THE WILDLAND-URBAN INTERFACE IN LASSEN COUNTY, CALIFORNIA:

A CHANGE ANALYSIS 2000 – 2015

by

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LIST OF ABBREVIATIONS

APN	Assessor Parcel Number
BLM	Bureau of Land Management
CAL FIRE	California Department of Forest and Fire Protection
CFPZ	Community Fire Protection Zone
CWPP	Community Wildfire Protection Plan
FHSZ	Fire Hazard Severity Zone
FRA	Federal Responsibility Area
GIS	Geographic Information System
HFRA	Healthy Forest Restoration Act of 2003
LRA	Local Responsibility Area
NLCD	National Land Cover Database
SRA	State Responsibility Area
USFS	United States Forest Service
USGS	United States Geological Survey
WUI	Wildland-Urban Interface

ABSTRACT

The expansion of low-density residential development into wildlands places a variety of stresses on Earth's natural systems. Urban sprawl is one of the many factors contributing to water shortages, higher resource costs, and increasingly destructive storms, all of which fit under the umbrella of global climate change (Gencer 2013). In California, it is wildfires that capture the headlines during the summer and fall months. With wildfires becoming a common occurrence within the California landscape, it is crucial that local government and agencies work to create proactive approaches to mitigate the severity of these events. The areas of chief concern occur where structures and infrastructure are intermixed or adjacent to wildland fuels; this area is known as the wildland-urban interface (WUI). Mapping the WUI is a useful resource for assessing which communities and developed areas are most vulnerable to wildfire. County cadastral data was used to assess the spatial extent of the WUI within Lassen County, California. This method is a large improvement to past studies because it eliminates the need to estimate the areas where housing is located. California Department of Forest and Fire Protection (CAL FIRE) Fire Hazard Severity Zone Maps were then overlaid to identify the areas in most need of emergency planning and preventative action. Results show that in 2015, the spatial extent of Lassen County's WUI was 1,016.67 sq. km. (392.54 sq. mi) and accounted for 101,666.68 hectares (251, 222.83 acres) or 8.32% of the study area. The WUI area included 5,456 residential structures (49.51% of the total housing), which was a 13.22% increase and a 1.89 percentage point increase from 2000. 81% of the WUI occurs on private lands.

CHAPTER 1: INTRODUCTION

The expansion of low-density residential development into wildland areas places a variety of hardships on Earth's natural systems. As communities sprawl, they replace agricultural lands and natural habitat, while simultaneously pillaging resources (Benfield 2001). Urban sprawl is one of the many factors contributing to severe drought, higher resource costs, and increasingly destructive storms, all of which fit under the umbrella of global climate change (Gencer 2013). In California, it is wildfires that capture the headlines during the summer and fall months. Sprawling urban development and human alteration of natural fire regimes have increased California's susceptibility to wildfires, which increases the risk to lives, natural resources, and the built environment (Theobald 2007). When residents place their homes in the wildland-urban interface they increase their vulnerability to wildfire.

1.1 Wildland-Urban Interface

The wildland-urban interface (WUI) refers to the area where human development meets natural areas such as forest, shrub lands, or grasslands (Radeloff et al. 2005). The US federal government recognizes three types of WUI: interface, intermix, and occluded. Definitions for each of the three types were published in the 2001 Federal Register (66 FR 751 2001). Interface communities are located immediately adjacent to wildland fuels. This means that there is a clear line between development and the wildland fuels. Interface communities typically have a higher density than intermix areas, but have been operationalized in past studies using a housing density threshold of one housing unit per 40 acres (Stewart et al. 2003; Radeloff et al. 2005; Wilmer & Aplet 2005; Tully 2013).

Intermix communities are comprised of structures that are dispersed throughout wildland fuels. Intermix communities do not have a clear line of separation between development and fuels. The housing density threshold of one housing unit per 40 acres is also used to operationalize the definition (Stewart et al. 2003; Radeloff et al. 2005; Tully 2013). The occluded community is generally located within an urban area, with structures that immediately abut an isolated area of wildland fuels. The two major elements that distinguish between the types of WUI are the location and density of the community in relation to wildland fuels. Previous studies have relied upon a variety of geospatial techniques to implement the Federal Register's definitions (Stewart et al. 2003; Radeloff et al. 2005; Wilmer and Aplet 2005, Theobald and Romme 2007; Tully 2013).

Nationally, humans cause 90% of wildfires (National Park Service n.d). The California Department of Forestry and Fire Protection (CAL FIRE) estimates that 95% of fires, within the State are caused by humans. Therefore, the probability for wildfires increases as the WUI expands. The importance of the WUI increases as development encroaches upon the surrounding natural environment, making these types of communities more prone to wildfires. California has the most homes in the U.S. located within the WUI at 5.1 million units (Radeloff et al. 2005). Furthermore, 7% of the state's landmass, 24% of the state's population, and 26% of its housing units are located within the WUI (Tully 2013). This places a large financial strain upon local, state, and government agencies. These agencies not only provide funding for proactive wildfire mitigation measures, but must also bear the costs of fighting wildfires.

The purpose of this study is to conduct a change analysis of the wildland urban interface (WUI) in Lassen County, California between 2000 and 2015. The study examines if the spatial extent of the WUI has increased or decreased and where any changes have occurred. The WUI maps are overlaid on CAL FIRE's Fire Hazard Severity Zone Map for Lassen County. Together, these maps will help to identify the areas in most need of fire and natural resource management.

Specifically, this study will help local and state fire districts identify the areas in most need of fuel reductions, fire mitigation, and resource allocations.

1.2 Motivation

In the conterminous United States, 38.5% of the nation's housing units are located within a WUI and about 99 million people live within a WUI (Radeloff et al. 2005; Stewart et al. 2010). The Healthy Forest Restoration Act of 2003 (HFRA) helps to protect communities against catastrophic wildfires by allocating federal funding to help reduce fire risk to homes located within a WUI. Specifically, HFRA provides funding for hazardous fuel reduction on federal lands. This is primarily based upon the dangers associated with a wildfire on federal lands spreading to a nearby community. The HFRA prioritizes project funding to communities with a community wildfire protection plan (CWPP). This ensures that local agencies have the opportunity to influence where hazardous fuel reduction projects take place within their jurisdiction.

California Senate Bill 1241 mandates that city and county jurisdictions revise the Safety Element chapter of their General Plan to address wildfires. Specifically, these jurisdictions must delineate local, state, and federal responsibility areas and address preventative wildfire measures for all CAL FIRE "very high" fire hazard severity zones areas. It also requires that the Safety Element be reviewed and updated as necessary to address the risk of fire in these areas in accordance with the Governor's Office of Planning and Research's "Fire Hazard Planning" document. The proposed study would help to fulfill the County of Lassen's State-required duty.

1.3 Study Area: Lassen County, California

Lassen County is located in the northeast section of California; it is bordered by Nevada to east. The county's area is 12,224.74 km² (4,720 mi²). In 2012, it was also the site of the Rush Fire, the second largest wildfire recorded in California history. The fire consumed 127,701.38 hectares (315,557 acres). Lassen County is particularly interesting as all twenty of its communities were listed in the Federal Register's List of Communities at Risk to Wildfire in 2001. The majority of the county is comprised of public lands. The county, state, and federal government own or manage 63% of the land (Figure 1).

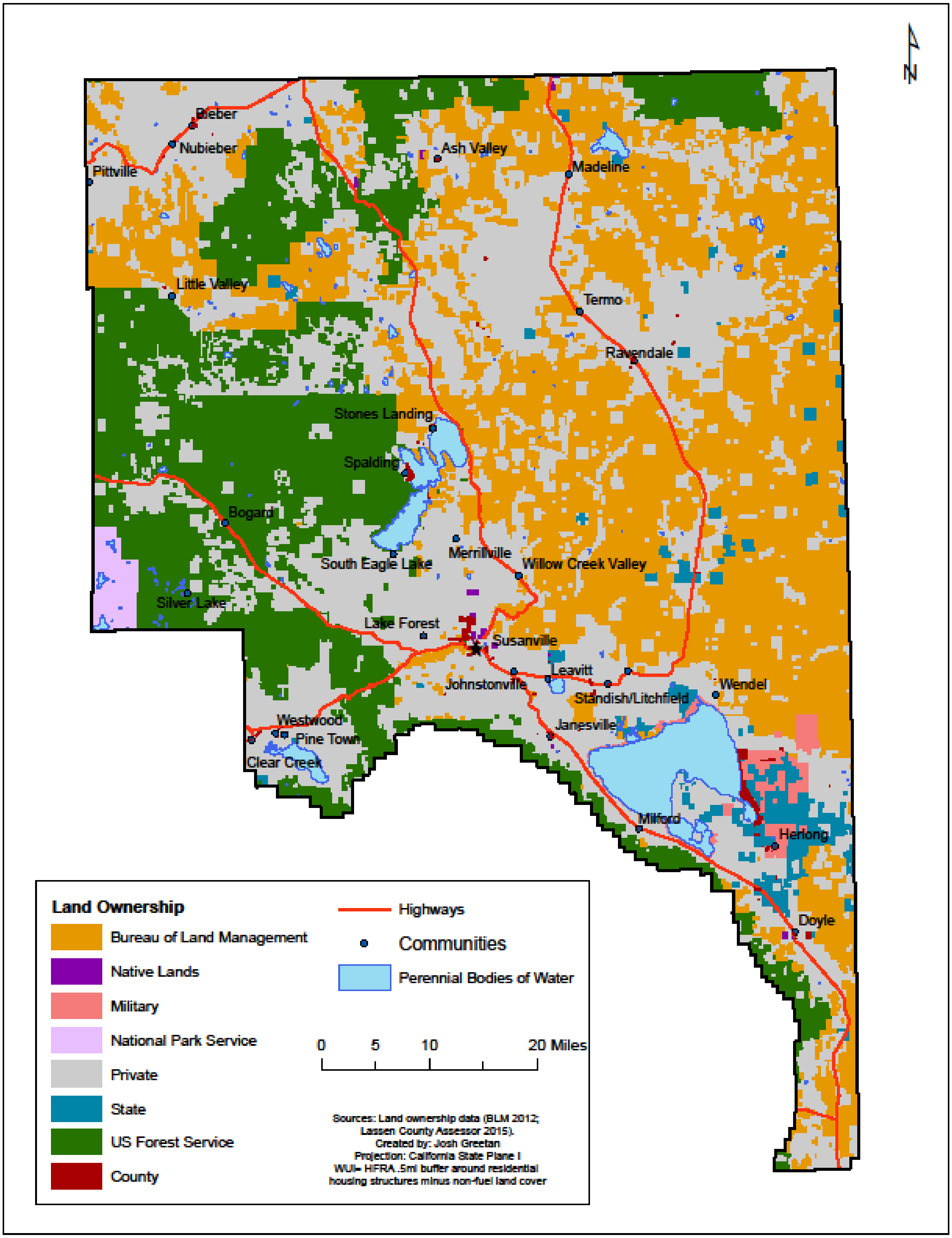

Figure 1: 2015 Land Ownership in Lassen County. Map shows the distribution of public versus private lands

Previous academic studies have mostly addressed the mapping of the WUI at a national scale (Stewart et al. 2003; Radeloff et al. 2005; Theobald and Romme 2007; Tully 2013); however, a handful of studies address the issue within smaller, more focused case study areas (Wilmer and Aplet 2005; Rozmajzl 2012). This project assesses the WUI at a scale in between those of the past endeavors, which will allow for a more precise and accurate measurement of the WUI.

Since the study doubles as a professional project, I had access to County data not available to the public. With access to the County Assessor's GIS files, the potential to model housing density at a more precise level than the 2010 Census may exist. This study expands upon dasymetric techniques used in Wilmer and Aplet's (2005) model for mapping the Community Fire Protection Zone (CFPZ). One improvement to their model will be the utilization of cadastral data to eliminate the need of US Census Blocks for estimating home locations.

The Assessor's parcel database contains a wealth of property and owner information and has the potential to map housing density in rural settings not recorded by the decennial Census. The Lassen County Public Works Department's transportation infrastructure shapefiles are more current than the 2010 Census roads shapefile. Finally, the County's rapport with other local, state, and federal agencies aided in the completion of this project; CAL FIRE was especially integral to this study, as they provided a wealth of data and informational resources.

CAL FIRE's most recent Fire Hazards Severity Zone Map for Lassen County was published in 2007. The updated WUI map builds upon CAL FIRE's hazard research and also provided the opportunity to utilize the most current datasets. These datasets include: 2015 Lassen County parcel data and National Land Cover Database (NLCD).

1.4 Organizational Framework

This thesis contains four additional chapters. Chapter 2 explores previous WUI mapping studies in order to analyze the variety of approaches available and the differences between them. This chapter serves as the cornerstone for operationalizing the WUI in the methods chapter. Chapter 3 presents the proposed cadastral-based approach for this study. Additionally, it provides the framework for measuring and analyzing the WUI. Chapter 4 presents the results of the proposed modeling technique. It is comprised of the outputs mentioned in Chapter 3. Chapter 5 discusses the implications of the study results, the successes and shortfalls associated with the proposed approach, and suggests opportunities for future research.

CHAPTER 2: BACKGROUND AND RELATED WORK

Although many studies use the same data and implement the federal definitions in a similar manner, the techniques employed yield conflicting outputs (Stewart et al. 2009; Tully 2013). The following chapter provides a discussion of the discrepancies between data, models, and the analytical techniques of previous WUI studies. The first section discusses the history of WUI mapping and the variety of methods used over time. The second section explores the definition effect (Platt 2010; Tully 2013).

2.1 Geographic Modeling of the WUI

The first study to operationalize the Federal Register's definitions for WUI used 2000 US Census Block Group data with a minimum housing density of 1 housing unit per 40 acres, and 30-meter pixel National Land Cover Data (NLCD 1992) to map the WUI in the conterminous US (Stewart et al. 2003). The study included the following land cover classes as wildlands in its assessment: forests (coniferous, deciduous, and mixed), native grasslands, shrubs, wetlands, and transitional lands (e.g. clear-cuts). It excluded orchards, arable lands (agricultural lands and row crops), and pasture (Stewart et al. 2003). The analysis addresses two types of WUI: interface and intermix.

The study's geographic modeling is primarily based upon the definitions provided within the Federal Register (66 FR 751 2001); however, Stewart et al. further define each of the two types to visualize them within a geographic information system (GIS). According to the Federal Register, the interface WUI occurs "within the vicinity" of wildlands vegetation, however the term "vicinity" is not defined. Stewart et al. use a 2.4 km (1.5 mi) buffer that extends from Census blocks meeting the minimum housing density criteria. This is based on the estimated distance a firebrand can travel from a wildfire, through the air, and potentially ignite a home or fuel near it (California Fire Alliance 2001; Stewart et al. 2003). Interface areas have 1 or more homes per 40 acres, have less than 50% vegetation cover, and are within 1.5 mi of an area comprising 500 ha (1236 acres) with vegetation cover of more than 75%. Intermix areas have the same criteria for housing density threshold, but must have more than 50% vegetation cover (Stewart et al. 2003).

While Stewart et al. calculate the land mass and locations for both interface and intermix separately, they use the term WUI interchangeably for both types and aggregate the two types for the final map deliverable. They concluded that the WUI covered 9.3% (175 million acres) of the conterminous US and 36.7% (42.2 million) of the total housing units. A major limitation of the study was that it did not address fire risk as national data was not yet available.

Radeloff et al. (2005) further refined Stewart et al's (2003) efforts to map the WUI within the conterminous US by modifying vegetation classifications. The vegetation and land cover types used were nearly identical to those of Stewart et al. (2003), with the addition of grasslands/herbaceous and woody and emergent herbaceous wetlands. The study expanded upon the classes omitted with the following exclusions: 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). Similar to Stewart et al. (2003) housing density and vegetation coverage were then calculated for each Census block to operationalize intermix and interface areas.

Definitions for interface remained similar to those used by Stewart et al. (2003) and had only a few additional criteria. Radeloff et al. used a minimum threshold area of 3.1 sq. mi. for heavily vegetated areas within the 1.5 mi buffer in order to exclude urban parks from the assessment. Another key alteration to Stewart et al.'s (2003) model was the splitting of Census blocks.

