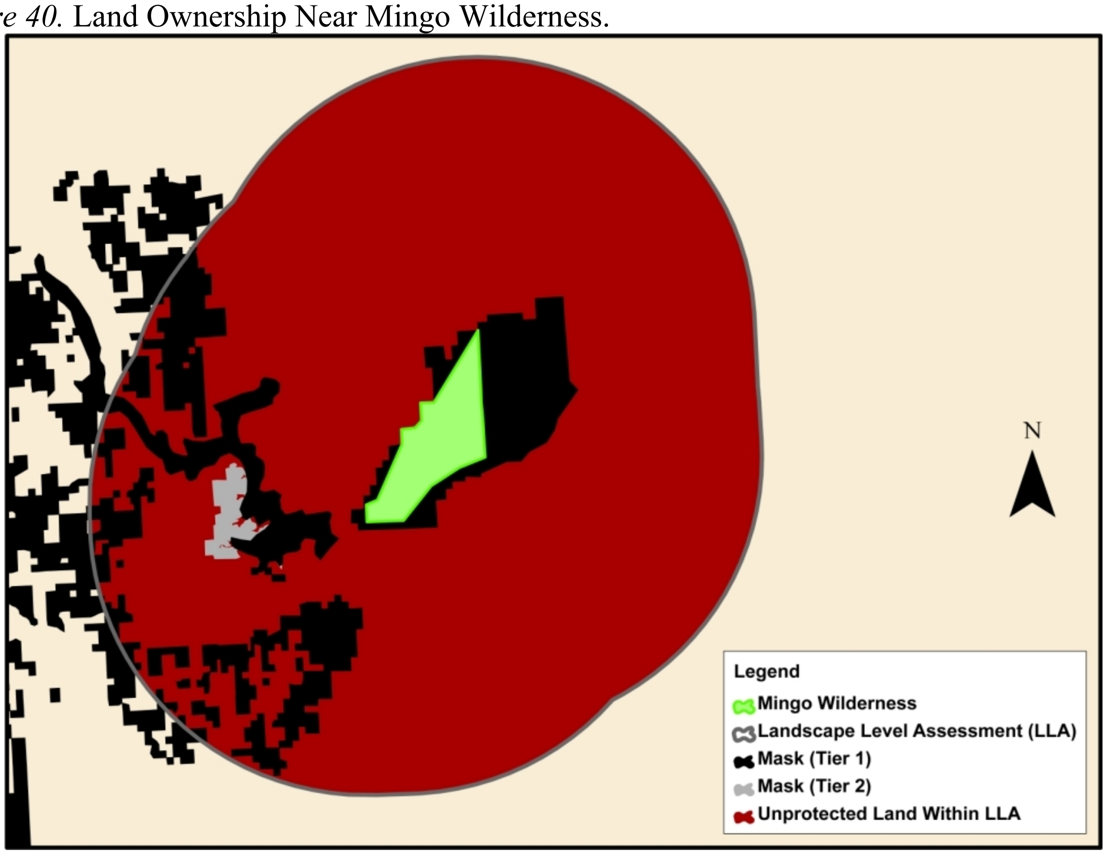

Figure 41. Protected Land Near Mingo Wilderness.

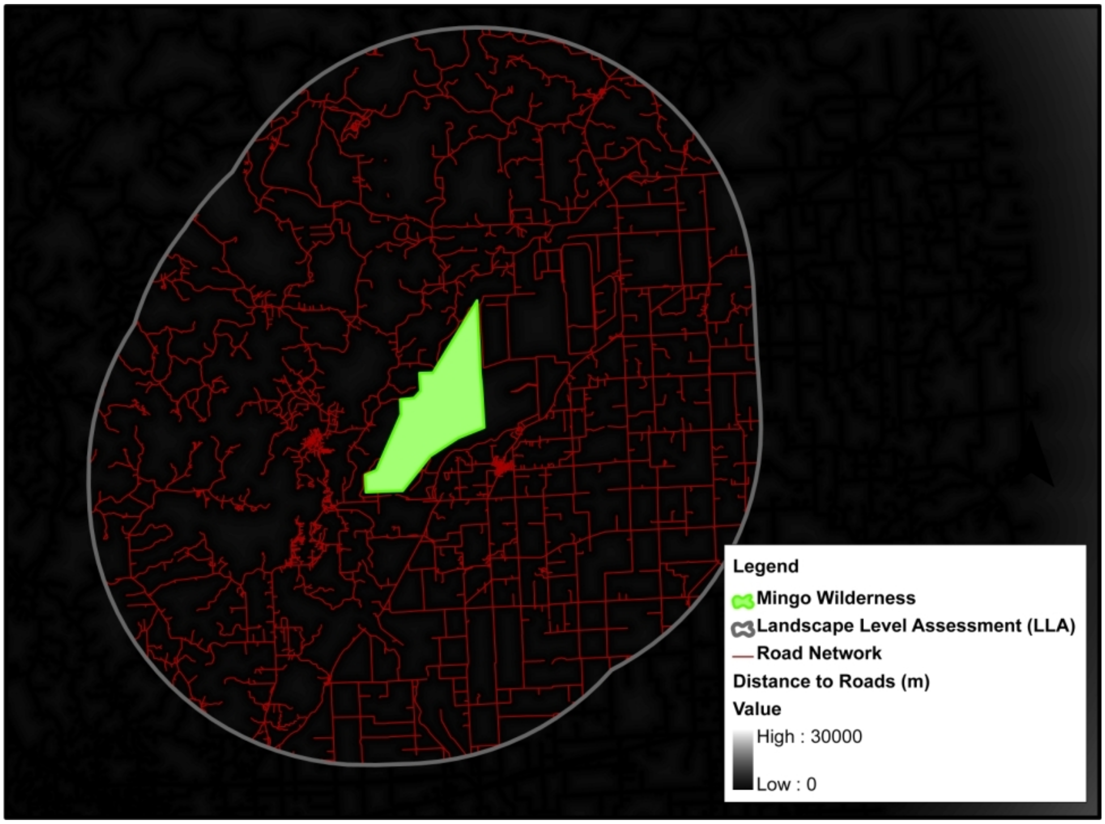

Figure 42. Distance to Nearest Road for Land Near Mingo Wilderness.

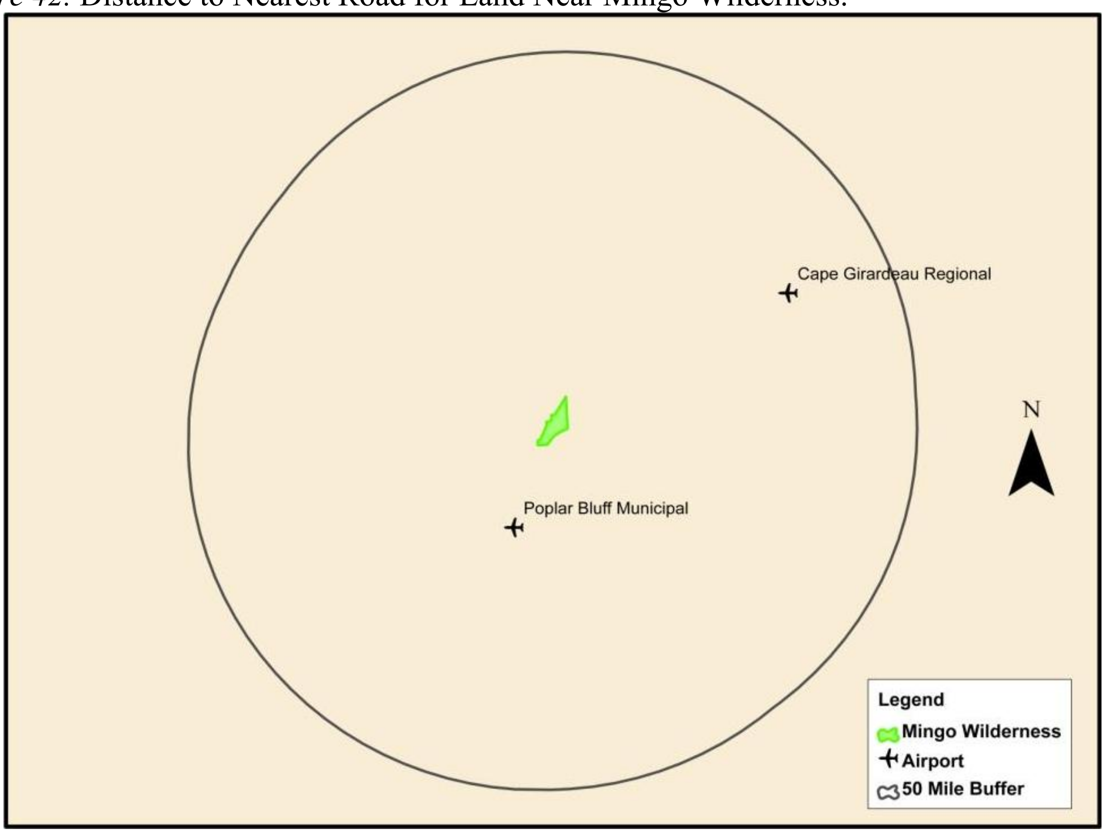

Figure 43. Airports Within 50 Miles of Mingo Wilderness.

Figure 44. Glacier View Wilderness Area.

