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# The wildland-urban interface in the conterminous United States 2000-2010

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By

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# The Wildland-Urban Interface in the Conterminous United States 2000-2010

A Thesis

Presented to

The Faculty of

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In Partial Fulfillment

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# Abstract

The wildland-urban interface (WUI) is an area where homes, structures, and human development are interspersed or adjacent to wildland fire fuels. While prior works have mapped the extent and character of the WUI, the release of recent datasets such at US Census 2010, as well as spatially explicit vegetation height data, now allows for an updated model for mapping the WUI across the conterminous United States (CONUS). In addition, logical iterative improvements in WUI mapping techniques are presented which incorporate existing methods with novel techniques to map the current extent of the WUI using new housing density, vegetation, administrative, hydrologic, and road datasets. This thesis reviews the context in which WUI mapping came to prominence, and describes existing methods while exploring potential improvements. Appendix One, a stand-alone paper intended for publication further explores existing methods, presents a new WUI mapping geographic information system (GIS) model, and goes on to describe model results for the CONUS for years 2000 and 2010. The 2010 CONUS WUI occupied 227,376,491 acres, 11.79% of the CONUS, an expansion of 12.2 million acres from 2000, 5.7% growth. Model results suggest the WUI population was 126.4 million, 45.23% of the total population, an increase of 18.1 million since 2000, 14.34% growth. The number of WUI housing units was 63.4 million, 48.45% of total housing units, an increase of 10.1 million since 2000, 19.03% growth. For both 2000 and 2010, the WUI remained 97% vegetated to 3% non-vegetated land cover.

# Acknowledgements

I would like to thank the invaluable contributions of my thesis committee. Without their expertise, guidance, and patience, this work would not be possible. In addition, I would like to thank Jacob Lesser for his contributions in the early stages of the project, as well as Gerry Gabrisch and Stefan Freelan for their contributions and consultation on many of the GIS issues encountered. Finally, I am indebted to Stowe Talbot for his generous donation to Huxley College of the Environment.

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# Introduction

Wildland fire is a world phenomenon on the rise, and the United States is no exception to this trend (Bowman *et al.* 2009). Predictions about climate change and future climate variability suggest that wildland fire will remain a relevant and growing issue well into the future (Westerling *et al.* 2006). Alongside an increase in global wildland fire, there has been a significant increase in domestic US expenditures on wildland fire management and acres burned (Calkin *et al.* 2005; Abt *et al.* 2009). Given finite financial resources to address this complex problem, policy makers must begin to address the scope of the wildland fire issues facing the United States in a practical matter (Allen and Gould 1986; Chapin III *et al.* 2008). As Carroll et al. state, "solutions to the problems associated with fire danger are best thought of in terms of long-term system improvements rather than short term fixes" (Carroll *et al.* 2007). One landscape where long term improvement is possible is that of the wildland-urban interface (WUI). The WUI, put simply, is an area where homes, structures, and human development are interspersed or adjacent to wildland fire fuels.

Without a clear understanding of the location, character, and growth of the WUI, home owners and communities face higher risk of losses from wildland fire. Despite previous efforts to quantify the location, character, and extent of the WUI, new data and techniques are available to update the picture of how human development, vegetation, and wildland fire interact across the landscape. When analyzed appropriately, these data can provide home owners and policy makers with useful information for making appropriate land use decisions about past, present, and future wildland fire management in the wildland-urban interface and beyond.

Currently, there are several accepted definitions of the WUI in the US The variety of definitions owes particularly to the complexity, context, and purpose involved in operationalizing a loosely defined, yet familiar phenomena (Stewart *et al.* 2009). At a federal level, the WUI is defined as one of three types: interface, intermix, or occluded wildland-urban interface:

> Interface Community - The Interface Community exists where structures directly abut wildland fuels. There is a clear line of demarcation between residential, business, and public structures and wildland fuels. Wildland fuels do not generally continue into the developed area. The development density for an interface community is usually 3 or more structures per acre, with shared municipal services. Fire protection is generally provided by a local government fire department with the responsibility to protect the structure from both an interior fire and an advancing wildland fire. An alternative definition of the interface community emphasizes a population density of 250 or more people per square mile.
>
> Intermix Community - The Intermix Community exists where structures are scattered throughout a wildland area. There is no clear line of demarcation; wildland fuels are continuous outside of and within the developed area. The development density in the intermix ranges from structures very close together to one structure per 40 acres. Fire protection districts funded by various taxing authorities normally provide life and property fire protection and may also have wildland fire protection responsibilities. An alternative definition of intermix community emphasizes a population density of between 28–250 people per square mile.
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> Occluded Community- The Occluded Community generally exists in a situation, often within a city, where structures abut an island of wildland fuels (e.g., park or open space). There is a clear line of demarcation between structures and wildland fuels. The development density for an occluded community is usually similar to those found in the interface community, but the occluded area is usually less than 1,000 acres in size. Fire protection is normally provided by local government fire departments (US Department of the Interior (USDI) and US Department of Agriculture (USDA) 2001).

While much work has been done on the issue of wildland fire and the WUI, the extent and character of the present day CONUS WUI remains unclear. Thus, mapping the current extent of the WUI remains a research need. Previous models developed circa 2005 using US Census data from 2000 suggest the conterminous United States (CONUS) WUI covers 9% of all land area ($719{,}156\ km^2$) and 39% (45,202,810) of all houses (Radeloff *et al.* 2005). An alternative model, also using US Census 2000 data suggests the CONUS WUI covers 5.9 % of land area ($465{,}614\ km^2$) and 10.7% (12,401,796) of all homes (Theobald and Romme 2007). Despite variations in WUI modeling assumptions and model outputs, all previous

WUI modeling results point to the WUI as covering significant portions of the US landscape (Stewart *et al.* 2003; Radeloff *et al.* 2005; Wilmer and Aplet 2005; Theobald and Romme 2007).

While previous WUI models rely largely on the Federal Register's minimum housing density criteria, they have considerable variation when it comes to determining proximity to vegetation. This thesis proposes a new technique which utilizes spatially explicit vegetation height data to produce a WUI map which conforms to local conditions. In addition, no study to date has assessed the extent of this unique landscape across the CONUS using US Census data more recent than 2000. With the release of new 2010 US Census data, as well as previously unavailable data on vegetation height, there are a variety of logical improvements to existing WUI modeling techniques.

In response to the release of new US Census and LANDFIRE vegetation data, this thesis presents a new geographic information systems (GIS) model which uses these and other publicly available datasets to build upon existing methods. The model allows for the use of a variety of public datasets and user needs, and proposes a consistent WUI definition for comparing the WUI over time. The bulk of the thesis work is reported in Appendix One, a paper to be submitted for peer-review that introduces a new model to map the WUI, and presents model outputs at the CONUS and state level to answer three research questions.

## Research Questions

- What is the extent of the WUI and how has it changed since 2000?

- How many people and housing units occupy the WUI and how has that changed since 2000?
- What are the vegetation characteristics of the WUI and how has that changed since 2000?

# Context

Improvements on existing WUI mapping efforts are suggested for a variety of reasons. Previous efforts relied upon older datasets such as US Census block data from 2000 as well as vegetation data ranging from 1992-2002 (Stewart *et al.* 2003; Radeloff *et al.* 2005; Wilmer and Aplet 2005; Theobald and Romme 2007). With the release of Census 2010 and LANDFIRE vegetation layers, it is now possible to model an updated WUI map, and assess change since 2000. Furthermore, because of iterative improvements in WUI mapping it is now possible to blending existing methods to incorporate new datasets previously unavailable. Areas of potential improvement are outlined below in three sections: Vegetation, Housing Density, and Dasymetric Mapping.

## Vegetation

LANDFIRE data is a high resolution (30m) vegetation dataset available for the entire US and includes a variety of vegetation data pertaining to wildland fire. Of interest to WUI mapping is the incorporation of LANDFIRE's Existing Vegetation Height (EVH) layer. Vegetation height is an important consideration when developing a community protection zone (CPZ) because maximum sustained flame length and consequently a suitable firefighter safety zone can be estimated by multiplying vegetation height times eight (Butler and Cohen 1998; Nowicki 2002).

A community protection zone is the area between communities at risk and potential wildland-fire fuels. Previous efforts to approximate the CPZ relied on either isometric buffering from communities at risk (Stewart *et al.* 2003; Radeloff *et al.* 2005; Wilmer and Aplet 2005), or variable buffering using general vegetation type data (forest, grassland, shurubland) when determining the CPZ (Theobald and Romme 2007). Isometric buffering is defined as buffering target features by a static distance. Target features in the context of the WUI mapping efforts are defined as census blocks meeting the minimum Federal Register WUI housing density criteria of >1 housing unit/40 acres (Wilmer and Aplet 2005), or the Federal Register housing density definition and some combination of US Census blocks percent vegetation to non-vegetation, and proximity to patches of vegetation (Stewart *et al.* 2003; Radeloff *et al.* 2005; Theobald and Romme 2007). Variable width buffering employs cost distance surfaces derived from vegetation type data layers to produce variable width buffers radiating outward from target features.

It is important to note that while emphasis on individual housing units must play a part in the development of a community protection zone (CPZ), additional modifications to vegetation beyond the home may improve the ability of firefighters to defend the community as a whole (Nowicki 2002). A more spatially explicit, variable width CPZ based on vegetation height, rather than vegetation type or isometric buffeing offers logical improvements to existing methods when delineating CPZ's and allows the shape and distance of the CPZ to conform to local conditions rather than being uniform (Theobald and Romme 2007). As noted, a linear buffer of four times the maximum sustained flame height is a suitable safety zone for firefighter protection when defending potentially flammable structures (Butler and Cohen 1998), while maximum sustained flame height can be approximated as twice the existing vegetation height (Nowicki 2002). Thus a suitable community protection zone can be approximated as a zone between communities at risk and adjacent vegetation buffered by eight times vegetation height.  The release of LANDFIRE EVH data allows for the buffering of CONUS vegetation based on height inputs, thereby allowing for the creation of a more spatially explicit CPZ when mapping the WUI. No CONUS WUI mapping efforts to date have included explicit considerations of vegetation height, but Theobald and Romme 2007 did identify the need to refine weights for variable width buffers in future work.  The model described in Appendix One offers potential refinement to this process through the use of LANDFIRE EVH and a corridor function executed in GIS.

While the use of EVH data is in and of itself a potential improvement in WUI mapping, Euclidean distance variable width buffering from vegetation, based on height alone does not make intuitive sense. The community protection zone exists *between* potential wildland fire fuels and the community itself.  Thus buffering vegetation away from the community overestimates the CPZ to be included in the WUI mapping efforts.  The use of a corridor function in the ArcGIS environment allows for the creation of a directional CPZ between communities at risk and potential wildland fire fuels, further refining existing methods for mapping the CPZ portion of the WUI.  A corridor function in the ArcGIS desktop environment relies on two cost distance layers as inputs, and is explained in greater detail in the excerpt below:

> *"The corridor tool returns a raster in which, for each cell location, the sum of the cost distances (accumulative costs) for two input accumulative cost rasters is calculated. The sum of the two raster costs identifies for each cell location the least-cost path from one source to another source that passes through the cell location." (ArcGIS Help 10.1 Resource Center).*
>
> *The output raster [from the corridor tool] does not identify a single least-cost path between the two sources but identifies the range of accumulative costs between the sources. That is, the least accumulative cost to reach source 1 plus the least accumulative cost to reach source 2 equals the total accumulative cost of a path passing through a cell. It is the least accumulative cost if a path is routed through the cell from source 1 to source 2.*
>
> *If all cells with values less than a maximum accumulated distance (or threshold) are selected from the corridor raster, the resulting output raster will correspond to a swath (or corridor) of cells that do not exceed a specified cost. The resultant threshold output can be viewed as the least-cost corridor of cells." ('Creating a least cost corridor' 2013).*

For the purposes of creating the CPZ, this thesis proposes the creation of two Euclidean distance cost surfaces (rasters) at 30 meter pixel resolution to serve as corridor inputs. The first cost distance surface is generated outward from census blocks meeting the minimum WUI housing density (as defined in the Federal Register) of 1 housing unit/40 acres, by the maximum sustained flame length times eight, plus one pixel. This serves to capture vegetation and potential buffers within the maximum potential CPZ, while excluding vegetation beyond this distance. The resolution of 30 meters was chosen because it matches the resolution of nationally available LANDFIRE data. While maximum EVH varies by state, the maximum vegetation height is assumed to be 60 meters, and thus a maximum possible buffer of 480 meters (60 meters times 8). One additional pixel is added to account for potential vegetation occurring beyond 480 meter, but with a buffer that reaches the outermost portion of census blocks with greater than or equal to 1 housing unit/40 acres. Thus the maximum possible CPZ from communities at risk is modeled as 510 meters.

With a cost distance surface generated from census blocks meeting the minimum housing unit density threshold, a second cost surface input is generated using Euclidean distance buffers eight times the EVH value, rounded up to the nearest 30-meter pixel. The results is a raster layer with six buffer classes of 30, 60, 90, 210, 420, and 480 meters. For the purposes of creating the CPZ portion of the WUI when using the corridor tool, the respective sources are target density census blocks and vegetation, while the cost paths are Euclidean distance layers generated from each source layer independently of one another.

The maximum accumulated distance (threshold) is set independently for each vegetation class with values ranging from 30 to the maximum vegetation buffer distance plus 30 (one pixel width). The reclassified corridor output incorporates general directionality between potential wildland fire fuel buffers and census blocks meeting target density, while excluding otherwise included CPZ radiating away from vegetation and communities at risk.

## Housing Density

Previous studies relied upon Census 2000 data when modeling the WUI (Stewart *et al.* 2003; Radeloff *et al.* 2005; Wilmer and Aplet 2005; Stewart 2007; Theobald and Romme 2007). The release of the 2010 US Census allows for an updated WUI map incorporating the most up-to-date, nationally available data. In addition, the use of consistent method and US Census 2010 data allows for comparison and analysis of the WUI over time.

## Dasymetric Mapping

"Dasymetric mapping may be defined as a kind of areal interpolation that uses ancillary data to aid in the areal interpolation process" (Mennis 2003). In the context of WUI mapping, this generally refers to data layers which are used to refine US Census blocks using a binary dasymetric approach that removes areas from blocks unlikely to contain housing units. With areas unlikely to contain housing units are removed, housing unit density is recalculated using the original housing unit count divided by the recalculated census block area. The recalculated housing density can thereby be used to identify areas meeting the minimum housing density threshold, while excluding areas unlikely to contain housing units.

Dasymetric mapping was employed by both Wilmer and Aplet and Theobald and Romme in their attempts to map the WUI. Both efforts removed public lands from census blocks, and recalculated housing density (Wilmer and Aplet 2005; Theobald and Romme 2007). However, Theobald and Romme built upon existing methods by including road density as an additional dasymetric layer. We argue that including both public lands, as well as areas of low-road density in the model makes intuitive sense when dasymetrically modifying census blocks. Furthermore, the removal of water features via the USGS Area Hydrography layer offers additional refinement by removing water features unlikely to contain housing units.

# Summary of Existing Models

While previous CONUS WUI modeling efforts rely on publicly available data and have many similarities, it is clear from the release of previously unavailable datasets and the iterative growth of WUI mapping techniques, that there are areas where existing methods can be logically improved. Nevertheless, each model offers its own strengths and weaknesses. I describe three of the leading models below.

### Wilmer and Aplet 2005

The Wilmer and Aplet method offers considerable simplicity in modeling the WUI. The reliance on dasymetrically modified census blocks using public lands as the sole dasymetric input allows for a computationally elegant method for identifying blocks meeting the Federal Register definition of 1 housing unit/40 acres. Additionally, the use of only one category of WUI and isometric buffering from census blocks (meeting target housing unit density) results in a model and outputs that are easily explained. Nevertheless, the Wilmer and Aplet technique ignores additional dasymetric layers which can be incorporated given recent advances in both desktop computational power and the release of the Protected Areas Database (PADUS). Additionally, the use of an isometric buffer ignores local vegetation conditions which have been shown to affect the amount of CPZ to be considered when mapping the WUI (Nowicki 2002).

### Radeloff et al. 2005

Radeloff et al. proposed a distinct methodology for mapping the WUI through the use of a vegetation based metric to distinguish between different categories of WUI (Interface & Intermix). While the method offers insights into the gradient of WUI types, it nevertheless ignores dasymetric layers when calculating housing density. Radeloff et al. instead use equal-area housing density calculations across unmodified census blocks. While elegant, this technique fails exclude areas unlikely to contain housing units from WUI model outputs. Furthermore, their use of proximity to vegetation as an input for WUI mapping, ignores spatially explicit vegetation characteristics, and instead uses isometric buffering from census blocks.

### Theobald and Romme 2007

Theeobald and Romme's methodology offers several advantages over existing methodologies. It employs the use of dasymetric mapping to remove areas presumed not to contain housing from census blocks, recalculates housing unit density, and develops variable width buffers from census areas meeting the Federal Register WUI housing unit density threshold. The use of both dasymetric mapping and variable width buffers based on vegetation types improves upon existing methods by creating a variable width CPZ based on local conditions (Theobald and Romme 2007). However, as they themselves noted, the general assumptions used in generating buffer distances are arbitrary, relying solely on vegetation type. With the release of LANDFIRE EVH it is now possible to incorporate spatially explicit vegetation height into WUI models, to produce a CPZ based on local vegetation conditions.

## Conclusion

In lieu of the growth of WUI modeling techniques and the release of new datasets, it is clear there is space for the exploration of a new WUI model which builds upon existing methods while incorporating their respective strengths. While choices on the respective strengths and weaknesses of previous models are somewhat arbitrary, the integration of previous model elements are intended to best incorporate newly available data, while building upon recommendations in previous efforts. This thesis presents Appendix One, a stand-alone article intended for scholarly publication. Appendix One provides background on WUI fire issues, surveys previous WUI mapping, and proposes a new model to blend new and existing techniques with new datasets. It goes on to examine WUI model outputs for years 2000 and 2010, and describe the growth, housing, population, and vegetation characteristics of the WUI. As a stand alone paper, Appendix One presents the first ever portrayal of WUI change from 2000-2010, presents model results, and draws conclusions on the nature of WUI growth across the CONUS for that time period.

# Appendix One

# Change in the Wildland-Urban Interface 2000-2010

## Abstract

The wildland-urban interface (WUI) is an area where homes, structures, and human development are interspersed or adjacent to wildland fire fuels. While much work has been done previously to map extent and character of the WUI, the release of recent datasets such at US Census 2010, as well as spatially explicit vegetation data now allows for an updated model for mapping the WUI across the conterminous United States (CONUS). In addition, logical iterative improvements in WUI mapping techniques now allow for the incorporation of existing methods with novel techniques to map the current extent of the WUI using recent housing density, vegetation, administrative, hydrologic, and road datasets. These iterative changes are presented as a GIS model used to map the WUI in the United States for 2000 and 2010 to assess change in the WUI over that time period. The 2010 WUI occupied 227.3 million acres, 11.79% of total area representing an expansion of 12.2 million acres since 2000 (5.7% growth). The 2010 WUI population was 126.4 million, 45.23% of total population, an increase of 18.1 million since 2000 (14.34% growth). The number of 2010 WUI housing units was 63.4 million, 48.45% of all housing units, an increase of 10.1 million since 2000 (19.03% growth). For both 2010 and 2000, the WUI remained 97% vegetated to 3% non-vegetated land cover.

# Introduction

Wildland fire has been part of the landscape since as early as the Carboniferous Period and a regular landscape actor since the Mesozoic Era (Agee 1993). Its ecological niche is well documented over the course of the modern era (Leopold *et al.* 1963; Habeck and Mutch 1973; Backer *et al.* 2004; Noss *et al.* 2006). Despite widespread acknowledgement of wildfires ecological role, cultural and political tension exists over the proper place of wildfire on the US landscape. One region of particular interest is that of the wildland-urban interface (WUI). The WUI exists where homes and associated structures are built among forests, shrubs, or grasslands (Radeloff *et al.* 2005), and has been identified by the Federal Government as a management priority (US Congress 2003). Expansion of the WUI is resulting in an increased risk of fire to homes and private property across the United States (Schoennagel *et al.* 2009), and has been predicted to expand to at least 513,670 $km^2$ by 2030 (Theobald and Romme 2007).

Previous geographic information system (GIS) models developed circa 2005 suggest the WUI in the conterminous United States (CONUS) covers 9% of all land area ($719{,}156\ km^2$) and 39% (45,202,810) of all housing units (Radeloff *et al.* 2005). An alternative model suggests the WUI covers 5.9 % of land area ($465{,}614\ km^2$) and 10.7% (12,401,796) of all housing units (Theobald and Romme 2007). With the release of newly available data and the continued development of literature on the WUI and fire, it is time to reassess the WUI at a national scale. While there are several popular definitions for the WUI and how it is best modeled, there remains no standard method for modeling this unique landscape over time. In addition no study to date has assessed growth of the WUI in the CONUS using data more recent than 2000.

Therefore, this paper proposes a new GIS model to map the WUI using publicly available datasets. The model blends existing methods with iterative model developments to map the current WUI and as assess change over time. This work describes the context in which the WUI has come to prominence, reviews existing methods for modeling the WUI, describe the new model, and presents model results. The model uses the most up to date, publicly available datasets to map the WUI, and introduces novel techniques to answer three research questions:

## Research Questions

- What is the extent of the WUI and how has it changed since 2000?
- How many people and housing units occupy the WUI and how has that changed since 2000?
- What are the vegetation characteristics of the WUI and how has that changed since 2000?

# Background

In the United States, wildland fire has often been associated with catastrophe. Several large fires, beginning with the Peshtigo Fire of 1871 in Michigan and Wisconsin (1.28 million acres burned and an estimated 1,500 killed); the Great Hinkley Fire of 1894 near Hinkley, Minnesota (estimated 1.6 million acres burned and an estimated 400-800 killed); and the

Great Fire of 1910 in the Northern Rockies (3 million acres burned and 86 killed) (You and forest fires 1980; Pyne 1982; Brown 2006; Egan 2009), fueled demand for a national response. In tandem with the rise of the internal combustion engine and industrial manufacturing, the response came largely with the 1905 creation of the US Forest Service (USFS). The USFS would go on to develop a fire suppression regime that grew to become incredibly effective. In 1913, USFS Chief Forester Henry Graves went so far as to state that fire suppression was to take precedence over all other agency activities (Pyne 1982), and by 1935 was epitomized by the USFS slogan, "all fires out by 10 a.m." The slogan would become a virtual reality with 97-98% of all fires extinguished upon initial attack from the 1930's until present day (Dombeck *et al.* 2004). Despite such success, the remaining 2-3% of wildfires are the most destructive, and account for the majority of homes lost, acreage burned, and firefighting expenditures (The National Blue Ribbon Panel on Wildland Urban Interface Fire 2008; Zybach *et al.* 2009).

Alongside aggressive USFS fire suppression from the 1930's onward, the United States experienced a period of significant population growth. This population growth coincided with a century of urban expansion fueled largely by widespread automobile ownership (Davis *et al.* 2012). As population, automobile ownership, and the number of houses grew (Figure 1), so too did the area where human development coincided with the potential for wildland fires. Historical estimates suggest up to 14 million acres of non-industrial forests were converted to urban use between 1952 to 1997, with projected urban growth from 2000-2050 to increase from 3.1% to 8.1%, an area of 392,400$km^2$(Alig and Butler 2004; Nowak and Walton 2005). This is an area slightly larger than the state of Montana.

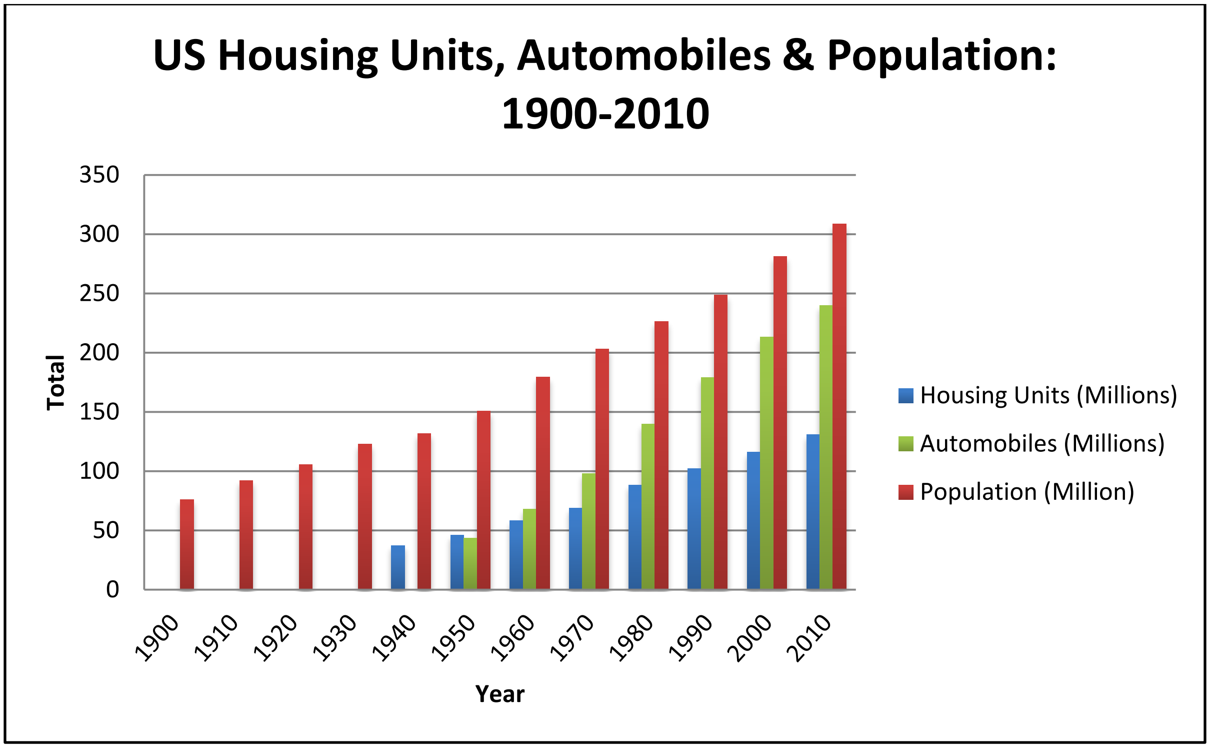


**Figure 1: US Housing, Automobiles, and Population Growth (Statistical Abstract of the United States: 2012)**

The success of fire suppression and the surge in population, housing units, and suburban/exurban growth has not come without cost. As early as 1963, the USFS "Leopold Report" noted ecological changes in natural fire regimes as the product of fire exclusion (Leopold *et al.* 1963). Despite widespread recognition of wildland fire's role as a natural landscape actor, fire suppression expenditures and area burned have increased steadily since the 1970's (Figure 2) (Calkin *et al.* 2005; Zybach *et al.* 2009). It is in this environment of rising expenditures, suppression, and acreages burned, that the WUI/wildfire dynamic has come to be recognized.

