Mitigation Assessment Team Report

Marshall Fire

Building Performance, Observations, Recommendations, and Technical Guidance

FEMA P-2320 / Revised April 2025

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Acronyms and Abbreviations

AAR	After Action Report
AHJ	Authority Having Jurisdiction
ASCE	American Society for Civil Engineers
ASTM	American Society for Testing and Materials
BCAT	Building Code Adoption Tracking
BCEGS	Building Code Effectiveness Grading Schedule
BMP	Best Management Practice
BRIC	Building Resilient Infrastructure and Communities
BSDS	Building Science Disaster Support
CBC	California Building Code
CDC	Centers for Disease Control
CMU	concrete masonry unit
CPAW	Community Planning Assistance for Wildfire
CSFS	Colorado State Forest Service
CWPP	Community Wildfire Protection Plan
CWPC	Community Wildfire Planning Center
ESS	energy storage systems
FAC Net	Fire-Adapted Communities Network
FEMA	Federal Emergency Management Agency
FLASH	Federal Alliance for Safe Homes
FPRF	Fire Protection Research Foundation
FRWRM	Forest Restoration and Wildfire Risk Mitigation Grant Program

GEER	Geotechnical Extreme Events Reconnaissance Association
HB	House Bill
HERS	Home Energy Rating System
HOA	Homeowners Association
HIZ	Home Ignition Zone
HVAC	Heating, Ventilation and Air Conditioning
I-Codes	International Codes
IBHS	Institute for Building and Home Safety
IBC	International Building Code
ICC	International Code Council
IEBC	International Existing Building Code
IECC	International Energy Conservation Code
IFC	International Fire Code
IgCC	International Green Construction Code
IRC	International Residential Code
IWUIC	International Wildland-Urban Interface Code
kWh	kilowatt hour
Li-ion	lithium-ion
LTRG	Long Term Recovery Group
MAT	Mitigation Assessment Team
mph	miles per hour
MST	Mountain Standard Time
NEC	National Electrical Code
NFPA	National Fire Protection Association

NIBS	National Institute of Building Sciences
NIST	National Institute for Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NWCG	National Wildfire Coordinating Group
NWS	National Weather Service
OSB	Oriented Strand Board
OSHA	Occupational Safety and Health Administration
PBS	Public Broadcasting System
PIRG	Property Insurance Research Group
Pre-MAT	Preliminary Mitigation Assessment Team
PV	Photovoltaic
RESNET	Residential Energy Services Network
SFPE	Society of Fire Protection Engineers
SB	Senate Bill
SLTT	state, local, tribal and territorial
SVI	social vulnerability index
SWIFT	State Wildland Inmate Fire Teams
UBC	Uniform Building Code
UCADB	Uniform Code for the Abatement of Dangerous Buildings
UCANR	University of California Agriculture and Natural Resources
UL	Underwriters Laboratories
USDA	U.S. Department of Agriculture
USFA	U.S. Fire Administration

USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WFLC	Western Forestry Leadership Coalition
WUI	Wildland-Urban Interface
WWA	West Wide Wildfire Risk Assessment

Executive Summary

The Marshall Fire was the most destructive fire in Colorado history with respect to buildings burned[1].

The Marshall Fire was a wind-driven wildfire that started on December 30, 2021, shortly before 10:30 a.m. MST in Boulder County, Colorado. The fire quickly spread to the Town of Superior and later to unincorporated Boulder County and the City of Louisville due to high winds with recorded gusts of up to 115 mph. By 5 p.m. MST the fire was estimated to be 1,600 acres, increasing to 6,200 acres by 10:00 a.m. MST on December 31, 2021. By the next day, the winds died down and heavy snow extinguished the fire and covered over 1,000 destroyed single- and multi-family houses and commercial structures in Louisville, Superior, and unincorporated Boulder County (Boulder County, 2022). This fire was unique in that it originated in grasslands/flatlands near a heavily populated area and traditional suburban developments.

MITIGATION ASSESSMENT TEAM DEPLOYMENT AND OBSERVATIONS

Several factors have been attributed to the devastation caused by the Marshall Fire: extreme winds, long term drought, unseasonably high temperatures, and limitations in existing wildfire safety and planning regulations. Because of the unique nature of the incident, a fast-moving grass fire became a highly destructive urban conflagration that directly and indirectly impacted several communities and the greater Boulder County area. As a result, the Federal Emergency Management Agency (FEMA) Building Science Disaster Support (BSDS) Program deployed its first-ever wildfire Mitigation Assessment Team (MAT) to evaluate building performance during the fire.

This was the first opportunity for FEMA's BSDS Program to deploy the MAT to assess building performance following a wildfire. FEMA believed it was important to study this fire because the nature of the origin, weather conditions, and impacts on the built environment in the nontraditional WUI represent risks that need to be better understood by planners, developers, government officials, and the public-at-large.

The MAT was deployed to Louisville, Superior, and unincorporated areas of Boulder County, Colorado, to evaluate damaged houses 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 the wildfire-urban interface (WUI) and more general building

[1] *Boulder County 2022-2027 Hazard Mitigation Plan*

codes and standards, as well as design, construction, land-use planning, and defensible space practices can be improved to increase community wildfire resilience, particularly as the risk to landscape is continuously evolving and putting more communities at risk (e.g., beyond perceived WUI).

SUMMARY OF DAMAGE OBSERVED

The structures affected by the Marshall Fire vary greatly across the damaged areas. In general, the observations of the MAT found that many of the impacted residential structures were built in the early 1980s and early 1990s although even newer structures sustained some damage or were declared a total loss. The majority of the damaged or destroyed residential buildings in the affected areas included the following consistent construction materials, detailing, and other architectural features:

- One- or two-story light-timber framed structures.
- Exterior wall systems typically consisted of Oriented Strand Board (OSB) sheathing clad with either a brick veneer or fiber cement siding material.
- Roofing systems observed typically consisted of asphalt-composite shingles or metal shingle systems.
- Glazing systems included both single- and multi-pane windows.
- Most structures did not have flame- or ember-resistant vent protection coverings.
- Many structures also had combustible non-structural attachments such as fences and decks.

The MAT observed structural hardening vulnerabilities (from the top of structure down) that are susceptible to wildfire damage. While many of these vulnerabilities to fire are already well-established and well-known points of weakness in the building or home's exterior envelope, codes and standards in effect in the impacted Boulder area prior to the fire did not require houses to be hardened against wildfire. Some key vulnerable features are:

- Roof components (e.g., roof covering, underlayment, chimneys)
- Roof to wall interfaces
- Exterior wall components
- Exterior wall to foundation interfaces
- Opening protection (e.g., vents, windows, doors)
- Joint systems (e.g., head-of-wall, bottom-of-wall, wall-to-wall interfaces)
- Non-structural attachments (e.g., fences, decks)
- Appurtenant structures (e.g., sheds)

Generally, houses with combustible siding, fences, and decks were more likely to be damaged or destroyed than those with fire-resistant or noncombustible components. Combustible fences along the interface of grasslands/open spaces and neighborhoods acted as wicks that enabled fire spread to structures. Single-pane windows were also observed to be more easily damaged or destroyed than multi-pane windows. Most houses were vulnerable to ember intrusion via unprotected inlet and outlet vent openings. Many landscaping features were observed to be inconsistent with current

Home Ignition Zone (HIZ) standards. Lists of fire-resistant native plants did not appear to be readily available to homeowners for landscaping purposes. Neighborhoods with closely spaced houses (e.g., less than 30 feet of separation) were more likely to have structure-to-structure fire spread and disproportionate levels of damage. Before the Marshall Fire, local wildfire mitigation efforts appeared to focus on houses in the mountains and foothills with less emphasis on the plains/grasslands.

Neighborhoods with closely spaced houses (e.g., less than 30 feet between structures) were more likely to have structure-to-structure fire spread and disproportionate levels of damage.

The MAT also observed a relationship that was not widely recognized prior to the Marshall Fire between some community-level planning features and wildfire behavior. In particular, the MAT observed the presence of drainage ditches used for flood control and other greenbelts used for recreation that served as wildfire "superhighways" due to the presence of unmanaged biomass and hazardous vegetation. These land-use features ultimately provided receptive fuel loads and facilitated increased spread and severity of wildfire conditions from the wildlands/open spaces into suburban and urban neighborhoods.

While the winds during the Marshall Fire were very strong with recorded gusts up to 115 miles per hour (mph), widespread significant wind damage was not observed. Most of the wind damage that may have occurred was likely consumed by the fire. The MAT did observe several occurrences of roof tiles/shingles being uplifted or removed and some cases of siding being blown off exteriors of houses. In addition, anecdotal information suggests that windborne debris may have played a role in breaching some building envelopes, particularly through glazed openings, which may have allowed embers and flames to reach the interiors of some buildings. Though significant wind damage was not observed, wind played a major role in the fire spread and hampered firefighting efforts in the event.

MAT RECOMMENDATIONS

The MAT uses observations to draw conclusions and make actionable recommendations. The conclusions and recommendations presented in this report are based on the MAT's field observations; evaluation of relevant codes, standards and regulation; as well as information gathered from interviews with first responders and subject matter experts. They are intended to guide homeowners and building owners, community planners, design professionals, contractors, state, local, tribal and territorial (SLTT) officials, building code professionals, and standards organizations. Some additional recommendations are directed to FEMA and other industry partners. Chapter 6 provides detailed information on the conclusions and recommendations, including a summary table. The recommendations have been summarized and grouped into overarching concepts here:

- **Holistic Wildfire Resiliency** – Recent events have highlighted that a more holistic approach to wildfire resiliency is needed. Actions can and should be taken at the **Community** level, **the Neighborhood/Subdivision** level, and at the individual **Parcel/Building** level. Actions must be taken at all levels for disaster preparedness, planning, response, mitigation, and recovery especially for the wildfire hazard.

- **Community -** Community planners, officials, developers, and residents also need to understand the relationship of their community to the surrounding area in the context of wildfire. Large scale landscape management and fire suppression needs should be considered including establishing and maintaining fuel breaks, managing community open spaces in-house or through contracted landscapers, and ensuring sufficient evacuation routes are available and well-marked. Local hazard mitigation plans should address wildfire risk and actions for the community as well as those required at the **Neighborhood/ Subdivision** and **Parcel/Building** levels. As evidenced with the Marshall Fire, dry grasslands in combination with high winds and inconsistent implementation of WUI practices at various scales in the built and natural environment can pose a significant threat.

- **Neighborhood/Subdivision** - Building owners, developers and design professionals need to incorporate natural hazard mitigation, especially for the wildfire hazard, when designing neighborhoods and subdivisions in striving for the perfect balance between economics and risk. There are many well-known practices and resources available. In many cases, the MAT observed spacing of 10–15 feet between houses. With this type of spacing between homes, it is important for entire neighborhoods to undertake mitigation actions. Similarly, community planners, designers, and engineers need to consider natural topography effects on wildfire and potential unintentional effects mitigation for one hazard can have on another.

- **Parcel/Building** - Much research has been completed and communicated focusing on building and parcel level mitigation and this remains an important area of focus. The MAT observed several instances of houses that had been hardened and established defensible space that survived, while houses around them burned to the ground.

All levels of action should include evaluation, customization, and adoption of model codes for wildfire by the appropriate Authority Having Jurisdiction (AHJ). See Building Codes and Standards recommendation below.

- **Standardized Wildfire Terminology and Public Education** - The Marshall Fire highlighted how the public perception of wildfire and wildfire risk differs from the accepted definitions understood by experts. The WUI is perceived as the forested mountain and canyon areas. Current terminology needs to be updated, expanded, and socialized into a suite of definitions used to define wildfire risk. This can be used universally and be better understood by the public, so awareness of risk is increased especially as the wildfire risk expands into urban areas. Federal agencies may want to agree upon some additional terms to help distinguish between different areas subject to wildfire risk. Public education materials should be enhanced with visual aids to clearly communicate wildfire, wildland, and WUI concepts.

- **Wildfire Hazard and Risk Considerations** – Creating nationwide consensus-based wildfire risk maps that link to building codes, zoning and mitigation actions at building, neighborhood and community-scales will help agencies, planners, builders, design professionals, and property owners not only to understand wildfire hazards and risks, but also what actions, policies and programs should be taken to help mitigate that risk. This would align with how other natural hazard like wind, seismic and flood risk addressed.

- **Building Codes and Standards** – While there are multiple recommendations related to building codes, they generally can be summarized in a few categories.
  - **Property Protection and Survivability** – Recognizing that building codes are written to address life-safety concerns, this event highlighted that firefighting resources can be stretched very thin such that they cannot defend all properties that are threatened. However, most people have an expectation or a desire that their home or building should be able to survive a wildfire especially in suburban and urban areas. A second performance objective for building codes should be developed to address the ability of a building to survive a fire without defensive actions. There are many validated and widely accepted passive mitigation actions that can be taken. Communities could adopt a version of the International Wildland-Urban Interface Code (IWUIC) that most closely meets their needs and expectations. Additionally, some simple code revisions in the International Code Council (ICC) parent codes, the International Building Code (IBC), the International Residential Code (IRC) and the International Existing Building Code (IEBC) should be considered for the non-designated WUI areas as the wildfire risk expands into urban areas.
  - **Wildfire Resiliency at Scale** – The IWUIC currently addresses mitigation mostly at the building and parcel levels. As discussed in the Holistic Wildfire Resiliency recommendation above, multiple levels of action must be leveraged. The IWUIC should be expanded to include mitigation at multiple scales to provide a more holistic approach to wildfire risk mitigation, which is particularly important in suburban areas like the Boulder/Louisville/Superior area.
  - **IWUIC: Close Known Gaps and Integrate of Latest Research** – The IWUIC currently includes requirements that are not consistent with the latest wildfire research (e.g., such as for vent screens and decks). The IWUIC, other state WUI codes and testing standards have numerous gaps in wildfire-specific requirements on various building components, systems, and details. The IWUIC should be updated to align with these research findings.
  - **Incorporate IWUIC into ICC Parent Codes by Reference** – Incorporating the IWUIC into the IRC and the IBC by reference would promote stronger wildfire code compliance in high-risk areas.
  - **Statewide Building Code Adoption Including IWUIC**– The MAT recommends adopting a statewide building code to provide a standard basis for all jurisdictions in the state. This helps with providing mutual aid in addition to providing a uniform level of safety and hazard resistance across jurisdictions. This approach also would allow the State to meet FEMA’s State Mitigation Planning Policy guidance to address building codes in all standard hazard mitigation plans and for enhanced plans to develop a strategy for statewide building code adoption and implementation.

Chapter 1: Introduction

The *Marshall Fire was the most destructive wildfire incident in Colorado history—approximately 6,000 acres were burned, over 1,000 buildings destroyed, and over $510 million in damages.*[2]

The Marshall Fire was a wind-driven wildfire that started on December 30, 2021, shortly before 10:30 a.m. MST in Boulder County, Colorado. While the official cause of the fire is still unknown, the fire is believed to have started from multiple ignition points leading to a grass fire in a neighborhood off State Highway 93 and Marshall Road. The fire then rapidly spread to the Town of Superior and later toward the cities of Louisville, Broomfield, and unincorporated Boulder County due to high winds with recorded gusts of up to 115 mph. By 5:00 p.m. MST the fire had spread to an estimated 1,600 acres, increasing to 6,200 acres by 10:00 a.m. MST on December 31, 2021.

Noteworthy Marshall Fire Metrics

- Unusually humid spring with above average growth of grass, followed by unusually warm and dry summer/fall and then lack of snow prior to incident.
- Recorded wind gusts of up to 115 mph (NWS, 2022).
- Most destructive wildfire in Colorado history, with an estimated $500 million in damages (Phillips, 2022).

In response to a request for technical support from FEMA's Region 8 Office in Denver, Colorado, FEMA's BSDS Program deployed a Pre-Mitigation Assessment Team (Pre-MAT) to Colorado in January of 2022 to collect perishable data and undertake a preliminary evaluation of the performance of residential and commercial buildings during the Marshall Fire. As a result of the Pre-MAT observations and the unique nature of the event, FEMA deployed a full MAT to the area in August 2022 to conduct interviews and collect additional data.

The objective of this MAT report is to provide actionable recommendations to improve residential building performance under wildfire conflagration conditions. It describes the MAT's observations during the field deployments, draws conclusions based on those observations, and provides recommendations for actions that property owners can take to help increase the resiliency of their homes and neighborhoods to future wildfires. It also provides recommendations that local government officials, planners, builders, design professionals, and homeowners' associations can implement to reduce the potential impacts of wildfires on communities and improve their resilience.

This MAT report also considers the multi-hazard nature of events, such as the Marshall Fire, which had a strong interaction between wildfire and wind. Field observations also noted a relationship between wildfire and natural- and man-made flood control systems, primarily drainage ditches, which served to rapidly propagate and intensify wildfire behavior from the wildland/open spaces into and within suburban communities. Mitigation strategies for this (and other future) events require a multi-

[2] *Boulder County 2022-2027 Hazard Mitigation Plan*

perspective approach that considers the interplay between various hazards and addresses them collectively.

Some of the topics evaluated by the MAT include building and fire codes and standards; vulnerabilities of structural elements and systems to wildfire, structure spacing, smoke and ash infiltration; defensible space; and management of parks and common spaces. Wind played an important role in the spread of the fire, accelerating the movement of flames, hot gases, and embers across open space and then quickly into suburban neighborhoods. Though wind-related damages to buildings were observed only sporadically, it is likely that wind-borne debris caused impact damage to the exterior envelop of buildings, particularly through glazed openings, increasing the vulnerability of those structures to embers, hot gases, and flames entering the structures directly. Also noted was the role of combustible non-structural attachments such as wood fences and decks, which provided fire pathways leading to the structure.

This was the first opportunity for FEMA's BSDS program to deploy the MAT to assess building performance following a wildfire. It draws collaboratively from other efforts to study the Marshall Fire, including those of the Geotechnical Extreme Events Reconnaissance Association (GEER), Insurance Institute for Business and Home Safety (IBHS), the ICC, National Institute for Standards and Technology (NIST), and state and local level efforts such as those led by the Colorado Division of Fire Prevention and Control on behalf of the Mountain View Fire Department, Louisville Fire Department, and Boulder County.

This fire was unique in that it originated in grasslands/flatlands near a heavily populated area and traditional suburban developments. High winds quickly spread the fire closer to the Town of Superior and City of Louisville as well as parts of Unincorporated Boulder County. FEMA believed it was important to study this fire because the nature of the origin, weather conditions, and impacts on the built environment in the nontraditional WUI represent risks that need to be better understood by planners, developers, government officials, and the public-at-large. Most people believe that wildfire risk is generally limited to heavily forested areas. It is important to convey that wildfires can occur in any vegetated area and spread by ground, wind, or both to populated areas.

1.1. Organization of the Report

This MAT report is divided into six chapters and four appendices.

- Chapter 1 (this chapter) provides an introduction to this report including objectives, the organization of the report and fire basics such as terminology and history. It also discusses an overview of Boulder County and a history of recent wildfires in the area.
- Chapter 2 discusses the Marshall Fire event including its impacts and extent as well as the MAT background and process.
- Chapter 3 presents the wildfire regulatory mechanisms including building codes, standards and regulations that were in effect at the state and local levels at the time of the fire, and updates

made to state and local codes and standards since the fire occurred. It also provides an analysis of conflicts between and omissions from some of the primary codes and standards that are used to protect buildings against wildfire.

- Chapter 4 describes the MAT observations at the community and neighborhood scale related to land use planning and neighborhood design, management of parks, and other common spaces. It also provides best management practices and recommended plants.

- Chapter 5 describes the MAT observations at the parcel and building scale related to the performance of primarily residential but also some non-residential buildings and appurtenant structures exposed to the fire, smoke and ash infiltration, vulnerabilities associated with defensible space, and structure fire separation distances.

- Chapter 6 presents the MAT's conclusions and recommendations and is intended to help guide recovery efforts for communities impacted by wildfire as well as planning and preparedness efforts for communities susceptible to wildfire. It provides strategic recommendations to improve codes and standards, community planning and design, and construction guidance.

In addition to the report chapters, this report includes the following appendices:

- Appendix A: Acknowledgements
- Appendix B: Bibliography
- Appendix C: Glossary
- Appendix D: Homeowner's Guide to Risk Reduction and Remediation of Residential Smoke Damage
- Appendix E: Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire
- Appendix F: Homeowner's Guide to Reducing Wildfire Risk Through Defensible Space
- Appendix G: Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire
- Appendix H: Mitigation Strategies to Address Multi-Hazard Events
- Appendix I: Best Practices for Wildfire-Resilient Subdivision Planning
- Appendix J: Wildfire-Resilient Detailing, Joint Systems, and Interfaces of Building Components

1.2. Wildfire Basics

Wildfires are a natural part of many of Earth's wildland ecosystems and play a number of important roles in maintaining healthy forests, including clearing out understory biomass, providing soil nutrition, controlling invasive species, and supporting ecological cycles (Bowman, 2009). Humans have not only used fire to shape the landscape and support numerous survival needs, but also sought to suppress fires that threatened their homes and towns. The federal government's approach has evolved from suppressing all fires on forested lands to recognizing fire as an ecological process, using prescribed fire, as well as more preparation, collaboration, and oversight.

Fundamentally, three ingredients are necessary for fires to occur (aka “the ignition triangle”): oxygen, which starts and sustains combustion; heat, which raises the fuel temperature or simply heats fuel to its ignition point; and fuel, which sustains and carries flames. Eliminating or reducing one or more of these components is the basis of fire mitigation and suppression techniques.

Wildfires, however, are more complex and challenging than the ignition triangle. The nature of the wildfire problem is a product of natural and/or man-made ignition sources, vegetative fuels, topography, weather, and characteristics of the built environment (e.g., building typologies, urban fuel loads, density). Understanding how these factors interact, along with fire history, fire ecology, climatology, and human interactions with these various facets, is central to developing appropriate and effective mitigation strategies.

Each year only a small fraction of wildfires become large enough to result in significant negative impacts. These low percentages can be attributed to a combination of favorable environmental conditions, limitations in adoption and/or implementation of WUI codes and standards, limited knowledge of wildfire hazards/risks, limited resources for retrofits, increasing construction in high wildfire areas, availability of firefighting resources to effectively respond to fire incidents especially during the incipient stages of fire development, and the evolution of the risk. Refer to Sections 1.3.2 and 1.3.3 for additional details and specifics about the wildfire environment in Boulder County.

- **Weather** – is the most variable element of the wildland fire environment. Important components of fire weather that influence wildfire behavior are temperature, relative humidity, precipitation, wind, and atmospheric stability. All these elements have the potential to enhance or retard wildfire spread and intensity.

- **Vegetation** – is the primary fuel source for wildfires and, along with weather, is a key factor in determining the risk of wildfire hazards. In the WUI, both wildland vegetation and urban fuels present a hazard. Urban sources of fuel such as combustible structures (e.g., houses, businesses, industrial facilities, outbuildings), combustible non-structural features (e.g., decks, fences, ornamental landscaping), vehicles, fuel tanks, etc., can contribute to the fire environment and significantly influence the fire behavior and overall hazards. Locally, the abundance of non-native trees and shrubs used as landscaping vegetation and screening has a negative effect on the overall wildland fire environment. Thus, linking the potential risk of a large-scale, destructive wildland fire to the adjacent vegetation and associated characteristics.

- **Topography** – is the configuration of the earth’s surface and is the most stable of the elements in the fire environment. Topography significantly impacts wildfire behavior as it influences local winds by sheltering areas from prevailing winds or channeling winds through prominent canyons and drainages. Factors of topography that affect fire behavior include slope, aspect, terrain features, and elevation with the steepness of slope being the most influential.

There are many terms that carry specific meaning in the context of wildfire. This section provides a few key definitions and explanations of some of these terms as they are used in this MAT report. A more comprehensive glossary is in Appendix C for reference. The majority of these definitions come from the National Wildfire Coordinating Group's (NWCG's) online glossary[3], other nationally recognized fire organizations and from existing FEMA terminology.

- **Conflagration** – A large destructive fire that causes substantial destruction (National Fire Protection Association (NFPA) 101®, Life Safety Code Handbook).
- **Wildfire** – A wildfire is an unplanned, unwanted fire burning in a natural area.
- **Wildland** – A natural environment that has not been significantly modified by human activity.
- **Wildland-Urban Interface** (WUI)– The line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetation fuels.

1.2.1. EVOLUTION OF RISK

Over the last 35 years, the number of reported wildfires has stayed the same but more have become catastrophic events measured in more than just acreage. Lives lost, property damage, and post-fire impacts such as landslides, flash floods, and mudslides are elements of wildfire impacts to individuals and communities.

Changes in weather, development patterns and the slow development and adoption of wildfire safety codes, standards and practices are exacerbating the impacts of wildfire threats in the U.S. Many parts of the western U.S. are experiencing reduced precipitation, warmer spring and summer temperatures, and longer, drier fire seasons (Westerling and Bryant, 2008). While other parts of the U.S. that have not historically suffered from major wildfire threats (e.g., Eastern U.S.) are likely to increase in susceptibility(U.S. Global Change Research Program, 2018).

The boundary or interface between urban and wildland development is a very dynamic element that shifts every year. As more people move into wildland areas, the relative wildfire risk dramatically increases due to the higher consequence of having more people and property exposed to the wildfire hazard. The population living in the WUI has grown significantly; from 1990 to 2010, the WUI had the largest rate of growth compared to any other land use type. During this time, there was a 41% increase in houses and a 33% increase in the land area considered to be within the WUI. These trends underline that there are not just more severe wildfires, but more development and more people living in wildfire-prone regions and areas that could be prone to wildfires in the future.

[3] https://www.nwcg.gov/publications/pms205

1.2.2. THE EVOLVING DEFINITION OF THE WILDLAND-URBAN INTERFACE

The WUI is often defined as a transition area where unoccupied land and human development meet. Historically, the WUI has been primarily associated with the intersection of uninhabited wildland (primarily perceived as forested areas) with human development. This perception has led many people who live in suburban and urban areas “near the WUI” to believe they are not at risk from wildfire because they are not specifically at the interface of wildlands, or they live adjacent to large open spaces of primarily grass and shrublands (instead of forestlands).

> The National Wildfire Coordinating Group (NWCG) (2009) defines the WUI as the “line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetation fuels.”
>
> A common misperception of the WUI is that it occurs only near forested areas. Grasslands and shrublands can also be in the WUI.

As environmental conditions continue to change the landscape and as human development continues to expand into vegetated areas near what has traditionally been deemed the WUI, it has been identified that the definition of “interface” may need to change or terms such as “intermix” and “occluded”[4] may need to be better socialized to convey wildfire risk to communities.

> *Interface* – The interface community exists where structures directly abut wildland fuels.
>
> *Intermix* – The intermix community exists where structures are scattered throughout a wildland area.
>
> *Occluded* – The occluded community generally exists in a situation, often within a city, where structures abut an island of wildland fuels (e.g., park or open space).
>
> A more comprehensive glossary is in Appendix C for reference.

Figure 1 illustrates the range of WUI conditions and associated terminology where wildlands and the built environment intermingle. As this continuum moves from the natural environment to urban, town centers, the associated wildfire hazards and risks posed to structures and people inherently shift and thus necessitate different strategies to reduce these risks.

