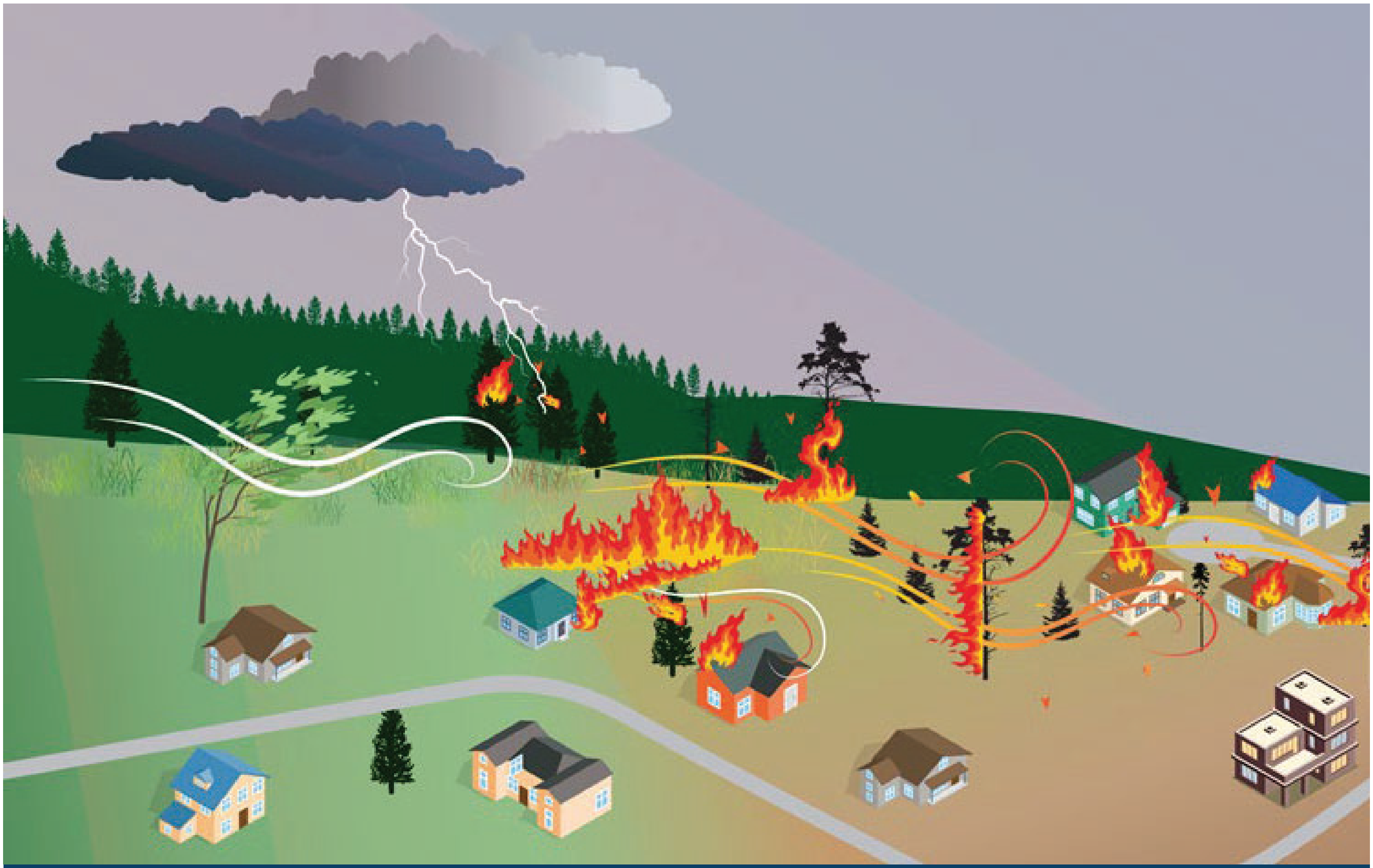

Marshall Fire Mitigation Assessment Team: Mitigation Strategies to Address Multi-Hazard Events

Revised April 2025

FEMA

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1. Introduction

On December 30, 2021, a wind-driven Marshall Fire burned across exceptionally dry grassland into Colorado communities, resulting in the most destructive fire in state history. The damage to communities resulting from the combination of these hazards (i.e., drought, wind, and wildfire) demonstrates the need for a multi-disciplinary approach to wildfire mitigation. This document provides strategies to reduce the risk of wildfire loss exacerbated by other hazards and address post-wildfire-created hazards.

Because of the unique nature of the incident, where extreme winds coupled with long term drought, high temperatures, and limited wildfire regulatory adoption, a fast-moving low-intensity grass fire became a highly destructive urban fire directly and indirectly impacting several communities and greater Boulder County area. The Federal Emergency Management Agency (FEMA) deployed its first-ever wildfire Mitigation Assessment Team (MAT) to evaluate building performance during the fire. The MAT was deployed to Louisville, Superior, and unincorporated areas in Boulder County, Colorado, to evaluate damaged homes and commercial structures. MAT members evaluated components and systems of primarily residential structures to determine the effectiveness of various building materials, design, and construction practices for wildfire resiliency. The MAT used the information gathered to evaluate how wildfire-urban interface (WUI) building codes and standards, as well as design, construction, and defensible space practices can be improved to increase community wildfire resilience. This is important as the landscape is continuously evolving due to changing weather patterns and putting more communities at risk.

2. Purpose

This document is intended to help planners, developers, local land management personnel and private property owners identify how wildfires interact with other natural hazards and mitigate the impact of these multi-hazard events. The document will cover natural hazard interactions, common pathways for wildfire spread and strategies to mitigate wildfire and post-wildfire impacts. The information in this document can be used to guide the incorporation of site-based wildfire mitigation strategies into planning, community siting and zoning requirements. This document can also guide the adoption of proactive planning, development and maintenance strategies that can minimize future risk of multi-hazard events. To create a comprehensive approach to property protection, the mitigation strategies outlined in this document should be used in conjunction with wildfire-resistant building codes and standards (i.e., ICC model codes). Hazards covered in this document include wildfire, drought, lightning, high wind, extreme heat, flood, and landslide.

Note: This document should be read in conjunction with Marshall Fire MAT document *Best Practices for Wildfire-Resilient Subdivision Planning*.

3. Key Issues

- Wildfires, and especially urban wildfires, are an ongoing concern for the geographical areas affected by the Marshall Fire. While wildfires are a natural component of many ecosystems, the risk of more dangerous and intense fires has increased due to various land management practices (including fire exclusion and suppression policies), human error or arson, ecosystem-damaging insects and disease, invasive species such as cheat grass and changing weather patterns.

- A fire can result in major losses of property and structures, especially in the wildland-urban interface, areas where human development meets or intermingles with landscapes that support wildland fire. Communities are increasingly exposed to wildfire in the areas where development has encroached on wildfire-prone rangeland, grassland, and forested areas. Community location and design, (e.g., housing density, accessory structures, combustible building material, landscape design and maintenance) can also make communities more susceptible to wildfire damage.

- Fire season in the Western United States typically extends from spring to late fall, and in some cases year-round. Fire hazard conditions arise from the combination of hot weather, an accumulation of vegetation that will act as a fuel source, and low moisture content in air and fuel. These conditions, especially when combined with other natural hazards such as high winds, elevated temperatures, and drought, increase the potential for more extreme wildfire behavior.

- Communities should use a multi-disciplinary approach to wildfire mitigation to reduce wildfire loss exacerbated by other hazards and address hazards that could develop post-wildfire, such as flooding and debris flows. Planners, developers, and land managers pursuing a multi-disciplinary approach to wildfire mitigation should consider the following key take-aways:

  - Natural hazards events can contribute to other key fire hazard conditions (i.e., topography, fuel, and weather) that cause wildfires to ignite and spread (Figure 1).

  - Wildfires can increase the likelihood and severity of secondary hazard events, such as flooding and debris flows.

  - Development strategies in the wildland-urban interface may not adequately address mitigation best practices or may inadvertently exacerbate the effects of multi-hazard events.

  - Wildfire mitigation requires a multi-disciplinary approach that collectively addresses the impact of natural hazards on wildfire risk through effective land management and building techniques.

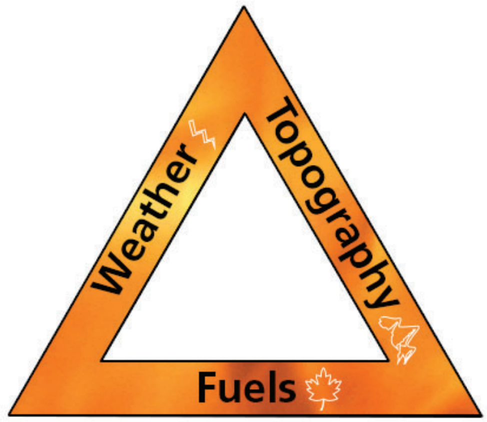

Figure 1. Topography, fuel, and weather are the three fire hazard conditions that are most influential on the growth and behavior of a wildfire (NPS/C. Boehle).