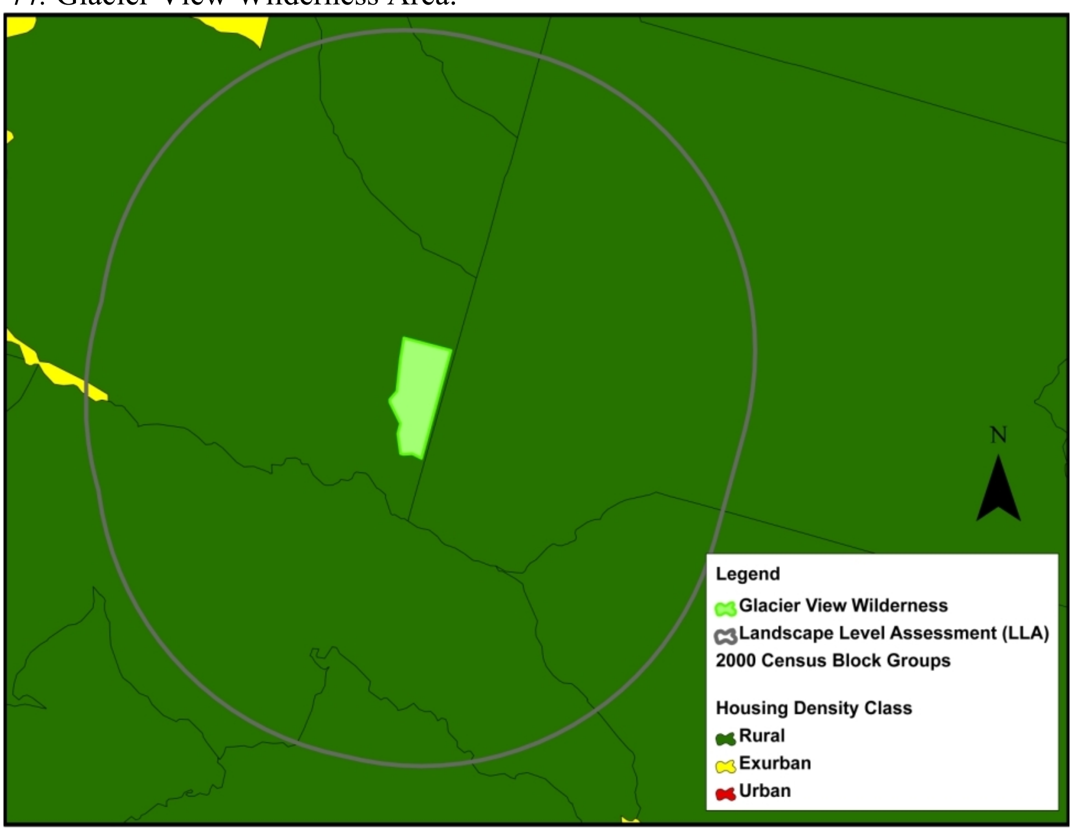

Figure 45. Census Block Groups Near Glacier View Wilderness.

Figure 46. Land Ownership Near Glacier View Wilderness.

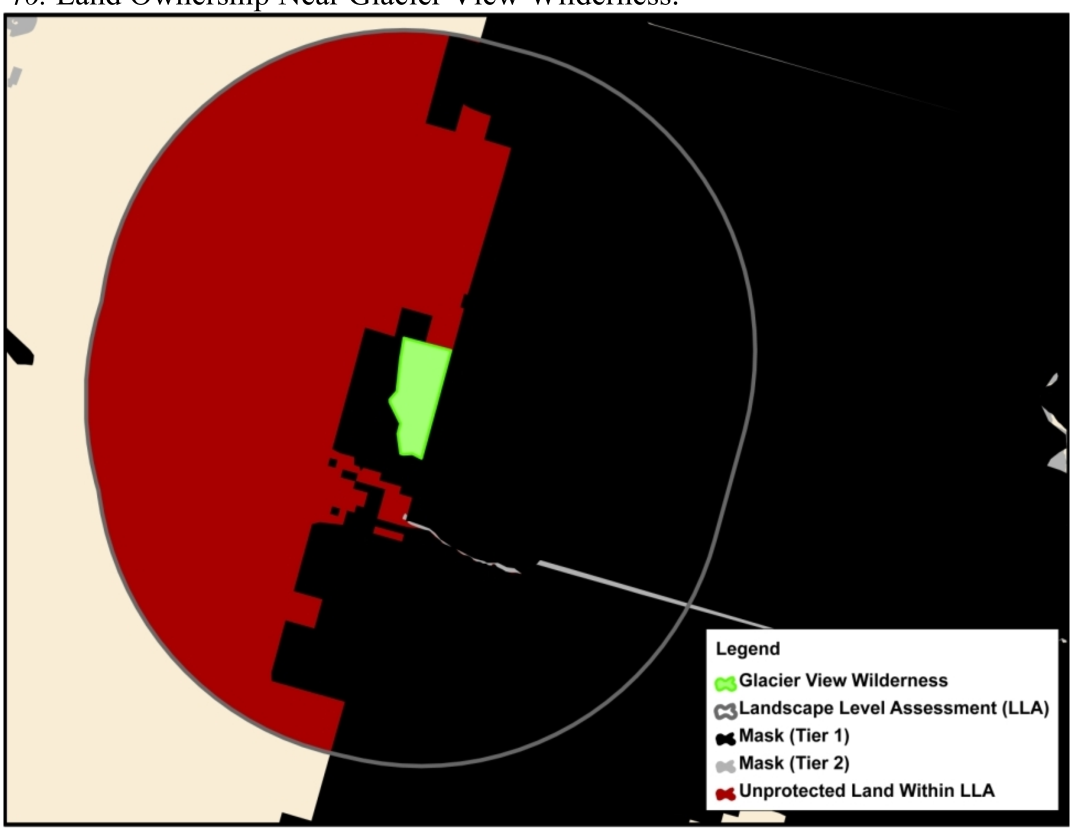

Figure 47. Protected Land Near Glacier View Wilderness.

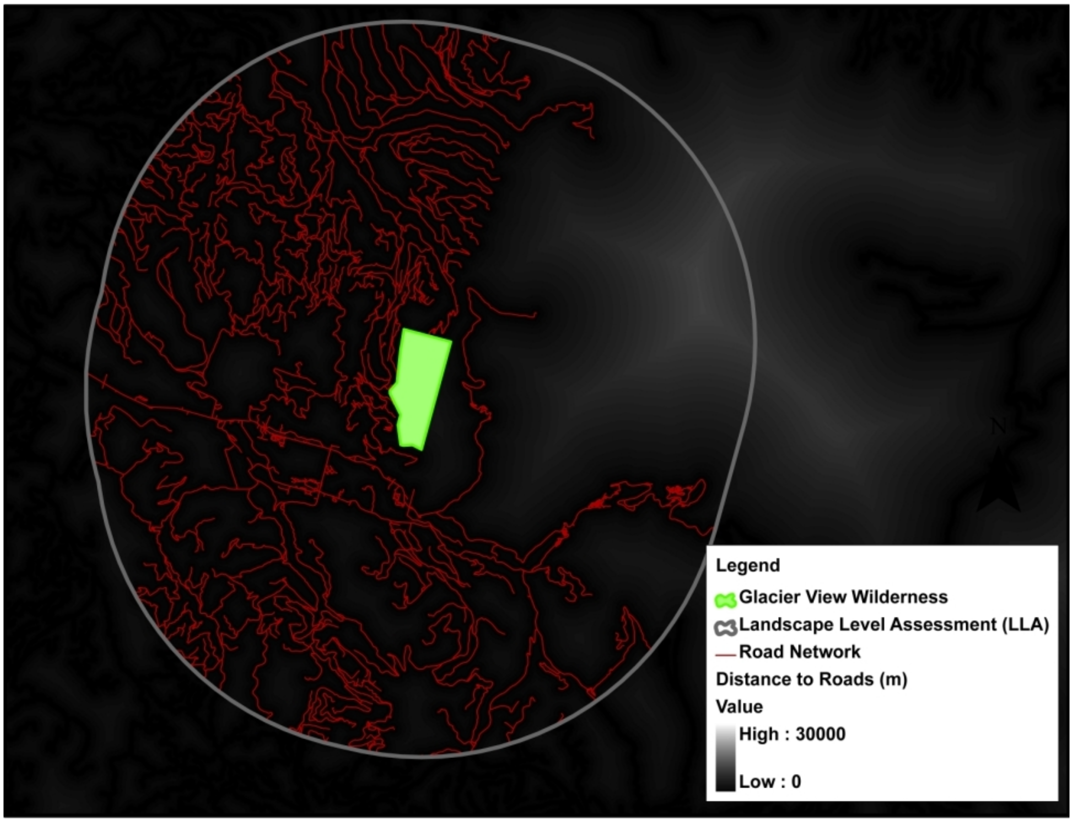

Figure 48. Distance to Nearest Road for Land Near Glacier View Wilderness.

