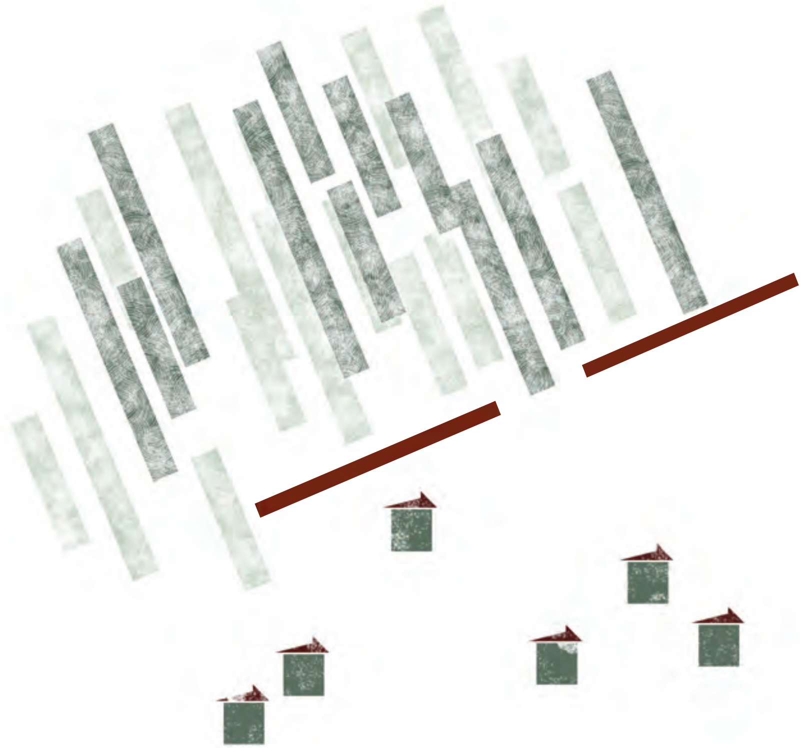

Resilient Fuel Break Design

Translating Ecological and Social Resilience Theory into Fuel Break Design Within the Pacific Northwest

Kelli Barker

Approval

Submitted in partial fulfillment of the Master's of Landscape Architecture, Department of Landscape Architecture, University of Oregon, on June 15, 2020.

Masters Project Chair:
Robert Ribe

Master's Project Committee Members:
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Masters Projecy Chair Approval

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Master's Project Commitee Member Approval

Date __________________ Signature ____

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Abstract

The goal of this research is to assess the potential for fuel breaks, as a fire management tool, to positively influence the resiliency of ecological and social systems within the region of the pacific northwest. Landscapes of the Pacific Northwest have historically been managed by fire regimes, both naturally occurring and human initiated. The buildup of woody debris, as a result of human maintenance regimes, in combination with climate change have led to an increasing risk of wildfires, affecting ecosystems and the safety of people. Fuel breaks may have potential to act as a fire management tool to increase the resilience of both social and ecological systems affected by the absence and presence of wildfire. This research focusses on Portland, OR, utilizing Forest Park, its adjacent neighborhood Northwest Heights, and the respective area of private forest land in between as a case study. Fuel break design elements are distinguished through a literature review and then categorized under sub categories of ecological and social resilience to be applied to the case study. The results of this research are a table of fuel break design elements, translated from resilience theory, and an evaluation of the case study for the application of a fuel break design and the inclusion of the designated design elements.

Acknowledgements

Thank you to my friends and family who have supported me through my years in graduate school. You have been a constant source of encouragement for me.

To Rob Ribe, Chris Enright, and Mark Eischeid, thank you for the guidance and support through the creation of this project.

Lastly, thank you to my cohort. It has been a joy to learn and grow with you all.

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Chapter One

Introduction, Case Study & Methods

Figure 1.1
Image from Sky Lakes Wilderness. This landscape has evolved with wildfire, allowing it recover and re-establish species post fire.

1.1 Introduction

The goal of this research is to assess the potential for fuel breaks, as a fire management tool, to positively influence the resiliency of ecological and social systems within the region of the pacific northwest. Resiliency can be defined as "the ability of materials, structures etc. to withstand a shock or stress, and their ability to self-correct once this shock has occurred" (Fitzgerald et al., 2005). Two of the leading causes of shock and stress affecting natural systems today are climate change and human landscape maintenance regimes. Both of these are drivers of disturbance influencing the potential for wildfire events to start in addition to influencing their intensity and scope.

Landscapes of the Pacific Northwest have historically been managed by fire regimes, both naturally occurring and human initiated. The landscape has evolved with fire, leading to the adaption of plant species and resulting in specific ecologies that have allowed these species to thrive (see *Figure 1.1*). Climate change in combination with human maintenance regimes have led to a shift in fire regime dynamics, affecting ecosystems and the safety of people. Areas that were once allowed to burn are maintained so as to avoid natural fire events that may create hazardous conditions for nearby residences. Woody debris and understory thatch build up as a result of infrequent burns, increasing the fuel load and resulting in fires that burn too intensely for even an adapted environment to withstand and over greater expanses of land (Agee, et al., 2000; Amo et al., 2005; Cohen, 2008). Due to increasing temperatures and extreme weather events caused as a result of climate change, the risk of intense fire events is greater than ever before. Homes, located on the edges of urban environments within the WUI (wildland urban interface) are at great risk to quickly spreading, severe fires that have proliferated from Western management styles. Fuel reduction techniques have become a widely implemented fire management tool in the face of increasing wildfire events.

A fuel break is defined as, "a strategically located wide block, or strip, on which a cover of dense, heavy, or flammable vegetation has been permanently changed to one of lower fuel volume or reduced flammability" (Green, 1977). Fuel breaks may act to increase resilience of homes within the WUI by buffering the spread and or intensity of fire to nearby residences, while also creating breaks in the landscape that make it safer for fires to burn where they naturally would. There currently exist no standards for fuel breaks; they are typically site specific designs, influenced by project goals, local perceptions and the amount of funding for their creation and maintenance (Agee et al., 2000).

In order to protect residents within the WUI, policy makers have favored design methods meant to provide the greatest level of security for the lowest cost to implement. These approaches often disregard the needs of the local ecology, negatively impacting its diversity of habitat and species types. A better understanding of how fire management tools may act to positively influence both systems is needed.

This research will examine how the application of social and ecological resilience frameworks to fuel break design may create equitable fire management tools. I will be using a research by design method, incorporating information gathered from literature and first person interviews with professionals to inform three prescriptive fuel break designs, effective within a case study in the Pacific Northwest. Resilience frameworks will be applied individually and then together to assess where overlap between prescription methods may exist. By doing so, this research looks to create a better understanding of the potential tradeoffs between different goals of stakeholders that may affect the acceptability and funding of fire management projects, such as fuel breaks. If done consciously, fuel breaks may strike a balance in supporting the local ecology as well as successfully buffering nearby residences from fire, allowing both systems to respond in a more resilient manner.

This reserach utilizes Forest Park, located in Portland, Oregon, and the Northwest Heights neighborhood as a case study for applying prescriptive fuel break designs. All measures will seek to align with fire management goals set out by the Portland Parks and Recreation Bureau.

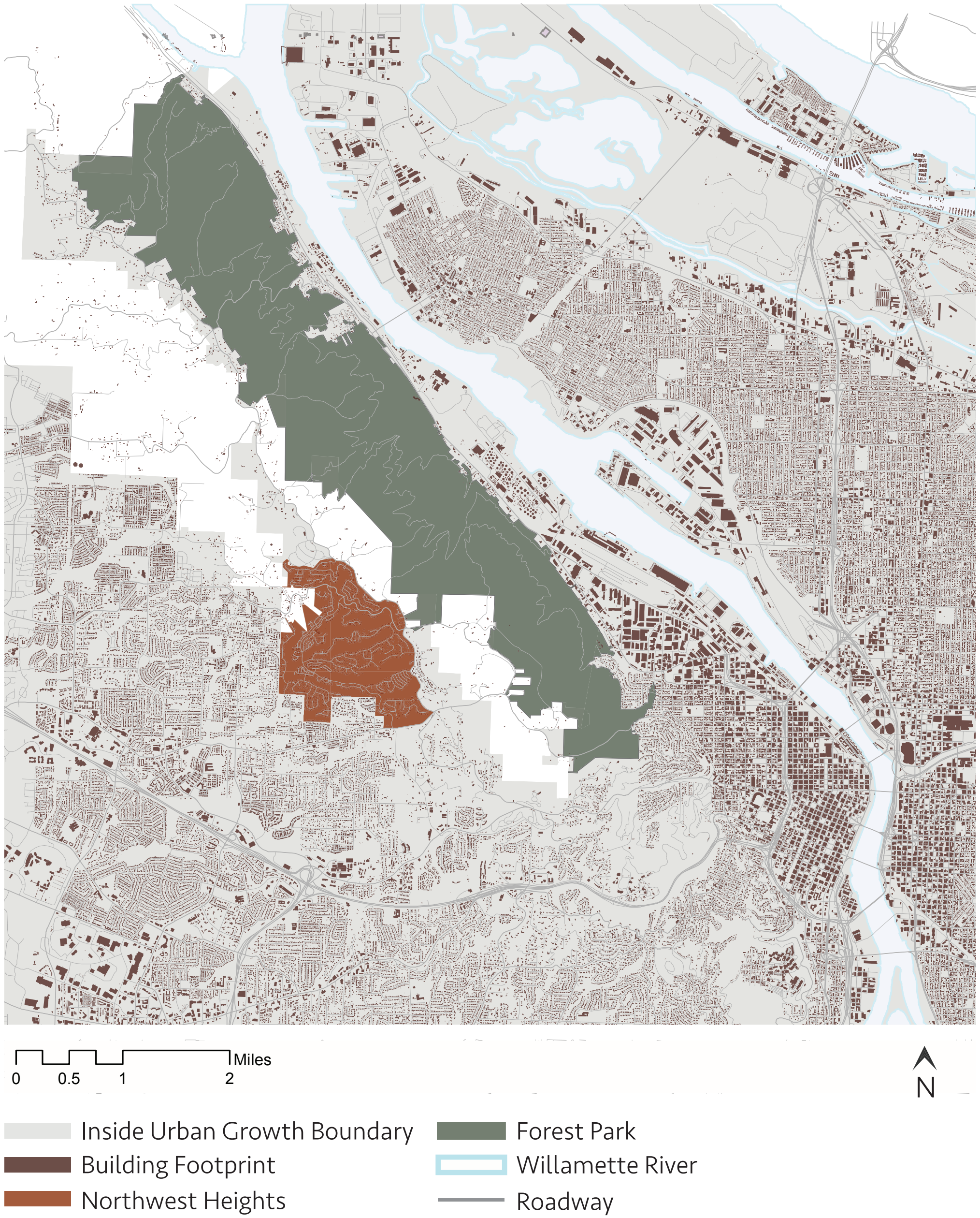


Figure 1.2
Case study context map.

1.2 Case Study

Context

This research focusses on Portland, OR as the context for the case study. The parameters of the case study include Forest Park, the neighborhood of Northwest Heights, and the respective area of private forest land in-between as the setting to test the potential of fuel breaks as resilient, prescriptive fire management techniques (***Figure 1.2***). For this study, Forest Park represents the fuel source for fire ignition, while the Northwest Heights constitutes the at risk urban development within the WUI. This designated area represents an ideal case study because of its close proximity to developed land, its historical connection to fire, and site characteristics including vegetation and topography that influence fire behavior. The city of Portland has defined the maintenance and use of park grounds, making them a key policy influencer in this study. Other influential stakeholders of the park include residents of the nearby neighborhoods (including Northwest Heights) and recreational users of Forest Park.

Figure 1.3
Image from the Wild-woods trail in Forest Park. The trail follows a terraced ledge along the steep slopes. (Hikespeak, 2020)

Forest Park

Today, Forest Park is seen as an iconic part of the Portland landscape, providing spectacular views to the dense, urban center, and acting as a natural respite for residents. The park is located just two miles west of the metropolitan downtown, is bordered on the south by Burnside street, on the north by Newberry road, on the west by skyline boulevard, and on the east by St. Helens Road (see *Figure 1.4*) (Houle, 1987). Nearby residential areas of concern consist of the West/Northwest neighbors: Northwest Heights, Northwest Industrial, Linnton, Southwest Hills, Hillside, to the Pearl district.

Part of the Tualatin mountain range, the park acts as a corridor, linking the urban forest of Portland to larger habitat patches to the West (Portland Parks and Recreation Bureau of Planning, 1995). The land is characterized by steep slopes to the North and South with a complex of secondary ridges and stream channels across the southern face. The park itself stretches 7.5 miles long, 1.5 miles wide, and contains 70 miles of trails. It is comprised of 4800 acres of primarily mixed conifer and deciduous woodland stands and is one of the largest urban parks in the United States (Houle, 1987). See *Figure 1.3* for an exemplary image of plant structure, topogrpahy, and trails within Forest Park.

In 1903 the land that later would be known as Forest Park was noted by the Olmstead brothers as critical for conservation because of its potential for recreational use and for what today is referred to as ***ecosystem services***. It wouldn't be until 1948 that the park would officially be dedicated. The time in between is defined by a history of logging and slash-burn practices within the forest-

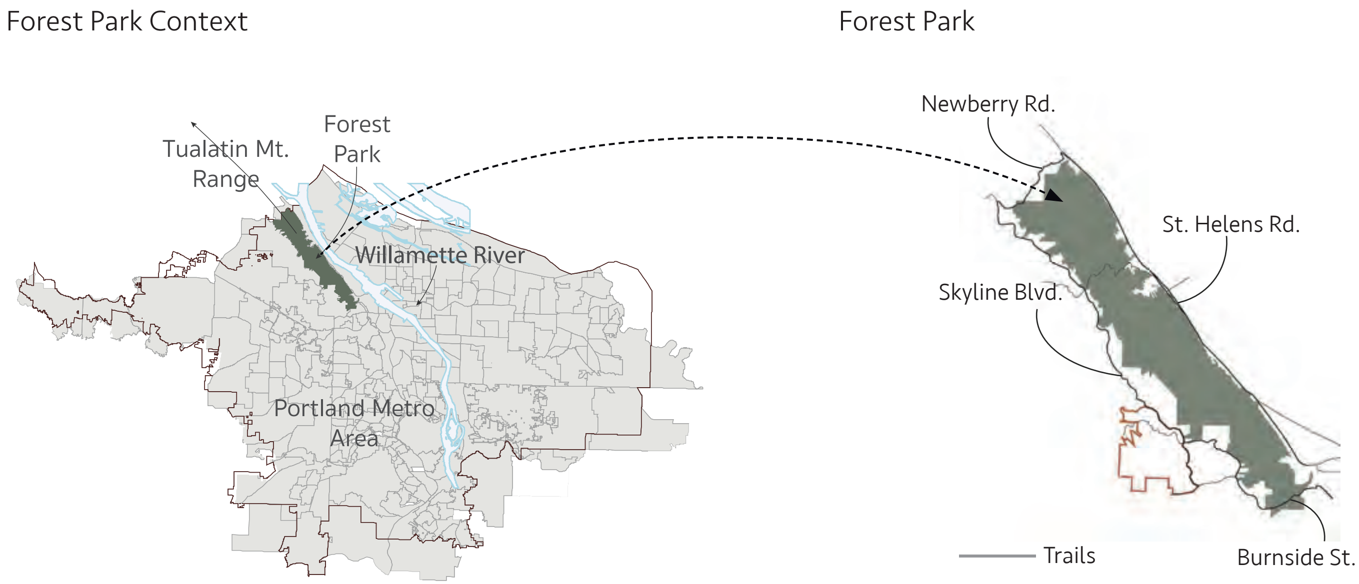


Figure 1.4
Forest Park within the context of the city of Portland, OR.

ed area that left the land exposed and the slopes unstabilized by vegetative roots. The removal of trees changed the ecosystem dramatically and contributed to landslides, which damaged roads and residential lots. Following the seizure of the land by Multnomah county in 1928, Forest Park finally took on a defined boundary and restoration efforts were able to take place (Houle, 1987).

Fire has played a role in shaping the park's ecosystems. There have been three stand replacing fires over the last 120 years. In 1889, 400 acres were burned. In 1940, the "Bonney Slope" fire burned 170 acres of park land. The last recorded major fire event was in 1951, which burned over 900 acres of the park. The entirety of the Tualatin Mountain range, which the park is connected to, is defined by a mixed severity fire regime, which indicates that during an average fire event 20-70% of the canopy is burned (Perry et al., 2011) It is widely known that fires have long been the dominant maintenance method and driver of diversity for this ecosystem (Forest Park Desired Future Condition, 2011).

Risk of a wildfire event within Forest Park is influenced by topography and regional weather patterns. Concerns include sun exposure on the parks southern ridge, steep ravines and strong Summer wind from the North.

Figure 1.5
Image of the Northwest Heights Neighborhood located in Portland, OR (PDX listed, 2020)

Northwest Heights

Northwest Heights is a prosperous, suburban neighborhood located on the Northwest side of Portland. It is characterized by homes lining steep, terraced slopes and a lush forest line to the north (see *Figure 1.5*). This neighborhood borders the city of Beaverton to the West, the Forest Park neighborhood to the Northwest and East, and Skyline Boulevard directly North. Just beyond Skyline Boulevard is Forest Park, between which lies private, forested land.

The population of residents living there is 5,505. Of those, 83% own their homes, with the median home value equaling $655,698 (Niche, 2020). Forest fires from the North are of great concern to residents whose real estate investments are at risk of fire damage. Additionally, the proximity of forested land to a high density residential area is of concern for the safety of people in a wildfire scenario.

Northwest Heights was chosen to be included in this study firstly because it is a dense urbanized area within close proximity to dense, forested land with a historical connection to fire regimes (Forest Park) (see *Figure 1.6*). The existing pattern of vegetated corridors extending from forested land to the North, which may act to transfer wildfire through the built environment, made this site compelling to test fuel break designs. Additionally, Northwest Heights represents a direct link to other urbanized land to the South and Southwest, which makes it a potential corridor to spread fire from forested land into urban areas.