4. Definitions

- Burn Boundary: The boundary defining the area burned by a fire (U.S. Geological Survey).
- Debris Flow: Fast-moving, deadly landslides. They are powerful mixtures of mud, rocks, boulders, entire trees - and sometimes, homes or vehicles (National Weather Service).
- Defensible Space: The area or space around homes and buildings where vegetation and other features (e.g., trash, firewood piles) are managed to reduce the structure's risk of ignition due to radiation (heat), direct flame impingement or exposure to firebrands from a wildfire (Adapted from Bell et al. 2007). Defensible space also provides firefighters, if able and available to respond, with a place of relative safety to conduct firefighting operations (e.g., control or suppression fire, search-and-research) during a wildfire or urban conflagration.
- Dry Lightning: Cloud-to-ground lightning accompanied by rain that evaporates before it hits the ground (U.S. Forest Service).
- Extreme Heat: A period of high heat and humidity with temperatures above 90 degrees for at least two to three days (Ready.gov).
- Fire Break: A natural or constructed barrier used to stop or check fires that may occur, or to provide a control line from which to work (NWCG).
- Fuel Break: A natural or man-made change in fuel characteristics which affects fire behavior so that fires burning into them can be more readily controlled (NWCG).
- Firebrands: Any source of heat, natural or human made, capable of igniting wildland fuels. Flaming or glowing fuel particles that can be carried naturally by wind, convection currents, or by gravity into unburned fuels (NWCG).

- **Hydrophobicity**: Resistance to wetting exhibited by some soils, also called water repellency. The phenomenon may occur naturally or may be fire-induced (NWCG).

- **Ignition-Resistant Material**: A type of building material that resists ignition or sustained flaming combustion sufficiently to reduce losses from wildland-urban interface conflagrations under worse-case weather and fuel conditions with wildfire exposure of burning embers and small flames (2021 IWUIC).

- **Ladder Fuel**: Fuels which provide vertical continuity between fuel sources, thereby allowing fire to carry from surface fuels (i.e., grass) into the leaves and branches of trees or shrubs with relative ease (NWCG).

- **ICC Model Codes**: The International Code Council's model codes provide the most robust standards for hazard-resistant building construction and design. These include the International Residential Code (IRC), the International Building Code (IBC), the International Fire Code (IFC) and the International Wildland-Urban Interface Code (IWUIC) among others.

- **National Fire Protection Association (NFPA®) 1140**: Standard for Wildland Fire Protection: Provides minimum requirements for wildland fire management (e.g., building materials, automatic sprinkler systems, fire separation distance) and the associated professional qualifications for wildland fire positions.

- **Prescribed Fire**: A wildland fire originating from a planned ignition in accordance with applicable laws, policies, and regulations to meet specific objectives (NWCG).

- **Rockfall**: Abrupt movements of masses of geologic materials, such as rocks and boulders, which become detached from steep slopes or cliffs (USGS).

- **Shaded Fuel Break**: Fuel breaks built in timbered areas where the trees on the break are thinned and pruned to reduce the fire potential yet retain enough crown canopy to make a less favorable microclimate for surface fires (NWCG).

- **Wildland Urban Interface (WUI):** The line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetation fuels (National Wildfire Coordinating Group).

5. How Natural Hazards Interact with Fire Hazard Conditions

Hazardous topographic and fuel conditions, combined with weather conditions and an ignition source work together to influence the probability, intensity, and severity of wildfire behavior. Natural hazards events can also influence these fire hazard conditions to increase the risk or severity of a wildfire. In wildfire-prone areas, post-fire conditions can also increase the risk of secondary natural hazards, or “cascading effects”, such as floods and landslides downslope of burn boundaries. See Figure 2.

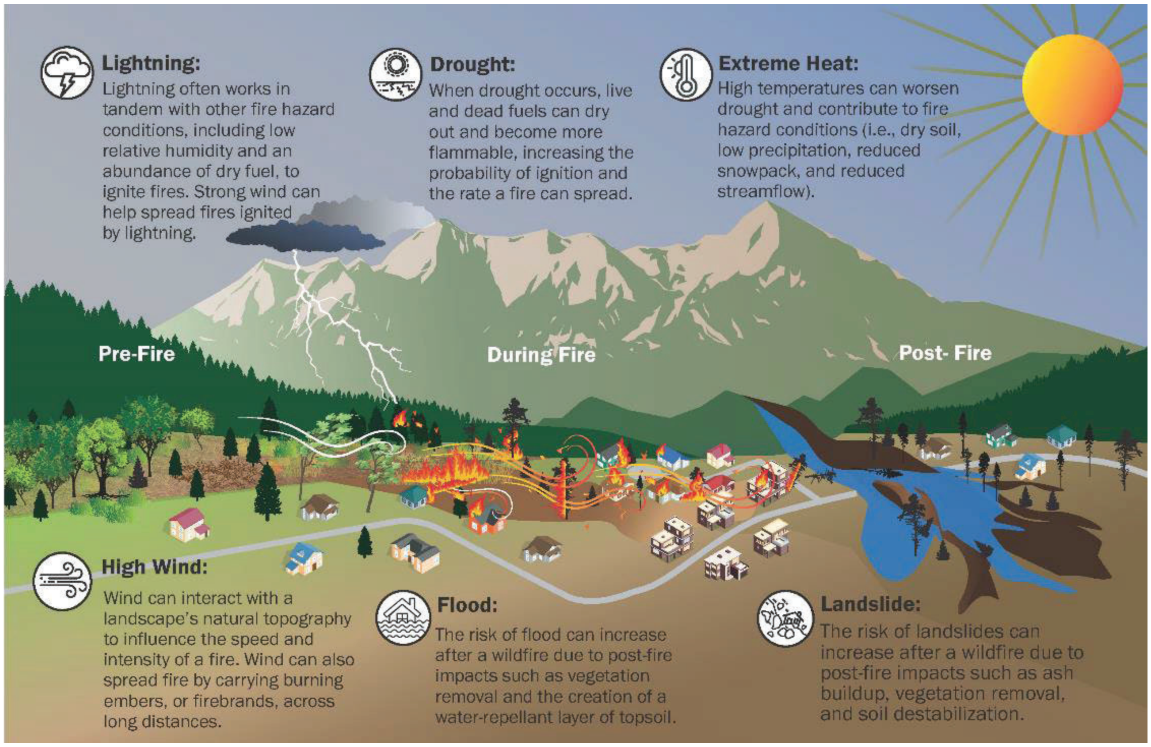

Figure 2. Hazards that contribute to or result from wildfires.

5.1. Hazards Included in this Document

DROUGHT: Drought has been shown to interact often with other factors, (e.g., vegetation density and condition, topography, fire weather, management activities) to affect fire intensity, severity, extent, and frequency (Littell, 2016). When drought occurs, both live and dead vegetation can dry out and become more flammable, increasing the probability of ignition and the rate a fire can spread.

Drought is a natural event in Colorado, due to its semiarid climate. Drought conditions can occur slowly over several years, without a clear beginning or end. Long droughts are not necessary to increase the hazard potential for large wildfires; studies show that irregular or rapid occurrence of arid conditions lasting 30 days or more is sufficient to dry both dead and live fuels (Cohen & Deeming, 1985; Riley et al., 2013). It is likely that drought conditions beginning in October 2021 contributed to both the severity and intensity of the Marshall Fire. Higher than normal temperatures and low precipitation levels increased the likelihood of ignition and created dry vegetation to fuel the fire's spread. According to the Boulder County Hazard Mitigation Plan, droughts in this region are expected to be more likely and persistent in the future.

LIGHTNING: Dry lightning - lightning accompanied by rain that evaporates before it hits the ground - is the most likely type of lightning to ignite a wildfire (U.S.F.S Wildland Fire Assessment System, n.d.). The National Interagency Fire Center recorded over 7,000 lightning-caused wildfires in 2022.[1] The presence of fire hazard conditions, including high heat, low relative humidity, and a high volume of dry fuels, can increase the likelihood of ignition caused by a lightning strike. Strong winds can also help spread wildfire once ignited. Rangeland and grasslands landscapes are vulnerable to lightning strikes and can be especially vulnerable to rapid wildfire spread due to the abundance of quick burning "flash" fuel. Drought can further increase the risk of lightning igniting a fire by creating conditions that are more favorable for dry lightning strikes (i.e., dry air and limited precipitation) and increasing the volume of dry vegetation that can ignite.