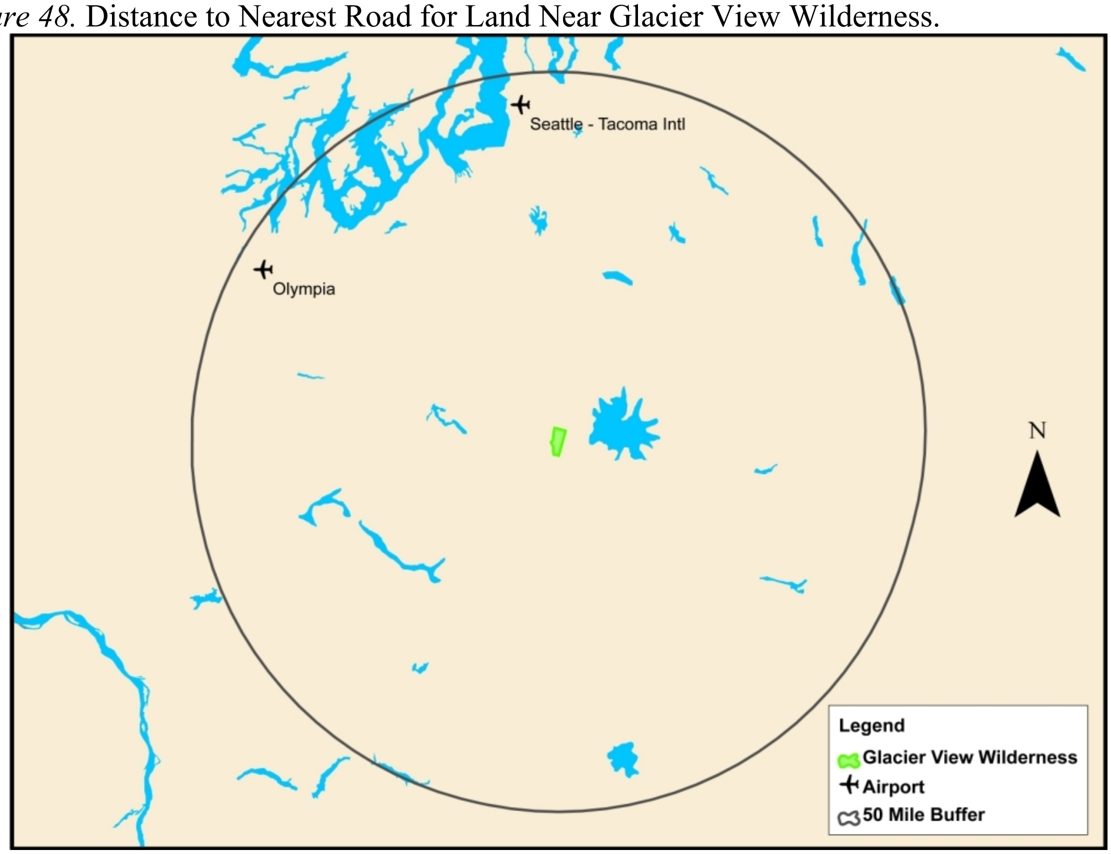

Figure 49. Airports Within 50 Miles of Glacier View Wilderness.

Figure 50. Kisatchie Hills Wilderness Area.

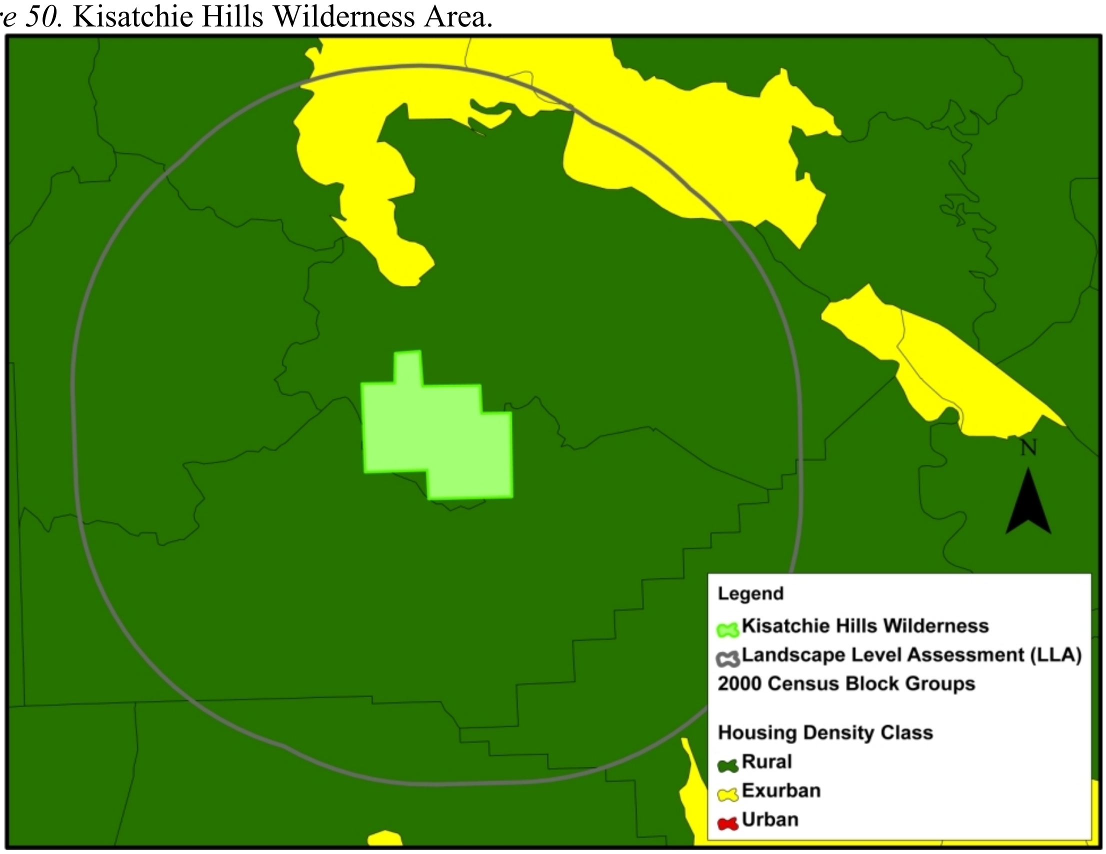

Figure 51. Census Block Groups Near Kisatchie Hills Wilderness.

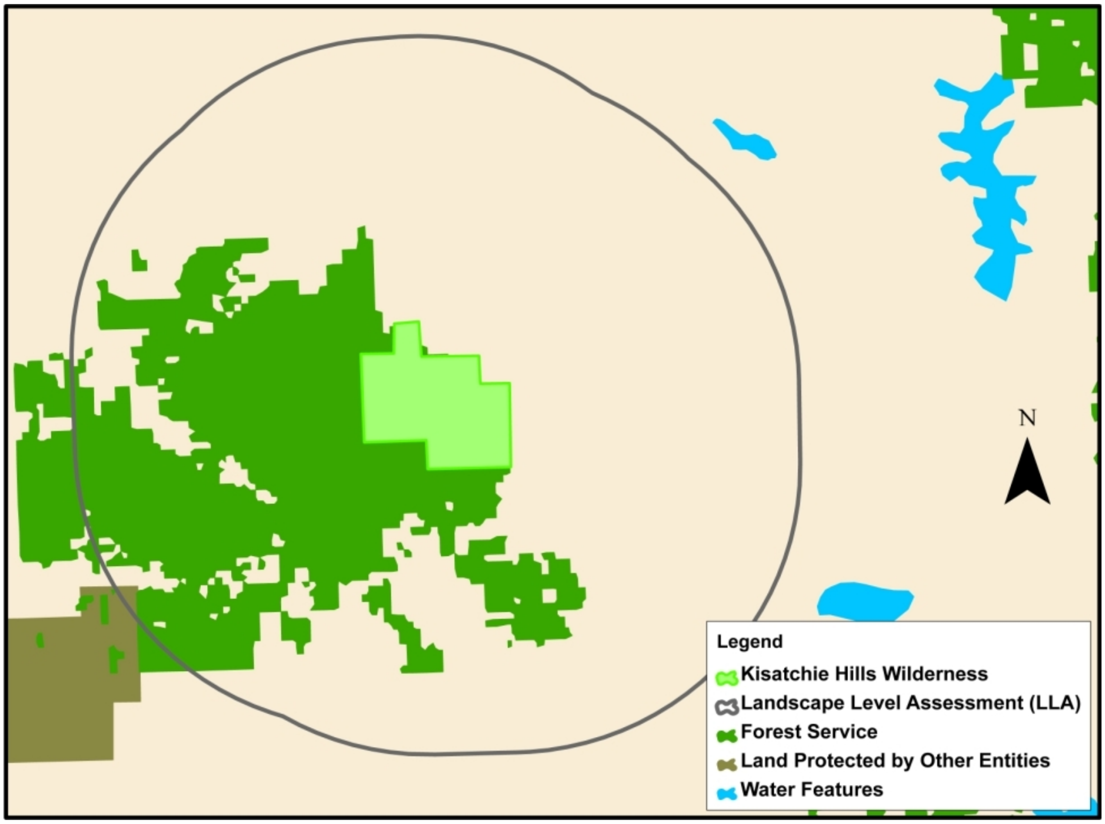

Figure 52. Land Ownership Near Kisatchie Hills Wilderness.

