



Community Planning Assistance for Wildfire

Basics of Wildland Fire Behavior & The Wildland-Urban Interface

March 2019

Table of Contents

INTRODUCTION	3
TRAINING OBJECTIVES.....	3
WHAT IS THE WILDLAND-URBAN INTERFACE?.....	3
THE BASICS OF WILDLAND FIRE AND WUI FIRE BEHAVIOR.....	7
Wildland Fuels and Fire Behavior	7
The Fire Triangle	9
The Heat Transfer Process	9
Factors Influencing Wildland Fire Behavior	11
Built Fuels and Fire Behavior	18
Structure Vulnerabilities	18
Structure Location on Slope	20
Structure Density	20
REVISITING THE DEFINITION OF THE WUI	20
SPATIALLY DEFINING THE WUI	20
WUI HAZARD AND WUI RISK	21
WUI Hazard.....	21
WUI Risk.....	21
A Special Caution Regarding Fire Response Capabilities	23
WUI RISK AND WUI HAZARD ASSESSMENTS	23
SUPPORTING WUI HAZARD AND RISK ASSESSMENT WITH GIS.....	23

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INTRODUCTION

Wildland fire occurs as a natural disturbance process to varying degrees of frequency and intensity in almost all the vegetated ecosystems across North America. The vegetation (grasses, plants, trees) in these ecosystems contributes as fuel to these fires and can be referred to as *wildland fuels*. As a natural disturbance process, wildland fires are generally considered beneficial to most of the ecosystems they occur in; however, due to human presence and other human values derived from the land base, unplanned wildland fires are generally considered to have a negative impact and are referred to as *wildfires*. Man-made structures (buildings and infrastructure) and cultivated vegetation (landscaping) in and adjacent to these ecosystems also contribute as fuel to wildfires. These man-made structures can be referred to as *built fuels*. For simplicity purposes, we will refer to all vegetation (natural and cultivated) as *wildland fuels*. A wildfire involving both wildland fuels and built fuels is referred to as a *wildland-urban interface fire*.

TRAINING OBJECTIVES

This training will provide the participants with a basic introduction to:

1. Wildland and wildland-urban interface fire behavior;
2. The definition of the wildland-urban interface;
3. What makes structures/infrastructure and communities vulnerable to wildfire losses;
4. Defining wildfire hazard vs. wildfire risk;
5. How wildfire hazard and risk are assessed;
6. How wildfire risk can be reduced.

WHAT IS THE WILDLAND-URBAN INTERFACE?

Traditionally, the wildland-urban interface (WUI) is defined as¹:

“The line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels. Describes an area within or adjacent to private and public property where mitigation actions can prevent damage or loss from wildfire.” (See figures 1 and 2, below.)

¹ National Wildfire Coordinating Group (NWCG) Glossary of Wildland Fire Terminology:
<http://www.nwccg.gov/glossary/a-z>



Figure 1 Traditional definition of the wildland-urban interface

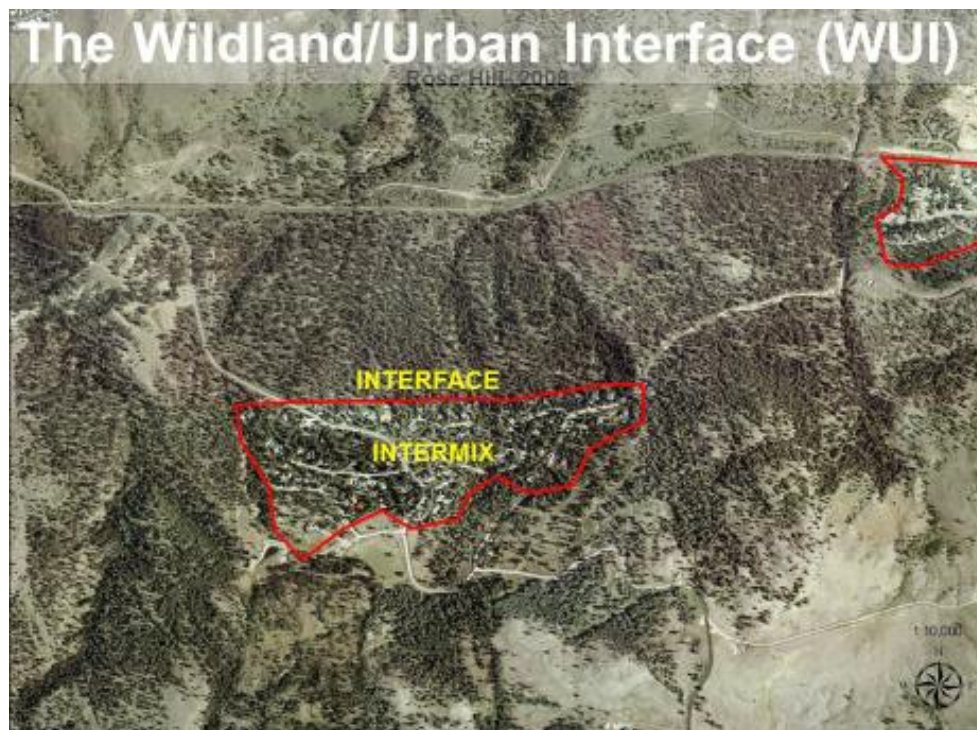


Figure 2. Traditional definition of the wildland-urban intermix

This definition works very well at “fitting” the WUI into a spatial “box” for planning purposes, but when we examine how fire spreads from wildland fuels to the built fuels and study the resulting losses, we find that **this traditional definition might not accurately define the true WUI.**