Boulder County is predicted to experience more severe thunderstorms, more frequent lightning strikes and more wildfires ignited by lightning strikes in connection with rising global surface temperatures (Boulder County Hazard Mitigation Plan, 2022).

HIGH WIND: Many locations that are at risk for wildfires, particularly those at risk for grassland fires, are also subject to high winds. Wind is one of the most important factors in wildfire behavior because it can bring fresh oxygen to a fire and push the fire toward a new fuel source. Wind can also interact with a landscape's natural topography to influence the speed of a fire. For example, due to wind speed-up-effects, adding an extra 10 degrees of upslope can double the speed of a fire.

Wind can increase the spread of wind-driven embers, also known as firebrands, out ahead of the fire into unburned areas. Embers can travel long distances and have the potential to ignite unburned fuels ahead of a fire. During a fire, wind-borne debris can also breach building envelopes, cracks, and unscreened vents, allowing embers and flames to enter the structure and cause ignition.

Strong sustained winds, moving through drainage ditches and across a relatively flat grassland was one of the key factors that allowed the Marshall Fire to spread quickly. Additionally, embers were observed in video from first responders on scene of the Marshall Fire and are believed to be a key factor in the rapid advance of the wildfire (Figure 3).

[1] National Interagency Fire Center. 2022. Lightning-Caused Wildfires. https://www.nifc.gov/fire-information/statistics/lightning-caused

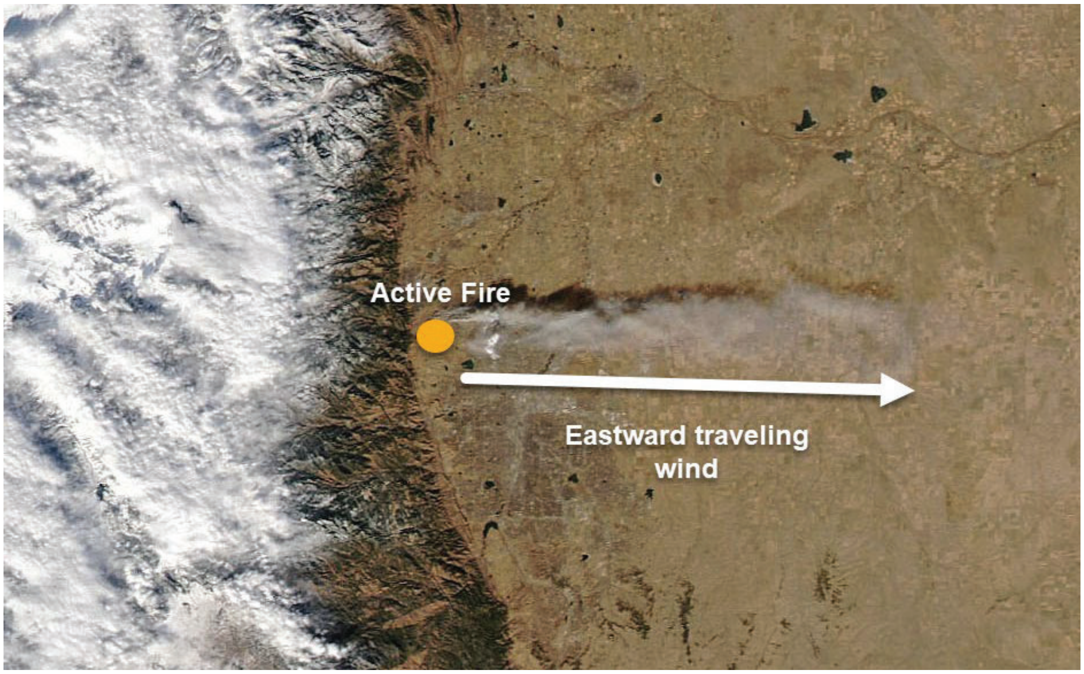

Figure 3. Wind gusts measuring 115 mph travelled east down the slope of the Rocky Mountains spreading the fire across grass and brush into unincorporated Boulder County, Louisville and Superior. Wind-driven embers landed on and helped ignite structures (NASA Earth Observatory, Dec 30, 2021).

EXTREME HEAT: Extreme heat is a period of high heat and humidity with temperatures above 90 degrees for at least two to three days. High temperatures can have worsening effects on fire-prone landscapes already impacted by drought and contribute to low soil moisture and reduced amounts of natural water sources. In mountainous regions, warmer springtime temperatures can cause earlier snowmelts, reducing overall snowpack and decreasing runoff when it is needed during dry summer months. These effects combine to create larger volumes of dry fuel that can ignite more quickly and burn for longer periods of time.

Between July 1 and December 29, 2021, the area impacted by the Marshall Fire experienced the second warmest temperature ever recorded in that time period (Miller, 2022). Higher-than-normal temperatures and low precipitation levels contributed to the drought conditions that preceded the Marshall Fire. According to the Boulder County Hazard Mitigation Plan, Boulder County will see an increase in the frequency and the length of extreme heat events, resulting in more record-setting high heat days lasting for longer periods of time (2022).

FLOOD: Flooding can occur in the days, weeks, months, or years after a wildfire because of the dramatic change in terrain and ground conditions. Wildfires can leave soil free of vegetation that would absorb water and, in some cases, make the soil itself hydrophobic, increasing the speed and volume of runoff. As a result, even moderate rainfall on a burned area can significantly increase the risk of a flash flood and mudflow

> If you can look uphill from where you are and see a burnt-out area, you are at risk of flash floods. (National Weather Service, n.d.)

downslope and downstream. Flooding and associated erosion can pollute water resources, threaten human life, and cause damage to homes and other structures. Burn scars such as those left by the 2010 Fourmile Canyon Fire have already increased the risk of flooding in Boulder County (Boulder County Hazard Mitigation Plan, 2022). See Figure 4.

Figure 4. The 2010 Fourmile Canyon Fire helped create conditions that led to flash flooding in the Boulder area in September 2013 (Will von Dauster, NOAA, n.d.).

LANDSLIDE: Following a wildfire, burned areas are especially vulnerable to floods, subsequently creating the conditions that enable erosion and several types of landslides, including mudslides, debris flows and rockfalls. Extreme rainfall events in burned areas can further increase the potential for flood and landslides to occur.

Debris flows are a fast-moving, dangerous form of landslide that combines mud, rock, boulder, trees and sometimes cars and buildings. Ash deposited on the ground during a wildfire may overlie hydrophobic soil. This ash may have the ability to absorb water and when it becomes saturated, it can start to flow downhill. The downhill, channelized movement of ash and eroded sediment can progressively accumulate with other sediment sources, such as channel beds and waterway banks, resulting in high volume, fast-moving debris flows. Buildings and other structures located near ditches, rivers, floodplains and in low elevations are especially vulnerable to damage from floods and debris flow (Figure 5).

The U.S. Geological Survey (USGS) maintains a Post-Wildfire Debris Flow Hazard Assessment Viewer online for the Western U.S. that shows the likelihood of a debris flow post- wildfire and estimates the magnitude of the flow where debris flows occur. These maps can be used to identify areas that could be at-risk so appropriate actions can be taken to warn residents and protect infrastructure before a debris flow event occurs. https://usgs.maps.arcgis.com/apps/dashboards/c09fa874362e48a9afe79432f2efe6fe