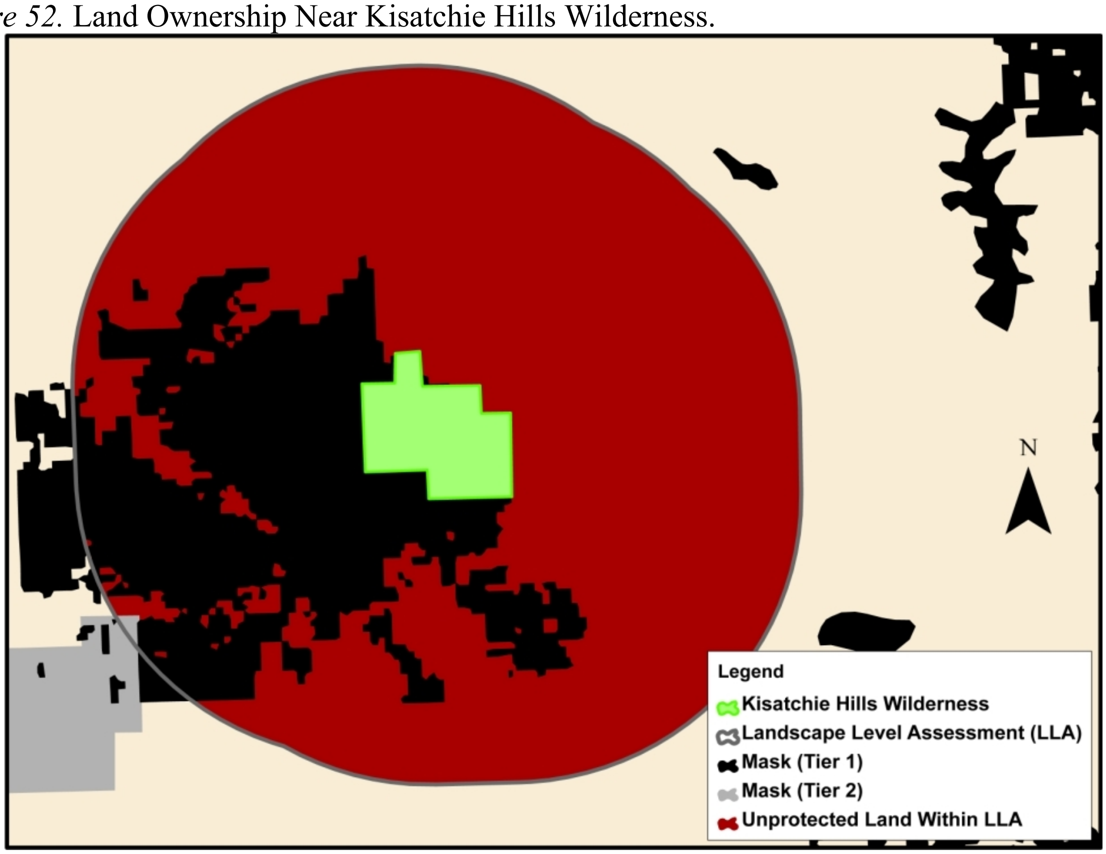

Figure 53. Protected Land Near Kisatchie Hills Wilderness.

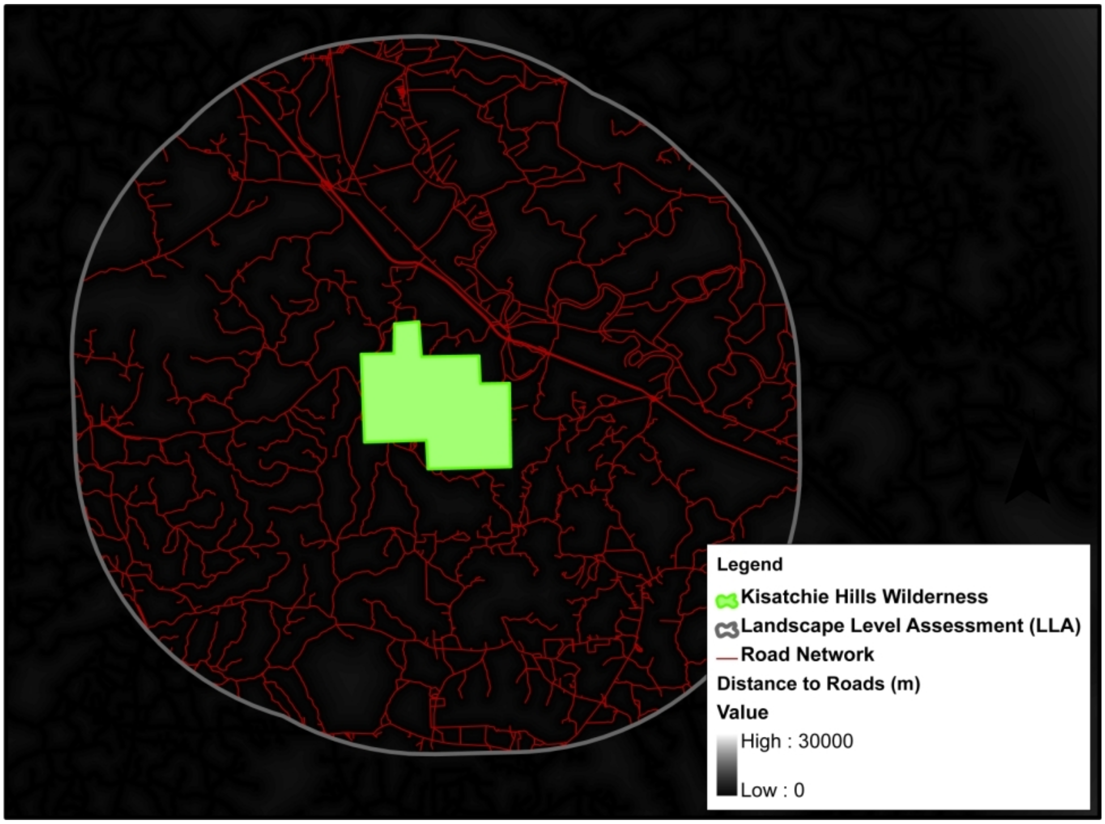

Figure 54. Distance to Nearest Road for Land Near Kisatchie Hills Wilderness.

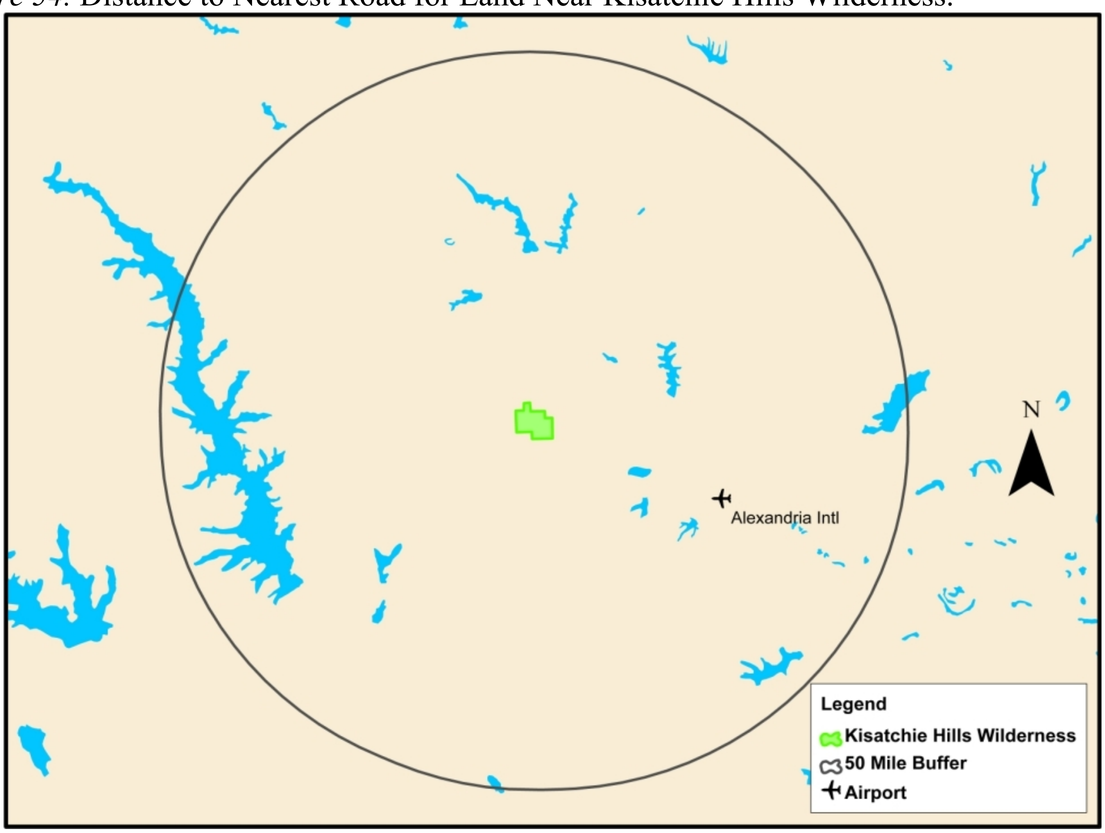

Figure 55. Airports Within 50 Miles of Kisatchie Hills Wilderness.

Figure 56. Ishi Wilderness Area.

Figure 57. Census Block Groups Near Ishi Wilderness.

Figure 58. Land Ownership Near Ishi Wilderness.