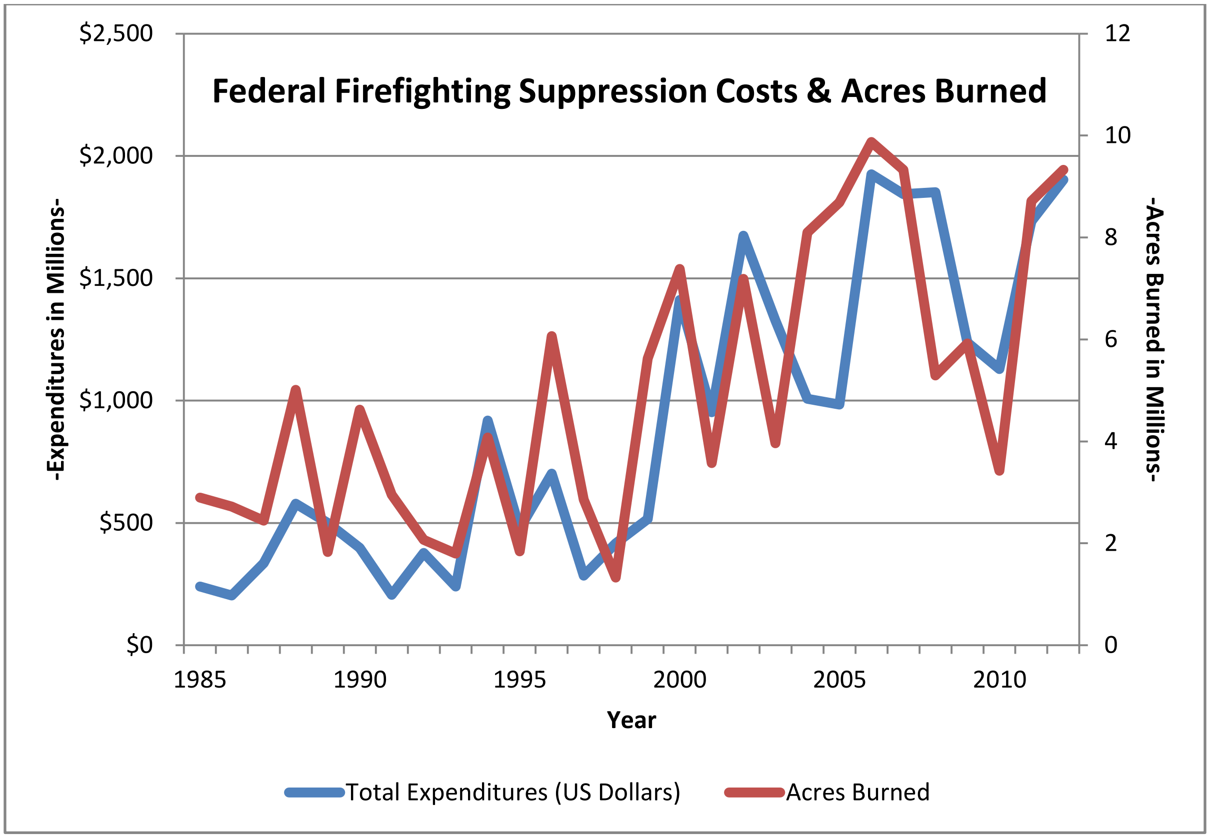


**Figure 2: Wildfire Acres Burned and USFS Fire Expenditures (NIFC 2013)**

## Geographic Modeling of the WUI

Motivated largely by fuel reduction authorizations in the Healthy Forest Restoration Act, the first serious attempts to map the WUI began in 2003. Several pivotal articles were published outlining a series of methodologies for using GIS to map the WUI at a CONUS scale. Each method relied heavily on the WUI definition published in the 2001 US Federal Register which defined the WUI as one of three types:

> Interface Community - The Interface Community exists where structures directly abut wildland fuels. There is a clear line of demarcation between residential, business, and public structures and wildland fuels. Wildland fuels do not generally continue into the developed area. The development density for an interface community is usually 3 or more structures per acre, with shared municipal services. Fire protection is generally provided by a local government fire department with the responsibility to protect the structure from both an interior fire and an advancing wildland fire. An alternative definition of the interface community emphasizes a population density of 250 or more people per square mile.
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> Occluded Community- The Occluded Community generally exists in a situation, often within a city, where structures abut an island of wildland fuels (e.g., park or open space). There is a clear line of demarcation between structures and wildland fuels. The development density for an occluded community is usually similar to those found in the interface community, but the occluded area is usually less than 1,000 acres in size. Fire protection is normally provided by local government fire departments (US Department of the Interior (USDI) and US Department of Agriculture (USDA) 2001).

Despite varying techniques to operationalize the Federal Register definition, each publication pointed to the WUI as a significant geography in the United States. Several of the leading models are described below.

### Stewart et al. 2003

The first ever national portrayal of the CONUS WUI came in 2003 with the work by Stewart et al., presented at the Proceedings of the Second International Wildland Fire Ecology and Fire Management Workshop (Stewart *et al.* 2003). The study operationalized the Federal Register WUI definition, by using US Census 2000 census blocks meeting a minimum housing unit density of 1 housing unit per 40 acres, and identified suitable wildlands using 30 meter pixel data derived from 1992/1993 in the form of the 1992 National Land Cover Database (1992 NLCD). Land cover classes included as wildlands were forests, native grasslands, shrubs, wetlands, and transitional lands. Vegetative classes excluded were orchards, arable lands, and pasture.

Two WUI categories, interface and intermix, were identified using the Federal Register definitions. The Federal Register defines interface WUI as housing "within the vicinity" of wildland vegetation, but does not explicitly define "vicinity." Stewart et al. rationalized a 2.4 km (1.5 mi) buffer extended from blocks with suitable housing density, roughly the distance a firebrand can fly from a fire (California Fire Alliance 2001; Stewart *et al.* 2003). Thus, interface was operationalized as areas meeting the housing unit density criteria while having less than 50% vegetation cover within 2.41 km (1.5 mi) of an area (made up of one or more contiguous census blocks) over 500 hectares (1236 acres) that are more than 75% vegetated. Intermix was identified as areas meeting the density threshold while containing greater than 50% defined vegetation classes (Stewart *et al.* 2003). It should be noted that their analysis did not incorporate fire risk data in their analysis. Results from their analysis concluded that the WUI covered 9.3% of CONUS land area (175 million acres), while containing 36.7% (42.2 million) of total housing units.

### Wilmer and Aplet 2005

A second major effort to operationalize the Federal Register WUI definition came in 2005, and was developed by Wilmer and Aplet (henceforth described as WA) of the Wilderness Society. The WA method, detailed in the paper "Targeting the Community Fire Planning Zone - Mapping Matters" sought to create a consistent method for using GIS to map communities at wildland fire risk and the "community fire planning zone" (CFPZ). The CFPZ would serve as a modified term for the WUI when mapped using the WA method. WA crafted a modified method that allowed for WUI comparison across state boundaries, suitable for use in national policy making. While falling short of mapping the CONUS CFPZ, the paper describes the methods for, and results from, mapping the CFPZ in three disparate regions of the country; the Colorado Front Range, the Central Idaho Ecosystem, and the Greater Yosemite area in California (Wilmer and Aplet 2005).

The methodology employed by WA built upon the work done previously by Stewart et al. 2003. Using US Census 2000 data, the minimum housing density would remain at 1 housing unit per 40 acres but would rely on a modified, dasymetric approach. “Dasymetric mapping may be defined as a kind of areal interpolation that uses ancillary data to aid in the areal interpolation process”(Mennis 2003). WA used binary dasymetric mapping by removing public lands from US Census 2000, census blocks, recalculating housing unit density using the modified blocks, and selecting blocks meeting the minimum density of 1 housing unit per 40 acres. WA justified the decision to remove public lands on the assumption that homes are not generally build on public lands, and thus public lands should be removed from consideration when determining housing density. They did not specify categories of WUI, but instead isometrically buffered modified census blocks by 0.5 miles (0.8 km). Finally, they removed non-wildland fire fuels from the target density census blocks to approximate the CFPZ. Landcover was derived from the 30-meter resolution 1992 National Land Cover Dataset (1992 NLCD) and was used to determine non-wildland fire fuels. Non-wildland fuel classes were water, barren, rock, agriculture, and urban areas. Because the WA technique was applied to only selected regions of the country, figures for the on the extent of the CFPZ at the CONUS scale were not produced.

### Radeloff et al. 2005

The same year as the publication of the WA technique, Radeloff et al. (2005) would publish a further refinement of previous WUI mapping efforts. Similar to the previous WUI mapping efforts of Stewart et al. (2003), Radeloff et al. also used US Census 2000 data and employed the 1 housing unit per 40 acres minimum threshold. Non-wildland vegetation land cover classes were removed from the 30-meter resolution 1992 NLCD. Classes removed were low-and high-intensity residential, commercial/industrial, orchards/vineyards, pasture/hay, row crops, small grains, fallow, urban/recreational grasses, bare rock/sand/clay, quarries, open water, and perennial ice/snow (Radeloff *et al.* 2005). The remaining land cover classes were used to determine percent vegetation cover for individual census blocks. Housing unit density was also calculated for each census block and used in conjunction with percent vegetation land cover to define two classes of WUI. Intermix WUI was defined as: >1 housing unit/40 acres, less than 50% vegetation cover, and within 1.5 miles (2.4 km) of an area with greater than 75% vegetation cover. A minimum-area threshold of 3.1 $\text{miles}^2$ (5 $\text{km}^2$) for heavily vegetated areas within 1.5 miles was used to avoid including residential areas within 1.5 miles of small urban parks. If the census block was partially within 1.5 miles of the heavily vegetated areas, the block was then split, retaining only the portion within the 1.5 mile buffer. Intermix WUI was defined as blocks with the minimum housing unit density and comprising of 50% or greater vegetation land cover classes.

Aside from removing portions of interface WUI census blocks that were beyond 1.5 miles from heavily vegetated areas, the Radeloff et al. 2005 technique is identical to the Stewart 2003 model. Radeloff and Stewart are co-authors on both papers outlining the methods, and thus similarities are not surprising. Nevertheless, the improvements in 2005 did contribute logical improvements to the existing methods. Results of the 2005 analysis are similar to Stewart et al. 2003, with the CONUS WUI covering 177.7 million acres (9.4% of land area) and including 44.3 million housing units (38.5% of total housing units). A follow-up study in 2007 applied the same methods as the 2005 study but included a robust sensitivity analysis. The results of this analysis concluded the model yielded stable results over time (Stewart 2007).

**Theobald and Romme 2007**

In 2007 Theobald and Romme (henceforth referred to as TR), presented an additional method for mapping the WUI in the paper "Expansion of the wildland-urban interface." The TR method used updated data for establishing the extent of the WUI, and provided additional refinements to map the WUI with a focus on fire hazard. Building on the work of WA, TR used dasymetric mapping to remove protected areas, as well as water features from census blocks, and recalculated housing density using the new area totals (Theobald and Romme 2007). TR utilized the Protected Areas Database (PADUS) to remove protected areas, and utilized US Census 2000 data to remove water features.

Distancing itself from previous works, the TR method employed the use of a variable width buffering technique to buffer areas meeting the minimum target density threshold of 1 housing unit/40 acres. Previous methods relied upon isotropic buffering, which buffers target features uniformly, regardless of surrounding vegetation conditions. Instead of a uniform buffer, variable width buffering uses variability in local vegetation types to drive buffer distances when determining community protection zone (CPZ) distances (Theobald and Romme 2007). Maximum buffer distances were set at three intervals, 0.5 miles, 0.5-1 miles, and 1-2 miles, and used in conjunction with cost-weighted distances based on vegetation type to generate variable width buffers.

Vegetation characteristics were derived from a combination of sources to create a synthetic vegetation map based on the 2001 NLCD and the US Department of Agriculture's FUELMAN datasets with respective resolutions of 30 $m^2$and 1 $km^2$. The two datasets were combined to provide increased resolution when classifying major vegetation types within and near the WUI. Finally, raster data processing was used to convert dasymetrically refined census blocks to 1ha resolution raster cells, and housing units spread throughout the refined blocks weighted by the density of major roads. Major roads were derived from 2004 Census TIGER line files and road density computed using a moving neighborhood analysis with an 800 m radius, and classified into four categories based on ad hoc comparison: very low (0.0-0.25 km/km2), low (0.25-1 km/km2), medium (1.0-5.0 km/km2), and high (>5.0 km/km2). Weights of 1, 2, 3, 4 were assigned, and used to allocate housing density values to cells within census blocks (Theobald 2005). Results from the TR analysis suggested a significant reduction in WUI extent over previous methods, with the WUI covering 115.1 million acres, and containing 12.5 million housing units.

**The Definition Effect**

Despite relying on similar definitions and data, differences in WUI mapping techniques can result in widely divergent model outputs (Table 1) (Stewart *et al.* 2009; Platt 2010). Differences such as the nearly 60 million acre discrepancy between the results of Radeloff et al. 2005 and Theobald and Romme 2007 point to the critical importance of understanding the analytical methods and definitions used in the production of WUI maps. As such, comparison of individual WUI results drawn from different methods is impractical for assessing WUI change over time.

Notwithstanding, the work presented in the following section does not explicitly critique previous methods, but rather hybridizes previous WUI mapping techniques to produce a new GIS model. As such model results are best interpreted in the context in which they were developed. The model draws on perceived strengths of existing methods and offers potential improvements through the use of previously unavailable datasets and new buffering techniques. It is customizable and allows users to output WUI maps given individual user needs and relies on publicly available data to ensure access to the widest possible audience.

| Author | Stewart et al. | Wilmer & Aplet | Radeloff et al. | Theobald & Romme |
|---|---|---|---|---|
| **Year Published** | 2003 | 2005 | 2005 | 2007 |
| **Housing Density Data** | 2000 Census | 2000 Census modified by removing public lands | 2000 Census | 2000 Census modified by removing public lands, and distributed using road density from 2004 TIGER line files |
| **Density Threshold** | 1 housing unit/40 acres | 1 housing unit/40 acres | 1 housing unit/40 acres | 1 housing unit/40 acres |
| **Vegetation** | NLCD 1992 | NLCD 1992 | NLCD 1992 | NLCD 1992/FUELMAN 2002 |
| **Resolution** | 30 Meters | 30 Meters | 30 Meters | 30 Meters, augmented with 1 $km^2$FUELMAN vegetation subcategories |
| **Buffer Distance** | 2.4 km | 0.8 km | 2.4 km | 0.8-3.22 km |
| **Buffer Method** | Isotropic | Isotropic | Isotropic | Variable |
| **Dasymetric Overlays** | None | Public Lands | None | Public Lands, Low Road Density Areas |
| **Vegetation Classes Included** | forests, native grasslands, shrubs, wetlands, transitional lands | Forests, shrubland, grasslands, herbaceous wetlands | Forests, native grasslands, shrubs, wetlands, transitional lands | Forests, shrubland, grassland, wetlands, transitional lands |
| **Categories of WUI** | Interface: more than 1 housing unit per 40 acres, have less than 50% vegetation, and are within 2.41 km of an area (made up of one or more contiguous Census blocks) over 500 ha that is more than 75% vegetated | One category defined as the Community Fire Protection Zone (CFPZ). > 1 housing unit per 40 acres. | Interface: more than 1 housing unit per 40 acres, having less than 50% vegetation, and are within 2.41 km of an area (made up of one or more contiguous Census blocks) over 500 ha that is more than 75% vegetated | Interface: >1 unit per 1.4 acre and >10ha patch |
| | Intermix: 1 housing unit per 40 acres, and have more than 50% vegetation | | Intermix: 1 house per 40 acres, and have more than 50% vegetation | Intermix 1 unit per 2.4-40 acre |
| **Acres Identified** | 175,124,915 | n/a | 177,707,043 | 115,173,663 |
| **Percent of CONUS Area** | 9.3% | n/a | 9.40% | 6.00% |
| **Housing Units in WUI** | 42,297,763 | n/a | 44,348,628 | 12,500,000 |
| **Percent of CONUS Housing Units** | 36.7% | n/a | 38.5% | 13% |

**Table 1: Previous WUI Mapping Methods Matrix**

# Methods

This section outlines the methods used to map the 2000 and 2010 WUI. All analysis was executed using the ArcGIS desktop environment. Due to dataset limitations or lack of availability for the two timeframes, inputs are the best available approximations to the analysis year, and thus vary slightly from 2000 to 2010. The years 2000 and 2010 were selected due to the recent release of 2010 US Census housing unit and population data, allowing for comparison to model results using 2000 Census data.

## Datasets

### WUI 2000

GIS data layers used for the WUI 2000 mapping and analysis were the following:

- Housing density from US Census 2000 census blocks with housing unit and population counts.
- Road density derived from US Census 2000 Roads.
- Water features from US Census 2010 Area Hydrography.
- Vegetation height from USGS LANDFIRE version 1.0.5 Existing Vegetation Height (EVH).
- Vegetation type from USGS LANDFIRE version 1.0.5 Existing Vegetation Type (EVT).
- Public/protected lands from USGS Protected Areas Database version 1.2 (PADUS).

**WUI 2010**

GIS data layers used for the WUI 2010 mapping and analysis were the following:

- Housing density from US Census 2010 census blocks with housing unit and population counts.
- Road density derived from US Census 2010 Roads.
- Water features from US Census 2010 Area Hydrography.
- Vegetation height from USGS LANDFIRE version 1.1.0 Existing Vegetation Height (EVH).
- Vegetation type from USGS LANDFIRE version 1.1.0 Existing Vegetation Type (EVT).
- Public/protected lands from USGS Protected Areas Database version 1.2 (PADUS).

## Analysis

The framework for analysis remained the same for both 2000 & 2010 with only model inputs varying to correspond to the appropriate year being modeled, i.e. Census 2000 census blocks for the 2000 WUI model, Census 2010 census blocks for the 2010 WUI model. Inputs were preprocessed to select data by state to reduce processing times. Model results were output to tabular format and aggregated to produce final CONUS figures. Figures for interim model processes are available in Appendix Three. For each state, census blocks were refined to identify census blocks with a target density of greater than, or equal to,1 housing unit/40 acres to meet the Federal Register definition (US Department of the Interior (USDI) and US Department of Agriculture (USDA) 2001). Census blocks are the smallest statistical areas at which the US Census Bureau tabulates housing units. The size of individual census blocks ranges from small urban blocks to large rural blocks containing no housing units covering hundreds of square miles. Despite variability in block size, without knowledge of the location of individual housing units, census blocks are the most accurate and accessible data sources to assess WUI change at the landscape scale (Zhang and Wimberly 2007). Because housing units provide a better measure for predicting WUI change, housing unit density is typically selected over population density (Liu *et al.* 2003).

Similar to previous efforts, we employ the use of ancillary data to identify areas where housing units are not likely to be found (Wilmer and Aplet 2005; Theobald and Romme 2007). To this end, blocks were refined using dasymetric mapping. Because housing units are aggregated to the census block level, housing unit density is assumed to be equal across individual census blocks, when in reality housing unit density is variable across the landscape. Using a binary dasymetric approach, areas of census blocks assumed to not contain housing units were erased, and housing unit density recalculated using the original housing unit count and the refined polygon area.

Layers used in the erase function included water features, protected/public lands, and low-road density areas. Water and public/protected lands were identified using the hydrologic features layer, while protected/public lands were taken from the PADUS database. The US Census Area Hydrography feature set was dramatically improved from 2000 to 2010, thus the 2010 Area Hydrography dataset was used for both the 2000 and 2010 analysis. PADUS version 1.2 was used for both 2000 and 2010 model inputs for similar reasons. While both hydrologic features and the public/protected lands have changed somewhat from 2000-2010, the relatively slow change in these features, over a 10 year timeframe seems unlikely to have dramatic effects on model outputs at the state and CONUS scale.

Road density was derived from US Census 2000/2010 data, and calculated borrowing a modified methodology from Theobald and Romme (2007). Road density ($km/km^2$) was calculated using a moving neighborhood with an 800 m radius. The radius used was arbitrary but supported by a moderately strong correlation between housing and road density (Theobald 2003). Road density was classified into four categories: very low (0-.25 $km/km^2$), low (.25-1 $km/km^2$), medium (1-5 $km/km^2$), and high (>5 $km/km^2$). While the inclusion of road density calculations does increase processing times in the ArcGIS environment, it nevertheless provides for a more spatially explicit view of areas that are unlikely to contain housing units. Areas identified as having very low road densities low (0-.25 $km/km^2$) were selected, and merged with hydrologic features and protected/public lands layers. These areas were then erased from the US Census blocks, and housing density calculated using the newly refined blocks. Census blocks with a resulting housing unit density greater than or equal to 1 housing unit per 40 acres (0.025 housing units per acre) were selected, to meet the Federal Register WUI definition. No maximum density was excluded.

Once census blocks with the target density were selected, wildland fire vegetation was identified using LANDFIRE Existing Vegetation Height (EVH). EVH represents the average height of the dominant vegetation for a 30-meter grid cell. At 30-meter resolution and national coverage, LANDFIRE is the highest resolution, publicly available vegetation dataset available for the CONUS analysis. While previous work relied on either isotropic buffering or arbitrary buffer distances of census blocks derived from National Landcover Dataset general vegetation classes, the addition of the EVH dataset allows for a more sophisticated, variable width buffering between potential wildland fire fuels and the target census blocks.

Rational for vegetation based, variable-width buffering follows the logic that homes that do not ignite, do not burn. As home loss is the principle problem in WUI fire, preventing ignition is of critical importance (Cohen 2001). We sought to develop buffers to roughly capture a range of firefighting objectives, such as structural protection and firefighter safety. With fire suppression crews often deployed to defend houses during wildland and WUI fires, creating defensible space between wildland fire and homes is considered a high priority and contributes to fewer homes lost. Research shows that a linear buffer of four times the maximum sustained flame height is a suitable safety zone for firefighter protection (Butler and Cohen 1998). Maximum sustained flame height is related to vegetation height, and approximated to be twice the height of existing vegetation (Nowicki 2002).

Thus, EVH pixels were buffered using a Euclidean distance function with a maximum distance of eight times the height of the existing vegetation, rounded up to the nearest 30-meter pixel. As a result, six classes of buffer distances were produced to create a variable width vegetation height based, cost distance surface extending from non-developed EVT vegetation in all directions (Table 2).

| Existing Vegetation Height Pixel Value | EVH Vegetation Class | Assumed Vegetation Height (Meters) | Max Sustained Flame Length (Meters) | Safety Zone (Meters) | Number of 30 Meter Pixels | Total Buffer (Meters) | Total Buffer (ft) |
|---|---|---|---|---|---|---|---|
| 100 | Sparse Vegetation Height | 1 | 2 | 8 | 1 | 30 | 98 |
| 101 | Herb Height 0 to 0.5 meters | 0.5 | 1 | 4 | 1 | 30 | 98 |
| 102 | Herb Height 0.5 to 1.0 meters | 1 | 2 | 8 | 1 | 30 | 98 |
| 103 | Herb Height > 1.0 meter | 1 | 2 | 8 | 1 | 30 | 98 |
| 104 | Shrub Height 0 to 0.5 meters | 0.5 | 1 | 4 | 1 | 30 | 98 |
| 105 | Shrub Height 0.5 to 1.0 meter | 1 | 2 | 8 | 1 | 30 | 98 |
| 106 | Shrub Height 1.0 to 3.0 meters | 3 | 6 | 24 | 1 | 30 | 98 |
| 107 | Shrub Height > 3.0 meters | 3.75 | 7.5 | 30 | 1 | 30 | 98 |
| 108 | Forest Height 0 to 5 meters | 5 | 10 | 40 | 2 | 60 | 197 |
| 109 | Forest Height 5 to 10 meters | 10 | 20 | 80 | 3 | 90 | 295 |
| 110 | Forest Height 10 to 25 meters | 25 | 50 | 200 | 7 | 210 | 689 |
| 111 | Forest Height 25 to 50 meters | 50 | 100 | 400 | 14 | 420 | 1378 |
| 112 | Forest Height > 50 meters | 60 | 120 | 480 | 16 | 480 | 1575 |

**Table 2: Existing Vegetation Heights & Buffer Values**

With the vegetation buffers calculated independently of census blocks, census blocks with target density were converted to 30-meter raster layers, and buffered by the maximum community protection buffer of 480 meters plus 30-meters using a Euclidean distance function. 480 meters is eight times the maximum assumed vegetation height of 60 meters. There are undoubtedly tress taller than 60 meters in the United States, however there are extremely few communities surrounded by forests with an average height of greater than 50 meters, and unlikely that they could produce sustained flame lengths greater than 100 meters (Nowicki 2002). An additional pixel was added to account for a potential placement of a housing unit on the edge of a target density census blocks, resulting in the maximum buffer from census blocks meeting target density requirements of 1 housing unit/40 acres, of 510 meters.

A corridor function was executed between the Euclidean buffered census blocks and the Euclidean buffered vegetation, and reclassified to only include the maximum cost path of eight times (to the nearest 30 meter raster value) the existing vegetating height, to create a directional buffer around selected census blocks. The directional buffer assumes a non-linear, cost distance path between potential wildland/WUI fire fuels and selected census blocks. Because this function assumes a non-linear cost distance path(ways), it overestimates potential defensible space, but nevertheless does incorporate general directionality between selected census blocks and potential wildland/WUI fire fuels. This differs from existing methods by conceptually reducing the area assumed to be an appropriate buffer between census blocks meeting target housing unit density and potential wildland-fire fuels. Finally, non-wildland fire fuels were removed from areas inside selected blocks, while retaining community buffers generated via the corridor function (Wilmer and Aplet 2005).

The use of a variable width buffer in conjunction with a corridor function is a logical modification to existing methods because it a) uses vegetation height data to produce defensible space buffers from potential wildland fire fuels, and b) provides a more spatially explicit, directional CPZ extending from census blocks meeting target density.