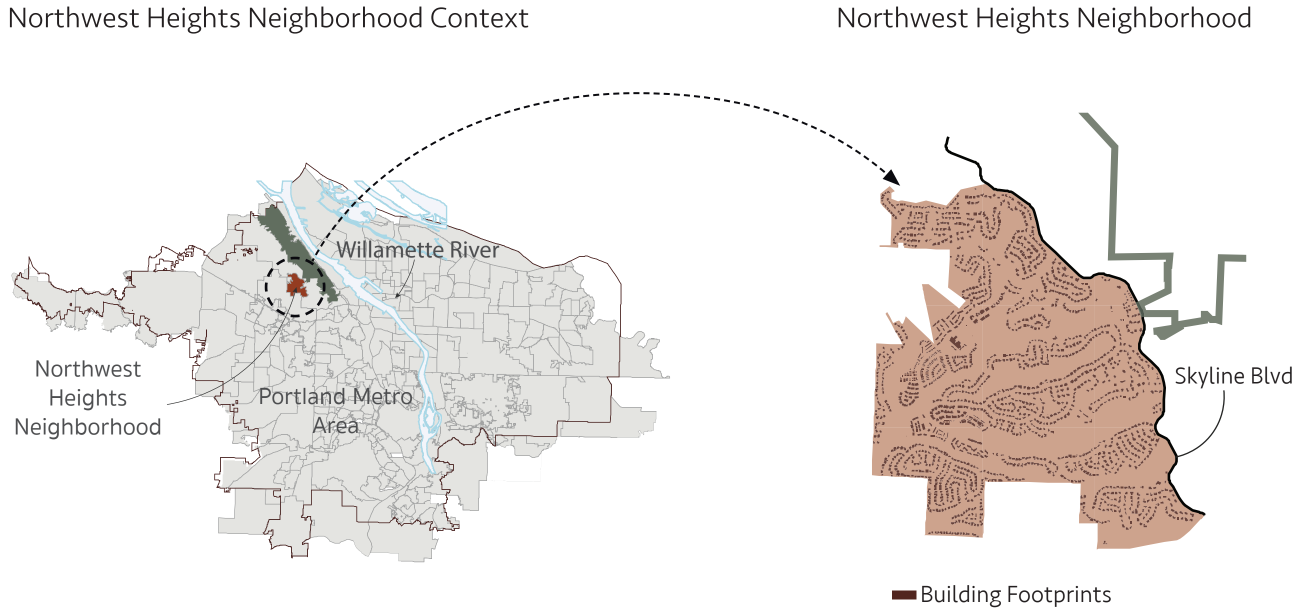
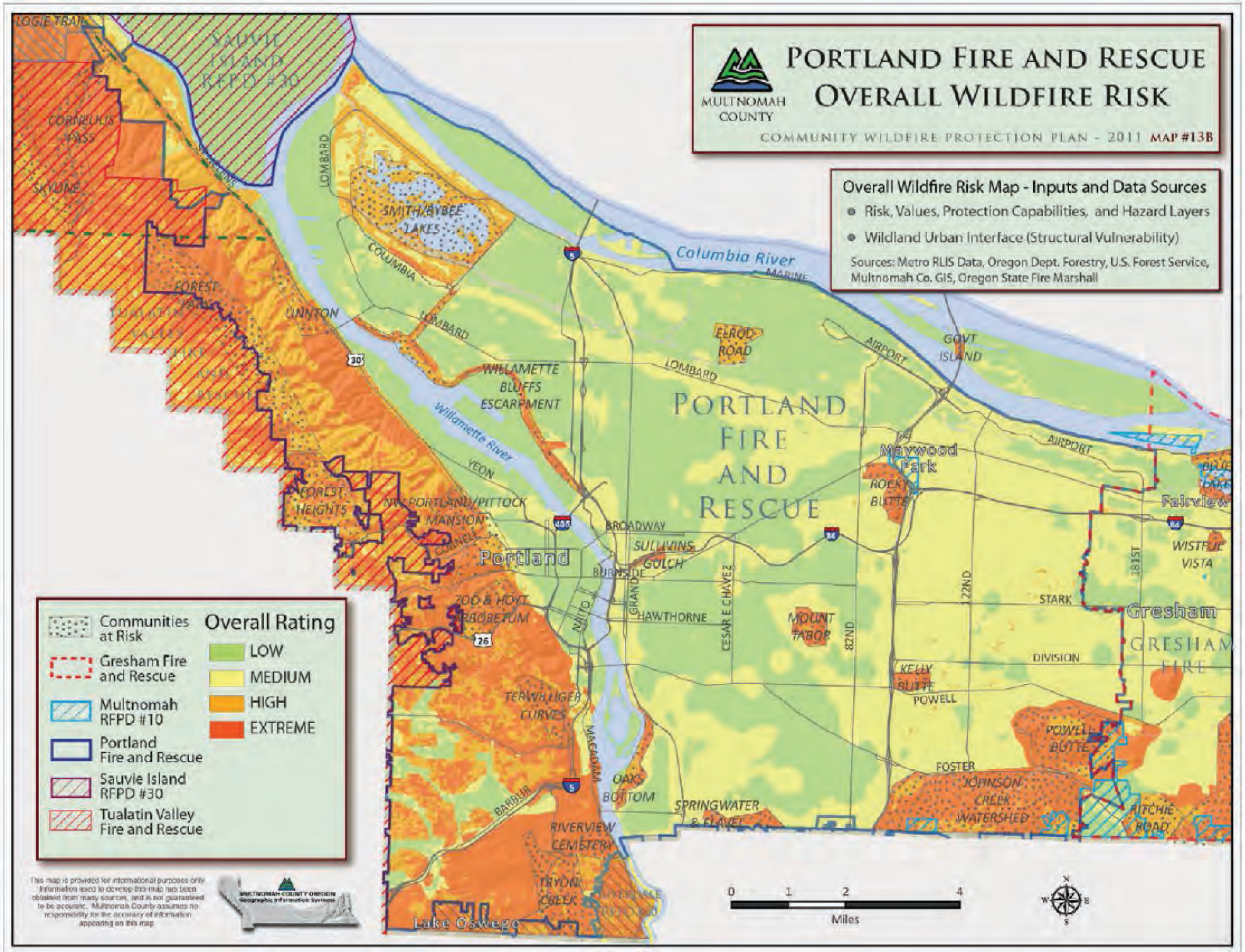


Figure 1.6
Northwest Heights Neighborhood within the context of the city of Portland, OR.

Since Northwest Heights is recognized as an official neighborhood of Portland, they are reognized as a stakeholder who is affected by the risk of wildfire. Residents may have the ability to influence the implementation of fire managment tools around their neighborhood in addition to what kind of tools are used. This neighborhood's potential to be directly involved in decision making processes makes it an ideal selection for studing the application of social resilience prescriptions.

Figure 1.7
Portland Fire and Rescue Overall Wildfire Risk (*Image source: Multnomah County*).



Fire Management Plans in Forest Park

Wildfire risk within Forest Park and is noted as a concern by the city of Portland in multiple planning documents including: Forest Park Desired Future Condition (2011), Forest Park Wildlife Report (2012), Forest Park Natural Resource Management Plan (1995), and Portland Wildfire Fuel Reduction Project 2006-2010 (see *Figure 1.7* for a comprehensive map of wildfire risk). A gap analysis report for Portland, within the Forest Park Natural Resources management plan (subsection ecological prescriptions- reduction of catastrophic fire risk) OR (2009), asserts the need for long-term maintenance of vegetation so as to maintain safe fuel loads in key locations of Forest Park. In order to address this, the city of Portland has distributed grant money to Portland Parks & Recreation, Environmental Services, and Fire & Rescue organizations towards efforts to create short and long term goals to reduce the chance of wildfire events in and around Forest Park. Fuel breaks may be applicable tools in the effort to achieve the goals set out by these organizations.

Additional issues related to fire are the result of poor infrastructure, contributing to limited access to nearby urban areas. Access to Forest Park and private forest for fire fighters is limited by narrow streets and limited access points. Fuel breaks in particular are noted for their ability to slow the advance of fires, which may provide additional time and easier access for fire crews to get to the site. They may be directly applicable, providing an engineered method for vegetation removal along the southern border where the risk to residents is high. This research will assess whether fuel breaks in this study area may act to alieve concerns of neighbors while achieving fire management goals consistent with those of Forest Park.

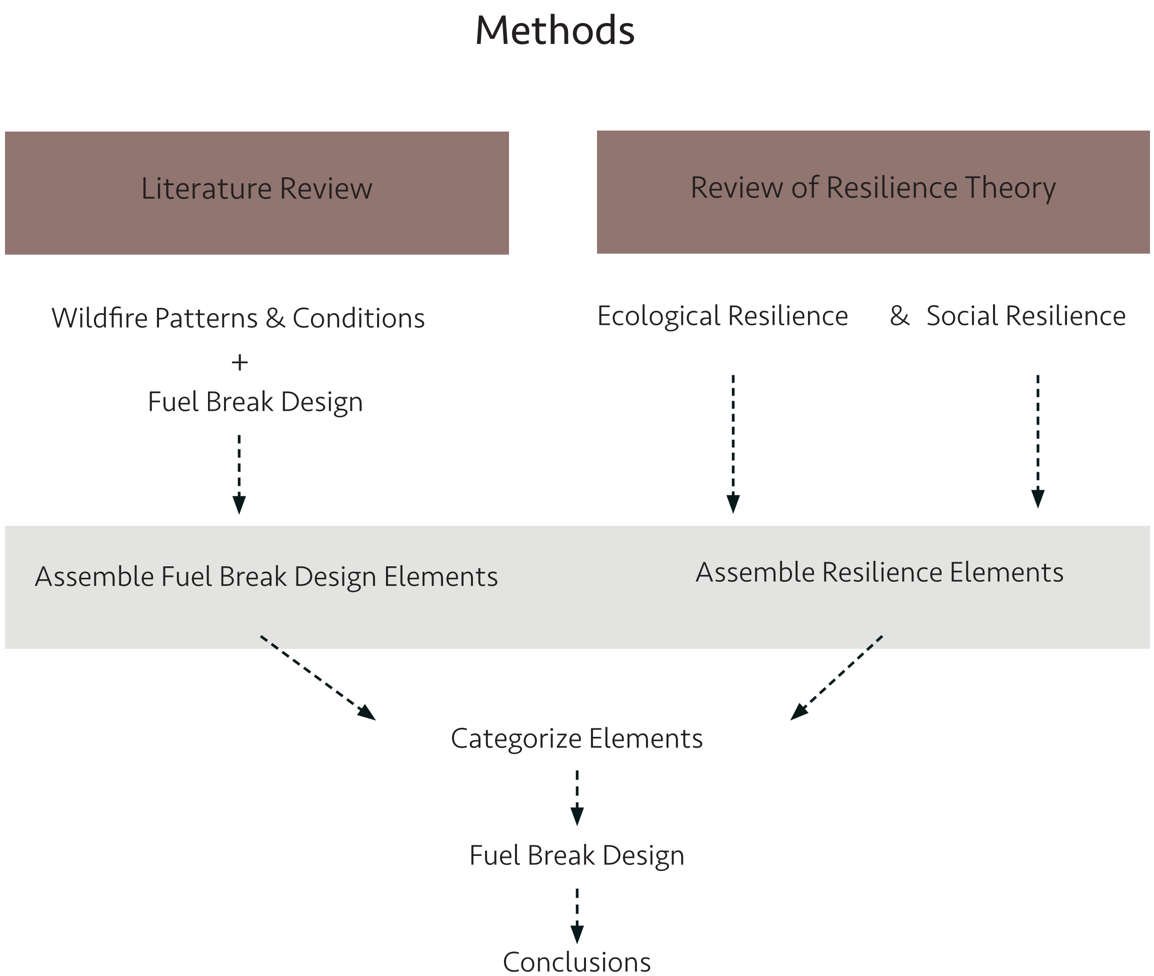


Figure 1.8

Methods process diagram.

1.3 Methods

Data Sources

Raster and vector data used within this study that are supplied by Oregon Metro RLIS include: Forest Park, hill shade, canopy cover, streets and arterials, buildings footprints, property lots, zoning, neighborhoods, urban growth boundary, city of Portland boundary, and Multnomah county boundary. Contours used within the study area maps are generated in Arcmap using the hill shade data supplied by Oregon Metro RLIS. Vegetation data is supplied through Oregon State's LEMMA (*Landscape Modeling, Mapping & Analysis*) data source and includes: canopy cover (CANCOV), shrub cover (SHRUBCOV), and Forest Type (FORTYPCOV). The Fire Risk map is supplied by Multnomah county (*Figure 1.7*).

Design Translations

To create the table of *Design Translations*, a two part literature review is conducted. The first section includes an overview of pre and post wildfire conditions and fuel break case studies. Informing this section are peer reviewed articles and books, guidebooks, and interviews with professionals. The second section includes a review of resilience theory, and the sub categories of ecological and social resilience. The result of the two-part literature review is a table of key ecological and social resilience elements connected to their associated fuel break design elements (see *Table 3.1* and *Table 3.2*), the connections of which will be described in detail in chapter four.

The definition of resilience supplied by Folke et al. (2010) is used as the basis for which the subsets of social and ecological resilience are categorized under. The subset of ecological resilience is described by the definition provided by Bergen et al (2001). Social resilience is described by the definition provided by Fitzgerald et al. (2005). The established definitions are distilled to a list of defining elements (see *Figure 3.2*). Categorization of social and ecological resilience elements is based upon noted similarities and or direct connection to the elements of the base definition provided by Folke et al. The resilience elements are used as the base for which the fuel break design elements, determined by the first part of the literature review, are categorized under.

Fuel Break Design

To determine which homes within the study are at the greatest risk to quickly spreading, intense wildfire, a two-part process is completed, which includes the creation of a base map and two design strategies specified for ecological and social resilience. The base map delineates a hierarchy of fire risk areas and is used identify areas that require greater vegetation removal closest to homes. The base map is created through the analysis of wind, slope, canopy cover, and delineation of home ignition zones. It is used as the basis by which two fuel break design strategies are applied. Additionally, the base map expresses the fuel break design area. The fuel break design area is separated into two parts: the neighborhood of Northwest Heights, and the combined land of Forest Park and the respective area of private forested land in between.

The neighborhood is treated in two parts: the core and the outliers. The core includes homes south of Skyline Boulevard and any group of three or more homes within fifty feet of one another. The outliers include all individual homes North of skyline boulevard, fifty feet or farther from another home. A preliminary home ignition zone of 100' feet is delineated for all outlier homes.

The length of the fuel break is equal to that of the perimeter of the core neighborhood, which is roughly 1,500'. The fuel break is offset from the core neighborhood by 50' in order to increase the distance between the 'wildfire treatment zone' and homes, which begins just North of Skyline Boulevard. The total width is informed by conclusions made by Safford et al. (2009), which suggets that the minimum width for a fuel break should be between 400-500 meters (roughly 1300’-1600’). These findings are used in combination with conclusions by Bennett et al. (2010), which asserts that minimum fuel break widths, within the states of Oregon and Washington, begin at 300’. These findings ultimately informed the design of a fuel break which includes four, connected segments of 300’, which are termed as buffers, adding up to a total width of 1200’ (see *Figure 1.9)*. The choice to include four buffers is made under the assumption that fuel treatment width would not be uniform across the entire length of the fuel break and would require room to extend and contract based upon the prescriptions applied. Additionally, a wider fuel break area is capable of including a majority of outlier homes, therefore increasing the range of home wildfire risk reduction.

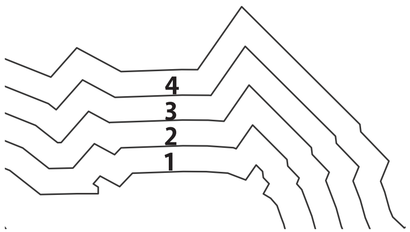


Figure 1.9 Four, 300’ buffer zones are designated within the fuel break design area.

There are four levels of fuel reduction represented in the design strategies – low, moderate, moderately high, and high (Levels of fuel reduction will be defined in further detail in chapter four). Fuel reduction is not assumed to be uniform within any one patch or buffer zone; the location of fuel reduction is dependent upon site specific topography and vegetation distribution.

Base Map

The first layer of the base map focusses on wind and slope together. Using Arcmap, slope is reclassified into four groups: gentle/flat (0-20%), moderate (20.1-40%), moderately steep (4.1-60%), and steep (60.1-100%). Wind is assessed by the direction it approaches residences. Since Northern winds area widely assumed to have the greatest intensity and are therefore more commonly associated with the ignition and movement of wildfire, this study only analyzes winds coming from a northern direction. Listed in order of respective intensity, wind directions analyzed in this study include direct North moving up slope toward structure, Northwest or Northeast (classified as crossing slope at an angle), and direct North moving down slope toward structure.

Slope and wind are cross analyzed respectively by their intensity level, the result of which is the first level of the hierarchical fire risk assessments. Each outlier home is assigned an individual risk level. Key points along the Northern edge of the core neighborhood are designated for risk assessment. Risk is assigned on the site map by an arrow ranging in size and color to represent wildfire risk.

The second layer incorporated into the base map is canopy density, which is defined by the amount of canopy species within one defined area. Canopy density, is reclassified into four groups based upon percentage of canopy cover: low (0-20%), moderate (20.1-40%), moderately high (40.1%-60), and high (60.1-100%). Patches of high canopy density are associated with higher wildfire risk. The risk assessment map is overlaid with the canopy density map and assessed for overlaps within their respective high risk zones. Risk zones are compared against one another, reassessed and filtered.

Design Strategies

Using a three-step process, two fuel breaks designs are created specifying strategies for ecological and social resilience respectively. Each part is divided into ecological and social resilience strategies, resulting in a fuel break design for each. The purpose of providing two fuel break designs is to assess how differing design goals influence the final product, providing insight into how we design for complex systems within the WUI.

Part one involves the application of select fuel break design elements designated in the table of translations, created in Section 2.3. Fuel break design elements are selected based upon their feasibility of application within the scope of this project based upon known and unknown information about the site and people within the neighborhood of Northwest Heights. The product of this application is two fuel break designs, one more optimized for ecological resilience and another for social resilience.

Part two incorporates dominant tree species data to inform prescriptive fuel reduction strategies within the fuel break area. Dominant canopy species data (GNN species map, series FORTYPCOV, supplied by LEMMA) is used to categorize patches into their inferred seral stage. Each seral stage is assigned to a fuel treatment associated with a specific level of vegetation removal, which are specified for ecological and social resilience strategies.

Fuel treatments for each seral stage are further broken down into groups based upon the characteristics of slope and shrub density underneath the tree canopy: flat/gentle slopes with dense shrub cover and steep slopes with dense shrub cover. Flat/gentle slopes are classified to (0-40%) and steep slopes as (40.1-100%). The result is two sets of fuel treatments for every seral patch, which are distinctly different between ecological and social resilience strategies.

Part one and part two are brought together in part three. Parts one and two are overlaid on top of the base map. Retained from part one is the buffer zone of highest fuel reduction. Part two is used to define fuel reduction prescriptions within the remaining buffer zones. This is completed for both ecological and social resilience strategies, resulting in two design maps.

Chapter Two

Literature Review

2.1 Literature Review

How Fuel Breaks Function

Commonly used fire management applications include: fuel breaks, fire breaks and prescribed burning. Each application may be used separately or together within any treatment area. A Fuel break, as defined earlier is, "a strategically located wide block, or strip, on which a cover of dense, heavy, or flammable vegetation has been permanently changed to one of lower fuel volume or reduced flammability" (Green, 1977). This definition implies that the treatment is specifically affecting the plant material, otherwise known as the fuel source, within the treatment area. The lowering of fuel volume, commonly referred to as *fuel reduction*, may range from the thinning of fuels to complete removal of above ground fuels.

It is important to note that fuel breaks are not meant to stop fires from advancing; they are a treatment meant to slow and or redirect fires (Kennedy et al., 2014). Fuel breaks are an appropriate application within the wildland urban interface because of their ability to be applied over large swaths of land. They may act to slow the approach of a wildfire long enough for first responders to arrive on site and control it, providing nearby residents with enough time to evacuate.

Different from a fuel break, a fire break is meant to stop the spread of fires and reduce fire intensity. Fire breaks are often used to manage prescribed burns, and involve the treatment of vegetation and land (Wheeler, 2014). Fire breaks include but are not limited to natural features in the landscape, such as waterways, trails, rocky outcrops and cleared land. Prescribed burning is a fuel reduction treatment, which acts to reduce available, flammable vegetation on site. Any application within the WUI that introduces fire into the treatment area, such as with prescribed burning, is unlikely to be approved due to the proximity of the application to residences.