Radeloff et al. split and then removed portions of Census blocks falling outside of the 1.5 mile buffer area from wildlands. The results of the analysis were similar to those of Stewart et al.'s (2003) analysis. Radeloff et al. concluded that the WUI comprised 9.4% (177.7 million acres) of the conterminous US and included 38.5% (44.3 million) of the total housing units.

2.1.2 Dasymetric Mapping Approaches

Dasymetric mapping is a type of areal interpolation that uses ancillary data to more accurately distribute an attribute over a large areal unit. When mapping the WUI, dasymetric techniques are used to remove areas such as hydrographic features and public lands, unlikely to contain housing units from the US Census blocks. Housing unit density is then recalculated using the original housing unit counts divided by the area of the refined Census block. The removal of areas unlikely to contain housing allows for a more accurate spatial distribution of housing across the Census blocks. Wilmer and Aplet (2005) was one of the first studies to use these methods for mapping the WUI (see Figures 2 and 3).

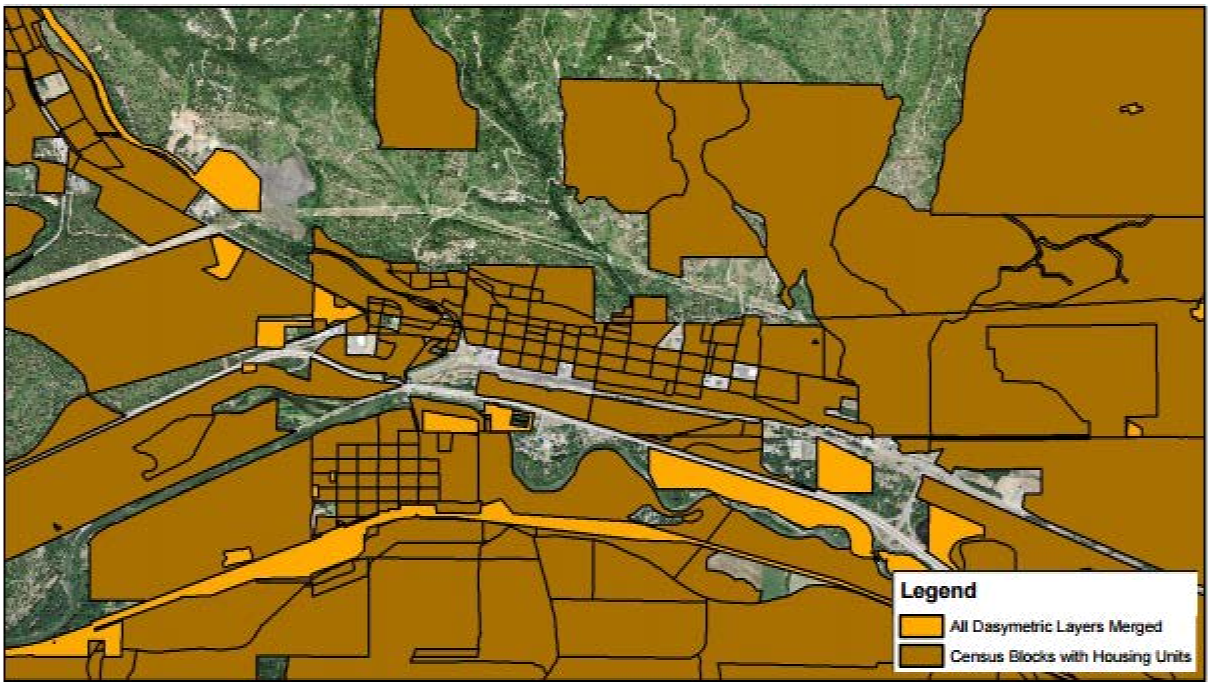

Figure 2: Example of dasymetric layers, to be removed, overlaid upon census blocks (Tully 2013)

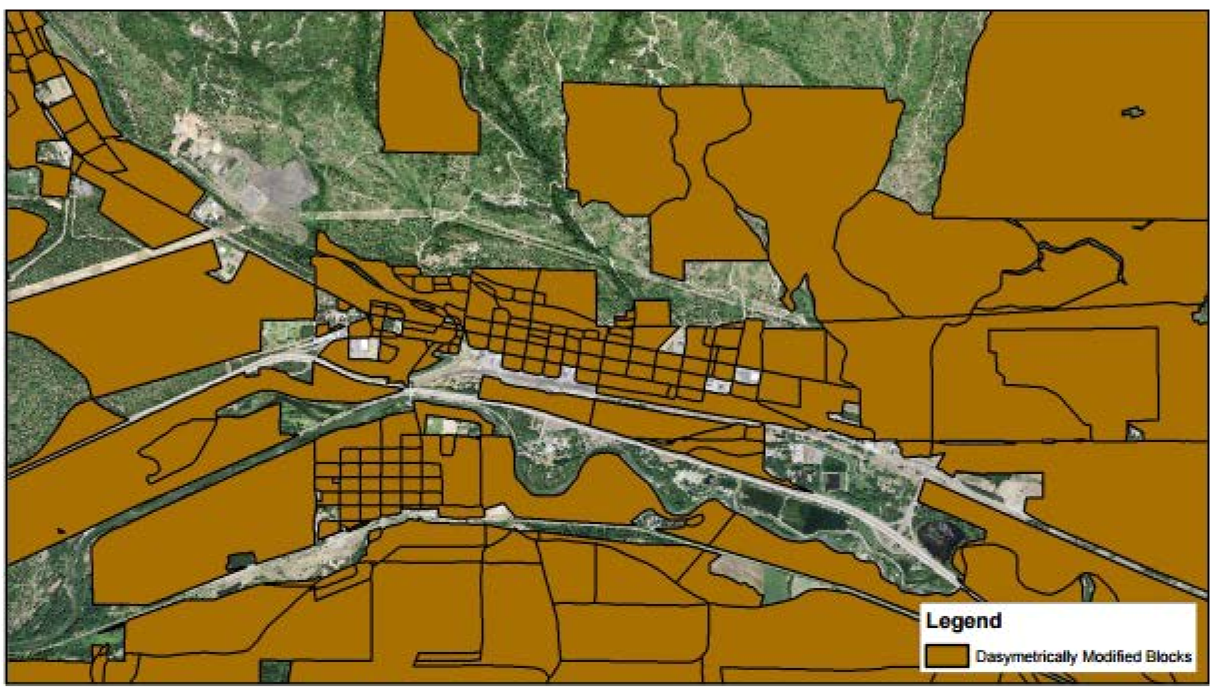

Figure 3: Example of census block after the removal of dasymetric layers (Tully 2013)

In 2003 Congress adopted the Healthy Forest Restoration Act (HFRA). The HFRA helps to protect communities against catastrophic wildfires by allocating federal funding to help reduce fire risk to homes located within a WUI. Specifically, HFRA provides funding for hazardous fuel reduction on federal lands. This is primarily based upon the dangers associated with a wildfire on federal lands spreading to a nearby community. The HFRA prioritizes project funding to communities with a community wildfire protection plan (CWPP). This ensures that local agencies have the opportunity to influence where hazardous fuel reduction projects take place within their jurisdiction.

Since the HFRA provides incentive for communities to establish a CWPP, Wilmer and Aplet (2005) aimed to develop a consistent method for using a GIS to map communities prone to wildfires. Wilmer and Aplet's study sought to define and map an area they refer to as the "community fire planning zone" (CFPZ) in three separate case study areas: The Colorado Front Range, the central Idaho Ecosystem, and the Greater Yosemite area in California. The study built upon earlier models by using a dasymetric mapping approach to remove public lands from the analysis (Schmidt et al. 2002; Aplet and Wilmer 2003; Stewart et al. 2003).

Wilmer and Aplet removed public lands from 2000 Census blocks, recalculated housing density for each block, and then selected those which met the minimum housing density threshold of 1 housing unit per 40 acres. Instead of discriminating between the two WUI categories (intermix and interface), Wilmer and Aplet isotropically buffered the modified census blocks by 0.5 mi in order to encapsulate a community's physical footprint. They then removed non-wildland fuel classes (water, barren, rock, agriculture and urban areas) from census blocks meeting density criteria to approximate the CFPZ. Since the WUI is defined as the developed area intermixed or adjacent to wildland fuels, this decreases the spatial extent of the WUI but retains the CFPZ area. While the study did not map the WUI at a national scale it created a simple method for calculating the CFPZ and WUI by utilizing dasymetric approaches to modify census blocks.

Theobald and Romme (2007) sought to refine previous methods for modelling the WUI (Stewart et al. 2003; Aplet and Wilmer 2003; Wilmer and Aplet 2005; Radeloff et al. 2005) in order to create a more spatially precise map of the WUI within the conterminous Unites States. Expanding upon Wilmer and Aplet's dasymetric mapping techniques (Wilmer and Aplet 2005), Theobald and Romme utilized the USGS's Protected Areas Database (PADUS) to remove public lands and protected areas from 2000 Census blocks. The study also utilized Census hydrography data to remove water features from Census blocks.

Unlike previous works (Stewart et al. 2003; Wilmer and Aplet 2005; Radeloff et al. 2005), the Theobald and Romme buffered blocks that met the minimum housing density threshold of 1 housing unit per 40 acres with a variable-width buffering technique based upon cost-weighted distances of surrounding vegetation types and their probability to spread wildfire. Instead of solely using a uniform buffer, based upon the estimated distance firebrands can travel from the front of a wildfire, this approach creates a more liberal estimation of risk zones (California Fire Alliance 2001). This produced a drastically reduced estimate of the WUI. When compared to the estimates of past studies (Stewart et al. 2003; Radeloff et al. 2005; Wilmer and Aplet 2005). The study used three buffer intervals: 0.5 mi, 0.5-1.0 mi, and 1.0-2.0 mi. These figures are based upon treatment zones for fuel reductions and proactive fire mitigation (Nowicki 2002; Hann and Strohm 2003; and Theobald and Romme 2007).

Theobald and Romme combined 2001 NLCD (30-m resolution) and US Department of Agriculture's (USDA) FUELMAN datasets (1km resolution (Schmidt et al. 2002)) to classify vegetation types within the vicinity of the WUI. In addition, Theobald and Romme (2007) also used 2004 Census TIGER files and road density calculations to weight housing density. Theobald and Romme classified road density into four different types, and then removed areas with the lowest road density classification, on the premise that these areas would not have enough residential development to meet the housing density threshold. The study concluded the WUI comprised 115.1 million acres and contained 12.5 million homes (Theobald and Romme 2007).

Similar to previous approaches Tully used a binary dasymetric approach to remove areas of census blocks assumed to not contain housing units (Wilmer and Aplet 2005; Theobald and Romme 2007); specifically, water features, public and protected lands, and low-road density areas were removed from census blocks (Tully 2013). Housing density was then recalculated based upon the original housing unit count and the modified block area (Tully 2013). The most noteworthy improvement to those of previous efforts was the integration of the USGS LANDFIRE Existing Vegetation Height (EVH) into analysis.

LANDFIRE EVH data allows for a more accurate and precise variable width buffering that is based upon local vegetation types and their height. The zone for firefighter safety can be calculated by creating a linear buffer four times the maximum sustained flame height (Butler and Cohen 1998). Maximum flame height is estimated to be twice the height of existing vegetation (Nowicki 2002; Tully 2013). Tully buffered EVH pixels by a maximum distance of eight times the height of existing vegetation, and then rounded up to the nearest 30-meter pixel. The largest safety zone buffer was 510 meters.

Tully then used a corridor function to create a directional buffer around census blocks meeting the minimum housing density threshold. This allows for an estimated defensible space to be created through the buffering process. This estimation can be used to help clear and reduce wildland fire fuels within or near the WUI. Non-wildland classes were then removed from census blocks; however, community buffers were retained in these areas (Tully 2013). Tully concluded that the 2010 WUI covered 11.79% (227,376,491 acres) of the conterminous United States and encapsulated 48.45% of the total housing units (Table 1).

Table 1: Past WUI studies & their methods

Author	Stewart et al.	Wilmer & Aplet	Radeloff et al.	Theobald & Romme	Tully
Year Published	2003	2005	2005	2007	2013
Housing Density Data	2000 Census	2000 Census modified by removing lands	2000 Census	2000 Census modified by removing public lands, and distributed using road density from 2004 TIGER line files	2000 Census & 2010 Census modified by removing public lands, low road density areas from 2004 & 2010 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	1 housing unit/ 40 acres
Vegetation	NLCD 1992	NLCD 1992	NLCD 1992	NLCD 1992/ FUELMAN 2002	LANDFIRE 1.0.5 (2011)
Resolution	30 meters	30 meters	30 meters	30 meters augmented with 1sq.km. FUELMAN vegetation subcategories	30 meters
Buffer Distance	2.4 km	0.8km	2.4km	0.8-3.22km	4m-510m
Buffer Method	Isotropic	Isotropic	Isotropic	Variable	Variable
Dasymetric Overlays	None	Public Lands	None	Public Lands, Low Road Density Areas	Public Lands, Low Road Density Areas, National hydrography
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	LANDFIRE Existing Vegetation (Herb, Shrub, Forest)
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 Intermix: 1 housing unit per 40 acres, and have more than 50% vegetation	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 Intermix: 1 housing unit per 40 acres, and have more than 50% vegetation	Interface:>1 unit per 2.4 acre (based upon 250 people/sq. mi)and >10 ha patch Intermix: 1 unit per 2.4-40 acres	≥ 1 housing unit per 40 acres
Acres Identified	175,124,915	n/a	177,707,043	115,173,663	215,116,195 (2000) 227,376,491(2010)
Percent of conterminous US	9.3	n/a	9.4%	6%	11.15% (2000) 11.79% (2010)
Housing Units in WUI	42,297,763	n/a	44,348,628	12,500,000	53,269,202 (2000) 63,408,552 (2010)
Percent of housing in conterminous US	36.7%	n/a	38.5%	13%	46.25% (2000) 48.45% (2010)

2.2 The Definition Effect

Although each of the studies operationalize the Federal Register's definitions, subtle differences in purpose, implementation, and approaches result in divergent WUI mapping outputs (Stewart et al. 2009; Platt 2010; Tully 2013). This is more commonly referred to as "the definition effect" (Platt 2010; Tully 2013). While studies may utilize the same datasets and housing density threshold of one housing unit per 40 acres to operationalize WUI definitions differences in purpose can drastically alter the final output (Stewart et al. 2009). For example, Wilmer and Aplet (2005) and Stewart et al. (2005) both use the same US Census data to measure housing and the same National Land Cover Data to characterize vegetation, but their variations in purpose result in different outputs.

While Wilmer and Aplet (2005) and Stewart et al. (2005) use the same datasets and housing density thresholds to map the WUI, their methods are geared towards different objectives. The purpose of the Wilmer and Aplet (2005) study is to identify areas where wildland fuels can be treated; Stewart et al.'s. (2005) focus is to determine where and in which type of WUI housing structures are located. Both methods start by identifying areas that meet the target housing density threshold and then characterize vegetation within or adjacent to the blocks; however, the Wilmer and Aplet (2005) method is primarily concerned with identifying vegetative fuels with the goal of reducing them through wildland fuel treatments (Stewart et al. 2009). Stewart et al.'s (2005) methods seek to quantify the number of housing units within the area in order to aid policymakers in addressing wildfire management policy, in hopes of providing protection to human settlements in hazardous areas. While these small changes in focus may seem insignificant, Stewart et al. (2009) conclude that the Wilmer and Aplet (2005) method results in the classification of double the spatial extent of Stewart et al.'s (2005) method.

Stewart et al. (2009) use the state of California as an example to illustrate the differences in WUI mapping outputs between the methods of Wilmer and Aplet (2005) and Stewart et al. (2005). The large discrepancy between these two models stems primarily from the buffering techniques used to address each respective study's purpose. Wilmer and Aplet (2005) use a 0.5mi buffer based upon the HFRA definition for treating wildland fuels outside of the CFPZ, while Stewart et al. utilize the National Fire Plan's (2001) 1.5 mi buffer, which is based upon the estimated distance a firebrand can be carried by wind. Wilmer and Aplet (2005) first buffer the CPZ and then utilize a pixel-by-pixel retention approach, which only removes individual 30-meter pixels in nonvegetated areas after the initial buffer has already been completed. Conversely, Stewart et al. (2005) excludes Census blocks that do not meet their operational definition of 50% wildland vegetation. These two seemingly subtle differences result in Wilmer and Aplet's (2005) method having twice as much WUI for the state of California (Figure 4).