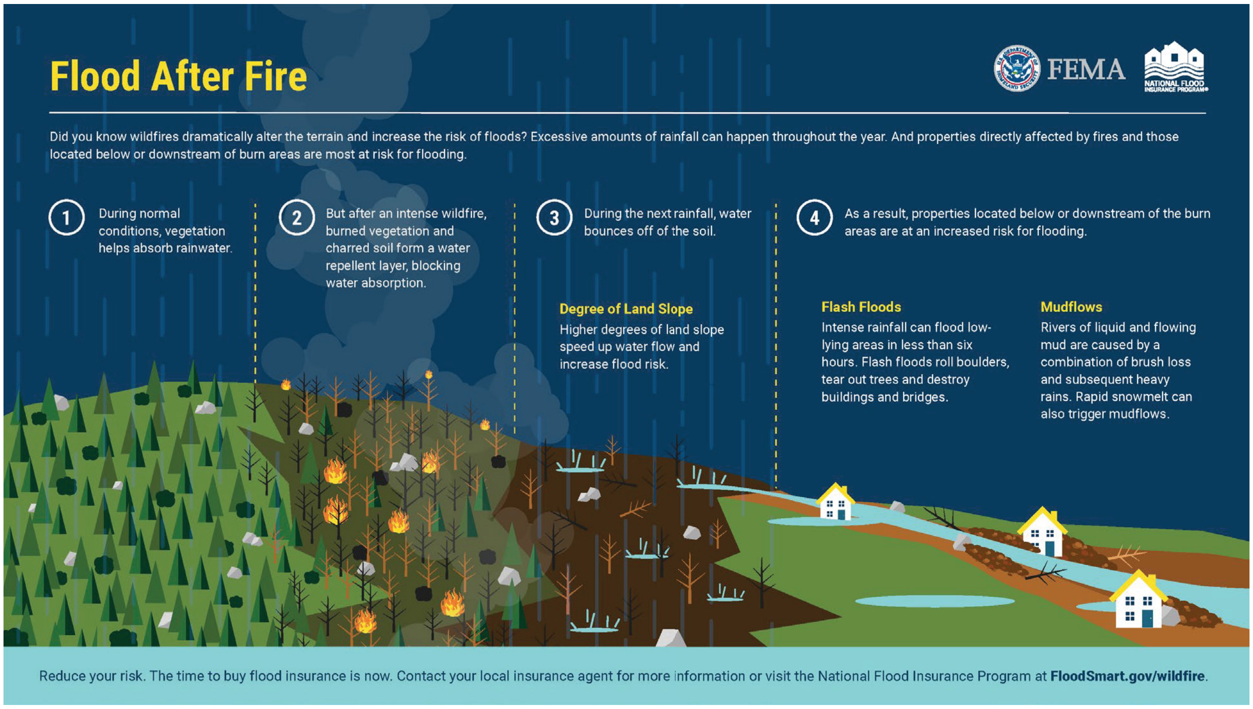

Figure 5. The risk of flood and mudflows can increase after a wildfire due to post-fire impacts such as ash buildup, vegetation removal, soil destabilization and the creation of hydrophobic soil.

6. Pathways for Wildfire Spread

Across different geographies, natural and fire hazard conditions (topography, fuel, and weather) can interact with natural hazards to create multiple pathways for wildfire spread. The following section provides a high-level understanding of these common pathways (outdoor space, waterways, forests, structure to structure) for wildfires to ignite and spread.

6.1. Grasslands & Outdoor Spaces

> Grasslands and open spaces still qualify as wildland-urban interface or intermix areas and can be at risk to wildfire.

Wildfire can ignite and spread in both undeveloped lands, such as open shrublands and grasslands, and in outdoor spaces of developed areas. In developed areas, outdoor spaces serve essential community roles for residents in the form of greenbelts, grazing areas, parks, and other recreational spaces. However, grasslands and outdoor spaces can become avenues where wildfire is able to burn rapidly and spread to residential areas (Figure 6). Rangeland and grasslands landscapes are vulnerable to lightning strikes and can be especially vulnerable to rapid wildfire spread due to the abundance of quick burning “flash” fuel. Low humidity, high temperatures and an abundance of dry fuel can increase the probability of ignition. Strong winds can also carry burning embers across grasslands and outdoor spaces to ignite buildings.

While grassland and shrubland fires are typically low-intensity and fast-burning, they are also easy to ignite and spread rapidly. If this landscape is not properly maintained, it may become overgrown with flammable invasive species such as cheatgrass and become too dense. Vegetation growing in outdoor spaces, such as grasslands and greenbelts, can die-off or dry out seasonally and during periods of drought or abnormally high temperatures. Greater quantities of fuel, including invasive species, increase a fire's burning potential while long dry periods enhance flammability and increase the probability of wildfires. Dry vegetation can also act as a ladder fuel, carrying embers from the ground to taller vegetation or structures such as decks or fences. Open grassland was observed as the first fuel to burn in the Marshall Fire and contributed to the rapid advancement of the fire from wildland to communities.

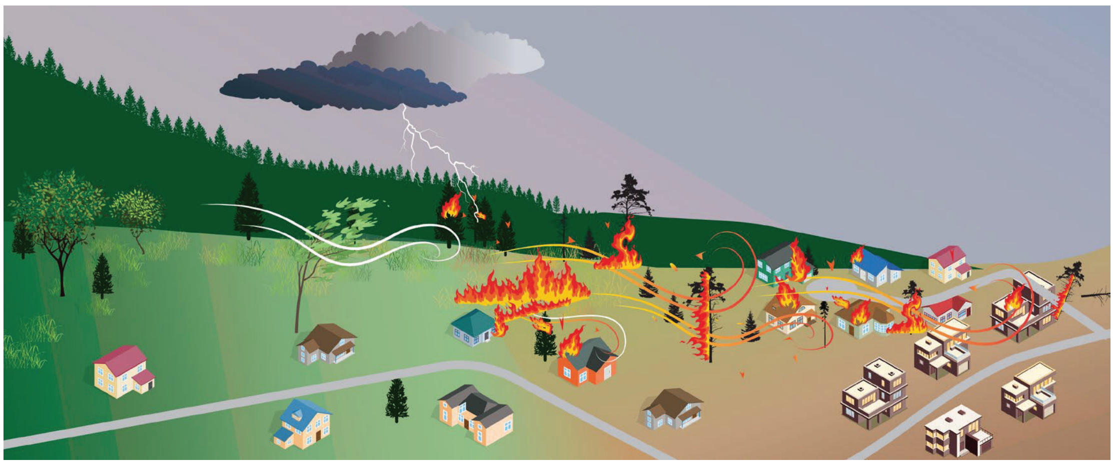

Figure 6. Grasslands and outdoor spaces can become avenues where wildfire is able to burn rapidly and spread to residential areas.

6.2. Dry Drainage Pathways

Natural and man-made drainages filled with dry vegetation are a common pathway for the rapid advancement of wildfire (Figure 7). If not properly maintained, drainages such as stream beds, natural channels and man-made drainage ditches can be overgrown with vegetation and become conduits for wildfire spread or sources of ember creation. In the areas impacted by the Marshall Fire, the combination of an unusually wet spring followed by a significant drought allowed vegetation in nearby drainage ditches to grow rapidly and then dry out. This process created a channelized and contiguous fuel source that allowed the Marshall Fire to progressively burn from grasslands through communities, akin to a superhighway.

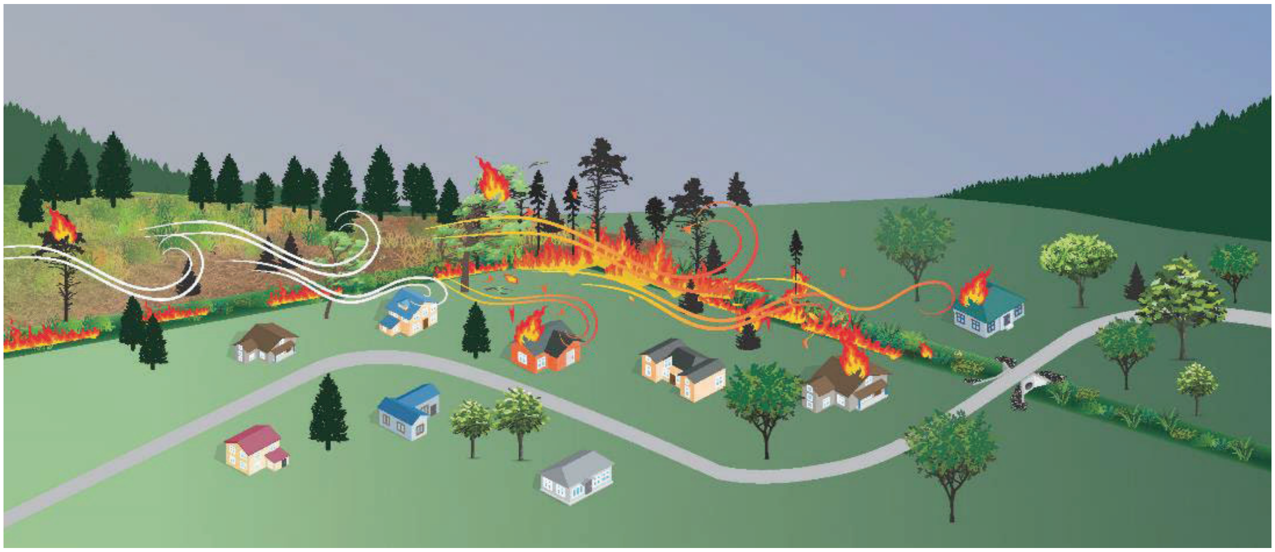

Figure 7. When fire ignites in stream corridors and drainage ditches, the abundance of dry fuel creates a superhighway for fire to spread through grassland to developed areas.

6.3. Forests and Woodlands

The types of fuel sources in forest landscapes can have a significant impact on wildfire spread. Continuous surface fuels and abundant ladder fuels can ignite quickly and lead to the rapid spread of fire. Forests with large volumes of fuel produce greater heat and can increase fire spread via ember production spotting out ahead of the fire.