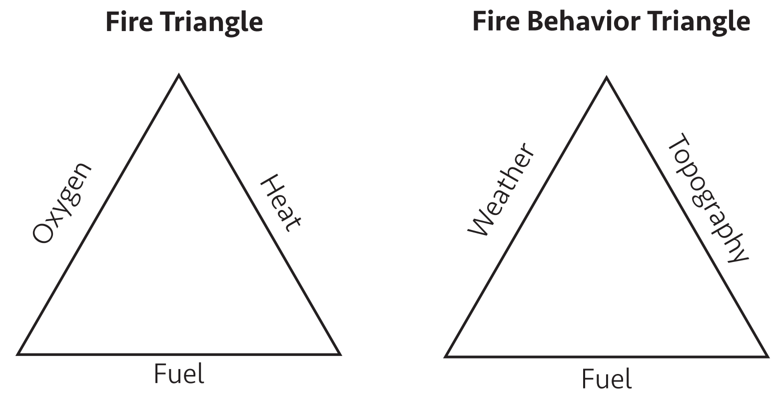
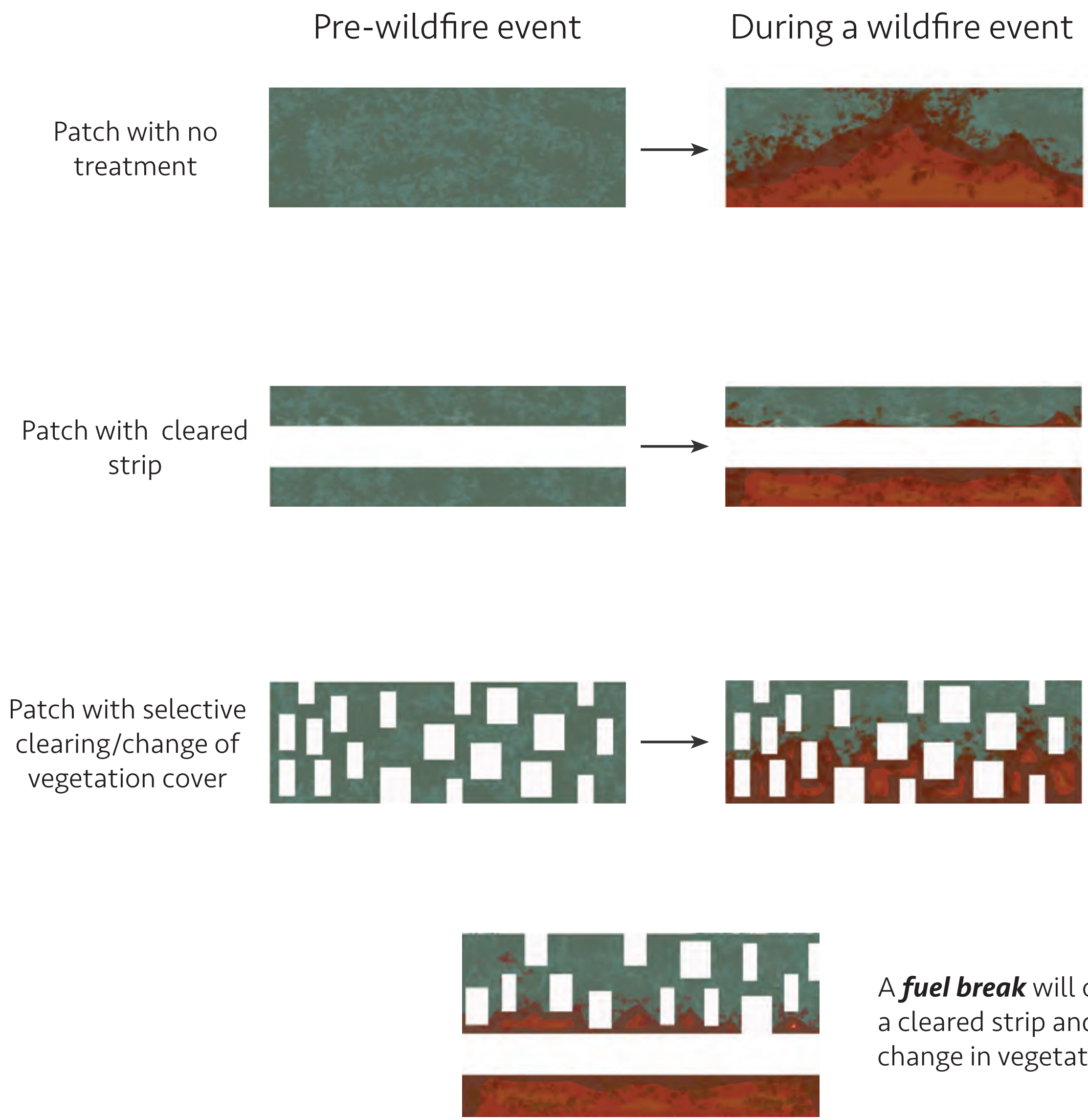


Figure 2.1
Fire triangle and fire behavior triangle.

To be able to design fuel breaks, an understanding of the factors influencing fires to start and potentially spread is required. Three elements must be present in order for a fire to start: fuel (plant material), heat, and presence of oxygen (see ***Figure 2.1**, fire triangle*). Each element is dependent upon the other for a fire to start, with different proportions of each changing the probability of a fire event happening and the intensity of which it will burn. Additionally, there exists three influential elements affecting the behavior of fire: weather, topography, and fuel. The element of fuel is able to feed a fire and change its behavior (see *Figure 2.1*, ***fire behavior triangle***).

Fuel in particular is the only element that people have the ability to influence directly. Through the removal of vegetation, people have the ability to control where fuels exist in the landscape, thus influencing fire start, spread, and intensity. Vegetation is also important because of its ability to indirectly influence heat and oxygen levels. Vegetation changes biophysical environments by creating shade and blocking wind that may push oxygen into a site, both of



Fire Tends to spread in a 'V' formation (Finney, 2001). When supplied with enough continuous fuel load, a wildfire ia able to spread. Depending on the fuel load, the intensity of a fire may increase as it consumes more fuel.

A strip of land cleared of all vegetaion may starve a wildfire of fuels, not allowing it to spread forward. If the cleared strip is not wide enough, fire may be able to jump the break. This type of clearing is associated with ***fire breaks***.

Selective clearing/change in vegetation cover breaks up the spreading formation of a fire in order to create smaller, less intense patches of fire. This treatment slows the progression of wildfire and is often integrated into ***fuel breaks***.

A ***fuel break*** will often incorporate both a cleared strip and selective clearing/ change in vegetation cover.

Figure 2.2
Patterns of fuel removal and their effect. Patterns are not based upon modelled data.

which influence fire. By selectively removing vegetation, through the application of designed fuel breaks, one is able to affect fuel, heat, and oxygen at the site level (see ***Figure 2.2 for examples)***.

Fire, and the landscape in which it exists, is three-dimensional; therefore, fuel treatment designs must consider biophysical interactions across the surface, below ground, and through the canopy of the landscape (see ***Figure 2.3)***. Patches desirable for fire spread are not just distributed on a horizontal plane through the landscape, but also in vertical sections. Fuels are often described as existing within three vertical sections of a landscape, the first being ground fuels, followed by ladder fuels, and lastly canopy fuels (Agee et al., 2000). Fuel break treatments function within all three of the vertical layers and across horizontal transects of the landscape. Fuel, heat, and oxygen are likely to exist in different ratios within all vertical and horizontal area of the landscape.

To add even more complexity, different fuel types within each canopy layer will require different treatments. Knowing what plant species are present, along with their bulk density, will directly inform the appropriate fuel treatment, which is why fuel break treatments are often site dependent and not universal (Kennedy et al., 2014).

Fuel breaks have been shown to be successful at intercepting wildfires at the ground level, but are still under scrutiny for their effectiveness in controlling the airborne spread of wildfire through firebrands. Firebrands are, "any source of heat capable of igniting wildland fuels, such as brush or trees" (Hargrove et al., 2000). They are typically composed of pieces of burning plant material that become suspended into the air and spread by wind, convection currents, or gravity (Hargrove et al., 2000). Firebrands pose a great risk to spreading wildfires because of their ability to travel far distances, creating new wildfire start points outside of the treatment area.

Assessing how far a firebrand may travel is difficult and highly variable depending on weather conditions, fire intensity, and the weight of the individual fire brand. A study conducted by *JFSP* and *Oregon State University* found that in comparison to other evergreen species, such as grand fir, ponderosa pine, and western juniper, Douglas fir generated the most embers per kilogram of mass loss (Blunck et al., 2019). This suggests that thinning of mature Douglas fir within a fuel break may limit the chance of fire brands landing closer to residences. The safe distance to retain wildfires away from homes is also determined by the distance a firebrand may travel; therefore, fuel treatment area may need to be extended to account for this distance.

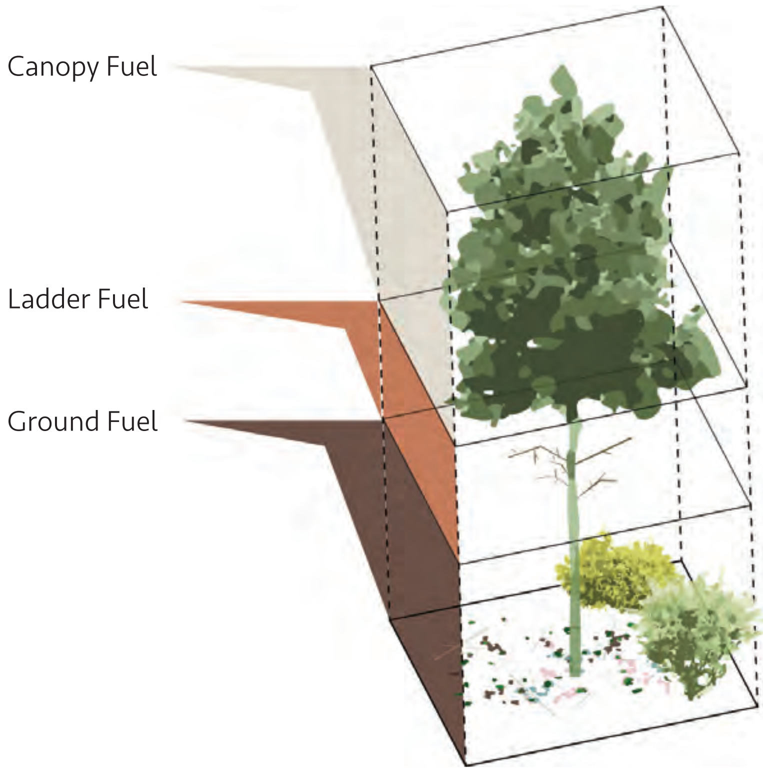


Figure 2.3
Three layers of fuels expressed within forest vegetation strudture: ***Canopy, Ladder, and Ground fuels.***

Fire Prone Species and Succession

Understanding succession within Forest Park is necessary to understanding the lifecycle of fuels and when fuels that are most vulnerable to catching fire are present. In this case, vulnerability is based upon the species ability to withstand catching fire and not its ability to regenerate post fire. Specific species are associated with certain phases of forest succession, which is a determined by the lifecycle of each individual species. Since disturbance, such as a forest fire, tends to occur in patches and not homogeneously across a landscape, forests tend to be composed of a matrix of patches at different successional stages. This means that at any given time, the landscape may be constituted of a mix of vulnerable and resilient species depending on the stage of various patches. Additionally, the dispersal of patch types at any given stage of succession may not be distributed evenly within a landscape. One forest may contain a higher percentage of area at an early stage of succession, while another may contain a greater area at a late succession stage.

In the context of Forest park, six successional stages are present, each of which constitute as specific amount of patch area within the park. Disturbance, which leads to changes in successional stage, have been diverse with historical events over the last 150 years. Logging activities in the early 1900s cleared hundreds of acres of late successional forest stands. At this point, the land was brought back to an early succession phase. The amount of early successional patches in the park today is not representative of how historic disturbance, such as fire, would interact with the landscape (Houle, 1987). The six successional stages represented in Forest Park: grass-forb, shrub, hardwood with young conifer, conifer topping hardwood, mid-aged conifer, and old growth (see *Figure 2.4)*.

The grass-forb stage is characterized by an abundance of grasses, Canadian thistle, bracken fern, and fireweed. After disturbance, such as a fire, the landscape is exposed to light, which allows dormant seeds to germinate. In the shrub stage, hardwood species such as Red alder, Bigleaf maple, Willow, Bitter cherry, and shrubs such as thimbleberry, salmonberry, red-flowering current, Indian plum, and blackberry are abundant. Young hardwood saplings are also seen. Seeds of native shrubs may be brought in by wind or animals where they are caught in the low, ground vegetation associated with the first stage (Houle, 1987). Shrubs provide fine fuels capable of sustaining a wildfire; therefore, landscape patches at the shrub stage are particularly vulnerable to wildfire. Young saplings also represent fine fuels capable of sustaining a wildfire in ideal conditions. In a wildfire scenario, saplings may be tall enough to allow flames to reach ladder fuels of older trees, exposing canopy levels fuels to fire and accelerating the spread of wildfire.

In the hardwood with young conifer stage, hardwood species have grown above the level of shrubs and are the dominant vegetation. Also present are a few evergreen saplings, such as Douglas fir, present in the understory. Unlike hardwood species, which require more light, evergreen species are shade tolerant and can survive under the dense canopy of other species. In this phase, saplings still pose a risk for spreading wildfire into the upper canopy. As the name suggests, during the conifer topping hardwood phase evergreen species begin to overtake the hardwood species, growing much taller than and eventually shading them out. Douglas fir and Western Hemlock are now the dominant species, with some scatterings of Bigleaf maple and Red alder in the understory remaining (Houle, 1987).

A mixed-age conifer stand represents an evergreen dominated forest, where the majority of hardwood species have died off. Shade tolerant evergreen trees and understory shrubs, such as western hemlock, western red cedar, grand fir, sword fern, Oregon grape, red huckleberry, vine maple, and salal, persist in this phase. Last is the old growth phase, wherein evergreen species in the over story reach maximum growth potential for height and diameter. The understory in this phase is composed of a complex of downed trees and snags. Currently, Forest Park contains less than 0.5% of old growth within its boundary (Houle, 1987).

Figure 2.4
Composition of evergreen to deciduous species within the six successional stages within Forest Park.

Certain species are noted as being more vulnerable to catching fire or dying from fire damage than others. Vulnerability to fire is determined by bark thickness, height of ladder fuels, canopy density, and root depth. James K. Agee identifies twelve key evergreen species within Washington and Oregon and makes conclusions on which have the greatest and lowest susceptibility to fire. Tree species identified to have the greatest susceptibility are: Noble fir, White pine, Lodge pole pine, Western hemlock, Engelmann spruce, and Sitka spruce. Those with greater resistance include: Mountain hemlock, Western red cedar, White/grand fir, Ponderosa pine, Douglas-fir, and the Western larch (Agee, 1993).

Of the susceptible species listed, it is noted that thin bark and root char are key limiting characteristics of these species that makes them vulnerable to fire. Bark acts as a physical barrier protecting the inner cambium of the tree. Because of the water content, bark also helps to diffuse heat. Water, as mentioned earlier, may act to absorb heat that would otherwise transfer to fuels. The thicker the bark a woody plant has, the greater area for heat diffusivity there is (Agee, 1993).

Common Hardwood species within Forest Park include Bigleaf maple, Red alder, and Oregon white oak. Bigleaf maple is noted as being the most vulnerable species to fire, because of its thin bark, followed by Red alder. Oregon white oak is noted as being highly fire resistant (FEIS, 2019). While the low branching style, and thin bark of deciduous trees make them theoretically inadequate for fire resistance, they are notable for the water content of their leaves. As in bark, water in leaves is a great heat diffuser. It is thought that deciduous trees offer greater fire suppression properties to forests than evergreen because of their ability to absorb a great deal of heat before the woody vegetation catches fire (Bennett et al., 2010).

Evergreen species, which dominate much of the later successional stages, are thought to generally be less susceptible to fire than deciduous species. This is in part because of two factors: bark thickness and stand age. Evergreen species tend to have thicker bark than deciduous species, making them better at resisting heat. Additionally, many species of evergreens have longer lifespans than deciduous trees and are able to grow very tall over time, lending to them retaining higher ladder fuels that make canopy fires less likely, allowing them to persist. Late successional stands with greater amounts of older trees tend to be more fire resistant than earlier successional evergreen stands however.

In regards to the compared fire risk of deciduous species, all early successional stages may qualify as having high fire risk. Mid-successional deciduous species may be thought of as comparable to late successional evergreen species. This is determined by weighing the properties of water content (greatest within deciduous species) against bark thickness and canopy height (greatest within evergreen species).

> ***In conclusion**, stages including small shrubs and saplings present the biggest source of fuel for fire. Shrubs and saplings, with their thin bark, and small diameter branches hold much less water than older trees, making them ideal for heat conduction. Additionally, their low ladder fuels make it easy for canopy fires to occur, which is likely to be detrimental to all woody plants. Early successional phases, when young saplings are present, are periods with greater potential for fire damage. This means that within the first ten years following a disturbance (such as a fire event). The chance of having another damaging fire event is potentially higher than any other time period because of the prime fuel sources available. Lastly, it can be assumed that increasing temperatures and changing weather patterns will affect the potential for fire events, potentially increasing their likelihood.*

Nonnative and Invasive Species Introduction

Fuel breaks utilizing the 'common method', where ground through canopy layers of vegetation are removed, not only leave the soil exposed to the elements, but may act as footholds for nonnative species to germinate (Merriam et al., 2007). Open areas of disturbed soil, as are left by the creation of conventional fuel breaks, are ideal places for nonnative seeds to land. The churning of the soil, as often occurs during plant removal, is thought to disrupt the seedbank, making native species less likely to germinate readily. Machinery, used for mass vegetation removal, may track in seeds from other sites, inadvertently adding new species to the seedbank. A lack of competition and increased sunlight make the perfect conditions for nonnatives to take hold. Additionally, nonnatives may act to change soil nutrient and water levels once they take hold, making soil conditions less appropriate for native species. Since nonnatives displace native species, they are a direct threat to ecosystem diversity.

A study conducted in California showed that nonnative species were more abundant adjacent to fuel breaks and that the concentration of nonnatives was highest closest to fuel breaks, suggesting that the fuel break was the initial point of seed entry. The same study showed a correlation between the amount of overall vegetation present and the presence of nonnative species. Cleared land had the highest amount of nonnatives present. Land with ground covers to mid-level shrubs present contained less. Land with over story canopy contained the least (Merriam et al., 2007).

Ground covers, in the form of woody debris or duff, have been shown to decrease the chance of invasion by nonnatives (Merriam et al., 2007). Leaving this kind of debris is not ideal however, given that a buildup of fine, dead vegetative materials is an excellent fuel source for fires to start (Ingalsbee, 2005). A green, native ground cover may be the ideal choice to block nonnative seeding while not supplying enough fuel to encourage a fire.

There are many additional benefits to having a vegetated ground cover. Low lying vegetation may reduce soil exposure, contribute to habitat connectivity, and may provide an additional food source for wildlife. Additionally, any amount of vegetation can contribute to increased humidity levels, which as mentioned previously, may help decrease heat transfer to plant material.

Fuel Break Design

The recommended area that a fuel break covers is determined by the amount of vegetation present, the topography of the site, and the presence of natural fire breaks. The minimum, suggested width of a fuel break is 200' wide (Bennett et al., 2010). Because vegetation cover within forests of North Western Oregon is classified as dense, it is recommended that fuel breaks in this region be at minimum 300’ wide (Bennett et al., 2010). The presence of steep slopes necessitates an increase of the width of the break in order to maintain its effectiveness in the scenario of an intense fire. It is recommended that for every 10% increase of the slope, the lowest point of the break should be extended five feet on average (Bennett et al., 2010). The presence of natural features should determine where the fuel break treatment area is located and its extent, by means of influencing biophysical elements on the site. The presence of natural features may be effective enough in limiting fire movement that a fuel break width may be reduced. Additionally, natural features may necessitate that different proportions of a fuel break may be allocated on either or both side of the feature (Bennett et al., 2010).

Within the area of a fuel break, effective prescriptions for vegetation removal may be homogeneous or heterogeneous across the treatment area. This includes removal through the vertical sections of the canopy as well. When designing fuel breaks, one must decide how much fuel must be removed from each fuel layer. Given that fuels are one of the three factors for fires to start and proliferate, it can be said that where fuels exist in the landscape there is potential for fire under desirable conditions. Because of this, fire management plans have typically opted to remove the maximum amount vegetation within the treatment area, with the intention of starving a fire of any fuels.

This conventional method, provides a high chance of success in preventing the spread of fires, but often has a negative impact on local ecology of a site. Vegetation is a key component of habitat, supporting shelter and food needs of species as well as changing the biophysical environment. Heavy removal, across a 200-300’ breadth, may fragment habitat, leading to smaller patches of interior habitat and creating gaps that allow excess light and wind in. There is a direct tradeoff between leaving fuels and removing them; leaving fuels may result in a weak fuel break. In order to achieve the same level of effectiveness, the width the treatment area may have to be greater than one with no fuels present, thus creating a wider area of habitat disturbance (Bennett 2010; Finney, 2001).

> ***When designing fuel breaks**, one must ask what the goal of **the treatment is and who or what should be protected.** Providing for a resilient environment on either side of a fuel break may be difficult to do if one fuel break prescription pushes the brunt of disturbance to one side. Fuel breaks, as a fire management tool, might be flexible enough to bridge the gap between the needs of social and ecological systems, increasing resiliency on both sides of the fuel break.*

Interestingly, leaving some tree canopy may be more advantageous than previously thought. While plant material such as trees and shrubs do act as fuels in the landscape, they may also act to increase understory humidity and moisture levels. When tree canopies are removed, understory plants have greater exposure wind and to sunlight, which is a heat source (Agee et al., 2000; Agee et al., 2005; Bennett et al, 2010). Heat causes plants to lose moisture through evapotranspiration, which leads to drier fuels, thus making the chance of ground level fires more likely. When evapotranspiration occurs, heat is transferred to water molecules within the plant material, causing the water to dissipate as vapor. Once water is gone, heat may transfer to the plant material, the fuel. If air or soil moisture levels are high, this effect of heat on fuels will be limited. Wind exacerbates the drying of plant fuels by facilitating the movement of water vapor in the air, increasing evaporation rates, and reducing air humidity levels. ***In conclusion**, fuel breaks that prioritize clearing may inadvertently increase the risk of fire within the treatment area by increasing the exposure of the landscape to sun and wind (Reinhardt et al., 2008).*

Understanding that fires are most likely to start within ground fuels, it is suggested that fuel removal take a ground up approach (Agee et al., 2000; Agee et al., 2005). It is advised that canopy fuels not be removed unless absolutely necessary because of their value for habitat connectivity and maintaining moisture levels in the understory (Ingalsbee, 2005). Thinning of the canopy, may create enough distance between individual trees or patches of fuels to keep wildfire from directly spreading from one to another (Agee et al., 2000; Agee et al., 2005). Some authors suggest that thinning may also reduce competition of resources for the residual trees, allowing them to grow faster, accelerating the rate by which they reach old growth status (Agee et al., 2005). Older trees, which typically have thicker bark and greater moisture content may be most appropriate to leave in fuel breaks because of their ability to resist heat transfer (Agee, 1993; Amo et al., 2005; Ingalsbee, 2005). Long term goals of landscapes managed for fire should support the longevity of the oldest growth on site and designate key small diameter trees to maintain for the purpose of replacing those old growth trees in the future (Agee et al., 2005).