## Sensitivity Analysis

To test the stability of our WUI definition, we conducted a sensitivity analysis. In accord with previous WUI studies, we considered a stable definition one in which the percent change in model outputs (WUI acres, homes, population, and percent vegetated) is always smaller than the percent change to a single parameter (housing unit density, vegetation buffers) (Stewart 2007). In addition, we also removed components of the WUI model itself (variable width buffers, directional buffering, and dasymetric mapping) to gauge their effect on WUI model outputs.

The size of the CONUS dataset, 11.1 million census blocks, precluded the use of all states for the sensitivity analysis. Instead we selected seven states representing disparate geographies, housing, population, and vegetation characteristics across the CONUS based off of previous WUI mapping efforts (Stewart 2007). States selected were California, Colorado, Florida, Michigan, North Carolina, New Hampshire, and Washington. Collectively, these states represent 2.2 million census blocks, 21% of total CONUS census blocks.

WUI model parameters were modified and selected states reprocessed to assess overall model stability. Minimum housing unit density was both halved, and doubled, representing 1 housing unit per 80 acres, and 1 housing unit per 20 acres respectively. Similarly, variable width vegetation buffers were halved, and then doubled. Finally, individual modeling steps were wholly removed. The corridor function was removed to eliminate directional buffering, vegetation was isometrically buffered by the maximum CONUS vegetation buffer of 480 meters to eliminate variable width buffering, and dasymetric modification of census blocks was excluded.

# Results

This section presents data analysis results for each of our three research questions. The first section presents WUI 2000 and 2010 model outputs and provides descriptive statistics to assess WUI extent and change over time at the state and CONUS scale. The second section describes WUI housing units and population for both 2000 and 2010, while the third section describes vegetated characteristics of the WUI for the same time periods.

## Research Question 1: Results

### What is the extent of the CONUS WUI and how has it changed since 2000?

#### *Analysis*

Model results were output to raster format at 30-meter resolution and tabulated to calculate the overall footprint for the 2000 WUI. The 2000 WUI covered 215,116,195 acres, 11.15% of the study area (Table 3, Figure 5). The WUI was highly variable by state; with the majority of the WUI occurring in the Eastern US. The state with the most WUI acreage was North Carolina with 13,265,126 acres, and the state with the least WUI acreage was North Dakota with 185,964 acres. Percent of the state as WUI ranged from 60.1% in Connecticut to only 0.41% in North Dakota, with the average across all states 19.81% (Figure 5).

Overall, the 2010 WUI covered 227,376,491 acres or 11.79% of the study area (Table 3, Figure 3, Figure 5). Again the WUI was highly variable by state; with the majority of the WUI occurring in the Eastern US. Similar to 2000 results, North Carolina had the most WUI acreage with 13,522,989 acres and North Dakota had the least WUI acreage with 242,479 acres. Percent of the state as WUI ranged from 58.49% in Connecticut to only 0.54% in North Dakota, with the average across all states 20.42% (Figure 4, Figure 5).

The state with the most absolute WUI growth was Texas with an increase of 1,535,405 acres. Connecticut had the greatest absolute contraction in WUI, losing 51,168 acres. Percent change in WUI from 2000-2010 was highly variable across states (Table 3, Figure 6). North

Dakota experience the strongest WUI growth, 30.39% since 2000. Delaware experienced the strongest WUI contraction, 5.01% since 2000. Average growth for all states and Washington, D.C. was 8.15%, but six northeastern states,  Connecticut, Delaware, Maryland, Massachusetts, New Jersey, and Rhode Island all lost WUI acreage between 2000 and 2010. Overall, the WUI grew by 12,260,296 acres from 2000-2010, 5.7% growth.  Relative percent difference in CONUS WUI land cover grew from 11.15% in 2000 to 11.79% in 2010, an increase of 0.64 percentage points. Figure 7 depicts CONUS WUI footprints for 2000 and 2010.

| State | Abbreviation | Acres 2000 WUI | Acres 2010 WUI | WUI Growth 2000-2010 |
|---|---|---|---|---|
| Alabama | AL | 9,119,551 | 9,264,781 | 1.59% |
| Arizona | AZ | 1,429,914 | 1,751,108 | 22.46% |
| Arkansas | AR | 4,680,055 | 5,206,951 | 11.26% |
| California | CA | 6,957,234 | 7,320,446 | 5.22% |
| Colorado | CO | 2,373,971 | 2,784,417 | 17.29% |
| Connecticut | CT | 1,917,775 | 1,866,607 | -2.67% |
| Delaware | DE | 404,595 | 384,315 | -5.01% |
| District of Columbia | DC | 7,946 | 8,234 | 3.63% |
| Florida | FL | 6,425,465 | 7,049,350 | 9.71% |
| Georgia | GA | 10,810,369 | 11,565,270 | 6.98% |
| Idaho | ID | 1,260,236 | 1,556,532 | 23.51% |
| Illinois | IL | 2,524,492 | 2,586,042 | 2.44% |
| Indiana | IN | 4,664,799 | 4,752,517 | 1.88% |
| Iowa | IA | 870,753 | 941,189 | 8.09% |
| Kansas | KS | 938,101 | 1,021,109 | 8.85% |
| Kentucky | KY | 8,378,695 | 8,643,417 | 3.16% |
| Louisiana | LA | 4,787,178 | 5,183,336 | 8.28% |
| Maine | ME | 4,398,766 | 4,658,448 | 5.90% |
| Maryland | MD | 2,350,858 | 2,330,973 | -0.85% |
| Massachusetts | MA | 2,703,808 | 2,697,689 | -0.23% |
| Michigan | MI | 9,184,501 | 9,443,085 | 2.82% |
| Minnesota | MN | 2,873,532 | 3,221,462 | 12.11% |
| Mississippi | MS | 7,402,729 | 7,590,723 | 2.54% |
| Missouri | MO | 4,830,264 | 5,478,577 | 13.42% |
| Montana | MT | 1,592,898 | 1,935,226 | 21.49% |
| Nebraska | NE | 498,057 | 591,664 | 18.79% |
| Nevada | NV | 443,414 | 480,233 | 8.30% |
| New Hampshire | NH | 2,611,164 | 2,728,738 | 4.50% |
| New Jersey | NJ | 1,687,993 | 1,668,228 | -1.17% |
| New Mexico | NM | 1,411,169 | 1,511,819 | 7.13% |
| New York | NY | 10,958,425 | 11,114,619 | 1.43% |
| North Carolina | NC | 13,265,126 | 13,522,989 | 1.94% |
| North Dakota | ND | 185,964 | 242,479 | 30.39% |
| Ohio | OH | 7,165,715 | 7,478,944 | 4.37% |
| Oklahoma | OK | 3,301,440 | 3,726,430 | 12.87% |
| Oregon | OR | 3,181,715 | 3,429,543 | 7.79% |
| Pennsylvania | PA | 11,210,669 | 11,248,993 | 0.34% |
| Rhode Island | RI | 375,573 | 372,641 | -0.78% |
| South Carolina | SC | 7,096,452 | 7,289,829 | 2.72% |

| State | Abbreviation | Acres 2000 WUI | Acres 2010 WUI | WUI Growth 2000-2010 |
|---|---|---|---|---|
| South Dakota | SD | 431,544 | 536,276 | 24.27% |
| Tennessee | TN | 9,191,766 | 9,486,819 | 3.21% |
| Texas | TX | 10,912,536 | 12,447,941 | 14.07% |
| Utah | UT | 525,948 | 637,113 | 21.14% |
| Vermont | VT | 2,318,633 | 2,489,314 | 7.36% |
| Virginia | VA | 9,796,835 | 10,312,663 | 5.27% |
| Washington | WA | 4,344,205 | 4,701,763 | 8.23% |
| West Virginia | WV | 5,947,529 | 6,016,819 | 1.17% |
| Wisconsin | WI | 4,958,493 | 5,611,737 | 13.17% |
| Wyoming | WY | 455,747 | 541,326 | 18.78% |
| CONUS Total | - | 215,116,195 | 227,376,491 | 5.70% |

**Table 3: WUI Acreage by State and Percent Growth 2000-2010**

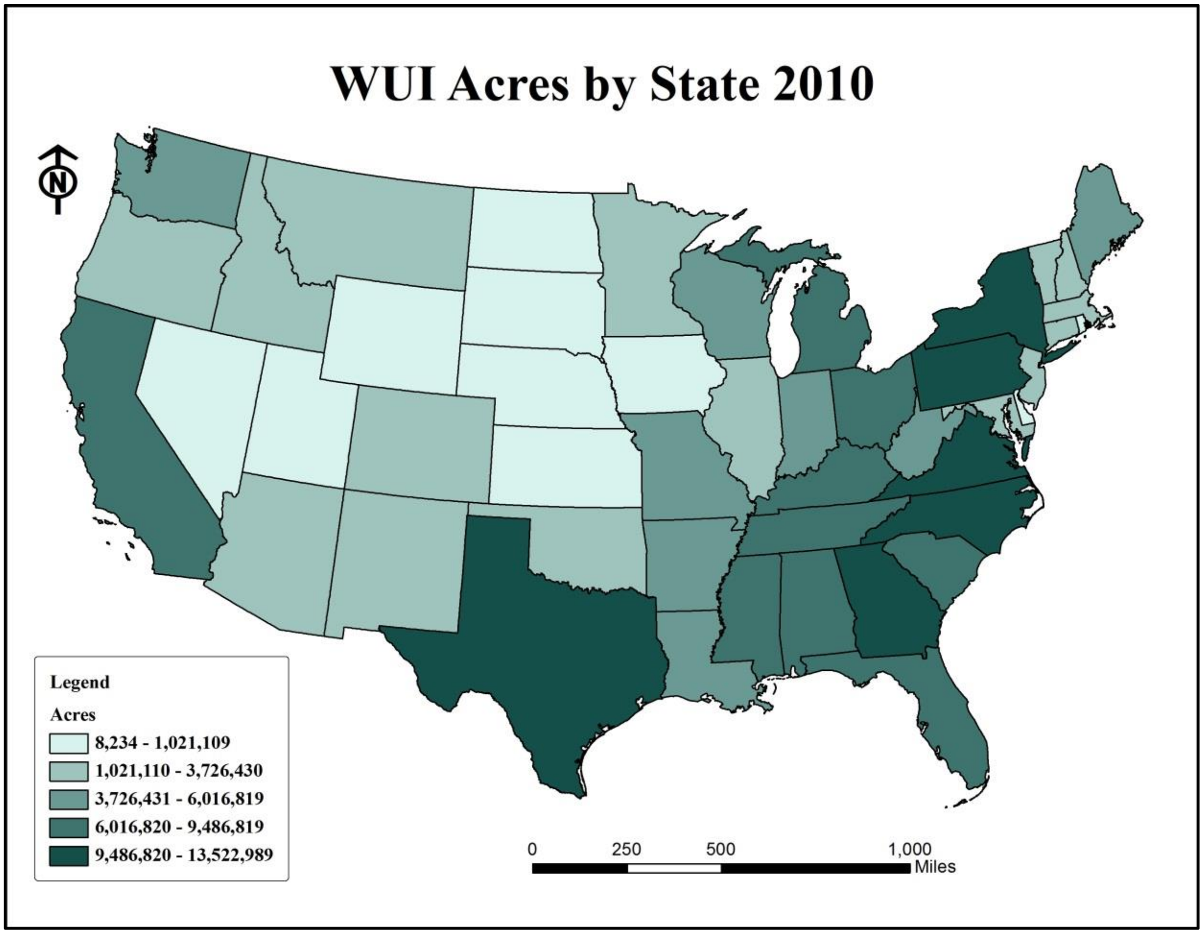



**Figure 3: 2010 WUI Acres by State**

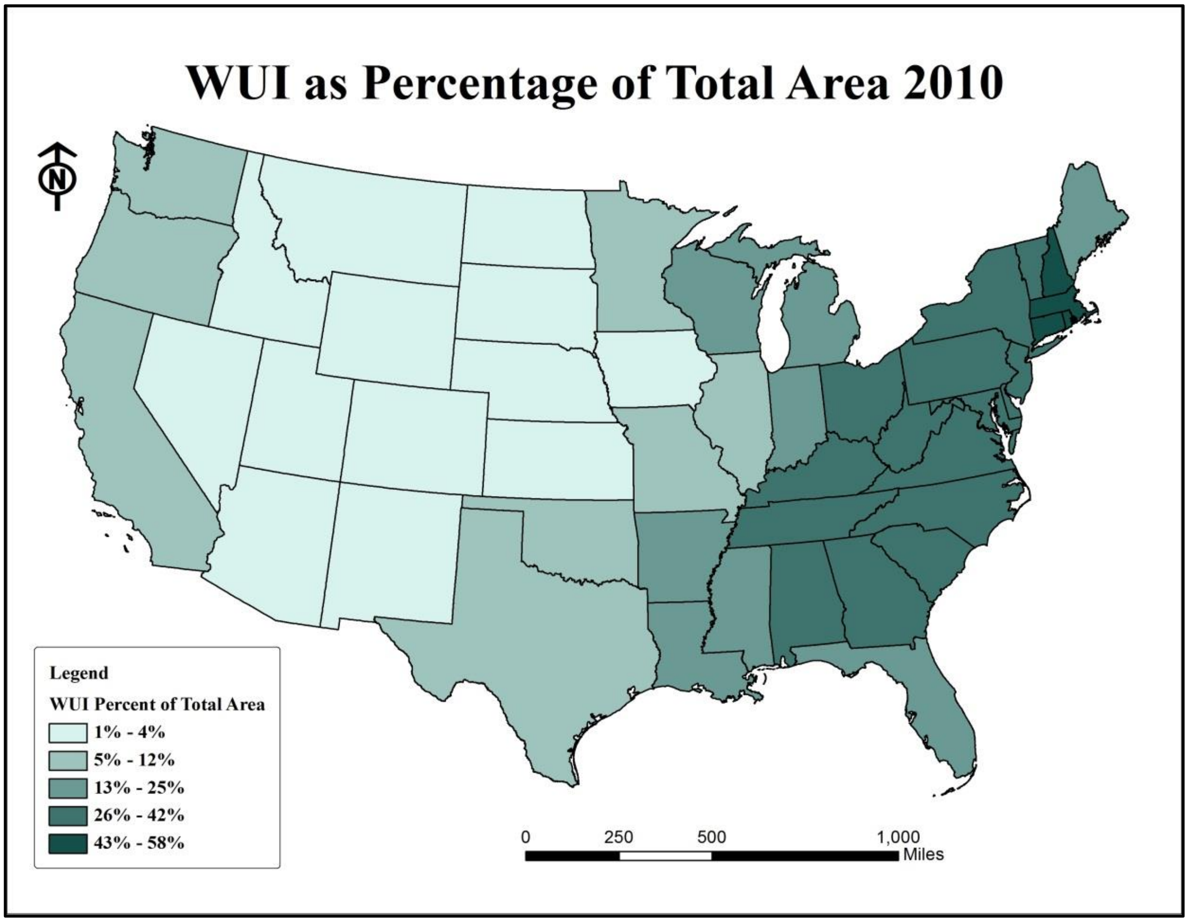


**Figure 4: 2010 WUI as Percentage of Total Area by State**

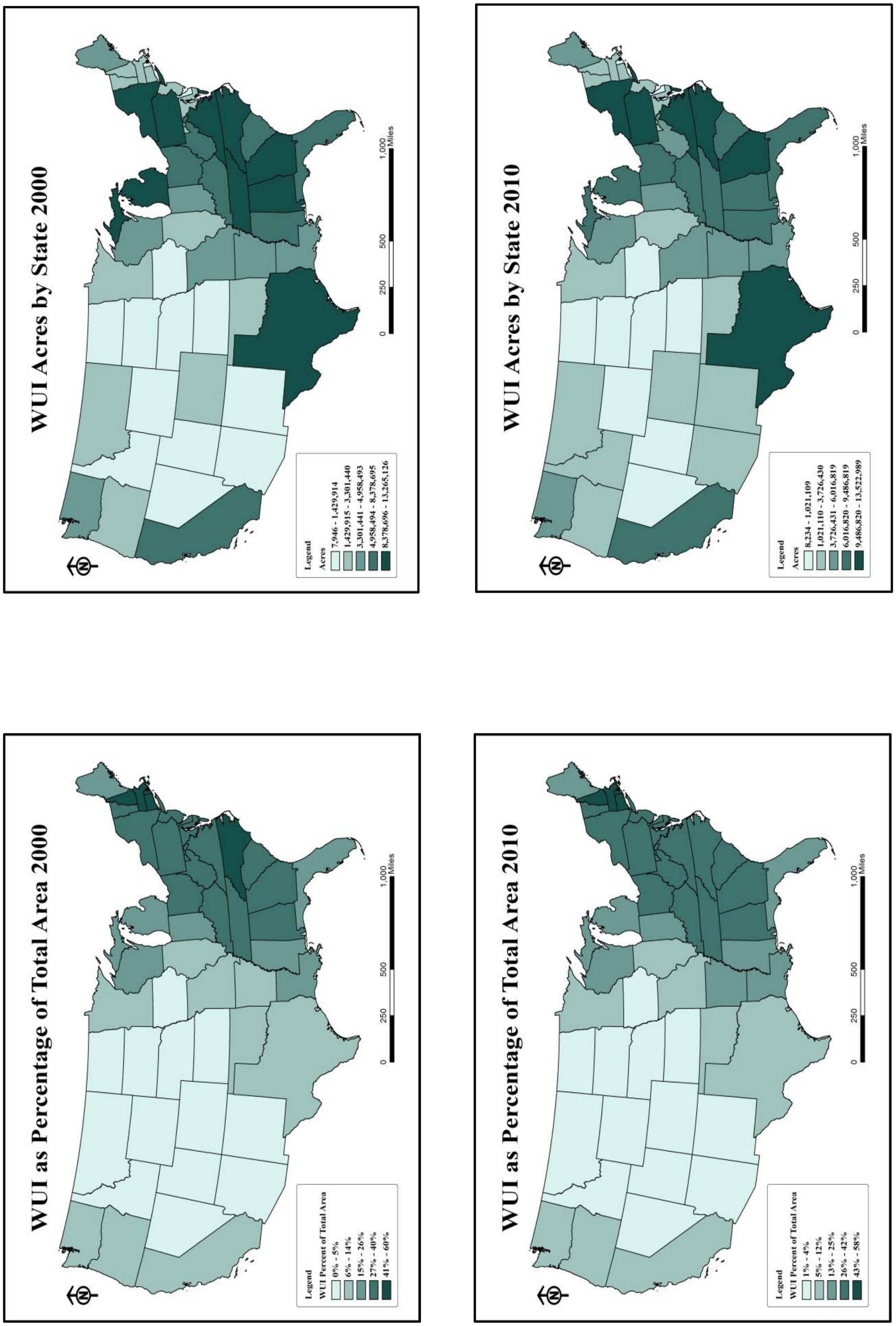



**Figure 5: Percentage of Total Area by State and Total WUI Acreage by State 2000-2010**

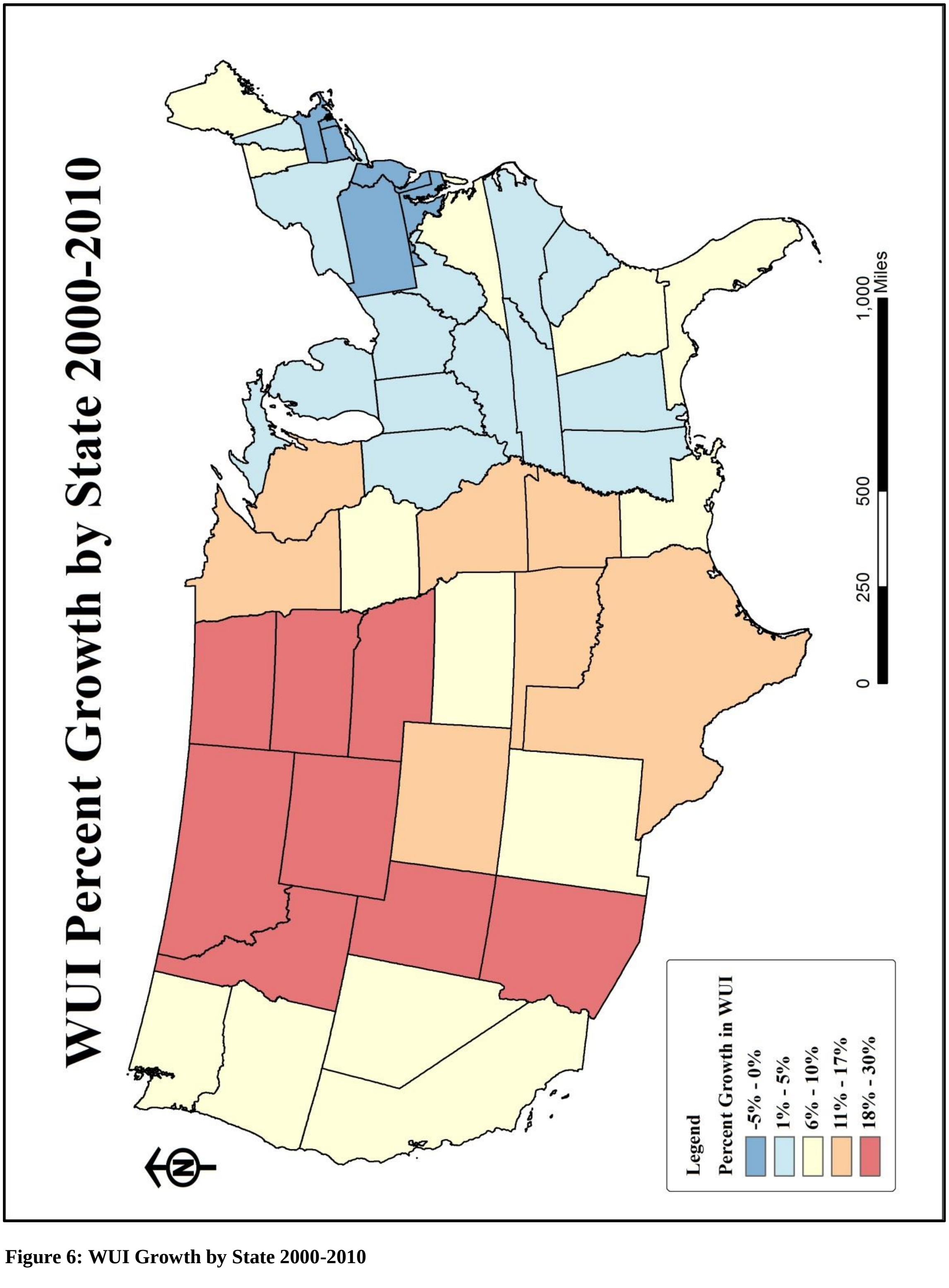



**Figure 6: WUI Growth by State 2000-2010**

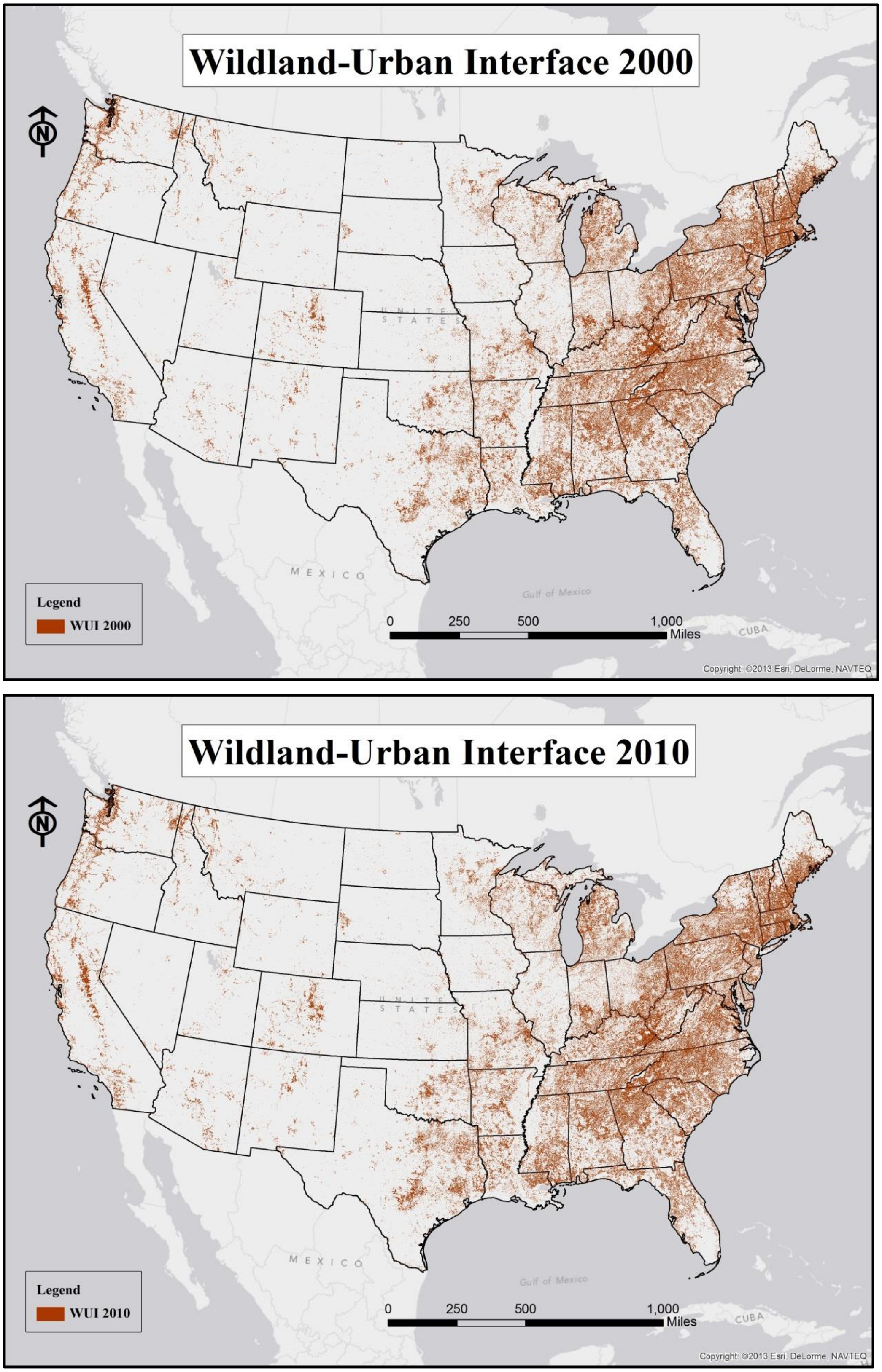



**Figure 7: WUI Extent 2000-2010**

## Research Question 2: Results

### How many people and housing units occupy the WUI and how has that changed since 2000?

#### *Analysis*

WUI outputs were intersected with Census 2000 and Census 2010 census blocks containing housing units to determine WUI housing units and population (Table 4, Figure 8, Figure 10). In 2000, the percent population in the WUI ranged from 81.08% in Georgia to 19.37% in Illinois. The WUI population was 126,443,856, 45.23% of total population. The percent of housing units in the WUI ranged from 80.71% in Georgia to 19.7% in Illinois. The number of housing units in the WUI was 53,269,202, 46.25% of all housing units.