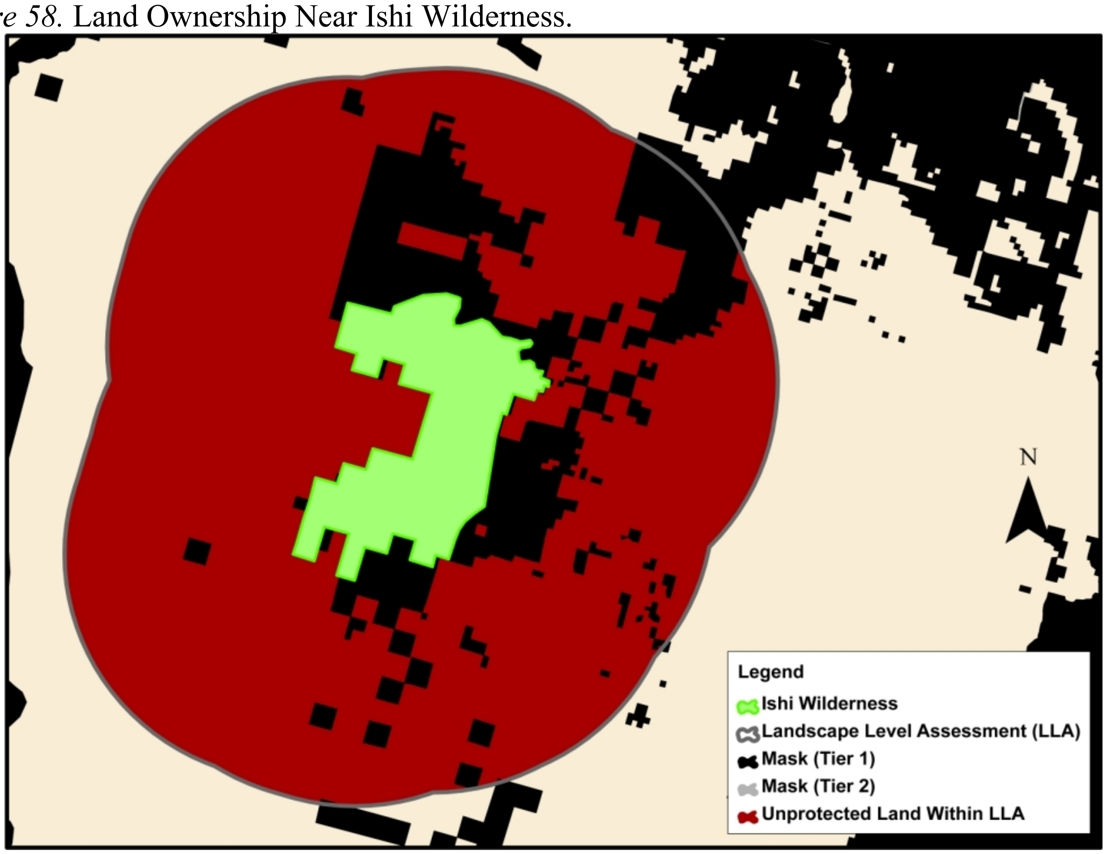

Figure 59. Protected Land Near Ishi Wilderness.

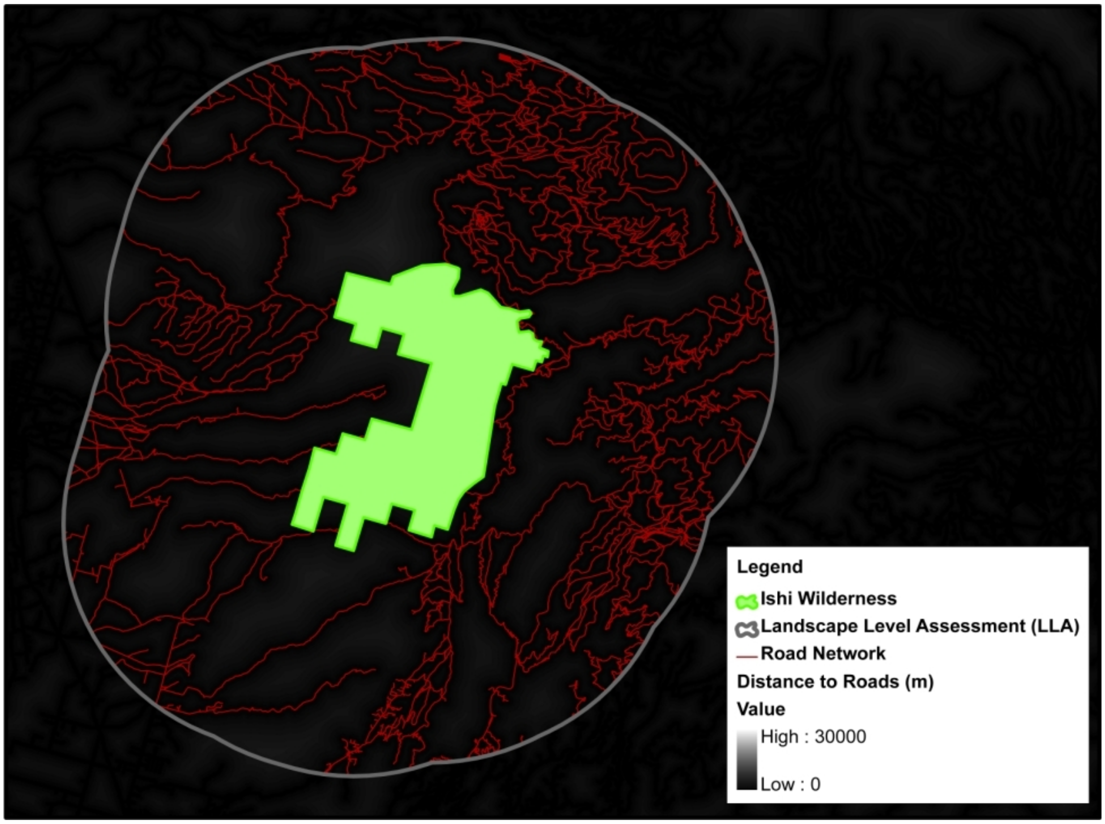

Figure 60. Distance to Nearest Road for Land Near Ishi Wilderness.

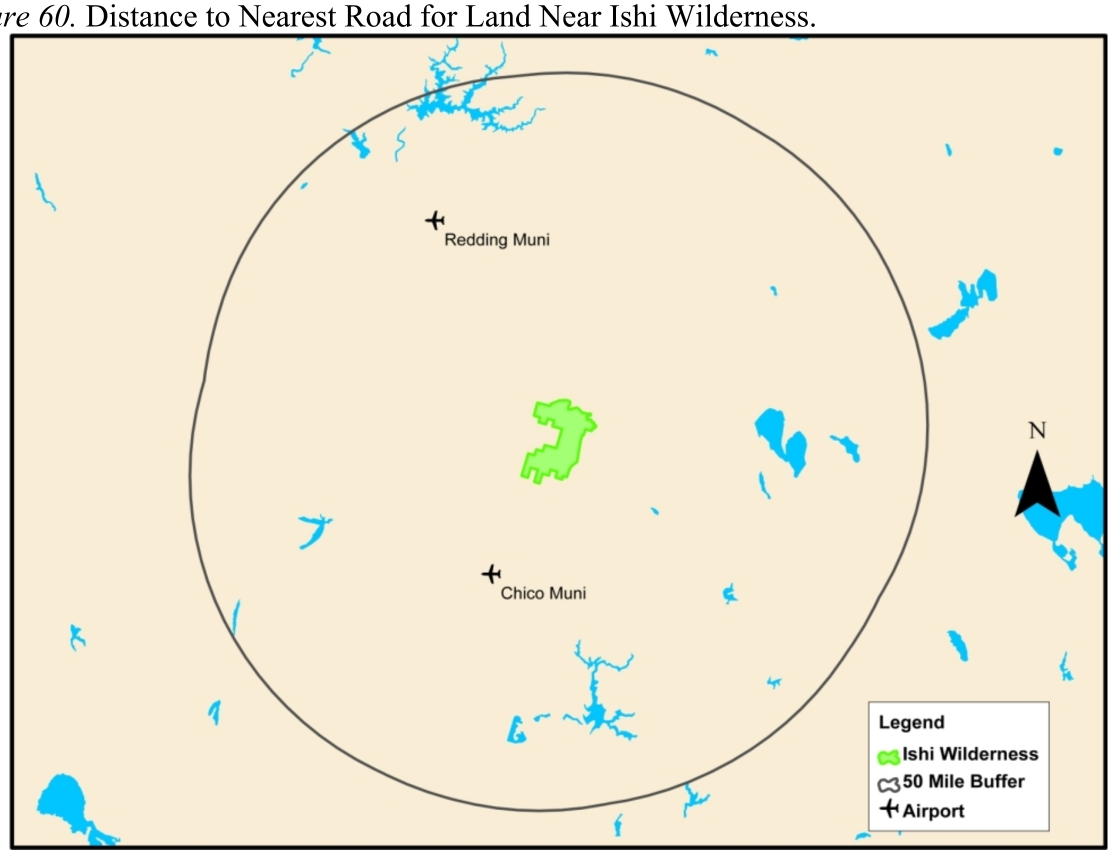

Figure 61. Airports Within 50 Miles of Ishi Wilderness.

Figure 62. Mountain Lakes Wilderness Area.

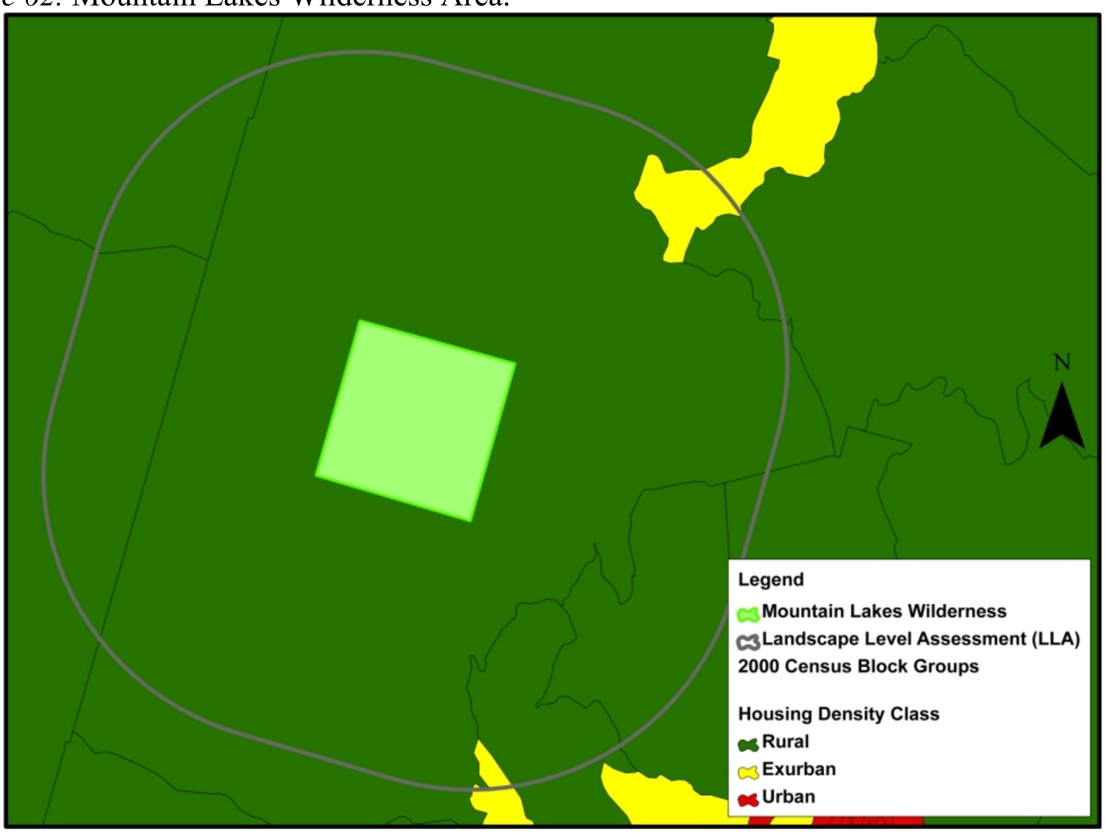

Figure 63. Census Block Groups Near Mountain Lakes Wilderness.