Historic Connection to Logging

There are multiple political and economic factors influencing the goals of fuel break designs. Factors include the amount of funds available and the desires of stakeholders.

Stakeholders are those who are directly impacted by policy decisions or have specific interest in a project and are directly involved with the setting of design goals. Goals for fuel break designs within the wildland urban interface of the Western U.S. have historically been focused on preventing wildfire from spreading into residential communities, allowing ecological considerations to be neglected (Reinhardt et al., 2008).

Fuel treatments can be very costly. Federal land management agencies spent $2.7 billion on fuel treatments in the western US between the year 2001 and 2006 (Syphard, 2011). It can be inferred that amounts spent today are equal to if not greater than previous years based on the increasing concern for fire management. Funding stands to be one of the most difficult factors to navigate. Vegetation removal on its own is expensive, especially when one considers implementing a complex, mixed vegetation plan, involving selective tree and lower canopy removal, such as would be required to create an ecologically conscious fuel break design. Because of this, fuel break designs have favored the homogeneous removal of vegetation for the sake of cost and time.

Logging companies stand to gain a lot from a partnership with the BLM (Bureau of Land Management) and have historically been involved with fuel break projects. Logging companies offer their tree removal services, towards the creation of fuel breaks, in exchange for logs to sell at market. Logging can be highly disruptive to ecological systems. Heavy machinery used during the extraction process compacts soils and disrupt seed banks. Loggers prefer to take trees with larger diameters at breast height.

Fire and landscape patterns

Patterns of fire movement are highly influenced by topography and site specific natural features, such as ridges and rivers, which may act to cut off the spread of fire or discourage its progression by reducing the presence of fuel, heat, and oxygen. Topography, such as hills and valleys directly influence fire movement by way of diverting and channeling winds through the landscape (see ***Figure 2.5)*** . This changes biophysical elements as well as actively influencing fire movement. Additionally, fires produce convective heat, which accelerates them to move uphill with wind movement. Wind currents move down and up out of valleys, pushing flames uphill as they leave. There is a strong correlation between slope steepness and the rate at which fire spreads up hill; wind and convective heat will move wildfire faster up steep slopes.

Natural features influencing fire movement include ridges, rocky outcrops, grazed land, and waterways. The presence of a natural feature does not dictate a fire boundary, however, since not

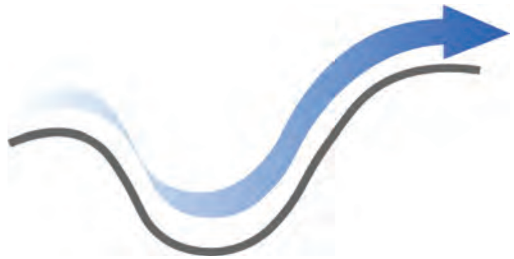


Figure 2.5
Wind picks up speed as it moves down and up, out of valleys.

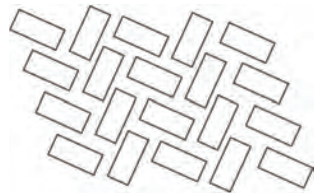


Figure 2.6
Herringbone pattern.

all features are made the same. For example, a river with a complex, interwoven channel system containing multiple fuels break across a wide expanse is more effective than a single channel with only one fuel break point (Swanson, 1981). It is important to note that natural features may change over time as well. For example, grazed land that once did not supply enough fuels to maintain a fire may undergo succession, gaining small trees and shrubs that would eventually build the fuel load enough to sustain a fire. In this example, land that was formerly fire retardant fluctuates to a fire prone landscape. Conversely, a fire may desiccate the fuel load of a patch in the landscape, making it far less fire prone than before.

Fluxes of landscape patches from fire prone to fire retardant, and vice versa, create a patchwork of land with varied levels of fire potential. As one patch shifts to high fire potential, another is shifting to low fire potential. This maintains that large areas of continuous fire prone patches are not able to burn at once, which contributes diversity within the landscape. Modern fire maintenance techniques promote fire suppression, which disrupts the natural fluxes of fuel within patches, which contributes to a homogeneous landscape, and thus less diversity (Ingalsbee, 2005). Site specific diversity, as is maintained by natural fires, is associated with ecological resilience and therefore represents the ideal for maintaining productive ecological systems. Fuel break designs that encourage diversity of patch types are therefore encouraging resiliency (Bergen et al, 2001).

Fuel breaks are designed to interrupt the spreading formation and rate of fires. They are typically placed against the grain of the topography, oriented adjacent to ridges, so as to intercept fires as they move across the landscape. Because a moderately intense fire is likely to surpass a single section of treated fuels, it is recommended that fuel breaks have multiple wildfire interception points. A study conducted by Mark A. Finney (2001), analyzing fuel breaks within a simulated model, found that overlapping treatment areas have the greatest success of reducing the rate of fire spread. In particular, it was found that a herringbone pattern is most preferable for intercepting fire spread (see *Figure 2.6)*. This, however, assumes away the influence of topography, natural features, and vegetation types. Across the extent of a linear fuel break, patterns of vegetation removal may morph to fit the needs of the kind of landscape it transects. ***By delineating where changes in topography occur, along with where natural features, fuel breaks may be designed to better respond to the specific site and thus be more functional in slowing the spread of fire.*** This research will explore options for how these considerations can inform design.

Fuel Break Case Study

The placement of a fuel break can determine whether it is successful at buffering wildfire. In a study conducted by Alexandra Syphard, in Los Padres National Forest, California, showed that few fuel breaks within the study area ever intersected wildfires. In fact, 79% of fires occurring between 1980 to 2007 on site did not intersect with a fuel break. Of those that did, there was a 46% success rate of the break to slow and or curtail fires. Success of the fuel breaks that did intersect fires was strongly correlated with access by fire crews. The second correlating factor for fuel break effectivity was maintenance. Sections with vegetation maintained to the standards of the fuel break exhibited slower spread rates and increased accessibility of fire fighters to the site. Lastly, topography played a key role in slowing fire progression. Less than 1% of fires progressed over ridgetops through the mountain range (Syphard et al., 2011).

What can be concluded *from this study is that successful fuel break design should use site analysis of topographic features, biophysical elements, historic fire data, and potential access points for fire crews to determine the best placement for fuel breaks. In terms of ecological considerations, if fuel breaks are sited properly, fewer may need to be used in order to be successful, thus limiting the amount of habitat disturbed.*

Chapter Three

Applying Resilience Theory

3.1 Resilience Theory

By analyzing resilience theory, this study seeks to gain a better understanding of social and ecological systems and how fuel breaks work within them. The resilience of ecological and social systems is of increasing importance in the face of climate change, which is directly linked to global warmer that contributes to wildfire events. Specifying elements of fuel break design in order to increase resilience is therefore crucial. This portion of the study identifies key elements of ecological and social resilience and described. Elements of fuel break design, identified within the literature review, are categorized under each of the resilience elements to create a table of design translations. The resulting table may be used to assess whether the resilience of a fuel break design may be increased and to gain a better understanding of the resilience elements that driving a given fuel break design. It is important to note that not every site may be able to incorporate all aspects of resilience within one design area. The table provides options that may be tested and or applied within fuel break design.

Defining Resilience

Resilience is defined by Fitzgerald et al. is, "the ability of materials, structures etc. to withstand a shock or stress, and their ability to self-correct once this shock has occurred" (Fitzgerald et al., 2005). This definition provides a general understanding of resilience that may be applied to any field and is applicable for describing the reactions of a system to catastrophic disturbances. The definition provided by Folke et al., which is being used for this research, provides a more detailed understanding of the interactions occurring within a system that influence resilience and is applicable for describing system reactions at different levels of disturbance. It is a preferable definition to use because it is defined so as to be applied to ecological and social systems, which are precisely the systems being focused on in this research.

Folke, et al. describes resilience as, "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks, and therefore identity, that is, the capacity to change in order to maintain the same identity." The identity of the system refers to its regime. A regime refers to the set of parameters that define the stable state a system exists within. The definition by Folke et al. asserts that change is a functional way for systems to respond to disturbance. Change refers to the ability of the system to introduce new functional pieces and lose ones that are no longer serving a purpose within the system. Reorganization allows for these pieces to shuffle and replace one another.

System flexibility is important to allow for replacement and reorganization. Reorganization must occur within the regime parameters for the system to maintain its identity (Folke et al., 2010). Flexibility is directly applied to the regime and its ability to redefine its parameters to accept change. The greater amount of flexibility a system has, the better able it is to adjust following a disturbance. If a system is too rigid, it may not have the capacity to reorganize causing the system to cease functioning as before. When this happens, the system falls into a new regime, with a new identity (Folke et al., 2010).

It is important to note that resilience theory can be applied to variety of system types at different scales and often at the same time. Resilient design should consider how each scale interacts with others. For this research, I am working at the neighborhood scale and the scale of an individual lot, using Forest Park and its immediate residential areas as the context (map to be referenced). I am applying resilience theory to ecological and sociological systems within the study area. This research will assess how one form of resilience affects another, specifically looking at how to co-design for the resilience of both ecological and social systems.

The resilience of a system is determined by persistence, adaptability and transformability. Persistence refers to maintaining the pieces of a system that influence the function, structure, and feedbacks as they are. Adaptability refers to system capacity to respond to external factors by changing internal responses. Transformability refers to an ability to change and potentially lead to new long term evolution of the system. This often involves a reorganization of how different pieces interact within that system (Folke et al., 2010) .

Ecological Resilience

Ecological resilience focusses on the ability of any natural system(s), within a specified scale, to respond to shock and adapt to change. Resilience within ecological systems is indicated by its diversity and complexity. Diversity is a product of the number of species, genetic variation within species, and functional diversity. Complexity of the system evolves from diversity and the complex interactions of sub-system scales. Driving the development of ecological resilience is functional tolerance, energy input, and the ability to self-organize and evolve (Bergen et al., 2001). Each of these can be understood within the founding components of resilience (persistence, adaptability and transformability).

For fire prone landscapes, a wildfire regime is defined by the average intensity of fire events at one scale. Fire intensity is determined by the average percent of canopy that is burned during a fire event. The Tualatin mountain range, where Forest Park connects to, is historically characterized by a mixed severity fire regime, which indicates that during an average fire event 20-70% of the canopy is burned (Perry et al., 2011). Historically, in systems maintained by fire regimes, moderate fire is a necessary disturbance for many plant and animal species to thrive.

Ecological systems have long been adapted to coexist with disturbance, which is directly linked to increasing diversity and complexity of ecosystems. Disequilibrium of a system makes reorganization and change easier to occur at a variety of scales. During a disturbance, the system is affected disproportionately at each scale, creating a complex of different functional states. The interactions between these diverse states form the spatial structure of the system. In this way, disturbance redefines the system's structure and functions to be more complex (Holling, 1996). It is important to note, however, that every system has a tolerance for disturbance and too much disturbance may change the identity of that system. This is referred to as functional tolerance, which is a driver of system flexibility (Holling, 1996). It is widely accepted that more complex and diverse systems are able to tolerate more disturbance than simpler ones.

In order to integrate ecological resilience into design for forests, one must first consider where the structure and or function of a system needs to be improved, then decide what natural processes may be improved through design. Ecological design is defined as, "any form of design that minimizes environmentally destructive impacts by integrating itself with living processes...," and, "...respects species diversity, increases habitat quality, and attends to all the other preconditions of human and ecosystem health." (Bergen et al. 2001). In many ways, this definition is already considering resilience theory by way of describing an integration of policy, or governing action plans, with ecological systems. Successful ecological design mimics natural processes, or fills a gap left by a disturbance of an ecological system (Bergen et al., 2011). This can be thought of as adding a new piece to a system undergoing reorganization, as occurs during the process of building resilience.

***Fuel beaks designed for ecological resilience** should ideally be able to respond to changes in the landscape and enhance the complexity of a system that isn't experiencing regular disturbance. This requires a great deal of specificity. Since historic forests are heterogeneous, plant and animal species will vary between patches. Fuel breaks must be specific to habitat types, identified by the plant and animal communities present, in addition to historical disturbance regimes associated with that habitat. Specifications should reference the key factors for ecological resilience: functional tolerance, energy input, and the ability to self-organize and evolve.*

Functional tolerance is directly linked with diversity and complexity. Given that a fuel break is created by the selective removal of vegetation, one can increase diversity by prioritizing retaining native vegetation and select patches of vegetation for habitat purposes (Bennett et al., 2010). To increase variation in the landscape in order to promote diversity and complexity, the orientation and pattern of vegetation removal within the fuel break may be specified to retain diverse patches of habitat and vary stand structures. Maintenance, in the form of vegetation removal, is a form of energy input required for the upkeep of fuel breaks. In natural systems, it can be hard to keep specific plant species from growing back within the break area; selecting plant species that will require less maintenance over time, or that will compete with invasive species, is recommended so as to lower energy inputs (Bergen et al., 2011). Lower the energy inputs are associated with increased resiliency. Lastly, to increase resilience, one may consider replacing dysfunctional species with ones that are better suited for a changing landscape, therefore promoting adaption.

Social Resilience and Fuel Break Design

Social resilience focusses on increasing the ability of social systems, specifically communities, to withstand shock or stress and the ability to correct itself afterwards. This kind of resilience relies heavily on the ability to share information and resources, as well as the ability to form a shared set of community values and goals to inform policy making. Politics, economics, and cultural identity of the community highly influence the ability for these components to be achieved (Fitzgerald et al., 2005).

Fire is a direct threat to social systems because it can severely damage homes, injure people if not lead to fatality, and also has the effect of causing distress to people. Communities within the WUI have a great risk to these negative social impacts of wild fire. Fire management methods, such as fuel breaks, may act to make communities more resilient against fires and their secondary impacts by means of reducing the physical threats of fire and potentially giving people more time to react during a fire event. Driving the development of social resilience within fire management methods are: community engagement, damage prevention, location, and adaption.

In order for fire management methods to be successful, they must be integrated into a larger action plan that considers the communities needs/wants, without which the community will be unwilling to follow through with prescriptions. Needs and wants are determined by the value a community places on their sense of security and property, and what they are willing to give up in order to secure these. In the realm of this study, it may mean agreeing to additional taxes to fund fire management methods, giving up trail access, or accepting fuel break construction and therefore a new aesthetic identity of the landscape.

Within the realm of fire management, sociological resilience is typically achieved by implementing management techniques that are low cost and offer the greatest chance of protecting residences and valued land resources. This often equates to fuel break designs that meet maximum standards for width (a typical break width is suggested to be between (400-500 meters) and involve complete fuel reduction, or complete removal of all vegetation (Kennedy, Maureen C., Morris C. Johnson, 2014). This encompasses what I will be referring to as the 'common method' when it comes to fire management techniques. The thought process behind this makes sense. The less connectivity of fuel sources, the less likely a fire is able to spread. The slower the spread rate, the more time fire crews have to reach the site and take action to control the fire. Since fire patterns cannot be precisely predicted, despite the efforts of scientists to map potential patterns, it may be best to look towards preventative measures with the greatest chance of increasing success in fire control.

In terms of locating fuel breaks to increase social resilience, it is important to consider two factors: fire crew access and spatial justice. Locating fuel breaks where fire crews may have better access to fire prone areas is important to increase the speed at which crews are able to begin control efforts. Immediate treatment is necessary within the WUI to secure residents and their homes from wildfire damages. A study conducted in Los Padres, California showed that patches of cleared land created by fuel breaks act as key access points for fire crews to reach fires (Syphard et al., 2011). The second factor of spatial justice considers what social groups are being prioritized for safety measures. Fuel breaks should be equitably distributed through all at risk areas to not exclude any social groups from security efforts (Fitzgerald et al., 2005). In order to increase social resilience, community perceptions of the landscape may need to be adapted to express new values. In many ways, the landscape is defined by the cultural values and uses applied to it. For the neighborhoods that surround forest park, there is likely a shared identity for all of the people living there that they live on the upper hillsides, spotted with old conifers and shady deciduous trees. Their choice to live in that neighborhood likely defines their value o forest aesthetics and proximity to nature. Fuel beaks, by nature, change the vegetation, and will undoubtedly change the experience of community members with their surrounding landscape. People may have to change their position on the aesthetics of a lush tree line or look for alternative shading methods in order to implement fire management techniques that ultimately would increase their sense of security. ***Here, design work must consider the cultural values people of a given community put on certain defining characteristics of the landscape and assess what amount changes are appropriate.***

Comparison of Tradeoffs

Between the two branches of resilience discussed, fire management plans tend to focus more on social resilience rather than ecological (Arno & Fiedler, 2005). Policy makers, who are the lead contributors of fire management plans, are primarily concerned with the safety of people and their property, often unintentionally undervaluing ecological concerns. The common method, associated with social resilience, is effective in maintaining community security, making it the ideal design choice for such policy makers. Additionally, because the common method does not require much specificity, a crew can quickly remove large swaths of vegetation, providing the additional incentive of being time effective and cost efficient.

There is a direct tradeoff between social and ecological fire management methods however. The common method often lacks the site level specificity required to address the ecological needs of a site, even negatively influencing the local ecology. Here, increasing the resilience of one system negatively affects the other. Well designed and innovative fuel breaks may act as a flexible fire management tool capable of bringing the goals of both social and ecological resilience together (see ***Figure 3.1)***.

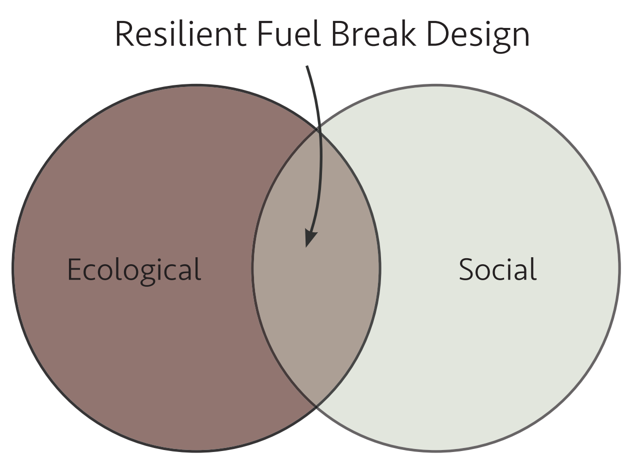


Figure 3.1
Resilient Fuel Break Design is at the intersection between design for ecological and social resilience.

Figure 3.2
Categorizing
Resilience Elements

Resilience

Ecological Factors

Persistence
- Functional tolerance
- Energy input

Adaptability
- Self-organization
- Redundancy

Transformability
- Evolution

Indicators
- Diversity of patch types, spe-cies, & species composition
- System functionality main tained

Social Factors

Engagement
- Creation of action plans

Adaptability
- Aesthetic identity
- Activities

Prevention
- Increase physical security
- Increase sense of security

Location
- Access
- Equitable distribution

Indicators
- Policies reflect communty goals/values
- Physical and sense of security increased

Categorizing Resilience Elements

Resilience elements, distinguished for ecological and social resilience respectively, are categorized in ***Figure** 3.2*. Key resilience elements are noted and further distilled to their defining parts. For ecological resilience they are: functional tolerance, energy input, self organization, redundancy, and evolution. For social resilience thay are: creation of action plans, aesthetic identity, activities, increase physical security, incrase sense of security, access, and equitable distribution.

In ***Tables** 3.1* and *3.2*, the defining elements for each resilience strategy are paired with fuel break design interventions, distinguished from the literature review. The decision making for each category is further discussed in ***Section** 3.2*.