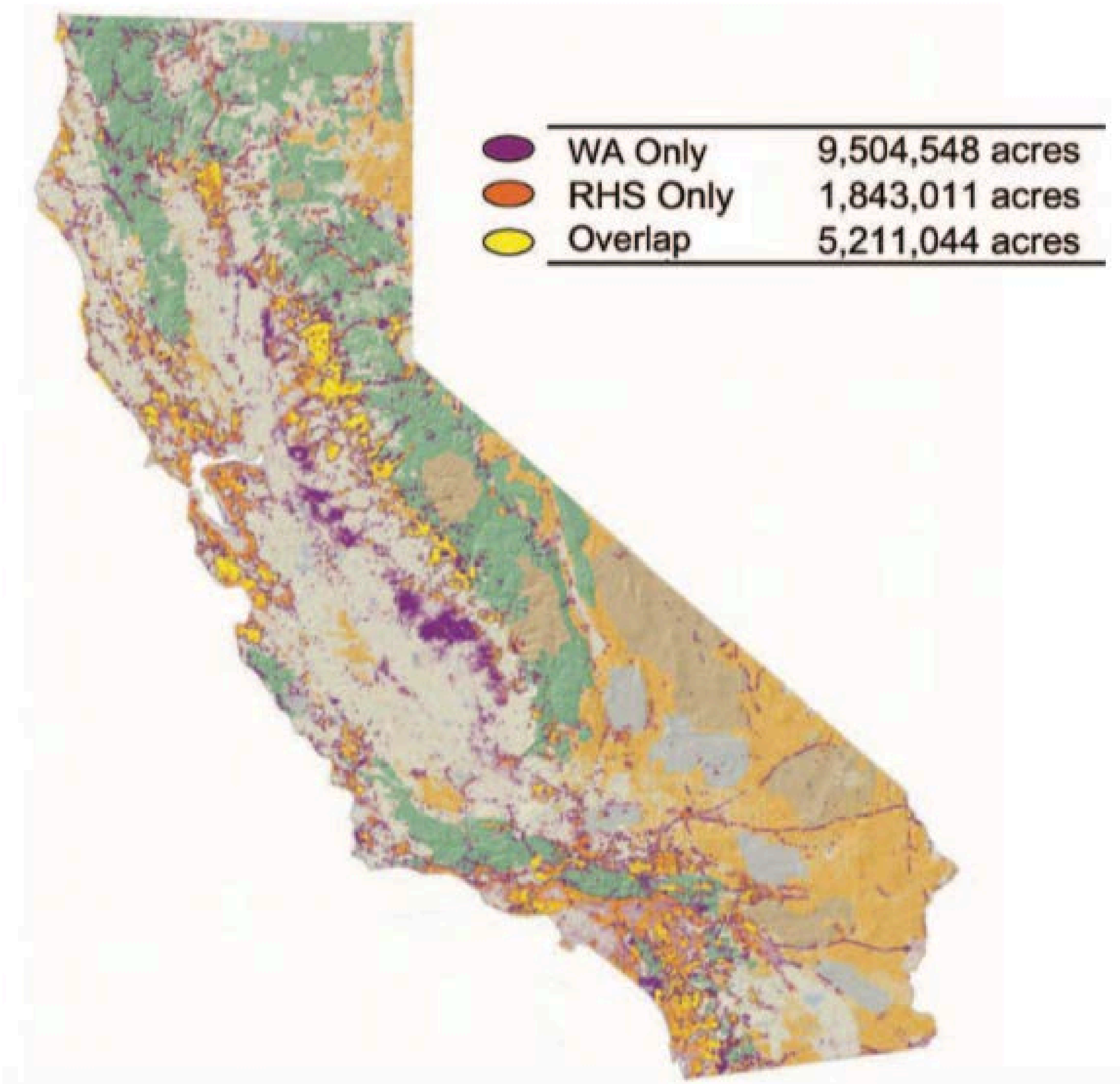

Figure 4: Comparison of result of Wilmer & Aplet (2005) and Stewart et al. (2005) (Source: Stewart et al. 2009)

Density thresholds are another critical component that often results in large discrepancies between models. Densities also revolve around interpretation of various WUI definitions in accordance to the focus of the study. Density can be measured for several WUI attributes such as population, vegetation, and housing; slight changes in the distribution of any of these can drastically alter the extent of the WUI. For example, previous studies have excluded entire Census blocks not meeting 50% vegetation density criteria (Stewart et al. 2003, Stewart et al. 2005, Radeloff et al. 2005); this results in an underestimation of the spatial extent of the WUI. In a similar fashion, Theobald and Romme (2007) used the Federal Register definition of 250 people per square mile instead in lieu of the housing density threshold of 1 housing unit per 40 acres for calculating the interface WUI. Furthermore, the study added the parameter that the interface area has to comprise a minimum of 10ha (24.7 acres) to promote clustering and eliminate isolated islands of WUI. This is problematic to many rural towns adjacent to wildland fuels that do not meet the population density; when small communities are excluded, based upon density parameters, it exponentially decreases the likelihood that these communities will receive federal assistance for fuel treatments.

2.3 Summary

Discrepancies between WUI mapping outputs are largely based upon the wide variety of definitions of the WUI. The variety in methods exists because maps vary with purpose and the intended audience (Stewart et al. 2009). It also demonstrates the elusiveness of the WUI. Because methods differ with purpose, no one single method can be all-encompassing when measuring the WUI. Therefore, each mapping approach should explicitly state the problem being addressed, the methods used, and the limitations of the datasets; this is especially true when the results have the power to shape policy.

CHAPTER 3: METHODS AND DATA

This study proposes a method for measuring the spatial extent of the WUI as part of a larger effort to assess how the WUI in Lassen County has changed from 2000 – 2015. Additionally, the study utilizes county cadastral data to digitize housing unit location, to measure the number of homes located in and out of the WUI. The digitized points representing housing structures were overlaid upon the Lassen County CAL FIRE Fire Hazard Severity Zone Map in order to get an accurate assessment of the WUI from a fire hazard standpoint.

3.1 Method Framework

The proposed method uses county cadastral data to locate residential parcels to map housing units in their actual geospatial location. This approach allows for a more accurate and precise estimate of the WUI. Use dwelling locations also negates the need to disaggregate Census blocks. The following workflow will be used to assess the WUI: 1) Locate residential parcels by running a query of assessor land use codes; 2) Create residential parcel layer from selected features in parcel layer; 3) Convert residential parcel polygons to centroids and then locate points to home location; 4) Buffer homes by 0.5 miles (HFRA 2003; Wilmer and Aplet 2005); 5) Remove non-wildland fuel types (water, rock, barren, agriculture, urban land cover classes) (Wilmer and Aplet 2005); 6) Compare extent of WUI and locations of homes to CAL FIRE hazard maps; 7) Compare extent of WUI with land ownership types; 8) Compare extent of WUI to fire responsibility areas.

3.1.1 Output Products

The proposed workflow will yield both feature datasets and tabular data. Together, these output types will be used to frame the scope of the relation between human settlements and areas prone to wildfire. Feature datasets will be used to create a series of maps that illustrate the spatial extent of the WUI in 2000 and in 2015, the location of housing structures in relation to the WUI, and the relation between WUI, residences, and fire hazard severity zones. These maps will then be used to make a variety of comparisons, the most important of which will be to assess the differences in using conventional WUI measurements versus the measurements of a structure-based approach to fire hazard. The study will also quantify multiple features.

Tabular data will provide a wealth of information to local government agencies including planning and emergency service departments. Data tables will be used to quantify the number of acres and houses within and outside of the WUI, detail how those numbers have changed temporally since 2000, and provide an assessment of fire risk across the county. The tabular data will also assess housing structures hazard to wildfires, by providing numerical counts for housing in moderate, high, and very high fire hazard areas. The generation of both graphics and tabular data for analysis will rely heavily upon cadastral data.

3.1.2 Data Sources

Parcel data, acquired from the Lassen County Assessor Office, are integral to identifying the location of residential parcels and housing structures within the county. The cadastral data along with parcel ownership data was used to improve upon conventional modeling approaches for mapping the WUI (Stewart et al. 2003; Radeloff et al. 2005; Wilmer and Aplet 2005). Together, these two sets of data will be used to identify the location of all residential parcels and then digitize the location of housing structures on a parcel.

The ArcGIS tools critical to achieving this workflow (see Appendix A) are “select-by-attribute”, “select-by-location”, “join”, “buffer”, “summarize”, “reclassify”, “combine”, “zonal geometry to table”, “extract mutli values to points”, and “feature to raster.” The join tool joins features with features and/or tables by a shared attribute value. The assessor parcel data will be joined with parcel ownership data by the assessor parcel number (APN); this unique number is associated with only one parcel and is assigned by the tax assessor for record-keeping and identification purposes. The "select-by-attribute" tool selects objects and/or features based upon specific attribute values. The "select-by-location" tool features from a target layer based upon their spatial location to features within a source layer. The "summarize" tool generates an output summary table that provides various statistical calculations on attribute information such as counts, averages, and minimum and maximum values. Once converted to raster format using the feature to raster tool, raster will be reclassified. The WUI rasters will then be combined with other rasters using the "combine" tool in order to assess the spatial relationship of WUI to other layers. "Zonal geometry to table" will then be used to calculate the area of each raster value. "Extract multi values to points" can then be used to quantify the number of homes in each of the various raster values.

3.2 Data Selection

The data necessary for completing the study were acquired from multiple governmental agencies (Table 2). The data used for this study include: NLCD land cover data (USGS 2001, 2011), parcel data (Lassen County Assessor Office 2015), parcel ownership information table (Lassen County Assessor office & CREST database 2015), BLM land ownership types and perennial water bodies. With exception of the data sourced from Lassen County agencies, all data for this study are free and easily accessible through digital downloads. All Lassen County datasets were sourced from the Planning and Building Services Division's drives.

Table 2: Datasets and Sources

Dataset	Source	Target Variables	Spatial Resolution	Temporal Resolution
Lassen County Roads	Lassen County Public Works	Road networks	County of Lassen	2004
NLCD	US Geological Survey	Land cover for vegetation identification	County of Lassen	2001 2011
Lassen County Assessor Parcels	Lassen County Assessor Office	Residential Parcels	County of Lassen	June 2015
Parcel Ownership Information	Lassen County Assessor Office & Crest Database	Assessor land use codes (table will be joined with parcel layer)	N/A	June 2015
World Imagery	esri	Will be used to hand digitize parcels	Global	Compilation
Fire Hazard Severity Zones	CAL FIRE	Severity Zones	County of Lassen	2007
Fire Responsibility Areas	CAL FIRE	Fire Responsibility Areas	County of Lassen	2008
Land Ownership Types	BLM	Will be used to identify the various agencies and governments that comprise the county	California	2012

3.2.1 Residential Parcels

This study proposes an improvement to past WUI mapping approaches by utilizing cadastral parcel data to temporally assess the change in the spatial extent of the WUI from 2000-2015. This study uses Wilmer & Aplet's (2005) methods for identifying the CFPZ as a means for mapping the WUI. A dasymetric approach will be used to isolate all residential parcels in order to eliminate the areas where housing does not exist (Wilmer & Aplet 2005; Theobald and Romme 2007; Tully 2013). This improves upon conventional WUI mapping methods by identifying the exact location of residential parcels, instead of redistributing housing units across refined Census blocks by removing land where housing is assumed not to exist.

Once the CREST parcel ownership table is joined with the assessor parcel layer, using the APN as the join field, a query can be conducted utilizing the "select-by-attribute" tool. A query expression was built which identifies all assessor use codes to select all residential parcels. Use codes help the Assessor to describe the different land uses occurring on a parcel for tax purposes and land value assessments (Table 3). The selected parcels were used to create a new layer, "Residential Parcels".

Table 3: Lassen County Assessor Use Code Index

LASSEN COUNTY USE CODES

Position 1 Primary Use	Position 2 Primary Descriptive	Position 3 Secondary Use	Position 4 Secondary Descriptive
A - Agriculture (econ.unit)	A - Agriculture	A - Agriculture (econ. Unit)	A - Condominium
B - Agriculture (non-econ.)	B - Bank	B - Agriculture (non-econ.)	B - Lassen I.C.
C - Commercial	C - Church	C - Commercial	C - Church
E - Williamson	D - Diversified	E - Open Space Contract	D - Diversified
G - Governmental (public schools, govt'l agencies)	E - Retail Outlet &/or Svc. Shop	I - Indurtrial	E - Retail Outlet &/or Svc. Shop
I - Industrial	F - Food Service/ Restaurant, bar, etc.	M - Multiple Use	F - Food Service/ Restaurant, bar, etc.
J - Governmental	G - Grazing	N - Reslcential	G - Grazing
M - Mobile Home Park	H - Hotel/Motel	P - Parking	H - Hotel/Motel
N - Residential	J - Garage/Auto Sales	R - Recreational	J - Garage/Auto Sales
O - Non-Renewal (Out)	K - Dry Farm	U - Undefined	K - Dry Farm
R - Recreational	L - Manufacturing &/or Light Industrial	X - Placenolder	L - Taxable Timber
S - Site Recreation	M - Misc. Improvement	Y - Institutional	M - Timber & Grazing
T - Mobile Home/ Trailer Site	N - Diversif. Com'l	0 - Appropriate	N - Hunting Club/Rights
TPZ Timber Preserve	O - Clubs & Fraternal	1 - (1's or 10's	P - Petroleum-whlse.
Y - Institutional	P - Petroleum-whlse.	2 - places)	Q - Quarry/gravel
U - Undefined	Q - Quarry	3 -	R - Review
Z - Not Assessed	R - Irrigated Crop	4 -	S - School
999 - Manufactured Home	S - Service Station	5 -	T - Timber Site
	T - Timber	6 -	X - Placeholder
	U - Uninhabitable/ Unfinished res	7 -	Y - Leasehold
	V - Vacant	8 -	Z - Professional Office
	W - No SW charge Imps	9 -	0 - Appropriate
	X - Placeholder		1 - (1's place)
	Y - Aircraft related		2 -
	Z - Professional Office		3 -
	1 - Single Res		4 -
	2 - Two Units		5 -
	3 - Three Units		6 -
	4 - Four Units		7 -
	5 - Five Units		8 -
	6 - Six Units		9 -
	7 - Seven Units		
	8 - Eight Units		
	9 - Nine Units		
	* For less than 10 houses always use this column		

Position 5 Primary Use	Position 6 Secondary Descriptive
M - MH secured to land	1 - One MH
	2 - Two MH's
	3- Three MH's
	9- MH Other

PARCEL TYPES

01	Exempt Property
02	Common Area for Condo or Subdivision
03	State Assessed Williamson Acts
05	Low-Value Exempt (<5001)
09	Manufactured Home Secured to Land
10	Secured Ordinary
11	Williamson Act Land
12	TPZ (Timber Preserve)
13	Special Factor
14	FBYV on Williamson Act
15	65% FBYV on Williamson Act
16	Assessed Mineral Rights
18	Future Wil. Act Non-Renewals (Protested)
19	General Proposition 8 (Decline in Value)
99	Split Parcel to be Deleted

EXEMPTION CODES	EX. CLAIM FORM TYPE
10 Homeowners	
20 School	S
40 Welfare	W
50 Religious	R
60 Church	C
80 Disabled Veterans	D

MH = Manufactured Home

"EFSA" = Williamson Farmland Securities Act ("E1SA" = Residence on Property)

After creating the residential parcel layer, housing was digitized for each parcel using aerial imagery and the assessor database. Housing density was not factored into this study for two reasons: 1) the distribution of housing was known 2) this study uses the definition that WUI occurs where development is intermingled or adjacent to wildland fuels. The need to utilize Census block layers is negated entirely by creating residential parcel and housing layers. The majority of past studies were conducted at the national level, a complete dataset of the conterminous US were necessary; this is why the US Census blocks were chosen. Census blocks are comprised of arbitrary boundaries and increase the modified aerial unit problem (MAUP). MAUP makes it appear as if housing is evenly distributed across the Census blocks, while a cadastral-based approach gives the exact parcel location.