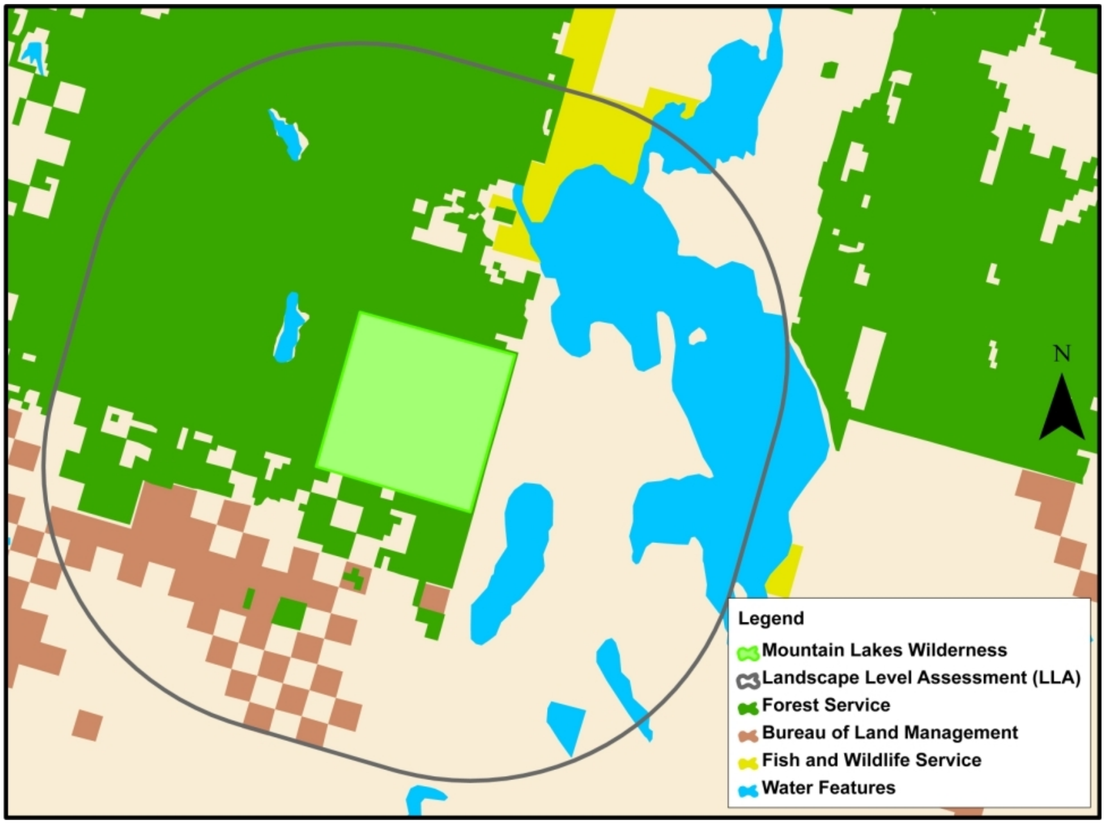

Figure 64. Land Ownership Near Mountain Lakes Wilderness.

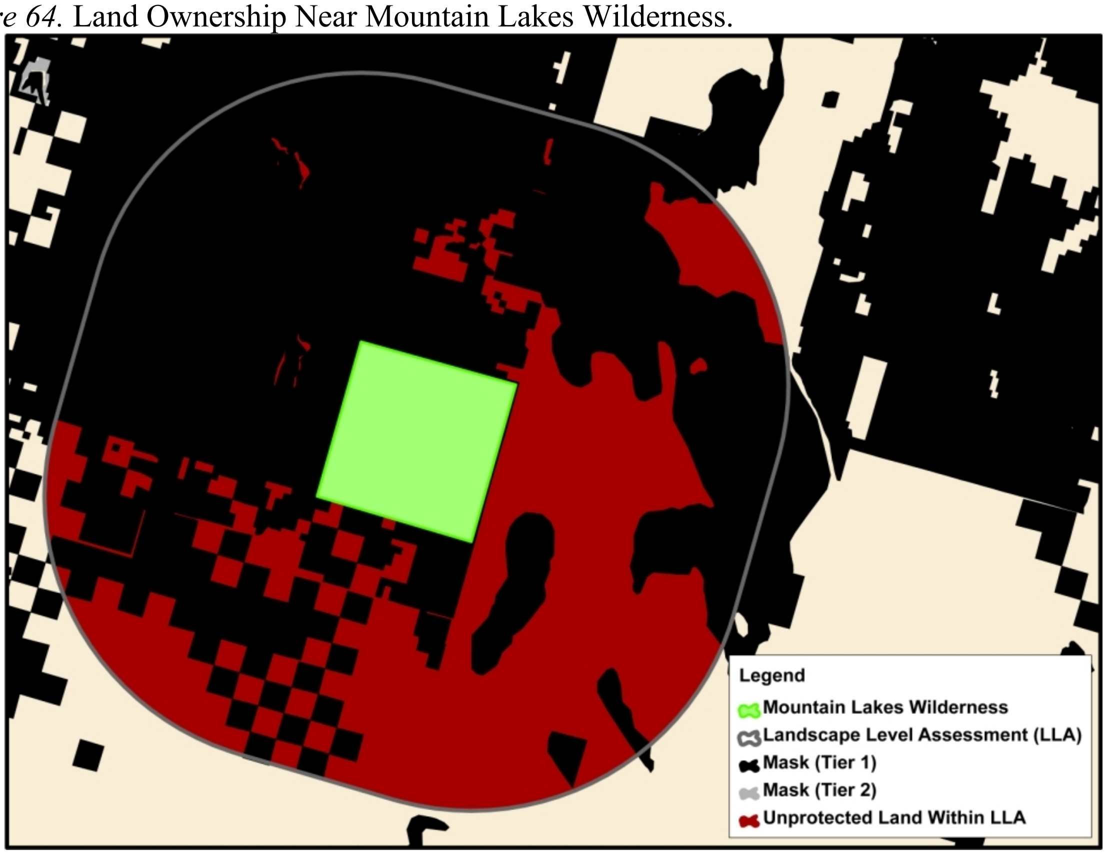

Figure 65. Protected Land Near Mountain Lakes Wilderness.

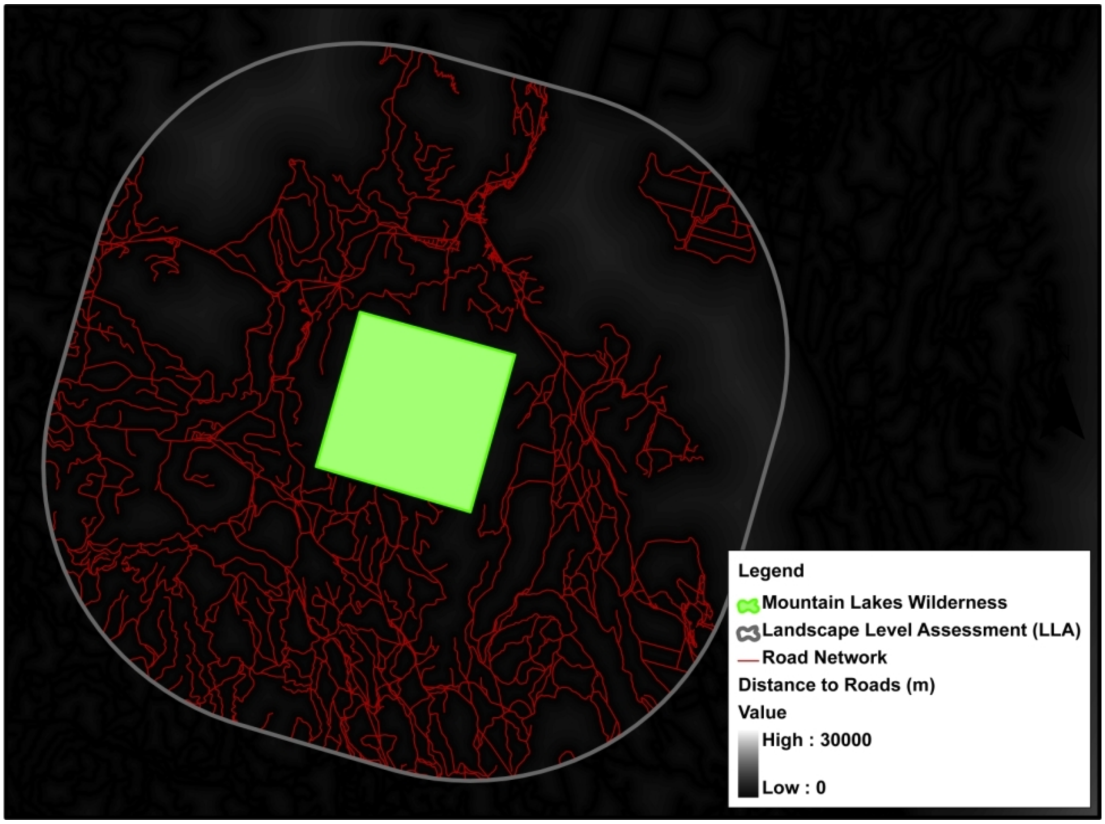

Figure 66. Distance to Nearest Road for Land Near Mountain Lakes Wilderness.