Table 3.1
Design translations: ecological resilience.

Ecological Resilience	Intervention
functional tolerance	creation of enclosed, safe to burn space
	Less disturbance of interior habitat
	Prioritizing native/rare species for preservation
	Take care to reduce vegetation removal in patches prone to erosion
	Retention of oldest trees on site
energy input	Removing fast spreading plants near break
	ground cover decreases nonnative and invasive species introduction to site
self organization	systematic clearing where disturbance is needed to encourage stand age diversity
	making room for new species/land use types
redundancy	Prioritizing specific patches of habitat for peservation
	Inclusion of species/land uses with similar function
evolution/adaption	Introduction of species adapted to Southern Climates
	Shift out of current fire regime- corresponding with shift in forest type
	Shift to human derived disturbance regime

Integrated Into Case Study Design

Table 3.2

Design Translations : Social Resilience.

Social Resilience	Intervention
Creation of Action Plans	Responds to the cultural needs of community
	Responds to the recreational needs of community
	Expects maintenance needs of fire management prescription
Aesthetic Identity	Change of identity with landscape aesthetic
	Systematic clearing to preserve key focal/access points
	Maintain landscape defining plant species
Increase physical security	Creation of wider, less vegetated fuel breaks
	More fuel breaks put in place
	Removal of vegetation closest to homes
	Removal of vegetation in herringbone pattern
Increase sense of Security	Fuel Break is set back a specific distance from homes
	Community trusts fire treatment prescriptions
Access	Access points for fire crews designated & maintained
Equitable Distribution	Fuel breaks are equitably distributed to all designated at risk areas

Integrated Into Case Study Design

3.2 Design Translations: Fuel Break Design Prescriptions Informed by Previous Studies

This section expands upon the reasoning behind the categorization of design interventions with their associated resilience element. Information gathered in the literature review is reiterated and synthesized for each of the design interventions listed.

Ecological resilience

Functional tolerance

Creation of enclosed, safe to burn space

Prescribed burns, which involve the intentional burning of select parts of the landscape, are one way of reducing fuel loads that would otherwise help to proliferate wildfire events. Large fuel loads are thought to result in fires that burn too intensely for even an adapted environment to withstand and over greater expanses of land (Agee, et al., 2000). Prescribed burns may occur within the fuel break area or before the fuel break (Cochrane et al., 2012; Ingalsbee, 2005).

Less Disturbance Interior habitat

Vegetation removal associated with fuel breaks is a form of disturbance that impacts habitat composition. If the goal of the fuel break is to increase the security of structures, and primarily homes within the WUI, fuel breaks may be placed closer to the structures. Additionally, by placing them closer to structures, fewer fuel breaks, covering less area may be needed. This option reduces fragmentation and aids in the conservation of interior habitat, which is home to a diverse array of species that can't or don't normally live within edge environments (Spies et al., 2010).

Prioritizing native/rare species

Since diversity is directly related to ecological resilience, keeping native/rare species is a way we can maintain the defining species of the region of the Pacific Northwest and promote heterogeneity within the landscape. Prioritizing native/rare species when thinning vegetation is one way of managing for diversity (Merriam et al., 2007).

Take care to reduce vegetation removal in patches prone to erosion

Heavy removal of vegetation on steep slopes may destabilize the soil, leading to erosion and or landslides that may disrupt forest composition and deplete soils on the hillside. Heavier fuel reduction treatments at the bottom of slopes may be able to intercept fire and reduce its intensity before it spreads uphill (Amo et al., 2005).

Retention of oldest trees on site

It is widely known that older trees provide more ecosystem services than younger trees; therefore, prioritizing the retention of them on site is crucial. Older trees tend to have thicker bark, have canopy fuels that are farther from the ground and contain less ladder fuels, due to the loss of lower branches over time, making them ideal candidates for resisting and surviving fire events (Agee et al. 2005; Ingalsbee, 2005).

Energy Input

Removing fast spreading plant species near break

This intervention focusses on the energy input of a natural system to grow plants where they are removed in the case of a vegetation removal for a fuel break. Since less energy input is associated with greater resilience, redirecting where the natural system places its energy is beneficial. Reducing rhizomatous plant species as well as invasive plant species is prescribed (Bergen et al., 2001).

Ground cover decreases nonnative and invasive introduction to site

Patches of ground are exposed during the creation of fuel breaks which are prime for the introduction of nonnative and invasive species. Invasive and nonnative species take up resources away from native species. Maintaining ground cover, wherever prescriptions allow, may help to reduce the introduction of invasive and nonnative species (Merriam et al., 2007).

Self Organization

Systematic clearing where disturbance is needed to encourage stand age diversity

In a natural system maintained under a fire regime, fire is a form of disturbance that selectively burns patches of forest, creating a matrix of patches at different successional stages. Fuel breaks in particular, have the potential to influence the re-organization of patch types within forests (Agee et al., 2005, Bennett et al. 2010).

Making room for new species and or land use types

Sometimes, species that once functioned well in a system are no longer able to provide. Re-organization of existing species composition may change how those species function as a whole. Additionally, new species may added to fill the functional gaps of a system left by species that no longer benefit it (Bennett et al. 2010).

Redundancy

Prioritizing specific patches of habitat for preservation

Fuel break designs should prioritize maintaining high quality patches of vegetation that act as main habitat nodes for specified species. Maintaining multiple patches will provide these species with multiple stopping points through the open fuel break. This can be achieved by creating a buffer of heavily cleared land around the chosen patch, reducing the connectivity of fuel sources within the designated patch to those around it (Bennett et al., 2010; Kennedy & Johnson, 2014; Merriam et al., 2007).

Inclusion of species/land uses with similar function

Selectively keeping plant species within the same functional group encourages functional diversity which is important in maintaining any natural systems in the scenario that a species is eliminated. This can be achieved by surveying plant species within the landscape in preparation for the installation of a fuel break.

Evolution/adaption

Introduction of species adapted to southern climates

Warming temperatures as a result of climate change may necessitate the adaption of the local flora to include species from southern climates (Bergen et el., 2001; Spies et al., 2010).

Shift out of current fire regime- corresponding with shift in the forest type

Natural systems are always in flux and changing. Fuel breaks may be maintained for shifts in species composition. For instance, prioritizing the planting and keeping of deciduous species over evergreen is preferred (Bennett et al. 2010).

Shift to human derived disturbance regime

As landscapes within the WUI shift out of fire regimes, human initiated disturbance, in the form of vegetation removal may be needed in order to maintain diversity within forests of the Pacific Northwest (Amo et al., 2005; Cochrane et al., 2012; Folke et al., 2010).

Social resilience

Creation of action plans

Responds to the needs of the community

A unique fire management action plan is created within each individual community. This plan meets the expectations and needs of the community, based upon their unique cultural and social groups, to ensure and or increase the safety of community residents (Fitzgerald, 2005; Folke et al, 2010)

Responds to the recreational needs of the community

The removal of vegetation completed within the fuel break area does not interfere with recreational activities that are deemed as essential by the community (Fitzgerald, 2005). These may include activities such as birding or plant ID-ing that may occur on easy to access trails.

Expects maintenance needs of fire management prescriptions

Maintaining a fuel break post application, by means of continued clearing of vegetation, is one determining factor affecting the success of this fie management tool. An understanding of what the realistic amount of maintenance that can be done post application can help planners determine the size of the fuel break to install and what prescriptions to make (Bennett et al., 2010).

Aesthetic identity

Change of identity with landscape aesthetic

Neighborhoods are defined by the topography and plant communities that surround them, which influences people choosing to live there. In particular, neighborhoods within the WUI may have to adapt to changes in the landscape including the loss of a lush tree line or the need to find new shade sources (Nielsen-Pincus et al., 2015). This transition is based off a community wide decision to trade this aesthetic for greater physical security.

Systematic clearing to preserve key focal/access points

Vegetation removal may have the positive result of opening up views to the landscape that would normally be hidden. Additionally, clearing vegetation may create new entry points to forested land, creating more recreational opportunities (Nielsen-Pincus et al., 2015). Key focal and access points may be identified during the planning process.

Maintain landscape defining plant species

Maintaining landscape defining plant species aids in defending a neighborhood's identity, which is connected to landscape (Nielsen-Pincus et al., 2015). Plant species composition and type are part of what define the landscape and may include native species.

Increase physical security

Creation of wider, less vegetated fuel breaks

A wider area of heavily cleared vegetation within a fuel break creates a wider buffer to protect homes from advancing wildfire (Cochrane et al, 2012).

More fuel breaks put in place

Since wildfire movement can be hard to predict, it is thought that more fuel reduction treatments will reduce the vulnerability of homes to unpredictable wildfire movement. The layering of additional fuel treatments so as to treat fire as it advances through the landscape is also recommended (Cochrane et al, 2012; Finney, 2001; Massada et al, 2011).

Removal of vegetation closest to homes

Maintaining heavy fuel reduction within the "home ignition zone" is an affective, proactive maintenance prescription to keep fire from spreading from vegetative fuels to the home. This is especially important for homes located in the WUI that are surrounded by dense, forest vegetation (Bennett et al., 2010).

Removal of vegetation in a herringbone patterns

Studies have shown that the orientation and pattern of vegetation removal within fuel breaks can determine how affective the break is at slowing the spread of wildfire and reducing its intensity. Layering fuel breaks so that they interact with wildfire at multiple points has been shown to be highly effective; arranging the layered fuel breaks in a herringbone has shown to be most effective in simulated studies of homogeneous environments (Finney, 2001; Reinhardt et al., 2008).

Fuel break is set back a specific distance from homes

A sense of security may be achieved by slowing the advance of wildfire farther from what is designated to be a close proximity to homes. This assumes that homeowners would feel less safe being able to observe wildfire nearby and have it appear close to their properties regardless of whether physical safety was affected (Massada et al., 2011).

Community trusts fire treatment prescriptions

In order for fire management plans to be effective, community members should trust that the prescriptions will increase their safety (Fitzgerald, 2005). With trust in the prescriptions comes follow through with fuel reduction strategies by homeowners and evacuation strategies, and the acceptance of aesthetic changes in return for a 'safer' environment.

Acesss

Acces points for fire crews designated and maintained

Fire crews require access to the landscape to treat wildfire. Patches of heavily cleared vegetation within fuel breaks have been shown to act as key access points. Designating key access points near high risk zones in the landscape and near fire hydrants or water sources is recommended (Syphard et al., 2011).

Equitable Distribution

Fuel breaks are equitably distributed to all designated at risk areas

The placement of fuel breaks is determined by where wildfire risk is present; placement is not based upon discrimination or bias. Fuel breaks are a resource to any community with a known risk to wildfire.

Chapter Four

Fuel Break Design

4.1 Fuel Break Design

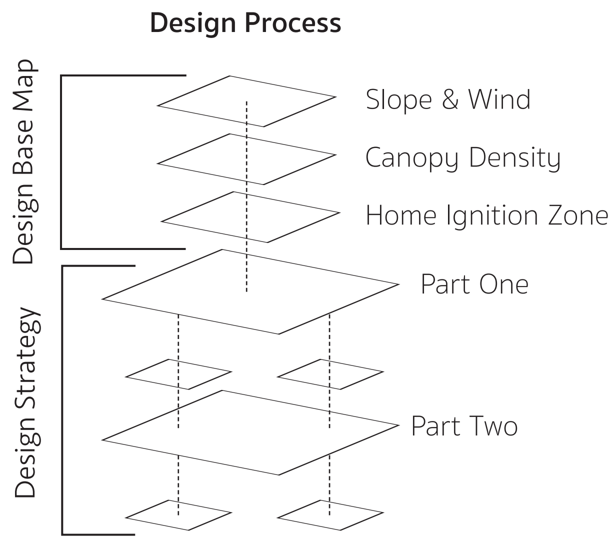
The design portion of this study results in two final fuel break designs, one specified for ecological resilience and another for social resilience. The design process involves the creation of a base map, which serves as the basis for applying design strategies (see *Figure 4.1*). The base map includes a two part analysis of wildfire risk, assessing slope and wind together, and canopy density. Along with home ignition zones, the base map will identify key points within the landscape that require moderate to heavy fuel removal based upon biophysical elements and topography.

Part one and part two of the design strategies section each provide different methods to express data and decision making within the fuel break area. Each part presents information at different scales, which when combined create a more comprehensize fuel break design.

Part one is focused on the application of the fuel break design elements, designated within the Design Translations table. The resilience prescriptions presented in the table are abstract without the addition of fine scale data and site observations. Broad design decisions are made by organizing the design area by zones of intervention. This step in the design process is useful in understanding the large-scale interactions of the prescriptions.

Part two is more systematic than the first, providing prescriptions within set boundaries that are independent of the buffer zones established in the base map and part one. It focusses on making prescriptions based upon the seral stage, or successional stage of a given patch. This step utilizes a forester's approach to designing fuel breaks. Unlike part one, part two is able to talk about site specific details.

Figure 4.1
Fuel break design
process diagram



Context

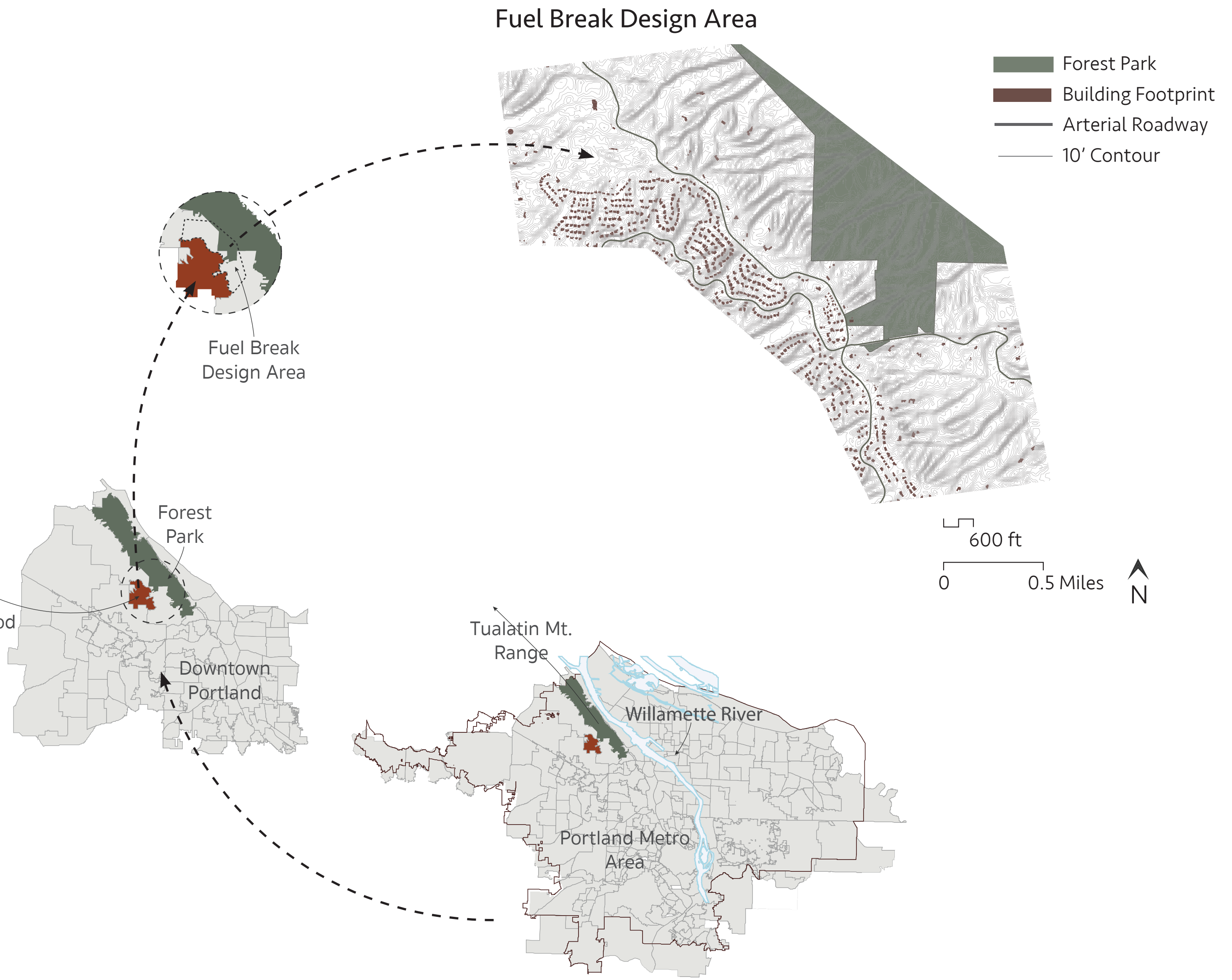
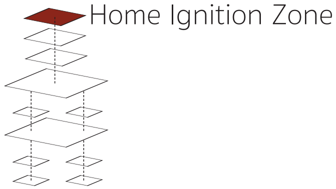


Figure 4.2
Fuel break design case study area and context within Portland.

Fuel Break Design Area

This study focusses on the interacting policy and design decisions made for the neighborhood of Northwest Heights and Forst Park. For this study, Northwest Heights represents a residential area at risk to wildfire, while Forest Park represents the wildfire soure. The sites location just over two miles from downtown Portland, OR, makes spreading wildfire within the park and its surrounding neighborhoods of great concern.

The fuel break 'design area' is situated in-between Northwest Heights and Forest Park (see ***Figure 4.2***). It is important to note that the fuel source of the park, the vegetation, extends past the border of Forest Park all the way up to the Skyline Boulevard at the Northern edge of Northwest Heights. This connecting area of land is a direct conduit of wildfire, capable of transfering wildfire from the park grounds to the neighborhood.The creation of a fuel break within the connecting area of land will break up the fuel load and potentially reduce the rate of spread and intensity of wildfire coming from North.



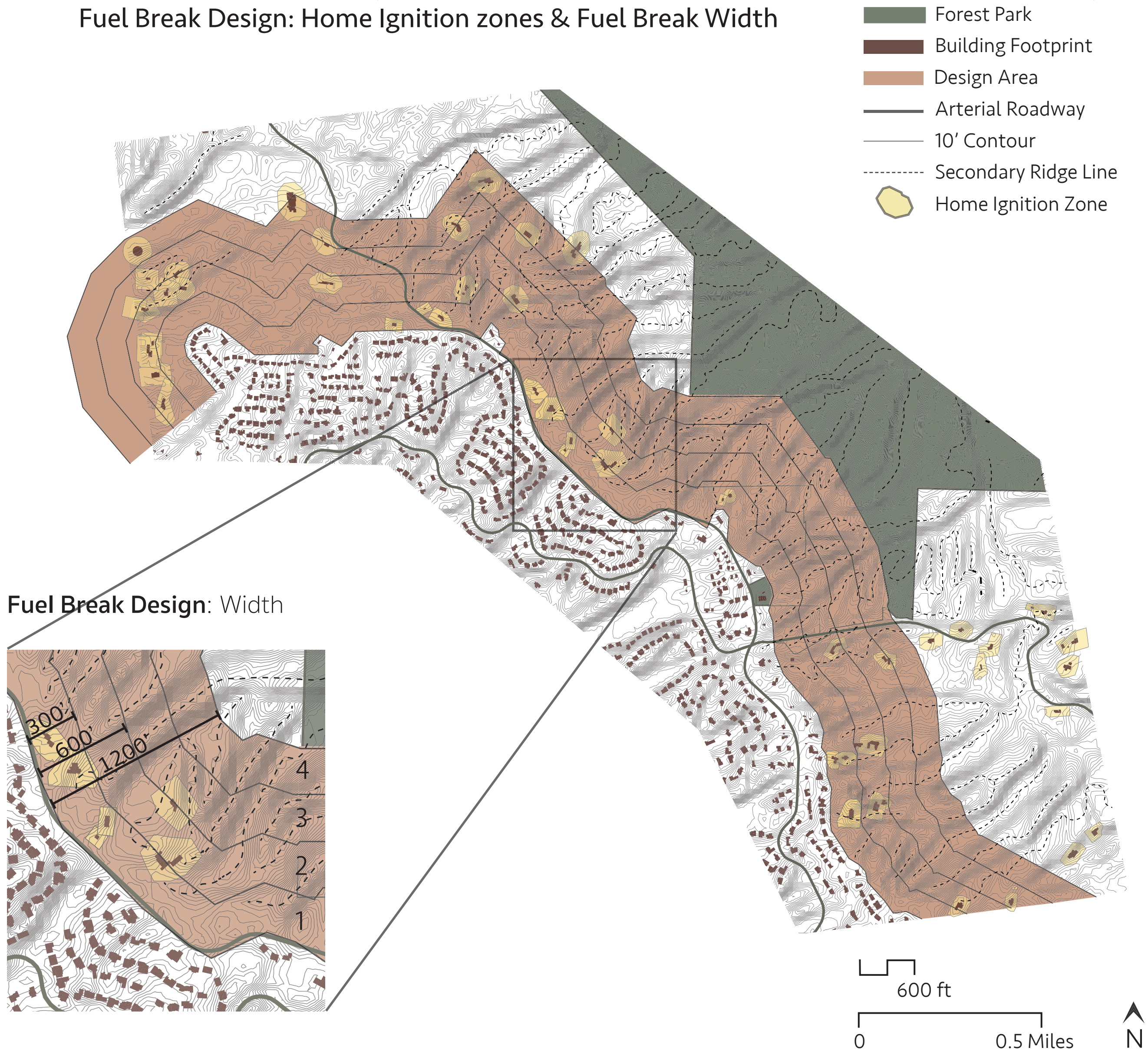


Figure 4.3
Establising the fuel break width and home ignition zones

Fuel Break Design
Home Ignition Zones

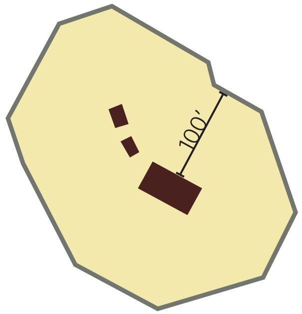


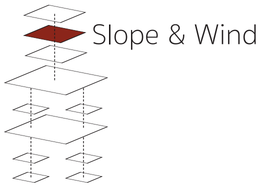
Figure 4.4

100’ home ignition zone designated for every outlier home.