Landscape management practices, along with the encroachment of human settlements in previously undeveloped land, have altered the relationship between fire and forest and woodland landscapes. For example, many forested areas in the Western U.S. are adapted to frequent, low-intensity fires; however, decades of fire suppression and fire exclusion practices have contributed to a buildup of vegetative fuel, increasing the risk of dangerous high-intensity wildfires. Woodland and forest management practices such as natural fire suppression and over grazing of aspen, have contributed to a decrease in the frequency of natural fire events but an increase in fire severity in Boulder County (Boulder County Hazard Mitigation Plan, 2022). Expanding human development has also introduced new ignition sources, such as uncontrolled campfires and damaged power lines, into fire-prone landscapes (Figure 8).

Figure 8. High winds can bring power lines into contact with trees, which can ignite and start a fire. Fire often spreads via wind-driven embers and dry vegetation.

6.4. Structure-to-Structure

Structure-to-structure ignition can help spread wildfire in developed areas (Figure 9). Fire can spread from structure-to-structure in three ways — via contact with flames and hot gases, embers and radiant heat emitting from another burning structure (e.g., fence, vehicle, shed or other ignition point). Several factors contribute to the risk of structure-to-structure ignition, including high density of buildings, outdated WUI building codes and construction methods, fuel accumulation and limited firefighting capacity. Natural hazards, such as drought and high wind, can also facilitate structure-to-structure spread by increasing the amount of fuel around structures and carrying embers from one structure to another. During the Marshall Fire, it was observed that houses were more likely to experience structure-to-structure ignition if they were located in denser housing developments with less than a 15-foot setback and were constructed without WUI codes[2]. Wood fences were also observed to have contributed to structure-to-structure ignition.

[2] Additional information on how the ICC model codes (IBC, IRC, IFC and IWUIC) provide protection against structure-to-structure ignition can be found in Marshall Fire MAT document *Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire* and Marshall Fire MAT document *Homeowner's Guide to Reducing Wildfire Risk Through Defensible Space*.

Figure 9. Structure-to-structure ignition occurs when flames, hot gases, embers, or radiant heat from one structure make contact with another structure.

7. Mitigation Strategies

Wildfire mitigation requires a multi-disciplinary approach that collectively addresses the impact of natural hazards on wildfire risk through land management and building techniques. The following strategies reduce the risk of wildfire loss that is often compounded by other hazards. In addition, several of these strategies assist in limiting the effects of post-wildfire hazards from flooding, erosion, and landslides.

- Ignition Resistant Construction
- Hazardous Fuel Mitigation
- Slope Stabilization and Erosion Control
- Channel Treatments
- Homeowner Flood and Debris Flow Mitigation Techniques

To be most effective, these strategies should be combined with the adoption and enforcement of hazard-resistant building codes (i.e., latest editions of the ICC model codes). Local planners may also consult the National Cohesive Wildland Fire Management Strategy[3] to design these strategies in coordination with national prevention, mitigation, and emergency response efforts and resources.

[3] https://www.forestsandrangelands.gov/strategy/thestrategy.shtml

7.1. Ignition-Resistant Construction

Hazards Combinations Addressed: Buildings are vulnerable to ignition via direct contact with flames, wind-driven embers, and radiant heat. High winds can increase the risk of ignition by carrying embers from wildlands to developed areas and from structure-to-structure. Drought and high heat conditions can also increase the amount of dry vegetation around the home, which can act as ladder fuels to carry fire from the ground to buildings.

Buildings constructed without the benefit of the latest ignition-resistant codes and standards are especially vulnerable to ignition and damage from wildfires. Wildfire can damage buildings in the following ways:

- Crevices, cracks and joints between walls and roofs provide sites for vegetation, dry fuels, and wind-driven embers to accumulate and ignite. Embers can also enter homes through vents and chimneys and ignite combustible materials inside.
- Flames can enter homes through broken windows and doors.
- Exterior walls and eaves are susceptible to damage from flames, embers, and hot gases.
- Decks, porches, balconies, and fences made from combustible material can provide surfaces for embers to accumulate and create conduits for fires to spread from other structures or vegetation to the home.

To protect buildings against ignition or damage from wildfires, planners and local government officials should incentivize and encourage adoption of ignition-resistant construction methods. For some jurisdictions this strategy may require the adoption and enforcement of the latest edition of the ICC model codes, including the IRC, IBC, IFC and WUI codes such as NFPA 1140: Standard for Wildland Fire Protection or IWUIC. Because these model codes primarily apply to new construction, planners and local government officials should consider incentives, such as micro-grants, tax credits, or rebates, to encourage homeowners to voluntarily install ignition-resistant retrofits. There are several low- to high-cost strategies that homeowners can implement to protect against ignition at these risk points. A few examples of low-cost strategies include:

- Installing 1/8-inch metal-mesh screening over vents
- Sealing gaps in walls and joints or adding fire-stopping block gaps (i.e., bird stop, eave closure or eave riser)
- Installing spark arrestors onto chimneys

The International Code Council's International Residential Code (IRC), the International Building Code (IBC), the International Fire Code (IFC) and the International Wildland-Urban Interface Code (IWUIC) provide the standards for hazard-resistant building construction and design.

Examples of medium- to high-cost strategies include:

- Building fences and gates with noncombustible material or leaving gaps between fences, gates, and homes
- Reroofing with a Class A fire-rated roof assembly
- Installing metal dual paned windows

Additional Resources

- FEMA Home Builder's Guide to Construction in Wildfire Zones provides a series of technical fact sheets on ignition-resistant construction for builders and contractors. https://defensiblespace.org/wp-content/uploads/2021/01/FEMA_2008_P-737-Home-Builders-Guide-to-Construction-in-Wildfire-Zones.pdf
- Marshall Fire MAT document *Homeowner's Guide to Preventing Structure Ignition from Wildfire* provides detailed information on homeowner strategies to prevent ignition from embers.
- Marshall Fire MAT document *Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire* provides detailed information on constructing buildings to prevent the spread of fire to an adjacent structure, shed, fence or vehicle.
- Marshall Fire MAT document *Wildfire Resilient Detailing, Joint Systems and Interfaces of Building Components* provides detailed information ignition-resistant building design targeting ember intrusion into homes.

7.2. Hazardous Fuel Mitigation

Hazards Combinations Addressed: Hazardous fuel maintenance is an important mitigation strategy in geographies affected by drought and extreme heat, where the accumulation of fuels can increase the probability of wildfire, and in geographies affected by high wind, which can spread embers from vegetation to structures. Hazardous fuels mitigation should aim to reduce fire intensity, structure ignition and wildfire spread. Consider using mechanical, prescribed fire and other biological or chemical treatments to mitigate hazardous fuels. In addition, fuel breaks and fire breaks can be used to reduce hazardous fuels and provide opportunities to slow or stop fire spread.

7.2.1. MECHANICAL MAINTENANCE

Mechanical fuel maintenance mitigates the risk of wildfire by reducing the amount of fuel and disrupting the vertical and horizontal continuity of the vegetation. Mechanical maintenance can apply to undeveloped areas such as open grassland, forest and shrubland landscapes, as well as waterways. Mechanical maintenance can also be incorporated into community landscaping and designed to protect against the spread of wildfire in recreation areas and other outdoor spaces (Figure 10). Mechanical fuel maintenance can include:

- Thinning and limbing trees
- Mowing
- Removing underbrush and ladder fuel
- Chipping and mastication

These treatments help maintain healthy ecosystems and reduce the fire behavior of future fires. The mitigated conditions also provide firefighters with better and safer opportunities for wildfire response by reducing fire intensity. Mechanical fuels treatments are often combined with prescribed fire or grazing to create more effective hazard reduction.

Years of proactive fuel mitigation in the Umatilla National Forest, including 35,000 acres of hazardous fuel treatment and forest thinning, helped firefighters manage the 2022 Washington Lick Creek Fire (Wesemen, 2022). Upon encountering the treated area, the wildfire burned with less intensity and smaller flame length, allowing firefighters additional time to suppress the fire, despite hot, dry, and windy conditions that could contribute to its spread. No structures were lost during the Lick Creek Fire.

Figure 10. Hazardous fuel maintenance can be incorporated into community landscaping and design to provide protection against the spread of wildfire in open spaces, parks, recreational areas, and man-made drainages (U.S. Fire Administration, n.d.).

7.2.2. PRESCRIBED FIRE

Prescribed fire is a planned fire used to reduce excessive growth of shrubs, brush, and trees in fire-prone landscapes. See Figure 11. The introduction of more frequent, controlled burns can reduce the risk of more intense, unwanted, fire in the treated area by reducing the fuels that feed them ("Prescribed Fire", n.d.). The Colorado Division of Fire Prevention and Control provides technical assistance to state and other agencies conducting prescribed fires. The Division offers training and guidance for the use of prescribed burns on private land through the Certified Burn Program[4].