Two examples that visually explain this very well are the Horse River Fire (Ft. McMurray, Canada) in 2016 and the Waldo Canyon Fire (Colorado Springs, CO) in 2012. Both the photos of the Horse River Fire (Figure 3) and the Waldo Canyon Fire (Figure 4) show very clearly that structures were lost deep into the urban development area and well beyond what has been traditionally defined as the WUI. Note the significant barriers (roads), the lack of direct proximity of wildland vegetation, and the remaining green trees and vegetation adjacent to destroyed structures.



Figure 3 Horse River Fire (Ft. McMurray Canada) 2016



Figure 4. Waldo Canyon Fire (Colorado), 2012

To better explain these examples, which are representative of the majority of WUI occurrences where significant structure losses occur, Dr. Jack Cohen (USDA Forest Service- Retired) developed the “WUI Disaster Cycle” concept (below). This concept describes the events when a fire escapes the initial attempts to suppress it (Initial Attack) and its progression to structure involvement; multiple structure involvement and finally an urban conflagration where fire suppression resources are overwhelmed, and disastrous losses occur. 92- 98% of wildfires are suppressed at the initial attack stage; it is that 2- 8% of fires that escape initial attack that are responsible for these large-scale losses.



Figure 5. Jack Cohen's WUI Disaster Cycle concept

In reviewing examples like the Waldo Canyon Fire and the Horse River Fire and reading through the following sections on “The Basics of Wildland Fire and WUI Fire Behavior,” you will begin to understand that the WUI is not restricted just to the boundary where the forest meets structures; rather, the WUI extends well beyond that forest boundary, deep into urban development, and is dependent on a complex “set of conditions”.

To reflect this complexity and for the purposes of CPAW, the wildland-urban interface is better defined as:

Any area where the combination of human development and vegetation have a potential to result in negative impacts from wildfire on the community.

THE BASICS OF WILDLAND FIRE AND WUI FIRE BEHAVIOR

Any substance that will ignite and combust (burn) is fuel. In a wildfire situation, the two main fuels we have defined are wildland fuels and built fuels. To understand how to define the WUI and the concepts used to assess and mitigate the WUI, the planner must first have a basic understanding of how fire ignites, spreads and behaves in its interactions with wildland and built fuels.

Wildland Fuels and Fire Behavior

For simplicity, we had previously defined wildland fuels to include wildland (natural vegetation and cultivated vegetation (landscaping)). Regarding fire, there are three types of wildland fuel and three basic types of wildland fire (see Figure 5 and Figure 6):

- **Ground** fuel: includes all combustible substances below the surface litter of the organic soils. This is the fuel layer involved in *ground fires*.
- **Surface** fuel: includes all combustibles less than 39 inches (breast height) above ground level and one year's litter accumulation. This layer can include lower *ladder fuels*. This is the fuel layer (and possibly the ground fuel layer) involved in *surface fires*.
- **Aerial (Crown)** fuel: all combustible material higher than 39 inches (breast height) above ground level. This layer can include upper ladder fuels. These fuels, along with the surface fuel layer (and possibly the ground fuel layer) are the fuels involved in *crown fires*.