Home ignition & Fuel Break Width

Home ignition zones, consisting of a 100’ buffer, are delineated for all ‘outlier homes’(*Figure 4.4*). The home ignition zone is the area in which fuels, or vegetation, must be cleared or reduced in volume. to reduce the chance of wildfire reaching the home. The vegetation surrounding a home may act as a conduit for wildfire to reach the structure. Within the 100’ buffer, high vegetation removal is prescibed (see *Table 4.2*).

The fuel break width is composed of four 300’ ‘buffer zones’, adding to a total width of 1200’ (see *Figure 4.3*). The width of the fuel break is informed by findings from Safford et al. (2009) and Bennett et al. (2010). The choice to include four buffer zones is made under the assumption that fuel treatment width would not be uniform across the entire length of the fuel break and would require room to extend and contract based upon the prescriptions applied. This fuel break area is capable of including a majority of outlier homes, therefore increasing the range of home wildfire risk reduction.



Base Map: Slope & Wind

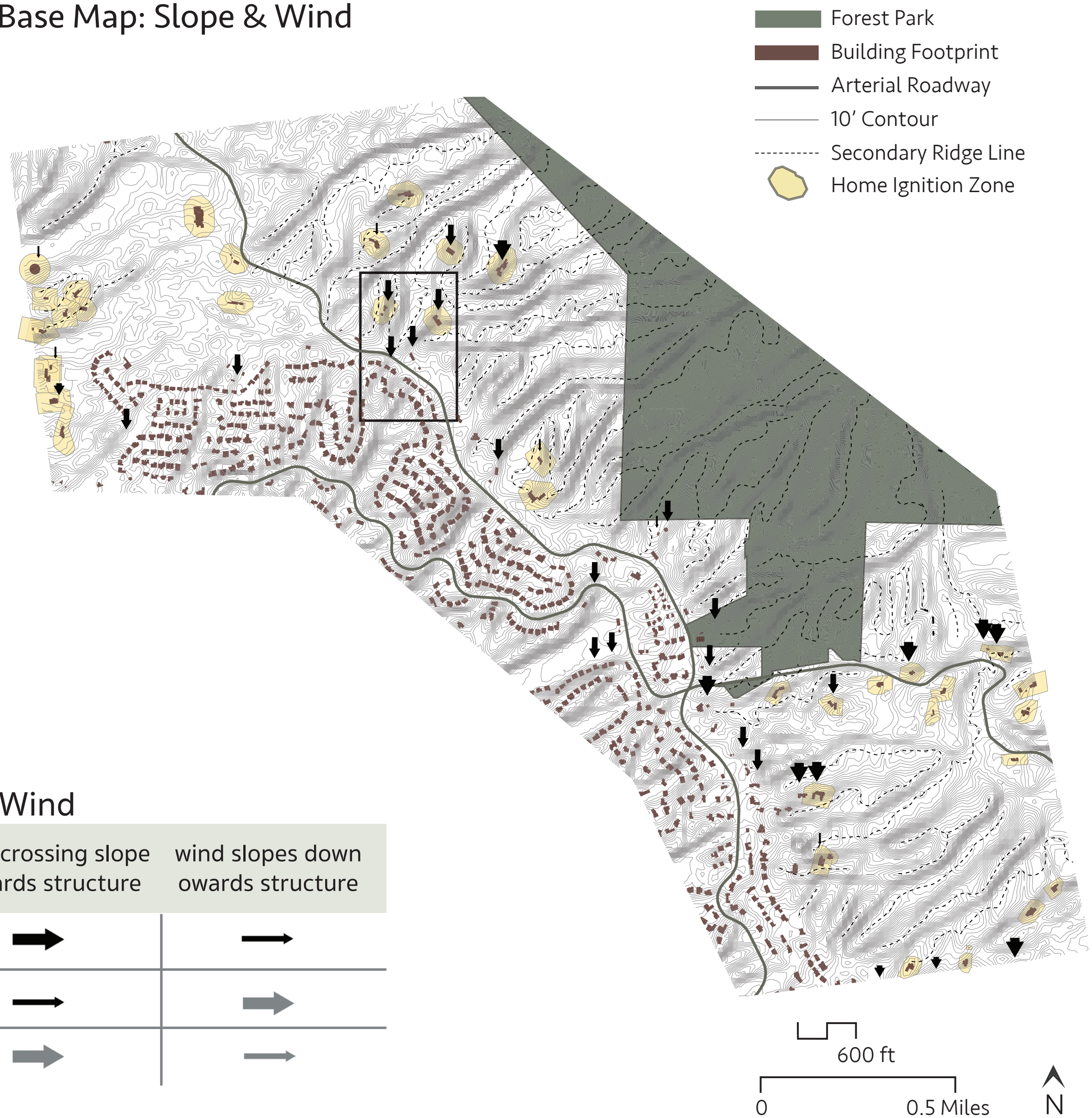


Figure 4.5
How wind and slope affects wildfire risk expressed as ranked arrows.

Table 4.1
cross analyzing wind and slope to determine wildfire risk.

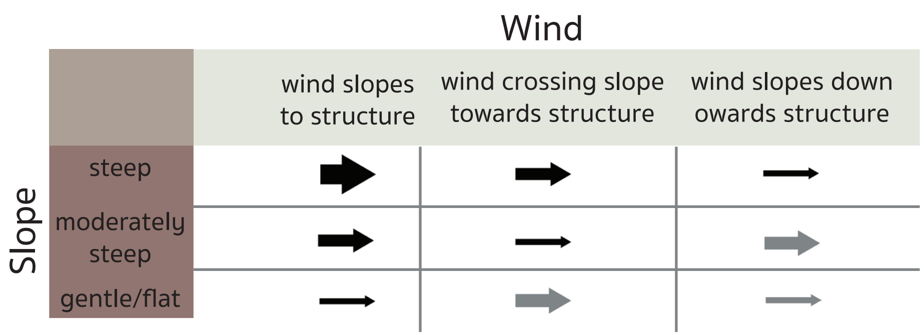
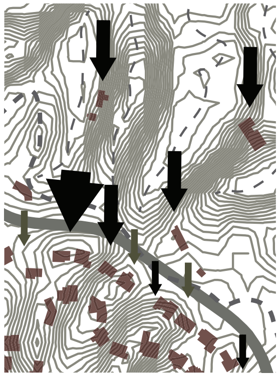


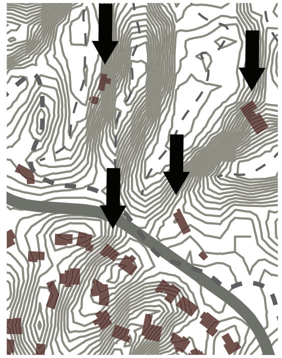
Figure 4.6
Ranking of wildfire risk assessment (wind & slope) explained.

Risk Assessment: Slope & Wind

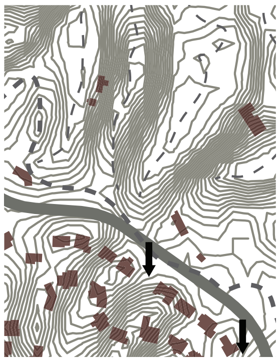


0 600’

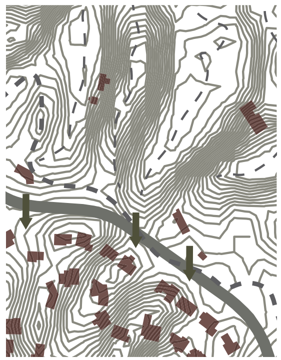
• Home sits on or above land exhibiting 60.1-100% slope. Wind aproaches structure directly from the North.



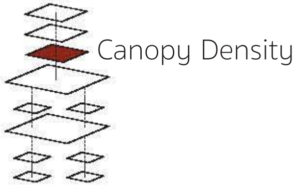
• Home sits on or above land exhibiting 60.1-100% slope. Wind aproaches structure at an angle.
• Home sits on or above land exhibiting 40.1-60% slope. Wind approaches structure from directly from the North.



• Home sits on or above land exhibiting40.1-60% slope. Wind aproaches structure at an angle.
• Home sits on or above land exhibiting 20.1-40% slope. Wind approaches structure from directly from the North.



• Home sits on or above land exhibiting 0-20% slope. Wind aproaches structure at an angle.



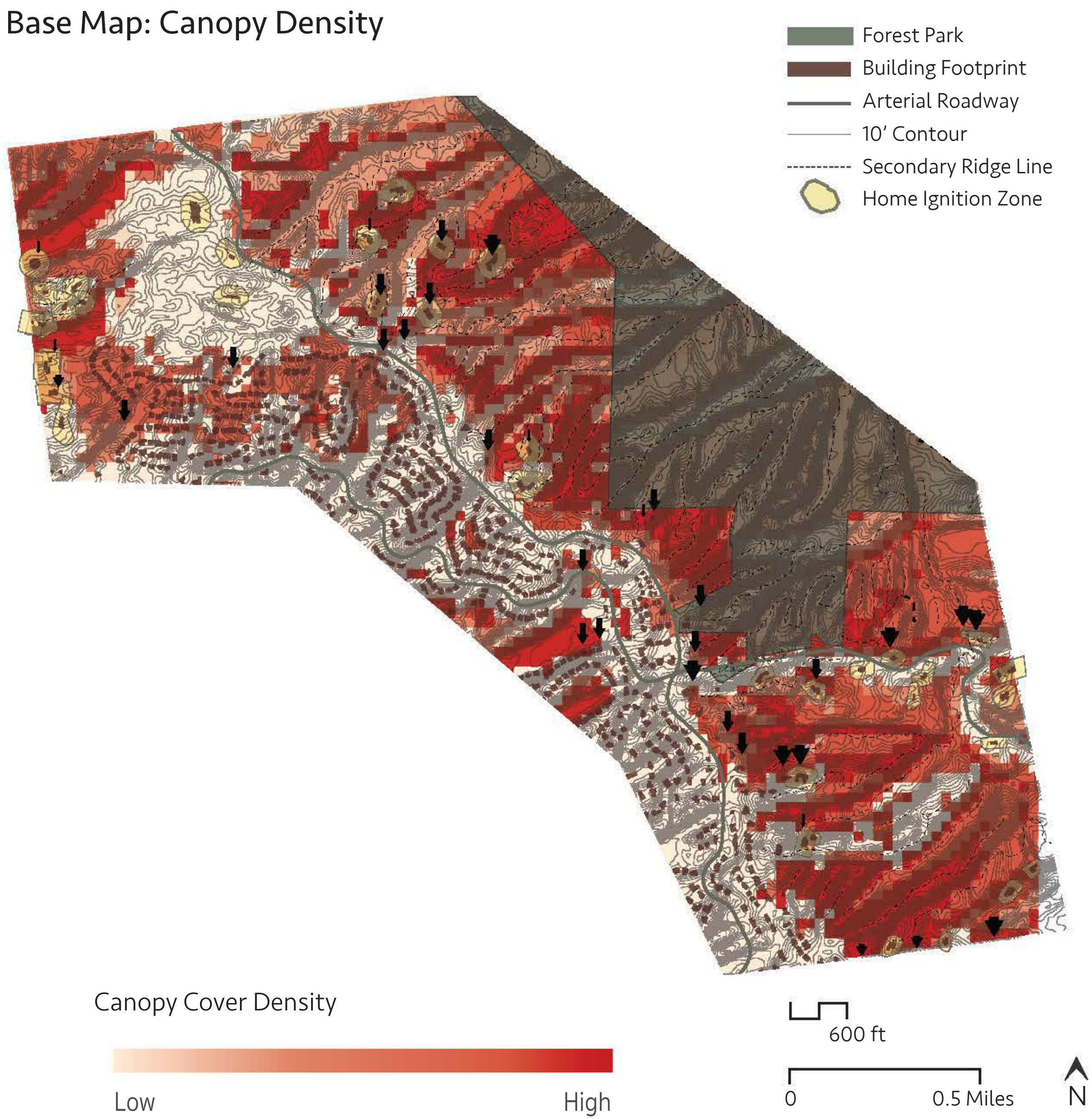


Figure 4.7
Adding cover to the wildfire risk assessment.

Base Map: Canopy Density

The ***Base Map: Canopy Density*** (*Figure 4.7*) builds upon the factors of ***slope and wind (****Figure 4.5****)***, by adding in the factor of canopy density. Canopy density refers to the continuity of fuels, considering the amount of vegetation within one given area. Continuous fuel loads allow wildfire to spread, while dense vegetation cover supplies the fire with ample fuels, lending to more intense wildfire events. Therefore, wildfire risk is deemed to be highest where large patches of high density fuels exist in the landscape.

Canopy density map, reclassified into four levels of canopy density, is overlaid ontop of the ***Base map: Slope and Wind***. Perceived fire risk is reassigned to give a higher ranking at points with dense canopy cover. In the process, designated high risk points assigned in the ***Base map: Slope and Wind*** are filtered out, demoted in rank, or raised in rank.

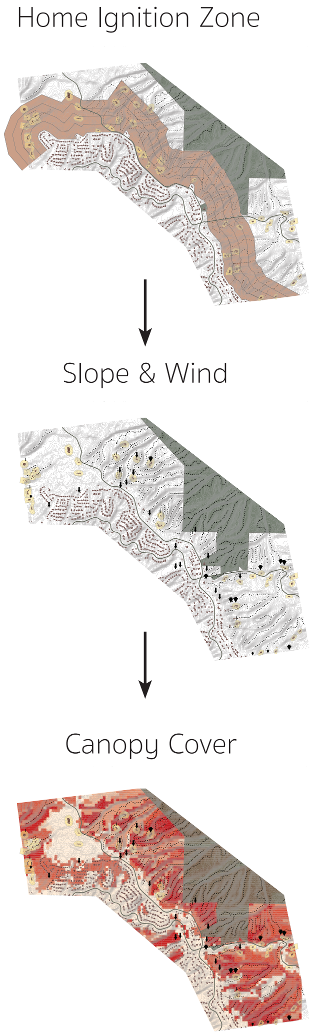


Figure 4.8
compilation of process maps.

Base Map: Complete

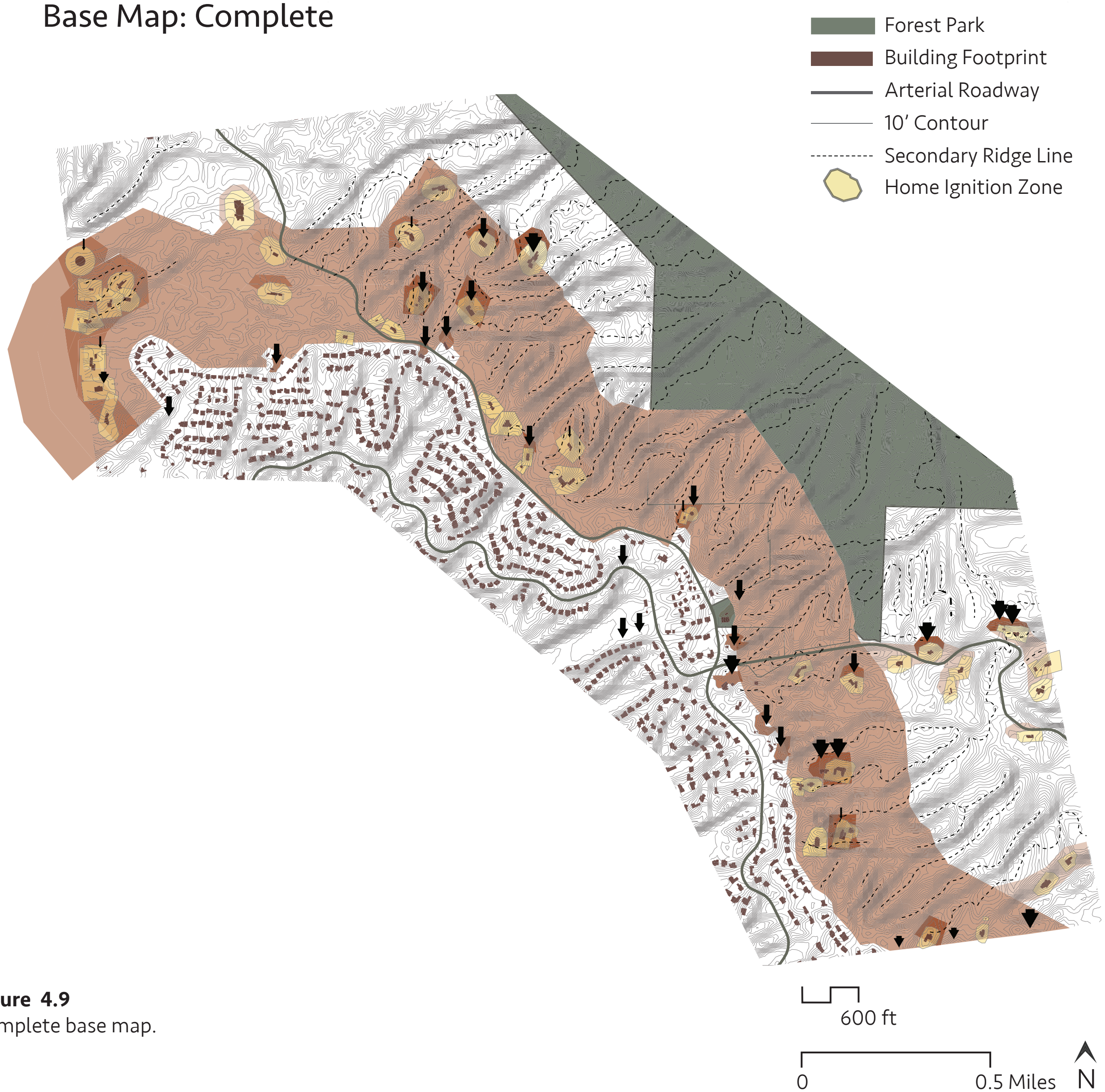


Figure 4.9
Complete base map.

Prescriptions for vegetation removal

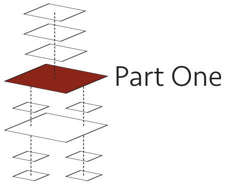
Intensity of Vegetation Removal	Canopy Prescription	Ladder & Shrub Prescription
Low	5-10’ between drip lines	0-20% removal
Moderate	10-15’ between drip lines	40% removal
Moderately High	10-20’ between drip lines	60% removal
High	20-30’ between drip lines	80% removal

Table 4.2
Intensity of vegetation removal color key. Intensity will vary depending on the buffer zones (see *figure 4.3*) and prescribed level of vegetation removal (see *Table 4.3*).