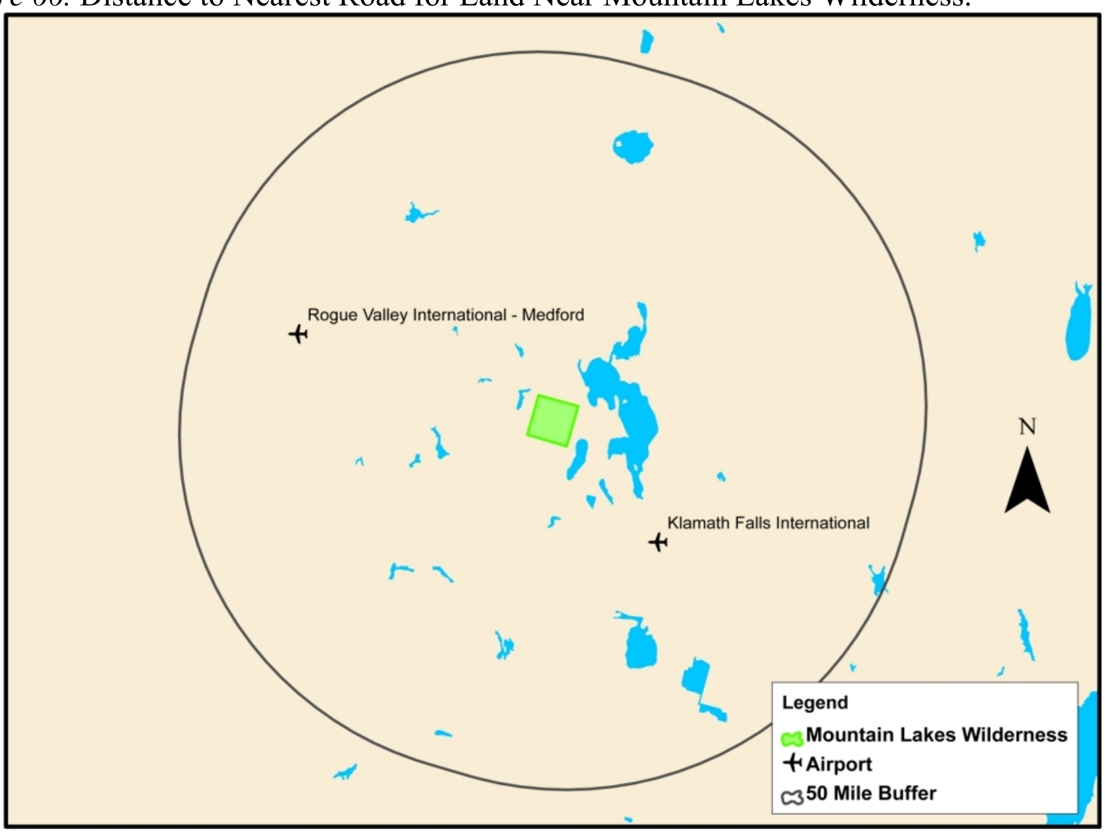

Figure 67. Airports Within 50 Miles of Mountain Lakes Wilderness.

Figure 68. Soldier Creek Wilderness Area.

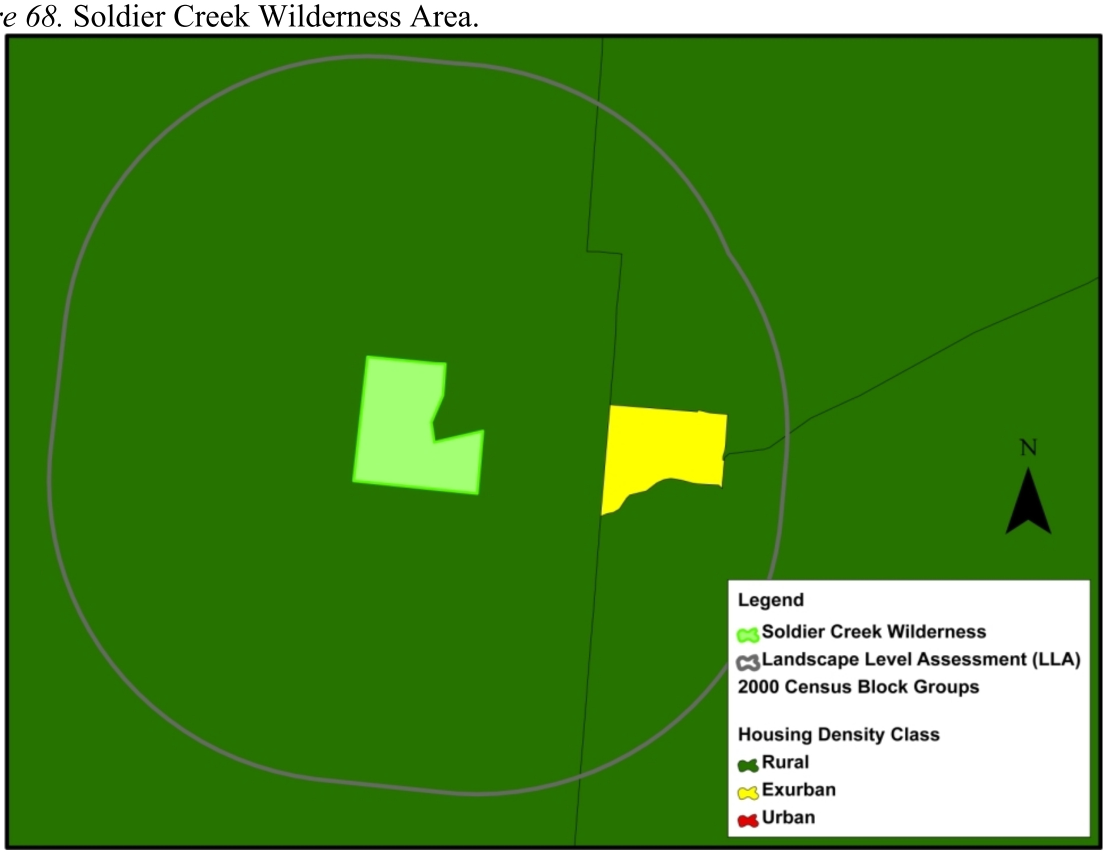

Figure 69. Census Block Groups Near Soldier Creek Wilderness.

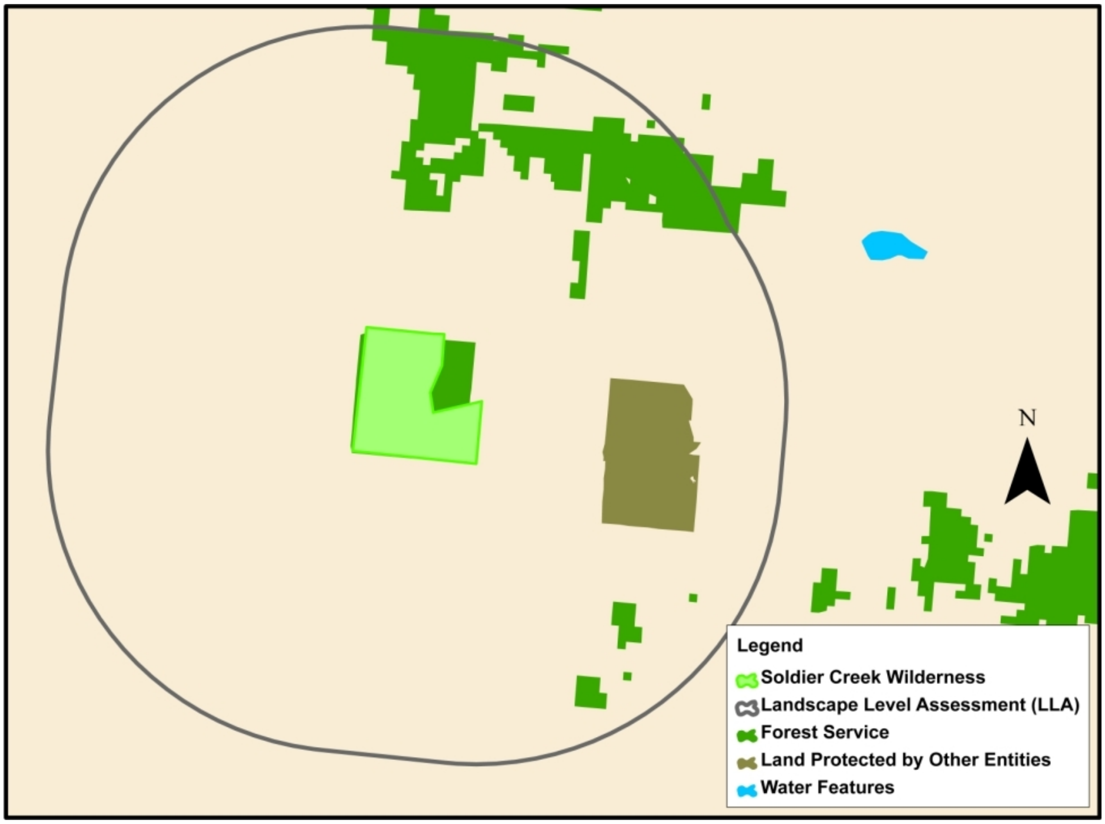

Figure 70. Land Ownership Near Soldier Creek Wilderness.