Figure 11. Prescribed fire used to reduce woody debris accumulation and encourage native plant regeneration in Necedah Refuge, WI (U.S. Fish and Wildlife Service (USFWS), n.d.).

Additional Resources

- Wildland Fire: What is Hazard Fuel Reduction? (U.S. National Park Service) provides a high-level description of fuel management strategies including prescribed fire. https://www.nps.gov/articles/what-is-hazard-fuel-reduction.htm
- Wildland Fire Management | Fire Prevention and Control (colorado.gov) describes how the Division uses hazardous fuel mitigation techniques, including prescribed fire, to mitigate the risk of wildfire. https://dfpc.colorado.gov/wildlandfire
- Watershed Protection & Management | Denver Water details the fuel management program funded by the "From Forests to Faucets" program. https://www.denverwater.org/your-water/water-supply-and-planning/watershed-protection-and-management

[4] https://dfpc.colorado.gov/certifiedburnprogram

Invasive Species Management

Wildfire intensity and severity can be increased with the presence of flammable invasive plants, such as cheatgrass, buffelgrass and salt cedar. Firefighters may also unknowingly spread invasive species while responding to wildfires by carrying seeds of invasive plants on their gear or transporting water with aquatic invasive species to new locations. After a fire, the absence of vegetation in a burned area can provide an opportunity for invasive species to move in, further reducing ecosystem health.

Targeted removal and reduction of invasive plant species may be combined with other hazardous fuel mitigation techniques to reduce the likelihood and severity of a wildfire. Invasive species management may involve several strategies, including:

- Mechanical maintenance
- A combination of chemical treatments and grazing
- Prescribed fire
- Ecosystem restoration, including replanting native species
- Ecosystem conservation, to protect existing native species

Additional Resources

- Teaming Up to Take On the Double Threat of Invasives and Wildfires provides background on the relationship between wildfires and invasive species. https://doi.gov/wildlandfire/teaming-take-double-threat-invasives-and-wildfires#:~:text=Often%2C%20invasive%20plants%20have%20an%20advantage%20over%20native,unknowingly%20spread%20invasive%20species%20while%20responding%20to%20wildfires
- Wildland Fire | National Invasive Species Information Center provides additional resources and case studies on managing invasive species to improve wildfire resiliency. https://www.invasivespeciesinfo.gov/subject/wildland-fire
- Decontaminating Firefighting Equipment to Reduce the Spread of Aquatic Invasive Species provides a guide to reducing spread of invasive species during wildfire suppression. https://fwp.mt.gov/binaries/content/assets/fwp/conservation/ais/reports/nrcg-how-to-guide-for-decontamination-of-wildfire-equipment-_1.pdf

7.2.3. FUEL & FIRE BREAKS

A **fire break** is a strip of cleared land that provides a gap in vegetation or other combustible materials that is expected to slow or stop the progress of a wildfire (Figure 12). Examples of fire breaks include:

- Constructing a barrier or stripping vegetation down to bare soil (requires routine maintenance).
- Man-made features such as roads or natural features such as rivers, lakes, or ponds.
- Part of a home's defensible space. Pavers, rocks, and driveways, typically installed within 100 feet of the home, can be used to create small fire breaks between the home and other structures or landscapes.

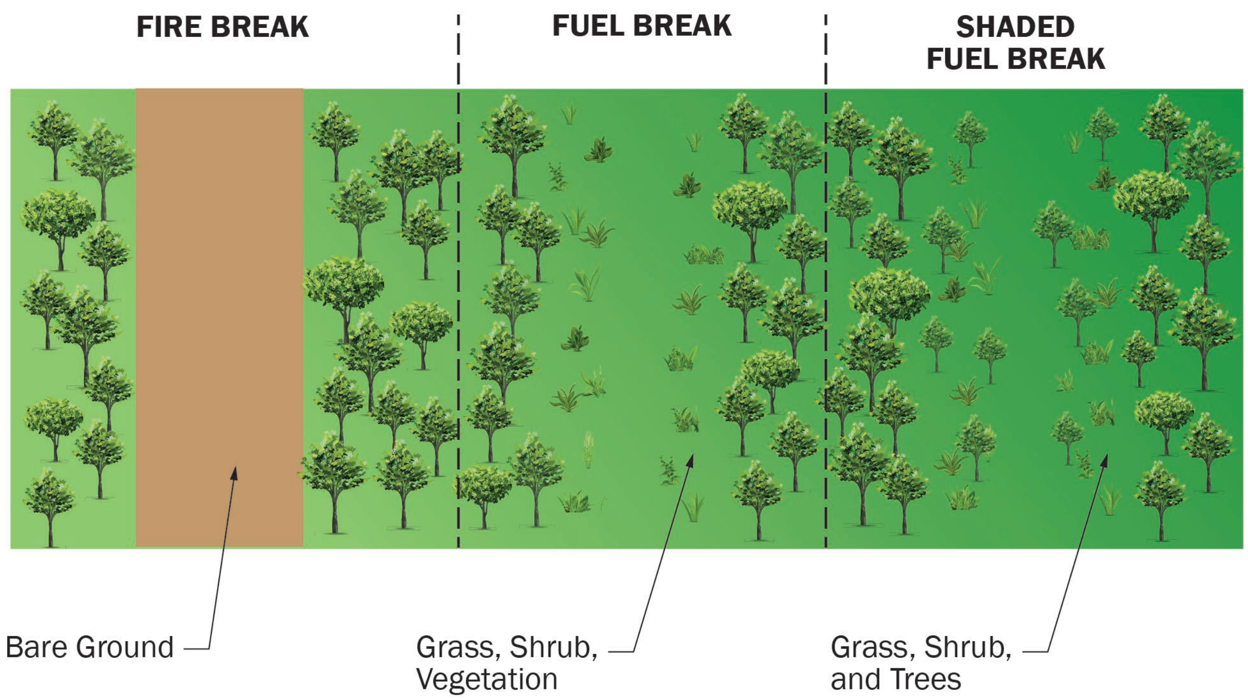

Figure 12. Fire breaks and fuel breaks can be used by homeowners and community planners to prevent or slow the progress of fire.

Fire breaks can provide multiple benefits to a community, including additional ingress and egress routes during a fire. However, planners should be cautious when constructing a fire break near sloped areas or watershed areas prone to runoff. Without vegetation to slow water flow, bare earth fire breaks increase runoff and erosion in some cases. The benefits for wildfire mitigation should also be weighed against impacts on wildlife and watersheds resulting from the removal of vegetation and wildlife habitat.

A **fuel break** is a natural or man-made change in fuel characteristics that affects fire behavior so that fires burning into them can be more readily controlled. Fuel breaks limit wildfire spread and intensity by reducing horizontal and vertical densities of fuel. Fuel breaks may be more appropriate where complete removal of vegetation is not desired or where key wildlife habitat must be protected. Fuel breaks can be created by:

- Thinning tree stands and pruning remaining trees to remove ladder fuels.
- Removing ground vegetation and dead trees to create an open space.

Fuel breaks played an important role in protecting communities in Silverthorne, Colorado from the 2018 Buffalo Fire (Figure 13). Summit County constructed fuel breaks by creating 300-to-500-foot open spaces between the Silverthorne subdivisions and nearby lodgepole pines (Krake, 2018; Adams, 2018), as shown in Figure 13.

A **shaded fuel break,** created by thinning and pruning trees, can reduce fire potential and still provide shade and aesthetic appeal. While a shaded fuel break will not stop a wildfire, it can slow the advance of the wildfire front to allow firefighting additional time to act to suppress the fire. A wildland fuels expert should be consulted when designing fire breaks, fuel breaks and shaded fuel breaks.