[4] as defined by the U.S. Forest Service, Bureau of Indian Affairs, Bureau of Land Management, Fish and Wildfire Service and National Park Service in the Federal Register on January 4, 2001, or from CAL FIRE

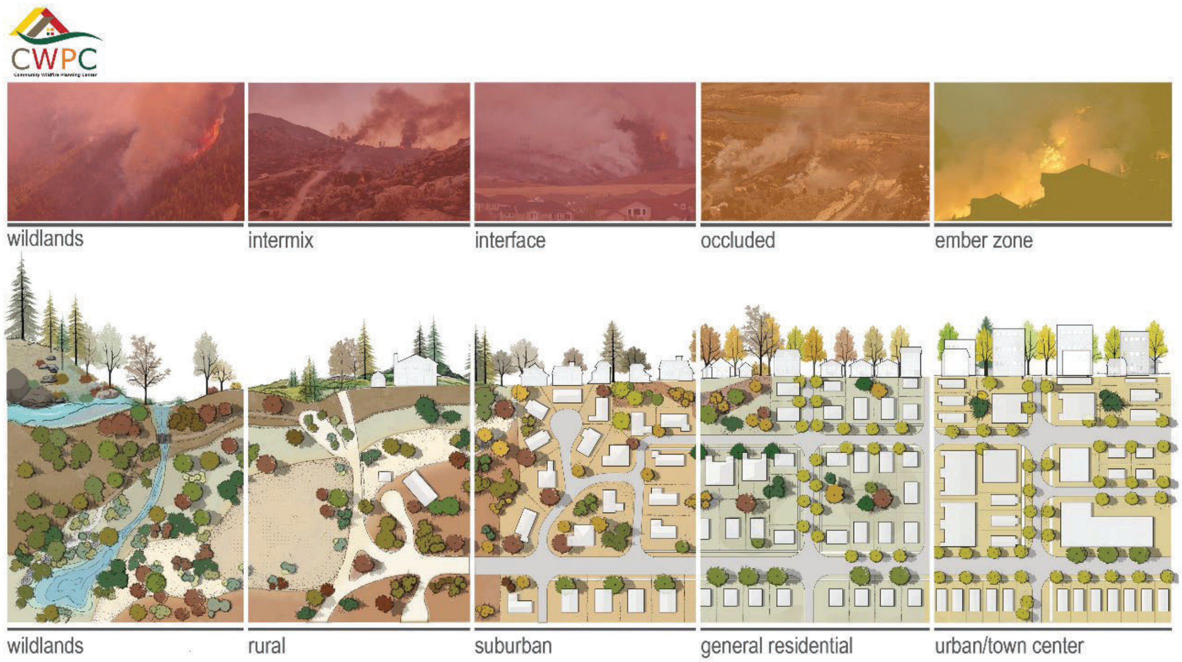

Figure 1. Communicating a continuum of environmental conditions will allow planners, engineers, community officials, and residents to better understand their wildfire risk (Image courtesy of Community Wildfire Planning Center).

Numerous agencies and organizations, including the U.S. Forest Service (USFS), the State of California, the State of Washington, the State of Oregon, and NIST, have already established more comprehensive and substantive definitions for the WUI to encompass the broad range of environmental settings (e.g., topography, vegetation, weather) and built environment conditions (e.g., rural, semi-rural, urban, building typologies) where wildfires pose a major threat. Wildfire/fire safety professionals and the industry need to continue to provide ongoing educational tools, resources, and public awareness campaigns to reinforce and contextualize existing definitions that are relevant to specific regions, communities, and neighborhoods. This includes mainstreaming the definitions of the wildland-urban interface and intermix with broader vegetative categories such as grasslands and shrublands, such that the general public as well as planning and design professionals (e.g., planners, architects, and engineers), contractors, and government officials have a clearer understanding of the potential risk of their community to wildfire. Based on this understanding, they can then take the necessary steps to mitigate these risks.

Currently the evolution is occurring around the need for consensus-based wildfire hazard and risk maps. Various forms of wildfire hazard and risk mapping layers have been developed by some state and federal agencies to address a variety of applications (e.g., land use management); however, a national consensus-based wildfire risk map for community planning and wildfire building safety does not currently exist. Current practices in assessing wildfire risks to the built environment are not based on risk-informed approaches analogous to other hazards (e.g., seismic, wind), where recurrence intervals and damage potentials are quantified at the national level.

In 2021, Congress passed the Wildland Fire Mitigation and Management Commission Act including the formation of the Wildland Fire Mitigation and Management Commission[5]. The commission is tasked with forming federal policy recommendations and strategies on ways to better prevent, manage, suppress, and recover from wildfires. This commission and its' workgroups are currently exploring needs and opportunities that could drive actions regarding how we assess and communicate wildfire risk.

1.2.3. MULTI-HAZARD WILDFIRE INTERACTIONS

Wildfire behavior is largely influenced by fuel, weather, and topography but other natural hazards can also influence wildfire behavior and severity. For example, lightning is a common ignition source for wildfire, especially in conditions of low relative humidity and abundant dry fuels. Extreme heat can work in tandem with drought to increase the volume of dry fuel available for ignition. High winds can increase the speed with which wildfires travel, help spread embers to ignite new fuel sources, and hinder fire suppression efforts.

In turn, wildfires can influence the severity and behavior of other natural hazards. In post-fire conditions, the significant loss of vegetative cover and erosion control can increase the risk of secondary natural hazards, such as floods, landslides, and debris-flows in and downslope of burned areas. These post-wildfire hazards often have cascading effects on the local natural and built environment, including incursions of invasive species, loss of watershed function, as well as impacts to critical infrastructure, buildings, and people.

For the purposes of this report, wildfires that occur in combination with other natural hazards are considered "multi-hazard wildfire events." The natural hazards that make up a multi-hazard wildfire event along with wildfire are lightning, drought, extreme heat, high wind, flood, and landslide (see Figure 2).

[5] https://www.usda.gov/topics/disaster-resource-center/wildland-fire/commission

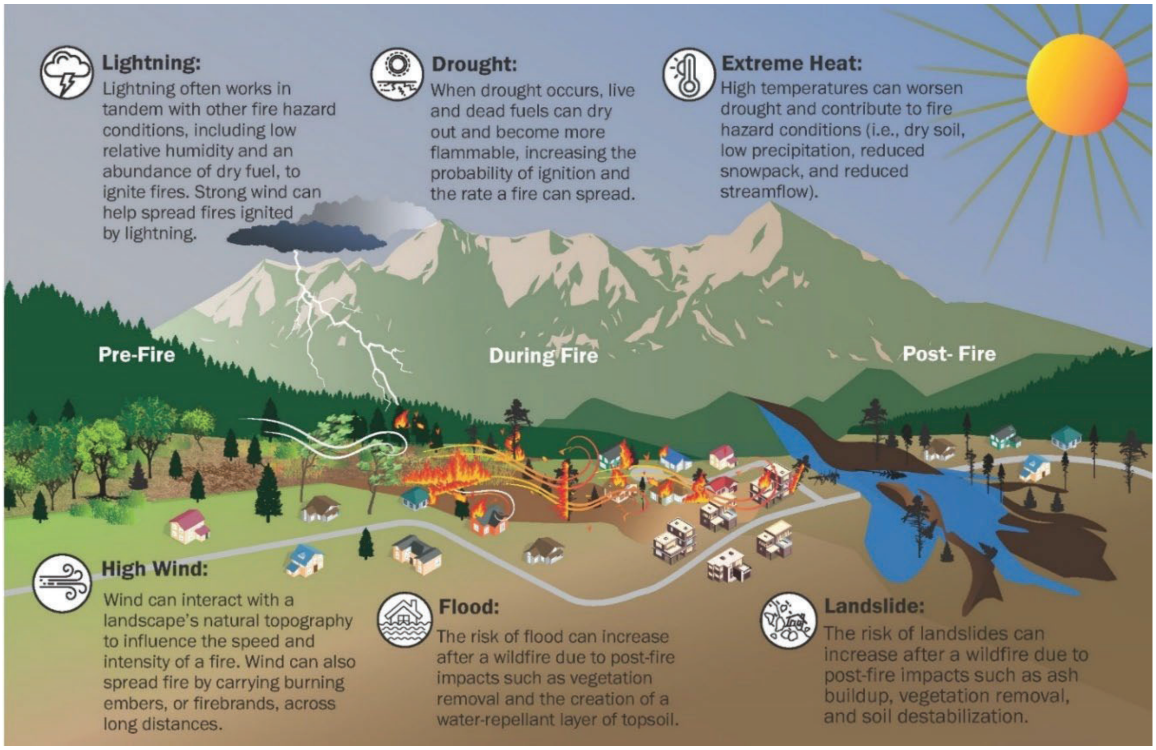

Figure 2. Multiple hazards can contribute to or result from wildfires.

Wildfire mitigation strategies are evolving to keep pace with changing weather patterns and an expanding definition of wildfire risk. For example, the federal interagency NWCG is incorporating new science on the impact of drought and wind into fire personnel training (Schmidt, 2023). Consideration of wildfire as a "multi-hazard event" is not currently standard practice in wildfire mitigation and is an area of developing research.

1.3. Overview of Boulder County, Colorado

Boulder County covers approximately 740 square miles northwest of Denver (Figure 3). The western two-thirds of the county are generally mountainous and forested, while the eastern one-third is dominated by gently rolling hills and grasslands. Boulder County is home to over 300,000 people, most of whom live in the eastern one-third of the county. Incorporated towns and cities include Boulder, Erie, Jamestown, Lafayette, Longmont, Louisville, Lyons, Nederland, Superior, and Ward. The Boulder County 2022-2027 Hazard Mitigation Plan notes: "Most of the County is susceptible to wildland fires, with highest risk areas located in the Front Range Foothills in the central portions of Boulder County" (Boulder County, 2022).

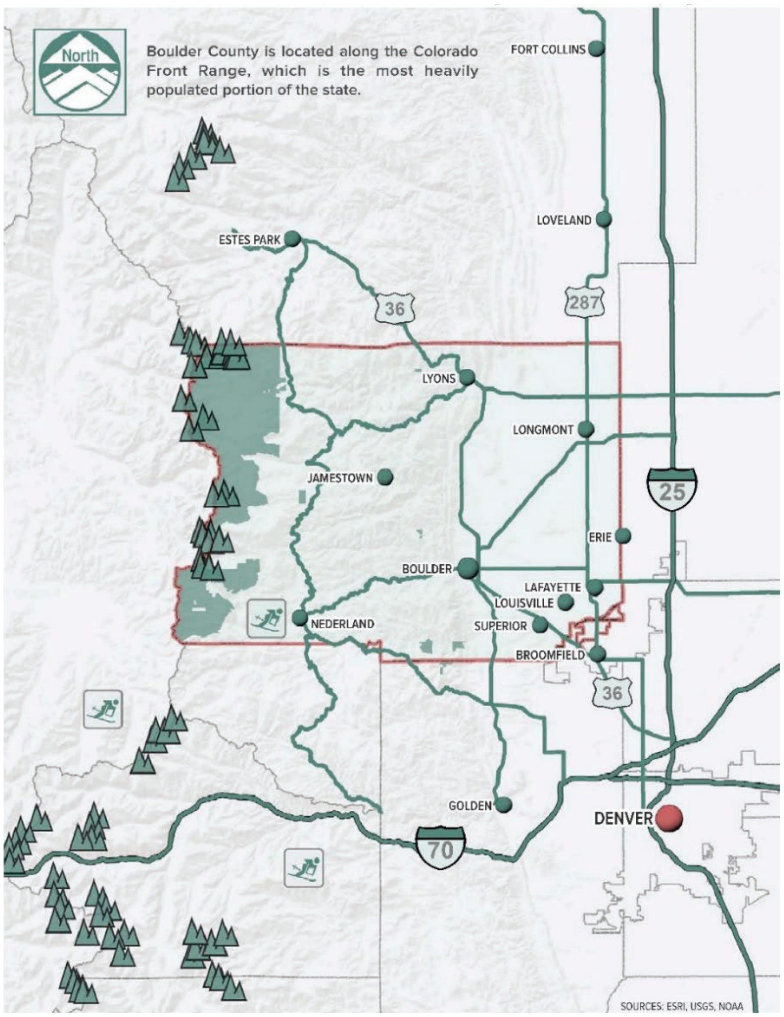

Figure 3. Boulder County Location Map (Boulder County Comprehensive Plan, 2020).

Locations in the Colorado Front Range region, including portions of Boulder County, are categorized in American Society for Civil Engineers (ASCE) 7-16 *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE, 2017) Section 26.5.2 as "special wind regions" meaning that those topographic areas have the potential to be hazardous due to wind. Wind contour maps for the special wind regions are available to determine design wind speeds that are specially produced and adopted by local jurisdictions in Colorado. Adopting the latest wind-related building codes and standards are important to ensure that new or retrofitted buildings will resist higher wind loads and wind debris to prevent additional damage that could propagate or spread wildfire. Boulder County currently has adopted the 2018 IBC and IRC. Both reference ASCE 7-16 for determining wind loads.

1.3.1. BOULDER COUNTY DEMOGRAPHICS

Table 1 presents U.S. Census data for Boulder County based upon 2019 American Community Survey estimates as well as social vulnerability index (SVI) values. Social vulnerability is quantified by aggregating 16 factors into four themes that summarize how socially vulnerable a region is to a disaster. Social vulnerability refers to a region's ability to prepare for and respond to a disaster caused by a natural hazard, such as a wildfire, or to human-caused threats. The Centers for Disease Control (CDC) calculates the social vulnerability by census tracts with scores ranging from zero (0) to one (1). Boulder County's SVI score indicates low vulnerability, and the City of Louisville and the Town of Superior SVI scores are categorized as low to moderate vulnerability.

Table 1. Demographic information for the Marshall Fire Area.

Demographic Measure	City of Louisville	Town of Superior	Boulder County	State of Colorado	National Average
Population, 2020	21,226	13,094	330,758	5,773,714	N/A
Population Increase 2010 to 2020	15.5%	15.5%	12.3%	14.8%	7.4%
Median Household Income	$103,017	$127,292	$88,535	$80,184	$71,400
Poverty Rate	5.9%	4.2%	11.7%	9.7%	11.4%
Homeownership Rate	70.6%,	58.2%	61.6%	65.2%	64.6%
Housing Units Constructed after 1990	42.9%	91.9%	40.7%	N/A	N/A
Median Home Value	$677,000	$576,800	$575,500	$397,500	$244,900
*SVI Calculated Value (CDC)**	*0.1384 - 0.3905*	*0.129 - 0.374*	*0.2062*	*N/A*	*N/A*

Sources: 2019 American Community Survey and CDC
**SVI scores from 0 to 0.333 are considered to have low vulnerability; scores from 0.334 to 0.666 are considered to be moderately vulnerable; and scores from 0.667 to 1 are highly vulnerable.*

1.3.2. BOULDER COUNTY WILDFIRE HISTORY

Historically, most wildfires in Boulder County have occurred during peak fire seasons in the summer but major fires have recently occurred in December, January, and February with approximately 64 fires occurring during March of 2011 (Boulder County, 2022), and the Marshall Fire in December. The most notable wildfires in Boulder County are the 1989 Black Tiger Fire, the 1990 and 2009 Olde Stage Fires, the 2003 Overland Fire, the 2010 Fourmile Canyon Fire, the 2016 Cold Springs Fire, and the 2020 Cal-Wood & Lefthand Canyon Fires (Boulder County, 2022, and Boulder County website). Table 2 summarizes major wildfires that have recently occurred in the area prior to the Marshall Fire.

Table 2. Recent Major Wildfires in Boulder County Prior to the Marshall Fire (Colorado State Forest Service).

Event Date	Event Name	Cause	Weather Conditions	Foothills or Flatlands	Number of Acres Burned	Impacts
October 2020	Cal-Wood Fire	Unknown	Red flag warning*	Foothills	600	Damaged 27 properties and destroyed 20 homes
October 2020	Lefthand Canyon Fire	Unknown	Cold and snowy	Foothills	460	Burned brush and timber 1 mile west of the Town of Ward
July 2016	Cold Springs Fire	Campfire	Heavy fuel loads, windy	Foothills	606	1,900 people evacuated; 1,000 homes threatened; 8 homes destroyed
March 2011	Lefthand Canyon Fire	Human (likely vehicle)	Red flag warning*	Foothills	622	223 homes evacuated
September 2010	Fourmile Canyon Fire	Out-of-control burn pile	Dry, windy (up to 40 mph) conditions	Foothills	6,200	168 homes (35% of homes in area) destroyed
January 2009	Olde Stage Fire	Energized power lines snapped	High winds (60+ mph)	Flatlands	3,008	2 homes and 3 barns destroyed
February 2006	Elk Mountain Fire	Discarded fireplace ashes	Dry, windy (wind speed up to 32 mph with gusts up to 44 mph)	Foothills/ Flatlands	600	Grasslands, apple orchard, two farm trucks destroyed
October 2003	Overland Fire	Tree fell on power line	High winds	Foothills	3,500	12 homes destroyed; post-fire debris flow in the Spring
September 2000	Walker Ranch Fire/ Eldorado Fire	Human (likely discarded cigarette)	Drought, high winds	Foothills	1,100	No homes destroyed and no loss of life
November 1990	Olde Stage Fire	Arson	High winds (80+ mph)	Flatlands	3,000	10 homes and 5 outbuildings destroyed
July 1989	Black Tiger Fire	Human (likely discarded cigarette)	Dry/drought, windy	Foothills	2,100	44 homes destroyed

Sources: Colorado Forest Atlas and Boulder County Hazard Mitigation Plan

**Red Flag Warnings:* *For Boulder County, a Red Flag Warning requires a combination of weather and fuels conditions (as determined by fire management) for any 3 hours or more in a 12-hour period.*

Figure 4 illustrates some of the most recent, large wildfires in Boulder County near the impacted areas of the Marshall Fire as documented in the Boulder County Hazard Mitigation Plan.

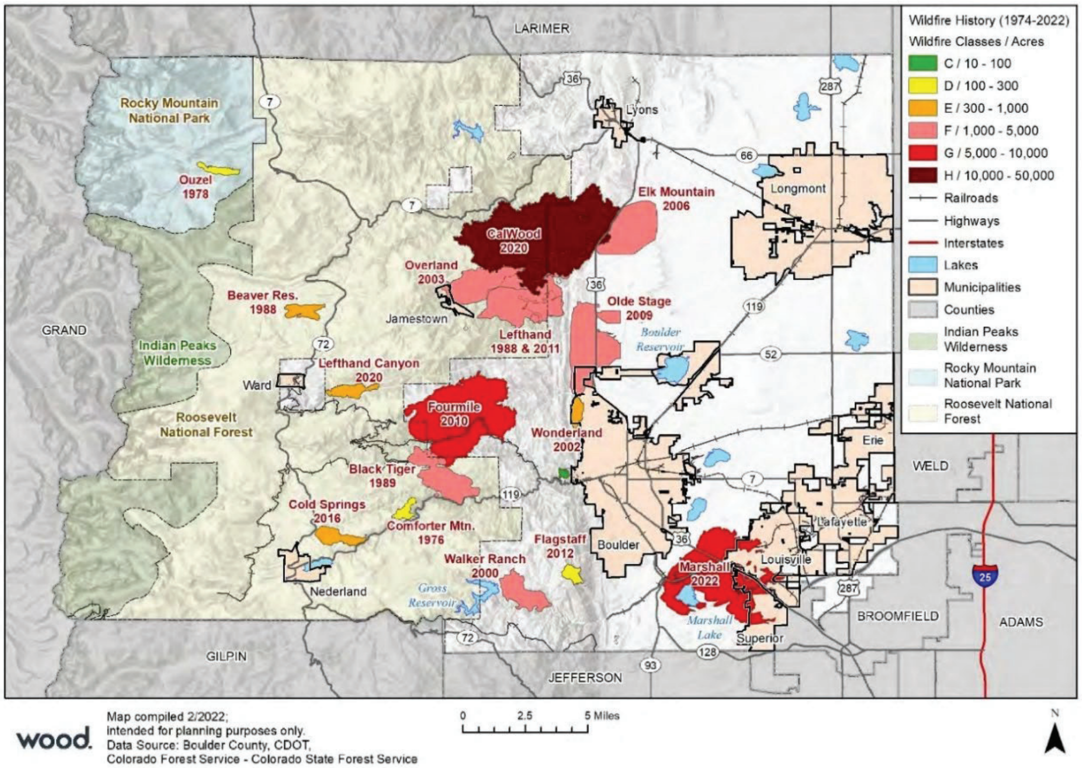

Figure 4. Historical Wildfires in Boulder County (Boulder County Hazard Mitigation Plan, 2022).

1.3.3. BOULDER COUNTY WILDFIRE ENVIRONMENTAL SETTINGS

Wildfires are historically part of Boulder County's landscape (e.g., weather and climate, vegetative coverage, topography) even prior to human development. Due to various land management practices (including fire exclusion and suppression policies), expanding development and human presence, invasive species and weather variation, wildfire is increasingly impacting communities within the local WUI.

Boulder County features a range of landscapes and ecosystems. From the plains to the Continental Divide, Boulder County is defined by three distinct forest types or life zones (lower montane, upper montane, and subalpine), with the mountainous life zones experiencing the majority of historic wildfires (Figure 5). Environmental factors such as aspect (i.e., compass direction that a terrain surface faces), slope, soil type, and fire history all influence where the transitions ("ecotones") between life zones occur in the county. The area of the Marshall Fire occurred in the lower montane ecotone.

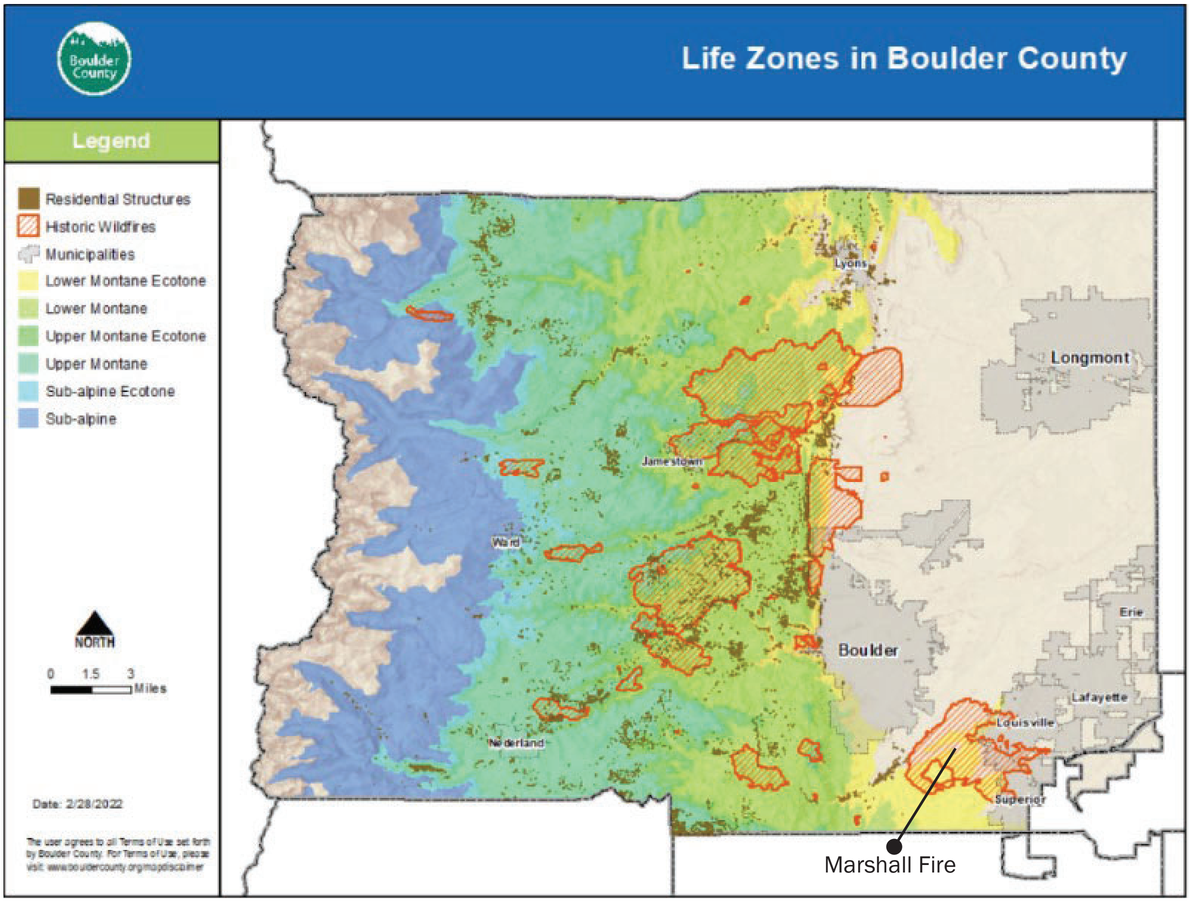

Figure 5. Life zones across Boulder County with past fire history overlay (Boulder County).

Many of Boulder County's residents live in the lower foothills, dominated by ponderosa pine and Douglas fir forests. These forests occupy the lower montane life zone (5,900–8,000 feet in elevation) with a historic fire frequency of 8–30 years. At higher elevations (7,500–9,200 feet), the upper montane life zone has an historic fire frequency of 50–300 years. The highest elevation life zone (at 9,000–11,500 feet), the subalpine life zone, has a historic fire frequency of 300 to more than 500 years (Figure 6) (Boulder County, U.S. Department of Agriculture (USDA) Forest Service).

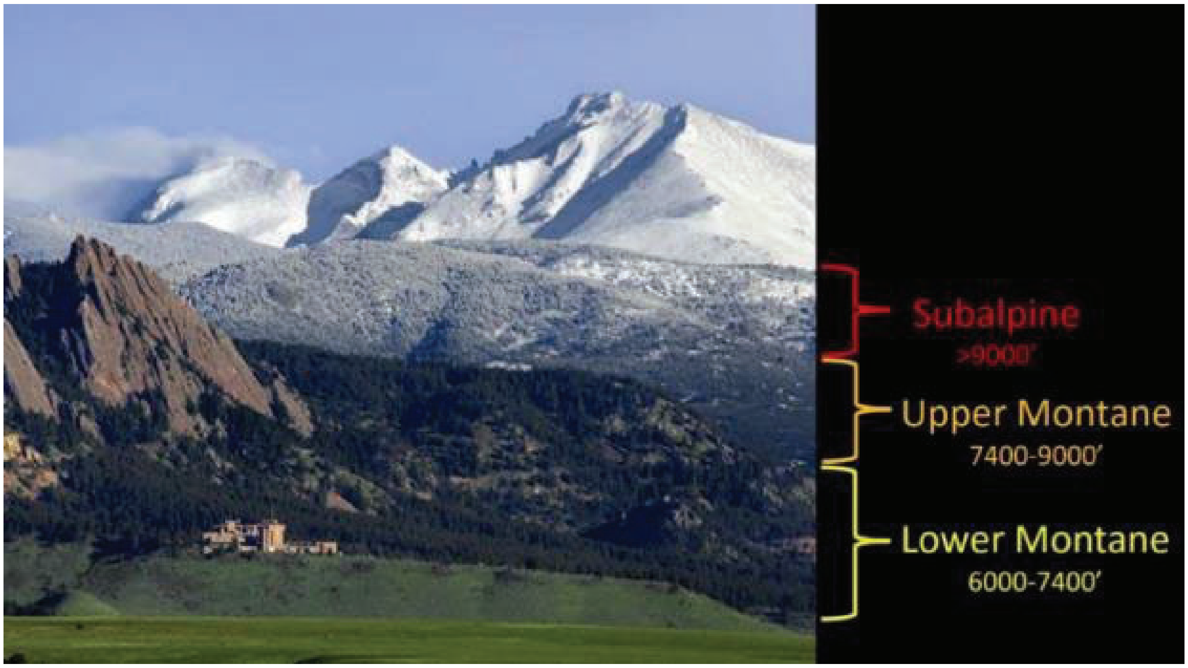

Figure 6. Three main life zones in Boulder County (USDA, Forest Service).