Similarly, the 2010 percent population in the WUI ranged from 82.92% in Georgia to 20.78% in Illinois (Table 4, Figure 8, Figure 10). The WUI population was 144,571,625, 47.14% of total population. The percent of housing units in the WUI ranged from 82.42% in Georgia to 21.29% in Illinois. The total number of housing units in the WUI was 63,408,552, 48.45% of all housing units.

For all states combined, the percent of population in the WUI grew from 45.23% in 2000 to 47.14% in 2010, an increase of 1.92%, but varied by state (Figure 11). Actual WUI population growth from was 18,127,769, 14.34% growth overall. The percent of total housing units in the WUI grew from 46.25% to 48.45%, an increase of 2.2%, but also varied by state (Figure 9). Actual WUI housing unit growth was 10,139,350, 19.03% growth overall.

Nevada saw the largest increase in percent of total population in the WUI, increasing from 30.04% in 2000 to 41% in 2010, an increase of 10.96%. Delaware saw the largest decrease in percent population in the WUI, declining from 64.7% in 2000 to 61.77% in 2010, a decrease of 2.93%. Nevada saw also saw largest increase in percent of housing units in the WUI, increasing from 31.69% in 2000 to 41.84% in 2010, an increase of 10.14%. Delaware posted the largest decrease in percent of housing units in the WUI from 63.96% in 2000 to 62.13% in 2010, a decrease of 1.83%.

| State | WUI Population* | | WUI Housing Units* | | Total Population* | | Total Housing Units* | | Percent of Population in WUI | | Percent Housing Units in WUI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2000 | 2010 | 2000 | 2010 | 2000 | 2010 | 2000 | 2010 | 2000 | 2010 |
| AL | 3,209 | 3,502 | 1,406 | 1,582 | 4,447 | 4,780 | 1,964 | 2,172 | 72.16% | 73.27% | 71.62% | 72.82% |
| AR | 1,612 | 1,821 | 710 | 834 | 2,673 | 2,916 | 1,173 | 1,316 | 60.31% | 62.45% | 60.55% | 63.34% |
| AZ | 1,923 | 2,840 | 874 | 1,309 | 5,131 | 6,392 | 2,189 | 2,845 | 37.47% | 44.42% | 39.91% | 46.02% |
| CA | 7,573 | 8,988 | 2,963 | 3,555 | 33,872 | 37,254 | 12,215 | 13,680 | 22.36% | 24.13% | 24.26% | 25.99% |
| CO | 1,468 | 1,942 | 656 | 896 | 4,301 | 5,029 | 1,808 | 2,213 | 34.14% | 38.62% | 36.27% | 40.48% |
| CT | 1,956 | 2,063 | 775 | 858 | 3,406 | 3,574 | 1,386 | 1,488 | 57.45% | 57.72% | 55.90% | 57.63% |
| DC | 143 | 143 | 66 | 72 | 572 | 602 | 275 | 297 | 25.02% | 23.84% | 23.93% | 24.24% |
| DE | 507 | 555 | 219 | 252 | 784 | 898 | 343 | 406 | 64.70% | 61.77% | 63.96% | 62.13% |
| FL | 8,867 | 10,686 | 4,121 | 5,190 | 15,982 | 18,801 | 7,303 | 8,990 | 55.48% | 56.84% | 56.42% | 57.73% |
| GA | 6,638 | 8,033 | 2,649 | 3,370 | 8,186 | 9,688 | 3,282 | 4,089 | 81.08% | 82.92% | 80.71% | 82.42% |
| IA | 789 | 908 | 329 | 395 | 2,926 | 3,046 | 1,233 | 1,336 | 26.96% | 29.80% | 26.69% | 29.58% |
| ID | 412 | 459 | 181 | 225 | 1,294 | 1,568 | 528 | 668 | 31.84% | 29.29% | 34.33% | 33.66% |
| IL | 2,406 | 2,666 | 963 | 1,127 | 12,419 | 12,831 | 4,886 | 5,297 | 19.37% | 20.78% | 19.70% | 21.29% |
| IN | 2,926 | 3,166 | 1,184 | 1,340 | 6,080 | 6,484 | 2,532 | 2,796 | 48.13% | 48.83% | 46.76% | 47.92% |
| KS | 739 | 873 | 297 | 368 | 2,688 | 2,853 | 1,131 | 1,233 | 27.49% | 30.61% | 26.28% | 29.82% |
| KY | 3,184 | 3,393 | 1,372 | 1,505 | 4,042 | 4,339 | 1,751 | 1,927 | 78.79% | 78.19% | 78.34% | 78.07% |
| LA | 2,171 | 2,368 | 886 | 1,000 | 4,469 | 4,533 | 1,847 | 1,965 | 48.58% | 52.24% | 47.97% | 50.89% |
| MA | 2,990 | 3,106 | 1,198 | 1,318 | 6,349 | 6,548 | 2,622 | 2,808 | 47.10% | 47.44% | 45.68% | 46.92% |
| MD | 3,470 | 3,663 | 1,360 | 1,477 | 5,296 | 5,774 | 2,145 | 2,379 | 65.51% | 63.45% | 63.38% | 62.10% |
| ME | 948 | 1,000 | 489 | 552 | 1,275 | 1,328 | 652 | 722 | 74.35% | 75.31% | 74.96% | 76.47% |
| MI | 4,121 | 4,247 | 1,838 | 2,024 | 9,938 | 9,884 | 4,234 | 4,532 | 41.46% | 42.97% | 43.40% | 44.65% |
| MN | 2,276 | 2,478 | 957 | 1,111 | 4,919 | 5,304 | 2,066 | 2,347 | 46.27% | 46.72% | 46.30% | 47.31% |

| State | WUI Population* | | WUI Housing Units* | | Total Population* | | Total Housing Units* | | Percent of Population in WUI | | Percent Housing Units in WUI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2000 | 2010 | 2000 | 2010 | 2000 | 2010 | 2000 | 2010 | 2000 | 2010 |
| MO | 2,366 | 2,717 | 1,018 | 1,219 | 5,595 | 5,989 | 2,442 | 2,713 | 42.29% | 45.37% | 41.69% | 44.94% |
| MS | 1,992 | 2,161 | 815 | 935 | 2,845 | 2,967 | 1,162 | 1,275 | 70.02% | 72.82% | 70.10% | 73.35% |
| MT | 394 | 457 | 181 | 231 | 902 | 989 | 413 | 483 | 43.64% | 46.17% | 43.92% | 47.75% |
| NC | 6,049 | 7,365 | 2,651 | 3,341 | 8,049 | 9,535 | 3,524 | 4,328 | 75.15% | 77.23% | 75.22% | 77.20% |
| ND | 142 | 161 | 61 | 75 | 642 | 673 | 290 | 317 | 22.04% | 23.95% | 21.11% | 23.71% |
| NE | 394 | 493 | 169 | 220 | 1,711 | 1,826 | 723 | 797 | 23.00% | 27.02% | 23.41% | 27.63% |
| NH | 917 | 997 | 410 | 471 | 1,236 | 1,316 | 547 | 615 | 74.19% | 75.76% | 74.99% | 76.61% |
| NJ | 3,808 | 3,933 | 1,455 | 1,556 | 8,414 | 8,792 | 3,310 | 3,554 | 45.25% | 44.74% | 43.97% | 43.77% |
| NM | 952 | 1,162 | 408 | 512 | 1,819 | 2,059 | 781 | 901 | 52.36% | 56.44% | 52.26% | 56.83% |
| NV | 600 | 1,107 | 262 | 491 | 1,998 | 2,701 | 827 | 1,174 | 30.04% | 41.00% | 31.69% | 41.84% |
| NY | 5,547 | 5,692 | 2,334 | 2,540 | 18,976 | 19,378 | 7,679 | 8,108 | 29.23% | 29.37% | 30.40% | 31.33% |
| OH | 5,243 | 5,429 | 2,131 | 2,336 | 11,353 | 11,537 | 4,783 | 5,128 | 46.18% | 47.06% | 44.56% | 45.57% |
| OK | 1,437 | 1,688 | 616 | 740 | 3,451 | 3,751 | 1,514 | 1,664 | 41.64% | 45.00% | 40.68% | 44.48% |
| OR | 1,391 | 1,523 | 601 | 698 | 3,421 | 3,831 | 1,453 | 1,676 | 40.65% | 39.77% | 41.38% | 41.63% |
| PA | 6,268 | 6,413 | 2,631 | 2,828 | 12,281 | 12,702 | 5,250 | 5,567 | 51.04% | 50.49% | 50.12% | 50.80% |
| RI | 417 | 428 | 175 | 191 | 1,048 | 1,053 | 440 | 463 | 39.73% | 40.71% | 39.74% | 41.11% |
| SC | 3,174 | 3,745 | 1,390 | 1,729 | 4,012 | 4,625 | 1,754 | 2,138 | 79.11% | 80.96% | 79.24% | 80.90% |
| SD | 213 | 259 | 91 | 117 | 755 | 814 | 323 | 363 | 28.23% | 31.86% | 28.31% | 32.23% |
| TN | 3,873 | 4,408 | 1,663 | 1,964 | 5,689 | 6,346 | 2,439 | 2,812 | 68.08% | 69.46% | 68.16% | 69.85% |
| TX | 8,082 | 11,043 | 3,254 | 4,439 | 20,852 | 25,146 | 8,158 | 9,977 | 38.76% | 43.92% | 39.89% | 44.49% |
| UT | 570 | 870 | 208 | 324 | 2,233 | 2,764 | 769 | 980 | 25.55% | 31.48% | 27.00% | 33.10% |
| VA | 5,067 | 5,615 | 2,075 | 2,368 | 7,079 | 8,001 | 2,904 | 3,365 | 71.58% | 70.18% | 71.45% | 70.38% |
| VT | 481 | 491 | 237 | 262 | 609 | 626 | 294 | 323 | 78.98% | 78.46% | 80.46% | 81.09% |
| WA | 2,877 | 3,373 | 1,186 | 1,453 | 5,894 | 6,725 | 2,451 | 2,886 | 48.82% | 50.15% | 48.38% | 50.35% |
| WI | 2,311 | 2,517 | 1,046 | 1,246 | 5,364 | 5,687 | 2,321 | 2,624 | 43.08% | 44.27% | 45.06% | 47.50% |
| WV | 1,345 | 1,359 | 617 | 642 | 1,808 | 1,853 | 845 | 882 | 74.35% | 73.35% | 73.04% | 72.80% |
| WY | 206 | 261 | 93 | 122 | 494 | 564 | 224 | 262 | 41.78% | 46.34% | 41.53% | 46.53% |
| CONUS Total | 126,444 | 144,572 | 53,269 | 63,409 | 279,583 | 306,675 | 115,183 | 130,878 | 45.23% | 47.14% | 46.25% | 48.45% |

**Table 4: WUI Housing Units and Population Totals 2000-2010 *Units in Thousands**

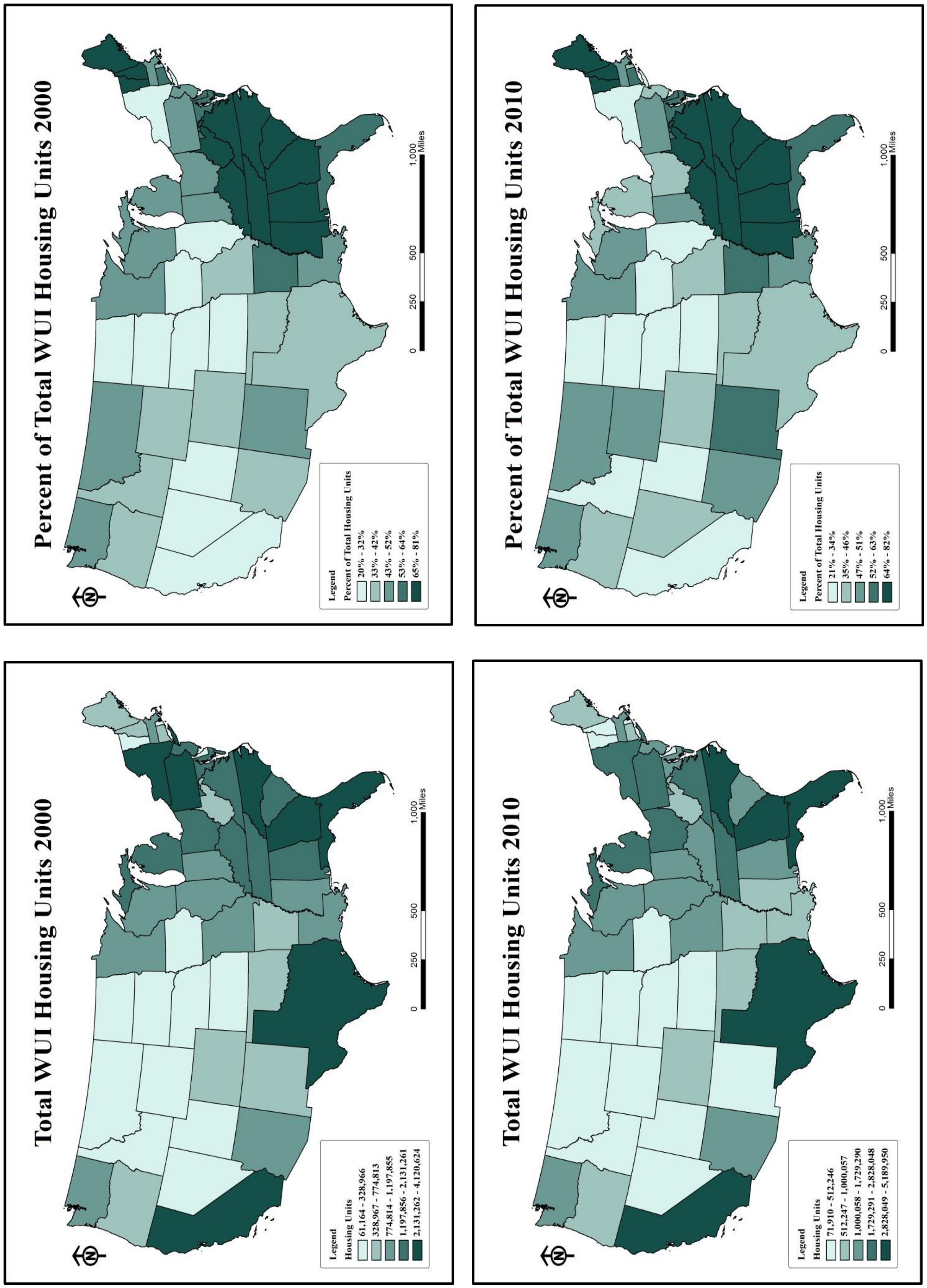
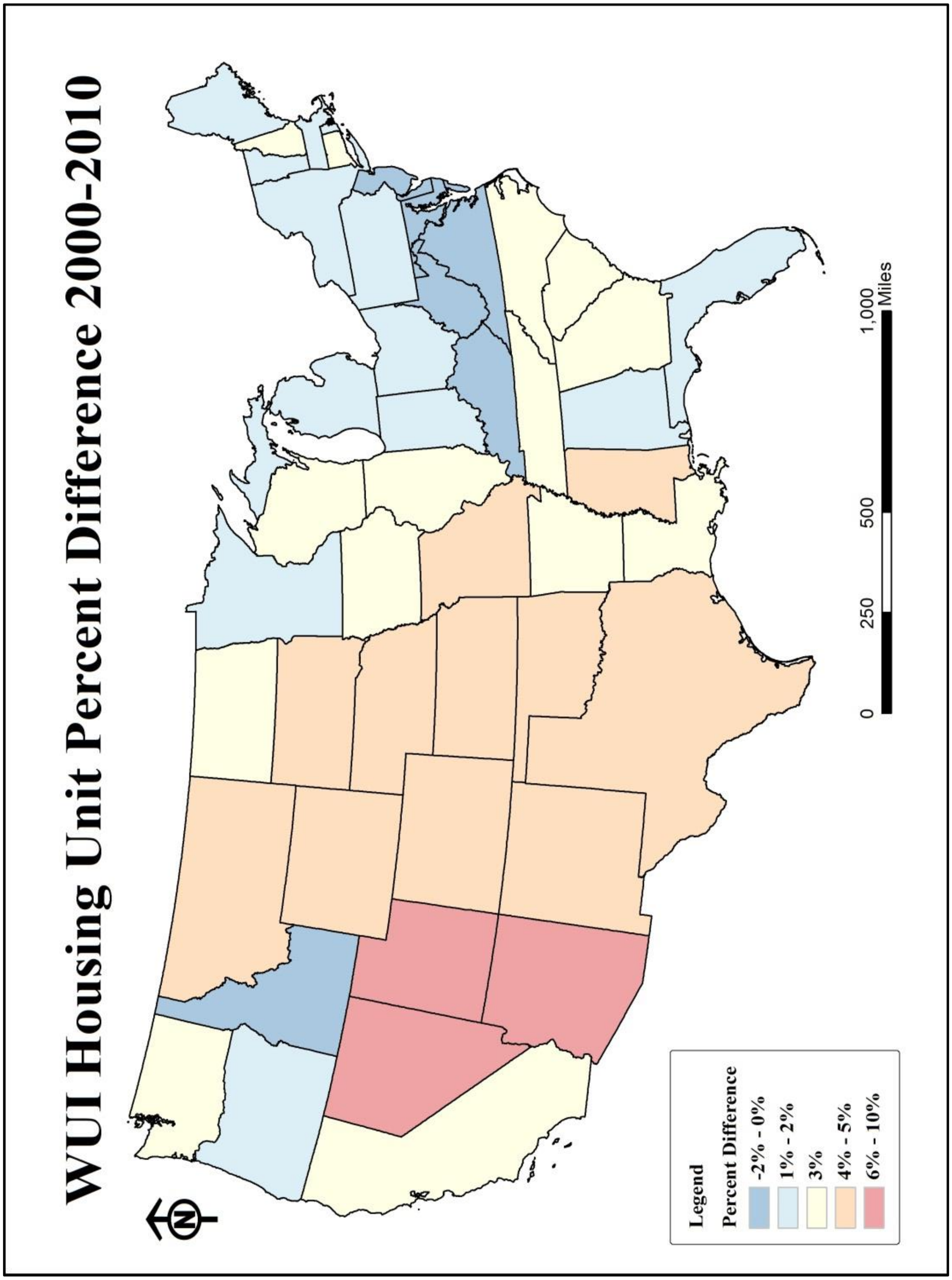



**Figure 8: WUI Housing Unit Totals and Percent of Total Housing Units in the WUI**


WUI Housing Unit Percent Difference 2000-2010
Legend
Percent Difference
-2% - 0%
1% - 2%
3%
4% - 5%
6% - 10%
0
250
500
1,000
Miles

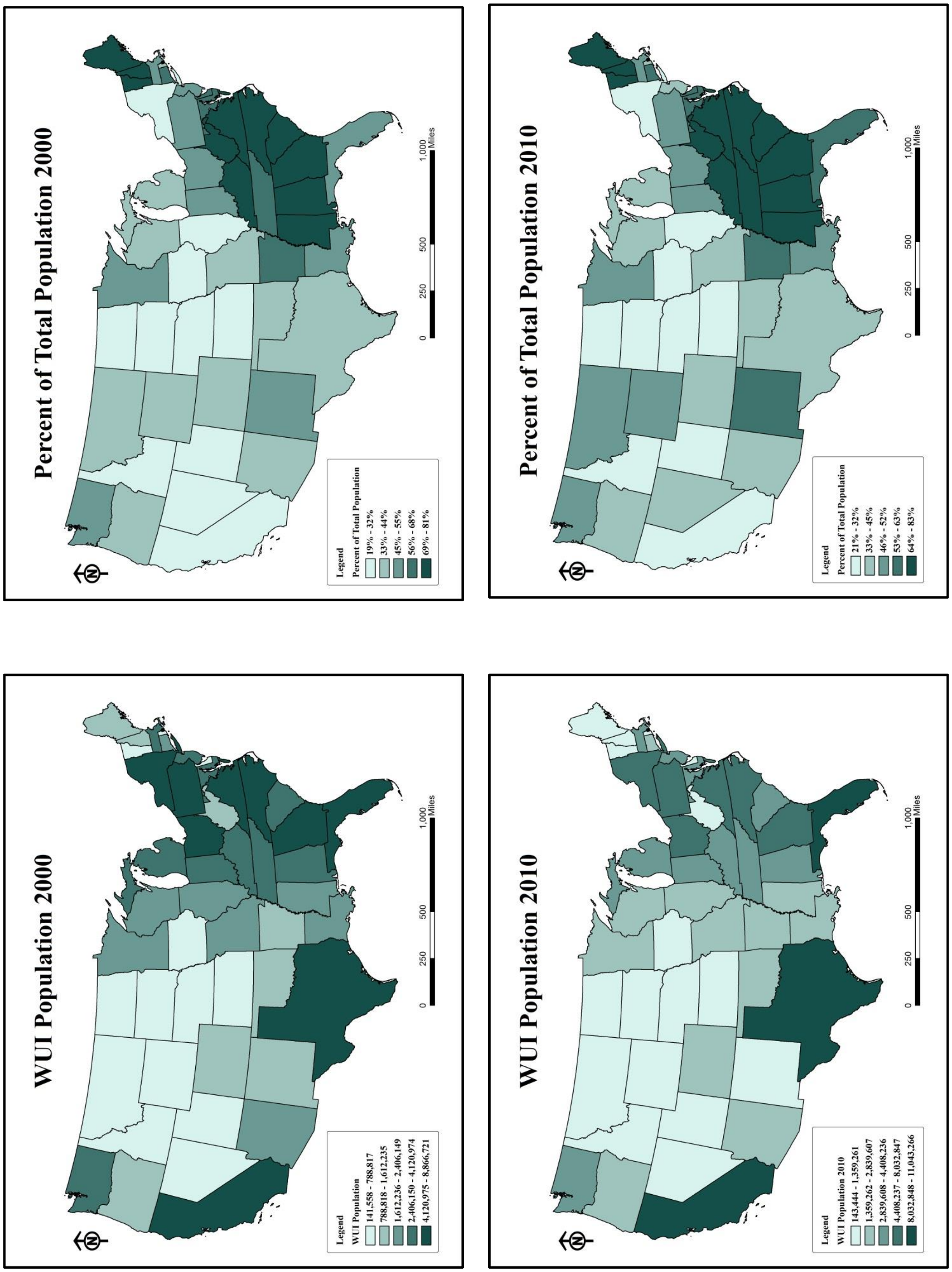



**Figure 10: WUI Population Totals and Percent of Total Population in the WUI**

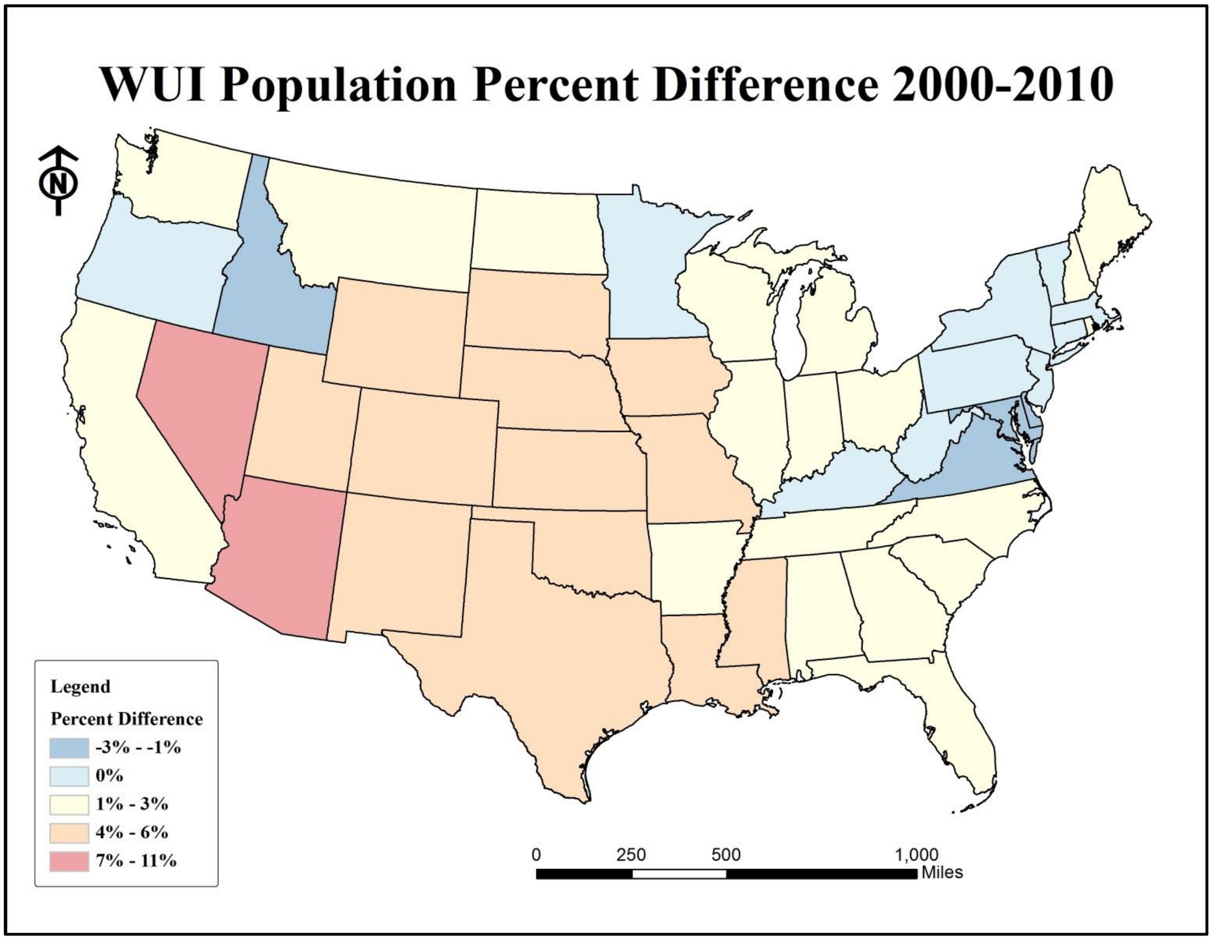


**Figure 11: Percent Difference of Total Population in the WUI 2000-2010**

## Research Question 3: Results

### What are the vegetated characteristics of the WUI and how has that changed since 2000?

#### *Analysis*

Model results for 2000 and 2010 were overlaid with Landfire Existing Vegetation Type (EVT) Landfire 1.05 and Landfire 1.1 respectively. Results were output to tabular format to calculate change in the WUI vegetation land cover from 2000-2010. EVH provides detailed vegetation type data, but were classified here by general vegetated land cover class to either