3.2.2 Housing Structures as Points

The US Census does not account for all housing structures within Lassen County, this study generated its own count by digitizing housing structures as points. The residential parcels will be converted to centroids using the "feature-to-point" tool. Centroids were then digitized, by moving the centroids over the residence location using aerial imagery (see Figure 5, 6, and 7).

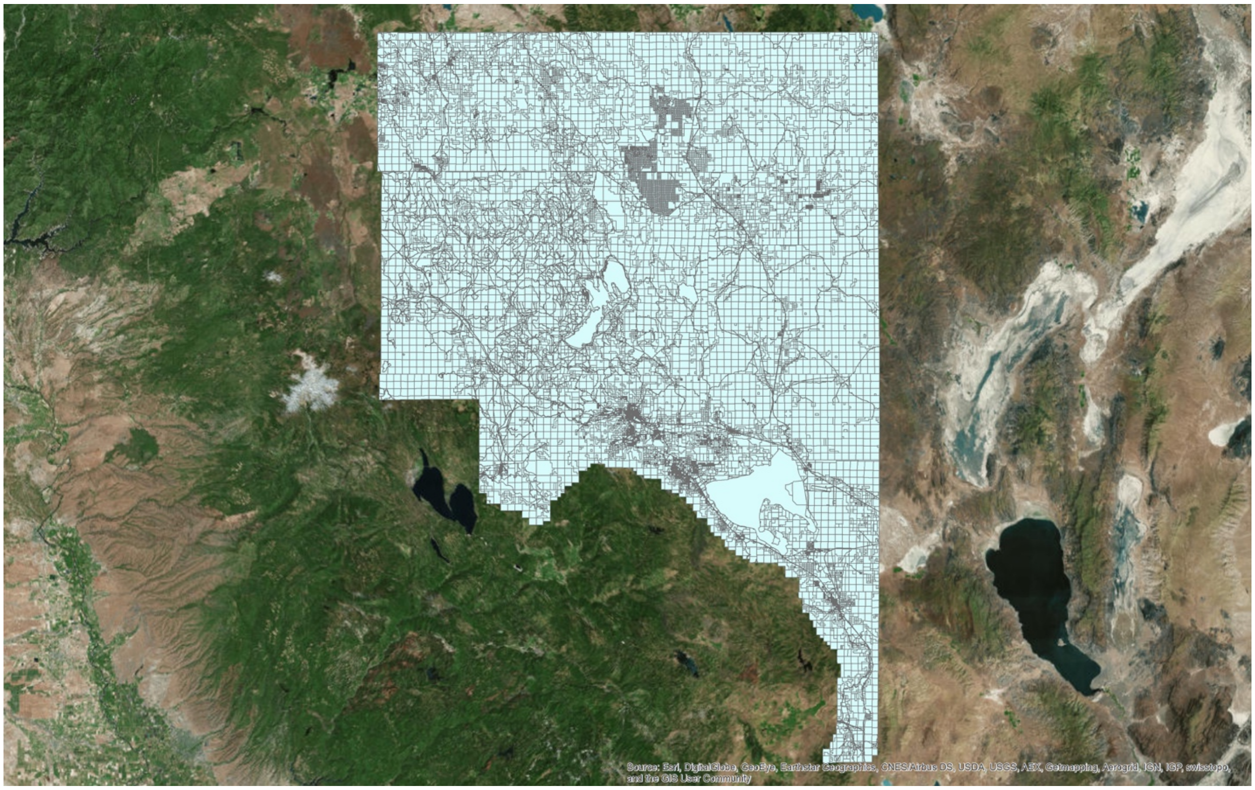

Figure 5: Lassen County Assessor Parcels (2015).

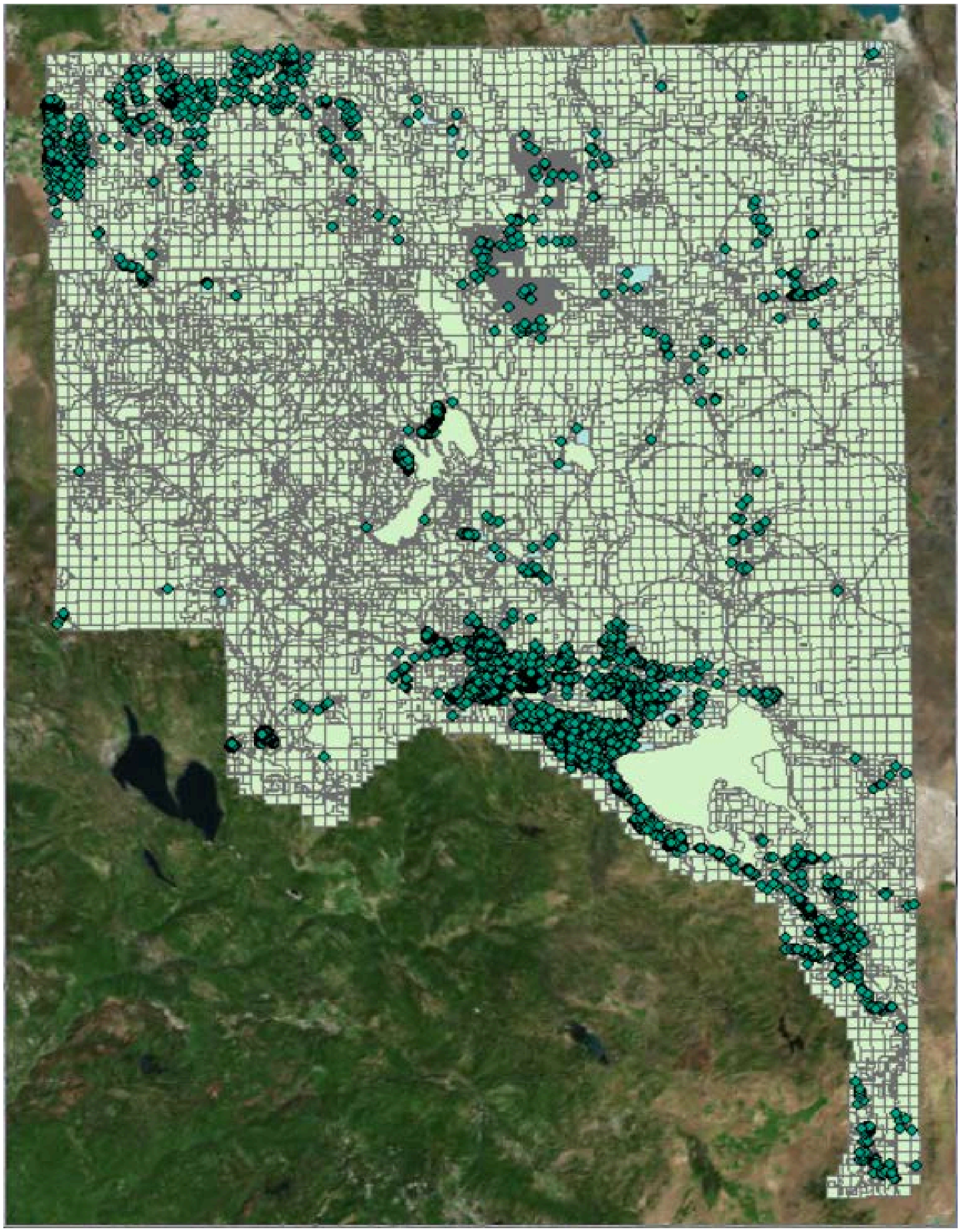

Figure 6: Residential parcels converted to centroids.

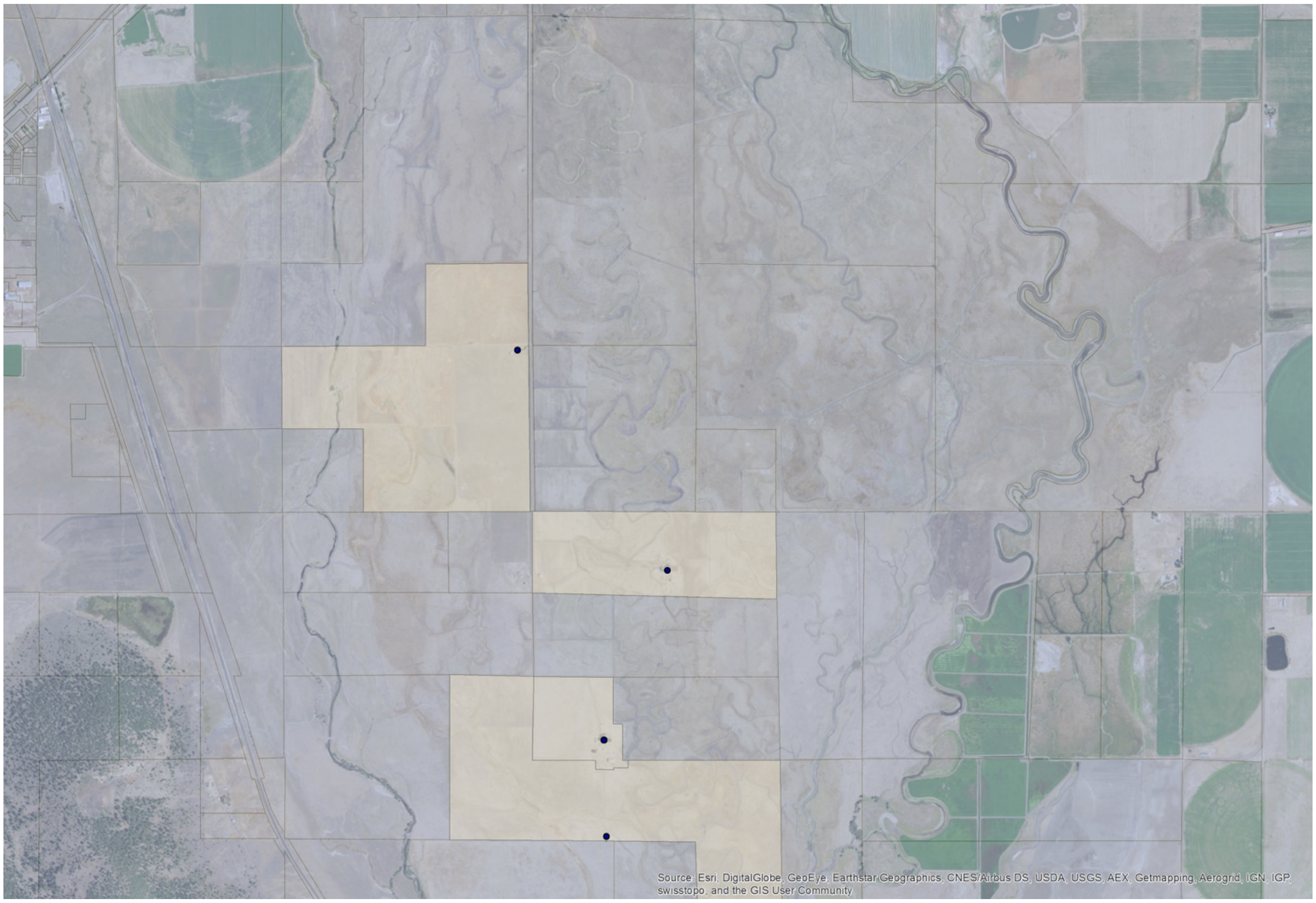

Figure 7: Digitization of houses as points. Centroids moved to location of residence.

The assessor use codes provide the number of residences per parcel. Parcels with more than one housing structure have multiple points, representative of each residence. There are a few limitations associated with this approach.

Aside from the amount of time it takes to hand digitize all of the housing, there are a few issues and limitations that must be addressed. This study only digitizes housing units, because the assessor does not keep a numerical count of structures on the property; this will also significantly reduce the time digitizing. When the residence cannot be delineated between other structures, the point was placed in between the structures in question. When tree cover is too thick to identify the residence location the point remained a centroid. The final key issue is that the Lassen County Assessor's Office does not keep annual legacy files for their parcel database or GIS system.

The mapping of residential parcels in the year 2000 requires slightly more effort since the Assessor's Office does not keep legacy files for each year. The Lassen County Planning and Building Services Department keeps a record of permits for all new residences constructed or placed within the county. This information is organized by a parcel's APN. The record also shows whether a previous residence was replaced by a new one. A report of all homes built or placed from January 2000 to June 2015 was generated in order to remove residential parcels created after 2000.

All APNs, listed in the generated permit report, were then selected using the "select-by-attribute" tool. The selected features were then copied to create a new layer that shows the growth of residential parcels in the county. The 2015 residential layer was then copied and duplicated; the same selected features were removed from one of the 2015 layers, which yielded all residential parcels as of January 1, 2000. This is beneficial to the study as it allows the same parcel-based approach to calculate a historic change in WUI from 2000-2015. It also shows the number of homes constructed within the WUI in the same timeframe.

3.2.3 Calculating the WUI

All homes were buffered by 0.5 mi (HFRA 2003; Wilmer & Aplet 2005) (see Figures 7 & 8). Many other studies use a 1.5 mi buffer that is based upon the estimated distance a firebrand can travel, which can result in ignition; however, this tends to overestimate the WUI. The 1.5 mi buffer should be used in areas of steep topography and thick vegetation, both of which have the potential to create particularly hazardous conditions (HFRA 2003). These buffers do not endorse the clearing of a 0.5 mi area around all residential parcels and communities; rather, they denote the areas where the community and governmental agencies should focus their attention in order to create a defensible space and proactively reduce wildfire risk (Wilmer & Aplet 2005). After the 0.5 mi buffers have been rendered for each residential parcel layer, they were converted to 30-meter raster layers and non-wildland vegetation types were removed.

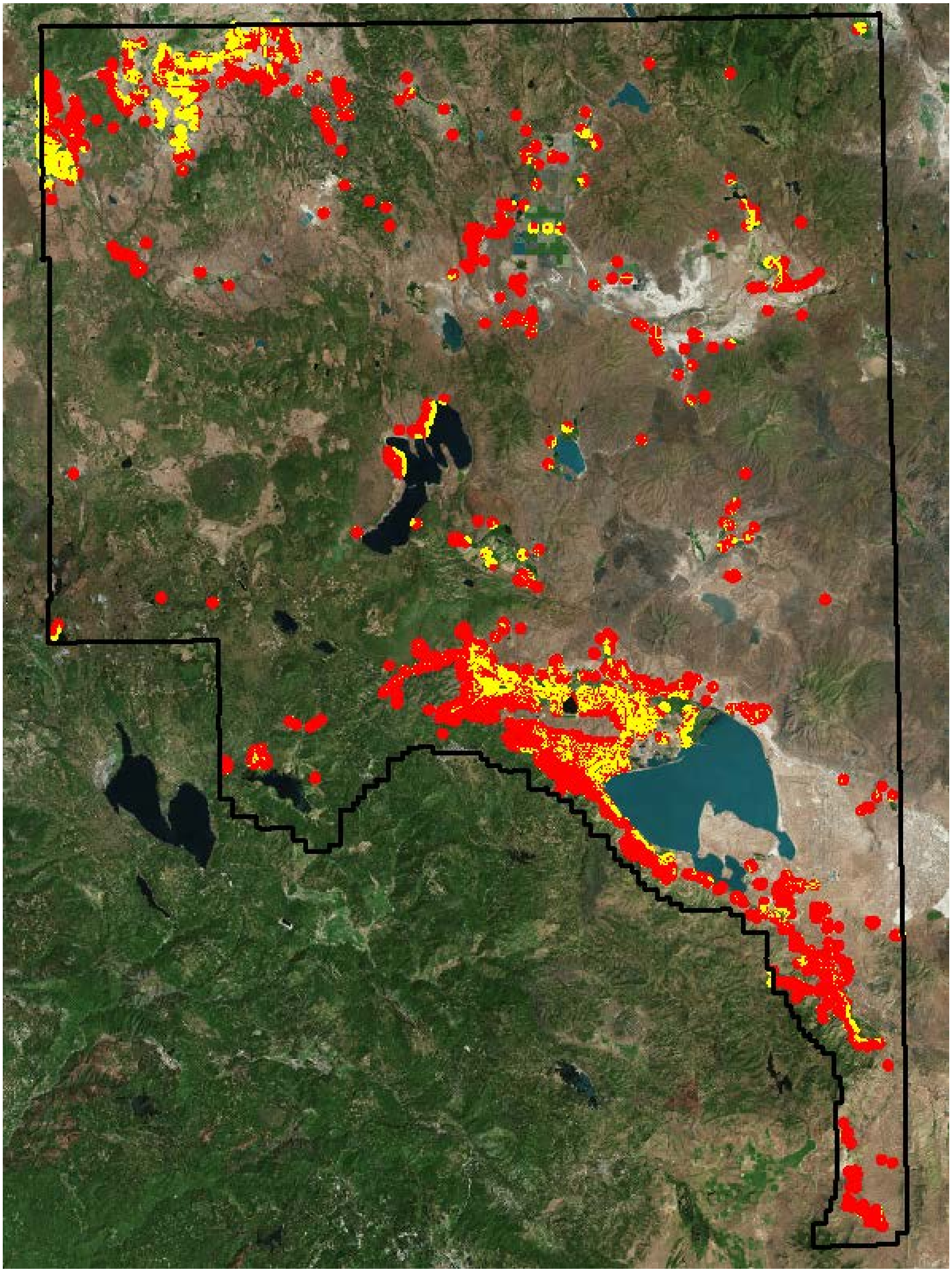

Figure 8: 2000 housing stock buffer (0.5mi) in yellow. 2000 WUI in red (after removal of non-wildland fuels)