Both the intensity and frequency of historic wildfires can be linked to life zones. In the dry, low-elevation, lower montane life zone, frequent fires have occurred with low to moderate intensity. In contrast, in the moister, cooler, higher-elevation life zones, the less frequent fires were mostly high-severity fires.

According to the Colorado Forest Atlas, the area where the Marshall Fire started and surrounding open/wildland space are considered high wildfire prone areas, ranging from moderate-high, high to high-very high hazard based on burn probabilities (Figure 7). Burn probability is the annual probability of any location burning due to wildfire, assuming high and extreme weather conditions. In Boulder County, some areas are considered "non-burnable" due to the associated fuel type (e.g., water, roads, towns, agricultural areas) and the limitations of current wildfire behavior models[6].

[6] Colorado Forest Atlas, Wildfire Risk Public Viewer, https://co-pub.coloradoforestatlas.org/#/, assessed August 5, 2022.

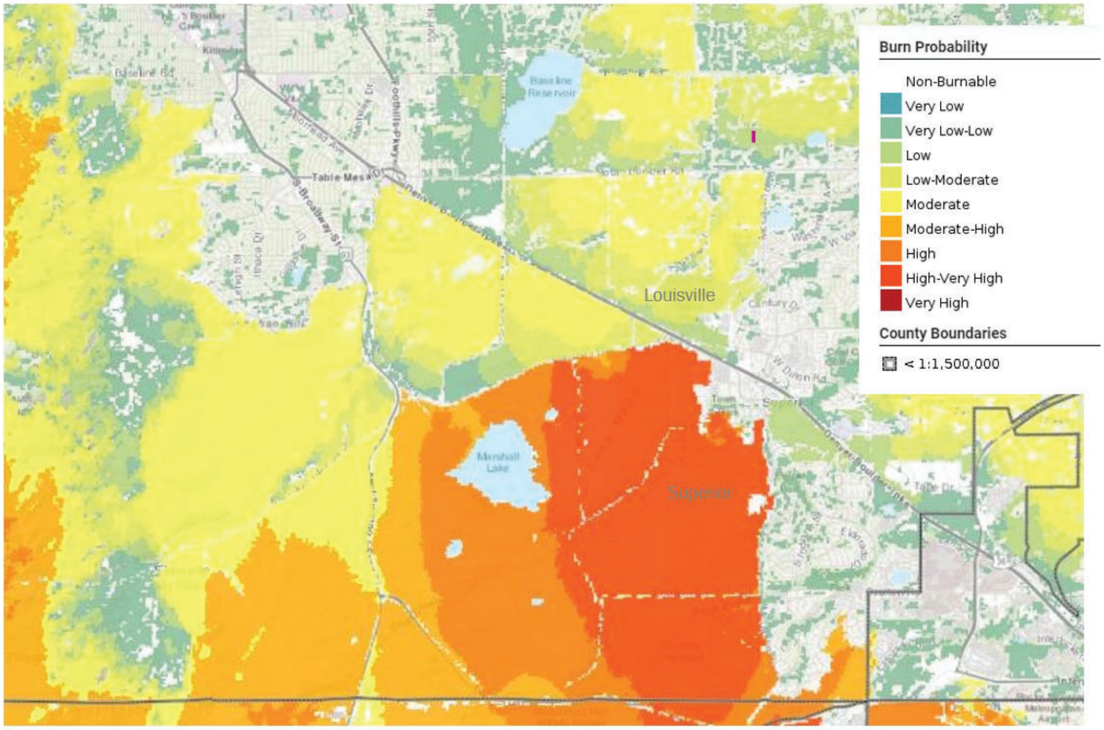

Figure 7. Relative burn probability across Boulder County (Colorado Forest Atlas).

Boulder County Weather and Climate

The climate in the immediate vicinity of the Marshall Fire perimeter is classified as "Humid Subtropical"—temperate, with hot summers and no dry season according to the Koppen-Geiger Climate Classification System. Weather is the most variable element of the wildland fire environment. Important components of weather that influence fire behavior are temperature, relative humidity, precipitation, wind, and atmospheric stability. Each element has the potential to enhance or hinder wildfire spread and intensity. Refer to Section 2.1 for weather conditions during and leading up to the Marshall Fire.

A typical fire season in the region usually does not begin until the herbaceous fuels are cured in late summer and fall. Depending on the amount and timing of springtime rains, this may occur as early as mid-August some years but can lag into September. On average, May is typically the wettest month of the year (3.21 inches) in this area per the Colorado Climate Center[7]. Summers are warm, drying out the living vegetation while also raising surface fuel temperatures. These conditions increase ignition potential and enhance the spread of wildfire. July is the warmest month of the year locally, with an average dry bulb temperature of 72°Farenheit. However, temperatures in excess of 85°Farenheit can occur from June through September.[8]

[7] https://climate.colostate.edu/normals_stn_select.html
[8] https://www.weather.gov/wrh/climate?wfo=bou

While temperature and precipitation play a key role, wind is the most critical element of the fire environment that influences large fire development and the ability of firefighters to successfully suppress a fire during initial suppression phases. Prevailing winds for summer fire season months in this area are from the west, though high wind events (i.e., gusts of 100-plus mph) in the foothills and along the adjacent plains are not uncommon for Colorado during winter months.

Boulder County Vegetation

Positioned in the foothills-plains of Boulder County, the impacted communities of the Marshall Fire (Superior, Louisville, and portions of unincorporated Boulder County) are primarily developed with the Rocky Flats National Wildlife Refuge to the south, and Boulder County open space to the west. In addition, parks, and open space (e.g., owned natural space, natural space under conservation easements and developed open space) comprise a large percentage of the land area (31% for Superior and 26% for Louisville) creating a mixture of WUI interface and WUI intermix.

The undeveloped lands are largely comprised of agriculture, shrublands and grasslands, as shown in Figure 8. Grassland and shrubland fires are low intensity, fast-burning fires. A main factor determining wildfire behavior is fuel load quantity and quality. Large quantities of fuel elevate wildfire burning potential, and long dry periods enhance flammability and increase wildfire probability in grassland and shrubland wildland ecosystems. Compared to forests, the availability of fuel in grasslands and shrublands is low; however, this fuel is very dry. Therefore, fires are easy to start and spread fast, which is also why they’re called “flashy fuels.”

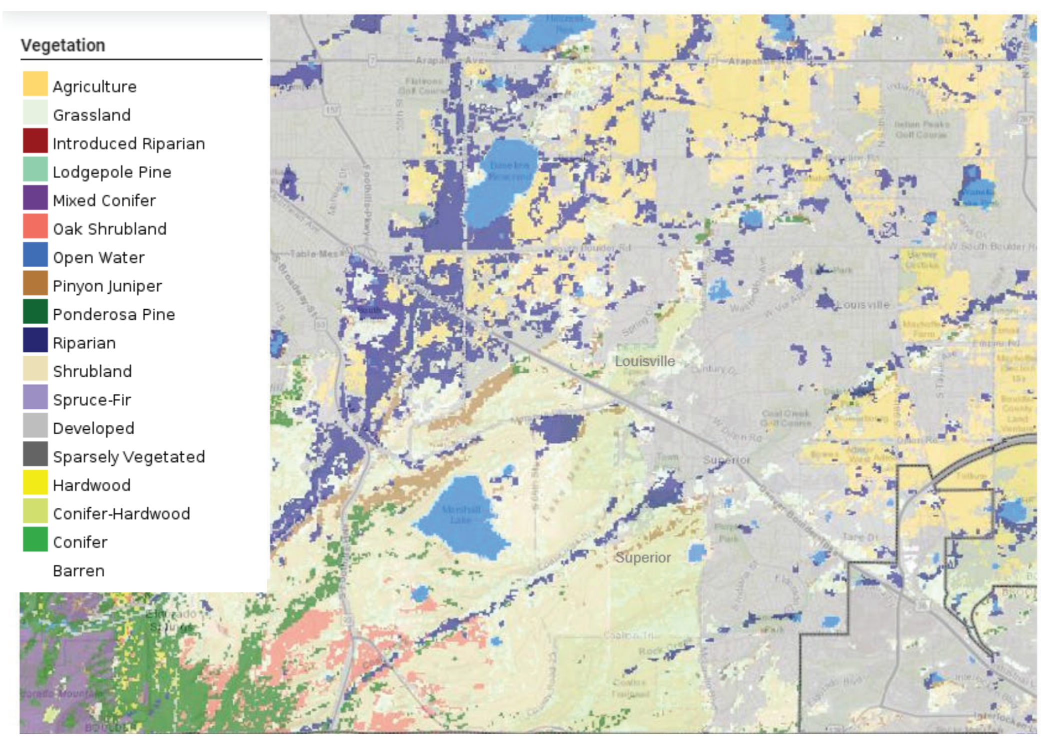

Figure 8. Vegetation map in and around the impacted communities of the Marshall Fire (Colorado Forest Atlas).

Boulder County Topography

As the communities impacted by the Marshall Fire are situated in the foothills-plains of Boulder County, the topography is generally characterized by plains and rolling hills. It provides a distinct transition from the foothills and canyons to much flatter terrain. It is a recognized wind corridor as exhibited by the windmills and National Renewable Energy Labs located here.

Chapter 2: The Marshall Fire Event and Impact

The Marshall Fire occurred on December 30, 2021, in Boulder County, Colorado. It was the state's most destructive fire to date and was declared by the National Ocean and Atmospheric Administration (NOAA) as a billion-dollar disaster (NOAA NCEI, 2022). Several factors have been attributed to its devastation: extreme winds, long term drought, unseasonably high temperatures, and limitations in existing wildfire safety and planning regulations.

The fire started near Marshall Road and Colorado Highway 93 during the morning of December 30, 2022 and moved quickly east due to strong mountain wave gusts and dry grassland fuels (National Weather Service (NWS), 2022). Though the exact cause of the fire remains under investigation, time-stamped dispatch reports, radar images, and personal accounts provide a timeline of events (See Figure 9). Sources pinpointed the origin to an area west of Marshall Lake, but once lit, winds carried embers and flames across open land and into densely populated areas (Scott, 2022).

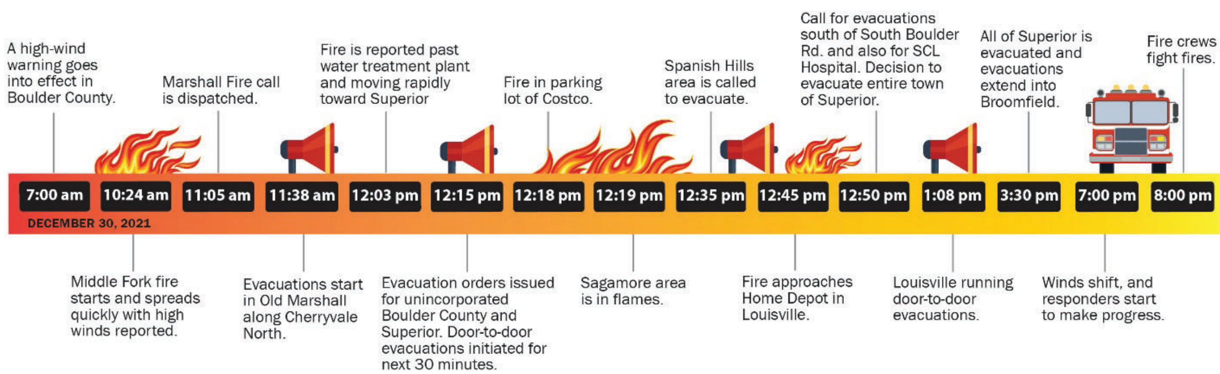

Figure 9. Marshall Fire Timeline Overview.

2.1. Marshall Fire Weather Conditions

Two environmental conditions have been tied to the start and spread of the Marshall Fire: drought and high winds. The combination of an unusually wet spring followed by significant drought during the second half of the year provided "perfect" environmental conditions that increased the likelihood of ignition and rapid spread of the fire. The first half of 2021 had higher than normal rainfall, spurring vegetation growth, particularly annual and perennial grasses, and other low-lying vegetation, which are easily ignitable and fast-burning fuels. A persistently dry pattern lasted through the fall and into winter of 2021 (GEER, 2022). Specifically, "in Denver, Colorado there were 1.92 inches of precipitation recorded between June 1 and December 30, which is the lowest precipitation level since 1939" (GEER, 2022; NWS, 2022). It is reported in the area impacted by the Marshall Fire that higher-than-normal temperatures combined with low precipitation levels caused drought conditions beginning in October 2021, and by December 2021, extreme drought conditions prevailed (GEER, 2022; NWS, 2022). Between July 1 and December 29, a day before the fire, the area temperatures averaged 60.3° Fahrenheit, the second warmest temperatures ever recorded in that time period (NWS, 2022).

On December 30, there was a windstorm within the area and a High Wind Warning was officially issued. Atmospheric pressures on the east side of the Rockies plummeted, leading to strong downslope winds (GEER, 2022). Sustained winds persisted throughout the day at 50 to 60 mph, with gusts up to 100 mph recorded along Highway 93 and a gust of 115 mph recorded just east of the intersection of Highway 93 and Highway 72. These gusts extended eastward up to and around Superior and Louisville. These strong, sustained winds helped move the fire front at a rapid rate (GEER, 2022). From the National Weather Service's analysis of the event, "high winds developed in the mid-morning hours on Thursday, December 30, 2021, the result of a mountain wave that developed as very strong westerly winds raced over the Front Range Mountains and Foothills and crashed down onto the plains" (NWS, 2022).

On December 30, winds were hitting the continental divide from the west, known as cross barrier flow. Further, there was a stable layer of air near the mountaintops, which forced a wave. When the wind hit the Rockies, it was forced up, but because of the stable layer of air near the top, the air was blocked and forced back down, creating a wave effect (Stein, 2021). Also, on that day, there was minimal wind shear, meaning there was very little change in wind speed as one moved up in the atmosphere (Stein, 2021). The stable layer and lack of wind shear that were in place that day played a key role in strengthening the mountain wave (Stein, 2021). These three factors—cross barrier flow, a layer of stable air near the mountaintops, and minimal wind shear—were major reasons the Marshall Fire behaved and moved the way it did.

Figure 10 depicts how the strong westerly winds moved down the mountain to the base of the foothills. From there, the winds pushed east into Superior and Louisville before weakening to the east (the jump region) (NWS, 2022). Easterly winds were also observed immediately to the east of the jump area, creating a rotor (NWS, 2022). An abrupt wind shift occurred late that day, sometime between 11:00 p.m., December 30 and 1:00 a.m., December 31. This shift was reported by responding fire personnel and was recorded by nearby weather stations (Colorado Division of Fire Prevention and Control, 2022). The wind shift resulted in cooler, wetter air entering the fire area, slowing the winds which aided fire suppression efforts.

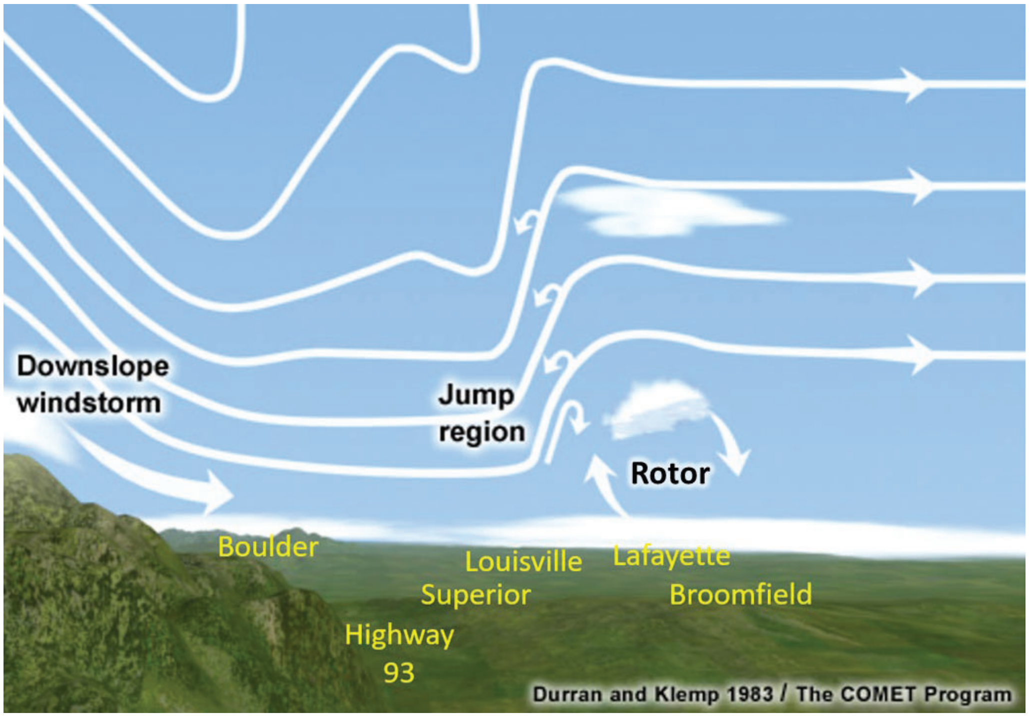

Figure 10. Conceptual model of a mountain wave (NWS, 2022).

2.2. The Marshall Fire as a Multi-Hazard Wildfire

The severity and behavior of the Marshall Fire was influenced by several natural hazards, including high wind and drought. These hazards worked in tandem with unusual weather and vegetative growth, the natural topography of the area, and characteristics of the built environment, including suburban housing density and abundant interwoven green spaces, to propel the fire through Superior, Louisville, and Boulder County communities.

Specifically, high winds combined with the natural topography of the area helped propel the fire (i.e., flames, hot gases, and embers) into communities. It was also observed that many of the impacted houses were adjacent to greenbelts, open spaces, and drainage ditches with an abundance of dry vegetative fuel. Drought conditions combined with unusual weather contributed to the amount of dry vegetative fuel, while the proximity of water collection and diversion features and greenbelts overgrown with vegetation created fuel "superhighways" for the fire to travel. High wind speeds also made the multi-hazard nature of the fire challenging for fire suppression efforts.

2.3. Impacts and Extent

Given the environmental conditions—high winds, unseasonably high temperatures and overgrowth in vegetation—and the inherent characteristics of the built environment, the Marshall Fire had catastrophic impacts on the Town of Superior, City of Louisville, and areas within unincorporated Boulder County. Homes burned at temperatures ranging from 300°Celsius to 900°Celsius (GEER, 2022). Figure 11 shows the extent of the Marshall Fire in Boulder County.

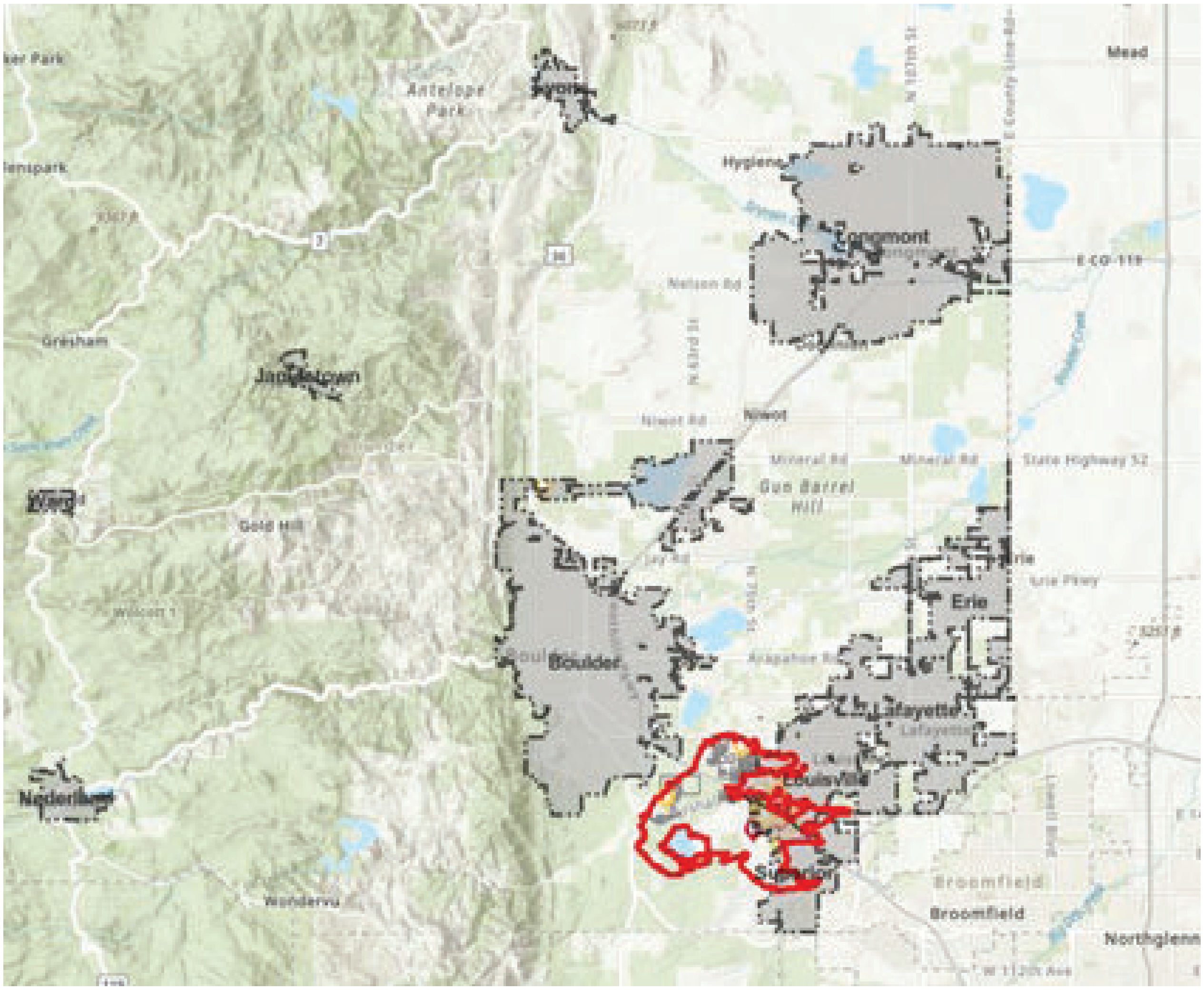

Figure 11. Marshall Fire Extent in Boulder County (Boulder County, 2023).

By the end of the day, over 6,000 acres had burned destroying over 1,000 structures and damaging over 170 additional structures across unincorporated Boulder County, Louisville, and Superior. Of those structures destroyed and damaged, 97% were residential structures. Across the three jurisdictions, the total residential damage exceeded an estimated $500 million (GEER, 2022). As of January 6, 2022, the Boulder County Office of Disaster Management completed a damage assessment of the impacted residential and commercial properties (Figure 12.).

The 2021 Marshall Fire was incredibly intense and consumed over 1,000 houses in Boulder County in less than 4 hours. By contrast, Boulder County lost 200 houses in 18 hours in the Fourmile Fire (2010) and 50 houses in 8 hours in the Cal-Wood Fire (2020).

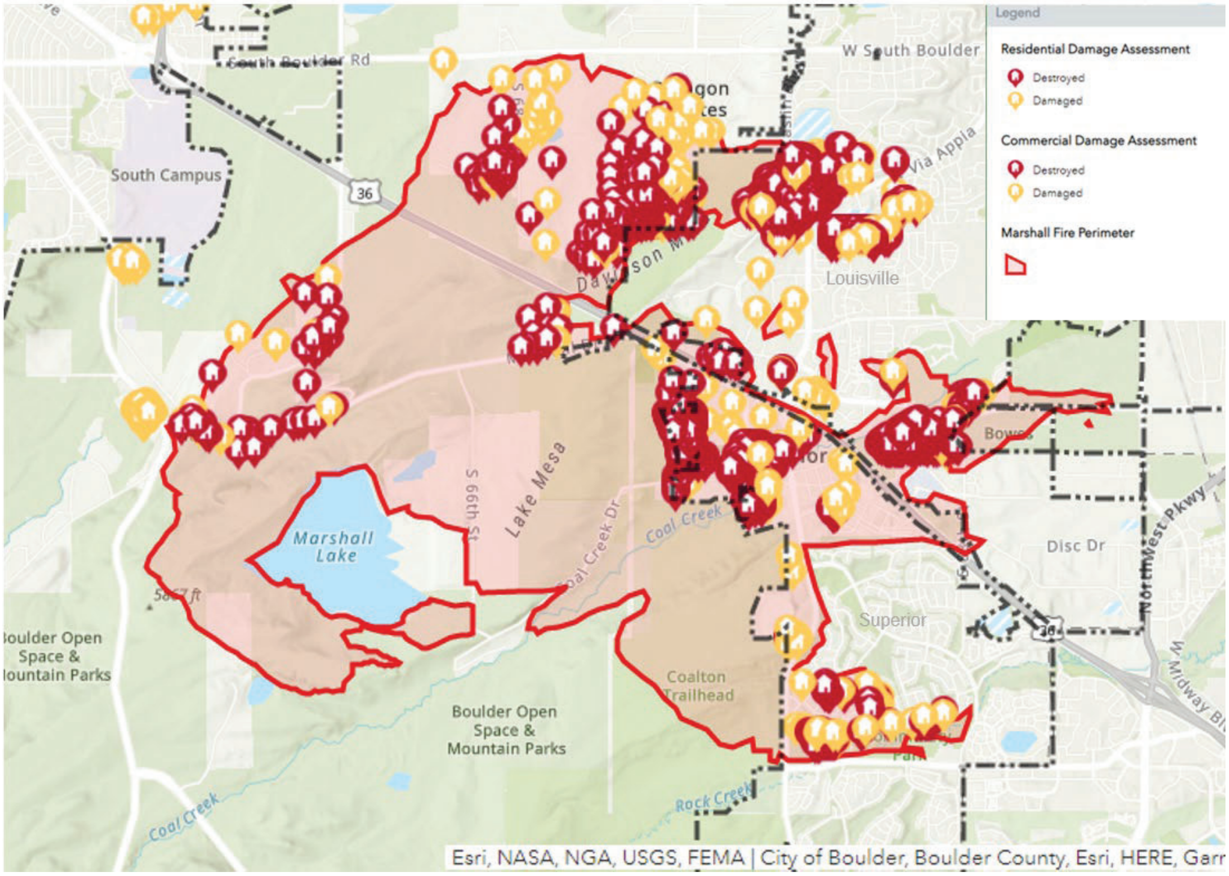

Figure 12. Destroyed (red) and damaged (yellow) structure locations in the Marshall Fire Perimeter (Boulder County, 2022).

Several manufactured home communities in Boulder County sustained substantial damage or were destroyed by high winds that accompanied the Marshall Fire ("Marshall Fire Recovery Milestones", n.d.). Rocky Mountain Public Broadcasting System (PBS) also noted that residents of manufactured homes were vulnerable to cold temperatures when utility companies turned off electricity and natural gas to prevent ignition by power lines (Moore, 2022).

In addition to property losses, more than 1,000 households were displaced by the fire. Survivors were eligible for some FEMA assistance, but many reported being underinsured. Many homeowners did not have insurance covering "guaranteed replacement cost" so rebuilding to current code with increased construction costs and supply chain issues presented challenges. The Marshall ROC (Restoring Our Community) was created to support survivors in housing recovery. It is a nationally recognized Long Term Recovery Group (LTRG). They are providing case management support to survivor households, are engaged in long-term community recovery planning, and have partnered with the Colorado Department of Local Affairs to seek reconstruction funding[9]. As of Spring 2023, hundreds of families are still recovering.

[9] https://marshallroc.org/dcm-committee/

2.3.1. BUILT ENVIRONMENT IMPACTS

The structures affected by the Marshall Fire varied greatly across the damaged areas. The majority of the built environment damaged in the event was residential construction; however, commercial structures were not immune. An estimated 1,084 residential structures were destroyed (550 in Louisville, 378 in Superior, and 156 in unincorporated Boulder County), with an additional 149 damaged. Seven commercial structures were destroyed (four in Louisville and three in Superior), and an additional 30 were damaged (Phillips, 2022).