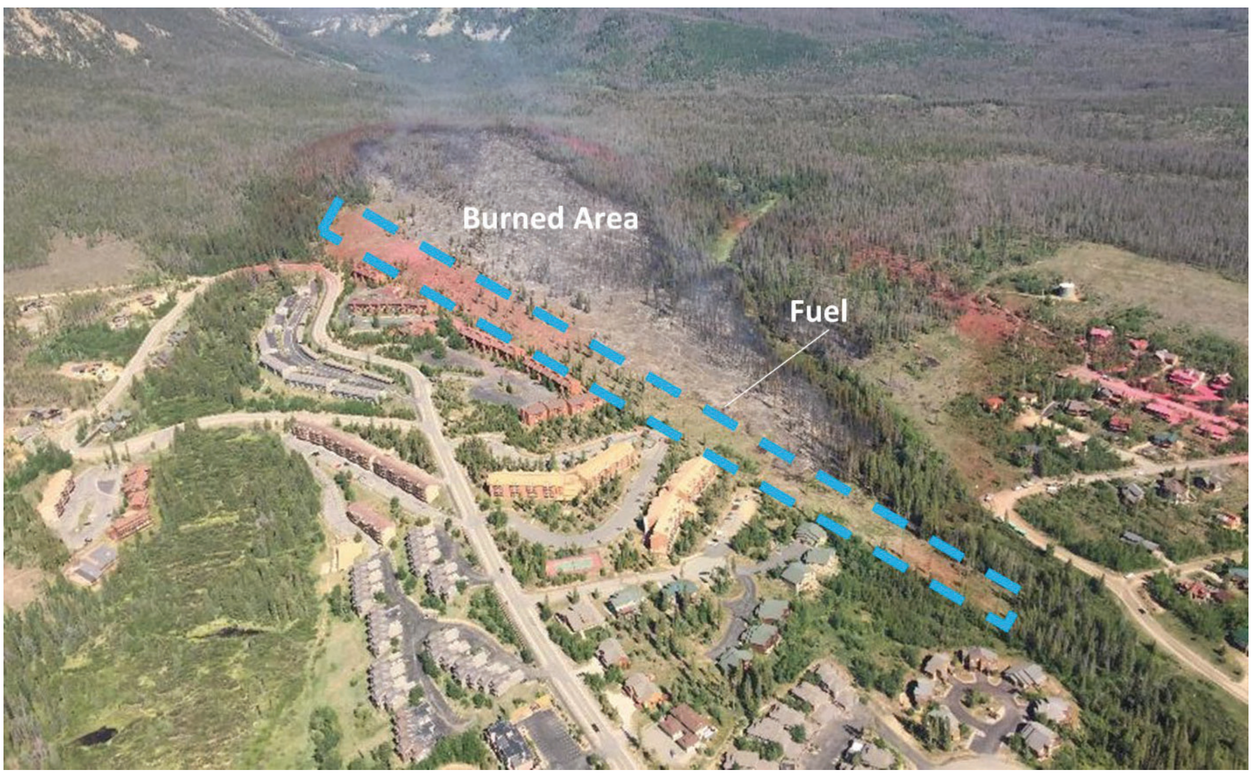

Figure 13. Fuel breaks (the blue line between the homes and forested area) played an important role protecting homes during the 2018 Buffalo Fire in Summit County (U.S. Forest Service).

Additional Resources

- Fuel Break Guidelines for Forested Subdivisions & Communities provides information for planners and land managers on fuel break design and maintenance. https://static.colostate.edu/client-files/csfs/pdfs/fuelbreak_guidellines.pdf
- National Resources Conservation Service provides guidance on fuel break and shaded fuel break siting and design. https://efotg.sc.egov.usda.gov/api/CPSFile/20901/383_PS_CA_Fuel_Break-Forestland_05-2020
- Assessing the Effectiveness of Fuel Breaks for Preserving Greater Sage-Grouse in the Great Basin | U.S. Geological Survey (usgs.gov) provides a case study for weighing benefits for fire suppression against wildlife impacts. https://www.usgs.gov/centers/fort-collins-science-center/science/assessing-effectiveness-fuel-breaks-preserving-greater#:~:text=USGS%20and%20Colorado%20State%20University%20%28Colorado%20State%20University%29,regimes%2C%20fuel%20break%20designs%2C%20and%20fire%20management%20access
- Marshall Fire MAT document *Best Practices for Wildfire-Resilient Subdivision Planning* provides information on incorporating fire breaks into open space planning.

7.2.4. DEFENSIBLE SPACE

Defensible space can be used at both the property and subdivision-scale, in combination with other hazardous fuel mitigation techniques, to help protect communities from wildfire.

Homeowners can build defensible spaces by reducing and removing vegetation and other combustible material around the home. See Figure 14. Defensible space is commonly combined with ignition-resistant construction. For example, the area within 5 feet of the home should be free of combustible structures and material, which may require maintenance or renovations to decks, balconies, fences, gates, outdoor furniture, and planters. More detailed information on designing defensible space around a home can be found in the Firewise Guide to Defensible Space[5].

Planners can also create a communal defensible space between neighborhoods and wildland areas, such as grasslands and woodlands, to help slow or stop the spread of flames via wind-driven embers and ground-level fuels. Communal defensible space may be useful for high density developments where the distance between properties creates overlap between their defensible spaces. communal defensible space can involve:

- Reducing fuels in outdoor spaces, ditches and seasonal waterways by mowing, grazing, clearcutting, thinning vegetation and through periodic prescribed fires by trained professionals.

[5] https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Preparing-homes-for-wildfire

- Constructing nonflammable or fire-resistant components (e.g., roads) to act as fire breaks.
- Removing or relocating outbuildings, accessory structures and vehicles that could create a pathway for fire to spread between properties or from structure-to-structure.
- More detailed information on designing defensible space in densely population communities can be found in the National Institute of Standards and Technology's Fire Hazard Mitigation Methodology[6].

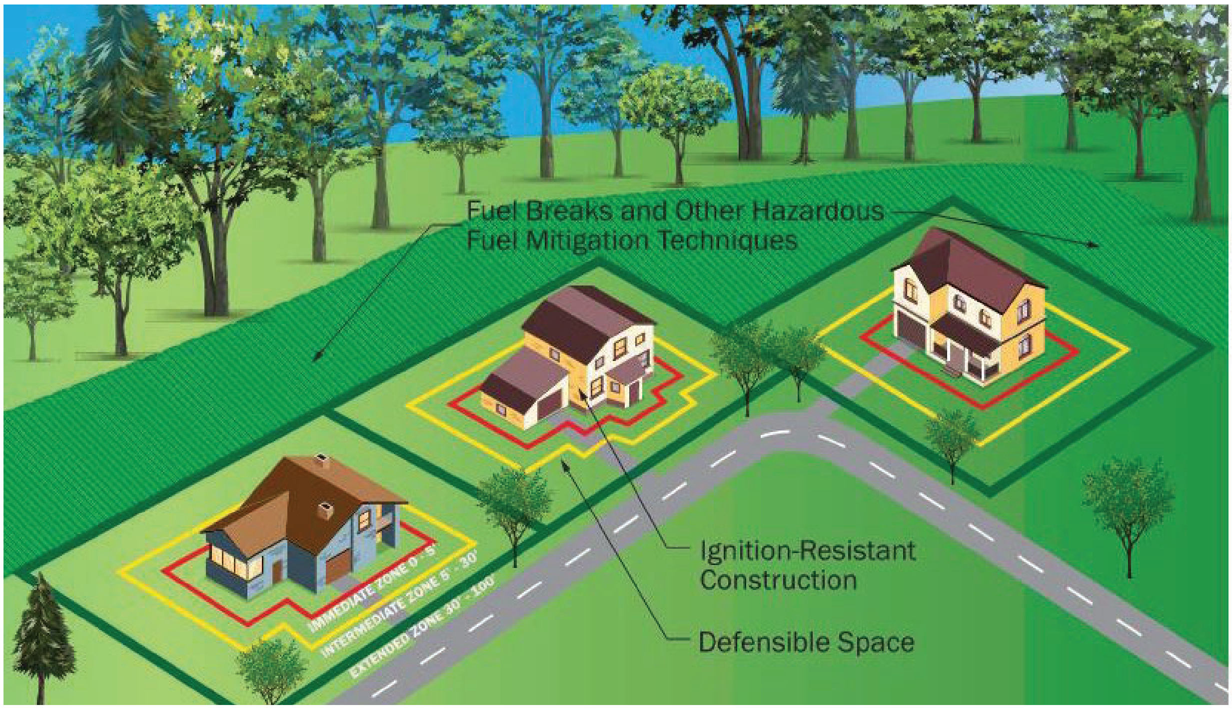

Figure 14. Property-level defensible space and ignition-resistant construction can be combined with community fuel breaks and fuel maintenance to create comprehensive wildfire protection for a subdivision or neighborhood.

[6] https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2205.pdf

Additional Resources

- Healthy Landscapes (fema.gov) provides information on designing a fire-adapted landscape around the home in conjunction with the National Cohesive Wildland Fire Management Strategy. https://www.usfa.fema.gov/wui/healthy-landscapes /
- Marshall Fire MAT document *Best Practices for Wildfire-Resilient Subdivision Planning* provides detailed information on designing defensible space in high density communities and at the subdivision-level.
- Marshall Fire MAT document *Homeowner's Guide to Defensible Space* provides detailed information for homeowners on designing defensible space and fire-resistant landscaping.
- National Institute of Standards and Technology's Fire Hazard Mitigation Methodology provides the latest technical knowledge on combining property and community-level WUI mitigation strategies, including defensible space, structural hardening, housing density, structure separation distance and property layouts. https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2205.pdf

7.3. Slope-Stabilization and Erosion Control

Hazards Combinations Addressed: Slope-stabilizing and erosion control practices are critical measures for reducing runoff and erosion in burned areas. The removal of vegetation and creation of hydrophobic soil after a fire introduces greater risk for floods and landslides post-wildfire.