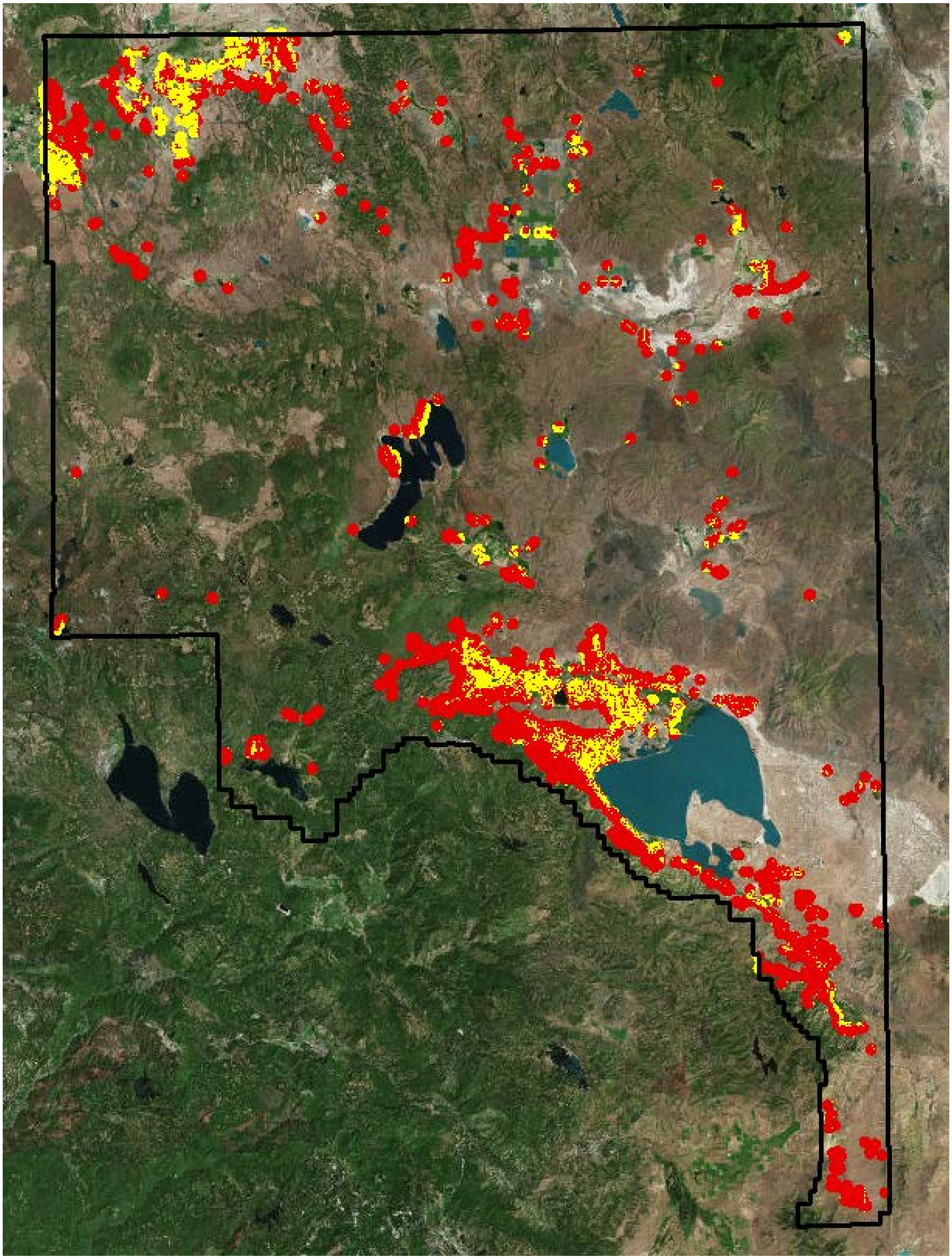

Figure 9: 2015 housing stock buffer (0.5 mi) in yellow. 2015 WUI in red (after removal of non-wildland fuels)

3.2.4 Removal of Non-Wildland Fuel Types

The 2001 and 2011 USGS's NLCD land cover datasets were used to examine vegetation cover within the study area. The classes of vegetation to be categorized as non-wildland fuel types are as follows:

> Class 11 (open water), 12 (perennial ice/snow), 22 (developed, low intensity), 23 (developed, medium intensity), 24 (developed, high intensity), 31 (barren land: rock/sand/clay), 81 (pasture/hay), and 82 (cultivated crops) (Radeloff et al. 2005; Wilmer & Aplet 2005).

Vegetation types categorized as wildland fuels will be weighted a "1" and non-wildland fuel types will be weighted a "0". Non-wildland classes were then removed (Wilmer & Aplet 2005; Tully 2013).

3.3 Wildfire Hazard Assessment

Once the WUI was defined and non-wildland fuel classes had been removed, CAL FIRE's Lassen County Fire Hazard Severity Zone map was overlaid. The map has three zone types: moderate, high, and very high hazard severity. These were weighted 1, 2, and 3 respectively. The number of homes within these zones was then quantified. Percentage of homes, private versus public lands, and the number of homes in and out of WUI were all calculated for each zone using the "summarize" and the "extract multi values to points" tools. This allowed for a number of comparisons to be made between a conventional WUI measurement and hazard based measurement.

3.4 Software and Hardware Used

-esri ArcGIS 10.3.1

-VMWare Horizon Client

-Apple iMac

- -2.0 GHz Intel Core i5
- -16 GB RAM 1600 MHz DDR3
- -OS X Yosemite, Version 10.10.5

-Apple MacBook Pro

- -2.9 GHz Intel Core i7
- -8GB RAM 1600 MHz DDR3
- -OS X Yosemite, Version 10.10.5

-hp desktop

- -Intel Core i3-3220 CPU at 3.30 GHz
- -4GB RAM
- -Windows 7 Enterprise 32-bit Operating System with Service Pack 1 installed

CHAPTER 4: RESULTS

The goal of this study was to develop a cadastral-based measurement technique for locating and analyzing spatial change in the WUI. The identification and location of residential parcels throughout the county is integral to gathering the precise location of the WUI and is a major improvement over previous studies as it eliminates the need to estimate where housing exists. Digitization of housing structures is another logical improvement as it not only provides the location of the structure(s), but also enables multiple opportunities for analysis through location and quantification.

This chapter reviews the lessons learned from the utilizing a cadastral-based approach for measuring the WUI. The results include the spatial extent of the WUI in the years 2000 and 2015. The 2000 and 2015 WUIs and housing stocks were then combined with other layers (land ownership types, fire responsibility areas, and CAL FIRE fire hazard severity zones) in order to analyze their relationships and measure change. Maps were then created to illustrate the spatial location of the WUI in comparison to these layers.

4.1 Residential Parcel Identification

As mentioned in Chapter 3, Lassen County Assessor land use codes were used to identify residential parcels within the study area. A total of 10,195 residential parcels were identified. Together, with the assessor database and aerial imagery, homes were then digitized as points. There were 11,019 homes digitized; these homes comprise the 2015 housing stock for the study. A list of all building permits issued for the construction or placement of new homes, by the Lassen County Planning & Building Service Department, from January 1, 2001 to June 2015 was generated. These homes and/or parcels were removed from the 2015 housing stock using the assessor parcel number (APN). The new selection was then used to create a 2000 residential parcel layer and 2000 housing stock layer. There were 9,360 residential parcels and 10,120 homes. The two housing stock layers were the foundation for determining the WUI.

4.2 Analyzing the WUI

Once all of the homes were located and digitized, they were buffered by .5 mi, based upon the HFRA recommendation (HFRA 2003). The buffers were then dissolved to merge overlapping geometry from the buffers created for each home. The buffer layers were then converted to 30-meter rasters and combined with the reclassified land cover rasters to remove the buffered areas not containing wildland fuels, using the "Combine" tool (Wilmer & Aplet 2005). The "Zonal Geometry to Table" tool was then used to calculate the spatial extent of the 2000 and 2015 WUIs.

The spatial extent of the 2000 WUI was 961.08 sq. km. (371.08 sq. mi.) and accounted for 96,108.01 hectares (237,488.06 acres) or 7.86% of the study area. Unsurprisingly, the WUI grew proportionately with the number of new homes placed in the county over 15 years. The spatial extent of the 2015 WUI was 1,016.67 sq. km. (392.54 sq. mi) and accounted for 101,666.68 hectares (251,223.83 acres) or 8.32% of the study area. The spatial extent of the WUI grew by 0.057 %, 55.59 sq. km. (21.46 sq. mi.), or 5,558.68 hectares (13,735.77 acres) from 2000-2015. Most of this growth can be attributed to the 899 homes placed in low density regions of the county. Most of the growth was seen in the northern region and in the satellite communities in close proximity to Susanville (Figure 10).

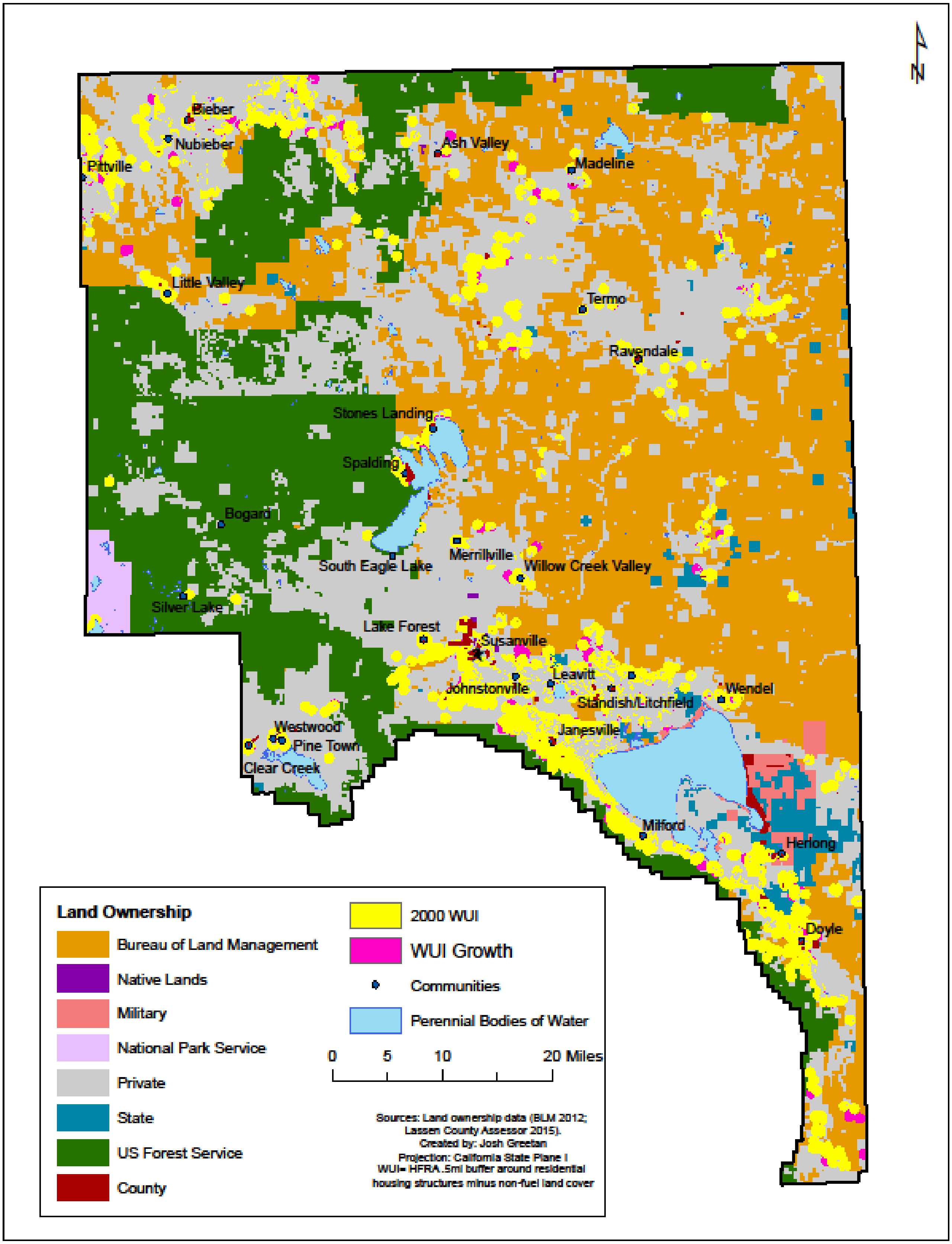

Figure 10: Change in WUI 2000 -- 2015

4.3 Land Ownership

It is important to differentiate between the types of land ownership where the WUI occurs in order to identify who is responsible for proactively treating fuels within the area. Although the majority of WUI is typically located on private property, it can also extend into public lands. WUI on public lands is usually attributed to the buffers extending into these property types, but can also result from private housing on or surrounded by public lands. Lassen County fits this typical WUI profile.

In 2000, 78,503.43 hectares (193,985.94 acres) or 81.70% of the WUI was located on private lands, 10,833.79 hectares (26.770.85 acres) or 11.27% on lands managed by the Bureau of Land Management (BLM), 3,789.43 hectares (9,363.88 acres) or 3.94% on U.S. Forest Service lands, and the remaining 2961.24 hectares (7317.38 acres) or 3.09% spread over county, native, National Park Service (NPS), and federal military lands. These numbers changed minimally over the 15 year time frame for the study. In 2015, 82,504.39 hectares (203,872.51 acres) 81.17% of the WUI was located on private lands, 12,096.76 hectares (29,891.69 acres) 11.90% on BLM lands, 3,974.38 hectares (9,820.90 acres) 3.91% on Forest Service lands, and the remaining 3,069.84 hectares (7,585.74 acres) or 3.02% distributed through county, native, NPS, and federal military lands (see Table 4 and Figure 11).