Residential Construction

In general, the observations of the Pre-MAT and MAT found that many residential structures were built in the early 1980s and early 1990s though some houses appeared to date back to the 1950s and earlier while others appeared to have been constructed within the past 10 years. While many houses constructed before the 2000s appeared to have been adversely impacted by the Marshall Fire, some newer structures also sustained damage or even total loss.

The majority of the damaged or destroyed residential construction observed was one- or two-story light-timber framed structures, as these were the most prevalent structure types in the affected area. These structures' wall systems consisted of OSB sheathing clad with either a brick or stone veneer, fiber-cement board, and vinyl siding material. Roofing systems observed consisted of asphalt-composite shingles, tile, or metal shingle systems. The MAT observed glazing systems in most of the damaged structures typically to be single-pane windows. Most structures observed, both damaged and remaining, did not have fire-resistant vent coverings or home fire sprinklers. Residential structures also had flammable attachments such as fences and decks. Section 5.2 provides information regarding MAT observations related to residential construction.

Commercial Construction

The Marshall Fire MAT focused on residential structures since they comprised the vast majority of damaged structures. Commercial buildings were not the focus of the analysis and therefore the information gathered about their performance was very limited; however, the MAT did note some impacts to commercial structures and obtained additional information during interviews with first responders. Commercial buildings featured stucco, brick, or stone facing exteriors and flat roofs with parapets, although some low slope shingle roofs were also observed. Where the framing was visible, it consisted of cold-formed steel studs, rafters, and joists.

Most commercial buildings appeared to fare reasonably well. Some wind damage was observed to roofs, where shingles and underlayment were torn off, exposing the sheathing. Wind damage was also apparent in some soffits where soffit coverings were partially dislodged. Several buildings that were not destroyed by fire appeared to have damage to the roofs and parapets. Some windows and glass doors were observed to be boarded up, though many appeared to have remained intact. A brand-new hotel that burnt down and an vehicle dealership building across the street both appeared to sustain damage from wind-blown embers, some of which were very large pieces of burning debris due to the wind. The MAT also observed some burned landscaping, such as trees and grass, adjacent to the buildings, and smoke damage was apparent on the exterior cladding at these locations.

Major retailers Target and Costco in Superior were damaged by the fire. Target experienced significant damage as water from the sprinkler system flooded the store, destroying merchandise. The roof also was significantly damaged.

Interviews with first responders provided additional information about how commercial buildings fared and what may have caused some of the damage. Specifically, first responders indicated:

- Large chunks of flaming debris carried by the wind shattered windows and entered some buildings.
- Roof ballast carried by the wind also may have contributed to broken windows that allow embers and flaming debris to enter the structure.
- Some sprinkler systems may not have worked properly because of the drop in water pressure in the community water distribution system.
- Diminished air quality resulting from smoke and ash infiltration required some air handling units to be shut down and resulted in evacuations of critical facilities such as hospitals.
- First responders had specific concerns about exterior tanks (oxygen, fuel) catching fire and exploding. They also were concerned about potential environmental impacts of lithium-ion (Li-ion) batteries catching fire.
- High winds damaged the Superior Town Hall roof as well as downing fencing and trees in multiple locations.

Critical and Lifeline Infrastructure

Avista Adventist Hospital which serves Louisville, Superior, and Broomfield as well as portions of unincorporated Boulder County fully evacuated the facility, including approximately 51 patients and 150 staff, at about 4:15 p.m. on December 30, 2021, due to loss of power and natural gas. Patients were transferred to sister facilities within the Centura Health network including Longmont United Hospital and St. Anthony North. After cleaning and smoke damage mitigation, the facility re-opened on January 18, 2022.

Community lifeline infrastructure is not typically addressed by a MAT; however, lifeline infrastructure plays an important role in a community's response to and recovery and resilience from a wildfire. Adequate water supply and pressure is necessary to fight fires. Roads can serve as both evacuation routes and fire breaks. Power and natural gas supplies must be managed to keep first responders safe. The GEER Association, some of whose members also contributed to the MAT efforts, conducted an in-depth evaluation of lifelines including water utilities, electricity, and natural gas, telecommunications, and transportation infrastructure and published their findings[10].

2.3.2. IMPACTS TO FIREFIGHTING OPERATIONS

The first evacuation order was issued at 11:47 a.m. to people living in the area between Highway 93, Marshall Road, and Cherryvale Road and with winds still increasing, an evacuation order was issued for both sides of Marshall Road between 76th Street and McCaslin Boulevard, by 12:15 p.m. (Miller, 2022). The fire then moved eastward as the winds shifted into Superior and Louisville, and between 12 noon and 2 p.m., mandatory evacuations had been issued for all of Superior, and areas south of Louisville that were heavily impacted (Miller, 2022).

Public safety agencies managed evacuation of the impacted communities. A unified command structure was established to coordinate fire suppression and public safety but was hampered by the uniqueness of this specific fire emergency event and the lack of interoperable communication equipment. Anecdotal information from residents in Louisville and unincorporated Boulder County suggests they had not received evacuation notices. Additionally, there were issues with registration requirements for cellular phone text or voice notifications.

The fast-moving nature of the fire amplified by high winds hampered firefighting efforts, as documented in interviews and other sections of this report. Water for suppression was limited by availability; lack of dry hydrants to access water from ponds, lakes, and stormwater facilities; and low water pressure (in the limited number of community hydrants) due to power interruption and failure affecting water supply from one of the pump stations. The Colorado Forest Service and National Forest Service have some fire suppression capability through aviation support, but their air suppression resources were not deployable due to high winds.

In the early hours of the fire, high wind conditions severely limited early suppression operations[11]. Under these conditions, both traditional and more advanced firefighting operations, using water, construction of fire lines, backfiring and aerial suppression tactics respectively, are usually ineffective. In addition, it is also unsafe for firefighters to be conducting suppression, structure defense and aerial operations in these conditions. These well-known issues were reported to the MAT and confirmed by local firefighters during field interviews. Firefighters reported that the winds either blew the water from the hoses right back at them or dispersed into a fine mist, making water suppression ineffective. In addition, fire hoses burned and sprung leaks during initial firefighting efforts. Firefighters also confirmed unsafe conditions as fire apparatus and equipment were damaged due to the high winds and intense fire conditions.

Due to the unsafe and extreme nature of the wind conditions that challenged suppression, firefighters focused on life safety objectives by supporting local law enforcement in public communication and evacuation. High wind conditions rendered water-based suppression techniques

[10] https://geerassociation.org/index.php/component/geer_reports/?view=geerreports&layout=build&id=103
[11] https://www.weather.gov/bou/MarshallFire20211230

ineffective, so non-water-based firefighting tactics such as removing combustibles (e.g., fences, outdoor furniture) were employed to help prevent fire spread. Wind-borne burning debris was a significant concern. Firefighters tried to saturate grasses, mulch, and wooden debris though vegetation dried out immediately due to wind and heat and reignited. Houses reignited after the flames were extinguished.

During the fire, many firefighting decisions had to be made “on-the-fly” as conditions changed rapidly. Due to the scale and severity of fire, intense wind conditions, and constrained firefighter resources, structure triaging was considered necessary for the safety of firefighter personnel and to increase the likelihood of structure defense where efforts would be considered the most effective. In communities with a single-entry point and exit, firefighters had to make decisions about when to “cut and run” for safety reasons. This was particularly relevant in the Sagamore neighborhood.

Firefighters strategically defended the hospital and a vehicle dealership. The hospital was defended to allow patient and staff evacuation, with adjacent townhouses (to the west) also defended to protect the hospital. The vehicle dealership was defended due to environmental and combustibility concerns for on-site stored lithium ion (Li-ion) batteries.

Impacts to utilities affected firefighting decisions as well. Natural gas was not shut off immediately in some neighborhoods. Firefighters had to let the gas flow and burn. Gas was eventually shut off to the entire Town of Superior when Target caught fire. Also, low water pressure due to power loss impacted the limited number of community hydrants and firefighting operations.

2.4. Marshall Fire Pre-MAT

Within one week of the Marshall Fire in Boulder County, Colorado, FEMA’s BSDS Program deployed a Pre-MAT assessment to collect perishable data including photographs and determine if a full MAT should be deployed. FEMA identified two teams to deploy to the Boulder area to evaluate conditions in Louisville and Superior, the two communities most acutely impacted by the event. The teams identified neighborhoods and structures to visit, including destroyed and damaged structures, as well as some undamaged structures adjacent to damaged or destroyed structures. Structures identified for evaluation were primarily residential, but also included several commercial buildings and critical facilities. Team members spent three days in the field collecting data, interviewing eyewitnesses and local agencies, and evaluating structures. The teams surveyed over 100 structures in various states including undamaged, partially damaged, and fully destroyed. Several interviews were also conducted with stakeholders, including residents in the impacted areas and various government agencies.

While in the field, the teams identified multiple potential vulnerabilities of structures to wildfires including combustible attachments, lack of opening protection from embers, limited fire separation distances between buildings, limited parcel-level vegetation management, and limited vegetation management in common and public open spaces. Based on their observations and data collected, the team recommended proceeding with a full mitigation assessment.

2.5. Marshall Fire MAT

FEMA deployed the full Marshall Fire MAT the week of August 15–19, 2022 consisting of two teams tasked to collect additional information. The Interview Team was primarily responsible for conducting interviews with local officials and department representatives. They met with representatives of Boulder County Parks, Boulder Planning Department, City of Louisville, Mountain View Fire and Rescue, Louisville Fire Protection District, and the Town of Superior. The Field Team was primarily responsible for collecting additional information from sites in unincorporated Boulder County, Louisville, and Superior. They visited sites that were not able to be observed during the Pre-MAT. They also evaluated open space and areas along the burn perimeter to determine inter-relationships with the built environment.

The seven interviews conducted by the MAT Interview Team revealed several key findings related to fire response, codes and standards, and building successes and vulnerabilities. Table 3 below summarizes key findings from the various interviews.

Table 3. Summary of MAT Interviews and Key Findings.

Interview Date	Interviewee	Key Findings
8/16/2022	Boulder County Parks	▪ The broad range of open space property ownership in Boulder County is a big issue that affects landscape mitigation projects moving forward. ▪ Even a large (100 foot) buffer zone would have been unlikely to have stopped the Marshall Fire driven by 100+ mph winds. ▪ The overall vegetation management strategy for Boulder County Parks of allowing agricultural tenants to manage the land with livestock grazing was relatively successful. ▪ FEMA funded replacement of 15 miles of damaged perimeter fencing with noncombustible steel posts (repurposed from recycled pipe casings) and barbed wire instead of wood.
8/16/2022	Boulder County Planning Department	▪ Even building materials like fiber-cement siding failed due to inadequate construction installation detailing, especially at the attic venting, gutters, and the base of the structure. Additionally, some houses had severe smoke damage that made them uninhabitable even though not directly impacted by the fire. ▪ If the building codes used in the mountains were used in the plains, there would have been fewer houses lost. Code features like defensible space and ember-resistant venting can go a long way to reduce the number of houses burned. ▪ City of Boulder had eliminated cedar shakes for new construction; hailstorms destroyed existing cedar shake shingles, so they are no longer in use. ▪ Boulder County had required Class A roofs in the mountains and Class B roofs in the grasslands. Now Class A roofs are required for new and replacement roofs everywhere in unincorporated Boulder County.

Interview Date	Interviewee	Key Findings
8/17/2022	City of Louisville	▪ Concerns about irrigation ditches. Vegetation in the ditches not always well maintained since the ditch company's primary concern is with moving water along, not maintenance. ▪ Main concern about grassland planting as a fuel is juniper, which may have been planted by residents and is a non-native, high hazard species. As a result of the Marshall Fire, the city will be looking at a wildfire mitigation plan with measures including mowing/buffer strips to knock down some of the fuel, getting rid of juniper trees and shrubs, and considering using livestock grazing to control grass. ▪ City is considering an ordinance to allow noncombustible fencing next to houses, even if combustible materials are required by local Homeowners Association (HOA). (Ordinance proposed and debated, but current status is unknown.) ▪ City also considering new WUI codes, but there are affordability concerns because many residents were massively under-insured. Other folks already started rebuilding, so it is hard to get the word out.
8/17/2022	Mountain View Fire and Rescue	▪ One firefighter stated "The Marshall was unlike anything he has experience in his 40 years as a firefighter. Fire spread rapidly due to 100 mph winds, with 2-foot flame heights having flame lengths that extended up to 200 feet; so, there was little that could be done to stop it." ▪ Decision was made to protect the vehicle dealership due to the potentially disastrous impacts of Li-ion batteries catching fire on site. ▪ Firefighting operations hampered due to high winds that damaged ground equipment and grounded air resources, communications issues between fire crews due to equipment inoperability, and lack of pressurized water to hydrants from loss of power to compressor station. ▪ Dispatch records cannot be shared due to an on-going investigation and are under a gag order, and information was redacted from the After Action Report (AAR). ▪ Working on water system improvements and adopting strong WUI fire codes, but there's a lack of consistency among municipalities.
8/17/2022	Boulder Office of Emergency Management	▪ The 2021 Marshall Fire was incredibly intense and consumed 1,100 homes in Boulder County in less than 4 hours. By contrast, Boulder County lost nearly 200 homes in 18 hours in the Fourmile Fire (2010) and had 50 affected homes in 8 hours in the Cal-Wood Fire (2020). ▪ Wood fences were "wicks" creating a combustible pathway for fire to flow directly to the structure. ▪ Proximity to open space and re-ignition of smoldering materials contributed to the fire and caused home ignition. ▪ Ignition-resistant fence materials should extend 3 to 5 feet from all walls and overhanging eaves so the house can survive without suppression resources.

Interview Date	Interviewee	Key Findings
8/17/2022	Louisville Fire Protection District	▪ The Marshall Fire started as a small grass fire, but moved incredibly fast, traveling eight miles in 30–40 minutes due to high winds and smoke. ▪ Old cedar fencing acted like wicks and was a major source of fire spread to buildings. ▪ In the Sagamore neighborhood in Superior, houses that burned were over 20 years old, closely packed together and constructed of weathered, dried materials and burned by radiant heat. Few had fire sprinklers. ▪ Structure-to-structure distance between houses made a difference in the amount of destruction (densely clustered houses were more likely to burn). ▪ Some houses had tile roofs and stucco walls and it looked like some of this material helped. One house still standing in the St. Andrews neighborhood had turned on sprinklers and evacuated.
8/18/2022	Town of Superior	▪ Evacuation plans need to be improved after pre-planned evacuation routes led to hours of traffic delays. ▪ Large amounts of fencing and trees came down due to high winds, as well as the Superior Town Hall roof. ▪ Superior has adopted WUI standards for some parts of the Town (Sagamore), but sensitivities to high residential rebuilding costs have led to opt-out provisions and delayed implementation of the adoption of some building codes. ▪ Looking at improving open space management (more hardscaping and grazing vs planting) and water supply.

Chapter 3: Regulatory Setting, Analysis, and Other Considerations

This section presents an overview of wildfire safety regulations, codes, standards and other guidance or policy documents at the state and local levels in the Town of Superior, City of Louisville, and unincorporated Boulder County prior to and post-Marshall Fire. Part of this analysis was informed by a FEMA white paper on Community Wildfire Resilience that evaluated wildfire safety regulations and current practices, primarily in the Western U.S. (FEMA, 2021). The intent of this information is to help identify and assist in advancing and prioritizing wildfire safety code development and adoption practices by state/local governments. It is understood that wildfire codes and standards at the state level and locally in the impacted communities are rapidly evolving, so the information in this chapter is a “snapshot” of the adopted wildfire regulatory frameworks/practices including the identification of gaps at the time of writing this report.

3.1. Overview of Colorado Wildfire Regulations

Based on the FEMA Community Wildfire Resilience white paper, Colorado, prior to the Marshall fire, had limited wildfire regulations at the state level, as most wildfire regulatory powers and duties reside with local jurisdictions. An evaluation of the State’s wildfire regulatory environment compared with that of other states suggests that Colorado’s regulatory maturity for wildfire is relatively low. Colorado is experiencing a rapidly growing population and expansion of the WUI, yet there are few state land use requirements for the WUI. As a result, many WUI risk reduction efforts are implemented locally.

Below is a high-level “snapshot” of the current state of WUI codes and standards, guidance documents and programs at the state level in Colorado:

- A Wildfire Resiliency Code Board was established in May 2023 to adopt state-wide model codes and standards that support structural hardening and reduce fire risk in the defensible space surrounding structures in the wildland-urban interface. Governing bodies in the wildland-urban interface are required to adopt and enforce a code that meets or exceeds the minimum standards of the code adopted by the Board within three months of the Board’s code adoption date. The Wildfire Resiliency Board is housed within the Colorado Department of Public Safety Division of Fire Prevention and Control.
- No WUI code at state level. At the time of this publication, the Wildfire Resiliency Board has not yet adopted model codes for the WUI areas. However, several cities and/or counties (e.g., Colorado Springs, Pueblo County, Boulder County, Eagle County, Summit County) have either adopted their own WUI code or part of the IWUIC (See Table 9 later in this section). Codes are mostly limited to new construction, improvements, and repairs at building-scale.

- No specialized wildfire codes for critical infrastructure such as roads, bridges, healthcare facilities, schools, police/fire stations or utilities.
- No engineering and construction design criteria and/or standards for various wildfire-specific protection systems (e.g., suppression, water supplies, emergency power, detection, and notification).
- No regulatory guidance on "how" to enforce wildfire codes and standards, particularly for local fire agencies.
- State provides wildfire hazard and risk maps through the Colorado Wildfire Risk Assessment Portal[12].
- Counties and municipalities are required to adopt a master plan, but only municipalities must address hazards. Colorado's 1041 Regulations give local governments authority for planning decisions related to areas or activities of statewide concern, including hazards.
- Some local programs and planning efforts exist: Community Wildfire Protection Plans (CWPPs), Community Planning Assistance for Wildfire (CPAW), Firewise communities.

The following sections provide further details on the level of WUI-specific regulatory guidance in Colorado prior to the Marshall Fire.

3.1.1. CODE OF COLORADO REGULATIONS BEFORE THE MARSHALL FIRE

At the time of the Marshall Fire, Colorado did not have an adopted WUI code and/or associated standards. The state did have some wildfire safety policies that help support wildfire risk mitigation efforts, including Senate Bill (SB) 21-258 enacted in 2021.

SB 21-258 – Wildfire Risk Mitigation

This policy concerns the administration of state assistance programs to mitigate the risk of wildfire. It relates to the creation of the wildfire-mitigation capacity development fund and the hazard mitigation fund. This act allows for the following:

- Gives the Colorado State Forest Service (CSFS) permission to issue forest restoration and wildfire mitigation grants for projects on federal lands.
- Increases the amount that the CSFS may use for the direct and indirect costs in administering the Forest Restoration and Wildfire Risk Mitigation Grant Program (FRWRM) from 3% to 7% of any amounts appropriated in any fiscal year.
- Allows the technical advisory panel that evaluates the proposals for forest restoration and wildfire risk mitigation grants to scale up and down in size.

[12] https://coloradoforestatlas.org/

- Expands the allowable uses of the FRWRM by allowing the grant program to fund capacity-building efforts to provide local governments, community groups, and collaborative forestry groups with the resources and staffing necessary to plan and implement forest restoration and wildfire risk mitigation projects.
- Allows the CSFS to hire non-temporary additional field capacity to support wildfire risk mitigation efforts.
- Creates the wildfire mitigation capacity development fund and the hazard mitigation fund.

3.1.2. NEW OR AMENDED STATE LEVEL BUILDING CODES AND STANDARDS

Since the Marshall Fire, the State of Colorado has yet to adopt a statewide wildfire code. In 2023, the State legislature created a board tasked with developing statewide building standards for the WUI. While efforts to establish statewide building standards for the WUI are ongoing, the Colorado State Legislature has passed several bills that aid wildfire risk mitigation following the Marshall Fire. This includes, but is not limited to, bills that:

- Support an increase in wildfire mitigation outreach efforts (SB22-007)
- Create incentives for local governments to participate in wildfire mitigation efforts (House Bill (HB)22-1011)
- Further regulate wildfire mitigation services including controlled burns (HB22-1132)
- Increase the resources available for fire protection services available for volunteer firefighters (SB22-002)
- Establish new insurance coverage requirements for loss declared fire disaster (HB22-1111)
- Create additional disaster preparedness and recovery resources (SB22-206)
- Provide funding for wildfire mitigation and recovery in forests (HB22-1012)
- Create provisions for fire suppression pond designations (SB22-114)

Please note that the Colorado State Legislature is very active in introducing and passing bills related to wildfire risk mitigation. In the span of time that this report was written, several additional bills have been introduced related to many facets of wildfire mitigation, such as wildfire detection, fire investigations, and grants to aid homeowners in retrofitting their homes for wildfire resiliency.

3.1.3. COLORADO STRATEGIC DOCUMENTS, PROGRAMS AND TECHNICAL RESOURCES

The following is a summary of some key strategic wildfire programs/plans in Colorado that were created prior to the Marshall Fire.

Colorado Strategic Wildfire Action Program

The Colorado Strategic Wildfire Action Program was created in 2021 in response to the devastating 2020 fire season. The program is designed to move state stimulus dollars to start on-the-ground work and fuel reduction projects as well as increase Colorado's capacity to conduct critical forest restoration and wildfire mitigation work. Fuel reduction efforts are supported by the Colorado Strategic Wildfire Action Program in two ways: (1) Fund wildfire mitigation work done by conservation corps and the Department of Corrections State Wildland Inmate Fire Teams (SWIFT) and wildfire mitigation workforce development training. (2) Strategically award funds for landscape-scale strategic wildfire mitigation projects.[13]

Colorado Forest Action Plan 2020

The Colorado Forest Action Plan was created by the CSFS and its partners and serves as an in-depth analysis of forest trends and offers solutions and guidance for improving forest health. One of the main themes of this Plan is "Living with Wildfire" which promotes risk-reduction practices as populations increase in the WUI.[14]

West Wide Wildfire Risk Assessment

Colorado is part of the Council of Western State Foresters and the Western Forestry Leadership Coalition (WFLC), which undertook a wildfire risk assessment of all lands for the 17 western states and select Pacific islands in 2011. This assessment, known as the "West Wide Wildfire Risk Assessment" (WWA) supports the use of science-based data to quantify the magnitude of the current wildland fire problem in the west, providing a baseline for quantifying mitigation activities and monitor change over time. It also provides a more standardized approach to comparison of wildfire risk across regional geographic areas. Colorado is using the WWA for state-level strategic wildfire resiliency planning and policy discussions.[15]

Colorado Forest Atlas Information Portal

Colorado has extensive, online, interactive wildfire hazard and risk-mapping tools (i.e., Forest Atlas Information Portal) that is available for public use (Figure 13). This online resource provides a range of data layers and information on Colorado's forests, wildfire hazards, State Forest service activities, and more. Notable applications include a wildfire risk reduction planner and a wildfire risk viewer .[16]

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[13] https://dnr.colorado.gov/divisions/forestry/co-strategic-wildfire-action-program

[14] https://climate.colorado.gov/2020-colorado-forest-action-plan#:~:text=The%202020%20Colorado%20Forest%20Action%20Plan%20provides%20a,forests%20face%20across%20political%2C%20jurisdictional%20and%20ecological%20boundaries.

[15] https://www.adaptationclearinghouse.org/resources/west-wide-wildfire-risk-assessment.html

[16] https://coloradoforestatlas.org/

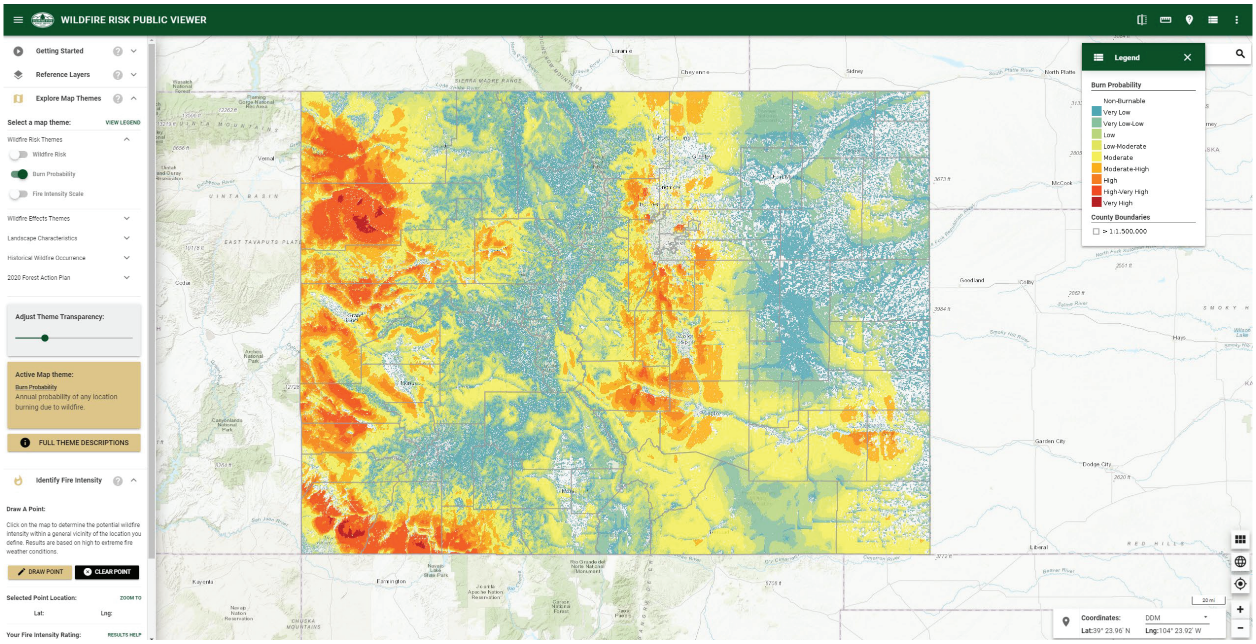

Figure 13. Colorado Forest Atlas Wildfire Risk Public Viewer (Colorado State Forest Service, 2022).

Wildfire Partners, Boulder County Colorado

WILDFIRE PARTNERS

Some counties have local community wildfire resiliency programs, such as The Wildfire Partners Program in Boulder County[17], which support homeowners in preparing for future wildfires. This program, and those similar to it, offers property-level wildfire risk assessments with detailed mitigation action recommendations as well as funding opportunities to implement projects and expert advice. Those that participate in the Wildfire Partners program and effectively pass final inspections receive a Wildfire Partners Certificate, which is accepted by local insurance companies to maintain or receive insurance coverage.

RealFire Program, Eagle County Colorado

Another local community wildfire resiliency program is the RealFire Program in Eagle County[18], which enables residents of Eagle County to receive property assessments from locally qualified assessors free-of-charge. This program operates very similarly to the Wildfire Partners Program in Boulder County. After the initial property assessment, homeowners receive a list of recommended property-specific mitigation actions that they must implement to receive a RealFire certificate, which

[17] https://wildfirepartners.org/

[18] https://realfire.net/

recognizes completion of the required mitigation actions and provides documentation for potential insurance benefits.

West Region Wildfire Council Site Visit Program

The West Region Wildfire Council[19] serves Delta, Gunnison, Hinsdale, Montrose, Ouray, and San Miguel counties of Colorado and runs a site visit program for residents that live in the WUI[20]. Residents may apply for a site visit, where a West Region Wildfire Council Mitigation Specialist and/or forester will meet with the landowner or community resident at their property to discuss site-specific wildfire risk and wildfire mitigation strategies.