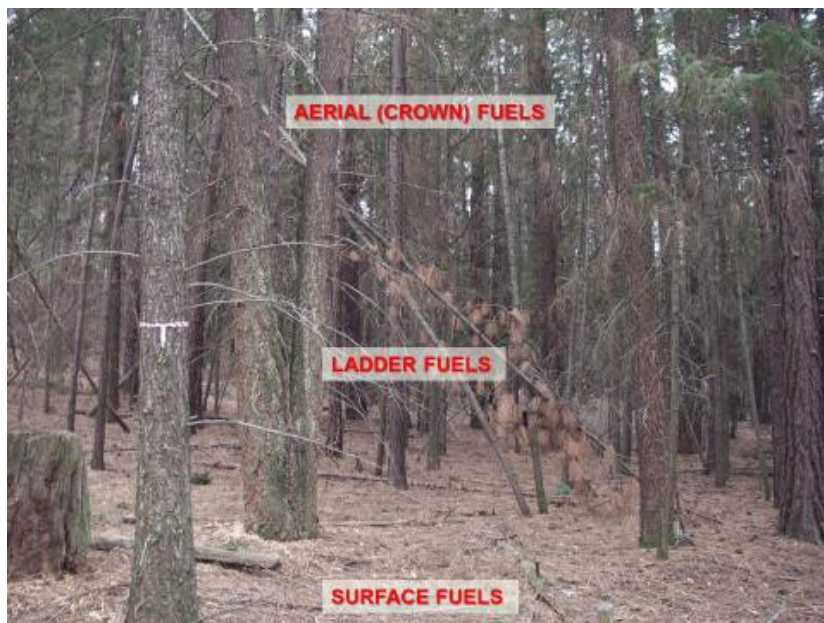


Figure 6 Wildland Fuels Surface and Aerial (Ladder and Crown) Fuel



Figure 7 Wildland Fuels Ground Fuels and Mineral Soil

Crown fires require a combination of a threshold surface fire intensity and ladder fuels to develop and sustain them (the exception are those crown fires driven by very strong wind events combined with steep slope and/or extremely dry conditions). Surface fires can burn without involving the ground fuel layer—this is typically a winter or spring fire event.

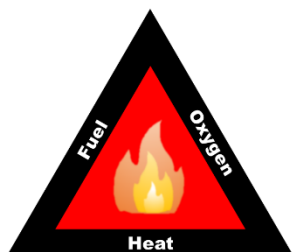


Figure 8. Vertical fire transition to crown fire influenced by ground, surface, ladder and aerial fuel loadings and arrangements

The Fire Triangle

To control and successfully fight wildfires and WUI fires, we must first understand what makes fire spread.

Three elements: *fuel, oxygen* and *heat* must be present to start and maintain a fire.



Fuel + Oxygen + Heat

Figure 9. The wildland fire triangle

In a wildland fire:

- Vegetation provides the fuel;
- Oxygen is in the air and;
- Heat results either naturally (lightning strike) or is introduced by people.

These three elements (fuel, oxygen, heat) are related to a triangle with each side representing one element. If any one of these elements is altered, the fire will behave differently; if one side of a triangle is removed, the fire extinguishes.



Figure 10. Removing and one of the three elements of the wildland fire triangle stops combustion

The Heat Transfer Process

Heat transfer process is the process by which heat travels from one body or object to another. There are three types of heat transfer processes:

Radiation: Transfer of heat through the air from warm surfaces to cooler surroundings (e.g., the heat you feel when you are sitting next to a campfire). Radiant heat from a crown fire or other individual significant heat sources (e.g., outbuildings, wood piles, single conifer trees, shrubs)

burning at distances less than 30 feet from a structure with wood walls can ignite the structure walls and break single pane windows—allowing ember entry to the interior of the building.



Convection: Transfer of heat by the movement of a hot air mass, usually upwards (i.e., burning objects below heat objects above). Rising convection heat can be “tilted” by the wind and slope, and therefore can transfer heat to receptive wildland or built fuels adjacent to the fire, or upslope and beyond the influence of radiant heat.



Conduction: Transfer of heat through solid matter (i.e., objects touching each other). A good example of conduction heat transfer is embers, generated from wildland or built fuels, that are carried through the air by convection and wind for a few feet to several miles that subsequently land on wildland fuels or built fuels. Embers are responsible for approximately 50% of structure ignitions in WUI fires.



Factors Influencing Wildland Fire Behavior

There are three key factors that influence wildland fire behavior:

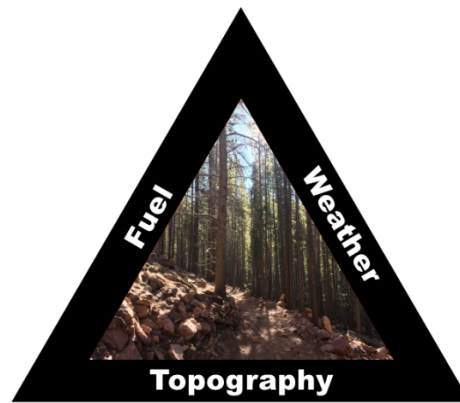


Figure 11. The wildland fire behavior triangle

Key Factors		
1. Fuel	2. Weather	3. Topography
Moisture	Wind	Slope
Size	Precipitation	Aspect
Spacing (continuity)	Relative Humidity	Terrain
Fuel Loading	Temperature	Elevation

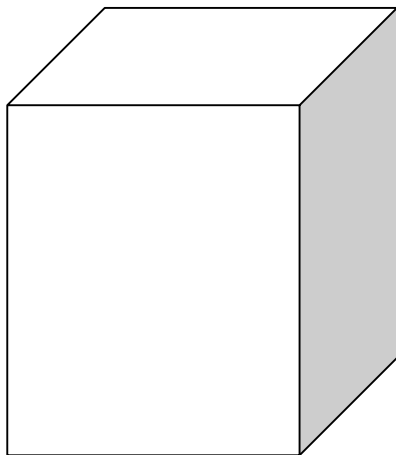
Wildland Fuels and Fire Behavior

Fuel Moisture

Fuel moisture content is the single most important fuel-related factor affecting fire behavior. Fire will ignite easier and spread faster in fuels with lower fuel moisture. Fuel moisture in wildland fuels is determined by:

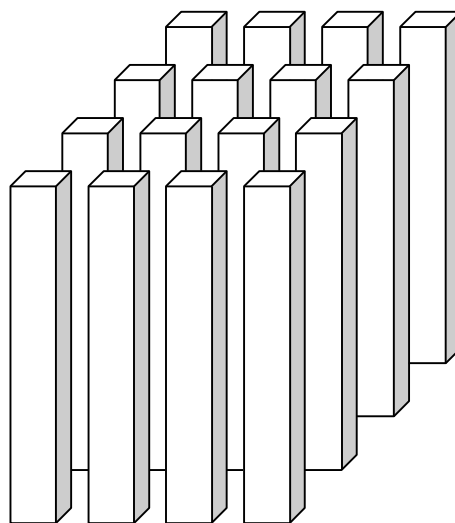
- Weather related factors affecting the amount of moisture in the fuel. For example, the amount and type of precipitation (e.g., rain, snow);
- Percentage of live or dead (cured) fuel. For example, green grass will not burn as well as brown grass.

Fuel Size



Surface Area = 6 m²

Heavy, slow-burning fuels include logs, stumps, large branch wood, trees and deep duff. These fuels take longer to ignite (due to moisture content), and fires spread slowly but burn longer with greater intensity. The moisture content change is slower due to a low surface area to volume ratio.



Surface Area = 18 m²

Light, fast-burning fuels include grass, dead leaves, tree needles, brush and small trees. They ignite quickly, result in fast spreading fires and act as kindling to light heavier fuels. The moisture content change is faster due to a high surface area to volume ratio.

Fuel Spacing (Continuity)

Fuel spacing refers to the arrangement of fuel on the landscape and can be considered as the fuel distribution in the horizontal and vertical directions. Fuel closer together increases the ability of fire to spread, while fuel spaced further apart decreases the ability of fire to spread.

Horizontal Fuel Spacing is usually described as “continuous” or “patchy”.

Vertical Fuel Spacing refers to the distance between surface fuels and aerial fuels. Fuels present between these two fuels are called *ladder fuels*.

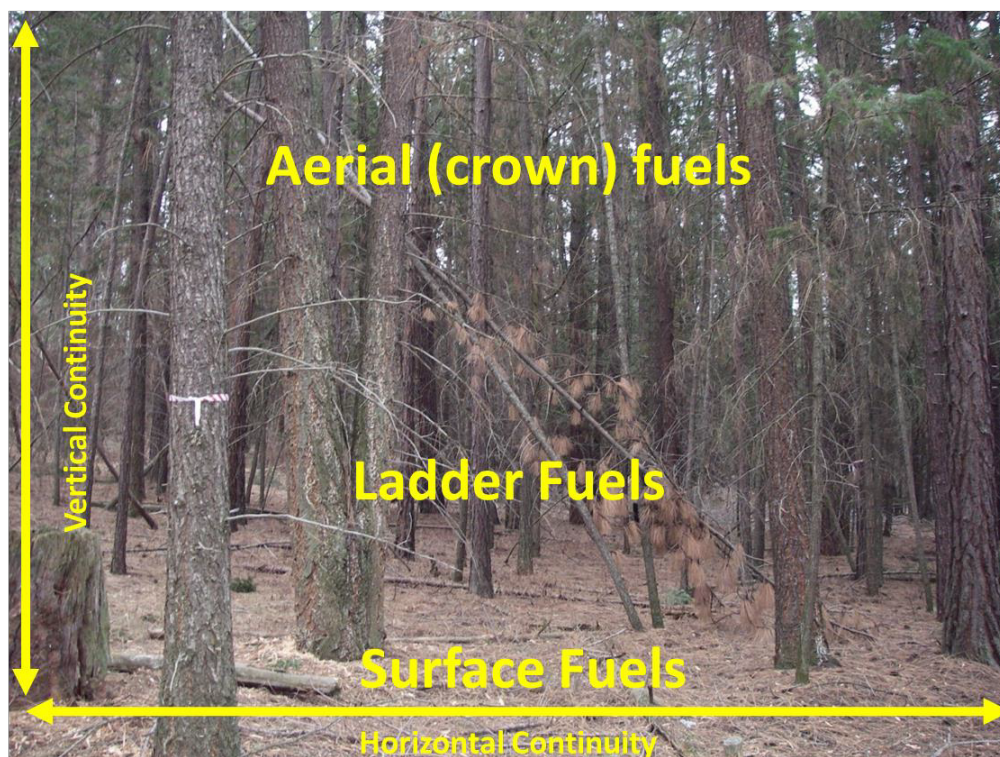


Figure 12. Horizontal fuel continuity in wildland fuels and a WUI fuel complex



Figure 13. Horizontal continuity at the community level WUI fuel complex

Fuel Loading

Fuel loading refers to the weight or mass of fuels in a given area, usually measured in tons per acre. Fuel loads may vary across the landscape. Higher density fuel loads will burn at higher intensities if fuel moisture conditions make all the fuel available for combustion.