Table 4: Changes in WUI land ownership acreage 2000- 2015

Land Ownership	WUI Acreage 2000	% of total acreage	WUI Acreage 2015	% of total acreage	Change from 2000-2015 (acres)	Percent Change
Private	193,985.94	81.70%	203,872.51	81.27%	9,886.57	5.10%
County	231.27	0.10%	243.88	0.10%	12.61	5.45%
BLM	26,770.85	11.28%	29,891.69	11.90%	3120.84	11.66%
U.S. Forest Service	9,363.88	3.94%	9,820.90	3.91%	457.02	4.88%
National Park Service	775.93	0.33%	770.37	0.31%	-5.56	-0.72%
State	4,197.46	1.76%	4,389.38	1.75%	191.92	4.57%
Native	797.93	0.34%	788.81	0.31%	-9.12	-1.14%
Military	1,314.79	0.55%	1,393.30	0.55%	78.51	5.97%

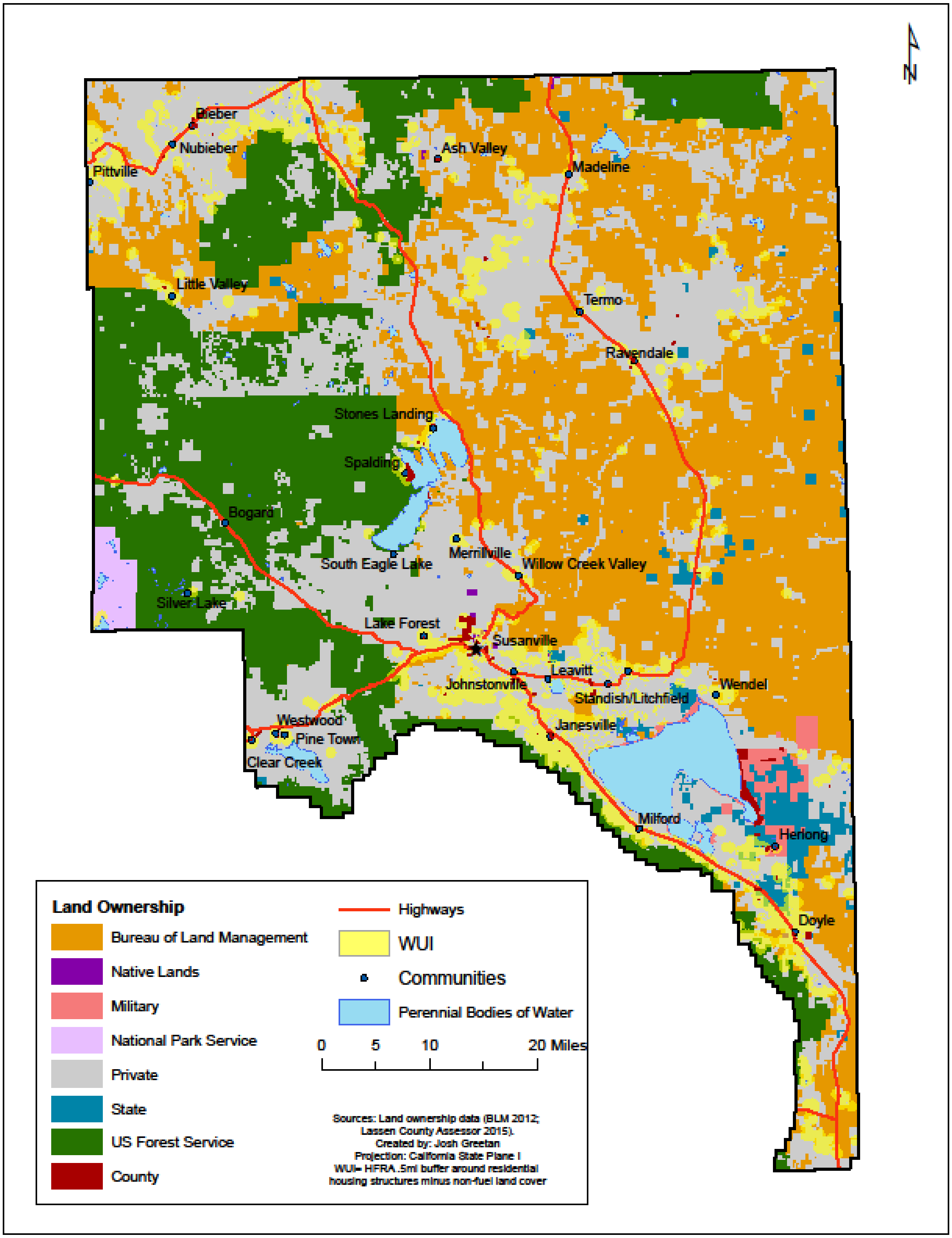

Figure 11: 2015 WUI and land ownership

4.4 Residential Structures

Although digitization of the housing as points is labor intensive, the housing stock datasets allow for multiple analyses to be conducted. Specifically, the study was able to quantify the number of housing structures in relationship to the 2000 & 2015 WUIs, designated fire agency responsibility areas, and CAL FIRE fire hazard severity zones (CAL FIRE 2007). The "Extract Multi Values to Points" tool was used to quantify the number of houses in each of the various layers. In 2000, 4,819 residential structures (47.62%) were located within the WUI. Out of the 899 new homes placed within the county from 2000-2015, 637 homes (70.86%) were placed in existing WUI or near wildland fuels, which resulted in the expansion of the WUI. The total number of residential structures located within the WUI, in 2015, was 5,456 (49.51%), which resulted in an increase of 13.22% from 2000.

4.4.1 Fire Hazard Severity Zones (FHSZ)

The study used a method which focuses on identifying wildland fuels in close proximity to housing in order to prioritize treatment in these areas (Wilmer & Aplet 2005; Stewart et al. 2009). The model does not calculate fire hazard however, which makes it difficult to determine which communities are in most need of fuel treatment and resource allocations. In 2007, CAL FIRE calculated fire hazard severity zones for the entire state. Their models factor in numerous variables such as fire history, existing and potential fuels, flame length, firebrands, topography, and average weather patterns by region, in order to provide an independent estimate of fire hazard for each county (CAL FIRE 2007). The integration of this data supplements the study by quantifying the number of homes in each zone in 2000 and 2015. This data also identifies which hazard zones the communities and the WUI are located in.

In 2000, 2,024 homes were located in a “Very High” hazard zone, and 1,569 of these structures were also found in the WUI (77.52%). 1,837 residential structures were located in “High” zones, 726 (39.52%) of which were in the WUI. 3,327 were located in zones classified as “Moderate”, 1,950 (58.61%) of which were in the WUI. The number of homes in each of these zone classifications increased through 2015 (Table 5). In 2015, there were 2,299 homes in “Very High” zones, 1,984 homes in “High” zones, and 3,714 in “Moderate” zones. The number located in a WUI also increased in each of these three zones (Figures 12).

Table 5: Number of homes within each FHSZ from 2000-2015

Fire Hazard Severity Zones	# of Homes in WUI (2000)/ % of total homes per zone	Total # of Homes (2000)	# of Homes in WUI (2015)/ % of total homes per zone	Total # of Homes in WUI (2015)	% increase in WUI	% increase total
Very High	1,569 (77.52%)	2,024	1,786 (77.69%)	2,299	13.83%	13.59%
High	726 (39.52%)	1,837	829 (41.78%)	1,984	14.19%	8.00%
Moderate	1,950 (58.61%)	3,327	2,245 (60.45%)	3,714	15.13%	11.63%
Non-wildland /Non-urban	435 (48.49%)	897	460 (46.61%)	987	5.75%	10.03%
Urban/Unzoned	139 (6.83%)	2,035	136 (6.68%)	2,035	-0.02%	0.00%
TOTAL	4,819 (47.62%)	10,120	5,456 (49.51%)	11,019	13.21%	8.88%

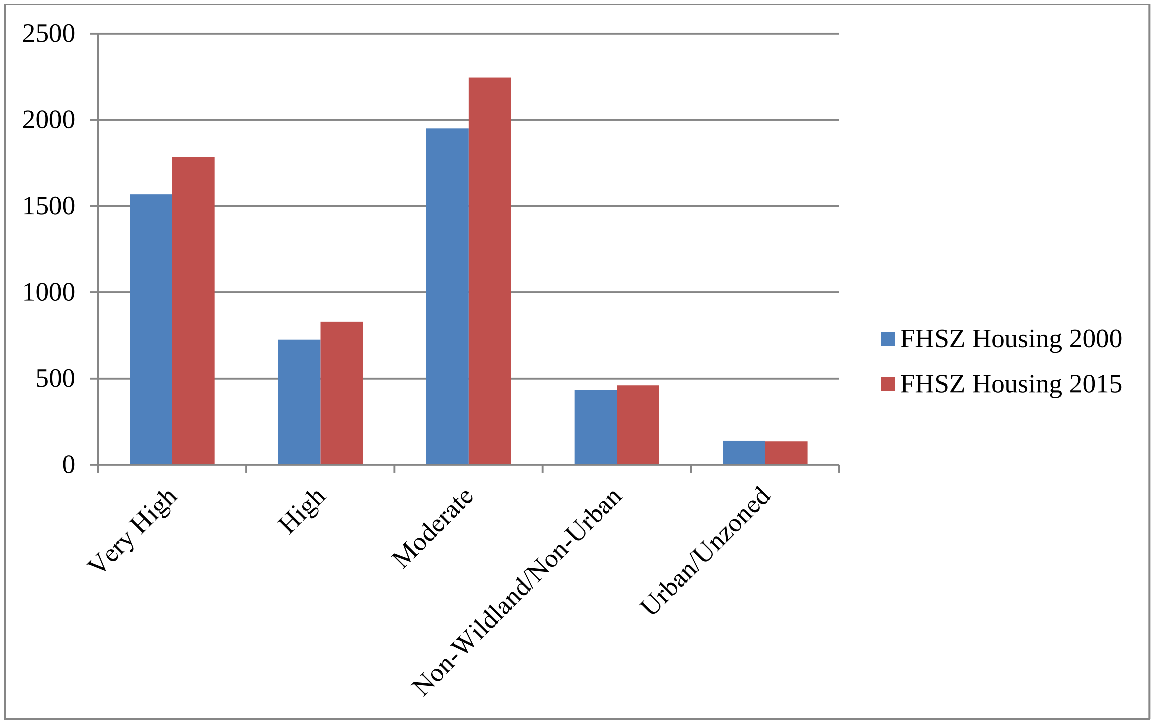

Figure 12: Comparison of the number of homes in the 2000 and 2015 WUIs and their relation to FHSZ

The overwhelming majority of the lands in the county are classified as "moderate" (see Figures 13 and 14). This category also has the most homes in 2000 and 2015. Lands and homes classified as "very high" are the second largest FHSZ type. The "high" class is the third largest group for both lands and homes in both case study years. While the WUI only accounts for a small portion of the county, 36% of it lies within areas classified at either "very high" or "high". These areas should be prioritized for proactive fire prevention activities.

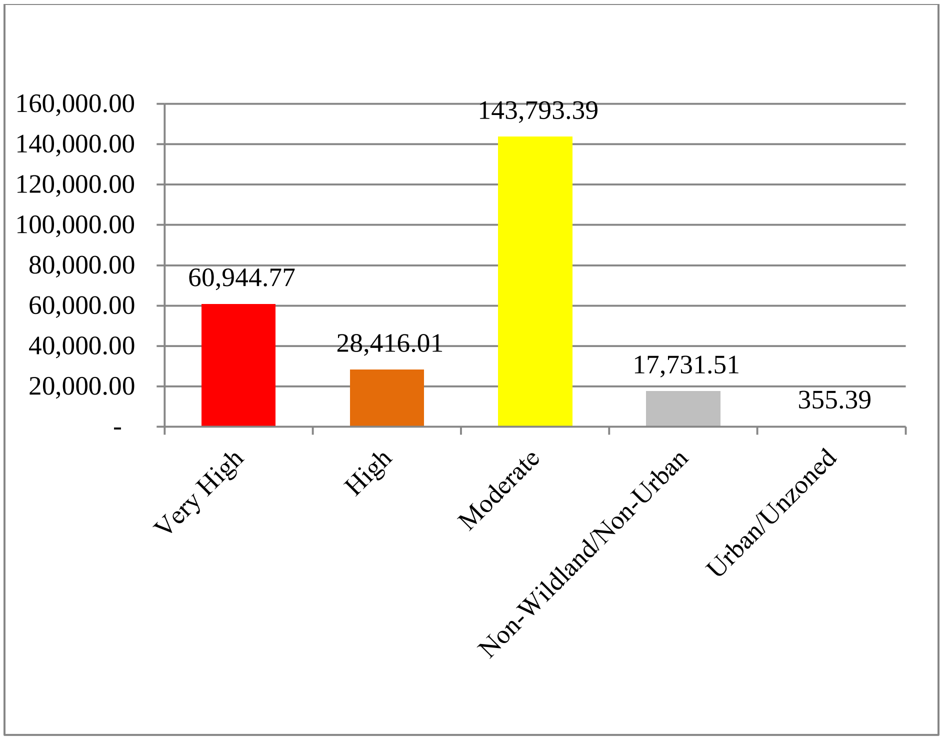

Figure 13: Total 2015 WUI acreage as it relates to FHSZ

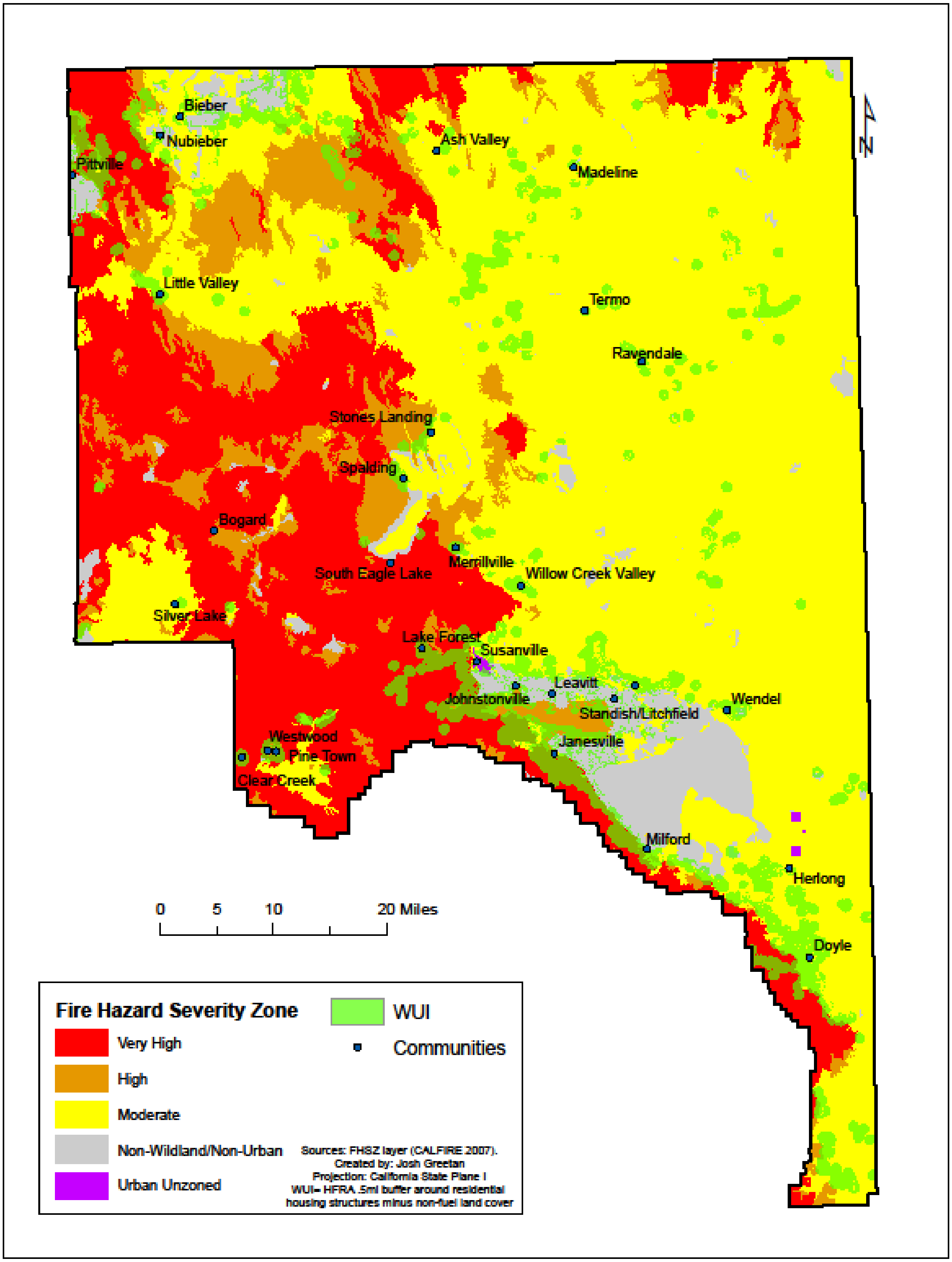

Figure 14: 2015 WUI overlaid on CAL FIRE FHSZ data

4.4.2 Fire Responsibility Areas

Fire responsibility areas indicate which government agency is responsible for providing fire protection, for maintaining and treating fuels in the area, and also who is financially responsible for a fire. In California, if a home is located within a state responsibility area (SRA) then that home owner must pay an annual “SRA Fire Prevention Fee” for each habitable structure on their property. These costs help pay for fuel reduction activities, FHSZ mapping, fire prevention education, and a variety of other fire prevention activities (CAL FIRE 2012). Some local fire districts also impose one time fire fees based upon the square footage of a new home in addition to annual fire prevention fee.