"Developed" or "Non-Developed." At the CONUS scale the WUI was overwhelmingly non-developed in both 2000 and 2010, with the developed to non-develop ratio remaining static at 3% developed to 97% non-developed. While the developed/non-developed ratio remained unchanged at the CONUS scale from 2000-2010, WUI vegetation characteristic varied by state (Table 5, Figure 12, Figure 13).

| State | 2000 | | | 2010 | | | Percent WUI Growth 2000-2010 | |
|---|---|---|---|---|---|---|---|---|
| | Developed Acres | Non-Developed Acres | Total | Developed Acres | Non-Developed Acres | Total | Develop-ed | Non-Develop-ed |
| AL | 270,206 | 8,849,345 | 9,119,551 | 279,552 | 8,985,229 | 9,264,781 | 3.46% | 1.54% |
| AR | 165,739 | 4,514,316 | 4,680,055 | 176,726 | 5,030,226 | 5,206,951 | 6.63% | 11.43% |
| AZ | 27,294 | 1,402,619 | 1,429,914 | 26,897 | 1,724,210 | 1,751,108 | -1.45% | 22.93% |
| CA | 209,604 | 6,747,630 | 6,957,234 | 256,738 | 7,063,708 | 7,320,446 | 22.49% | 4.68% |
| CO | 51,514 | 2,322,457 | 2,373,971 | 54,675 | 2,729,741 | 2,784,417 | 6.14% | 17.54% |
| CT | 50,949 | 1,866,826 | 1,917,775 | 53,845 | 1,812,762 | 1,866,607 | 5.68% | -2.90% |
| DC | 2,236 | 5,710 | 7,946 | 2,480 | 5,754 | 8,234 | 10.93% | 0.77% |
| DE | 11,722 | 392,872 | 404,595 | 12,255 | 372,061 | 384,315 | 4.54% | -5.30% |
| FL | 355,681 | 6,069,784 | 6,425,465 | 408,086 | 6,641,263 | 7,049,350 | 14.73% | 9.42% |
| GA | 404,270 | 10,406,098 | 10,810,369 | 423,377 | 11,141,893 | 11,565,270 | 4.73% | 7.07% |
| IA | 56,740 | 814,013 | 870,753 | 62,441 | 878,749 | 941,189 | 10.05% | 7.95% |
| ID | 32,372 | 1,227,864 | 1,260,236 | 34,938 | 1,521,595 | 1,556,532 | 7.93% | 23.92% |
| IL | 217,418 | 2,307,075 | 2,524,492 | 208,031 | 2,378,011 | 2,586,042 | -4.32% | 3.07% |
| IN | 200,093 | 4,464,706 | 4,664,799 | 192,467 | 4,560,049 | 4,752,517 | -3.81% | 2.14% |
| KS | 60,252 | 877,849 | 938,101 | 67,004 | 954,105 | 1,021,109 | 11.21% | 8.69% |
| KY | 246,869 | 8,131,826 | 8,378,695 | 253,673 | 8,389,745 | 8,643,417 | 2.76% | 3.17% |
| LA | 175,257 | 4,611,921 | 4,787,178 | 192,446 | 4,990,890 | 5,183,336 | 9.81% | 8.22% |
| MA | 92,219 | 2,611,590 | 2,703,808 | 102,152 | 2,595,537 | 2,697,689 | 10.77% | -0.61% |
| MD | 75,105 | 2,275,754 | 2,350,858 | 85,048 | 2,245,925 | 2,330,973 | 13.24% | -1.31% |
| ME | 84,918 | 4,313,849 | 4,398,766 | 76,906 | 4,581,542 | 4,658,448 | -9.44% | 6.21% |
| MI | 309,554 | 8,874,947 | 9,184,501 | 316,310 | 9,126,775 | 9,443,085 | 2.18% | 2.84% |
| MN | 127,161 | 2,746,370 | 2,873,532 | 136,263 | 3,085,199 | 3,221,462 | 7.16% | 12.34% |
| MO | 189,356 | 4,640,907 | 4,830,264 | 212,291 | 5,266,286 | 5,478,577 | 12.11% | 13.48% |
| MS | 250,619 | 7,152,110 | 7,402,729 | 262,046 | 7,328,678 | 7,590,723 | 4.56% | 2.47% |
| MT | 41,161 | 1,551,738 | 1,592,898 | 43,663 | 1,891,563 | 1,935,226 | 6.08% | 21.90% |
| NC | 299,718 | 12,965,408 | 13,265,126 | 294,994 | 13,227,995 | 13,522,989 | -1.58% | 2.03% |
| ND | 12,538 | 173,425 | 185,964 | 18,108 | 224,371 | 242,479 | 44.42% | 29.38% |

| State | 2000 | | | 2010 | | | Percent WUI Growth 2000-2010 | |
|---|---|---|---|---|---|---|---|---|
| | Developed Acres | Non-Developed Acres | Total | Developed Acres | Non-Developed Acres | Total | Develop-ed | Non-Develop-ed |
| NE | 36,421 | 461,636 | 498,057 | 44,396 | 547,269 | 591,664 | 21.90% | 18.55% |
| NH | 52,223 | 2,558,941 | 2,611,164 | 52,164 | 2,676,574 | 2,728,738 | -0.11% | 4.60% |
| NJ | 91,762 | 1,596,231 | 1,687,993 | 95,481 | 1,572,747 | 1,668,228 | 4.05% | -1.47% |
| NM | 22,531 | 1,388,637 | 1,411,169 | 20,473 | 1,491,346 | 1,511,819 | -9.13% | 7.40% |
| NV | 16,215 | 427,199 | 443,414 | 16,330 | 463,903 | 480,233 | 0.71% | 8.59% |
| NY | 252,972 | 10,705,453 | 10,958,425 | 249,634 | 10,864,985 | 11,114,619 | -1.32% | 1.49% |
| OH | 310,092 | 6,855,623 | 7,165,715 | 306,369 | 7,172,575 | 7,478,944 | -1.20% | 4.62% |
| OK | 121,934 | 3,179,507 | 3,301,440 | 142,087 | 3,584,343 | 3,726,430 | 16.53% | 12.73% |
| OR | 100,679 | 3,081,036 | 3,181,715 | 102,125 | 3,327,418 | 3,429,543 | 1.44% | 8.00% |
| PA | 344,582 | 10,866,088 | 11,210,669 | 361,064 | 10,887,929 | 11,248,993 | 4.78% | 0.20% |
| RI | 15,159 | 360,413 | 375,573 | 16,000 | 356,640 | 372,641 | 5.55% | -1.05% |
| SC | 217,176 | 6,879,276 | 7,096,452 | 219,821 | 7,070,007 | 7,289,829 | 1.22% | 2.77% |
| SD | 15,896 | 415,648 | 431,544 | 16,729 | 519,546 | 536,276 | 5.24% | 25.00% |
| TN | 280,019 | 8,911,747 | 9,191,766 | 276,808 | 9,210,011 | 9,486,819 | -1.15% | 3.35% |
| TX | 378,691 | 10,533,845 | 10,912,536 | 404,690 | 12,043,251 | 12,447,941 | 6.87% | 14.33% |
| UT | 12,074 | 513,873 | 525,948 | 13,148 | 623,965 | 637,113 | 8.89% | 21.42% |
| VA | 241,272 | 9,555,563 | 9,796,835 | 279,326 | 10,033,337 | 10,312,663 | 15.77% | 5.00% |
| VT | 56,619 | 2,262,014 | 2,318,633 | 52,016 | 2,437,298 | 2,489,314 | -8.13% | 7.75% |
| WA | 156,690 | 4,187,515 | 4,344,205 | 162,824 | 4,538,939 | 4,701,763 | 3.91% | 8.39% |
| WI | 215,766 | 4,742,727 | 4,958,493 | 221,924 | 5,389,813 | 5,611,737 | 2.85% | 13.64% |
| WV | 200,662 | 5,746,867 | 5,947,529 | 224,725 | 5,792,093 | 6,016,819 | 11.99% | 0.79% |
| WY | 12,123 | 443,624 | 455,747 | 11,867 | 529,460 | 541,326 | -2.12% | 19.35% |
| CONUS Total | 7,170,403 | 207,945,792 | 215,116,195 | 7,541,458 | 219,835,033 | 227,376,491 | 5.17% | 5.72% |

**Table 5: WUI Developed versus Non-Developed Land Cover 2000-2010**

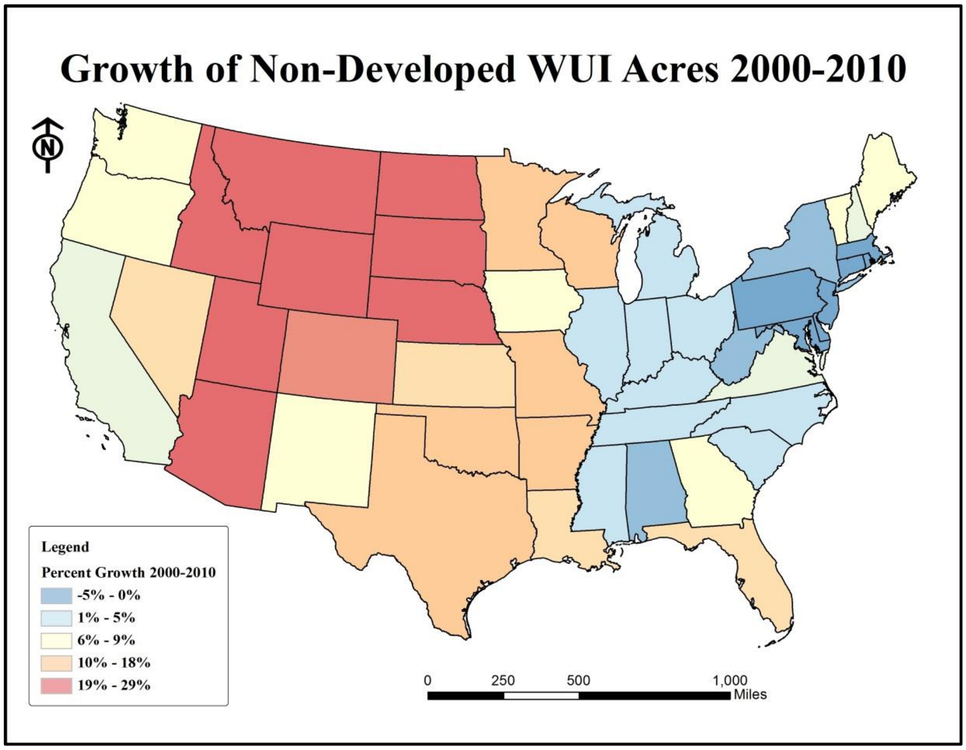



**Figure 12: Growth of Non-Developed WUI Acres 2000-2010**

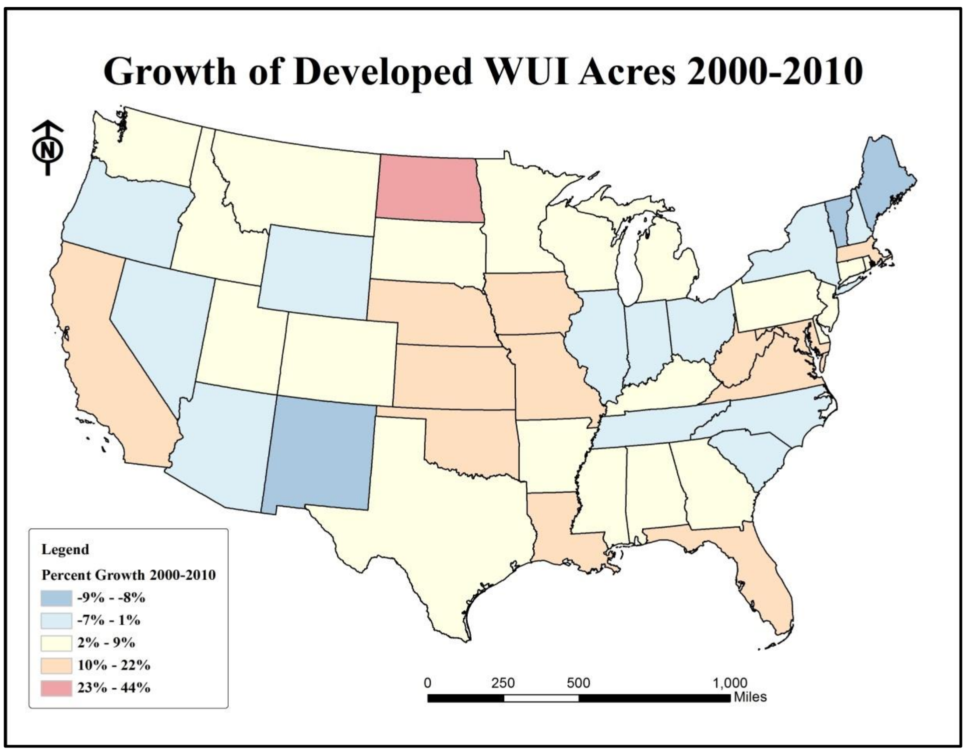



**Figure 13: Growth of Developed WUI Acres 2000-2010**

## Sensitivity Analysis: Results

Results from the model sensitivity analysis met our definition of stable insofar as the percent change in model outputs were smaller than the percent change made to any single parameter. Results from varying individual parameters varied across states, but were all within our stability definition (Table 6). All changes to model parameters had relatively similar effects on overall WUI extent, with the exception of excluding the dasymetric modification of census blocks. Overall, the exclusion of dasymetric mapping reduced the overall WUI extent by only 6.53%.

The doubling and halving of the Federal Register minimum housing density definition of 1 housing unit/40 acres had a more pronounced effect on WUI extent. Decreasing the minimum housing unit density to 1 housing unit/80 acres increased the WUI extent by 26.54%. Increasing the minimum housing unit density to 1 housing unit/20 acres decreased the WUI extent by 27.61%. California showed particular sensitivity to a decrease in the housing unit threshold, with an increase of 50.39% in WUI extent. Increasing minimum housing unit density resulted in fairly uniform response across all states, with an average reduction of 27.61% in WUI extent.

The halving and doubling of vegetation buffers yielded similar responses, with the halving of vegetation buffers reducing WUI extent by 16.12%. The doubling of buffers increased WUI extent by 35.32%. Washington showed the most responsiveness to vegetation buffers, with a reduction of 22.65% when buffers were halved, and an increase of 45.31% when buffers were doubled. New Hampshire showed the least responsiveness to vegetation buffers, with a decrease of 9.85% when buffers were halved, and an increase of 17.29% when buffers were doubled.

The removal of the corridor function was somewhat more variable, with results varying by state. Colorado's WUI extent grew by 64.35%, while North Carolina's WUI acreage grew by just 10.16%. Average WUI growth for all states was 30.1% when the corridor function was removed. Setting a static buffer from all potential wildland fire vegetation classes to the maximum vegetation buffer of 480 meters affected model outputs the most. Average WUI acreage growth was 38.75%, with California experiencing the most sensitivity, growing by 88.7%. North Carolina demonstrated the least sensitivity to setting a static buffer from potential wildland fire fuels, with growth of only 13.28%.

| Model Variation | Output Variable | CA | CO | FL | MI | NC | NH | WA | Average |
|---|---|---|---|---|---|---|---|---|---|
| Original WUI 2010 Outputs | Acres (Millions) | 7.32 | 2.78 | 7.05 | 9.44 | 13.52 | 2.73 | 4.70 | N/A |
| | Population (Millions) | 8.99 | 1.94 | 10.69 | 4.25 | 7.36 | 1.00 | 3.37 | N/A |
| | Housing Units (Millions) | 3.56 | 0.90 | 5.19 | 2.02 | 3.34 | 0.47 | 1.45 | N/A |
| | Ratio Developed to Non-Developed | 4:96 | 2:98 | 6:94 | 3:97 | 2:98 | 2:98 | 3:97 | 3:97 |
| Housing Unit Density Threshold 1 Housing Unit/ 80 Acres | Acres % Change | 27.69 | 50.39 | 21.73 | 28.15 | 12.85 | 17.58 | 27.40 | 26.54 |
| | Population % Change | 0.16 | 0.99 | 0.00 | 0.24 | -0.11 | -0.06 | 0.04 | 0.18 |
| | Housing Units % Change | 0.11 | 1.05 | -0.07 | 0.29 | -0.11 | -0.07 | 0.04 | 0.18 |
| | Ratio Developed to Non-Developed | 3:97 | 1:99 | 5:95 | 2:98 | 2:98 | 1:99 | 3:97 | 2:98 |
| Housing Unity Density Threshold 1 Housing Unit /20 Acres | Acres % Change | -27.88 | -35.89 | -23.87 | -32.71 | -23.26 | -26.70 | -22.99 | -27.61 |
| | Population % Change | -0.32 | -1.11 | 0.16 | -2.05 | -0.14 | 0.04 | -0.07 | -0.50 |
| | Housing Units % Change | -0.31 | -1.22 | 0.18 | -1.97 | -0.14 | 0.03 | -0.11 | -0.51 |
| | Ratio Developed to Non-Developed | 5:95 | 3:97 | 8:92 | 5:95 | 4:96 | 3:97 | 5:95 | 5:95 |
| Vegetation Height Buffers Halved | Acres % Change | -16.92 | -13.28 | -19.50 | -17.37 | -13.27 | -9.85 | -22.65 | **-16.1** |
| | Population % Change | -1.96 | -2.52 | -2.53 | -2.32 | -1.09 | -1.10 | -5.78 | -2.5 |
| | Housing Units % Change | -2.06 | -2.62 | -2.91 | -2.35 | -1.17 | -1.12 | -6.10 | -2.6 |
| | Ratio Developed to Non-Developed | 3:97 | 1:99 | 4:96 | 3:97 | 1:99 | 2:98 | 2:98 | 2:98 |
| Vegetation Height Buffers Doubled | Acres % Change | 40.48 | 38.28 | 41.84 | 41.98 | 22.10 | 17.29 | 45.31 | **35.3** |
| | Population % Change | 8.21 | 8.11 | 5.96 | 6.08 | 2.44 | 2.36 | 11.68 | 6.4 |
| | Housing Units % Change | 8.16 | 8.18 | 6.99 | 6.08 | 2.77 | 2.44 | 12.25 | 6.7 |
| | Ratio Developed to Non-Developed | 4:96 | 3:97 | 7:93 | 4:96 | 3:97 | 2:98 | 4:96 | 4:96 |

| Model Variation | Output Variable | CA | CO | FL | MI | NC | NH | WA | Average |
|---|---|---|---|---|---|---|---|---|---|
| Corridor Function Removed | Acres % Change | 45.38 | 64.35 | 22.77 | 27.21 | 10.16 | 16.16 | 24.66 | 30.10 |
| | Population % Change | 0.84 | 0.99 | 0.10 | 0.32 | 0.07 | -0.02 | 0.60 | 0.41 |
| | Housing Units % Change | 0.73 | 0.90 | 0.05 | 0.33 | 0.06 | -0.02 | 0.56 | 0.38 |
| | Ratio Developed to Non-Developed | 5:95 | 3:97 | 6:94 | 4:96 | 2:98 | 2:98 | 4:96 | 4:96 |
| Removal of Variable Width Buffer | Acres % Change | 55.65 | 88.70 | 31.09 | 36.28 | 13.28 | 20.64 | 25.60 | 38.75 |
| | Population % Change | 33.37 | 18.04 | 8.41 | 6.31 | 1.65 | 3.02 | 6.22 | 11.00 |
| | Housing Units % Change | 31.49 | 17.65 | 9.81 | 6.31 | 1.94 | 3.12 | 6.51 | 10.98 |
| | Ratio Developed to Non-Developed | 7:93 | 4:96 | 7:93 | 4:96 | 3:97 | 2:98 | 4:96 | 5:95 |
| Dasymetric Mapping Removed | Acres % Change | -3.52 | -15.31 | -4.46 | -7.27 | -2.83 | -6.69 | -5.67 | -6.53 |
| | Population % Change | -3.67 | -3.23 | -1.98 | -1.61 | -0.50 | -1.99 | -5.68 | -2.66 |
| | Housing Units % Change | -3.58 | -3.22 | -2.09 | -1.65 | -0.53 | -1.72 | -5.57 | -2.62 |
| | Ratio Developed to Non-Developed | 3:97 | 2:98 | 6:94 | 3:97 | 2:98 | 2:98 | 3:97 | 3:97 |

**Table 6: Sensitivity Analysis Outputs**

With a few exceptions, sensitivity analysis results had markedly diminished effects on overall population and housing unit counts when compared to the effects on WUI extent. For population totals, the only model variation that resulted in an average change of > ± 10% was the removal of the variable width buffer. Removing the variable width buffer and buffering all potential wildland fire fuels by the maximum buffer of 480 meters increased the WUI population by an average of 11%. Similarly, the removal of the variable width buffer was the only variation that resulted in an average housing unit change of > ± 10%. California and Colorado were particularly sensitive to this model parameter, with California's WUI population and housing unit totals both increasing by > 30%. Colorado's response was less, but still sizeable with >17% growth in both population and housing units.

# Discussion

WUI growth and wildfires are dynamic phenomena, and the recent growth of the WUI points to a continuing need to assess the WUI at the national level. Model results suggest WUI acreage grew by 5.7% from 2000-2010, an increase in total area as WUI of 0.64 percentage points. The 2010 WUI covered 227,376,491 acres, 11.79% of the CONUS, 47.14% of the population and 48.45% of housing units. Despite the large number of people and homes affected, WUI landcover was 97% non-developed.

Despite WUI growth trending upwards from 2000-2010, the character of the WUI varied between states. By state, average WUI acreage change was 8.15% growth, but several states, Connecticut, Delaware, Maryland, Massachusetts, New Jersey, and Rhode Island, all lost WUI acreage. North Dakota showed particularly strong WUI growth of 30.39%. The majority of the WUI was in the eastern United States, with the top 12 WUI states by acreage; AL, GA, KY, MI, MS, NY, NC, OH, PA, TN, TX, VA, all East of the Rocky Mountains. These 12 states combined, account for 54% of the total WUI, while accounting for only 26% of land area.

It should be noted that the results presented here differ from previous WUI estimates. Stewart et al. calculated the WUI comprising 9.3% of CONUS area, while Radeloff et al. calculated the WUI at 9.4%. Theobald & Romme's WUI model suggested the WUI covered only 6% of total area. Both the 2000 and 2010 WUI results presented here suggest the WUI covered a significantly larger area, ranging from 11.15% in 2000 to 11.79% in 2010. The reason such a dramatic difference in the WUI acreage is undoubtedly due in large part due to the definition effect (Platt 2010). The definition effect is the difference varying WUI definitions have on WUI model outputs. While previous models largely contributed to the development of the model presented here, there are considerable differences in the data and methods used. Previous models relied upon older datasets ranging from 1992 for vegetation to the 2000 US

Census for housing units and population. Similarly, previous models used different buffering methods, buffering distances, and target census block criteria. Changes such as these have been shown to effect dramatically affect WUI model outputs (Stewart *et al.* 2009).

While dasymetric mapping offers intuitive advantages to using raw census data, it still likely overestimates the number of homes and population affected by the WUI, and as the sensitivity analysis demonstrated, may have little overall effect on model outputs. Ideally, dasymetric mapping to establish housing unit density will eventually be replaced by data depicting the footprint of individual structures. Encouragingly, the recent release of Corelogic's report "*Wildfire Hazard Risk Report 2012"* revealed that the company had collected parcel level data on 131.2 million properties in the US, more than 97% of the total properties at the time of publication (Howard *et al.* 2012). Unfortunately, the dataset is not currently available for public use. Nevertheless, the use of this or similarly datasets holds the promise of significantly advancing future work.

It is also important to note that both the federal WUI definition and the model presented here do not specifically address wildland fire risk. Wildland fire severity and return-intervals vary by region, and assessing WUI fire risk is a high priority for future research. For example, WUI in the Pacific Northwest is dominated by 300-400 year fire-return intervals, while WUI in Southern California's chaparral dominated landscape typically has a much shorter fire-return interval of 2-3 years (US Department of the Interior, Geological Survey (USGS) 2013). Thus, local conditions should be considered when interpreting WUI model results. Furthermore, since home building materials and the homes' immediate surroundings are the primary factors determining home loss in the event of wildland fire (Cohen 2000), there is significant room to improve upon existing methods by integrating data describing both homes and vegetation in greater detail. Recent studies suggest that the arrangement and location of structures strongly affects their susceptibility to wildlfire and property loss (Syphard *et al.* 2012). The availability of a more spatially detailed datasets on the arrangement of homes and surrounding vegetation may well improve WUI mapping at both the local and landscape scales.

# Conclusion

The purpose of this study was to present a new geographic model for mapping the WUI and demonstrate its' use to explore CONUS WUI change from 2000-2010. As a result, the study was somewhat constrained to public data available at the national scale for two dates. While the use of US Census data is particularly well suited to this task, it may not be appropriate for all WUI studies, particularly at a community scale. Despite potential weaknesses in data used such as the use of relatively coarse 30-meter resolution vegetation data, the results and the model itself may also be useful when a more local WUI assessment is unavailable. Nevertheless, the work presented here should provide some guidance for future work on WUI issues. The GIS model is sufficiently flexible for individual user needs, and the use of publicly available, despite limitations, allows for a broad swath of potential users access to model inputs. In addition, the use of a nationally consistent WUI definition allows for WUI maps to be produced nationally to assess WUI change over time.

Perhaps most importantly, the work here sheds light on the issue of national WUI growth. It is likely that the growth of both population, housing units, and subsequently the WUI will continue well into the 21st century (Theobald 2005; Theobald and Romme 2007). As model results demonstrate, the WUI's footprint has grown considerably from 2000-2010. In the context of wildland fire, this suggests an ongoing and mounting problem for wildland fire and land use managers. Fire tends to occur most frequently where people, roads, and development are present (Cardille *et al.* 2001) and by definition, the WUI is where these features are co-located.