Individual Plant Flammability Characteristics

Characteristics of Fire Resistant Plants:

- Moist, supple leaves
- Little dead wood and tendency not to accumulate dead material
- Water-like sap with little or no odor
- Low amount of sap or resin material

Characteristics of Highly Flammable Plants:

- Contain fine, dry, dead material within the plant
- Plant stem, branches and leaves contain volatile waxes, terpenes or oils
- Leaves are aromatic
- Gummy, resinous sap with a strong odor
- Loose papery bark

Weather

Wind

Wind is the single most important weather factor affecting fire behavior and influences fire behavior by:

- Increasing or decreasing fuel moisture
- Bending the flames and convective heat ahead, heating, drying and igniting new fuels
- Carrying embers into new fuel sources (spotting)
- Feeding more oxygen to a fire
- Driving the direction of a fire

Precipitation

Precipitation influences fire behavior by affecting fuel moisture. The effect of precipitation on fuel moisture is mostly dependent on fuel size:

- Less precipitation is required to raise the fuel moisture content in fine fuels than in heavy fuels;
- Fine fuels will dry out faster heavy fuels;
- Precipitation may not wet ground fuels if they are located under a dense canopy;
- Duration of precipitation, not quantity, is the most important factor determining the effect of precipitation on fuel moisture.

Relative Humidity

Relative humidity influences fire behavior by affecting fuel moisture. Relative humidity is the percentage of water vapor present in the air. When the air is dry (low relative humidity), fuels are likely to dry out; when the air is damp (high relative humidity), fuels are likely to absorb moisture (fuel moisture increases). Typically, the relative humidity will increase overnight and decrease during the day.

Temperature

Temperature fluctuations affect relative humidity, thereby affecting fuel moisture. To a lesser degree, temperatures also influence the amount of preheating required to bring fuel to its ignition temperature.

Topography

There are four topographical factors that influence fire behavior:

- Slope
- Aspect
- Terrain
- Elevation

Slope

Slope is the single most important topographical factor affecting fire behavior. Slope affects fire behavior in the following ways:

- Flames are closer to fuels on the uphill side, heating and igniting these new fuels;
- Convective heat (rising heat) from the fire travels up the slope, heating and drying new fuels;
- The convective air may carry firebrands, which can ignite spot fires above the main fire;
- Embers and large burning material may roll downhill, igniting new, unburned materials below the fire;
- Firefighting efforts are hampered and slowed on slopes;
- Cooling at night and weather changes can cause winds to blow down slope.

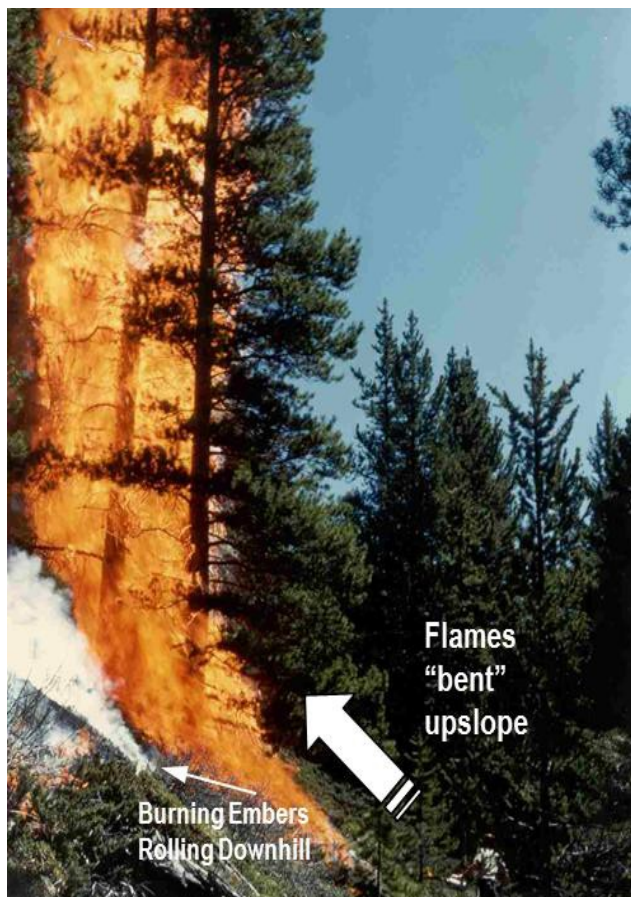


Figure 14. Slope influence on fire

Aspect

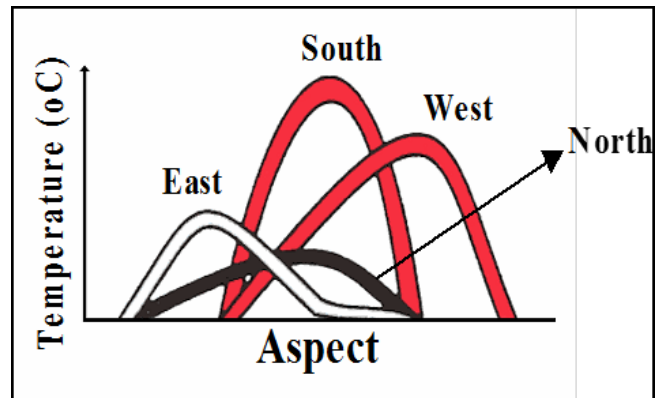
Aspect refers to the direction the slope faces. For example, a southwest aspect is a slope that faces southwest. The following aspect factors affect fire behavior directly:

- Southern slopes receive the most direct heat from the sun and therefore have higher temperatures;

- Fuels on south facing slopes typically have the lowest fuel moisture.



Figure 15. Aspect influence on fire



Terrain

Terrain is the variation in land features, which primarily affects fire behavior by altering wind direction and speed at a local level. It is useful to think of the wind patterns over terrain as water flowing in a river. Terrain affects wind patterns in the following ways:

- Turbulence or “eddies” can be generated on the leeward side when wind blows across ridges;
- Terrain restrictions, such as narrow portions of valleys, or knolls, can increase wind speed as the wind passes through, or around these restrictions;
- Steep-sided gullies or canyons running uphill can create a “chimney effect,” dramatically increasing uphill spread rates and intensity. In many cases these terrain features will also have heavy fuel loadings, increasing fire behavior.



Figure 16. Terrain influence on winds and fire

Elevation

Typically, air temperatures follow an elevation gradient with temperatures being warmer at lower elevations and cooler at higher elevations. Quite often, atmospheric conditions will cause a band of warm air to be trapped at mid- elevation between cool air at lower elevations and cool air above. In mountainous terrain this is a temperature inversion known as a thermal belt. Within the thermal belt, temperature will be higher and relative humidity will be lower than the elevations above and below, possibly creating extreme fire conditions when unexpected

BUILT FUELS AND FIRE BEHAVIOR

Built fuels include man-made structures that are important components of a community and are vulnerable to damage or loss through combustion during a WUI fire event. Some examples are buildings, attachments (e.g., decks, fences), utility poles and bridges. The focus on fire behavior and built fuels is buildings—typically homes—however, business and infrastructure losses can be significant during a WUI fire and many of the same ignition concepts can be applied to them as well.

Structure Vulnerabilities

Roof Assembly

During a wildfire or urban structure fire event, the roofs of structures can collect airborne embers and combustible debris. If the roof is constructed of flammable material it is highly susceptible to ignition from these embers. A large percentage of homes that burned in wildfires are a result of these roof ignitions.

Dormers and Walls Above Lower Roofs

Airborne embers and combustible debris can collect in the wall/roof junctions at the base of walls extending above roofs. The “piling up” of these embers in this junction can ignite combustible siding or ignite the combustible wall assembly behind non-combustible siding on any exposure of the building, thereby igniting the walls, or combustible material behind the walls of a structure.

Roof and Soffit Vents

Roof and soffit vents required to vent attics can provide openings for airborne embers to enter the attic spaces of homes and ignite combustible material in the attic space.

Gutter and Downspout Assembly

Airborne embers and combustible debris can collect in gutters and downspouts. Embers and debris can melt the gutters and downspouts and drop burning material to the base of the structure walls and combustible surface vegetation and materials below the gutter assembly.

Structure Walls

Radiant heat from adjacent burning wildland fuels or structures can ignite combustible exterior structure walls. In addition, airborne embers piling against the base of structure walls at the junction of structure walls and the surrounding finished grade can ignite exterior combustible siding, or the combustible wall assembly behind non-combustible siding.

Windows

Windows can crack and become displaced from window frames when exposed to the radiant heat generated from adjacent burning vegetation or adjacent structures, or the convective heat generated from fires burning downslope of a structure. This can create an opening for airborne embers to enter the structure and ignite interior combustible materials. Although all windows are susceptible to failing, single pane windows have been documented to fail sooner than thermal pane windows.

Attachments and Outbuildings (within 30 feet of structure)

Attached and detached decks, porches, carports, garages and outbuildings within 30 feet of main structures are considered attachments and can be the source of fire spread to the main structure. Deck and porch surface junctions with combustible siding walls can collect embers and combustible debris, igniting the structure walls. The area under decks and carport with combustible surfaces, vegetation or other combustible materials can ignite the deck structure from below which in turn can spread to the main structure. Attached or detached out buildings are susceptible to the same wildfire exposures as the main structure. Radiant heat generated from structures within 30 feet of the main structure can generate enough radiant heat to ignite combustible siding and break windows (allowing ember interior entry), resulting in ignition of the main structure.

Wood Fences

Wood fences attached to structures can act as a “wick”—allowing fire to spread along the fence to the structure and ignite the structure.