In 2000, 4,235 homes were located in SRAs, 5,823 in local responsibility areas (LRAs), and 62 in federal responsibility areas (FRAs). The number of homes in all three of these responsibility areas grew through 2015. In 2015, 4,955 homes were located in SRAs, 5,997 in LRAs, and 67 in FRAs. While FRAs comprise the largest responsibility type spatially, 70% of the WUI is in SRAs (Figure 15). Because few homes are located on federal lands, it is not surprising that the bulk of the WUI is in state responsibility areas. The 0.5 mile isotropic buffer used for mapping the WUI is rather conservative in comparison to those of past endeavors. If the buffer was changed to either one or one and a half miles the WUI would extend further into federal lands, changing the SRA and land ownership percentages (Figure 16).

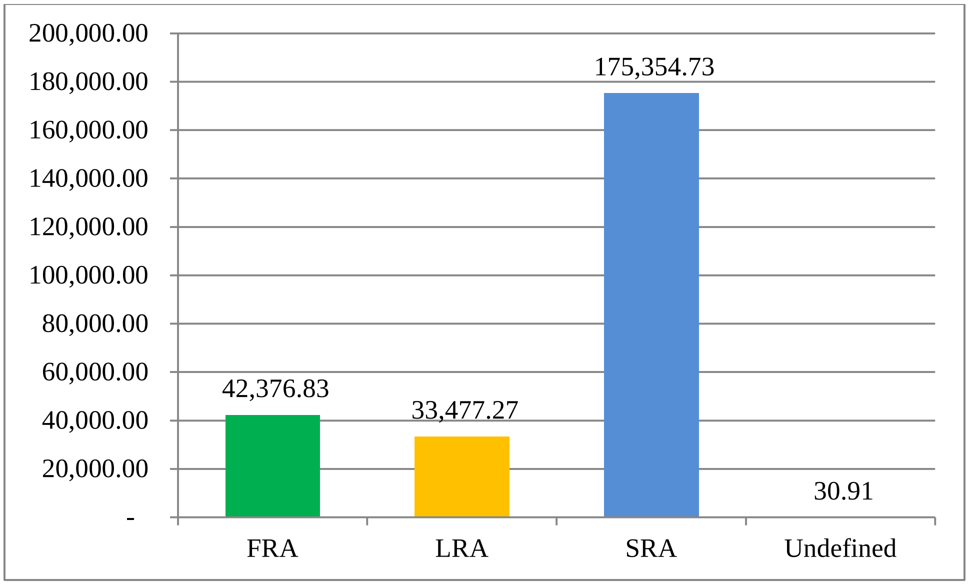

Figure 15: 2015 WUI acreage by responsibility area

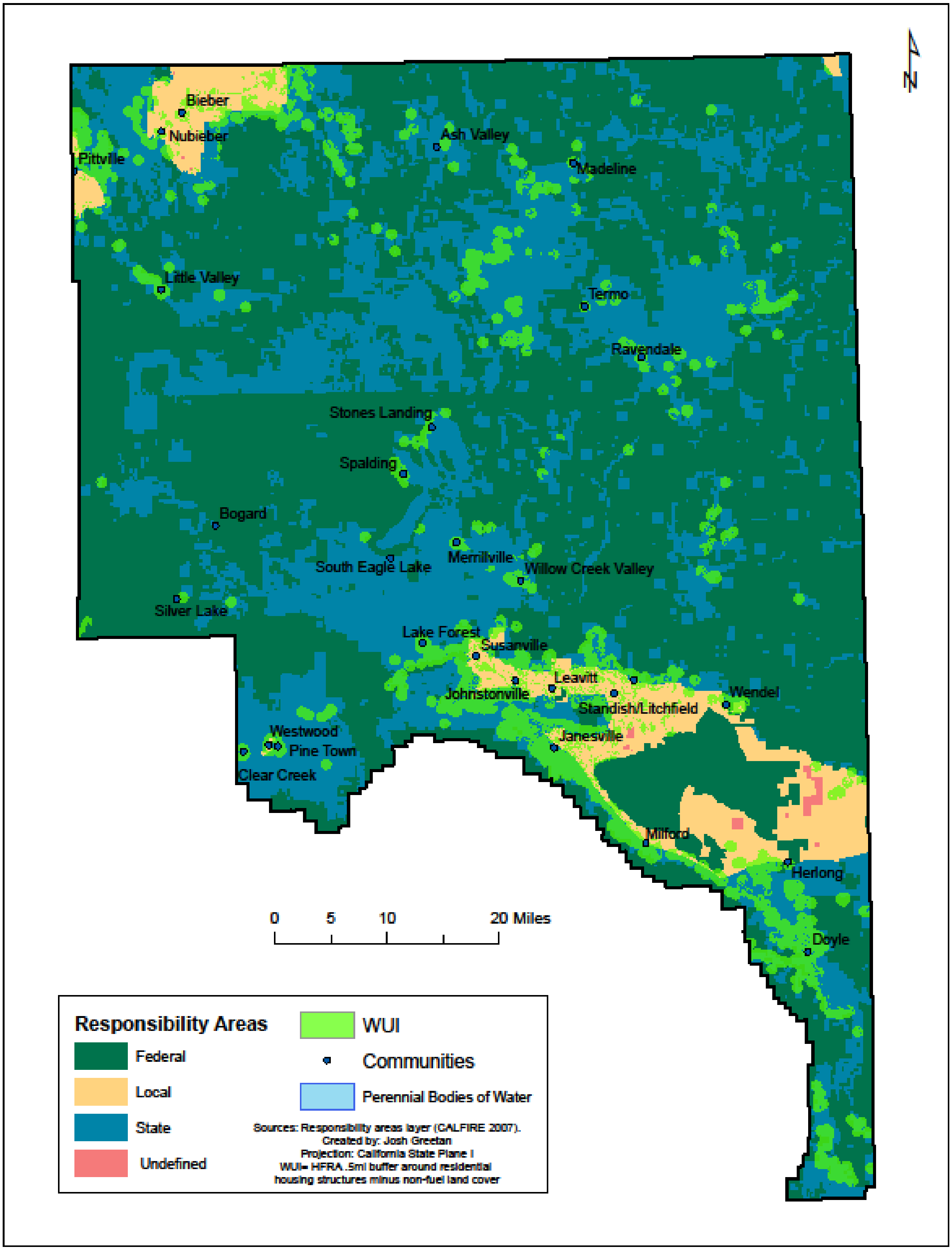

Figure 16: 2015 WUI overlaid over fire responsibility areas

CHAPTER 5: DISCUSSION AND CONCLUSIONS

The main objective of this study was to create a cadastral-based approach to map the 2000 & 2015 WUIs in Lassen County, California. The additions of digitized housing stock, FHSZ, responsibility areas, and land owner information allowed a variety of comparisons and change analyses to be conducted. Government agencies, property owners, and emergency response crews can all benefit from understanding more about the relationships the WUI has with these variables and how they have evolved over the past 15 years. This final chapter provides a summary of the study, a discussion of its results, their limitations, and suggestions and implications for future research.

5.1 Benefits of the Cadastral-Based Approach

The main advantage to using a cadastral-based approach is that it increases the levels of precision and accuracy for home location and the WUI. The utilization of local cadastral data negates the need to estimate, through dasymetric techniques, where housing is located. Previous studies, most of which were at the national scale, used Census blocks in combination with other datasets to remove the areas where housing was not likely to exist (i.e. public lands, water features) (Radeloff et al. 2005; Wilmer & Aplet 2005; Theobald & Romme 2007); however, this study used Lassen County Assessor parcel data to isolate all residential parcels within the study area. Esri World Imagery was then used to digitize housing structures. The use of assessor parcel information and aerial imagery yield a more accurate rendering of the WUI. Another major advantage is the ability to quantify the number of homes in the WUI, in FHSZs, and in responsibility areas.

Although the digitization of homes as points was extremely time consuming, it allowed for the number of homes in the WUI and other data layers to be quantified. The digitization only provides government agencies with statistical figures on the number of homes in areas of "very high" and "high" severity zones, but also provides emergency response crews the exact locations of homes in the area. Understanding the relationship between residential development, the WUI, and wildfire hazard zones is integral to proactive wildfire management. It not only helps to pinpoint where development occurs. and therefore where fire has the potential to cause human fatalities and destroy infrastructure and resources, but also identifies the areas where wildland fires could be permissible and actually help to restore the environment and natural fire regimes (Tully 2013). Finally, identifying the location of homes in the WUI and highest severity zones can help to prioritize state and federal assistance for preventive fire activities and fuel treatments.

5.2 Disadvantages and Limitations of the Cadastral-Based Approach

Although the utilization of Assessor parcel data offers multiple improvements to the endeavors of past studies, it also comes with a few disadvantages and many limitations. The biggest disadvantage was the time it took to create the two housing stock layers. While it only took an hour to create the 2000 and 2015 residential parcel layers, it took nearly 75 hours of digitization to create the housing stocks. Another issue is accessibility to data. While the general public might be able to request a copy of the parcel layer for the county, the Crest database that contains the use code is for official county use only and would not be made accessible to the public; however, this information measures could be taken to keep the sensitive data separate from the land use code.

5.2.1 Limitations of Housing Data

The assessor data used was from June 2015, as they only update their GIS database once a year, so this would not represent all housing built through the end of 2015. Another problem that arose was the discrepancies between the Assessor's office and the County Planning and Building

Department. When Planning and Building conducted a query of all new manufactured and constructed homes, from January 2001- June 2015, 63 of the residential parcels within the report, were not being assessed with a residential use code and therefore were not factored into the study. This number is insignificant as it equates to 0.01% of the 2015 housing stock. The City of Susanville was unable to generate a similar report with APNs, so new residential parcels built from 2000-2015 could not be determined for the City of Susanville; however, the Municipal Planning Office was able to state that 250 homes had been constructed or placed since 2000. Again, this number is insignificant as it equates to 0.02% of the 2015 housing stock.

Another limiting factor was that some parcels had more than one home. Since the method used to create the 2000 housing stock layer was to subtract homes and parcels listed in generated permit report by the county, the study was unable to determine which home came first from the aerial imagery used. This would not have a significant impact on the study as it would typically only affect the 2000 housing layer and then would only shift the 2000 WUI a matter of feet. The decision to represent housing as points likely provides a much smaller WUI estimate.

The representation of housing structures as points results in a conservative estimate of the WUI. The choice to represent housing as points saved an immense amount of time, as digitizing housing footprints as polylines would take a few months; however, buffering a small point results in much smaller WUI than buffering a 1,000 sq. ft. home. Another major limitation is that only housing structures were buffered, therefore accessory structures, commercial, and industrial buildings were not included. Although these buildings would be considered development, they were not included because of the time it would take to digitize all buildings within the county. Additionally, the assessor’s office does not keep a record of the number of structures on a parcel within their GIS; they only include housing counts within their database.

As previously mentioned, housing structures were represented, and the attribute information does not contain the number of units within each structure. The 2014 Census QuickFacts for Lassen County had a count of 12,741 housing units for the county, 13.4% of these units were found in multi-unit structures. 1,707 housing units were located in multi-unit structures; when this number is subtracted from the total count it leaves 11,034 units, which is just 15 more units than the 2015 housing stock created for this study. These calculations validated that the accuracy and validity of the housing stock datasets. The number of seasonal homes in the county was unavailable.

A decision to not use community density calculations was made as the study used cadastral data instead of Census blocks. Many of the prior WUI studies were at the national scale and relied upon Census blocks. In order to more accurately estimate housing location they used dasymetric techniques to disaggregate the blocks. Target housing densities were then used in order to prevent isolated pockets of WUI across the nation. However, since this studies focus was more oriented towards wildfire hazards in relation to housing it did not use a target housing density. Therefore, any housing located in or next to wildland fuels was considered a part of the WUI. The inclusion of the isolated areas provides a more accurate estimate of the actual WUI than taking a community based approach that excludes isolated rural housing. It also allowed for an analysis of the WUI to multiple other layers to be conducted. Housing counts within each of the other layers were then quantified.

5.2.2 Limitations of Other Data and GIS Tools

The “Zonal Geometry as Table” tool resulted in slight discrepancies in figures between various datasets, despite using the raster snap function and all raster resolutions being 30-meter. For example, the tool yielded a calculation of 1016.67 sq. km. for 2015 WUI layer, but an area of

1016.45 sq. km. for land ownership with WUI. The tool was reran and yielded slightly different calculations each time. This is attributed to resampling error, as all the rasters have a 30-meter resolution (esri, 2011).

The CAL FIRE FHSZ and responsibility area data were published in 2007. Further the CAL FIRE FHSZ data is an assessment of hazard, not risk. "Hazard" is based upon physical conditions and the likelihood an area will burn over a given time period, and does not account for fuel treatment activities. Fire "risk" is defined as the susceptibility of the development to fire. It accounts for all fuel treatments that have been conducted in the area, fire infrastructure systems, defensible space, and fire resistant building materials (CAL FIRE 2007). Therefore, fire risk is not factored into this study. All other limitations within the study revolve around the age of the data used.

The structural based approach used in this study allowed for quantification of the number of homes located within and out of the WUI. It also allowed for a quantification of the number of homes located within each of the fire hazard severity zones. It was interesting to see the differences between the number of homes in both the WUI and FHSZ layers, and the number for each FHSZ but not within the WUI. In 2015, 77.69% of the homes located in a "very high" FHSZ were also in the WUI. Only 41.78% of the homes located in a "high" FHSZ were also in the WUI. This shows that the WUI is not an accurate assessment of wildfire hazard to homes; in California, a combination of CAL FIRE's expertise (FHSZ data) and a WUI assessment should be utilized to give a more meaningful approach. In locations outside of California, it is critical to factor in other agencies', with an expertise in regards to fire, data and resources.

The NLCD data used for the two WUIs were from 2001 and 2011. It is unlikely that land cover changed drastically between 2011 and 2015 within the study area. The layer for land ownership type was from 2012, and did not include county lands. County lands had to be queried from the assessor parcel data, converted to raster, combined, and then new figures were calculated.

5.3 Future Research

The study could be easily replicated by other agencies, as long as they had access to parcel data with the number of homes on any given parcel within the attribute table. While the study offered logical improvements using a cadastral-based approach for mapping the WUI, it could still be further improved. Automated structure digitization could help reduce the time digitizing housing. Automated digitization would be especially useful to counties with a much larger housing stock. Automated digitization also has the potential to yield structural footprint geometry, which would give a more accurate WUI assessment; most importantly, it could digitize all structures within a study area, and could therefore create a more accurate estimate of existing development and change.

5.3.1 Existing Vegetation

Another possible improvement would be to incorporate existing vegetation data into the assessment. For this study NLCD land cover data was used in order to keep consistency; however, the integration of LANDFIRE data could also improve the study. LANDFIRE existing vegetation type (2012) is more accurate as it offers actual vegetation on the ground, while NLCD land cover data averages a percent coverage. Datasets within the LANDFIRE database, that would be useful, include: existing vegetation types, existing vegetation cover, and existing vegetation height. These datasets could be used to give estimates of potential flame height, burn rates, and help fire agencies calculate the distance of vegetation to treat. The use of LANDFIRE datasets would inevitably yield a more accurate assessment of fire hazard. The integration of social variables such as population, demographic data, and land values could also supplement the study.

5.3.2 Home Ignition Zone

Cohen (1998; 2001) defines the home ignition zone as the area 100-150 feet around the residence. Fuel treatments in this zone will reduce a home's probability of ignition from radiant heat (Cohen & Butler 1998; Cohen 2001; Platt 2010). This zone could be calculated using a Euclidean distance buffer approach. All homes located within the WUI could then be buffered by 150 feet. The rendering of the home ignition zone would delineate the area for defensible space immediately around a residence. The area beyond the home ignition zone is referred to as the "Community Protection Zone" and is captured by using the HFRA recommended 0.5 mile buffer (Wilmer & Aplet 2005; Theobald and Romme 2007; Platt 2010).