Community Wildfire Planning Center (CWPC)

The Community Wildfire Planning Center (CWPC) is a Colorado-based non-profit organization that provides wildfire education and action plans for individuals and communities[21]. It provides community-based property assessment programs, education trainings and outreach, wildfire project advisory support, and other community-based activities. The CWPC provides several online wildfire/WUI planning and resource tools: (1) WUI Planning Hub that contains tools useful for both homeowners and local jurisdictions; (2) an interactive map of other state and national-level wildfire resiliency planning tools and resources; and (3) a land use planning evaluation tool that can support local jurisdictions in planning and regulating WUI/wildfire risk mitigation planning efforts.

Fire-Adapted Communities

Colorado currently has three communities within the Fire-Adapted Communities Network (FAC Net): the Coalition for the Upper South Platte, Firewise of Southwest Colorado, and Summit County. FAC Net is the result of a partnership between the Watershed Research and Training Center, The Nature Conservancy, the USDA Forest Service, and the Department of the Interior. This is a national network of wildfire-resilience practitioners focused on building wildfire resilience capacity in fire-prone communities by supporting and connecting individuals and communities working on wildfire resilience. FAC Net provides resources, tools, and connections to increase resilience in "Fire-Adapted Communities."[22] In 2014, the FAC Learning Network included 10 hub communities across the United States, three of which were in Colorado.[23]

Firewise®

The NFPA, with funding received from the U.S. Forest Service, developed and manages the Firewise USA® Program. The program helps educate homeowners on appropriate steps to better protect their

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[19] West Region Wildfire Council | Working together to reduce wildfire risk (cowildfire.org)
[20] https://cowildfire.org/
[21] https://www.communitywildfire.org/
[22] Fire Adapted Communities Learning Network. 2022. https://fireadaptednetwork.org/.
[23] Colorado State Fire Service. *Colorado Fire Adapted Communities*. 2022. https://csfs.colostate.edu/wildfire-mitigation/colorado-fire-adapted-communities/.

home from wildfire through home hardening and vegetation management. Homeowners can form a Firewise USA® community (typically at a neighborhood level) by establishing a site boundary of focus, collaborating with local fire departments and emergency managers to create a framework of action for reducing the risk of wildfire.

NFPA® | FIREWISE USA® RESIDENTS REDUCING WILDFIRE RISKS

Firewise USA® communities gain significant education in wildfire risk reduction and may be eligible for homeowners insurance discounts. This program relies on homeowners at a grass-roots level, motivating and empowering homeowners to take action to protect their lives, the lives of their families and property in their neighborhood from wildfire. The program also provides resources to help homeowners learn how to adapt to living with wildfire and encourages neighbors to proactively work together to prevent losses.

Firewise USA® recognizes communities that meet its standards. This program was initiated in 2002 and now has nearly 1,000 active member communities in 40 states, as well as a participation retention rate of 80% over the past decade.[24] Colorado is ranked third for the number of recognized Firewise USA® sites[25] with more than 180 sites that have earned Firewise USA® recognition. Five of these sites are located in Boulder County, but none were impacted by the Marshall Fire.

3.2. Existing Community Level Wildfire Regulatory Mechanisms

In Colorado, building codes and standards are adopted at the community level according to "home rule" (Bernard, 2020) but the state can set a minimum standard for local building code adoption. For example, House Bill 19-1260, passed in 2019, requires local jurisdictions in Colorado to adopt and enforce one of the three most recent versions of the International Energy Conservation Code (IECC) upon adopting or updating any other building code (Colorado Energy Office, n.d.). Amendments to the IECC are permitted as long as they do not weaken the effectiveness or energy efficiency of the code. State agencies can also adopt and enforce building codes for state-led building projects.

Jurisdictions have a menu of options for establishing minimum standards for wildfire hazard resistance, including WUI Codes, such as the IWUIC, and the ICC's package of building codes, commonly known as the I-Codes. The ICC codes are updated every three years and include three primary model codes, the IBC, the IEBC, and the IRC. To become legally enforceable in Colorado, building codes must be explicitly selected and adopted through ordinance by an AHJ, such as the City

[24] National Fire Protection Association. Firewise USA®. 2022. https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Firewise-USA .

[25] Colorado State Forest Service. *Colorado Firewise USA® Sites*. 2022. https://csfs.colostate.edu/wildfire-mitigation/colorado-firewise-communities/ .

of Louisville or Boulder County. Responsibility for building code adoption and enforcement is often shared by multiple departments and offices of the local jurisdiction.

Local subdivision regulations do not currently include provisions that fully address wildfire risk.

3.2.1. UNINCORPORATED BOULDER COUNTY

In the unincorporated areas of Boulder County, the Board of County Commissioners is responsible for adopting local ordinances including building codes and their amendments. The Community Planning and Permitting Department, within the Office of the County Administrator, enforces those building codes, as well as zoning and land use codes. The Land Use Board of Adjustment adjudicates appeals regarding certain sections of the land use code and requests for variances. The Board of Review adjudicates technical appeals regarding the county's building code amendments and reviews proposed amendments to make recommendations to the Board of County Commissioners prior to adoption. As with similar offices listed for Superior and Louisville above, these offices have a role in managing defensible space, vegetative fuels, and other WUI-related issues.

WUI Building and Fire Codes and Standards

Boulder County has used building codes to mitigate the risk of wildfire since the 1980s ("Land Use Tool: Building Code", n.d.). For example, Class A fire-resistant-rated roofs have been required for all new houses in high-risk wildfire zones since 1989 (CWPP, 2011). These codes have been expanded upon by local amendment to include defensible space as well as noncombustible and ignition-resistant material. Boulder County's Building and Land Use Codes also require homeowners who are constructing new homes, or remodeling some existing houses, in wildfire prone areas to submit a wildfire mitigation plan before a building permit can be issued ("Wildfire Mitigation FAQ", n.d.). The plans must include, but are not limited to, the use of ignition resistant building materials, defensible space, and fuel reduction measures. For regulatory purposes, unincorporated Boulder County is divided into two Wildfire Zones (Figure 14). Wildfire Zone 1 includes the mountains and forested portion of the County, and Wildfire Zone 2 includes the plains and grasslands in the County (Boulder County, 2022).

> At the time of the Marshall Fire, most of the residential wildfire mitigation standards were required in Wildfire Zone 1 only. The areas directly affected by the Marshall Fire predominantly fall within Zone 2.

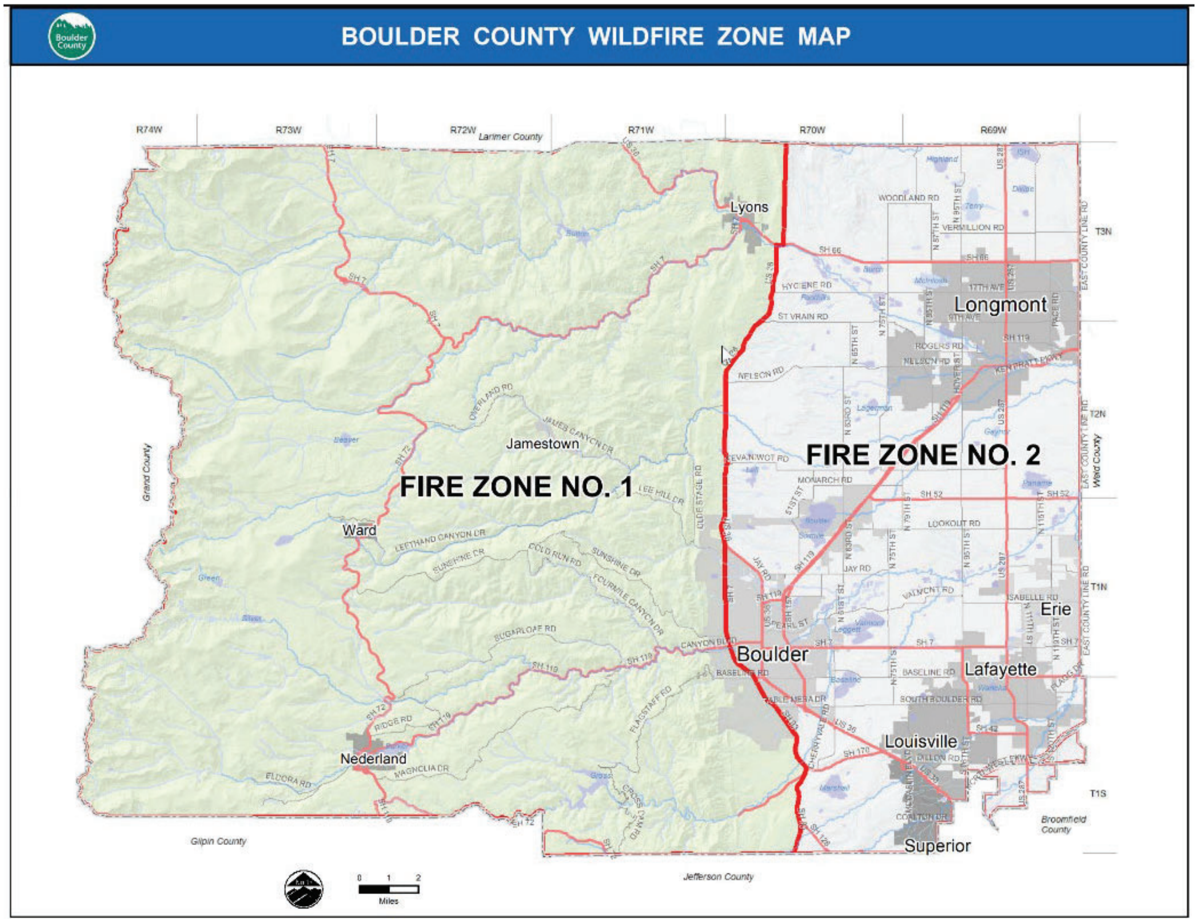


Figure 14. Boulder County is divided into two Wildfire Zones (Boulder County).

At the time of the Marshall Fire, the 2015 IRC was in effect in Boulder County with the following amendments:

- Boulder County considers fire sprinklers as a means of preventing fire spread from structure-to-structure or structure-to-vegetation and reducing structural damage, especially in cases where larger houses in more remote areas may require longer firefighter response times ("Fire Sprinkler System Plan", n.d.). These Section R313 amendments strengthen automatic fire sprinkler requirements above the 2015 IRC, which does not require an automatic residential fire sprinkler system, where one is not already installed, for existing townhouses where additions or alterations have been made, or for additions and alterations of existing one- and two-family dwellings.
  - Amended Section R313, Automatic Fire Sprinkler Systems.
  - Amended Section R313.2: Automatic residential fire sprinklers are not required for federally certified manufactured dwellings or state-certified factory-built dwellings that are certified to pre-2012 IRC editions.
  - Amended Section R313.2.1 to require an automatic residential fire sprinkler system, designed and installed in accordance with IRC Section P2904 of NFPA 13D, in existing one-

and two-family dwellings with additions when the sum of the total floor area is increased to 4,800 square feet or greater; and in existing one- and two-family dwellings with a floor area of 4,800 square feet or greater where permitted renovations or remodeling takes place in more than 50% of the structure.

Exceptions include one-time additions less than 200 square feet in floor area and carport additions that do not qualify as “Residential Floor Area” as defined by the Boulder County Land Use Code.

- Added Section R324.7: Access and Pathways for Rooftop Solar Energy Systems, which provides additional standards for roof access, pathways, and spacing requirements for rooftop solar energy systems. These standards are modelled after the City of Boulder Fire Department’s 2012 IFC adoption and strengthen the wildfire hazard mitigation provisions of the 2015 IRC. These additional requirements are significant for the county’s wildfire resilience given the potential increase in residential solar systems resulting from the adoption of Boulder County’s Solar Pre-Wire Option.
- Added Section R327: Establishing standards for defensible space, ignition-resistant construction material, Class A roof assemblies and roof coverings, and use of noncombustible material for buildings in Wildfire Zone 1 and 2. The addition of Section R327 strengthens the provisions for wildfire hazard mitigation above the 2015 IRC. However, at the time of the Marshall Fire, Wildfire Zone 2 had fewer wildfire hazard mitigation standards in place than in Wildfire Zone 1.
    - Subsection R327.4 lists detailed requirements for buildings in Wildfire Zone 1, including but not limited to: roof coverings, gutters, spark arrestors, fences, eaves, exterior walls, unenclosed under floor protection, decks, exterior windows and glazing, exterior doors, vents, detached accessory structures, and defensible space.
    - Subsection R327.5 lists requirements for buildings in Wildfire Zone 2. This subsection includes standards for roof coverings but omits the remaining standards required in Wildfire Zone 1.
- Added Section R328: Solar Pre-Wire Option, requiring new single-family detached residences to include a residential photovoltaic solar generation system or solar thermal system, or the foundational equipment that would facilitate future installation (e.g., upgraded wiring or conduit).
- Added Section R329: Electric Vehicle Charging Pre-Wire Option, which requires every one-- or two--family dwelling garage or carport to include a Level 2 (240-volt) electric vehicle charging receptacle outlet, or the foundational equipment that would facilitate future installation (e.g., upgraded wiring or electrical conduit).

Boulder County made the following change to the 2015 IBC:

- Added Section 723: Applying the ignition-resistant construction and defensible space requirements of the Boulder County IRC amendment to all new buildings, additions, and repairs, unless more restrictive requirements, such as those provided by the Boulder County Land Use Code, apply. This amendment strengthens the wildfire hazard mitigation provisions of the 2015 IBC.

Other Relevant Codes and Standards

At the time of the Marshall Fire, the 2017 National Electrical Code (NEC), the 2015 IBC, the 2015 IRC, the 2015 IECC, the 2015 IEBC, and the 2012 IFC, and the 2015 International Green Construction Code (IgCC) were in effect for Boulder County, with amendments.

The Boulder County Comprehensive Plan directly addresses the threat of wildfire and acknowledges the role of codes and standards, in addition to public education and land use management, in mitigating wildfire risk (2020). According to the CWPP, Boulder County aims to improve the wildfire resiliency of the existing housing stock, which is not subject to ignition-resistant standards for new construction. The CWPP identifies a goal to replace all wood roofs with Class A fire rated roofs using a combination of voluntary incentives, such as low-interest loans (2011). This goal is not currently operationalized into local ordinance. The CWPP emphasizes a voluntary incentive approach to wildfire mitigation for Boulder County's existing housing stock, as opposed to the regulatory approach (i.e., building and land use code) used for new construction (2011).

Additionally, all new residential construction and additions are also subject to the BuildSmart program, the county's residential green building code. The BuildSmart program first took effect in May 2008. The most recent edition of the code (effective January 1, 2016) is adapted from the 2015 IRC Chapter 11 standards for energy efficiency (Boulder County Land Use Department, 2017). BuildSmart standards aim to reduce harmful emissions from residential buildings, reduce landfill waste, conserve natural resources during construction, and improve indoor air quality. The expansion of homeowner-led wildfire mitigation strategies, such as completion of the Wildfire Partners Certificate, is also incorporated into the goals of the 2018 Boulder County Environmental Sustainability Plan (2018).

Code History

Historically, Boulder County has adopted new code editions at semi-regular intervals. Prior to adopting the codes in effect during the Marshall Fire, Boulder County adopted the following I-Code editions summarized in Table 4.

Table 4. Summary of Boulder County's International Code adoptions prior to the codes in place at the time of the Marshall Fire.

Effective Date	I-Code Adoptions	NEC Adoptions
July 1, 2003	2003 IBC and IRC	-
Jan. 1, 2008	2006 IBC, IRC, IECC	2005
Jan. 1, 2011–Dec. 31, 2013	2009 IBC, IRC, IECC 2010 IgCC – select portions only	2008
Jan 1, 2013–Dec. 31, 2015	2012 IBC, IRC, IECC 2012 IgCC	2011
Jan 1, 2016–Dec. 31, 2016	2015 IEBC	2014

Code history was selected for relevance to wildfire hazard mitigation and is not inclusive of all known building code adoptions. Available records for build code adoption history vary by jurisdiction. Building code adoption history prior to 2003 was not publicly available.

Current WUI Code

After the Marshall Fire, Boulder County strengthened the wildfire hazard mitigation provisions of its building code by expanding the existing WUI standards in Wildfire Zone 2. Specifically, it amended its 2015 IRC Section R327 to require that residential buildings in Wildfire Zone 2 meet additional standards for ignition-resistant construction material, Class A roof assemblies and roof coverings, and use of noncombustible material. Many of these standards were already in effect for Wildfire Zone 1. These amendments took effect on June 6, 2022.

The adoption of these WUI standards for Wildfire Zone 2 coincides with the Wildfire Partners Eastern County Expansion Program, as outlined in the Boulder County Hazard Mitigation Plan. If implemented, the Expansion Program would extend the operation of the Wildfire Partners program to the eastern portion of the county, encompassing grasslands and plains to support the enforcement of wildfire mitigation standards required by the Boulder County building code.

Finally, Boulder County is currently updating its Boulder County Community Wildfire Protection Plan. Updates will include, but are not limited to, an expanded understanding of wildfire risk in the grassland WUI, ember risk mapping, and identification of wildfire-risk reduction strategies (Halford, 2023).

Recovery And Repair

In response to the fire, Boulder County amended its Land Use Code to streamline the planning and building permit review processes and maintain standards for wildfire resilient construction (Community Planning & Permitting Department, 2022). Per the Land Use Code, redevelopment of a damaged property must mitigate the risk of wildfire to that property and its neighboring properties (2022). Appendix A of the Land Use Code specifies fire hazard mitigation construction standards effective beginning March 29, 2022, until June 6, 2022, when the Boulder County Building Code wildfire standards (i.e., the 2015 IRC Section R327 amendments) took effect.

New construction must also meet the requirements of the BuildSmart program, the county's residential green building code. Homeowners also have access to free EnergySmart advisors that can recommend modifications for improved energy efficiency, as well as the EnergySmart Rebuilding Better toolkit, which consolidates guidance on energy efficient and resilient construction, rebates, and incentives for post-Marshall Fire rebuilding ("Rebuilding Better", n.d.).

Finally, to offset the cost of rebuilding, Boulder County has reduced building permit fees by $4,400 for single-family homes and by 25% for accessory structures for permits filed by December 31, 2024 ("Marshall Fire Finances and Rebates", n.d.). Homeowners who lost their homes in the Marshall Fire and file a building permit by December 31, 2024, are also eligible for a $4,200 use tax rebate ("Marshall Fire Finances and Rebates", n.d.).

3.2.2. LOUISVILLE, COLORADO

In the City of Louisville, the City Council is responsible for adopting local ordinances, including building codes and their amendments. The Department of Building Safety is responsible for enforcing these building codes. The Building Code Board of Appeals adjudicates appeals from property owners contesting a building code official's interpretation and application of the city's building code to their property, and the Board of Adjustment adjudicates zoning variances. The Open Space Advisory Board advises the City Council on management of the city's open space properties, and the Planning Commission evaluates land use proposals and makes recommendations to the City Council; both offices have a role in managing defensible space, vegetative fuels, and other WUI-related issues.

WUI Building and Fire Codes and Standards

At the time of the Marshall Fire, the City of Louisville had not adopted any version of WUI code.

Other Relevant Codes and Standards

At the time of the Marshall Fire, the 2018 IBC, 2018 IRC, 2018 IEBC and 2018 International Fire Code (IFC) were in effect, with amendments. The 2021 IECC took effect on November 23, 2021, replacing the previously adopted 2018 IECC a month prior to the Marshall Fire. Louisville's 2021 IECC adoption included Appendix RC, Zero Energy Residential Building Provisions, Appendix CB, Solar Ready Zone (Commercial), and Appendix RB, Solar Ready Provisions (Detached One and Two-Family Dwellings and Townhouses). The 2020 National Electrical Code (NEC), published by the National Fire Protection Association, was also in effect.

The Louisville Fire Protection District 2021-2026 Strategic Plan does not explicitly address wildfire mitigation strategies or codes and standards. Louisville does not have a Community Wildfire Protection Plan, but it is co-coordinating the update to the 2011 Boulder County Community Wildfire Protection Plan in partnership with the Boulder County government. Louisville does not have specific wildfire resiliency codes, wildfire safety elements (in a comprehensive plan) or wildfire hazard/risk assessment processes for new construction during planning.

Code History

Historically, Louisville has adopted new code editions at semi-regular intervals. Prior to the adoption of the I-Codes, buildings in Louisville were constructed to the standards of the Uniform Building Code (UBC), a building code commonly adopted by western states until it was replaced by the ICC's IBC in 2000. Louisville also adopted relevant secondary UBC codes such as the Uniform Code for the Abatement of Dangerous Buildings (UCADB). Louisville's pre- I-Code adoptions are summarized in Table 5 and I-Code adoptions are summarized in Table 6.

Table 5. Summary of Louisville's building code adoptions before creation of the International Codes.

Adoption Year	UBC Edition	UCADB Edition	NEC Edition	Fire Code
1962	1961 UBC		1959 NEC	1960 Fire Prevention Code
1971	1970 UBC		1968 NEC	
1975	1973 UBC			
1977	1976 UBC			
1979	1979 UBC			
1983	1982 UBC			
1986	1985 UBC			
1988	1988 UBC			
1994	1991 UBC		1993 NEC	1991 Uniform Fire Code (UFC)
1995	1994 UBC	1994 UCADB		
1997	1997 UBC	1997 UCADB		1997 Uniform Fire Code

Table 6. Summary of Louisville's International Code adoptions prior to the codes in place at the time of the Marshall Fire.

Adoption Year	I-Code Adoptions	NEC Adoptions
2005	2003 IBC and IRC	
2010	2009 IBC, IRC*, IFC, IECC *Louisville amended 2009 IRC to remove automatic fire sprinkler requirements, limiting the wildfire hazard provisions of the 2009 IRC	2011
2014	2012 IBC, IRC, IFC, IECC	

Code history was selected for relevance to wildfire hazard mitigation and is not inclusive of all known building code adoptions. Available records for build code adoption history vary by jurisdiction.

Current WUI Code

To date, the City of Louisville has not adopted any WUI code, but the city has adopted the following changes to its building codes and standards to provide additional wildfire protections.

Acknowledging the role that wood fences played in facilitating the spread of the Marshall Fire, Louisville amended Title 17 of its municipal code; homeowners required by Planned Unit Development rules to install fences made from wood or other combustible material may use noncombustible material for the portion of the fence that connects the home to the side property line, ("Ordinance NO. 1838", 2022).

The City of Louisville and the Louisville Fire Department have also published an Ignition Resistant Construction Guide, detailing voluntary actions that homeowners can take to protect their homes against wildfire ("Ignition Resistant Construction Guide", n.d.). The guide, focused primarily on home hardening and fuels management, is intended to be implemented as a package rather than pick-and-choose strategies. The guide references sources such as the 2021 IWUIC, the California Office of the State Fire Marshal, the NFPA, and Colorado State University Extension.

In addition, the City of Louisville has updated several of its strategic and long-term plans to address wildfire mitigation, recovery, and repair post-Marshall Fire:

- The Louisville Annex of the Boulder County Hazard Mitigation Plan affirms the City of Louisville's commitment to enforcing disaster-resistant building codes; however, the City notes that code enforcement needs during the recovery stage outpace the capacity of their available staff and city budget. The plan identifies FEMA Hazard Mitigation Assistance grants and state grants as potential funding sources for post-disaster code enforcement projects (2022).

- The Louisville Strategic Plan briefly describes city goals to repair infrastructure and property damaged by the fire, reduce future risk, identify opportunities for disaster mitigation and preparedness, and increase community resilience ("Strategic Planning Framework 2023-2024", n.d.).

- The Louisville Marshall Fire Recovery Plan details a long-term milestone to adjust or add permits, ordinances, and internal policies to prepare for the broader recovery process and build back better ("Recovery Plan for Marshall Fire", 2022).

- The Department of Parks and Open Space plans to release a request for proposals for the completion of a Wildfire Mitigation Plan for city public lands, date to be determined ("What's New with Parks and Open Space", 2022).

- The City has begun development of a Wildfire Risk Assessment, to identify hazards, risks, and mitigation opportunities in Louisville's public lands.

Recovery And Repair

To facilitate more efficient and flexible rebuilding and repairs after the Marshall Fire, Louisville amended its building codes, allowable variances, and permitting process. Louisville notes that enforcement of local building codes during post-Marshall Fire reconstruction poses a challenge due to high need and limited staff capacity (Boulder County Hazard Mitigation Plan, 2022). Local building code amendments, inspection, and enforcement standards should be compared against best practices for disaster-resistant construction to ensure that reconstruction supports wildfire resilience.

Louisville made the following changes to the 2018 IRC:

- Louisville deleted Section P2904 from the 2018 IRC intending to remove the requirement for automatic fire sprinkler systems for single-family homes. Because IRC Section R313 "Automatic Fire Sprinkler Systems" is still in effect, the change is insufficient to remove the automatic fire sprinkler systems requirement for single-family homes. This change, if it were to take effect as intended, would limit the wildfire hazard mitigation provisions of the 2018 IRC.

- The 2021 IECC was made optional for homeowners facing financial hardship who are rebuilding or repairing their homes after the Marshall Fire. These homeowners have multiple options for meeting IECC standards:

    - Option A – rebuild according to the 2018 IECC prescriptive path, which specifies residential insulation, glazing, windows, mechanical, electrical, and air change requirements.

    - Option B – rebuild according to the 2021 IECC with a Home Energy Rating System ("HERS") rating of 50, or the prescriptive path. The HERS index is a scoring system established by the Residential Energy Services Network (RESNET) for measuring a home's energy consumption compared against a reference home (based on the 2006 IECC) as a baseline, which has a HERS value of 100. Values less than 100 mean the home is more energy efficient than the reference home, while values greater than 100 mean the home is less energy efficient than the reference home.

    - Option C – rebuild according to the 2021 IECC Appendix RC (Zero Energy). Appendix RC provides requirements for residential buildings intended to result in net-zero energy consumption over the course of a year. Homes built in compliance with Appendix RC should produce at least as much energy as they consume in a given year.

- While 2021 IECC compliance is optional for affected homeowners, Louisville has adopted incentives for voluntary adoption. On October 3, 2022, the City Council approved a Use Tax Credit program for residents who lost their homes in the Marshall Fire ("Marshall Fire Use Tax Credit Program", n.d.). Homeowners with building permits that comply with the 2021 IECC (with or without Appendix RC) will receive a 100% credit for the use tax paid on construction materials. Permits complying with the 2018 IECC will also receive credit for a percentage of the use tax paid.

- Additionally, residents whose property was damaged or destroyed by the Marshall Fire can apply for minor impact variances, which allow deviations of up to 10% from a published standard (for example, up to 1-foot deviation in a 10-foot rear setback, or up to 33% maximum lot coverage where 30% is permitted) ("Ordinance No. 1824", 2022). Reductions in setback distances or separation distances between houses could increase the risk of structure-to-structure fire spreading.

- Finally, homeowners that need to replace insulation, such as in an attic, due to the Marshall Fire can also apply for an expedited permit through a special online portal on the city website ("Insulation Replacement", n.d). This insulation must meet the energy efficiency requirements of Louisville's 2021 IECC adoption, which includes a simplified table of insulation requirements that meets, or in some cases, exceeds the requirements of the model code version.

3.2.3. SUPERIOR, COLORADO

In the Town of Superior, the Board of Trustees is responsible for adopting local ordinances, including building codes and their amendments. The Building Department, under the direction of the Town Manager, is responsible for enforcing these building codes. Like Louisville, Superior has additional offices that have a role in managing defensible space, vegetative fuels, and other WUI-related issues, namely the Planning Department and the Parks, Recreation, and Open Space Department.

WUI Building and Fire codes and Standards

At the time of the Marshall Fire, the Town of Superior had not adopted any version of WUI code.