Slope-stabilization and erosion control techniques (i.e., hillslope techniques) used to reduce the risk of floods and landslides post-wildfire include:

- **Slope-stabilization:** Primary efforts should be directed towards the slopes of recharge areas for streams that often lead to developed areas or watersheds that can impact water supplies.
- **Erosion Control:**
    - **Ground Roughening:** Roughening the ground enables better water absorption by the soil. This technique should not be used on steep slopes.
    - **Native Species:** Restoration of native vegetation via seeding and planting can help reduce erosion and prevent the intrusion of invasive species, which can often contribute to the probability and spread of fire.
    - **Mulching:** Mulching provides immediate ground cover to reduce runoff, absorb rainfall and helps protect germinating seeds. Typical mulching techniques include dry mulching (straw, woodchips, fiber), wet or "hydro mulching" (a combined water, organic material and a

tackifier) and slash spreading (chopped up woody debris). Mulching can be combined with seeding to support revegetation.

- **Erosion Control Mats:** These mats prevent erosion by absorbing rainfall and providing temperature and moisture control to the soil, allowing the area to revegetate. Mats are typically made from biodegradable material such as straw and coconut fiber and staked or stapled to the soil. Mats should be applied down the slope in strips with 6-inches of overlap. The top of the mats should be buried in the soil 8-12 inches deep. Erosion control mats are appropriate for small areas and hillsides adjacent to streams and wetlands.

- Erosion Barriers:
    - **Contour Log Felling/ Log Erosion Barrier:** When partially entrenched or staked to the soil surface parallel to the slope contour, logs can slow runoff and capture eroded sediment on hillsides. This strategy is most effective for low-intensity rainfall events, on slopes with a 25-to-60-degree grade and in areas with high- and moderate-burn severity. Note that small variations in installation can significantly reduce its effectiveness. Planners should consult with fire-treatment experts, such as their state forest service or extension agency, to provide guidance on implementing this strategy.
    - **Silt Fences:** In areas where runoff is fairly dispersed over similarly sloped areas, silt fences and super-silt fences can be used to trap eroded soil before it enters and degrades stream quality or clogs stormwater systems. Silt fences are made from permeable fabric installed parallel to the slope contour and are typically anchored to the soil with wooden stakes or metal t-posts. See Figure 15.

Figure 15. Silt fences and mulch can help prevent erosion after a wildfire (Gerry Shimek, USFWS, n.d.).

- **Fiber Rolls/ Straw Wattles:** In forested areas, fiber rolls or wattles, which are 25-foot-long tubes filled with straw, can be placed across the slope perpendicular to the direction of flow to intercept runoff and erosion. Wattles reduce erosion by shortening the slope length to slow runoff speed, trapping sediment, and providing a seedbed for vegetation recovery. They are intended for low-surface flows and should not be used in stream channels or gullies. See Figure 16.

Figure 16. Fiber roll or wattle filled with straw (Todd Plain, U.S. Army Corps of Engineers, n.d.)

Additional Resources

- NRCS Log Erosion Barrier Fact Sheet provides detailed information on installing log erosion control barriers. https://co-co.org/wp-content/uploads/2018/07/2012-Log-erosion-barrier-Fact-Sheet.pdf
- Texas A&M Wildfire Recovery Soil Erosion Control Practice Guide provides detailed information on implementing slope stabilization and erosion control methods. https://www.landcan.org/pdfs/Best%20Managment%20Practices%20-%20Practice%20Guide%20-%20STATEWIDE%20-%20revision,9-2012.pdf
- After Wildfire: A Guide for New Mexico Communities provides additional information on strategy implementation and effectiveness and a snapshot of cost estimates. https://afterwildfirenm.org/post-fire-treatments/report_print_section

7.4. Channel Treatments

Hazards Combinations Addressed: Channel-treatments control water and sediment movement in stream channels to reduce the risk of floods and landslides.

Channel treatments are typically high-cost and must be completed by an engineer or specialist. To be effective, channel treatments should be combined with hillslope treatments, such as slope stabilization and erosion control. Channel treatments used to reduce the risk of floods and landslides post-wildfire include:

Diversion channels or deflection walls can be used to slow and redirect the flow and movement of water across a slope rather than directly downward towards structures, streams, or wetlands.

- Diversion channels include a supporting ridge on the lower side and are often constructed using grass or other vegetation liners.
- Diversion channel size and depth for the area under management should consider topography and drainage patterns of the surrounding landscape.
- Diversion channels should direct runoff to sediment-trapping devices (e.g., check dams and sediment basins) where sediment can settle out before it is discharged to surface waters.

Check Dams: Straw, log, or rock check dams can be installed in diversion channels to slow the flow of water and reduce sediment buildup. Check dams are temporary measures and are most appropriate for gentle slopes in watersheds with small drainage areas. See Figure 17.

Figure 17. Straw bale check dams can reduce post-fire runoff from steep channels by capturing sediment during rainfalls (USDA Forest Service photo by Pete Robichaud, n.d.).

In-channel tree felling: Felling streamside trees can create barriers to trap channel debris. Trees are typically staggered in a herringbone pattern with treetops pointing upstream and roots partially buried.

Grade Stabilizer: Structure made of rocks, logs, or plant material installed in temporary channels to reduce incising and downcutting of the channel. Grade stabilizers are most useful for unstable channels.

Stream Bank Armoring: Reinforcement of a streambank with rocks, vegetation, or engineering covering (e.g., boulders, riprap, and gabion baskets) to reduce bank cutting and erosion. The benefits of this method should be weighed against impacts on wildlife and watersheds.

Channel Deflector: Engineered structures such as j-hooks, rock barbs and single- or double-wing deflectors designed to direct stream flow away from unstable banks.

Debris Dams & Basins: Designed to provide immediate protection against large sediment loads, floodwaters, floating debris, and landslides. This treatment often is considered a last resort because it must be designed by qualified engineers, is expensive to construct and requires repeated maintenance.

Additional Resources

- Home | Burn Severity Portal (usgs.gov) provides a comprehensive portal for federal resources on post-fire flood and debris flow mitigation. https://burnseverity.cr.usgs.gov/
- After the Burn: Assessing and Managing your Forestland after a Wildfire (usda.gov) provides detailed information on in-channel erosion and runoff control treatments. https://www.fs.usda.gov/rmrs/sites/default/files/documents/Yvonne%20C.%20Barkley.pdf
- After Wildfire: A Guide for New Mexico Communities provides additional information on strategy implementation and effectiveness and a snapshot of cost estimates. https://afterwildfirenm.org/post-fire-treatments/report_print_section
- Treatment Comparisons Table — After Wildfire (afterwildfirenm.org) provides a table for comparing treatment costs, maintenance, and effectiveness. https://afterwildfirenm.org/post-fire-treatments/which-treatment-do-i-use

7.5. Homeowner Flood and Debris Flow Mitigation Techniques

Homeowners can also implement several strategies at the property level to reduce damage and loss from post-fire flood and landslides. These strategies include:

- Sandbag, gravel, or permanent barriers (e.g., concrete walls)

- Wooden deflectors
- Window and door protections (e.g., rubber seals around door, plywood barriers over doors and windows)

These strategies include temporary and quick actions that can be implemented when there is a known risk of flash flooding or debris flow after a wildfire and are not inclusive of all homeowner mitigation techniques.

Additional Resources

- Boulder County Homeowner's Guide for Post-Fire Flood and Debris Flow provides instructions for homeowners on implementing temporary and permanent strategies to protect against damage from post-fire flood and debris flow. https://assets.bouldercounty.gov/wp-content/uploads/2017/02/4-mile-sand-bag-guide.pdf
- The National Weather Service Post Wildfire Flood and Debris Flow Guide catalogs resources on advisory and warning systems, flood insurance, homeowner emergency preparedness and homeowner mitigation guides. https://www.wrh.noaa.gov/lox/hydrology/files/DebrisFlowSurvivalGuide.pdf
- Flood After Fire: Your Increased Risk | FloodSmart provides homeowner information on flood insurance and minimizing flood losses. https://www.floodsmart.gov/wildfires
- After Wildfire I A Guide for California Communities provides a collection of technical and financial resources to help homeowners and community planners prepare for and understand the risk of post wildfire flooding and debris flows. http://www.readyforwildfire.org/wp-content/uploads/After-Wildfire-Guide-10JUNE2019_draft_final-ADA-compliant.pdf

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