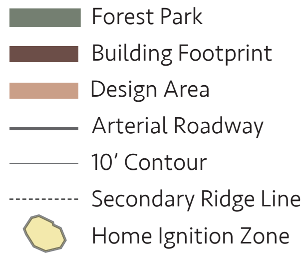
Base Map

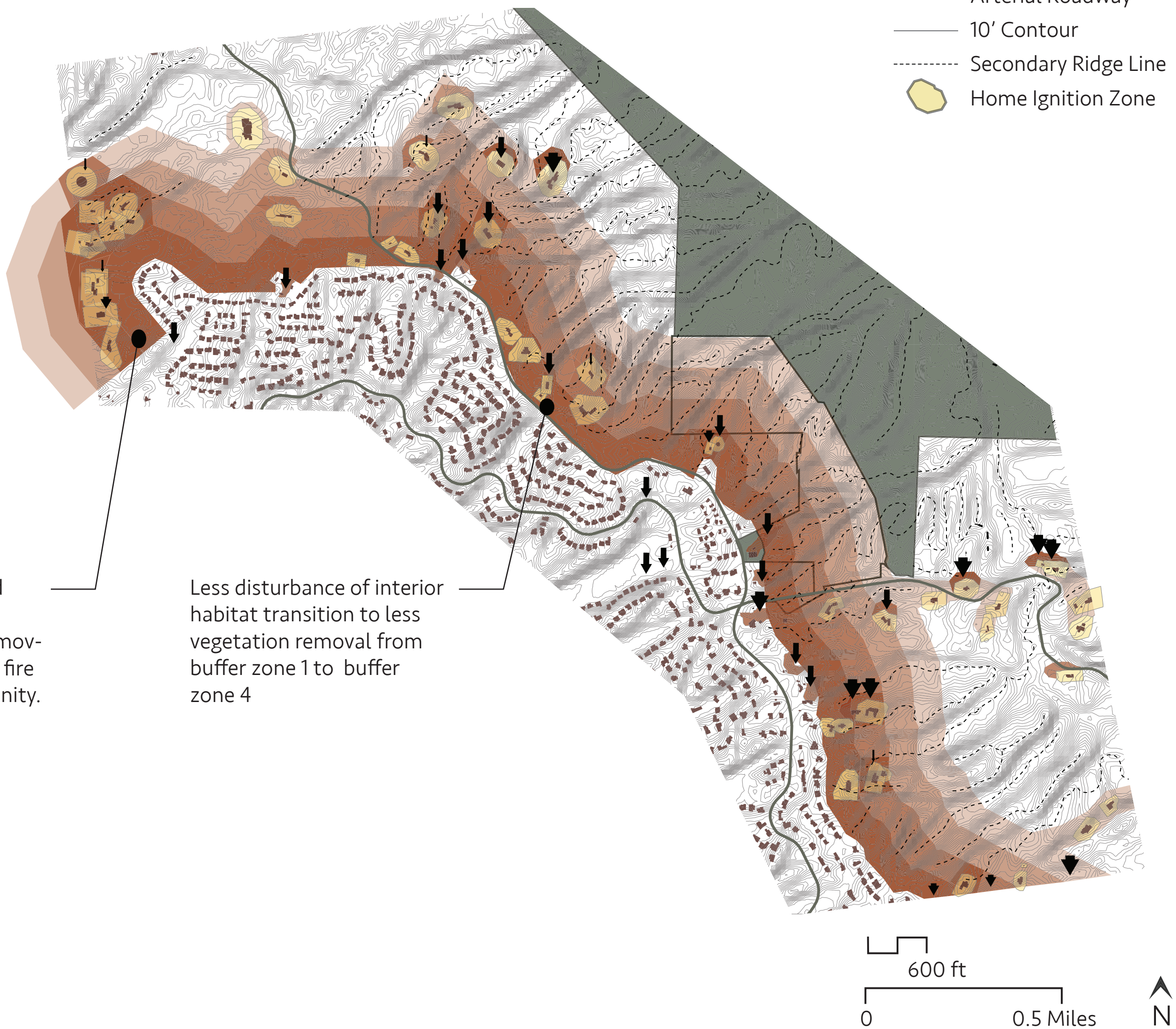
The complete ***Base Map (Figure 4.9)*** brings together the wildfire risk analysis completed in the base map layers ***slope and wind*** and ***canopy cover,*** with the designated home ignition zones and fuel break width (*Figure 4.8*). Base levels of vegetation removal are assigned based upon the denoted wildfire risk (see *Table 4.2* for levels of vegetation removal assigned in this study).

Homes exhbiting a high risk to wildfire, as denoted by the ranked arrows, are prescribed additional vegetation removal beyond the home ignition zone. Depending on the rank of the arrow, moderate to high vegetation removal is recommended. Additional vegetaion removal is recommended North of the home, where intense wildfire is most likely to approach. Clusters of outlier homes, as is seen in the North West of the design area, are prescribed moderate vegetation removal within the fuel break area.



Part One: Ecological Resilience Design Translations





Shift to human derived disturbance regime by manual vegetation removal lessens the effect of fire exclusion near community.

Less disturbance of interior habitat transition to less vegetation removal from buffer zone 1 to buffer zone 4

Figure 4.10
Fuel break design, part one. Applying prescriptions for ecological resilience

Part One: Applying Desing Translations

Building upon the base map, select design interventions are chosen from the table ***Design Translations*** (see ***Tables 3.1 and 3.2***) to be exhibited within the fuel break designs in ***Part One***. Interventions are selected based upon their feasibility to be applied and expressed within the fuel break design using supplied data and site specific information. Fuel break designs are divided in this part to express where design goals diverge to create ecological or social resilience.

Figure 4.10 exhibits the application of prescriptions specified for ecological resilience. Interventions selected include:

- ***Less disturbance of interior habitat***
- ***Shift to human derived disturbance regime***

Refering to ***Figure 4.10***, the greatest amount of vegetation removal occurs within buffer one, closest to the core neighborhood, transitioning to less fuel removal with every buffer out. The interior forest area is reserved as much as possible while still covering the base width of 300’ required for a fuel break within the states of Oregon and Washington (Bergen et al., 2010). The fuel removal within buffer zones 2 – 4 is transitions from moderately high to low, which allows for the retention of select canopy, shrubs, and ground covers. By doing so, there is potential to increase the amount of ground cover in addition to select patches of tree cover.

Part One

Part One: Social Resilience Design Translations

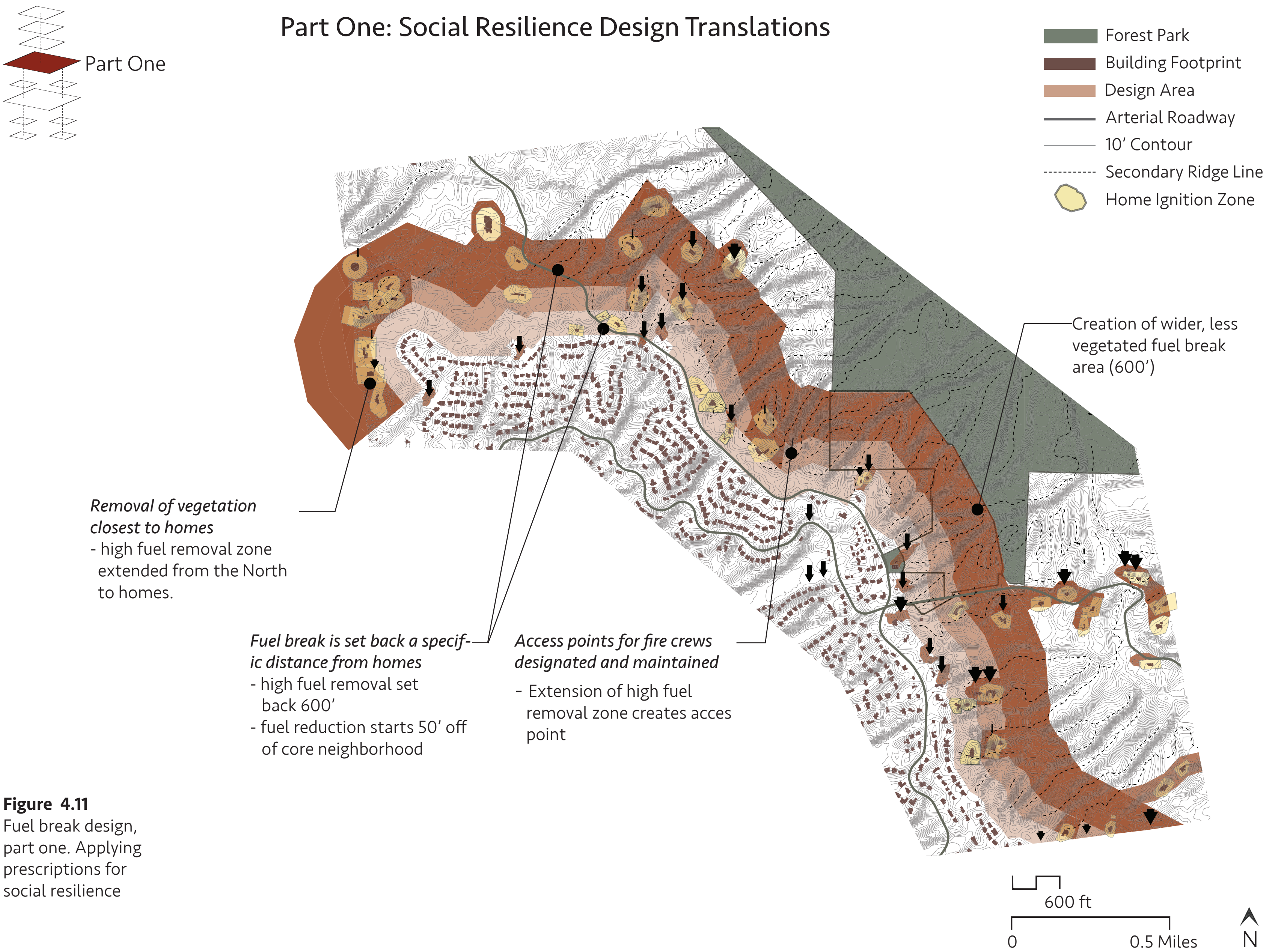


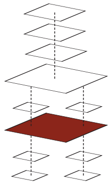
Figure 4.11
Fuel break design, part one. Applying prescriptions for social resilience

Part One: Applying Design Translations

Figure 4.11 exhibits the application of prescriptions specified for social resilience. Interventions selected include:

- *Creation of wider, less vegetated fuel break*
- *Removal of vegetation closest to homes*
- *Fuel break is set back a specific distance from homes*
- *Access points for fire crews designated and maintained*

The 1200’ wide fuel break provides enough room to extend fuel treatment zones. The heaviest fuel removal is extended from 300’ to 600’, which achieves the goal of a wider, less vegetated fuel break. Two prescriptions are in contrast with one another- setting back the fuel break a specific distance from homes and keeping the fuel break closer to homes appear to be in contrast with one another. The first is meant to create the sense of security by creating fuel breaks that would potentially slow oncoming wildfire farther away from the homes. The later is meant to ensure physical safety by reducing fuel loads closest to homes that could directly transfer fire into the housing division. The decision to place the greatest amount of vegetation removal within the outer segments of the fuel break is made using the logic that the extension of the zone of heaviest vegetation removal will bring the bulk of the fuel break closer to the core neighborhood. Lastly, key points for additional vegetation removal are marked for the purpose of creating cleared points for fire crews to access high risk points on the base map.



Part Two

Part Two: Dominant Canopy Type by Seral Stage

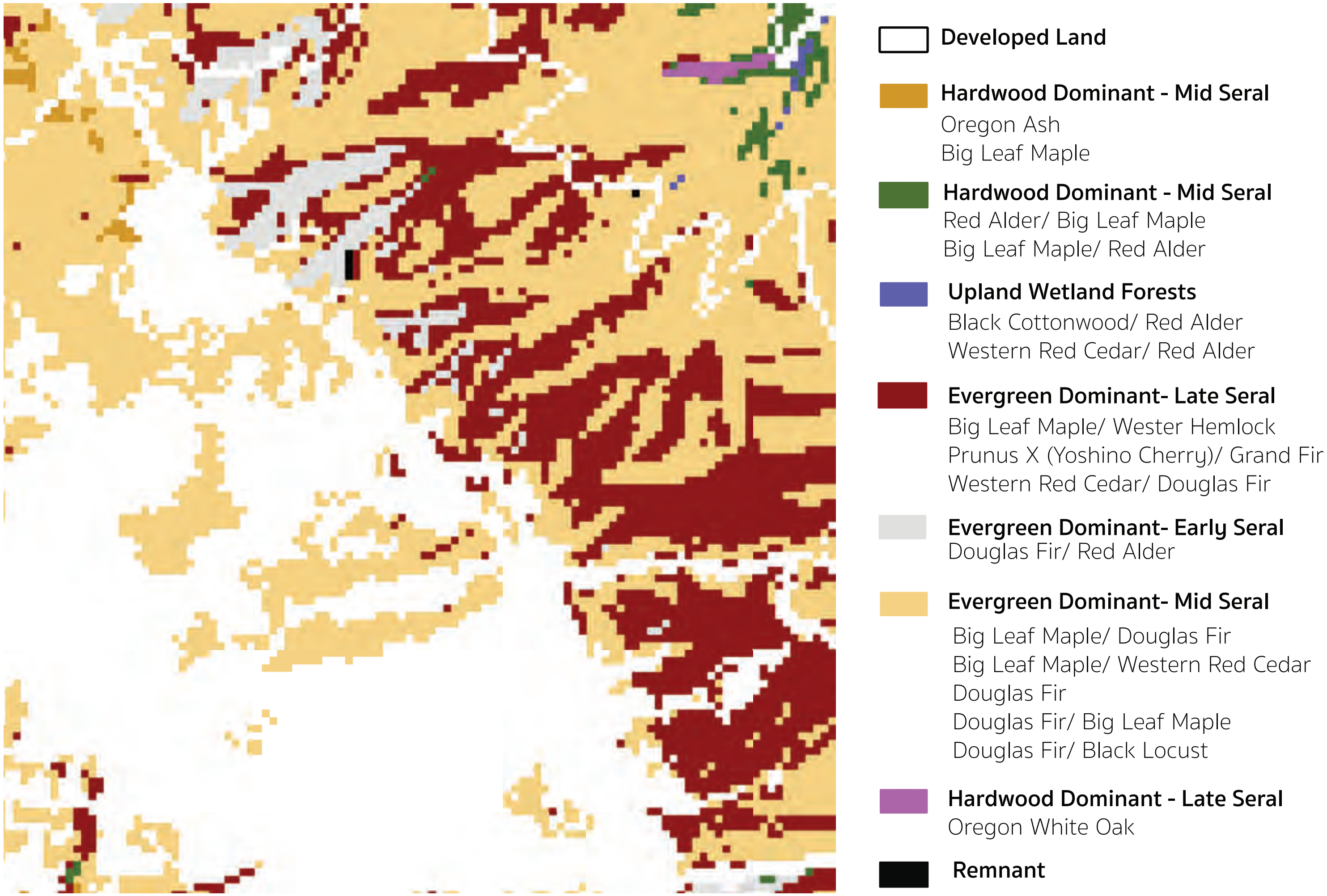


Figure 4.12
Dominant canopy species grouped by seral stage.

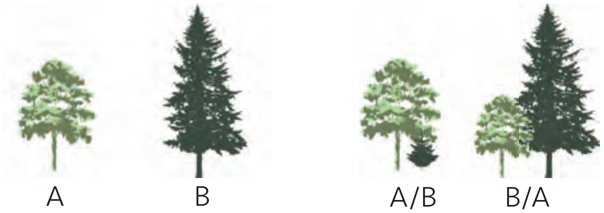


Figure 4.13
Corresponds to the dominant species expressed in *Figure 4.12*. The species listed before the slash is considered the dominant species. Dominant species are those that dominate the top most section of canopy.

Part Two: Dominant Canopy Type by Seral Stage

Dominant canopy type (as expressed in ***Figure 4.12***) identifies the two dominant specie within a given patch, using the symbology 'A/B' to distinguish which species comprise the majority of the overstory (see ***Figure 4.13*** for example). Dominant canopy species are grouped by ***evergreen*** or ***hardwood*** dominance and by their seral stage. This study focusses on the seral stages present within the fuel break design area, which includes: ***Evergreen Dominant- Late Seral***, ***Evergreen Dominant- Early Seral***, and ***Evergreen Dominant- Mid seral***.

Seral stage, synonymous with successional stage, is inferred by the type of species present within a given patch. Specific species at a given age are associated with specific seral stages. As discussed within the ***Literature Review***, ***section Fire Prone Species and Succession***, certain successional stages will contain more fire prone vegetation than others, making data on forest vegetation composition increasingly important. ***Table 4.3*** discusses the prescriptions for each seral stage in greater detail.

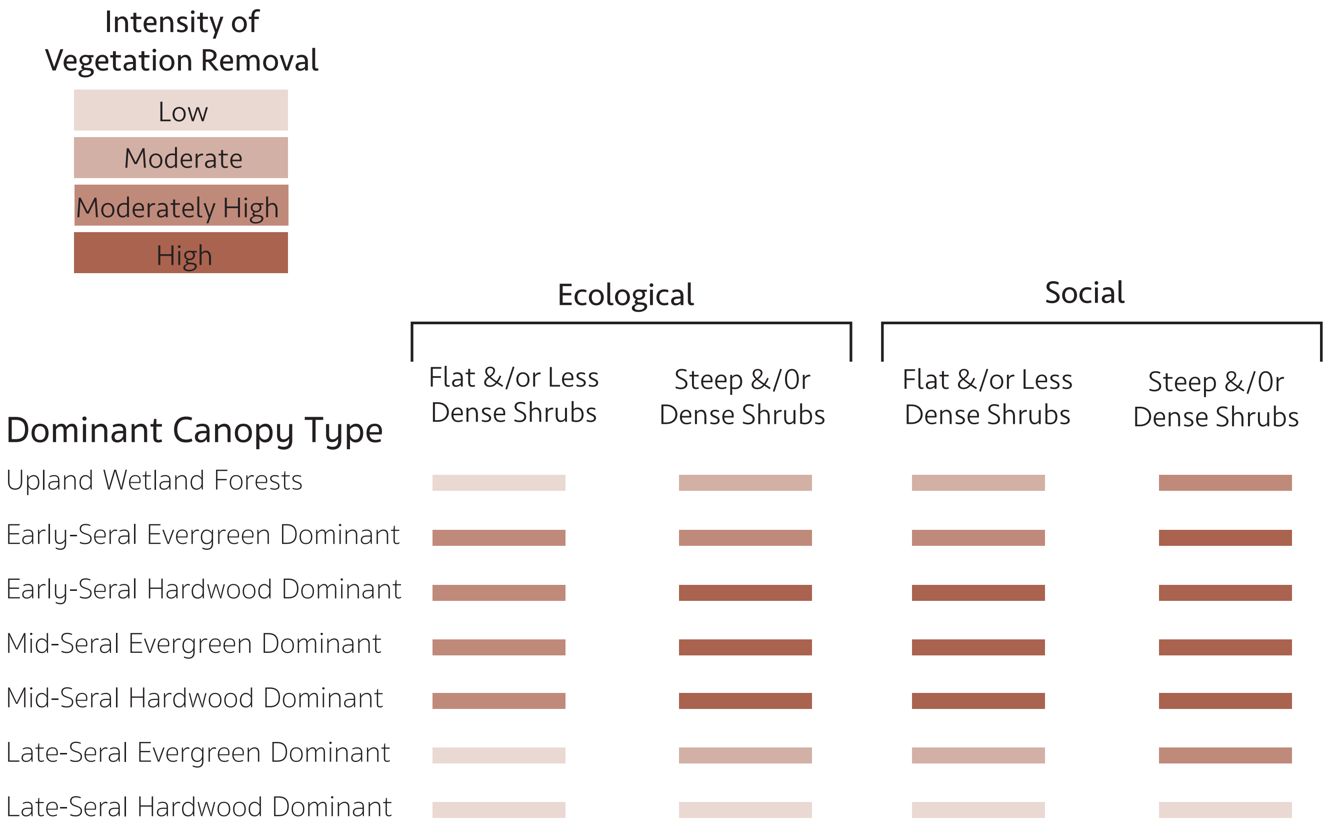


Table 4.3
Generic prescriptions for vegetation removal based upon dominant canopy type.