Other Relevant Codes and Standards

At the time of the Marshall Fire, the 2020 NEC, and the 2018 IBC, 2018 IRC, 2018 IFC, 2018 IEBC, and 2018 IECC were in effect, with amendments. These codes were adopted in August 2020.

Wildfire risk is not explicitly addressed in Superior's Land Use Code, the 2021 Parks, Recreation, Open Space and Trails Master Plan (updated post-Marshall Fire), or the 2012 Comprehensive Plan. Superior falls under the jurisdiction of the Rocky Mountain Fire Protection District. The Rocky Mountain Fire CWPP acknowledges the role of ignition-resistant construction in wildfire mitigation but does not reference specific construction standards (2010).

New residential construction, restorations of residential structures, and additions or renovations to residential structures of 500 square feet or greater are also subject to Superior's Green Building Program. Compliance with the adopted IECC is a requirement of the Green Building Program ("Green Building Program", n.d.).

Code History

Prior to the adoption of the I-Codes, buildings in Superior were constructed to the standards of the UBC and its secondary codes. Superior's pre- I-Code adoptions are summarized in Table 7. I-Code adoptions prior to the codes in effect at the time of the Marshall Fire are listed in Table 8.

Table 7. Summary of Superior's building code adoptions before creation of the International Codes.

Adoption Year	UBC Edition	UCADB Edition	NEC Edition	Fire Code
1989	1988		1987	1988 UFC
1996	1994		1996	1994 UFC

Table 8. Summary of Superior's International Code adoptions prior to the codes in place at the time of the Marshall Fire.

Adoption Year	I-Code Adoptions	NEC Adoptions
2001	2000 IBC, IRC, IFC, IECC	1999 NEC
2002		2002 NEC
2004	2003 IBC, IRC, IFC, IECC, and IEBC	
2007	2006 IBC, IRC, IFC, IECC, and IEBC	2005 NEC
2008		2008 NEC
2012	2012 IBC, IRC, IFC, IECC, and IEBC	2011 NEC
2015		2014 NEC
2017	2015 IECC	2017 NEC

Code history was selected for relevance to wildfire hazard mitigation and is not inclusive of all known building code adoptions. Available records for build code adoption history vary by jurisdiction.

Current WUI Code

Following the Marshall Fire, the Superior Town Board consulted WUI experts to consider applicable amendments to its residential building code. In May 2022, the Town Board directed the Town Attorney to prepare an ordinance detailing a residential WUI code. The WUI regulations considered include ignition-resistant and noncombustible building materials, roof and eave installation standards that minimize the exposure of wood sheathing, noncombustible or ignition-resistant decks, tempered or multi-layered glass windows, vents that have a mesh covering to prevent flame and ember penetration, a 5-foot zone of defensible space, and noncombustible fencing. However, the Town Board ultimately declined to adopt a town-wide WUI code ("Information for Meeting of the Superior Board of Trustees", 2022).

In July 2022, the Sagamore neighborhood in Superior adopted WUI regulations guiding the use of ignition-resistant materials, noncombustible building materials, Class A fire resistance-rated roof assembly and defensible space to reduce wildfire risk. These regulations were adapted from the proposed town-wide WUI code; however, homeowners affected by the Marshall Fire have the option to “opt out” of these new WUI building code standards (“Town of Superior Ordinance No. O-13, 2022). By allowing homeowners affected by the Marshall Fire to “opt-out” of newer model codes, these measures could reduce protections for residents in the event of a future fire.

According to the Boulder County Hazard Mitigation Plan (2022), the Town of Superior plans to install fire and wind-resistant materials at the Water Treatment Plant, Wastewater Treatment Plant, the Community Center, Park Field Office, all Parks structures, and the Town Hall. Examples of these materials and retrofits include cement board, brick, metal roofs, concrete retaining structures, pour-in-place playground safety surfacing, attic venting, and leaf gutter covers. The Plan identifies the FEMA Building Resilient Infrastructure and Communities (BRIC) grant program as a potential funding source to cover the estimated $5 million cost.

Recovery And Repair

Superior has also made several regulatory changes aimed at facilitating expeditious and flexible rebuilding and recovery after the Marshall Fire. Some of these changes potentially reduce protections for residents in the event of a future fire.

Effective starting March 28, 2022, the 2021 IECC was adopted with appendices RB, CB, RD, and CD, encouraging the installation of alternative energy and accompanying infrastructure for commercial and residential properties. Superior allows homeowners who owned the property at the time of the fire to “opt out” of the 2021 IECC and instead build to 2018 IECC standards (Town of Superior Ordinance No. O-2, 2022). Impacted homeowners who move to a different impacted property are still eligible to “opt out” of the 2021 IECC and instead apply the 2018 IECC standards to the new property (Town of Superior Ordinance No. O-7, 2022). As of February 2023, 70% of the residential building permits for homes damaged or destroyed by the Marshall Fire are designed to meet either the 2021 IECC, or a more energy efficient standard (“Majority of Permitted Rebuilds in Superior Choose Energy Efficiency”, 2023).

Additionally, in April 2022, the Town of Superior reduced its side yard setback requirements for accessory and principal structures abutting a street or alley in low- and medium-density residential districts (Town of Superior Ordinance No. O-3, 2022). In April 2022, the Sagamore neighborhood also amended its height, setback, and elevation requirements to allow for more expeditious and flexible rebuilding after the Marshall Fire. Changes include increasing maximum building height and reducing minimum building setbacks for the front sides of the building (Town of Superior Ordinance No. O-5, 2022). Reducing the required setback distances could reduce protections for residents in the event of a future fire.

In May 2022, Superior also amended the 2018 IRC Section R313.2 to allow owners of single-family townhomes affected by the fire to “opt out” of the required automatic residential fire sprinkler system installation (Town of Superior Ordinance No. O-8, 2022). This change limits the wildfire hazard mitigation provisions of the 2018 IRC.

Superior also streamlined insulation permit applications for impacted homeowners by removing the permit fee and the requirements for submission of plans. Listed insulation requirements meet, and in some cases, exceed the energy efficiency requirements of the 2021 IECC. Xcel Energy offered rebates on home insulation replacement through June 30, 2022 (“Permits for Insulation Replacement”, n.d.).

Finally, to offset the cost of rebuilding, Superior offers rebates equal to 47% of plan check and building permit fees and the Town’s portion of use tax to residents rebuilding their homes after the Marshall Fire (“Permit Fees and Tax Rates”, n.d.).

3.3. Additional Regulation Considerations - Energy Storage Systems

Both commercial and residential codes and standards provide fire safety protections for energy storage systems (ESS) but do not explicitly address the risk of wildfire. Within the fire safety standards for ESS, protections for Li-ion battery ESS are more limited.

Commercial Energy Storage Systems Regulations

The ICC publishes prescriptive requirements for ESS including specific requirements for fire-resistive construction, automatic fire sprinkler system protection, and detection and alarm system requirements. Within the I-Codes, the installation of ESS is controlled by the International Fire Code. Though these provisions govern the general fire safety, construction, and electrical installation requirements, they do not yet provide specific fire protection requirements for large-scale electrical storage systems using Li-ion batteries.

FM Global, in conjunction with NFPA’s Fire Protection Research Foundation (FPRF) and the Property Insurance Research Group (PIRG), have undertaken several studies aimed at understanding the performance of Li-ion battery ESS in fires. Results have formed the basis of FM Global Data Sheet 5-33 and NFPA 855. Data Sheet 5-33 is used by FM Global to address risk at FM-insured properties, whereas NFPA 855 refers to UL 9540A, a test method designed to enable a standard approach to determine the fire and explosion risks of Li-Ion battery energy storage systems. The 2023 edition of NFPA 855 also includes Annex G, an informational Guide for Suppression and Safety of Li-Ion Battery Energy Storage Systems. These documents provide guidance on separation distances or barriers between multiple units in an energy-storage system consisting of multiple batteries, as well as the distances between racks and walls in storage areas or enclosures where these units are stored. They also provide the basis for the recommended sprinkler designs for the storage areas and enclosures. Note that these standards are intended to protect ESS from fire spread within the building or adjacent to ESS assets and may be insufficient to provide protection against a wildfire.

Residential Energy Storage Systems Regulations

ESS protection provisions are relatively new additions to the model building codes. Provisions for residential construction first appeared in Section R327 of the 2018 IRC. The provisions were significantly expanded in the 2021 IRC. Additional standards related to vehicle impact protection can be found in the California modifications to the 2021 IRC (i.e., Section R328 of the 2022 California Residential Code). NFPA 855 also provides fire safety protections for residential ESS in parallel with the 2021 IRC, including unit spacing, unit capacity limitations, fire detection, and location.

The most recent provisions of the 2021 IRC (R328 Energy Storage Systems) provide requirements for the following (summarized):

- **Listing and labeling**: ESS must be listed and labeled in accordance with UL 9540 standards and marked "for use in residential dwelling units".
- **Installation:** Installation to be in accordance with NFPA 70, inverters listed and labeled in accordance with UL 1741 or provided as part of the UL 9540 listing. If connected to the grid, inverters are to be compatible with the local utility's system.
- **Spacing**: Minimum spacing between units to be 3-feet (R328.3.1). Smaller separation distances allowed based on documented compliance with fire testing described in Section 1207.1.5 of the International Fire Code.
- **Permissible Locations**:
  - Detached garages and accessory structures.
  - Attached garages provided the garage is separated from the dwelling unit living space with a common wall that has a minimum of:
    - 1/2-inch gypsum wallboard applied to the interior side of the garage wall
    - 1/2-inch gypsum wallboard applied to interior side of garage walls, if the garage is separated by a distance of less than 3 feet
    - 5/8-inch gypsum board applied to ceilings where there is a habitable space above the garage
  - Outdoors on exterior side of exterior walls located at least 3 feet from any door or window directly entering the dwelling unit.
  - Enclosed utility closets, basements, storage, or utility spaces within dwelling units provided they meet certain fire resistance requirements and do not open directly into sleeping rooms.
  - No installations allowed in sleeping rooms.

- **Energy Ratings**: Maximum unit size is 20 kWh. The maximum system aggregated size is 80 kWh and differs based on location. Larger systems to be installed per Section 1207 of the International Fire Code.
- **Fire Detection:** Smoke alarms are required unless they are in areas where smoke alarms cannot be used because of their rating or listing. In this case, a heat detector interconnected to the smoke alarms is required.
- **Impact protection requirements**: Protection using approved barriers for installations potentially subject to vehicle impacts or damage.
- **Ventilation**: If the system produces hydrogen or other flammable gases during charging mechanical ventilation is required to keep gas levels below acceptable levels (See 2021 IRC Section M1307.4).
- **Electrical Vehicle Use to Power Dwelling Unit:** Attachment of a vehicle to power dwelling unit must comply with the vehicle manufacturer's instructions and NFPA 70.

3.4. Regulatory Gap Analysis

3.4.1. GAPS IN MODEL WUI CODES

While Colorado has or is in the process of developing and/or adopting wildfire safety codes and standards, many model WUI codes and standards are still missing key fire safety requirements and associated fire testing, design, construction, inspections and maintenance standards. This section provides a high-level gap analysis of wildfire safety codes and standards at state and local levels in Colorado, as well as at the national level. The analysis is based on industry understanding and knowledge of fundamental fire safety engineering first principles, well-established or codified fire/wildfire risk control measures, and other national/international best practices for mitigating wildfire risks. Risk control categories have been identified as essential components for achieving more comprehensive wildfire-risk mitigation designs based on traditional fire safety concepts and industry best practices in wildfire-risk mitigation. Table 9 lists the risk control categories and summarizes gaps in current wildfire safety codes and standards at the local levels in the impacted zones, and at the national level.

Table 9. Gaps in Wildfire Safety Regulations in Current Local and National Codes and Standards

Wildfire-Specific Risk Control Measures	Local Level Regulations: Louisville, CO (2018 ICC Codes & Amendments)	Local Level Regulations: Superior, CO (2018 ICC Codes & Amendments)	Local Level Regulations: Unincorporated Boulder County (2015 ICC Codes & Amendments)	IWUIC 2021 Edition	NFPA 1[1] 2021 Edition	NFPA 1140[2] 2022 Edition
1. Ignition Sources	-	-	-	✓	✓	✓
2. Structural Hardening	-	-	✓	✓	See NFPA 1144	✓
3. Defensible Space (Parcel-Level)	-	-	✓	✓	✓	✓
4. Fire Department Access	-	-	✓	✓	✓	✓
5. Means of Egress	-	-	-	-	-	-
6. Suppression Systems	-	-	-	✓	-	✓
7. Firefighting Water Supplies	-	-	✓	✓	✓	✓
8. Detection Systems	-	-	-	-	-	-
9. Emergency and Public Communication Systems	-	-	-	-	See NFPA 1144	✓
10. Emergency Power	-	-	-	-	-	-

Wildfire-Specific Risk Control Measures	Local Level Regulations: Louisville, CO (2018 ICC Codes & Amendments)	Local Level Regulations: Superior, CO (2018 ICC Codes & Amendments)	Local Level Regulations: Unincorporated Boulder County (2015 ICC Codes & Amendments)	IWUIC 2021 Edition	NFPA 1[1] 2021 Edition	NFPA 1140[2] 2022 Edition
11. Smoke Protection	-	-	-	-	-	-
12. Vegetation Management (landscape-level)	-	-	-	✓	✓	✓
13. Planning	-	-	-	-	✓	✓
14. Existing Building Hardening	-	-	-	-	See NFPA 1144	✓

[1] The planning, construction, maintenance, education, and management elements for the protection of life and property from wildfire shall meet the requirements of NFPA 1 Chapter 17 and NFPA 1144. Within this table, 'See NFPA 1144' refers to regulations that are not covered in Chapter 17 of NFPA 1 but are covered in NFPA 1144.

[2] As part of the Emergency Response and Responder Safety Document Consolidation Plan, as approved by NFPA Standards Council, NFPA 1140 is a combination of Standards NFPA 1051, NFPA 1141, 1143, and NFPA 1144.

Though unincorporated Boulder County does have some amendments for structural hardening, defensible space, etc., there are many wildfire-specific risk-control measures that are unaccounted for. Additionally, Louisville and Superior have not adopted WUI codes that include regulations requiring the above-mentioned wildfire-specific risk control measures. Should these jurisdictions adopt the IWUIC, which is currently the most likely WUI code to be adopted, wildfire specific risk control measures would be increased. As demonstrated in the table above, even should these jurisdictions adopt the IWUIC there are still gaps within the IWUIC.

There are also opportunities within “green” building codes to enhance energy efficiency while simultaneously reducing vulnerability to natural hazards. For example, multi-pane windows using tempered glass as the exterior pane can improve both a building’s energy efficiency and fire resistance. The 2021 IWUIC Chapter 5 and NFPA 1144 Standard for Reducing Structure Ignition Hazards from Wildland Fire describes standards for fire-resistant exterior windows. Another potential dual benefit could arise from the construction of a tighter building enclosure (i.e., less air leakage through the building enclosure via walls, ceiling, widows, and doors). Less air leakage is ideal for energy efficiency and can help prevent wildfire smoke intrusion. Several houses in the area affected by the Marshall Fire experienced damage to interior finishes and contents by smoke entry into the building.

Some design options intended to add “green” value to the building can inadvertently make them more vulnerable to wildfire risk. For example, modest increases in wall insulation requirements and the desire to create homes that suffer less air leakage have resulted in the increased use of rigid foam insulation. Rigid sheet foam products are typically more flammable than fiberglass batt insulation and are often added to the exterior of a building. Despite its benefits for energy efficiency, additional research and testing may be required to determine this insulation’s flammability compared to other insulation types, such as fiberglass batt insulation, and its impact on the spread of fire to and through buildings. Future editions of ICC and local green building incentives could provide an opportunity to maximize dual benefits and reduce conflicts with WUI codes and other wildfire safety design standards.

3.4.2. GAPS IN WILDFIRE TESTING STANDARDS

Few wildfire-specific test standards currently exist. Those that do exist are currently more focused on exterior fire exposure. According to the American Society for Testing and Materials (ASTM) International website, there are several wildfire-specific test standards in development, including those focused on under-deck flame impingement exposure and performance of gutter cover devices. Even with these standards that are in development, there are still significant gaps, including wildfire exposure to exterior roof and wall surfaces (Table 10).

Table 10. Gaps in Wildfire Fire Test Standards at National Level

Building Component	Fire Test Standard	Main Purpose of Test(s)	Exposure Condition: Interior Fire	Exposure Condition: Hydrocarbon Fire	Exposure Condition: Exterior Fire	Known Wildfire Gaps
Roof covering	ASTM E108: Standard Test Methods for Fire Tests of Roof Coverings	Measure fire spread	-	-	✓	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure
Roof covering	UL 790: Standard Test Methods for Fire Tests of Roof Coverings	Evaluate resistance of fire penetration from exterior	-	-	✓	Fire test does not account for weathering of materials prior to fire exposure
Roof construction, Wall construction, Floor construction, Columns, & Beams	ASTM E119: Standard Test Methods for Fire Tests of Building Construction and Materials	Evaluate duration for which building elements contain a fire and/or retain structural integrity (Fire resistance)	✓	-	✓	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure
Roof construction, Wall construction, Floor construction, Columns, & Beams	UL 263: Fire Tests of Building Construction and Materials		✓	-	✓	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure

Building Component	Fire Test Standard	Main Purpose of Test(s)	Exposure Condition: Interior Fire	Exposure Condition: Hydrocarbon Fire	Exposure Condition: Exterior Fire	Known Wildfire Gaps
Joint Systems	ASTM E1966: Standard Test Method for Fire-Resistive Joint Systems	▪ Evaluate ability of a fire-resistive joint system to undergo movement without reducing the fire rating of the adjacent fire separating elements ▪ Evaluate duration for which building elements contain a fire and/or retain structural integrity (Fire resistance)	✓	✓	-	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure
Vents (Roof, Roof Eave, Wall Vent)	ASTM E2886: Standard Test Method for Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement	Evaluate the ability of exterior vents to resist the entry of embers and flame penetration through the vent	-	-	✓	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure ▪ Fire test does not evaluate ability of vents to limit entry of embers and flame penetration ▪ Fire test does not include evaluation of roof-ridge and off-ridge vents
Vents (Roof, Roof Eave, Wall Vent)	ASTM E2957: Standard Test Method for Resistance to Wildfire Penetration of Eaves, Soffits and Other Projections	Monitor the fire characteristics and the ability of eave overhangs and other projections to resist exterior fire penetration from underneath under the specified fire exposure conditions	-	-	✓	▪ Fire test does not account for weathering of materials prior to fire exposure ▪ Fire test does not account for impact of typical wildfire conditions (i.e., high wind & flying debris)

Building Component	Fire Test Standard	Main Purpose of Test(s)	Exposure Condition: Interior Fire	Exposure Condition: Hydrocarbon Fire	Exposure Condition: Exterior Fire	Known Wildfire Gaps
Interior Finishes	ASTM E84: Standard Test Method for Surface Burning Characteristics of Building Materials	Measure burn characteristics (i.e., smoke development and flame spread)	✓	-	-	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure
Interior Finishes	UL 723: Standard for Test for Surface Burning Characteristics of Building Materials	Measure burn characteristics (i.e., smoke development and flame spread)	✓	-	-	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure
Interior Finishes	ASTM E2768: Standard Test Method for Extended Duration Surface Burning Characteristics of Building Materials (Fire Retardant Treated Wood)	Measure burn characteristics (i.e., smoke development and flame spread)	✓	-	-	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure
Interior Finishes	NFPA 286: Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth	Determine the contribution of interior finish materials to room fire growth during specified fire exposure conditions	✓	-	-	Fire test does not account for weathering of materials prior to fire exposure

Building Component	Fire Test Standard	Main Purpose of Test(s)	Exposure Condition: Interior Fire	Exposure Condition: Hydrocarbon Fire	Exposure Condition: Exterior Fire	Known Wildfire Gaps
Exterior Finishes	NFPA 285: Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components	Determine the flammability characteristics of exterior non-load-bearing wall assemblies or panels	-	-	✓	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure
Exterior Finishes	NFPA 268: Standard Test Method for Determining Ignitability of Exterior Wall Assemblies Using a Radiant Heat Energy Source	Measure the ignitability characteristics of exterior wall assemblies and their potential of contributing to fire growth	-	-	✓	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure
Exterior Finishes	ASTM E2707: Standard Test Method for Determining Fire Penetration of Exterior Wall Assemblies Using a Direct Flame Impingement Exposure	Measure the ability of the exterior wall covering material or system to resist fire penetration from the exterior to the unexposed side of the wall assembly under the specified conditions of exposure	-	-	✓	▪ Fire test is specified for WUI ▪ Fire test does not account for weathering of materials prior to fire exposure
Doors	ASTM E2074: Standard Test Method for Fire Tests of Door Assemblies, Including Positive Pressure Testing of Side-Hinged and Pivoted Swinging Door Assemblies	Determine the ability of door assemblies to function as a fire-resistive barrier during a standard fire endurance test	✓	-	✓	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure

Building Component	Fire Test Standard	Main Purpose of Test(s)	Exposure Condition: Interior Fire	Exposure Condition: Hydrocarbon Fire	Exposure Condition: Exterior Fire	Known Wildfire Gaps
Doors	NFPA 252: Standard Methods of Fire Tests of Door Assemblies	Determine the ability of door assemblies to function as a fire-resistive barrier during a standard fire endurance test	✓	-	✓	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure
Doors	UL 10C: Positive Pressure Fire Tests of Door Assemblies	Determine the ability of door assemblies to function as a fire-resistive barrier during a standard fire endurance test	✓	-	✓	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure
Doors	UL 10B: Standard for Fire Tests of Door Assemblies	Determine the ability of door assemblies to function as a fire-resistive barrier during a standard fire endurance test	✓	-	✓	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure
Windows & Skylights	NFPA 257: Standard on Fire Test for Window and Glass Block Assemblies	Measure how well window and glass block assemblies prevent or slow the spread of fire	-	-	✓	▪ Fire test not explicitly designed for wildfire exposures ▪ Fire test does not account for weathering of materials prior to fire exposure

3.4.3. STRUCTURAL HARDENING GAPS IN CODES

In addition to structural hardening provisions that are already well-established (e.g., roof classifications, boxed eaves, façade materials, vent protection, decking requirements) in nationally recognized wildfire safety codes (e.g., IWUIC, NFPA 1140 or California Building Code (CBC) Chapter 7A), observations in the field highlighted a variety of new or not well-established vulnerabilities in the building envelope. These additional vulnerabilities are based on fundamental fire safety principles that are well known in building and fire codes for interior fire scenarios but are yet to be accounted for in exterior wildfire scenarios.

One main gap in current wildfire safety regulations is the critical importance of maintaining the integrity and continuity of the exterior building envelope to wildfires, especially as the wildfire risk expands into urban areas. This means that the exterior features of the building should not only be comprised of fire-resistant exterior building elements, components, and assemblies, but also appropriate fire-resistant joint protection systems, interface details, and other membrane and through-penetration systems. It is at the joints and interfaces of exterior building elements/components where flames, hot gases and embers can readily enter the interior or interstitial spaces of a home or building leading to ignition.

Another gap in wildfire safety regulations is the need to address fire hazards, risks and associated mitigation approaches for new technologies such as residential solar panel installations and associated battery storage systems (which are often mounted/attached to the exterior of a home). Details about vulnerabilities of joint systems have been discussed in Sections 5.2.2, 0.0.0, and 5.2.5 above.

For more information, refer to Marshall Fire MAT documents *Homeowner's Guide to Risk Reduction and Remediation of Residential Smoke Damage* (Appendix D), *Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire* (Appendix E) and *Wildfire Resilient Detailing, Joint Systems, and Interfaces of Building Components* (Appendix J) for additional information.

3.4.4. OTHER RELEVANT GAPS IN WILDFIRE CODES AND STANDARDS

There are a number of additional regulatory gaps not focused on testing standards that have been previously identified in the FEMA White Paper on Community Wildfire Resilience (Volume 2). See Table 11 for information regarding these identified gaps.

Table 11. Additional Gaps in Relevant Wildfire Safety Codes, Standards and Guidance Documents

Wildfire-Specific Risk Control Measures	Identified Gap
Existing Building Hardening	Limited resources for retrofitting existing building stock.
Fire Department Access	▪ Limited road design criteria during evacuations to account for emergency vehicle access. ▪ Limited right-of-way access and/or exemptions to environmental reviews for vegetation management of primary and secondary access/egress roads.
Means of Egress	▪ Limited resources to support evacuation for all populations. ▪ Limited guidance on decision making and planning tools for evacuation orders/warnings vs. shelter in place. ▪ Lack of guidelines for planning and preparedness for evacuation. ▪ Limited guidance for number, capacity, and separation of evacuation roadways.
Suppression Systems	▪ Lack of design criteria, performance specification, operations, long-term maintenance, testing and inspections for exterior sprinkler systems, hydrants, and associated water supplies for wildland/WUI firefighting operations. ▪ Lack of design criteria and performance specifications for special suppression systems and associated water and chemical supplies.
Firefighting Water Supplies	▪ Design criteria, performance specification, operations, long-term maintenance, testing and inspections for independent water supplies. ▪ Lack of design criteria, guidance and standards for first aid firefighting equipment, water/power supplies and training.
Detection Systems	▪ Limited guidance on early warning detection systems design criteria, performance specification, operations, long-term maintenance, testing and inspections. ▪ Lack of wildfire detection systems test standard.
Emergency Power	Lack of regulations, designs standards and performance specifications, operations, long-term maintenance, testing and inspections for micro-grids.
Planning or Entitlement Phase	▪ Limited guidance on design principles for wildfire resilience community/urban planning. ▪ Limited guidance on communal defensible space best practices. ▪ Limited trauma informed principals for planners, engineers, and other technical professionals working with communities during post wildfire disaster recovery and re-building. ▪ Limited design guidance, performance criteria, construction practices and operational procedures for construction, use, and maintenance of temporary refuge areas or shelters-in-place.
Externally Applied Fire-Resistant Material(s)	Lack of wildfire testing standard for use of externally applied chemical retardants, foam gels and other similar materials to achieve fire resistance of exterior building components.

Chapter 4: Marshall Fire Observations –Community and Neighborhood/Subdivision Level

Observations in this report are scaled by overall community level, neighborhood/subdivision level and individual parcel/building level, as illustrated in Figure 15. This chapter focuses on community- and neighborhood/subdivision level observations.

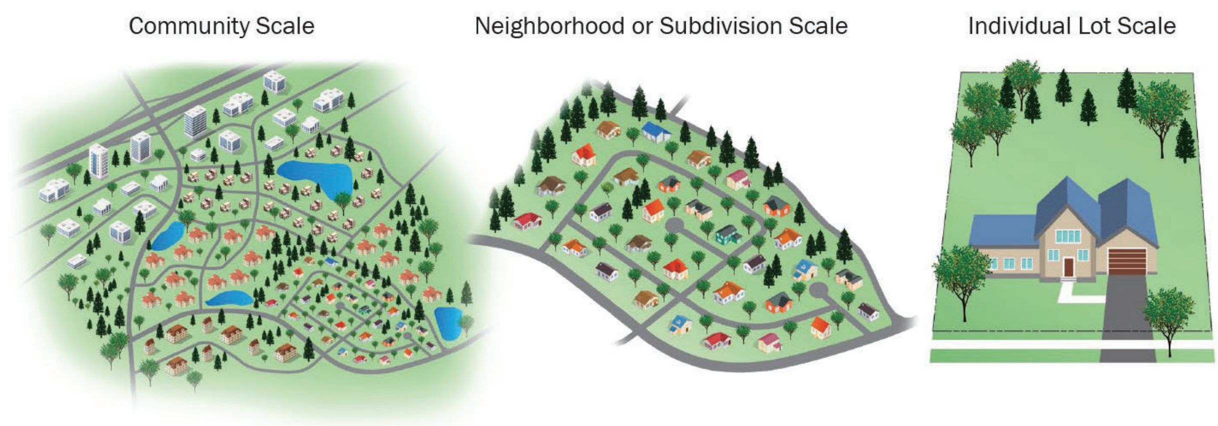


Figure 15. Visualization of community-, neighborhood- or subdivision-, and individual lot scale.