5.3.3 Social Variables

The integration of population, demographic data, and land value figures all have the potential to substantially supplement this type of study. Population and demographic data could help analyze the distribution of people living in and out of the WUI. It could also help to assess which houses are occupied year round and which are seasonal. Land value figures could reveal if disparities exist that keep certain income groups from living in urban areas. They could also help to estimate the potential costs of damage if a wildfire were to hit a community.

5.4 Conclusion

The main motivation for the study was to measure the change in WUI from 2000 – 2015, so that local governmental agencies and communities could be made aware of the growing hazard posed by wildfire in the WUI. By making the hazards known, communities can begin to address these issues; the best way to do this is through a community wildfire protection plan (CWPP). In order to be eligible to receive federal assistance for fuel treatment activities, communities must have an adopted CWPP. The Lassen County Fire Safe Council is a non-profit corporation made up of various local, state, and federal agencies, as well as other institutions. They have helped facilitate the CWPP process for the majority of the county. Together, with the partnering agencies, they prioritize high priority fuel reduction projects throughout the county. Upon completion, this study will be presented on behalf of the County of Lassen Planning Division at a Fire Safe Council meeting. Additionally, other components of this study will also live outside of academia.

The 2015 housing stock was distributed to emergency service agencies, so that they can quickly identify home location; this is especially useful when trying to determine home location on larger parcels. The County Planning and Building Department will also be able to maintain and use the housing and residential parcel layers for the Housing Element of the County General Plan and for other long range analyses.

The WUI measurement provided by this study is a rather conservative estimate as it uses the HFRA 0.5 mi buffer. Many other studies use a 1.5 mi buffer that is based upon the estimated distance a firebrand can travel, which can result in ignition; however, this tends to overestimate the WUI. The 1.5 mi buffer should be used in areas of steep topography and thick vegetation, both of which have the potential to create particularly hazardous conditions (HFRA 2003). Again, it is important to emphasize that the 0.5 mi buffer is not a recommendation to clear a distance of a 0.5 mi around all housing in the WUI; rather, it should serve as the focal area for communities to assess wildfire hazard and risks, infrastructural needs for combatting wildfires, and wildfire fuel reduction activities, all in order to improve public safety.

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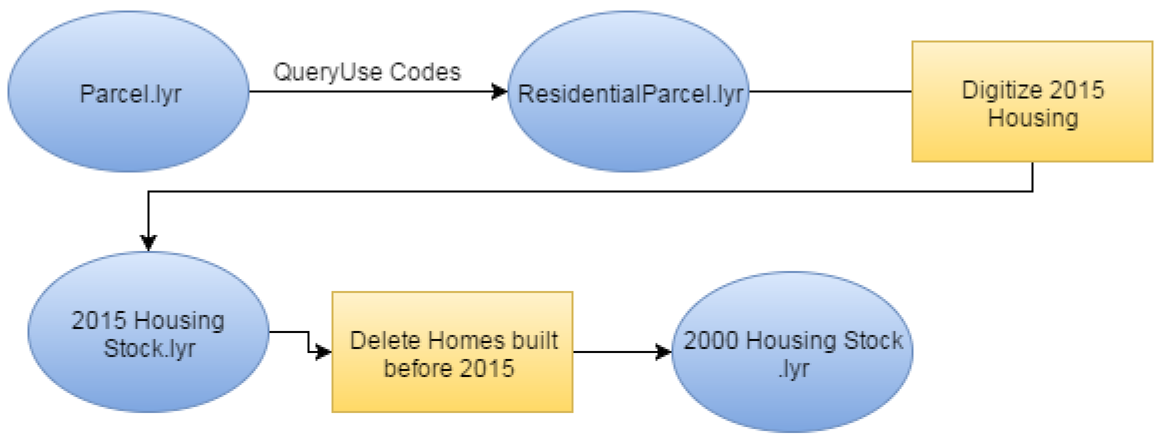
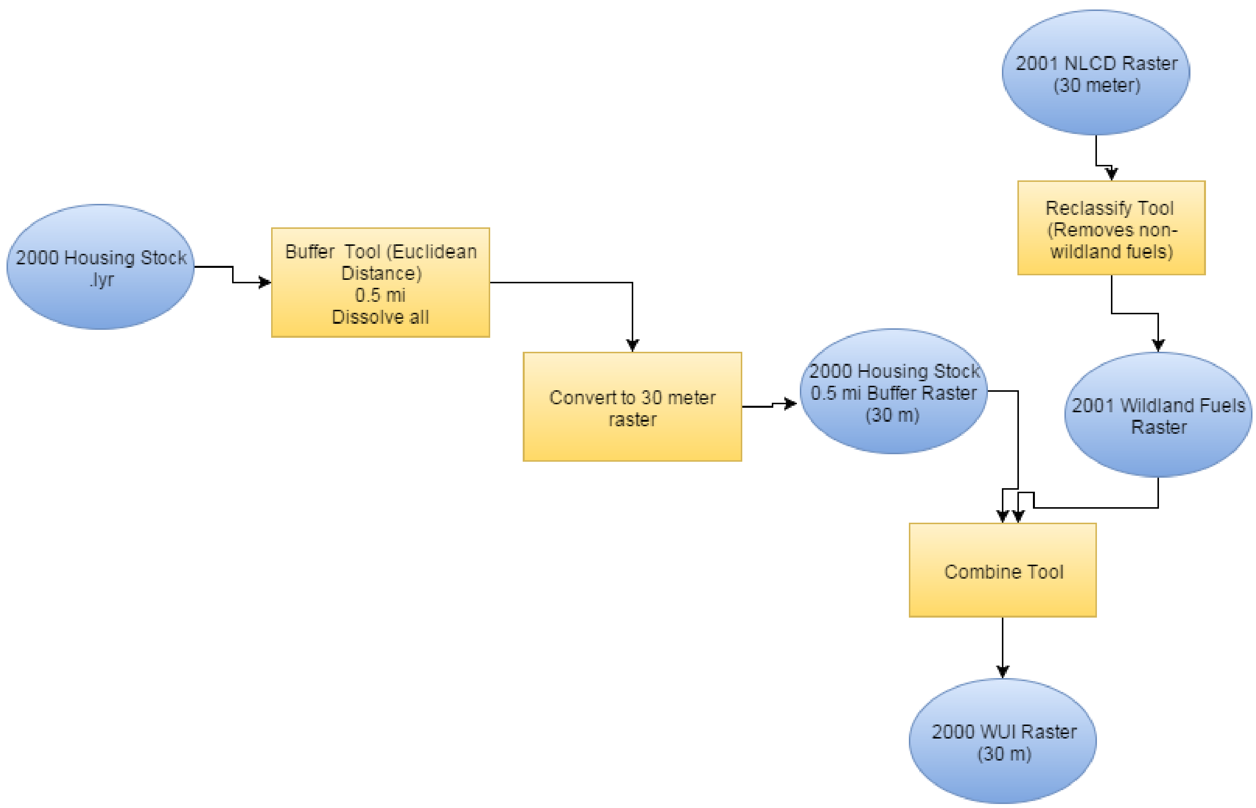
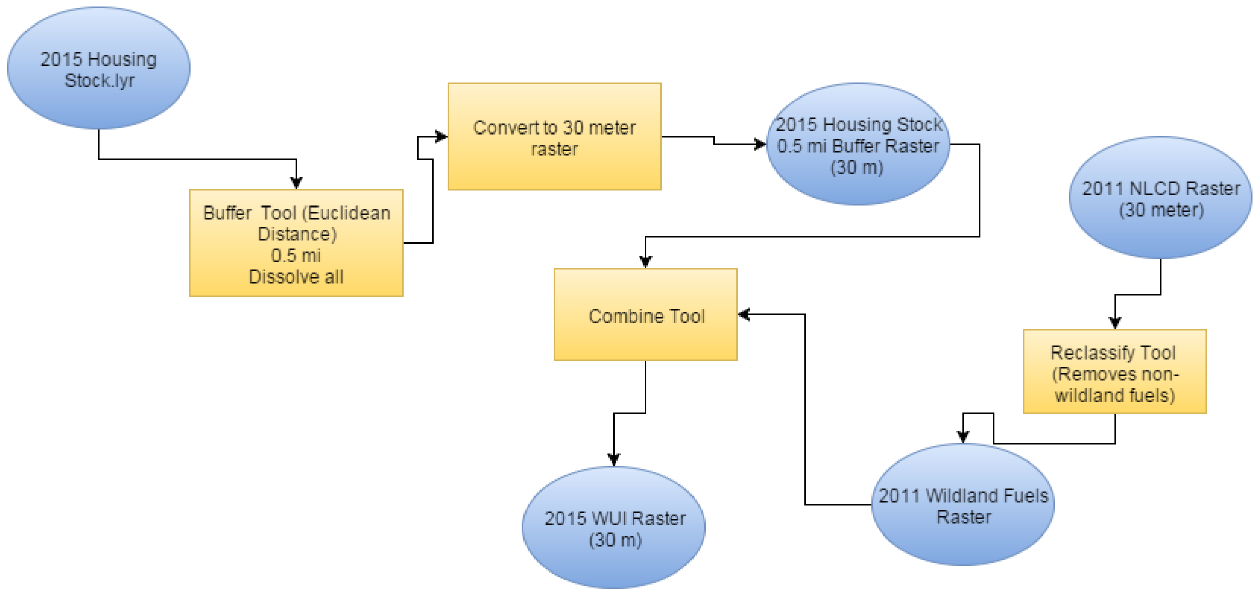
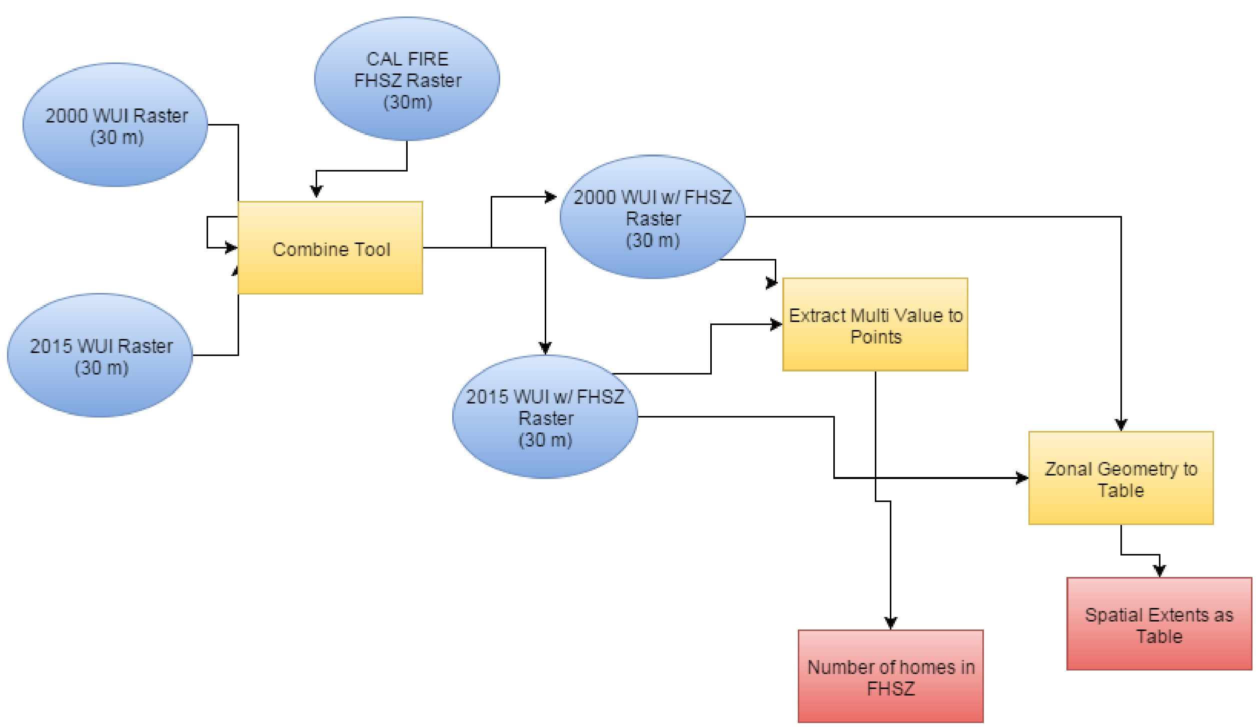
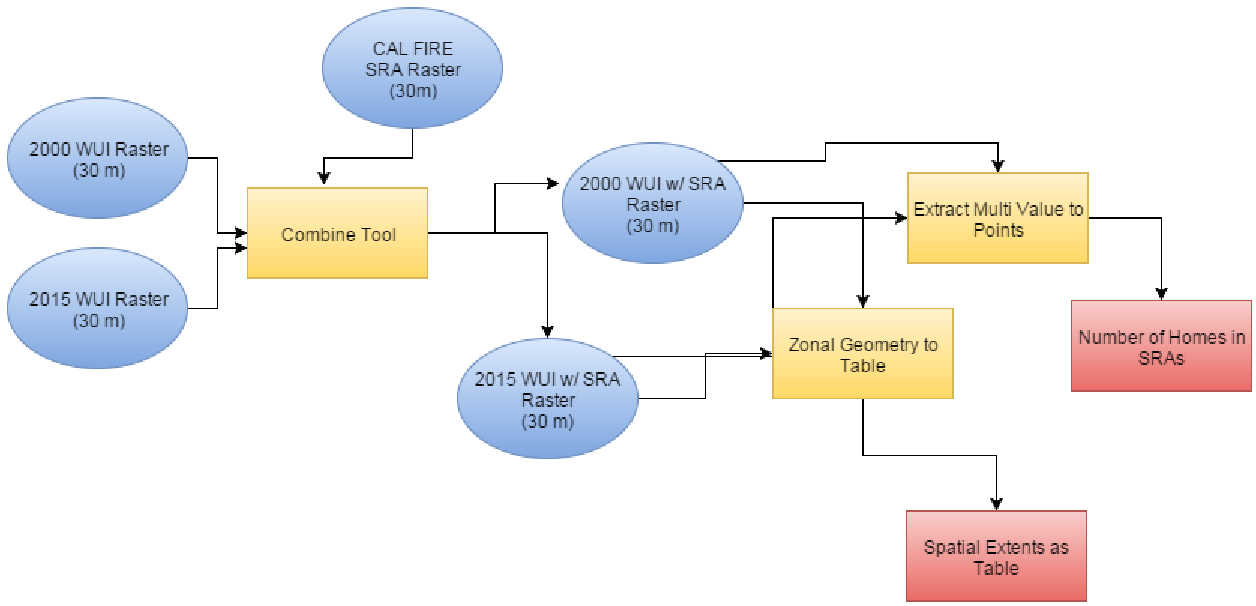
Appendix A: Flow Charts for GIS Work






2015 Housing Stock.lyr
Buffer Tool (Euclidean Distance) 0.5 mi Dissolve all
Convert to 30 meter raster
2015 Housing Stock 0.5 mi Buffer Raster (30 m)
2011 NLCD Raster (30 meter)
Combine Tool
Reclassify Tool (Removes non-wildland fuels)
2015 WUI Raster (30 m)
2011 Wildland Fuels Raster


CAL FIRE FHSZ Raster (30m)
2000 WUI Raster (30 m)
Combine Tool
2000 WUI w/ FHSZ Raster (30 m)
2015 WUI Raster (30 m)
Extract Multi Value to Points
2015 WUI w/ FHSZ Raster (30 m)
Zonal Geometry to Table
Spatial Extents as Table
Number of homes in FHSZ


CAL FIRE
SRA Raster
(30m)
2000 WUI Raster
(30 m)
2015 WUI Raster
(30 m)
Combine Tool
2000 WUI w/ SRA
Raster
(30 m)
2015 WUI w/ SRA
Raster
(30 m)
Extract Multi Value to
Points
Zonal Geometry to
Table
Number of Homes in
SRAs
Spatial Extents as
Table