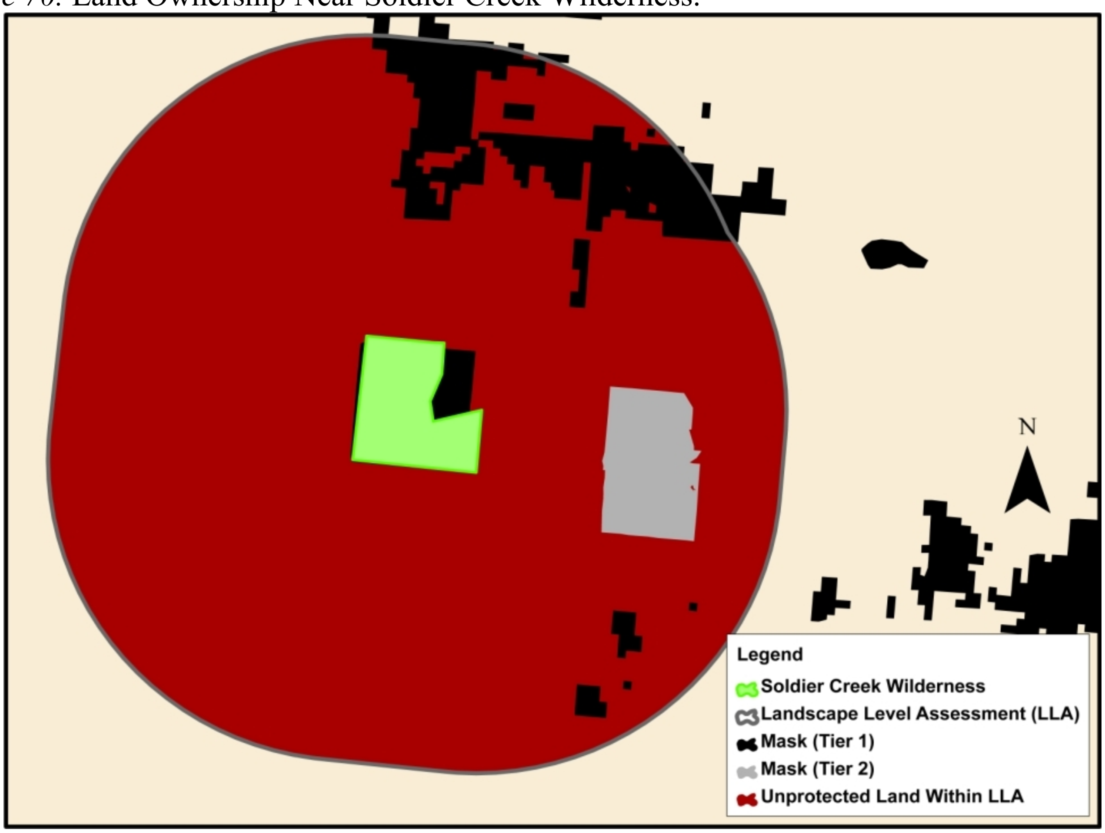

Figure 71. Protected Land Near Soldier Creek Wilderness.

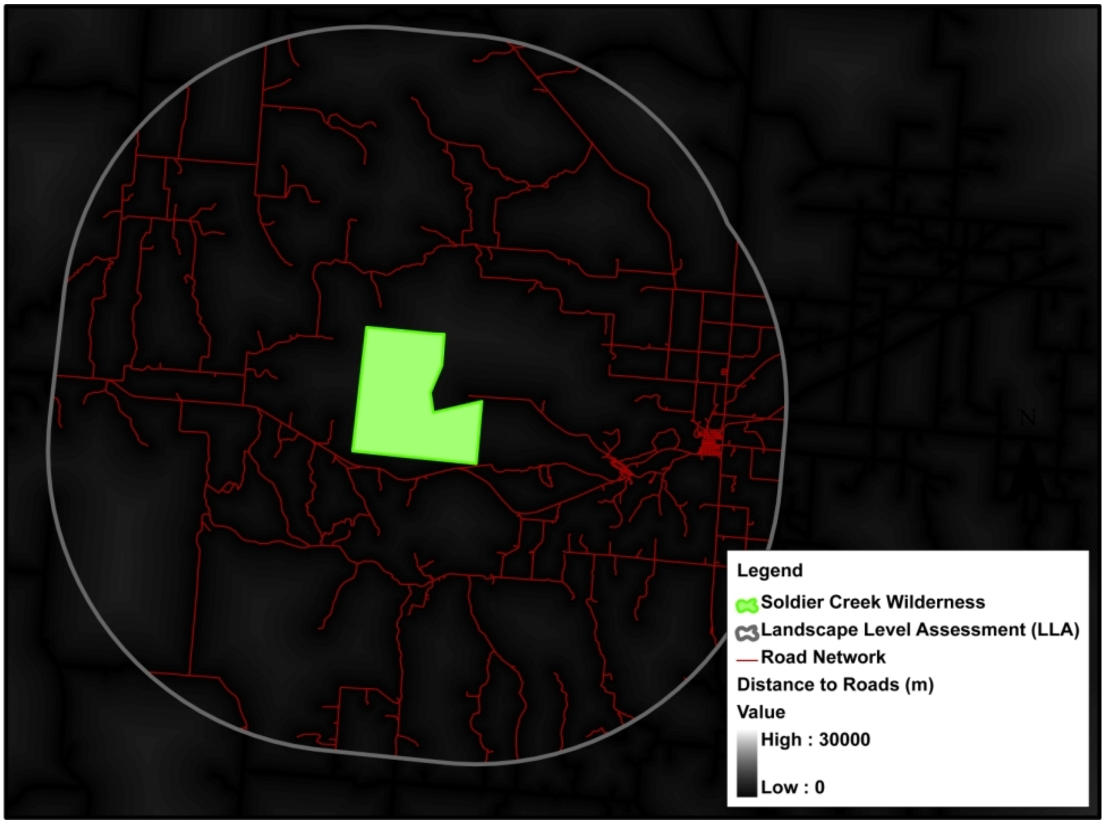

Figure 72. Distance to Nearest Road for Land Near Soldier Creek Wilderness.

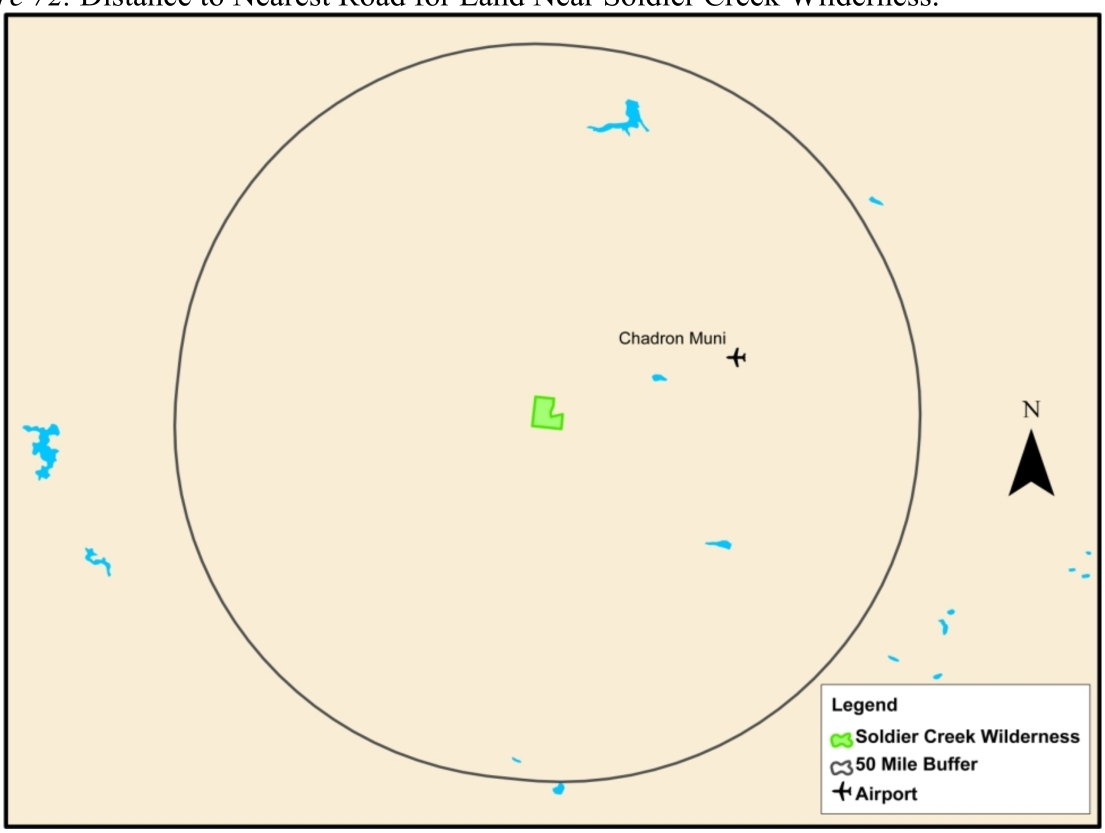

Figure 73. Airports Within 50 Miles of Soldier Creek Wilderness.