From a land use planning and design perspective, most of the homes and residential neighborhoods that were damaged or destroyed during the Marshall Fire had community-scale planning and design features that introduced unique wildfire vulnerabilities that increased their risk to wildfire hazards and impacts (Figure 15). These community-scale vulnerabilities can be grouped into three main categories:

- **Community-Scale Vulnerability #1:** Proximity to large, uninterrupted, mostly unmanaged open space.
- **Community-Scale Vulnerability #2:** Interwoven flood mitigation including water drainage ditches, greenbelts, and recreational spaces into urban development.
- **Community-Scale Vulnerability #3:** Semi-rural areas intermixed with grassland and shrubland vegetation.

Community-Scale Vulnerability #1 – The point(s) of origin of the Marshall Fire occurred in primarily rural, undeveloped lands in unincorporated Boulder County adjacent and intermixed with large, mostly unmanaged open space/wildlands on the outskirts of suburban Louisville and Superior. Due to this remote and undeveloped nature of the ignition points, coupled with the extreme winds at the time (i.e., over 100 mph), the fire was able to rapidly spread at uncontrollable levels and with little warning, growing to thousands of acres over moderately flat terrain (Figure 16). Because of these conditions, there was also little opportunity for first responders to contain and suppress, the fire before reaching more densely populated areas. If fire is able to travel uninterrupted or uncontained, it is able to gain in intensity, making it more challenging for first responders to manage. This inherent vulnerability of mostly unmanaged open spaces directly adjacent to or in close proximity to the built environment (in other words, the WUI) was evident by the disproportionate devastation observed in those communities that bordered on these types of open spaces, as was the case in the Sagamore neighborhood of Superior.

Figure 16 shows the open space just west of the Sagamore neighborhood at the WUI, pre- and post-fire. It was along this interface between development and mostly unmanaged open space where the Marshall Fire directly ignited combustible fuel loads in a suburban-urban environment. Property line fences and wood decking, along with highly flammable vegetation, led to the ignition of houses in this neighborhood. It was also along this interface where the wildfire transitioned into an urban conflagration, leading to the destruction of the neighborhood, and contributing to subsequent ignitions in adjacent neighborhoods. Similar phenomena were also observed in other residential areas in Superior within the WUI.

Figure 16. Example of typical unmanaged open space in the WUI of the Sagamore neighborhood in Superior, Colorado.

Community-Scale Vulnerability #2 – In addition to more "traditional" vulnerabilities of WUI described above, other community-scale wildfire vulnerabilities were also observed. The MAT observed the presence of several natural and man-made vegetative planning features as discussed in Section 1.3.3 (i.e., water drainage ditches, greenbelts, and recreational spaces) that are contiguous with traditional wildlands/WUI, but also interwoven and extending into several communities throughout the impacted areas and adjacent neighborhoods. These planning features, while providing valuable services to communities (e.g., flood control and mitigation, recreation, scenic views), also created pathways that readily channeled wildfire deeper into the built environment while also exacerbating localized wind speeds and fire intensities due to the natural topography (e.g., “chimney-like” conditions or steep slopes) and the density of biomass that typically flourishes in these natural or man-made features. These “fire superhighways” provided pathways for fire to readily spread into the urban-suburban landscape from the more traditional open/wildland spaces. This was observed in several neighborhoods in Louisville, Superior, and unincorporated Boulder County (Figure 17), including:

- In Louisville, wildfire travelled rapidly along Davidson Mesa into The Enclave and Centennial 6,7,8 neighborhoods and into Coal Creek neighborhoods via Coal Creek.
- In Superior, wildfire travelled rapidly along the Coal Creek drainage into Old Town and Discovery Park, and via multiple drainages that enter the Rock Creek neighborhood near McCaslin.
- In unincorporated Boulder County, wildfire travelled rapidly along Davidson ditch and Goodhue ditch into several neighborhoods.

These urban geographic features (e.g., drainages, greenbelts) can produce significant embers from burning vegetative fuels, including grasses, shrubs, and timber/woody plants. These areas can also be sources of surface and ladder fuels that provide wildfire flow paths which can ignite decks, fences, or other combustible fuels along the WUI and well into the urban-suburban environment, leading to urban conflagration (Figure 18).

This also illustrates the mitigation practices for one natural hazard, in this case flood, may affect the performance of the area in another natural hazard, in this case fire. Boulder County experienced a widespread flooding disaster due to extended periods of rain in September and October 2013. Significant flood mitigation activities were completed following the flood including positive drainage paths.

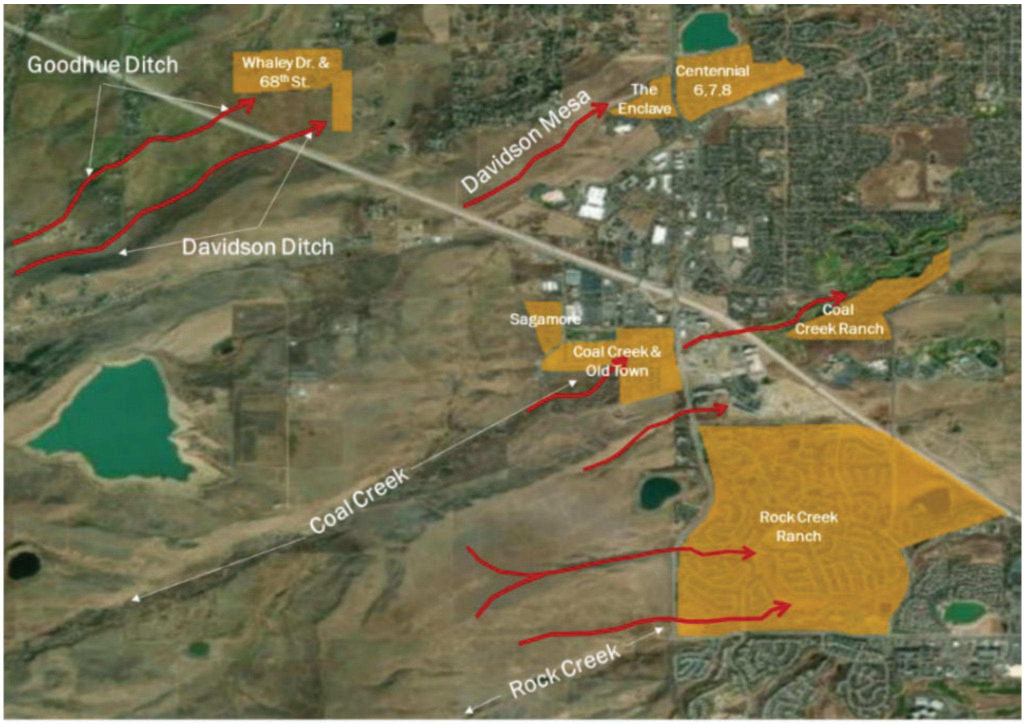


Figure 17. Neighborhoods with homes damaged/destroyed by fire spreading (red arrows) along observed drainage ditches & greenbelts.

Figure 18. Examples of Rock Creek drainage from Rock Creek Ranch (left) and Davidson Ditch (right).

Community-Scale Vulnerability #3 – In semi-rural areas of Unincorporated Boulder County intermixed with grassland and shrubland vegetation (as discussed in Section 1.3.3), the MAT observed significant residential building damage and destruction caused by the combination of wind-driven effects, drainage ditches, intermixed wildland fuels, and large, uninterrupted, mostly unmanaged open spaces with high amounts of biomass (Figure 19). This was observed in the neighborhoods off South Vale Road, along Marshall Road, in the Whaley Drive area, and around Spring Drive/Panorama Drive down into the Empire Drive area.

Figure 19. Examples of residences intermixed with wildland fuels in unincorporated Boulder County.

These three community-scale wildfire vulnerabilities, while observed in the impacted areas of the Marshall Fire, were also observed throughout adjacent communities/neighborhoods. Refer to Chapter 3 for how these land use planning and community-scale wildfire vulnerabilities are currently addressed in local land use planning codes, building and fire codes, standards and/or guidance documents.

4.1. Management of Parks and Other Common Spaces

The majority of the observed open spaces, drainage ditches, greenbelts and recreational spaces adjacent to, intermixed or interwoven with the rural and urban/suburban communities in the impacted areas of the Marshall Fire did not appear to have a long-term, wildfire-specific land resource management strategy. Such a strategy would help prevent, mitigate and/or manage vegetative fuel loads, particularly high hazard vegetation, adjacent to suburban/urban development.

Creating a long-term, wildfire-specific land resource management strategy may be a challenge due to the diverse set of stakeholders and jurisdictions responsible for managing these public and private land use spaces such as municipal parks, Boulder County open spaces, Boulder County conservation areas, and jointly managed county/city open space. Limited resources, limited wildfire-specific land use management and/or multi-hazard codes, and standards and guidance documents, etc. may also present challenges.

Regardless of the mixture of underlying financial, administrative, or legal constraints, the MAT observed that these natural and man-made land use features (i.e., mostly unmanaged, or minimally maintained vegetation in various open spaces, drainage ditches, etc.) amplified not only the intensity and behavior of the wildfire, but also the associated impacts to the surrounding communities. Conversely, where vegetation was well maintained (e.g., irrigated, mowed, trimmed back) fire intensity, spread, and associated damage were reduced.

Guidance on Best Management Practices & Recommended Plants

A range of best management practices (BMPs) for community-scale vegetation management are available through Colorado State University and the CSFS. While there is not a specific recommended fire-resistant plant list for Boulder County, the Colorado State University Cooperative Extension Service has developed a comprehensive Colorado list of fire- resistant plant, shrub, and tree species available at many nurseries which, combined with defensible space landscaping management practices, can reduce fire risk. The list includes species suggestions and maintenance requirements (Colorado Extension Service, 1999). It is always better to make native plant choices but even some native plants are highly flammable and will burn if they are not properly maintained.

While guidance resources are available (see reference box below), the MAT observed that application of these BMPs is not consistently implemented among land resource managers, homeowner associations (HOAs) and other managers of large open spaces and greenbelts.

Best Management Practices for Vegetation Management

- Colorado State Forest Service. (1999). Fire-Resistant Landscaping. https://extension.colostate.edu/docs/pubs/natres/06303.pdf
- Colorado State Forest Service. (2023). Urban and Community Forestry. https://csfs.colostate.edu/forest-management/community-urban-forestry/
- Colorado State University Extension. (2012). FireWise Plant Materials – 6.305. https://extension.colostate.edu/wp-content/uploads/2022/02/6.305-FireWise-Plant-Materials.pdf
- Boulder County. (2022). Prescribed Burn Projects. https://bouldercounty.gov/open-space/management/prescribed-burns/
- Wildfire Information Network Community of Practice - Surviving-Wildfire (2019). Selecting Firewise Plants. https://surviving-wildfire.extension.org/selecting-firewise-plants/

Invasive & Highly Flammable Plants

Invasive plants can have a higher potential for ignition than native vegetation because they often produce more flashy fuels which ignite and burn quickly (University of California Agriculture and Natural Resources, 2022). Invasive trees and shrubs typical within Boulder County include Trees of Heaven, Russian Olive, and Tamarix. Observed highly flammable tree species in eastern Boulder County include arborvitae, cedar, several species of juniperus and pinus, Douglas fir, spruce, cypress, and yew. Common ground covers such as cheat grass and pampas grass are also extremely flammable in dry conditions and were observed to be present. Many fire jurisdictions within high wildfire-prone areas have a list of common plants that are prohibited for use, but this local guidance is currently limited or unavailable in unincorporated Boulder County, Louisville and Superior, Colorado.

4.2. Local Wildland Interface and Multi-Hazard Conditions

The Marshall Fire exemplifies a multi-hazard wildfire event in which other natural hazards (i.e., high winds and drought conditions), influence the risk and behavior of the fire.

Traditionally, hazard mitigation plans such as the Boulder County Hazard Mitigation Plan approach natural hazards as singular, unrelated events; however, jurisdictions impacted by the Marshall Fire are beginning to integrate multi-hazard interactions into their wildfire recovery and mitigation strategies. Examples include:

- The Town of Superior plans to install fire and wind-resistant materials and hazard-resistant modifications to “harden” several public facilities (Boulder County Hazard Mitigation Plan, 2022).

- Boulder County co-developed the multi-jurisdictional Disaster Assistance Center in Lafayette, Colorado to support residents and businesses damaged by the fire and high winds. Approximately 16% of the $9,221,421 in financial assistance distributed to impacted households covers wind damage (“Marshall Fire Recovery Milestones”, n.d.).

Jurisdictions impacted by the Marshall Fire are also exploring mitigation strategies that can be applied to the landscape, community, and parcel levels to provide comprehensive protection for buildings and reduce wildfire risk in grasslands, parks, and open space. Many of these strategies can be adapted to address the impacts of events like the Marshall Fire. These strategies include but are not limited to:

- Mechanical Fuel Maintenance
- Prescribed Fire
- Prescribed Grazing
- Fire and Fuel Breaks
- Defensible Space
- Ignition-Resistant Construction
- Fire-Resistant Construction
- Homeowner Flood and Debris Flow Mitigation Techniques

For example, parcel-level ignition-resistant construction can be combined with community fuel breaks and landscape-level fuel management, such as prescribed grazing, to combat the combined effect of dry fuels and strong winds. Louisville has combined several of these strategies. In addition to publishing a homeowner’s guide to ignition-resistant construction, the city has also begun to mow high-risk public lands adjacent to private properties twice yearly (“City, Boulder County Continue to Make Progress on Fire Mitigation Efforts”, n.d.). The Boulder County CWPP also details fuel break design recommendations specific to Colorado’s arid climate; although not explicitly tied to multi-hazard events, this strategy is an example of adapting an existing wildfire mitigation technique to address a multi-hazard wildfire risk.

There are additional untapped opportunities to incorporate multi-hazard mitigation into comprehensive planning and wildfire mitigation including the 2023 update to the Boulder County

CWPP, Louisville's forthcoming Wildfire Mitigation Plan for City Public Lands, and other open space strategic and comprehensive plans. According to data and interviews collected by the MAT, high winds limited early firefighting operations, making traditional and advanced fire suppression options unsafe. While firefighters were able to employ effective alternatives, there may be additional opportunities to review and bolster fire suppression and response strategies for future high wind and fire events. Additionally, while they are not used extensively in the Western U.S., parcel-level windbreaks have been used in combination with other strategies to limit the speed and progression of low-intensity wildfires (South Australia County Fire Service; Country Fire Authority, n.d.).

Finally, while not a significant risk post-Marshall Fire, communities in wildfire-prone areas can use a combination of landscape maintenance and parcel-level building strategies to mitigate the risk of post-wildfire flooding and landslides. Following the Fourmile Canyon Fire, Boulder County proposed a combination of in-channel, slope stabilization, and erosion control techniques to reduce damage from flooding and debris flow across the burned areas ("Fourmile Canyon Fire Maps", n.d.).

Chapter 5: Marshall Fire Observations – Parcel and Building Level

As indicated in Chapter 2, most of the homes and neighborhoods damaged or destroyed in unincorporated Boulder County, Louisville and Superior were not required by local building and fire codes to satisfy WUI fire safety requirements. As such, well-established and well-known wildfire safety provisions for structural hardening (e.g., roof classifications, boxed eaves, façade materials, vent protection, decking requirements) and defensible space (or "landscaping") found in nationally recognized codes such as the IWUIC were not explicitly required or provided for most of the homes in the impacted areas. Additional vulnerabilities were also observed due to construction detailing that are not well-established and are known gaps in current WUI codes and standards.

5.1. Parcel-Level Wildfire Vulnerabilities

This section summarizes parcel-level observations of deficiencies in well-established defensible space practices that likely contributed to fire readily spreading from nearby wildland/open spaces or from adjacent structures to the home.

5.1.1. COMMON PARCEL-LEVEL LANDSCAPING ISSUES

Most of the damaged or destroyed homes and neighborhoods in unincorporated Boulder County, Louisville, and Superior were not required by local building and fire codes or planning ordinances to satisfy WUI fire safety requirements. As such, well-established and well-known wildfire safety provisions for defensible space found in nationally recognized codes such as the IWUIC were not explicitly required, enforced, or maintained for most of the residences.

Most homes and residences throughout the fire footprint had a range of defensible space deficiencies. Some of the more common deficiencies observed in the field, described in Table 12 included:

- Combustible mulches
- Woodpiles
- Trash and recycling receptacle storage locations
- Overgrown or unmanaged vegetation
- Hazardous plants and vegetative debris
- Clustering of trees and shrubs

Table 12. Examples of Common Landscape Issues.

Landscape Feature	Description	Observed Vulnerabilities
Combustible Mulches	Many parcels throughout the impacted communities contained combustible mulches immediately adjacent to structures (0–5 feet, HIZ Zone 0). Common landscape mulches included pine straw, shredded cypress wood and bark, and pine bark chunks. Use of combustible mulches were also observed in several communities actively in the recovery and rebuilding periods. Overgrown or minimally maintained landscaped beds with mulches may contribute to wildfire spread to structures or serve as an ignition source.	
Woodpiles	Firewood and other organic combustible materials (e.g., leaf piles) were frequently observed abutting or immediately adjacent to homes. Woodpiles and other organic materials are highly susceptible to ember ignition during a wildfire and present a major hazard for structure ignition when stored within the HIZ, particularly within 0–5 feet of the home.	
Trash and Recycling Receptacles	Stored waste, recycling receptacles and other non-organic fuel loads (e.g., plastic sheds, grills, lawnmowers) were observed immediately adjacent to structures. These receptacles and other high hazard fuel loads often contain combustible and flammable waste or fluids.	

Landscape Feature	Description	Observed Vulnerabilities
Overgrown Trees	Most neighborhoods in and immediately adjacent to the impacted areas of the fire did not have well maintained local landscaping or defensible space. Overgrown trees, grasses, and shrubs, as well as numerous high hazard plant species (e.g., juniper bushes, Italian cypress) were observed on a substantial number of properties within the HIZ, but particularly within the 0–5 feet of homes. Poorly maintained trees and shrubs (e.g., trees not "limbed-up" from surface fuels or hanging over roofs) directly adjacent to structures provide a path of fuel for wildfire to encroach on the home, leading to ignition.	
Hazardous Plants and Debris	Hazardous plants that had not been maintained were observed throughout the community. Plants that have not been watered or trimmed are vulnerable to ignition and are able to burn more readily when ignited.	
Clustering of Trees and Shrubs	Trees and shrubs that were densely clustered were found throughout many impacted or adjacent residential neighborhoods. Densely spaced vegetative fuels may contribute to wildfire spread by providing an uninterrupted path of fuel as well as ladder fuels which allow fire to spread to taller vegetation and structures.	

These common parcel-level landscaping features and vulnerabilities are also summarized in Table 13 based on the defensible zone in which they were observed.

Table 13. Examples of MAT observed hazardous landscaping by defensible zone.

Zone	Typical Features	Observed Vulnerabilities
Zone 0 (0–5 feet): “Ember-resistant Zone” or “Immediate Zone”	Defensible space within Zone 0 was rarely observed to be established	▪ Combustible mulches ▪ Overgrown trees adjacent to homes ▪ Woodpiles, trash, and recycling bins adjacent to homes
Zone 1 (5–30 feet): “Lean, Clean, and Green Zone” or “Intermediate Zone”	Defensible space within Zone 1 was not observed to be established throughout communities impacted by the Marshall Fire	▪ Combustible mulches, debris, and other ladder fuels ▪ Overgrown trees adjacent to homes ▪ Clustering of trees and shrubs ▪ Outbuildings within Zone 1
Zone 2 (30–100 feet): “Reduced Fuel Zone” or “Extended Zone”	▪ Fuel breaks in vegetation were not observed within Zone 2 ▪ Parcels commonly unable to accommodate 100 feet of defensible space	▪ Limitations in parcel sizes ▪ Adjacent to other properties ▪ Overgrown vegetation ▪ Closely spaced trees ▪ Little to no defensible space ▪ Outbuildings

Conversely, Figure 20 shows an example of an undamaged residence in Old Town Superior, which likely survived due to sufficient defensible space and structure-to-structure separation.

Figure 20. Example of a single-family home in Old Town in Superior, Colorado where ample defensible space and structure-to-structure separation likely contributed to its survival when numerous structures in the neighborhood were completely destroyed.

5.1.2. COMMUNAL DEFENSIBLE SPACE

Small parcel sizes were observed throughout the impacted and unimpacted neighborhoods of the Marshall Fire. Most of the impacted neighborhoods consisted of parcels/lots of sizes that precluded homeowners from satisfying best practices in defensible space on their own property. This resulted in numerous instances where residences were in close proximity (e.g., within 5–30 feet) of their property line or their neighbor's home with insufficient defensible space on their own property, compounded by a lack of fuel treatments or other forms of defensible space on the adjacent neighbor's property. Figure 21 shows an example of a residential neighborhood in Louisville, where numerous homes have small lot sizes preventing individual homeowners from achieving defensible space on their parcel. It also shows an example of overgrown vegetation between homes, which makes homes on either side of the property line susceptible to spot fire ignitions due to embers, which may lead to structure ignition and structure-to-structure fire spread.

Figure 21. Example of single-family residences in Louisville, Colorado with 5–8 feet to the respective property lines (right) and significant overgrown vegetation typical within Zone 0 and 1 of both homes' defensible space zones (left). Both homes are vulnerable to spot fires from embers or structure-to-structure fire spread due to poor vegetation management in the mutually shared defensible space.

5.1.3. PARCEL-SCALE STRUCTURE FIRE SEPARATIONS

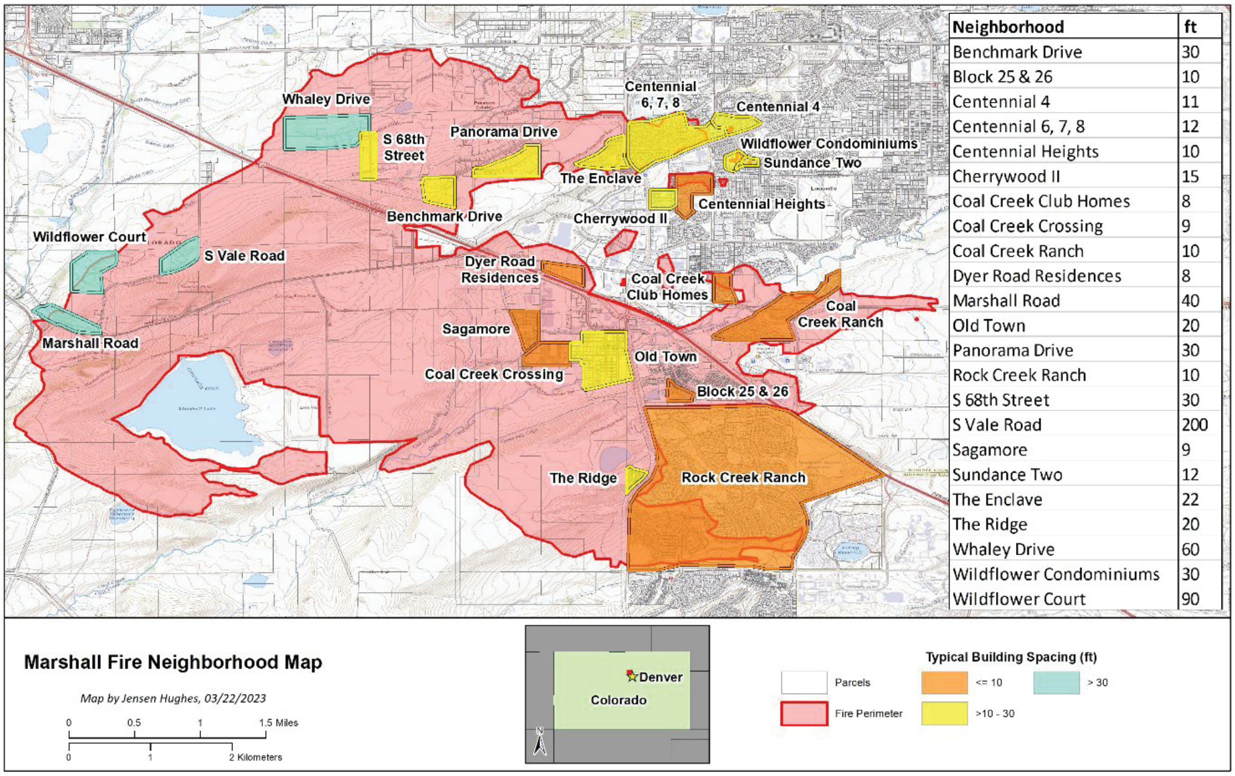
Many of the communities impacted by the Marshall Fire featured structures and buildings that were densely spaced with limited fire separation distances (i.e., less than 30 feet of separation). At the time of the fire, local planning, building and fire codes did not recognize most of these communities as being within the WUI or incorporate wildfire hazard and risk assessments as part of the planning or development process. According to a study conducted by Colorado Division of Fire Prevention and

Control, approximately 25% of the residences in the impacted areas—those both directly exposed to wildland/open space fuels and those inboard of the wildland interface)—had less than 10 feet of separation from an adjacent property, while at least 78% of impacted residences had their entire Zones 0 and 1 (0–30 feet) of their defensible space shared with an adjacent property. Note: This overlap of sharing of defensible space increased to 91% for residences indirectly exposed to wildland or open space fuels (Colorado Division of Fire Prevention and Control, 2022).

Figure 22 and Figure 23 show typical residential lot configurations where residential buildings are closely spaced (i.e., 8–30 feet apart). Figure 24 illustrates the minimum separation distances between residential buildings by impacted neighborhood.

Figure 22. Example of limited separation distances between residential buildings in Coal Creek Crossing in Superior Colorado.

Figure 23. Additional example of limited separation distances between residential buildings in the Sagamore neighborhood in Superior, Colorado.



Neighborhood	ft
Benchmark Drive	30
Block 25 & 26	10
Centennial 4	11
Centennial 6, 7, 8	12
Centennial Heights	10
Cherrywood II	15
Coal Creek Club Homes	8
Coal Creek Crossing	9
Coal Creek Ranch	10
Dyer Road Residences	8
Marshall Road	40
Old Town	20
Panorama Drive	30
Rock Creek Ranch	10
S 68th Street	30
S Vale Road	200
Sagamore	9
Sundance Two	12
The Enclave	22
The Ridge	20
Whaley Drive	60
Wildflower Condominiums	30
Wildflower Court	90

Figure 24. Minimum separation distances between residential buildings by impacted neighborhood in Superior and Louisville, Colorado.

Fire Ratings for Residential Exterior Walls

Current building codes do not typically require fire resistance ratings for exterior walls for single-family residences, almost regardless of fire separation distances to adjacent properties or structures. Fire rated exterior walls are required where the separation distance is five feet or less to the property line. This code exception on fire separation walls for single-family residences significantly increases the risk of structure-to-structure fire spread (or urban conflagration) particularly in a wind-driven wildfire incident.

Current building and fire codes are based on the presumption that fire suppression resources will provide structure protection to limit structure-to-structure fire spread under normal interior building fire scenarios. However, during a large wildfire or wind-driven fire incident, fire suppression strategies may be limited and unable to provide structure protection for many homes and businesses in the path of the wildfire due to limited road access, unsafe conditions for firefighters, and/or insufficient resources and staffing for the size of the fire.