Prescriptions by Seral Stage

Each seral stage, for evergreen and hardwood dominant, is assigned a generic level of vegetation removal (see ***Table 4.3***). ***Figure 1.14*** expresses prescriptions for each of the four levels of vegetation removal in section.

Prescriptions are seperated by application for ecological or social resilience and may differ between the two. Each prescription considers the seral stage of a given patch. Pacthes are further defined by the presence of flat to steep slopes and the density of understory shrubs.

Early seral- evergreen and hardwood dominant groups are prescribed moderately high to high vegetation removal. *Early seral* groups are noted for containing younger and or less fire resistant species. They are designated for heavier thinning to decrease this risk.

Mid seral- evergreen and hardwood dominant groups are prescribed moderately high to high vegetation removal. *Mid sera*l patches contain maturing trees at different stages. Heavier thinning is recommended to keep understory shrubs and saplings from acting as ladder fuels, channeling wildfire into mature canopies capable of supporting an intense fire.

Late seral- evergreen and hardwood dominant groups are prescribed low to moderate vegetation removal. *Late seral* groups are noted for containing mature and or more fire resistant species. They are prioritized to keep because of the ecosystem services mature forests can provide. One exception to this prescription exists – patches containing Late seral-evergreen dominant species are prescribed moderate thinning on areas with steep slopes and or dense shrubs. This is due to the risk of firebrands that may develop from mature Douglas fir trees and move to other patches of forest by wind and gravity.

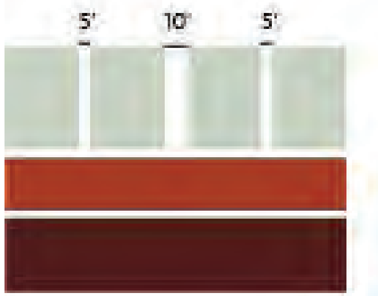
Sections

Low

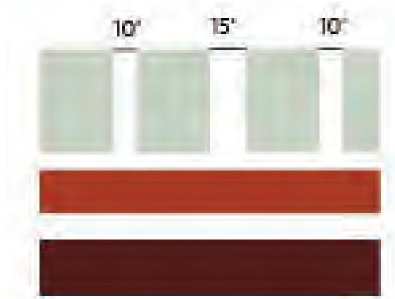
Canopy

Ladder

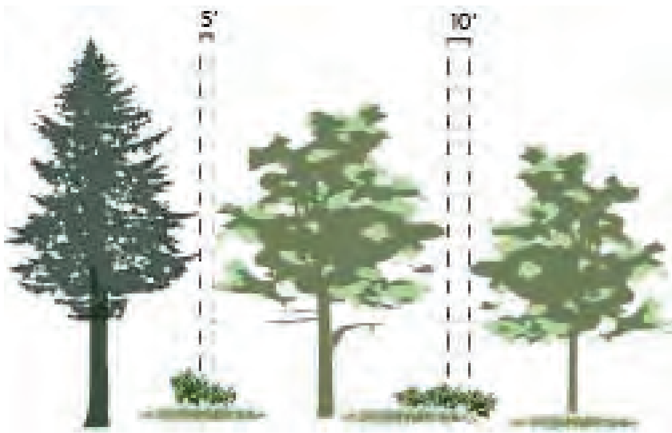
Shrub



Moderate

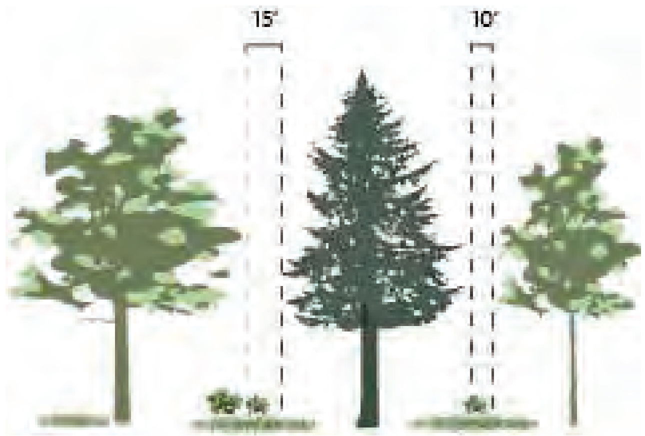


Low



Using a ‘***ground up***’ approach, shurbs and ground fuels are removed first from underneath of trees. Trees are thinned to maintain 5-10’ between drip lines.

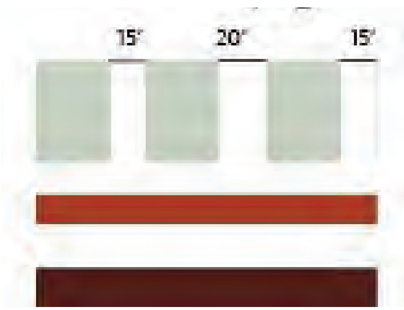
Moderate



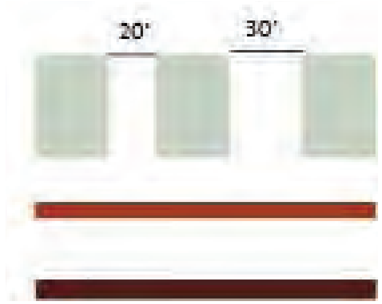
Trees are thinned to maintain 10-15’ between drip lines. Ladder fuels, such as low branches, are removed up to 30’. Shrubs are reduced select patches in open areas.

Figure 4.14 The four levels of vegetation thinning expressed in abstract sections above and illustrated below.

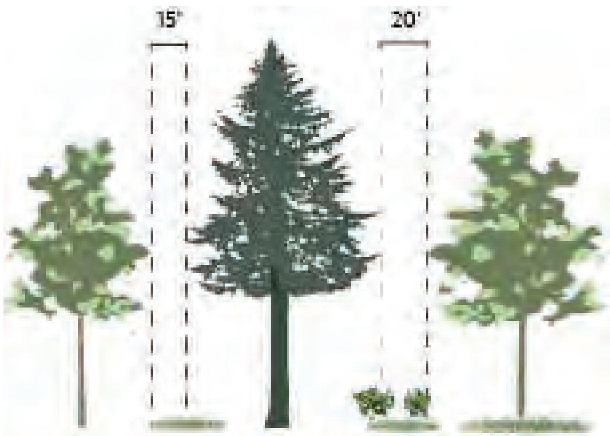
Moderately High



High

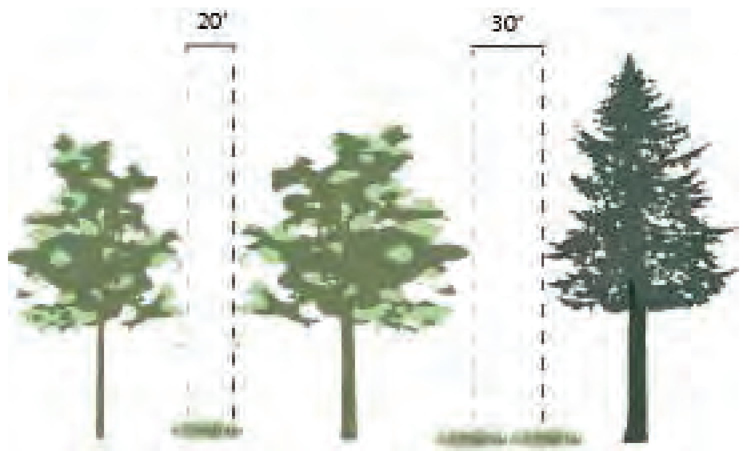


Moderately High

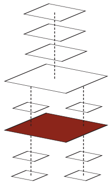


Trees are thinned to maintain 15-20’ between drip lines. Few to no shrubs remain in select patches.

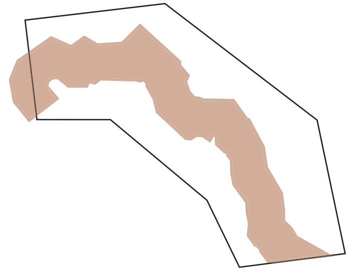
High



Trees are thinned to maintain 20-30’ between drip lines. All shrubs are removed. Grasses and forbs may grow into the cleared, open land.



Context



Ecological

Social

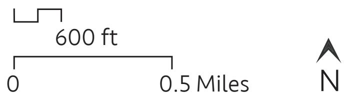


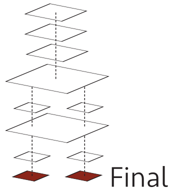
Figure 4.15
Generic prescriptions for vegetation removal based upon seral stage applied within the fuel break design area.

Part Two: Prescriptions by Seral Stage

Figure 4.15 express the application of the vegetation removal prescriptions assigned to each seral stage (see *Table 4.3)*. In *Table 4.3*, patches at a given seral stage are divided further by the presence of flat to steep slopes and the density of shrubs within the understory. This divsion shows up within the fuel break design area as smaller patches with distinctly greater fuel reduction prescriptions. These smaller patches are not simplified to match the dominant patch type so as to retain as much detail as possible within the fuel break design.

As is exhibited in *Figure 4.15*, prescriptions for vegetation removal are greater within the fuel break design area specified for social resilience in comparison to those specified for ecological resilience. This is expected given that ecological resilience prescriptions prioritize retaining vegetation that provides ecological services such as habitat.

In figures 4.16 and *4.17*, parts one and two are combined to form two final fuel break designs, one specified for ecological and another for social resilience.



Final Fuel Break Design: Ecological Resilience

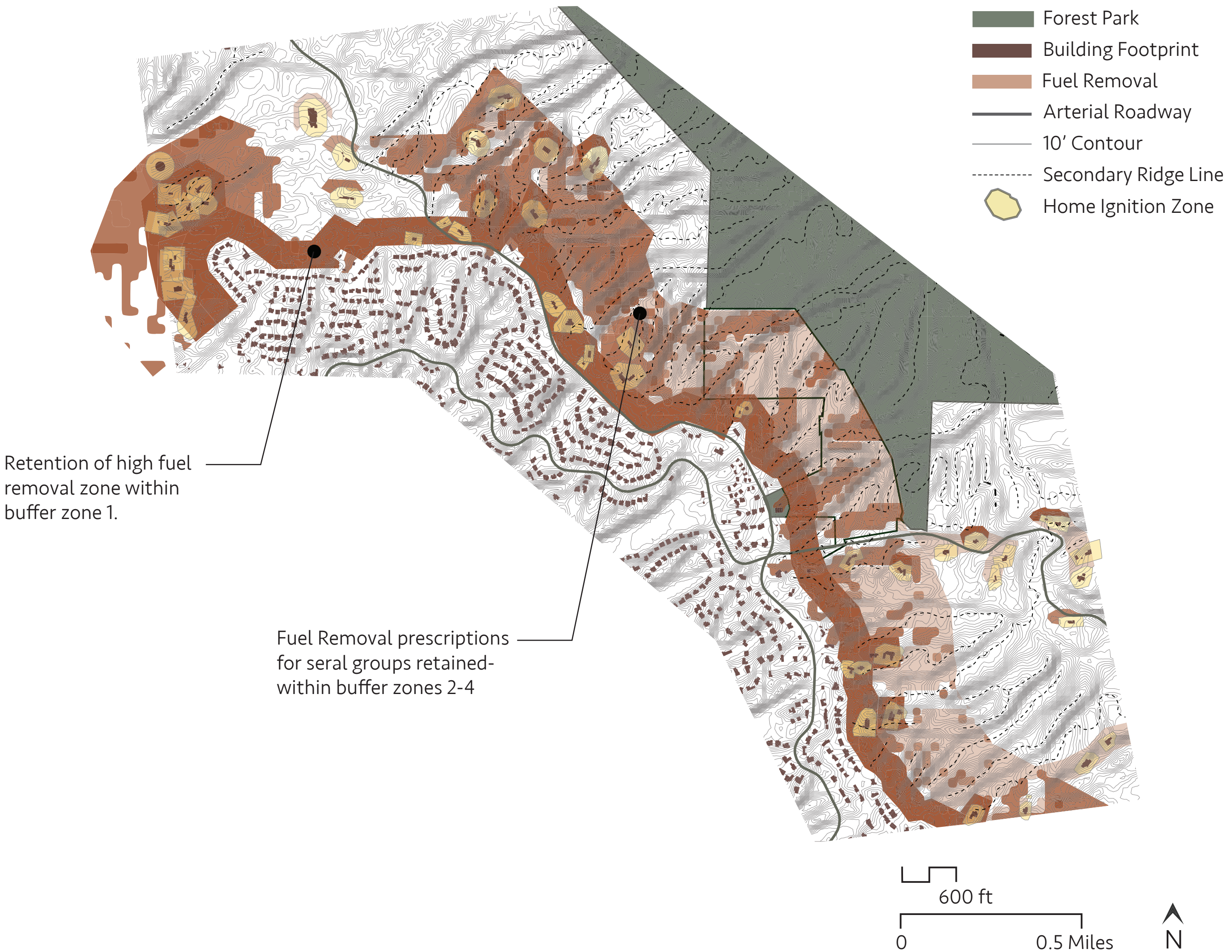


Figure 4.16
Final fuel break design specified for ecological resilience.

Final Fuel Break Design: Social Resilience

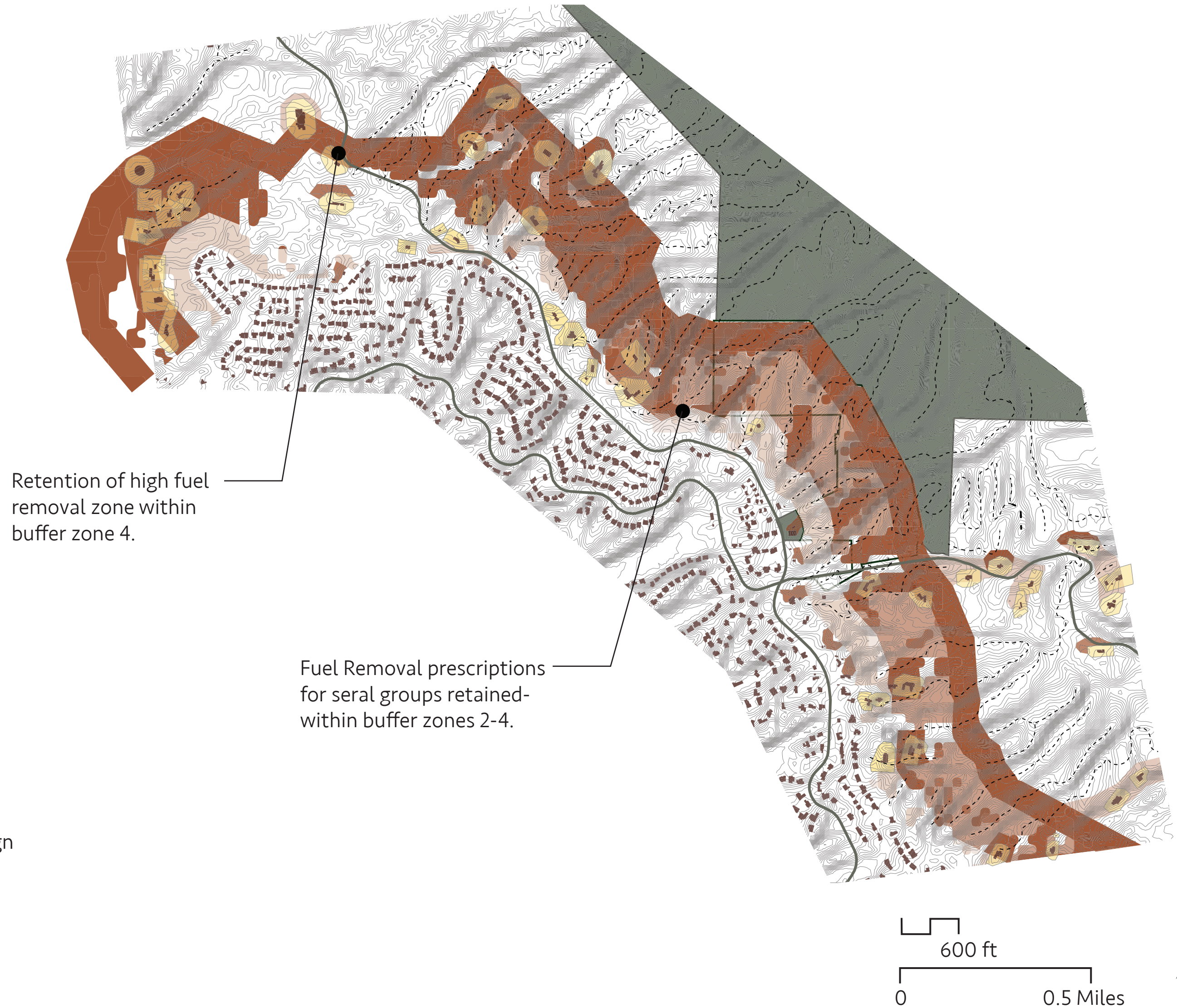


Figure 4.17
Final fuel break design specified for social resilience.

Chapter Five

Discussion

5.1 Discussion

Wildfires are complex natural events, involving many interacting and moving environmental factors that differ from one landscape to another. Designing for them, as a result, is challenging and requires a great deal of fine scale and macro data. Many of the items listed within the Design Translations table were not able to be included into the fuel break designs in this study due to a lack of specific information regarding site conditions and social factors. Smaller scale data, that is able to express on the ground conditions and features, in addition to more accurate data on plant species and age is required in order to create more feasible fuel break designs. Additionally, more information is required about perceptions of the neighborhood to wildfire risk and fuel break design elements.

It is important to note that the resulting fuel break designs created in this study are theoretical and are not meant to implemented in real life. They are an exploration, meant to examine the connection between social and ecological resilience strategies within fuel break design. It is also an exploration of how fuel breaks are applied in the landscape, examining the interactions between the many players that make fuel breaks functional.

There is potential for fire mapping software to be used to validate the design decisions made in this study. Fire mapping software is capable of calculating small scale interactions across a landscape, providing a more accurate picture of how fire move through a given landscape pre and post application of a fire management tool, such as a fuel break. In fact, using a fir mapping tool pre-design may allow one to more accurately distinguish high risk points, informing design decisions. In collusion with a proper mapping system, the results of this study have the potential to inform real fuel break design.

There is also potential to develop the fuel break designs in this study further by means of incorporating a participatory design method. Providing a platform to those living within neighborhoods adjacent to at risk forest land would allow designers to gain information about public opinions and ideas surrounding the application of fuel breaks. This information may change prescriptions to be more or less aggressive in vegetation removal and may better inform the location of vegetation removal.

This study can be strengthened by assessing differences within the fuel break design elements that were not able to be included due to lack of information. It can be concluded that this study is successful in identifying the gaps between ecological and social prescriptions that are assessed within the fuel break designs.

Notable differences between the social and ecological resilience strategies include the overall intensity of vegetation removal and which buffer zone(s) contained the heaviest vegetation removal. The ecological resilience strategy exhibited less intense vegetation removal, with the heaviest amount of vegetation removal designated within buffer zone one. The social resilience strategy exhibited greater vegetation removal, with the heaviest amount of vegetation removal occurring within the buffer zone(s) three and four.

The greater vegetation removal seen in the social resilience strategy has the effect of making for a more homogeneous fuel treatment across a given patch. A patch within the ecological resilience strategy may be prescribed medium to high vegetation removal, while the same patch within the social resilience strategy may prescribe total application of high vegetation removal. This is specifically seen in the Northwest of the design area. The difference is comparatively small between the results of the two methods, but could be significant when applied to other landscapes within the Pacific Northwest. In terms of increasing diversity of forest structure and stand age, this strategy may be limiting to ecological services.

Some similarities are noted between both strategies. The base map underlying each design strategy is intentionally used to set a standard for wildfire protection and is the same for each design strategy. Similar Patches of the same seral stage are treated comparative to one another, with the exception that patches within the social resilience strategy are prescribed greater overall vegetation removal within each patch.

The question remains, how can fuel breaks by designed so as to bridge the gap between social and ecological resilience prescriptions? This research does not supply a clear solution for this question, but is able to suggest that overlap can exist with the use specific prescriptions. As discussed within the literature review, findings have shown potential for less vegetation removal to decrease the risk of a wildfire starting, along with decreasing its spread rate and intensity. While this is a supported idea, it is not represented within the table *Design Translations*. The choice to not include this prescription was made to make the contrasts other design factors between ecological and social resilience strategies clearer. With the addition of fine scale, site specific data, further research may be conducted to determine how this prescription may best be applied within the landscape.

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