In understanding the relationship of human development to wildland fire, work on WUI issues can serve a two-fold purpose. One, to help targeting limited resources where wildland fire is unacceptable (homes and communities), and two, identify areas where wildland fire may be acceptable. Understanding the location, extent, and character of the WUI is a critical step in this process. If we're able to better protect homes and communities from wildland fire, the use of wildland-fire use has greater potential for use as a landscape management tool. Wildland fire use, unlike fire exclusion, can simultaneously restore natural fire regimes while reducing wildland fire-fighting expenditures and homes lost.

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# Appendix Two – Python Scripts for ArcGIS Desktop

## 1. Calculate Road Density

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
------
# RoadDensity.py
#   (generated by ArcGIS/ModelBuilder)
# Usage: RoadDensity <RawRoads_shp>
# Description:
# Obtain road density using km/km2 from vector roads layer using 800
meter moving window.
# ---------------------------------------------------------------------------
------

# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")

# Set Geoprocessing environments
arcpy.env.scratchWorkspace = "C:\\temp\\RoadDensityIntermediate"
arcpy.env.workspace = "C:\\temp\\RoadDensityIntermediate"

# Script arguments
RawRoads_shp = arcpy.GetParameterAsText(0)
if RawRoads_shp == '#' or not RawRoads_shp:
    RawRoads_shp = "C:\\temp\\RawRoads\\RawRoads.shp" # provide a
default value if unspecified

# Local variables:
RawRdsDen = RawRoads_shp

# Process: Line Density
tempEnvironment0 = arcpy.env.scratchWorkspace
arcpy.env.scratchWorkspace = "C:\\temp\\RoadDensityIntermediate"
#set snap raster to existing LANDFIRE
tempEnvironment1 = arcpy.env.snapRaster
arcpy.env.snapRaster = "C:\\temp\\RawLandfireEVH\\RawEVH"
tempEnvironment2 = arcpy.env.workspace
arcpy.env.workspace = " C:\\temp\\RoadDensityIntermediate"
arcpy.gp.LineDensity_sa(RawRoads_shp, "NONE", RawRdsDen, "30", "800",
"SQUARE_KILOMETERS")
```

```
arcpy.env.scratchWorkspace = tempEnvironment0
arcpy.env.snapRaster = tempEnvironment1
arcpy.env.workspace = tempEnvironment2
```

## 2. Select Low-Road Density and Convert to Vector

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
------
# SelectLowDensityandConverttoVector.py
#   (generated by ArcGIS/ModelBuilder)
# Usage: SelectLowDensityandConverttoVector <RawRdsDen>
# Description:Select from calculated road density low road density
areas
# ---------------------------------------------------------------------------
------

# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")

# Set Geoprocessing environments
arcpy.env.scratchWorkspace = "C:\\temp\\RoadDensityIntermediate"
arcpy.env.workspace = "C:\\temp\\DasymetricRoadsErase"

# Script arguments
RawRdsDen = arcpy.GetParameterAsText(0)
if RawRdsDen == '#' or not RawRdsDen:
    RawRdsDen = "C:\\temp\\RoadDensityIntermediate\\RawRdsDen" #
provide a default value if unspecified

# Local variables:
Reclass_line1 = RawRdsDen
Con_Reclass_1 = Reclass_line1
RasterT_Con_del1_shp = Con_Reclass_1
Input_true_raster_or_constant_value = "1"

# Process: Reclassify
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster =
"T:\\zzLandfire\\LF_1.1.0\\US_110evh\\grid2\\us_110evh"
tempEnvironment1 = arcpy.env.pyramid
arcpy.env.pyramid = "PYRAMIDS -1 NEAREST DEFAULT 75 NO_SKIP"
arcpy.gp.Reclassify_sa(RawRdsDen, "Value", "0 0.25 1;0.25 1 2;1 5 3;5
100 4", Reclass_line1, "DATA")
arcpy.env.snapRaster = tempEnvironment0
arcpy.env.pyramid = tempEnvironment1
```

```
# Process: Con
arcpy.gp.Con_sa(Reclass_line1, Input_true_raster_or_constant_value,
Con_Reclass_1, "", "\"VALUE\" = 1")

# Process: Raster to Polygon
tempEnvironment0 = arcpy.env.scratchWorkspace
arcpy.env.scratchWorkspace = "C:\\temp\\RoadDensityIntermediate"
tempEnvironment1 = arcpy.env.workspace
arcpy.env.workspace = "C:\\temp\\DasymetricRoadsErase"
arcpy.RasterToPolygon_conversion(Con_Reclass_1, RasterT_Con_del1_shp,
"NO_SIMPLIFY", "VALUE")
arcpy.env.scratchWorkspace = tempEnvironment0
arcpy.env.workspace = tempEnvironment1
```

## 3. Merge Erase Layers

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------
------
# MergeEraseLayers.py
#   (generated by ArcGIS/ModelBuilder)
# Description:
# Tool for merging all erase layers together.  Can potentially include
any number of pre-processed dasymetric erase layers.
# ---------------------------------------------------------------------
------

# Import arcpy module
import arcpy

# Set Geoprocessing environments
arcpy.env.scratchWorkspace = "C:\\temp\\IntermediateWorkspace"
arcpy.env.workspace = "C:\\temp\\DasymetricEraseLayers"


# Local variables:
#Set paths to all dasymetric erase layers.  Can include any number of
#layers so long as they're polygons
Low_Road_Density =
"C:\\temp\\DasymetricRoadsErase\\lowdensityroads.shp"
Protected_Lands = "C:\\temp\\ProtectedLands\\protectedlands.shp"
Water_Features = "C:\\temp\\WaterFeatures\\WaterFeatures.shp"
rastert_con_dis1_Merge_shp =
"C:\\temp\\IntermediateWorkspace\\rastert_con_dis1_Merge.shp"
EraseLayersMerge_shp =
"C:\\temp\\DasymetricEraseLayers\\EraseLayersMerge.shp"

# Process: Merge
arcpy.Merge_management("C:\\temp\\DasymetricRoadsErase\\lowdensityroads
.shp;C:\\temp\\ProtectedLands\\protectedlands.shp;
```

```
C:\\temp\\WaterFeatures\\WaterFeatures.shp",
rastert_con_dis1_Merge_shp,"")

# Process: Dissolve
tempEnvironment0 = arcpy.env.workspace
arcpy.env.workspace = "C:\\temp\\DasymetricEraseLayers"
arcpy.Dissolve_management(rastert_con_dis1_Merge_shp,
EraseLayersMerge_shp, "", "", "MULTI_PART", "DISSOLVE_LINES")
arcpy.env.workspace = tempEnvironment0
```

## 4. Batch Dasymetrically Modify Census Blocks

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------
------
# dasymetricallyeraseblocks.doc.py
#   (generated by ArcGIS/ModelBuilder)
# Description:
# Erase dasymetric erase layers from US Census 2010 blocks, add fields
to recalculate area, add fields to calculate housing unit density, and
select blocks ≥ 1 housing unit/40 acres, or ≥.025 housing units per
acre.
# ---------------------------------------------------------------------
------

# Set the necessary product code
# import arcinfo


# Import arcpy module
import arcpy

# Set Geoprocessing environments
arcpy.env.scratchWorkspace = "C:\\temp\\IntermediateWorkspace"
arcpy.env.workspace =
"C:\\temp\\DasymetricallyModifiedBlkswithTgDensity"


# Local variables:
DC_Select_shp = "C:\\temp\\CensusBlocks\\CensusBlocks.shp"
EraseLayersMerge_shp =
"C:\\temp\\DasymetricEraseLayers\\EraseLayersMerge.shp"
DC_Select_Erase_shp =
"C:\\temp\\IntermediateWorkspace\\CensusBlocks.shp"
Acres_Field_added = "C:\\temp\\IntermediateWorkspace\\CensusBlocks.shp"
Acres_Calculated = "C:\\temp\\IntermediateWorkspace\\CensusBlocks.shp"
Hu_Divided_by_Acres_Added =
"C:\\temp\\IntermediateWorkspace\\CensusBlocks.shp"
Hu_Divided_by_Acres_Calculated =
"C:\\temp\\IntermediateWorkspace\\CensusBlocks.shp"
```

```
Target_Density_Census_Blocks =
"C:\\temp\\IntermediateWorkspace\\CensusBlocks.shp"

# Process: Erase
arcpy.Erase_analysis(CensusBlocks_shp, EraseLayersMerge_shp,
CensusBlocks_Erase_shp, "10 Meters")

# Process: Add Acres Field
arcpy.AddField_management(CensusBlocks_shp, "Acres", "DOUBLE", "15",
"2", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Acres
arcpy.CalculateField_management(Acres_Field_added, "Acres",
"!shape.area@ACRES!", "PYTHON_9.3", "")

# Process: Add Field for HU divided by Acres
arcpy.AddField_management(Acres_Calculated, "HU_Acres", "DOUBLE", "8",
"3", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Calculated HU divided by Acres
arcpy.CalculateField_management(Hu_Divided_by_Acres_Added, "HU_Acres",
"[HOUSING10] / [Acres]", "VB", "")

# Process: Select HU divided by Acres ≥ .025
arcpy.Select_analysis(Hu_Divided_by_Acres_Calculated,
Target_Density_Census_Blocks, "HU_Acres >.025")
```

## 5. Batch Reclassify LANDFIRE EVH Layers

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------
------
# BatchReclassifyLandfireEVH.py
#   (generated by ArcGIS/ModelBuilder)
# Description: A tool for reclassifying LANDFIRE EVH Layers to Buffer
#Distance Values
# ---------------------------------------------------------------------
------

# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")


# Set Local Input variables:
evh = "c:\\temp\\RawLandfireEVH"
Reclass_al1 = "c:\\temp\\RawLandfireEVH\\Reclass_evh1"
```

```
# Process: Reclassify
tempEnvironment0 = arcpy.env.scratchWorkspace
arcpy.env.scratchWorkspace =
#SetWorkspace
"C:\\temp\\VegetationHeight"
tempEnvironment1 = arcpy.env.snapRaster
arcpy.env.snapRaster = "c:\\temp\\RawLandfireEVH"
tempEnvironment2 = arcpy.env.workspace
arcpy.env.workspace = "C:\\temp\\VegetationHeight"
arcpy.gp.Reclassify_sa(evh, "VALUE", "-9999 NODATA;-9999 12 NODATA;13
7;14 7;15 7;16 19 1;100 107 1;108 2;109 3;110 7;111 14;112 16",
Reclass_all, "NODATA")
arcpy.env.scratchWorkspace = tempEnvironment0
arcpy.env.snapRaster = tempEnvironment1
arcpy.env.workspace = tempEnvironment2
```

## 6. Variable Width Buffer Tool

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------
------
# VariableWidthBufferTool.py
#   (generated by ArcGIS/ModelBuilder)
# Usage: VariableWidthBufferTool <Selected_Census_Blocks>
<Selected_Veg> <Maximum_distance> <Snapto> <ModelOutput>
# Description:
# A tool for the creation of the variable width, vegetation height
#based, community protection zone around US Census blocks meeting
#target housing density using reclassified LANDFIRE Existing Vegetation
#Height.
# ---------------------------------------------------------------------
------

# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")
arcpy.CheckOutExtension("3D")

# Set Geoprocessing environments
arcpy.env.scratchWorkspace = "C:\\temp"
arcpy.env.workspace = "C:\\temp\\WUIOutput"

# Script arguments
#Set Census Blocks or other area to be buffered, a polygon layer.
Selected_Census_Blocks = arcpy.GetParameterAsText(0)
if Selected_Census_Blocks == '#' or not Selected_Census_Blocks:
    Selected_Census_Blocks =
```

```
"C:\\temp\\CensusBlocks\\CensusBlocksTargetDensity.shp" # provide a
default value if unspecified

#Set Vegetation Height raster layer to be used as model input. LANDFIRE
EVH in this example.
Selected_Veg = arcpy.GetParameterAsText(1)
if Selected_Veg == '#' or not Selected_Veg:
    Selected_Veg = "C:\\temp\\VegetationHeight\\reclassevh" # provide a
default value if unspecified

#Set maximum buffer distance as maximum vegetation buffer distance plus
one pixel width.
Maximum_distance = arcpy.GetParameterAsText(2)
if Maximum_distance == '#' or not Maximum_distance:
    Maximum_distance = "510" # provide a default value if unspecified
#Set snap to raster layer to ensure correct pixel snapping and overlay.
Snapto = arcpy.GetParameterAsText(3)
if Snapto == '#' or not Snapto:
    Snapto = "C:\\temp\\VegetationHeight\\reclassevh" # provide a
default value if unspecified

#set model output folder for WUI output
ModelOutput = arcpy.GetParameterAsText(4)
if ModelOutput == '#' or not ModelOutput:
    ModelOutput = "C:\\Temp\\Reclass_Plus1" # provide a default value
if unspecified

# Local variables:
EuclideanDistanceBlocks = Snapto
Reclass_EucD1 = EuclideanDistanceBlocks
Output_raster__2_ = Reclass_EucD1
Con_Times_Re1 = Output_raster__2_
EucDist_Con_1 = Con_Times_Re1
Output_raster = EucDist_Con_1
Reclass_Corr5 = Output_raster
outputfolder = Reclass_Corr5
Times_Reclas6 = outputfolder
Times_Reclas5 = Times_Reclas6
Plus_Times_R1 = Times_Reclas5
Output_direction_raster__2_ = Con_Times_Re1
Con_Times_Re2 = Output_raster__2_
EucDist_Con_2 = Con_Times_Re2
Output_raster__3_ = EucDist_Con_2
Reclass_Corr3 = Output_raster__3_
Output_raster__9_ = Reclass_Corr3
Output_raster__10_ = Output_raster__9_
Output_direction_raster__3_ = Con_Times_Re2
Con_Times_Re3 = Output_raster__2_
EucDist_Con_1__2_ = Con_Times_Re3
Output_raster__4_ = EucDist_Con_1__2_
Reclass_Corr3__2_ = Output_raster__4_
Output_direction_raster__4_ = Con_Times_Re3
Con_Times_Re4 = Output_raster__2_
```

```
EucDist_Con_4 = Con_Times_Re4
Output_raster__5_ = EucDist_Con_4
Reclass_Corr2 = Output_raster__5_
Output_raster__8_ = Reclass_Corr2
Output_direction_raster__5_ = Con_Times_Re4
Con_Times_Re5 = Output_raster__2_
EucDist_Con_5 = Con_Times_Re5
Output_raster__6_ = EucDist_Con_5
Reclass_Corr1 = Output_raster__6_
Output_direction_raster__6_ = Con_Times_Re5
Con_Times_Re4__2_ = Output_raster__2_
EucDist_Con_4__2_ = Con_Times_Re4__2_
Output_raster__12_ = EucDist_Con_4__2_
Reclass_Corr6 = Output_raster__12_
Output_direction_raster__7_ = Con_Times_Re4__2_
Blocks_to_Zero = EuclideanDistanceBlocks
Veg_Inside_Blocks = Blocks_to_Zero
Reclass_plus1 = Veg_Inside_Blocks
Reclass_EucD2 = EucDist_VT_C2
Output_direction_raster = Snapto
Reclass_recl1 = Selected_Veg
Input_true_raster_or_constant_value = "1"
Input_true_raster_or_constant_value__2_ = "2"
Input_true_raster_or_constant_value__3_ = "3"
Input_true_raster_or_constant_value__4_ = "7"
Input_true_raster_or_constant_value__5_ = "16"
Input_true_raster_or_constant_value__6_ = "14"

# Process: Euclidean Distance
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = "C:\\temp\\VegetationHeight\\reclassevh"
arcpy.gp.EucDistance_sa(Selected_Census_Blocks, EucDist_VT_C2,
Maximum_distance, "30", Output_direction_raster)
arcpy.env.snapRaster = tempEnvironment0

# Process: Reclassify
arcpy.gp.Reclassify_sa(EucDist_VT_C2, "Value", "0
NODATA;0.10000000000000001 520 1", Reclass_EucD1, "DATA")

# Process: Reclassify (2)
arcpy.gp.Reclassify_sa(Selected_Veg, "VALUE", "0 NODATA;1 1;2 2;3 3;7
7;14 14;16 16", Reclass_recl1, "DATA")

# Process: Times
arcpy.gp.Times_sa(Reclass_EucD1, Reclass_recl1, Output_raster__2_)

# Process: Select Veg Values of 1
arcpy.gp.Con_sa(Output_raster__2_, Input_true_raster_or_constant_value,
Con_Times_Re1, "", "\"VALUE\" = 1")

# Process: Euclidean Distance (2)
arcpy.gp.EucDistance_sa(Con_Times_Re1, EucDist_Con_1, "30", "30",
Output_direction_raster__2_)
```

```
# Process: Select Veg Values of 2
arcpy.gp.Con_sa(Output_raster__2_,
Input_true_raster_or_constant_value__2_, Con_Times_Re2, "", "\"VALUE\"
= 2")

# Process: Euclidean Distance Value 2
arcpy.gp.EucDistance_sa(Con_Times_Re2, EucDist_Con_2, "60", "30",
Output_direction_raster__3_)

# Process: Select Veg Values of 3
arcpy.gp.Con_sa(Output_raster__2_,
Input_true_raster_or_constant_value__3_, Con_Times_Re3, "", "\"VALUE\"
= 3")

# Process: Euclidean Distance Value 3
arcpy.gp.EucDistance_sa(Con_Times_Re3, EucDist_Con_1__2_, "90", "30",
Output_direction_raster__4_)

# Process: Select Veg Values of 7
arcpy.gp.Con_sa(Output_raster__2_,
Input_true_raster_or_constant_value__4_, Con_Times_Re4, "", "\"VALUE\"
= 7")

# Process: Euclidean Distance Value 7
arcpy.gp.EucDistance_sa(Con_Times_Re4, EucDist_Con_4, "210", "30",
Output_direction_raster__5_)

# Process: Select Veg Values of 16
arcpy.gp.Con_sa(Output_raster__2_,
Input_true_raster_or_constant_value__5_, Con_Times_Re5, "", "\"VALUE\"
= 16")

# Process: Euclidean Distance Value 16
arcpy.gp.EucDistance_sa(Con_Times_Re5, EucDist_Con_5, "480", "30",
Output_direction_raster__6_)

# Process: Reclassify (10)
arcpy.gp.Reclassify_sa(EucDist_VT_C2, "Value", "0 0;0 510 1",
Reclass_EucD2, "DATA")

# Process: Select Veg Values of 14
arcpy.gp.Con_sa(Output_raster__2_,
Input_true_raster_or_constant_value__6_, Con_Times_Re4__2_, "",
"\"VALUE\" = 14")

# Process: Euclidean Distance Value 7 (2)
arcpy.gp.EucDistance_sa(Con_Times_Re4__2_, EucDist_Con_4__2_, "420",
"30", Output_direction_raster__7_)

# Process: Cor 7 Values (2)
arcpy.gp.Corridor_sa(EucDist_Con_4__2_, EucDist_VT_C2,
Output_raster__12_)
```

```
# Process: Reclassify (12)
arcpy.gp.Reclassify_sa(Output_raster__12_, "Value", "30 450 2;450 930
1;NODATA 1", Reclass_Corr6, "DATA")

# Process: Cor 16 Values
arcpy.gp.Corridor_sa(EucDist_Con_5, EucDist_VT_C2, Output_raster__6_)

# Process: Reclassify (3)
arcpy.gp.Reclassify_sa(Output_raster__6_, "Value", "30 510 2;510 10000
1;NODATA 1", Reclass_Corr1, "DATA")

# Process: Cor 7 Values
arcpy.gp.Corridor_sa(EucDist_Con_4, EucDist_VT_C2, Output_raster__5_)

# Process: Reclassify (4)
arcpy.gp.Reclassify_sa(Output_raster__5_, "Value", "30 240 2;240 720
1;NODATA 1", Reclass_Corr2, "DATA")

# Process: Times (3)
arcpy.gp.Times_sa(Reclass_Corr1, Reclass_Corr2, Output_raster__8_)

# Process: Cor 2 Values
arcpy.gp.Corridor_sa(EucDist_Con_2, EucDist_VT_C2, Output_raster__3_)

# Process: Reclassify (5)
arcpy.gp.Reclassify_sa(Output_raster__3_, "Value", "30 90 2;90 570
1;NODATA 1", Reclass_Corr3, "DATA")

# Process: Cor 3 Values
arcpy.gp.Corridor_sa(EucDist_Con_1__2_, EucDist_VT_C2,
Output_raster__4_)

# Process: Reclassify (6)
arcpy.gp.Reclassify_sa(Output_raster__4_, "Value", "30 120 2;120 600
1;NODATA 1", Reclass_Corr3__2_, "DATA")

# Process: Times (4)
arcpy.gp.Times_sa(Reclass_Corr3, Reclass_Corr3__2_, Output_raster__9_)

# Process: Times (5)
arcpy.gp.Times_sa(Output_raster__8_, Output_raster__9_,
Output_raster__10_)

# Process: Corr 1 Values
arcpy.gp.Corridor_sa(EucDist_Con_1, EucDist_VT_C2, Output_raster)

# Process: Reclassify (7)
arcpy.gp.Reclassify_sa(Output_raster, "Value", "30 60 2;60 540 1;NODATA
1", Reclass_Corr5, "DATA")

# Process: Times (2)
arcpy.gp.Times_sa(Output_raster__10_, Reclass_Corr5, outputfolder)
```

```
# Process: Times (7)
arcpy.Times_3d(Reclass_Corr6, outputfolder, Times_Reclas6)

# Process: Times (8)
arcpy.Times_3d(Reclass_EucD2, Times_Reclas6, Times_Reclas5)

# Process: Reclassify (8)
arcpy.gp.Reclassify_sa(EucDist_VT_C2, "Value", "0 0;0 510 NODATA",
Blocks_to_Zero, "DATA")

# Process: Plus
arcpy.gp.Plus_sa(Selected_Veg, Blocks_to_Zero, Veg_Inside_Blocks)

# Process: Reclassify (9)
arcpy.gp.Reclassify_sa(Veg_Inside_Blocks, "VALUE", "0 0;0 16 5;NODATA
0", Reclass_plus1, "DATA")

# Process: Plus (2)
arcpy.gp.Plus_sa(Times_Reclas5, Reclass_plus1, Plus_Times_R1)

# Process: Reclassify (11)
arcpy.gp.Reclassify_sa(Plus_Times_R1, "VALUE", "0 1 NODATA;1 64 1",
ModelOutput, "DATA")
```