Structure Location on Slope

Structures situated mid-slope or at the crest of a slope can be impacted by both the convective heat and embers generated by fires burning below the structure. This will increase the risk of the structure igniting.

Structure Density

Recall that structures need to be considered as fuel themselves; and therefore, can contribute to the ignition and spread of fire to vegetation and other structures. Communities with dense structure layouts can facilitate a wildland-urban interface fire transitioning to an urban conflagration (i.e., fire spread from structure to structure) within the community, or vice versa.

REVISITING THE DEFINITION OF THE WUI

Through examples and a basic knowledge in wildland and WUI fire behavior and understanding the WUI Disaster Cycle, we can clearly see that the WUI is not restricted just to the boundary where the forest meets structures; in fact, it extends well beyond that boundary and deep into urban development and is dependent on a complex “set of conditions”. As previously stated,, the wildland-urban interface is better defined as:

Any area where the combination of human development and vegetation have a potential to result in negative impacts from wildfire on the community.

SPATIALLY DEFINING THE WUI

It is clear that the WUI is a set of conditions; however, it must still be spatially displayed in order to support land use planning decisions and regulations.

The SILVIS Lab approach originating from the Federal Registry² spatially defines the WUI based on the following criteria:

1. Housing density
2. Landcover³
 - **WUI Intermix:** Areas with ≥ 6.18 houses per km^2 and ≥ 50 percent cover of wildland vegetation
 - **WUI Interface:** Areas with ≥ 6.18 houses per km^2 and < 50 percent cover of vegetation located < 2.4 km of an area $\geq 5 \text{ km}^2$ in size that is ≥ 75 percent vegetated
 - **Non- WUI Vegetated (no housing):** Areas with ≥ 50 percent cover of wildland vegetation and no houses (e.g., protected areas, steep slopes, mountain tops)
 - **Non-WUI (very low housing density):** Areas with ≥ 50 percent cover of wildland vegetation and < 6.18 houses per km^2 (e.g., dispersed rural housing outside neighborhoods). **NOTE: THIS SHOULD BE CONSIDERED AS WUI INTERMIX!**
 - **Non-Vegetated or Agriculture (low and very low housing density):** Areas with < 50 percent cover of wildland vegetation and < 49.42 houses per km^2 (e.g.,

agricultural lands and pasturelands). **NOTE: THIS SHOULD BE CONSIDERED AS WUI IN EMBER ZONES!**

- **Non-Vegetated or Agriculture (medium and high housing density):** Areas with <50 percent cover of wildland vegetation and ≥ 49.42 houses density per km^2 (e.g., urban and suburban areas, which may have vegetation, but not dense vegetation). **NOTE: THIS SHOULD BE CONSIDERED AS WUI IN EMBER ZONES!**

² USDA and USDI. 2001. Urban wildland interface communities within vicinity of Federal lands that are at high risk from wildfire. Federal Register 66:751–777.

³ Schlosser, W.E. 2012. Defining the Wildland-Urban Interface: A Logic-Graphical Interpretation of Population Density. Kamiak Ridge, LLC

WUI HAZARD AND WUI RISK

All too often, the terms *WUI hazard* and *WUI risk* are used as interchangeable terms, or even combined to create the term “*WUI hazard risk*”. It is important to understand the difference between these two terms and use them appropriately in the community wildfire planning context.

WUI Hazard

The term *WUI hazard* is appropriately used in the context of describing the combination of the likelihood of a fire occurring and the intensity of the fire the wildland or built fuels present in a given area, or the combustibility of a given fuel type or fuel complex in general. Factors influencing the WUI hazard assessment may include:

- Wildland fuel models or fuel structure (distribution, size, loading, etc.)
- Built fuel vulnerability assessment (roof, walls, windows, fences, etc.)
- Historical fire cause and location (human vs lightning)
- Historical fire size
- Historical weather and fire season
- Historical wildland fire suppression success

WUI Risk

The term *WUI risk* describes the *WUI hazard* along with the factors that contribute to the susceptibility, or impact on highly valued resources and assets of a WUI fire occurring. Factors that contribute to the *WUI risk assessment* may include:

- Population demographics
- Public safety
- Ember transport modeling
- Structure and infrastructure vulnerability
- Natural resource values and vulnerabilities

- Watershed vulnerability
- Socio-economic values



Figure 17. The wildfire risk triangle

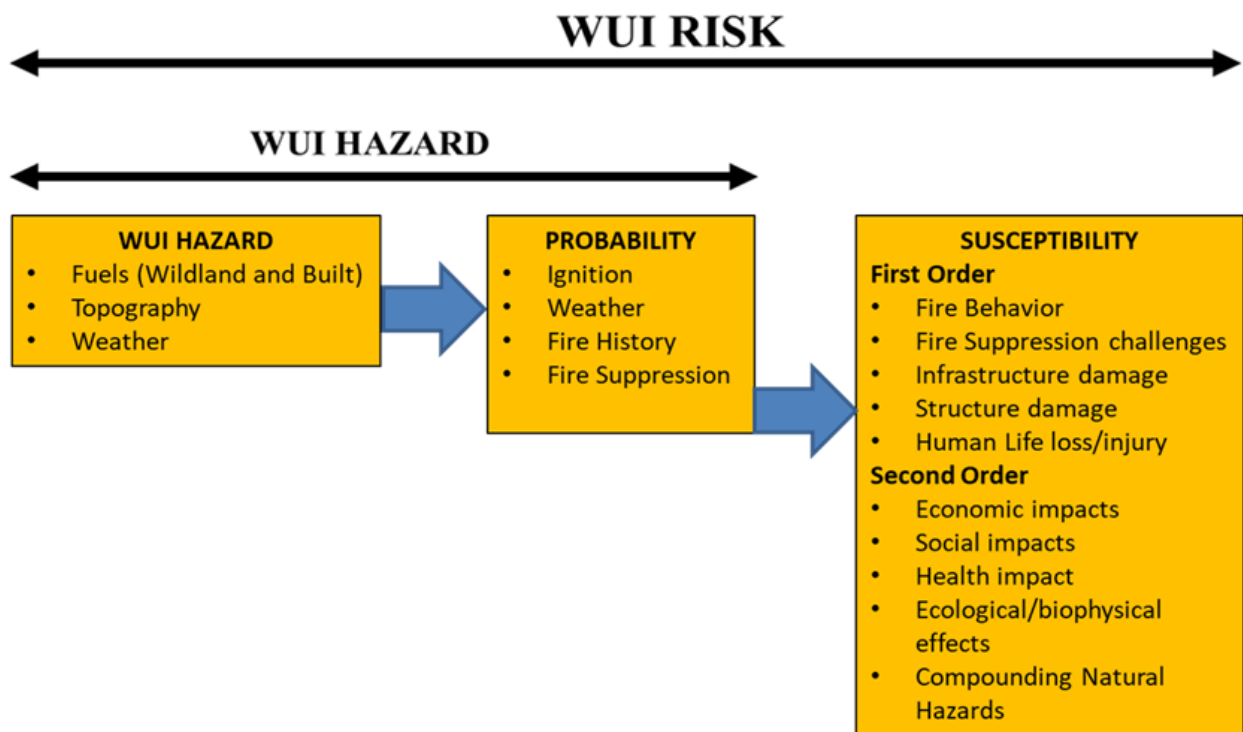


Figure 18. WUI Risk relationship to WUI hazard

A Special Caution Regarding Fire Response Capabilities

The fire response capabilities of a community (e.g., water source, response time, fire stations, fire apparatus) are often included as factors into a risk assessment. While the response capability is extremely successful during the initial attack phase of a wildfire, or in response to an isolated structure fire, these resources are almost always and immediately overwhelmed once either of these scenarios transition into a WUI fire involving wildland fuels and multiple structures. Once this transition is made, the success of reducing losses relies almost solely the mitigation and resiliency of the remaining factors. We therefore should approach the use of response to influence the WUI risk assessment.

WUI RISK AND WUI HAZARD ASSESSMENTS

It is important to know that WUI and wildfire risk assessments are developed for different purposes and scales of reference. The scale and purpose of a landscape level assessment must be appropriate to provide context for a community level assessment and a community level assessment must be at a scale to support Structure Ignition Zone level assessments.

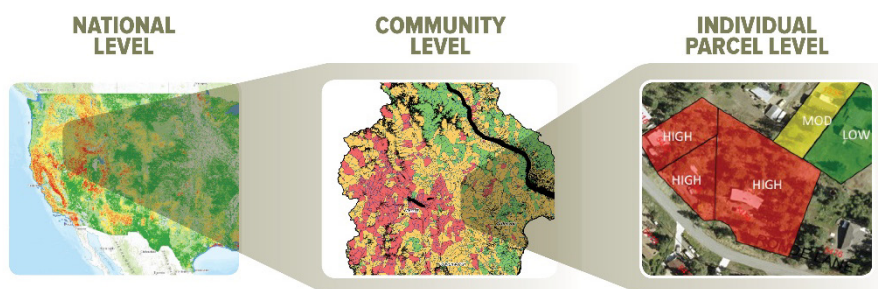


Figure 20. Example of national, community and individual parcel scales of risk or hazard assessments

SUPPORTING WUI HAZARD AND RISK ASSESSMENT WITH GIS

GIS has become a very integral and powerful tool used to support the analysis and spatial representation of WUI hazard and WUI risk. There are several GIS based wildfire hazard and risk assessment products available. Be sure to answer the following questions when selecting the appropriate GIS assessment product:

- Is the assessment tool scale appropriate for your use (e.g., is it a landscape level vs parcel level assessments)?
- Is the data used and outputs of the assessment tool appropriate for the information you require? (e.g., are appropriate factors used? Is it a risk or hazard output? Is it for wildfire or WUI? Does it assess the “set of conditions”?)
- What is the accuracy of the data used in the assessment tool (e.g., how up to date is that data? What are the sources?)