# Appendix Three – GIS Model Figures

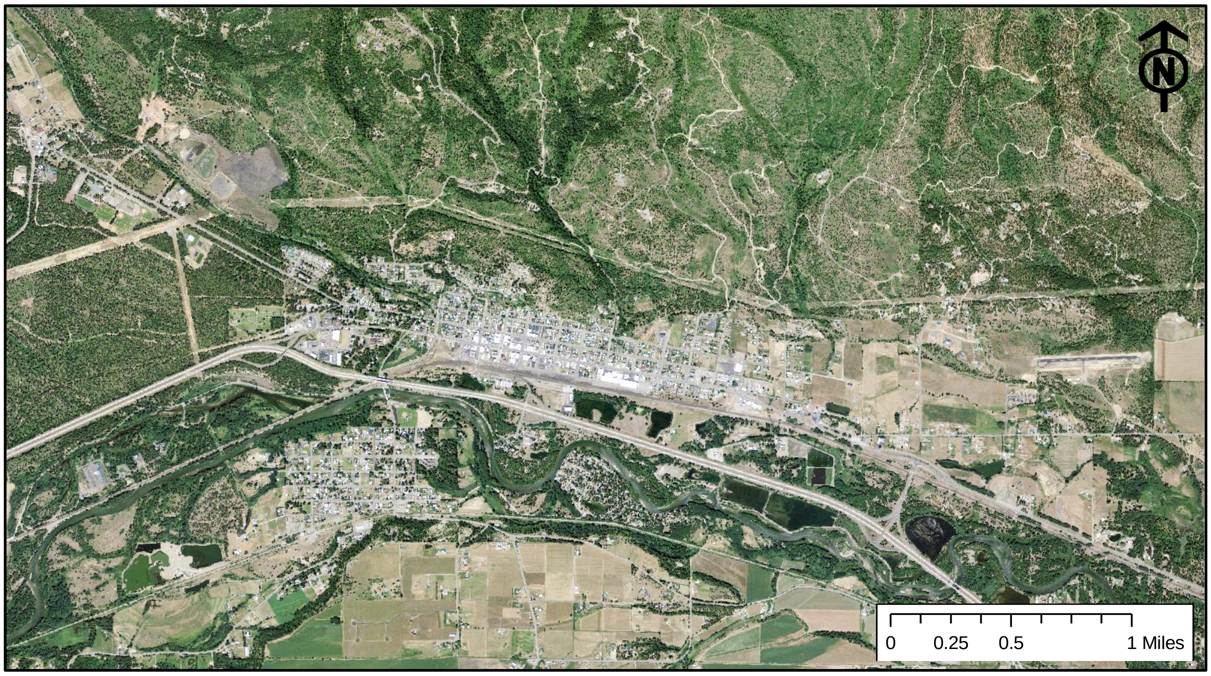


**Figure 14: Cle Elum, Washington, USA Aerial Photo**

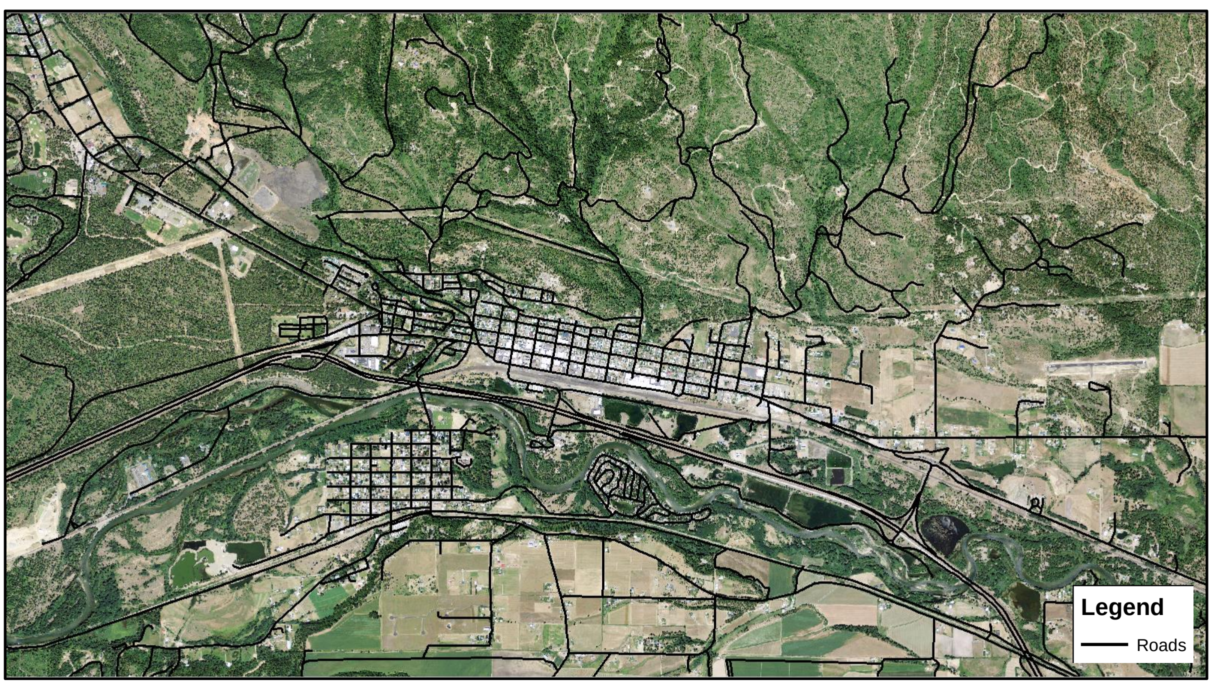


**Figure 15: US Census Roads**

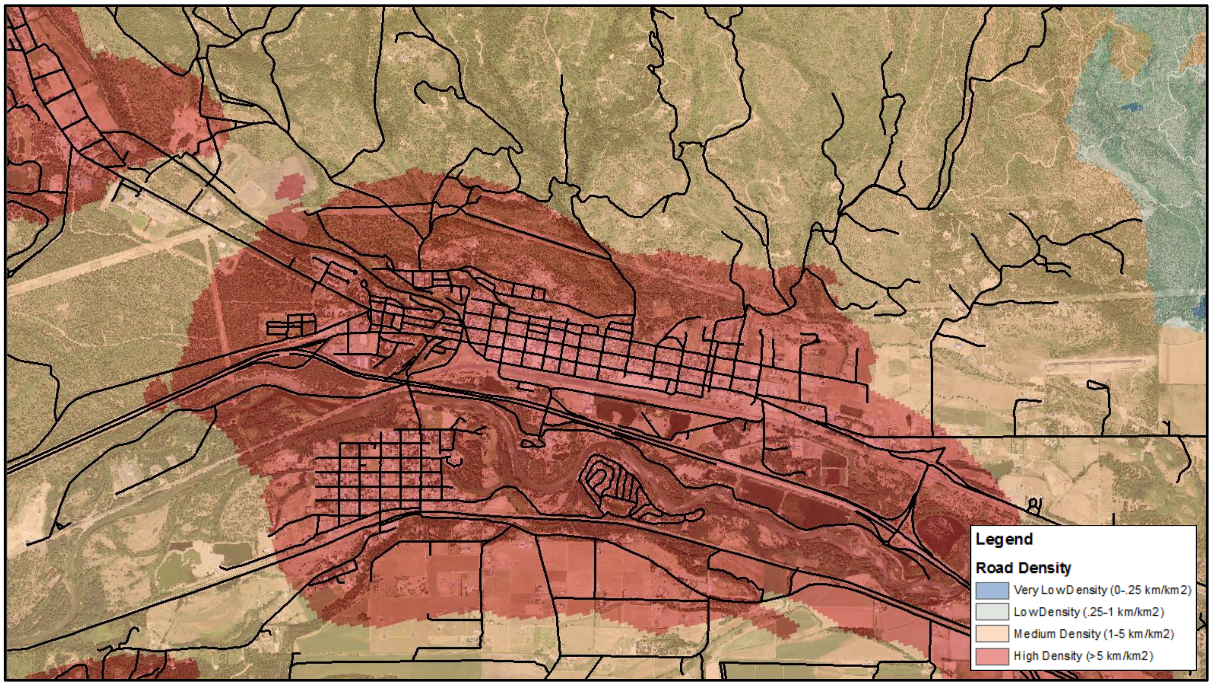


**Figure 16: Calculated Road Density Using 800 Meter Moving Window Analysis**

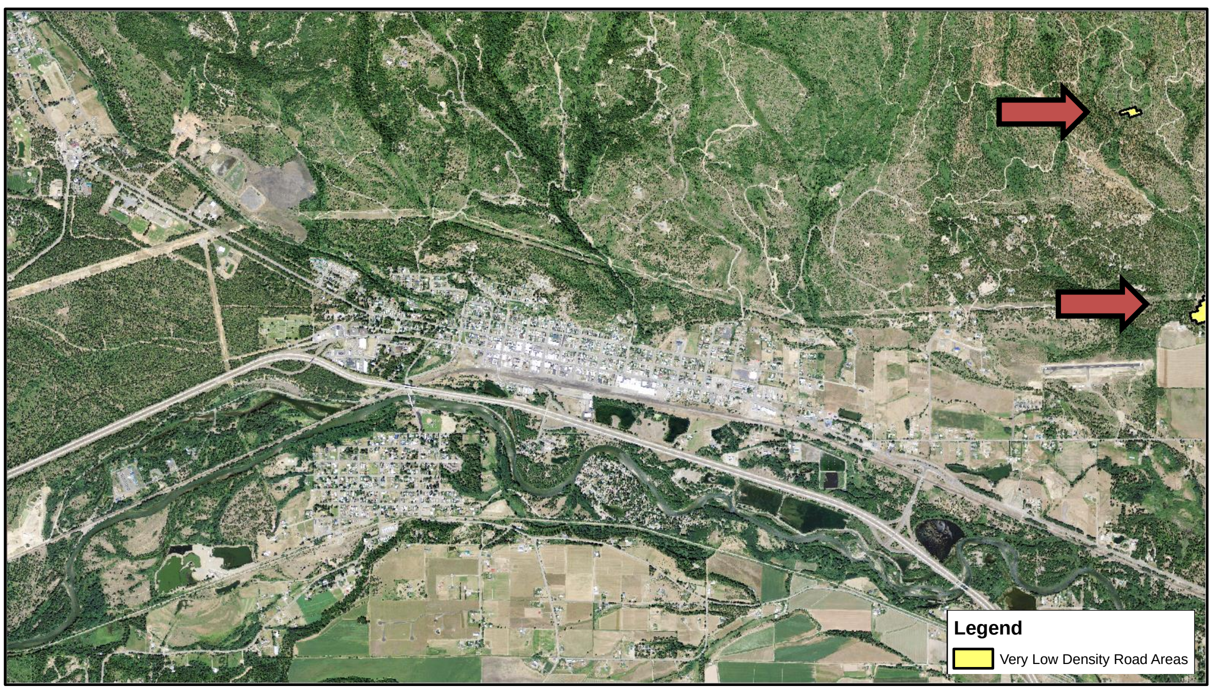


**Figure 17: Low Road Density Areas Selected and Converted to Vector for Dasymetric Erase**

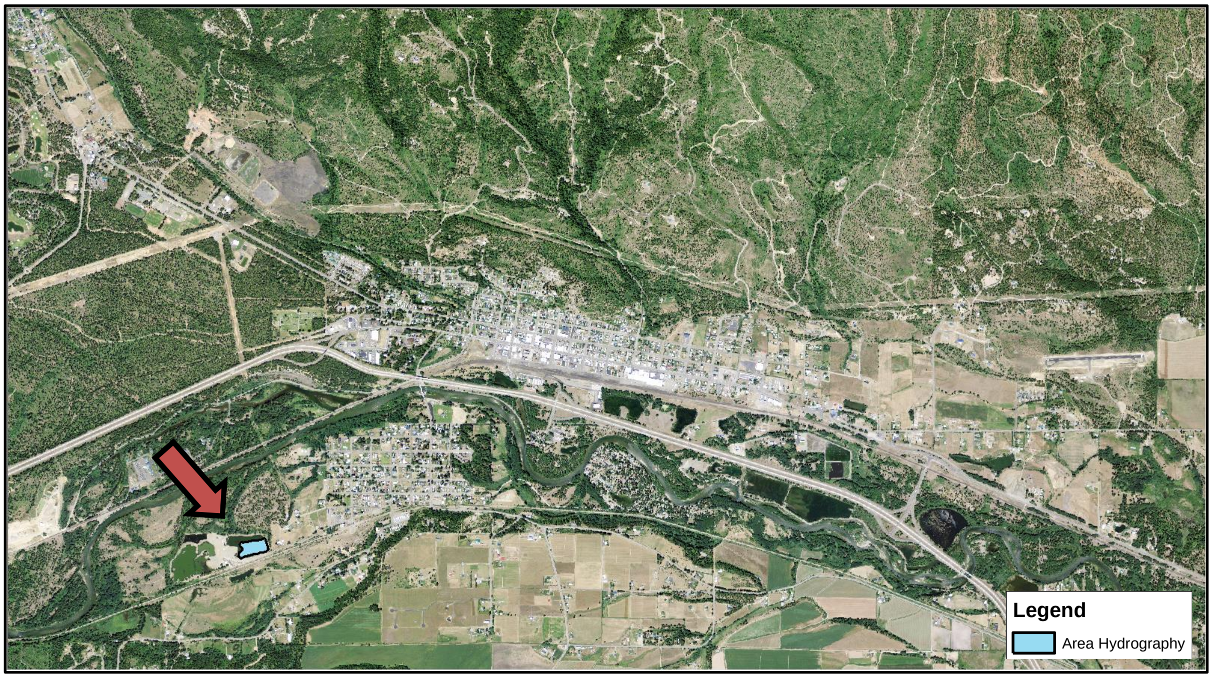


**Figure 18: US Census Area Hydrography for Dasymetric Erase**

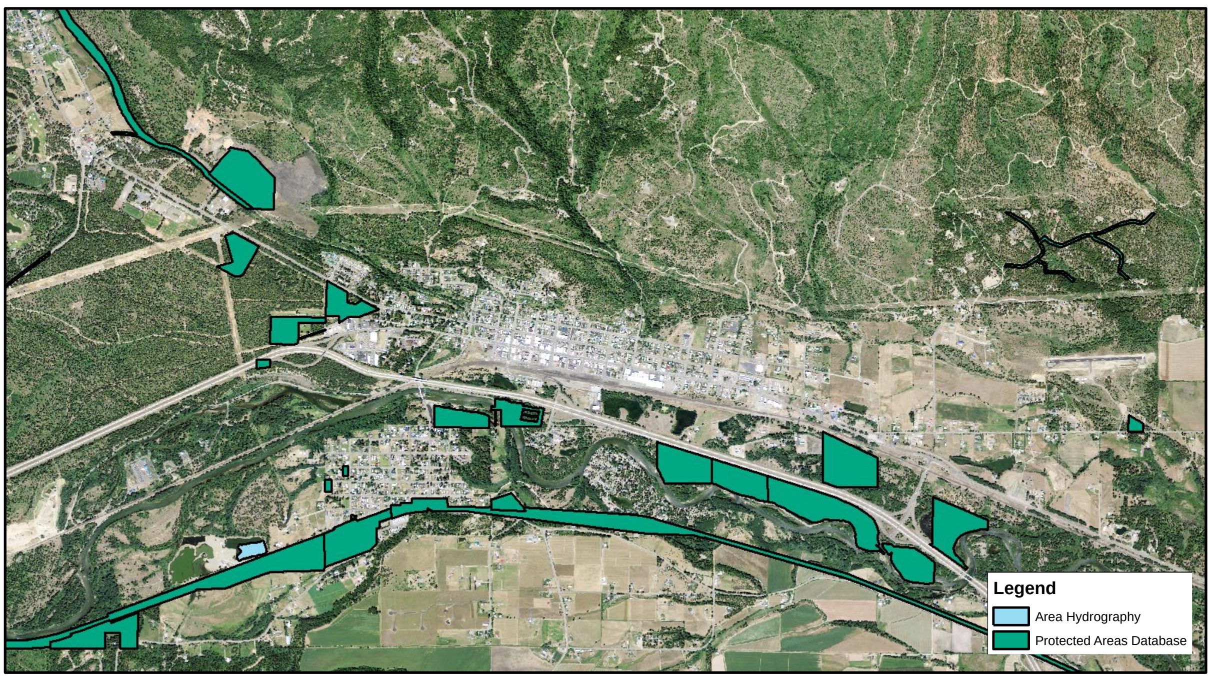


**Figure 19: Area Hydorgraphy and Public/Protected Lands Layers for Dasymetric Erase**

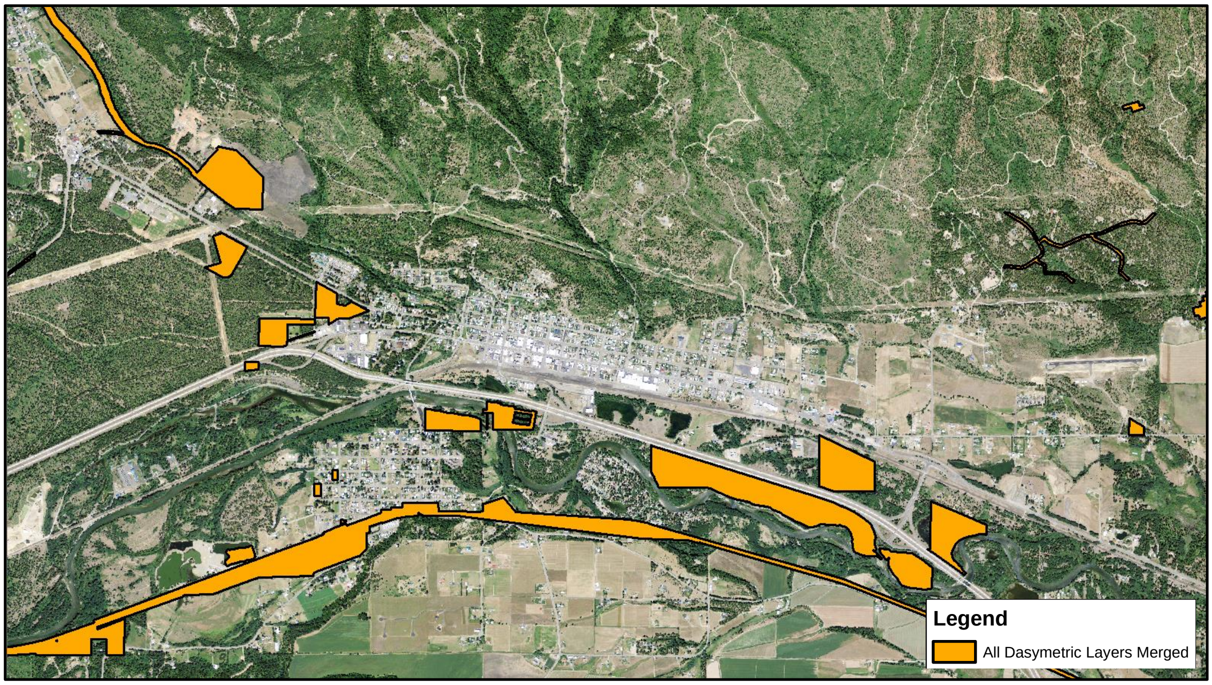


**Figure 20: Merged Dasymetric Erase Layers (Low Road Density Areas, Public/Protected Lands, Area Hydrography)**

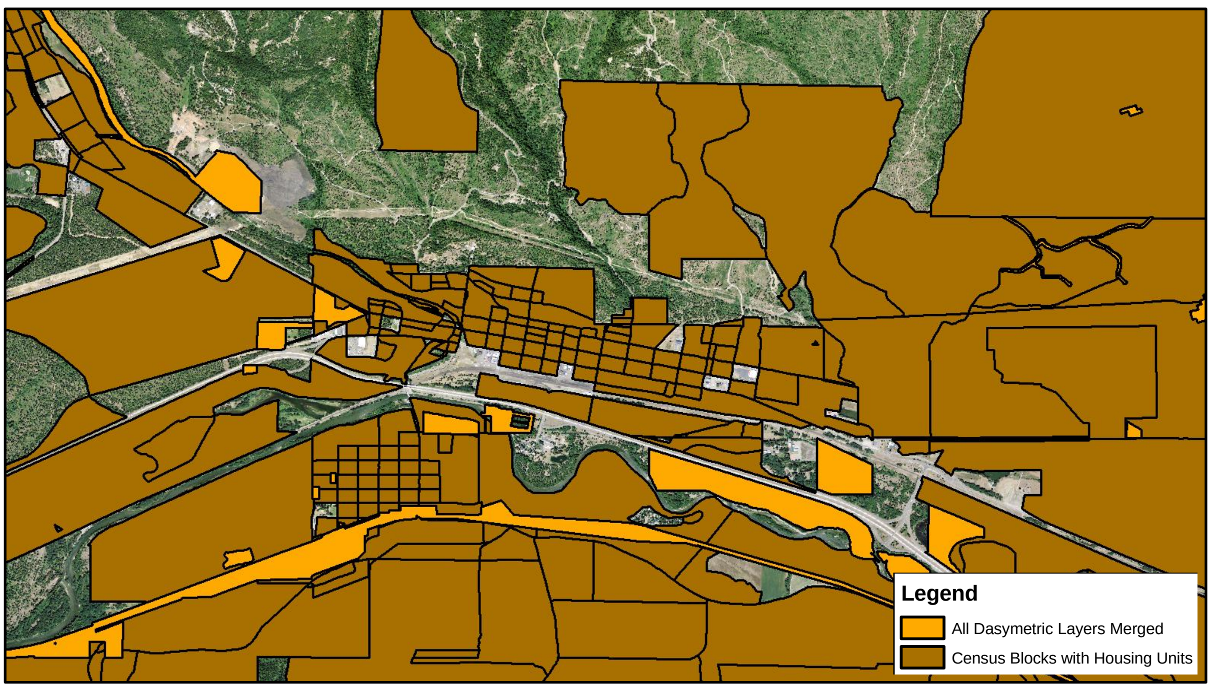


**Figure 21:US Census Blocks Containing Housing Units Overlaid with Dasymetric Erase Layers**

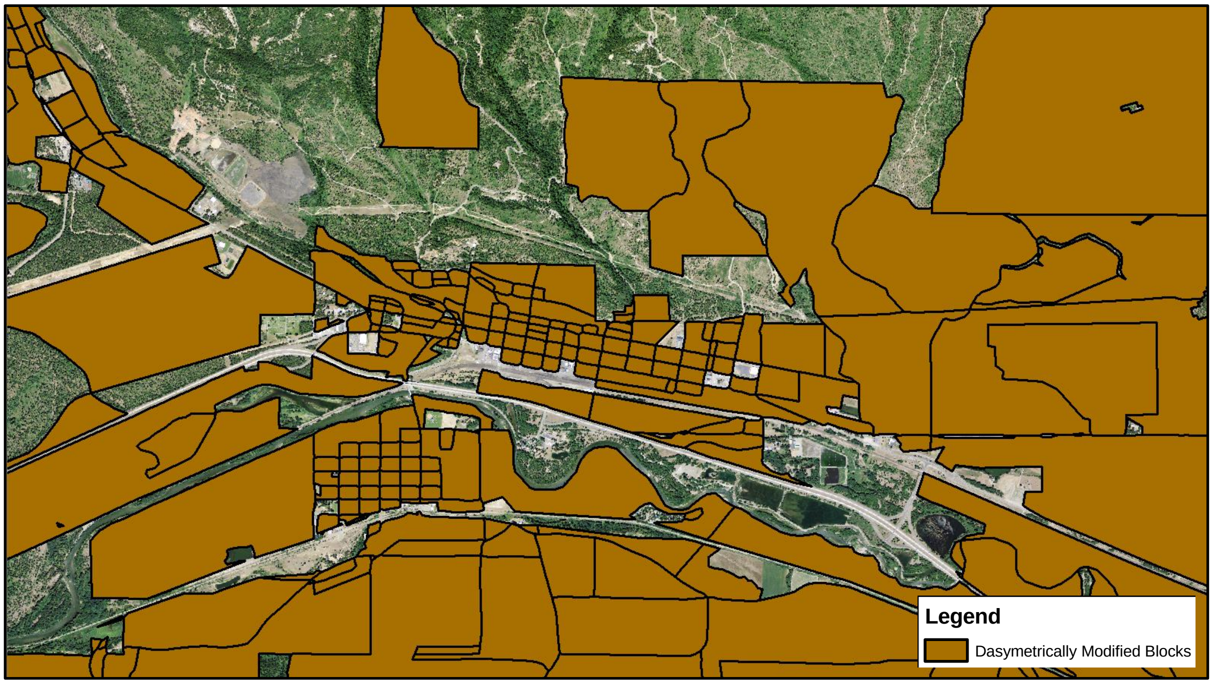

Figure 22: Dasymetrically Modified Census Blocks Containing Housing Units

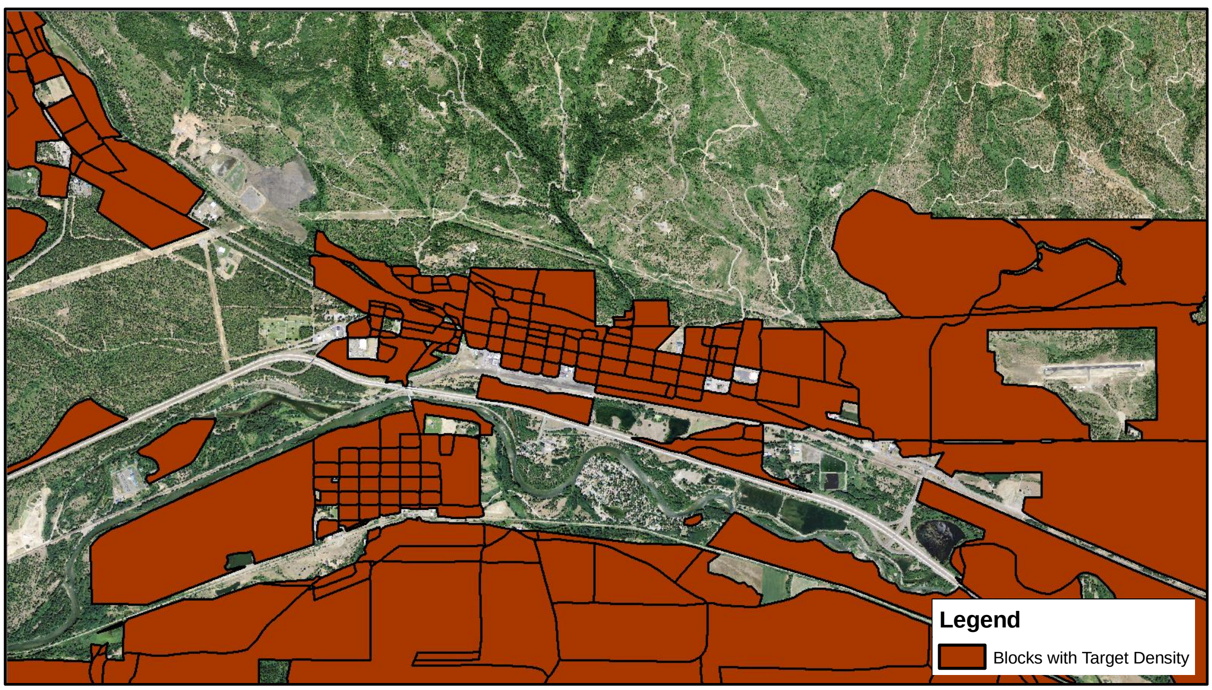

Figure 23: Modified Blocks with Housing Unit Target Density of ≥ 1 Housing Unit/40 Acres

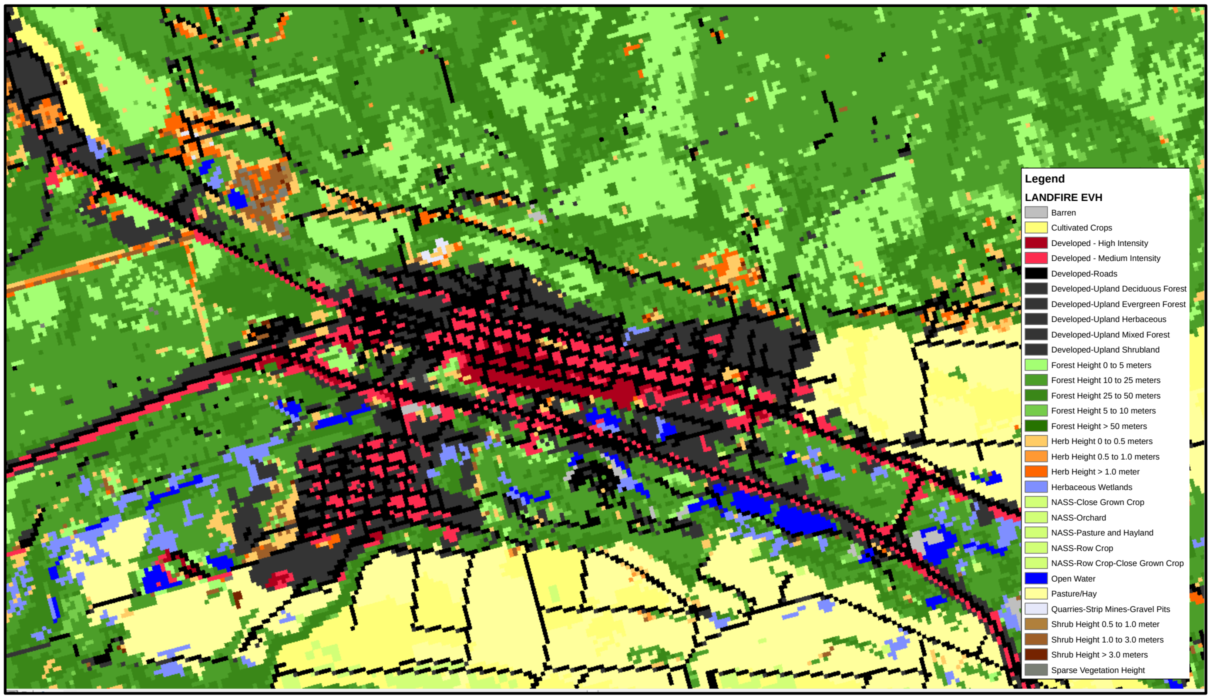


**Figure 24: Raw LANDFIRE 1.1.0 EVH Data**

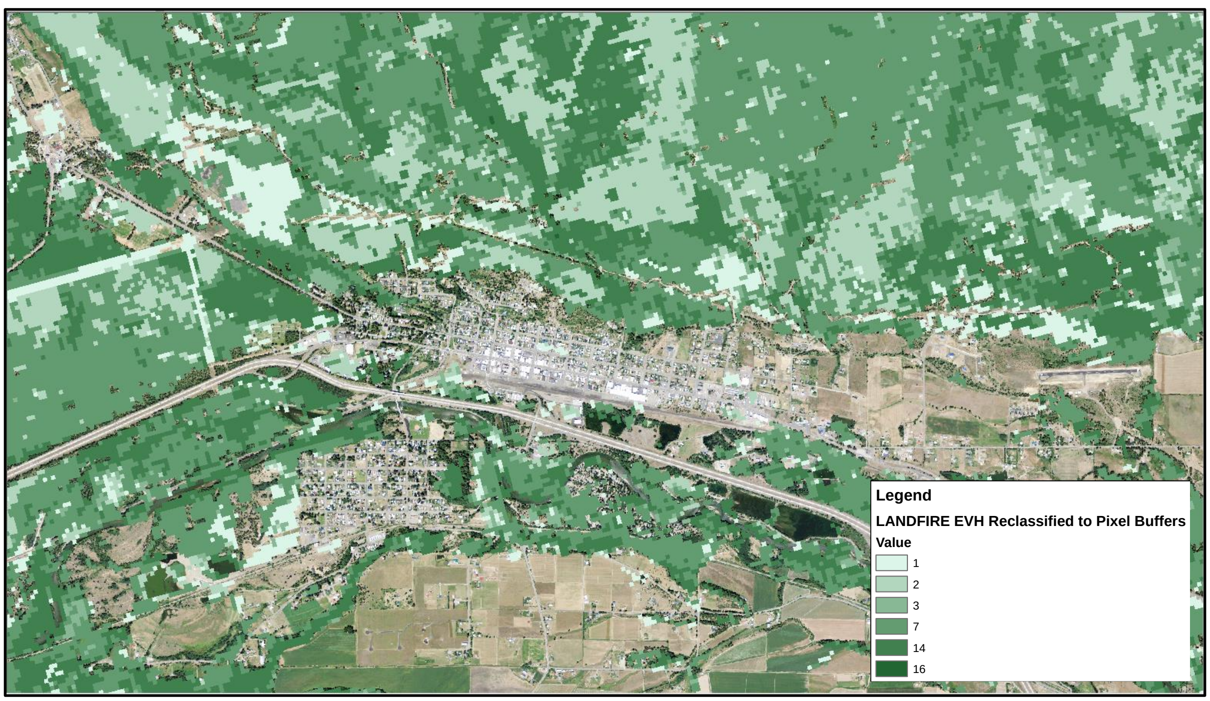


**Figure 25: Reclassified Potential Wildland Fire Fuels from Landfire EVH**

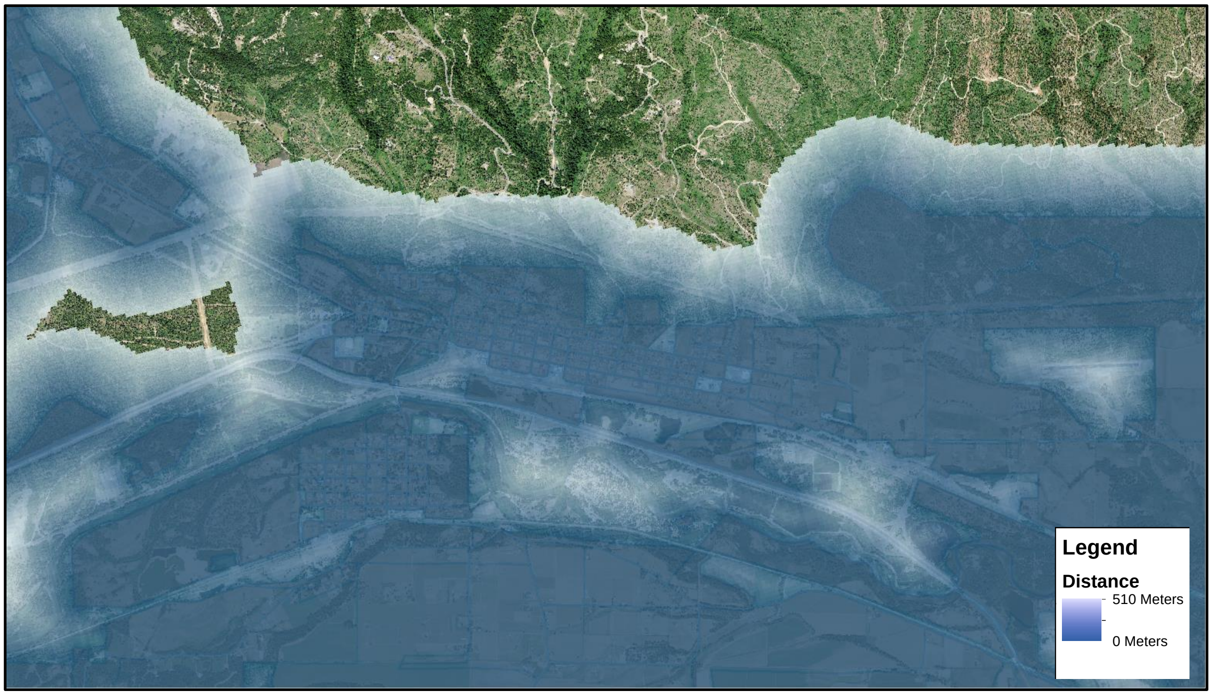

**Figure 26: 510 Meter Euclidean Distance Buffer from US Census Blocks Meeting Target Density**

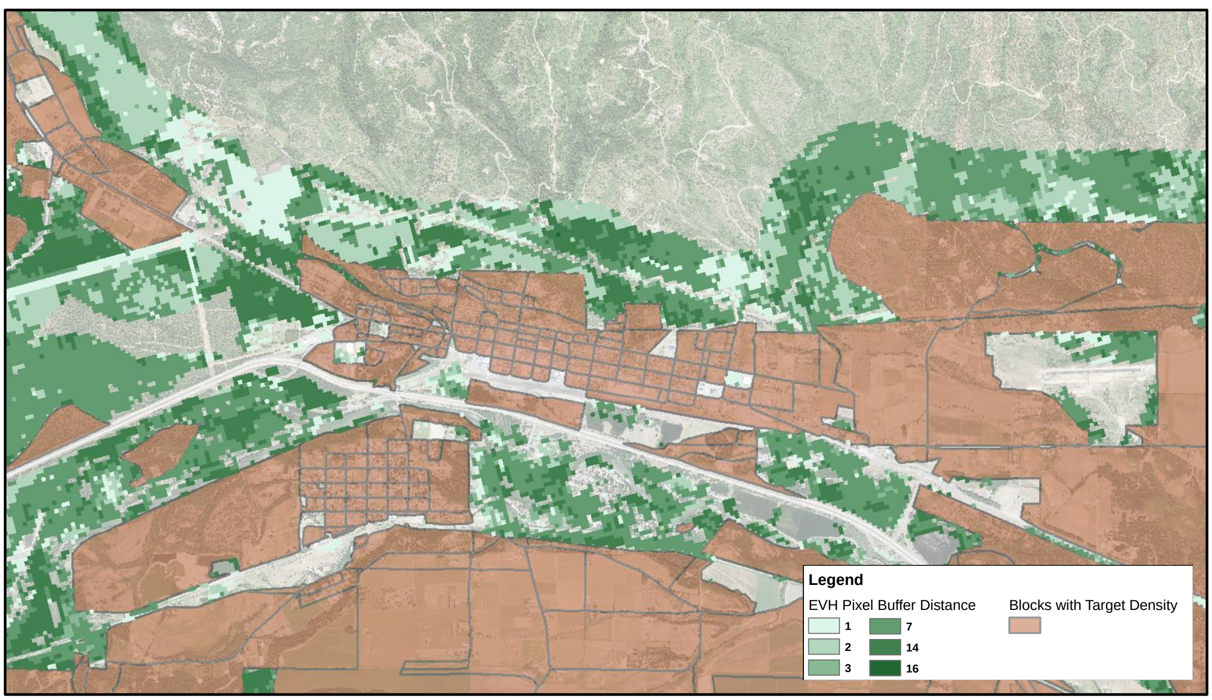

**Figure 27: Masked Potential Wildland Fire Fuels (Figure 25) Falling Within 510 Meter Buffer (Figure 26)**

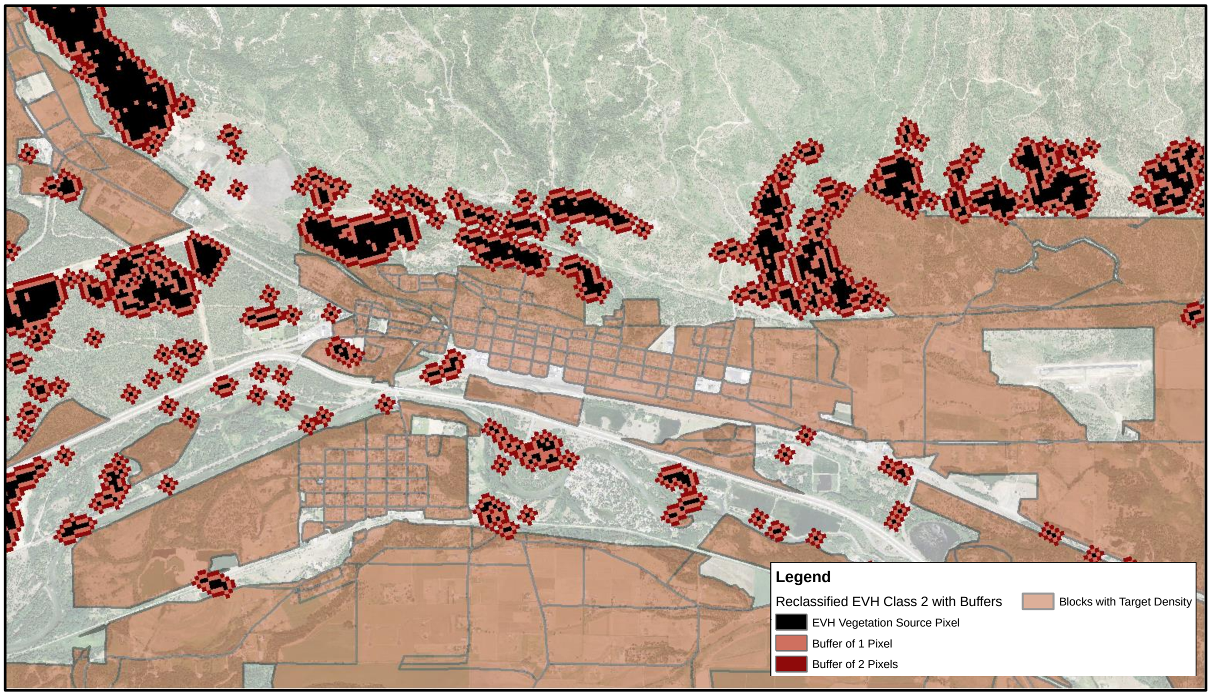


**Figure 28: Euclidean Distance Buffers for Reclassified EVH Height Classes (Table 2, Figure 25). Reclassified EVH class 2 depicted. Vegetation height between 0-5 meters, with the maximum height assumed for all pixels. Thus, 8 times 5 meters for a 40 meter buffer, but rounded up to the nearest 30 meter pixel, resulting in a 60 meter buffer radiationg in all directions.**

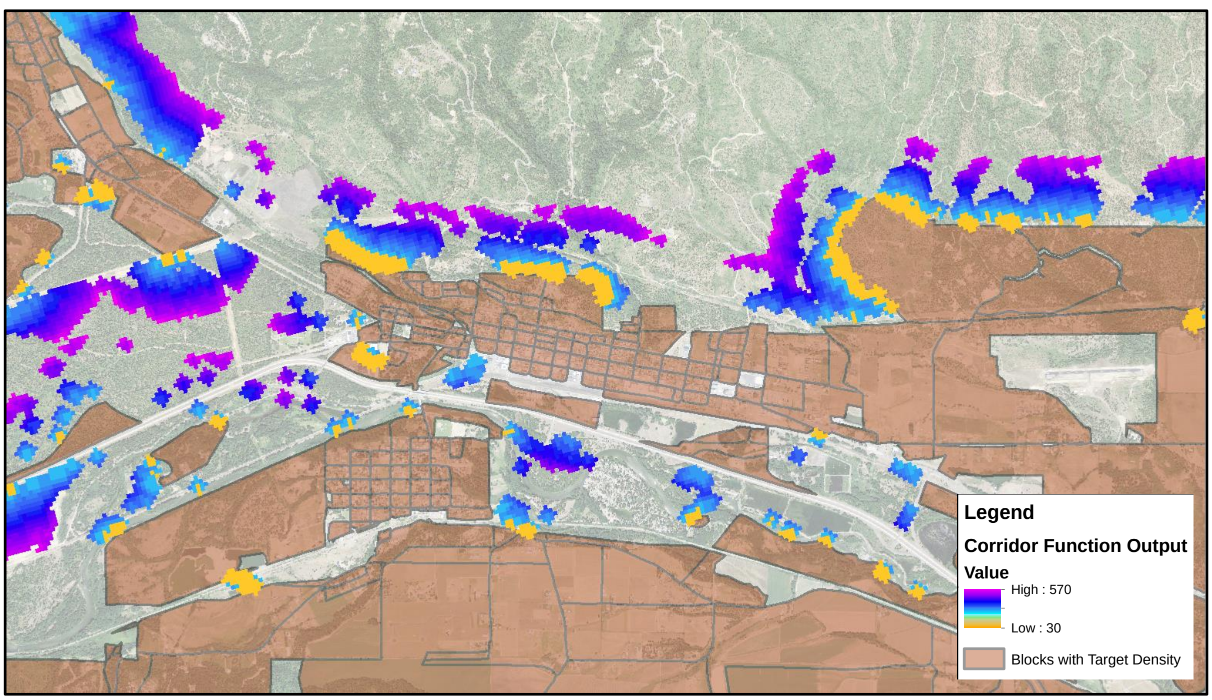


**Figure 29: Output from Corridor Function Reclassified EVH Class 2. Euclidean distance buffers from census blocks and potential wildland fire fuels (Figure 25) are used as the two inputs. Only pixels that overlap are retained at this step. Shading in blue to purple shows areas where the vegetation buffer extends, but directionally away from census blocks, thus it is excluded by reclassifying the raster layer to select all cells with values less than a maximum accumulated threshold for each vegetation height class. The function assumes non-linear corridor, and thus overestimates the potential buffer zones. Nevertheless it does offer general directionality between potential wildland**

**fire fuels, their buffers, and census blocks meeting the minimum density threshold. This step is iterated for each vegetation class in the input vegetation height layer.**

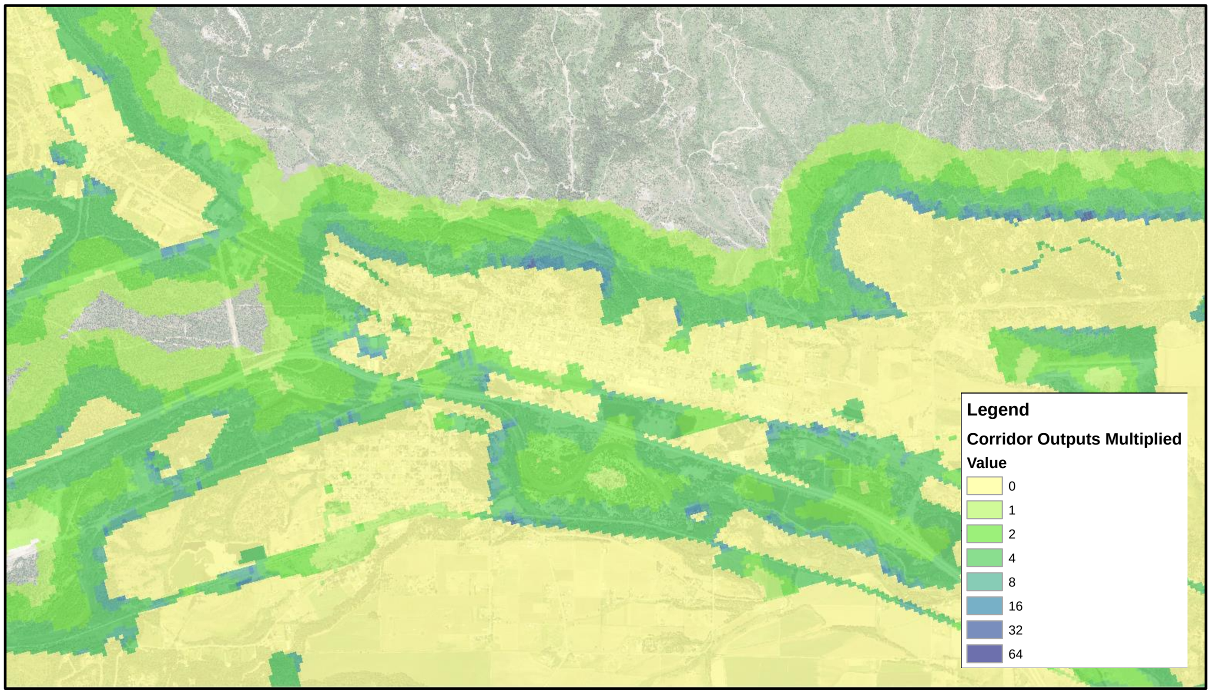


**Figure 30: All Reclassified Corridor Functions Multiplied Together. Zero values (yellow) indicate areas inside target desnsity census blocks.**

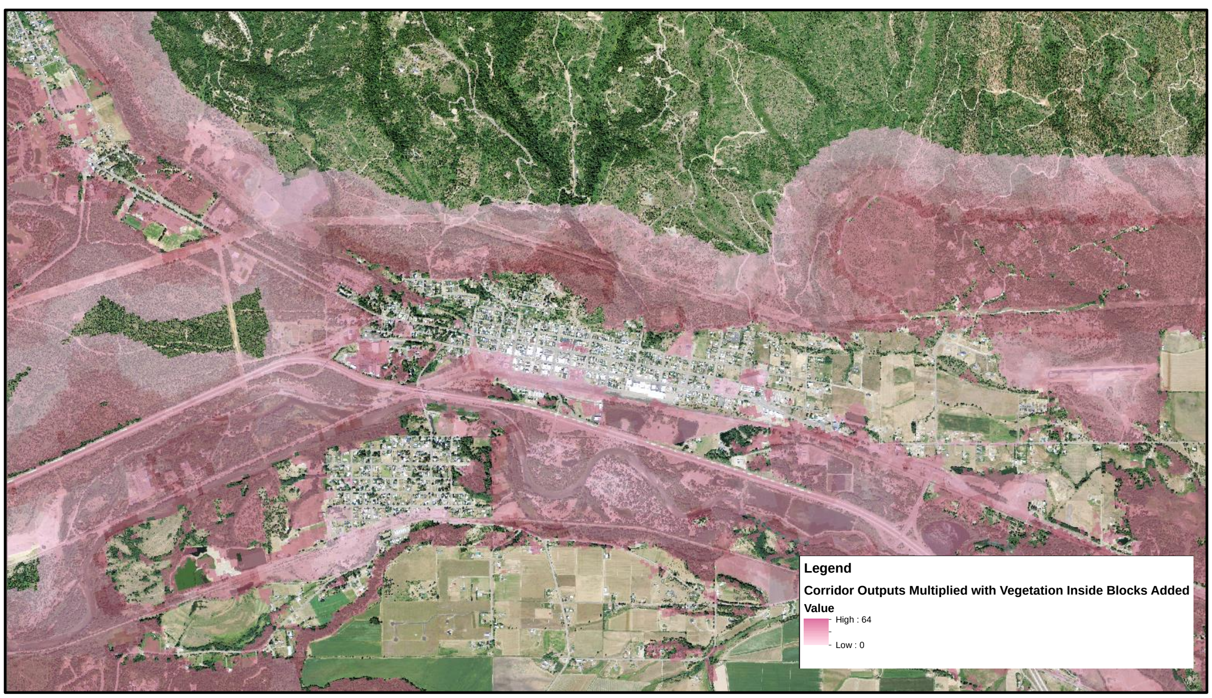


**Figure 31: Potential Wildland Fire Vegetation Added Back to Areas Inside Target Density Census Blocks**

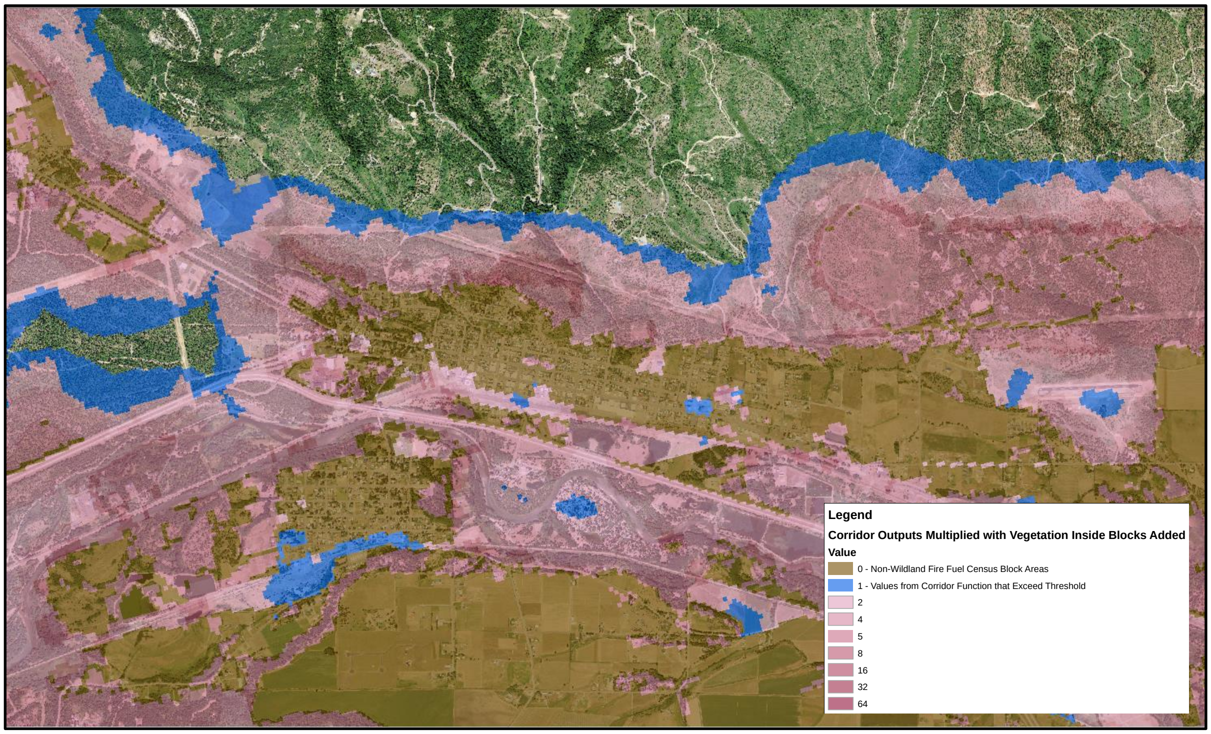


**Figure 32: Symbolized Combined Corridor Outputs and Vegetation Inside Blocks. Values in blue are artifacts retained to capture all potential vegetation buffers, but undesired for the final output. Areas in brown are the target density census blocks with non-fuel landcover classifications, while the pink areas depict our desired WUI model output areas.**

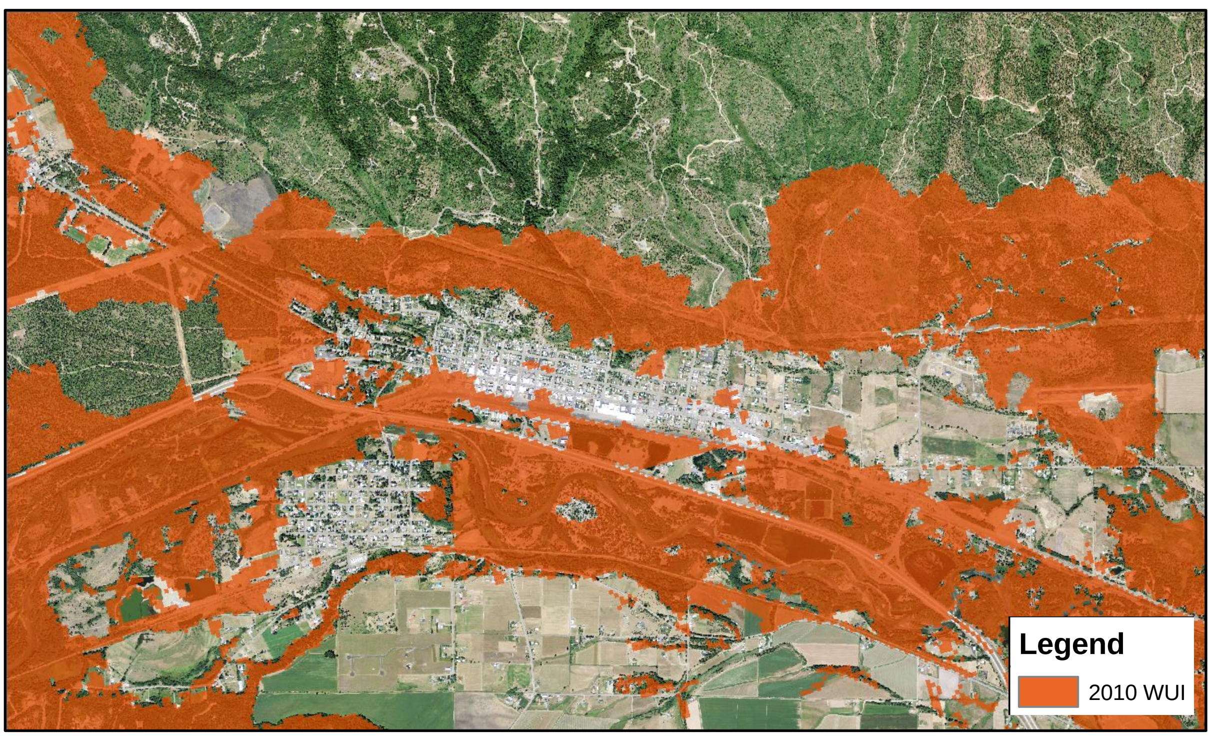


**Figure 33: Figure 32 Reclassified to Produce Final 2010 WUI Output**