5.2. Building-Level Wildfire Vulnerabilities

This section of the report summarizes observations of structural hardening vulnerabilities (from the top of the structure down) that are already well-established and well-known points of weakness, as well as new areas of concern observed during the MAT in the exterior envelope of a building or home. Table 14 presents a summary of risk for each building component of the exterior envelope.

Table 14 . Summary of Risk for Each Building Component of the Exterior Envelope.

Category	Building Component of Exterior Envelope	Relative Risk Ranking	Section Reference
Roof Components	Roof construction and coverings	Very High	5.2.1
Roof Components	Roof Vents	Very High	5.2.1
Roof Components	Chimneys	Medium	5.2.1
Roof Components	Solar Panels	Medium	5.2.1
Roof Components	Gutters	Medium	5.2.1
Roof Joint Systems	Roof-to-roof joints	High	5.2.2
Roof Joint Systems	Skylight-, chimney-, and vent-to-roof joints	Medium-High	5.2.2
Roof-to-Exterior Wall Components	Edge of roof detailing	Very High	5.2.3
Roof-to-Exterior Wall Components	Soffit and Soffit Vents	Very High	5.2.3
Roof-to-Exterior Wall Components	Head-of-wall to joints	Very High	5.2.3
Exterior Wall Components	Exterior wall construction and cladding	Very High	5.2.4
Exterior Wall Components	Garage doors	Medium	5.2.4
Exterior Wall Components	Fenestration and glazing	High	5.2.4
Exterior Wall Components	Tenant separation walls	Medium	5.2.4
Exterior Wall Components	Vents in exterior walls, crawlspaces, and basements	Very High	5.2.4
Wall System Joints	Wall-to-wall interfaces	High	5.2.5
Wall System Joints	Window-to-wall joints	Medium	5.2.5
Wall System Joints	Door-to-wall joints	Medium	5.2.5
Wall System Joints	Bottom-of-wall to foundation joints	Very High	5.2.5
Bottom of Exterior Wall Detailing	Bottom of Exterior Wall Detailing	Very High	5.2.6
Foundations	Foundations	Low	5.2.7
Attachments	Patios, decks, and balconies	Very High	5.2.8
Attachments	Fences	Very High	5.2.8

Category	Building Component of Exterior Envelope	Relative Risk Ranking	Section Reference
Smoke and Ash Infiltrations	Smoke and Ash Infiltrations	Low-Medium	5.2.9
Energy Storage Systems	Energy Storage Systems	Low-Medium	5.2.10

5.2.1. ROOF COMPONENTS

As previously discussed in Chapter 3, Boulder County was and still is divided into two wildfire safety regulatory zones based on relative risk of wildfires in those geographies—Wildfire Zone 1 and Wildfire Zone 2 as shown earlier in Figure 14. Wildfire Zone 1 is generally the mountains and more forested portions of the County, while Wildfire Zone 2 generally consists of plains and grasslands. The areas impacted by the Marshall Fire were primarily in Wildfire Zone 2, and by regulation are required to achieve a minimum Class B roofing classification. Note: The City of Louisville and the Town of Superior required Class A roofs starting in 2013 to provide better protection against wildfire; however, these requirements did not apply retroactively to existing structures. In recent years, the area has experienced several severe hail events resulting in the replacement of many roofs. See Table 15 for a description of the different roof classifications in building/fire codes.

Table 15. Summary of Roof Classifications per Building/Fire Codes.

Roof Classification	Technical Description	Examples
Class A	This is the highest rating for roof coverings. Roof coverings in this classification are effective against severe fire exposures, provide a high degree of fire protection to the roof deck, do not slip from position, and do not present a flying brand hazard. Note: Coverings that pass the "noncombustible" standard no longer automatically achieve Class A and must be tested per E108 or UL 790.	▪ Clay and concrete tiles ▪ Metal panels, sheets, tiles, shingles on noncombustible decks/framing ▪ Brick or masonry ▪ Exposed concrete ▪ Most modern asphalt fiberglass composition shingles (Note: Cellulosic fiber asphalt singles, roughly pre-1980s, would not be included) ▪ Other noncombustible materials tested in accordance with ASTM E108 or UL 790 ▪ (Special) Fire-retardant wood shingles or shake with an additional fire-resistant underlayment as required to pass ASTM E108/UL 790
Class B	Roof coverings in this classification are effective against moderate fire test exposure, provide a moderate degree of fire protection to the roof deck, do not slip from position, and do not present a flying brand hazard.	▪ Fire-retardant shakes and shingles without the fire-resistant underlayment

Roof Classification	Technical Description	Examples
Class C	Class C roof coverings, which are effective against light fire test exposures. Under such exposures, the roof coverings afford a degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands.	▪ Aluminum roof coverings ▪ Recycled plastic/rubber roof covering
Non-rated	Roof coverings in this classification failed the fire test or have not been tested at all.	▪ Untreated wood shakes

Source: Society of Fire Protection Engineers (SFPE) WUI Handbook

Roof Construction and Coverings

The majority of residential roofs in the impacted areas were comprised of asphalt shingles or composite tiles with moderate slopes. A few metal roofs were also observed, but this was not typical (Figure 25). Most residential roofs appeared to have enclosed eaves. Many roof lines tended to be complex with multiple levels, peaks, gables, and joints (Figure 26) where vegetative debris and embers can accumulate leading to ignition of the debris and potentially the home.

Figure 25. Remains of a residential structure with a metal shingle roof system.

Figure 26. Typical roof system in the Boulder, Colorado area. Roofs tend to have multiple levels, peaks, gables, and joints where debris can accumulate and be ignited by embers.

Roof Vents

As local jurisdictions at the time and prior to the fire had not adopted a WUI code, most homes and other structures in the footprint of the fire were not required to provide ember protection for any vents throughout the exterior envelope of the building (inclusive of all types of attic vents, ridge vents, gable/dormer vents).

The intrusion of embers through roof vents is a major vulnerability leading to structure ignition during wildfires. The main concern with roof vents is that they can provide several openings where windborne embers, flames, and hot gases from wildfires can enter the attic space of a home leading to ignition of interior building contents. In addition, attic spaces in residential homes are typically not sprinklered (even if the home is provided with a residential sprinkler system) and can consist of exposed combustible building construction materials and flammable goods (e.g., cardboard boxes, old furniture, dust). Both roof inlets and outlets are considered vulnerable as wind-driven fire incidents can easily overcome outlet pressures, allowing embers and hot gases to readily enter a home or structure via these unprotected openings.

As the majority of destroyed homes had little evidence remaining for the MAT to observe the type and/or condition of roof vent protection provided, the MAT observed roof vent conditions for adjacent undamaged houses. In the field, several types of attic vents and roof openings (i.e., inlets and outlets for dryers, fireplaces, Heating, Ventilation and Air Conditioning (HVAC) systems, and other ducts) were observed to lack ember protection. Figure 27 shows typical conditions observed throughout the impacted residential neighborhoods, where most roof vents (e.g., attic vents, roof ridge, gabled roof) were not provided with ember protection.

Figure 27. Lack of vent protection in attic vents, gabled roof attics, and soffits in Superior and Louisville, Colorado.

Where screening was provided, the MAT observed that the screening materials were 1/4 inch, which would allow ember intrusion potentially leading to ignition of combustible materials in the attic space. In one case, attic vents or blocking between trusses was possibly blown out due to high winds, creating an opening for embers to enter the roof structure (Figure 28).

Figure 28. Wood blocking or attic vents blow out possibly due to high winds.

Chimneys

The majority of houses observed in pre-event aerial imagery, as well as during post-event data collection, had chimneys. Most chimney exteriors were either brick or stone, which are more fire-resistant than ones covered by exterior siding. Combustible wood chimney chases were also observed in surrounding neighborhoods. Chimneys not properly constructed with flashing and counterflashing materials can introduce a point of entry for embers at the interface of the roof the chimney chasing. See Section 5.2.2 for more details.

Solar Panels

The MAT observed that some homes had roof-mounted solar panel systems; several installations had mesh enclosures for the underside of the panel systems. These perimeter enclosures limit vegetative debris or embers from collecting below the solar panels and potentially providing an ignition source. The use of mesh enclosures was not consistently observed for all roof mounted solar panel systems (Figure 29).

Figure 29. Example of observed unprotected solar panel installation.

There are currently no fire test standards for solar panels exposed to wildfires. Photovoltaic (PV) systems are typically required to meet or exceed the fire classification of the roof assembly they are mounted to. As such, solar panels are addressed by code, but not at length in regard to wildfire exposures, particularly to ember accumulation and in-situ conditions.

Gutters

Most gutters on remaining houses as well as gutters observed among the debris appear to have been aluminum. Most gutters did not have guards to prevent accumulation of vegetative debris in the gutters. While gutter guards are not required by residential building codes for wildfire safety, they can limit the need to manually remove debris from gutters. In the Marshall Fire, debris that accumulated in gutters could have provided fuel for embers if the gutters were not cleaned out prior to the wildfire.

5.2.2. ROOF JOINT SYSTEMS

Roof-to-Roof Joints

Visual confirmation or inspection of roof joint systems were not feasible by the MAT; however, given the lack of limited wildfire regulations at the time and prior to the incident, it is likely that most homes in the impacted areas were not designed or provided with fire-resistant joint systems at the roof. This would include joints systems and construction detailing to limit the intrusion of embers, hot gases, and direct flames from burning vegetative debris often found at various roof joints (e.g., roof valleys, roof to dormer joints, roof to exterior wall joints, expansion joints).

Commonly observed roof joint vulnerabilities included:

- **Complex roof designs:** Many roofs were observed to have complex designs (Figure 30). These complex designs increased the number of joints between roof assemblies and wall systems, ultimately increasing the number of areas vulnerable to collection of vegetative debris, ember accumulation, and gaps where embers can penetrate the building exterior envelope. Though complex roofs can be designed to be resistant to ember intrusion from wildfires (e.g., overlapping roof covering, flashing at valleys/interfaces, overlapping underlayment, flashing, and counterflashing at roof-to-wall joints), it is unlikely that appropriate ember resistance joint detailing was provided at all locations. This is of concern particularly at the roof-to-wall joints, where unprotected joints/gaps at the interface of a roof assembly (even if Class A or B rated) and combustible wall siding can be vulnerable to ember intrusion or ignition of adjacent vegetative debris leading to structure ignition. See additional discussion below.

Figure 30. Example of an observed complex roof design.

- **Woven valleys:** Some roofs were observed using a woven-valley method to protect roof valleys (Figure 31). It is unknown if the underlayment below the woven valleys would be resistant to ember intrusion and ignition.

Figure 31. Example of a woven valley.

- **Limited use of metal flashing:** Where roof joints exist between walls and roof surfaces, there were very few visible examples of homes where metal flashing and counterflashing were installed to protect the joint (Figure 32). Most roof joints and interfaces adjacent to dormers and other wall systems (at roof level) accumulate vegetative debris throughout the year. During a fire event, embers will also accumulate in these locations, often leading to ignition of the vegetative debris and potential ignition of adjacent combustible dormer or wall siding.

Figure 32. Example of observed areas where use of metal flashing could provide additional protections.

Currently, there are no fire test standards to evaluate the resiliency of roof joints or joint systems to ember intrusion, direct flame impingement, or thermal transmission of heat via convection, or radiation from wildfires. Although there are a variety of fire test standards for joints in interior building fire components, none are applicable to the fire conditions presented by exterior wildfires. Because no test standards exist, this is unaddressed by current building codes.

Skylights-, Chimneys- and Vent-to-Roof Joints

Most skylight-, chimney-, and vent-to-roof joints were observed to be in decent condition. Some homes were observed to have chimney-to-roof joints that appear to have some gaps (Figure 33). There was an overall lack of use of metal flashing and counterflashing to protect these types of joints, leaving these areas more susceptible to ember intrusion, particularly for chimneys with combustible chases (Figure 34). For skylight- and vent-to-roof joints, the MAT team was unable to observe if the interface of these components with the roof system had appropriate flashing to limit ember intrusion at the joints.

Figure 33. Example of observed gaps at chimney-to-roof joint.

Figure 34. Example of metal flashing at joint between the skylight unit and the roof.

5.2.3. ROOF-TO-EXTERIOR WALL COMPONENTS

Roof Edge Detailing

Roof edge detailing appeared to be in good condition on most homes. There were a few observed homes that had some gaps at the roof edges. The following is a list of commonly observed vulnerabilities:

- **Open edges at profile-tiled roofs:** Some homes were observed to have profile-tiled roofs without any type of mortar or bird-stopping to protect the gaps created at roof edges (Figure 35). This leaves roof edges vulnerable to ember intrusion.

Figure 35. Example of observed profile-tiled roof with gaps at the roof edge.

- **Limited use of metal flashing:** Many homes had flat-tiled roofs with no visible metal flashing provided at the roof edge (Figure 36). Metal flashing at the roof edge provides another layer of protection from ember intrusion.

Figure 36. Example of observed vulnerable areas where metal flashing could provide additional protection.

Currently, no fire test standard to evaluate ember intrusion, direct flame impingement, or thermal transmission of heat via convection, or radiation from wildfires for roof edge detailing exists. Due to the lack of test standards, roof edge detailing protection from wildfires is largely unaddressed. NFPA 1144 does include considerations for roof edge detailing, but NFPA 1144 by definition is a Standard, and not a model code document. As such, it is rarely enforced by local jurisdictions.

Soffits and Soffit Vents

Most of the homes observed by the MAT appeared to have enclosed eaves. Soffits also were enclosed, and most had soffit vents. Homes throughout the impacted areas of the fire appeared to have a range of soffit vent types, opening sizes, soffit materials and soffit vent configurations. Of the range of soffit characteristics, the MAT was not able to confirm if appropriate soffit vent protection was provided. Unprotected soffit vents (i.e., openings larger than 1/8-inch) would readily allow the intrusion of embers into the attic space or combustible interstitial wall or roof spaces of the home.

Figure 37 shows typical conditions observed throughout the impacted residential neighborhoods, where most vents (e.g., attic vents, roof ridge, gabled roof) are not provided with ember protection.

Figure 37. Observed vent protection for soffit eave vents in Superior and Louisville, Colorado.

Head-of-Wall to Roof Joints

Head-of-wall-to-roof joints were generally observed to be in good condition, but some gaps were present on homes. Currently, no fire test standard exists to evaluate ember intrusion, direct flame impingement, or thermal transmission of heat via convection or radiation from wildfires for head-of-wall to roof joints. While a variety of test standards for joints in interior building fire components exist, none are applicable to the fire conditions presented by wildfires. Because no test standards exist, this is unaddressed by current building codes.

5.2.4. EXTERIOR WALL COMPONENTS

Exterior Wall Construction and Cladding

Homes in the impacted area, both damaged and undamaged, generally were of light-timber framed construction. Most homes appeared to have a combination of siding, either brick or stone veneers around garages and brick or stone chimneys. Siding materials included fiber-cement board, vinyl, and composite board. Some homes were observed to have stucco exteriors.

Based on observations as well as information provided by firefighters, structures and portions of structures constructed from noncombustible materials such as brick, stone, and stucco fared reasonably well. While brick, stucco, or stone exposed to flames often appeared blackened, likely from smoke, soot, and ash (Figure 38 and Figure 39), exterior walls constructed from these materials often remained standing. In some cases, brick and stone facades appeared to fail, but this is likely due to the underlying structure failing.

Figure 38. While blackened by smoke, soot and ash, concrete and brick elements remained standing more often than most other exterior wall construction materials.

Figure 39. Concrete block and brick around garages often remained partially or fully standing.

Of the various types of siding that were observed, fiber cement board appeared to perform well. Some homes that remained standing had evidence of ember impacts to the exterior wall but did not lead to ignition (Figure 40).

Figure 40. Some homes with fiber cement siding showed evidence of ember impacts to the exterior facade but did not burn. In this case, the base of the wall system had little to no combustible fuels providing the embers a fuel bed for ignition.

In comparison with fiber cement siding, other siding types such as vinyl generally performed poorly. These other siding types did not offer good protection against embers, flames, and radiant heat. Some evidence of vinyl siding melting was observed. Homes with combustible siding on the full elevation were more likely to ignite than walls with a noncombustible material near the bottom and combustible material above (Figure 40).

Detailing at joints and interfaces of exterior wall systems introduced additional vulnerabilities in the exterior wall system, which are discussed in sections below and further in Marshall Fire MAT document *Wildfire Resilient Detailing, Joint Systems, and Interfaces of Building Components* included in Appendix J.

Garage Doors

Many garage doors that were observed were double-car size with some homes having another single-car garage for a third vehicle. The doors appeared to be constructed primarily of metal materials, although wood and composite material doors were also common. Many garage doors observed did not have weather seals around the perimeter of the garage door frame. Gaps between frames and exterior walls, frames and doors, doors and ground provided opportunities for ember entry.

Some two-car garage doors that remained standing were scorched and melted or buckled. Gaps were observed between the door and the frame, which may have allowed embers to enter and become trapped. Based on observations, tracks also may have separated from the door frames, which may have been the result of high wind pressures acting on the garage doors. This also would have allowed embers to enter garage spaces.

Fenestration and Glazing

Homes in the area were observed to have both single- and multi-pane windows. Observations in the field as well as reviews of pre-event aerial imagery indicate that skylights were not common, but the MAT did observe a few. Of the skylights that were present, it is unclear if they were properly designed to limit ember intrusion, if they may have been operable and left open, or if the frames failed and caused the skylight to fall out. Multi-pane windows showed evidence of the outer panes breaking (Figure 41). Some window frames that were observed appeared to have had the seals around the glass panes melted by the extreme heat, which would have caused the panes to drop out and allow embers and flames to enter the structure. There are also accounts of the wind blowing debris into windows, breaking the glass, and allowing embers to enter the structure. This phenomenon has been reported to have occurred at the Element Hotel (destroyed during the Marshall Fire) in Superior and may also have occurred in residential structures.

Figure 41. Some multi-pane windows showed evidence of the outer glass breaking.

Tenant Separation Walls

The UBC, which preceded the development of the IRC, provides requirements similar to the requirements of the IRC for fire-resistance-rated wall assemblies between building units. Since the publication of the 2000 IRC, fire-resistance separation requirements for townhouses and two-family dwelling units have been specified separately from other building types. A common level of protection allowed throughout the various editions of the IRC is a tenant-separation wall with a 1-hour fire rating with exposure from both sides (i.e., the fire exposure could be applied from either side of the wall). These tenant separation walls are required to be continuous from the foundation to the underside of the roof sheathing, deck or slab and extend the full length of the common wall. Later editions of the IRC have been updated to allow exceptions to this requirement.

The 2006 IRC and later editions allow 2-family dwellings to have tenant-separation walls that do not extend through the attic in special cases (2021 R302.3, for example) where:

1. The ceiling is protected by a 5/8-inch (15.9 mm) Type X gypsum board.
2. There is an attic draft stop meeting Section R302.12.1 specifications above and along the wall assembly separating the dwellings.
3. The structural framing supporting the ceiling is protected by a 1/2-inch (12.7 mm) gypsum board or equivalent.

This exception could offer less protection than the tenant separation wall requirements for townhouses (i.e., a fire resistance-rated wall assembly that is continuous to the underside of the roof sheathing) due to the tendency for a fire to enter a roof system from the exterior and spread through attics. Additional research is needed to determine how this exception could contribute to structure-to-structure spread of fire.

The MAT observed cases of fire spreading between housing units where a tenant separation wall was not built to extend up and through attic spaces (Figure 42). Notably, there was an observed case of fire damage to a townhouse built in 1998 in Superior where the tenant separation wall did not extend up and through the attic; this construction violates the fire-resistance-rated wall requirements of the 1994 Uniform Building Code, in effect at the time of its construction. This case suggests that gaps in inspection and enforcement may have partly contributed to the lack of continuous tenant separation walls and its impact on unit-to-unit fire spread. Due to limited MAT observations on this topic, it is not clear whether all damage of this type was due to code enforcement gaps or because some buildings were built before formal code adoption and enforcement of tenant separation wall requirements.

Figure 42. A Marshall Fire-damaged townhome built in 1998 in Superior with tenant separation wall not extending to underside of roof sheathing.

Vents in Exterior Walls, Crawlspaces and Basements

As local jurisdictions at the time and prior to the Marshall Fire had not adopted the IWUIC or local wildfire building ordinances, most homes and other structures in the footprint of the fire were not required to have or provided with ember protection for any vents throughout the exterior envelope of the building (inclusive of vents in exterior walls, crawlspaces and basements). The intrusion of embers through exterior wall, crawlspace, or basement vents is a major vulnerability that can lead to structure ignition during wildfires. The main concern with exterior wall, crawlspace, or basement vents is that they can provide several openings where windborne embers and convective heat from wildfires can enter the structure leading to ignition of interior building contents and other building components. Both vent inlets and outlets are sources of vulnerability, particularly due to the overpressures caused by fire and high wind conditions adjacent to the building façade.

As the majority of destroyed homes had little evidence remaining for the MAT to observe the type or condition of vent protection provided, the MAT evaluated vent conditions for adjacent undamaged homes. Several types of wall vents, crawlspace, and basement openings (i.e., inlets and outlets for dryers, fireplaces, and HVAC systems) observed by the MAT did not have ember resistant opening protection. Figure 43 shows typical conditions observed throughout the impacted residential neighborhoods, where most vents (e.g., crawlspace, basement vents, dryer vents) were not provided with ember protection to limit the intrusion of embers during a wildfire, particularly a wind-driven fire.

Figure 43. Lack of vent protection in exterior walls, crawlspaces, and basements in Superior and Louisville, Colorado.

5.2.5. WALL SYSTEM JOINTS

Detailing at various wall system joints and interfaces throughout the exterior envelope of homes (e.g., foundation-to-wall siding interface, window-to-wall joints, wall-to-wall joints) often have gaps or spaces at the interfaces between them, leaving these areas vulnerable to ember accumulation or intrusion. These gaps can lead to embers penetrating combustible interstitial spaces of exterior walls (See Figure 44). These spaces do not typically contain any kind of fire detection to notify building occupants of a fire or suppression systems to extinguish a fire. As such, a fire in combustible interstitial spaces due to ember intrusion can go unnoticed for long periods, allowing the fire to grow to uncontrollable levels before being detected (Refer to the Marshall Fire MAT document *Wildfire Resilient Detailing, Joint Systems, and Interfaces of Building Components* in Appendix J for additional information). This was observed by firefighters in the field during the Marshall fire.

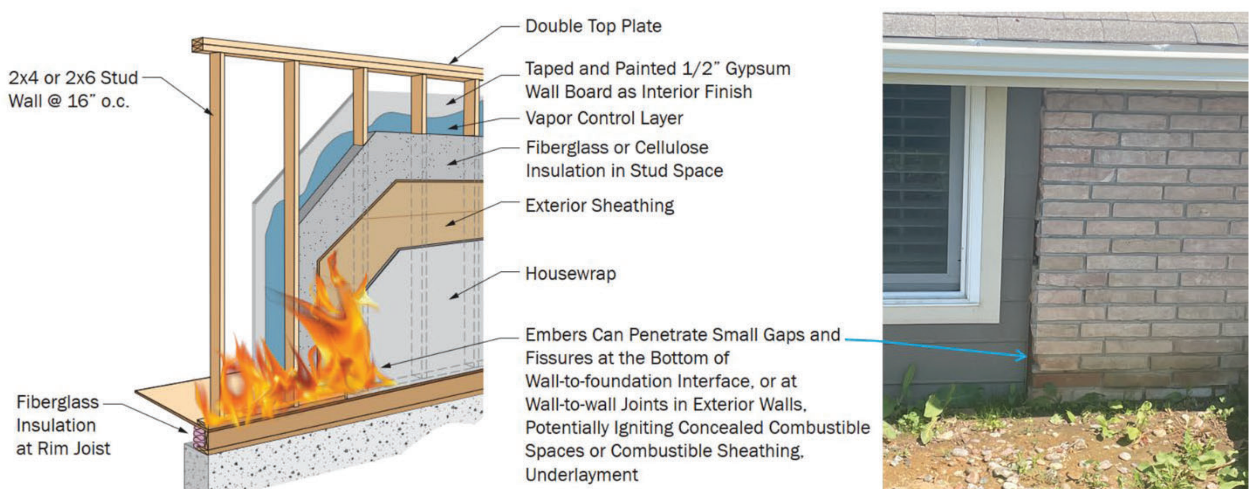


Figure 44. Example of gaps in common exterior wall construction (e.g., interfaces of wall systems, butt joints between siding, bottom-of-wall to foundation details) that can lead to ember penetration, and potential fire in combustible interstitial spaces. Note: At butt joints of exterior siding, embers may penetrate these joints leading to ignition of exterior combustible cladding before burning into the wall cavity.

Wall-to-Wall Interfaces

Of all the joint systems observed on the exterior of buildings, wall-to-wall interfaces were among those that appeared to have numerous gaps, cracks, or fissures present, particularly at the interface of different exterior cladding materials (e.g., brick façade with cement board siding). These gaps create spaces for combustible debris to accumulate (e.g., leaf litter, dust) over time, creating a fuel source within the interstitial spaces, gaps, or joints. These gaps can be in areas that are not easily accessible, which make it easier for combustible debris to accumulate unnoticed. During a wildfire event, embers can penetrate the gaps, readily igniting any combustible debris that may have accumulated. This could lead to ignition of the exterior cladding (where combustible) before burning into the interior wall cavity. Note: Even in joints or gaps where combustible debris does not readily accumulate (e.g., vertical gaps/joints), embers can still become lodged in the gaps and provide a potential source of ignition where combustible cladding or other combustible construction materials are present.

Currently, no fire test standard exists to evaluate ember intrusion, direct flame impingement, or thermal transmission of heat via convection or radiation from wildfires for wall-to-wall joints. While a variety of test standards for joints in interior building fire components exist, none are applicable to the fire conditions presented by wildfires. Because no test standards exist, this is unaddressed by current building codes.

Windows-To-Wall Joints

Window assemblies appeared to mostly be in good condition, with few observed gaps, cracks, or fissure at the joints between the window frame and wall assemblies. It should be noted that this was after the fire event where many windows may have been newly replaced.

Windows are required to comply with requirements to resist the effects of fire, but this does not necessarily address the joint between the window and the wall. Several NFPA test standards exist for the testing of window assemblies, however the mounting for the testing of the window assembly is often left up to the manufacturer. Therefore, any joint protections that the window manufacturer may provide in the field is not specifically being tested for wildfire exposures.

Doors-To-Wall Joints

Most door assemblies at the interface of the door frame and wall that the MAT was able to observe appeared to have minimal gaps or cracks. Some door assemblies had integrated “dog doors”, which typically do not come with ember protection systems. This is a gap in current codes and standards but is a major source for potential ember intrusion into a home.

Doors are required to comply with requirements to resist the effects of fire, but this does not necessarily address the joint between the door and the wall, the door undercut or the presence of “doggie doors”. The IWUIC and California Building Code both include special considerations for exterior doors, and several NFPA, Underwriters Laboratories (UL), and ASTM test standards exist for the testing of door assemblies. However, similar to tests for window assemblies, joint protections that the manufacturer may install in the field are not specifically being evaluated for wildfire exposures.

Bottom-of-Wall to Foundation Joints

The MAT observed bottom-of-wall to foundation interfaces or joints to have large gaps between the exterior cladding and the wall sheathing, and in some cases, exposed flammable wall cavities. The bottom edge of the wall assemblies did not appear to be detailed or constructed to protect the bottom edge of the assembly from ember, flame, or hot gas intrusion. The gaps observed were assumed to be due to the shifting of foundations, weathering, or other wear-and-tear of the exterior building components. Little to no mitigation measures had been taken to fill these observed gaps.

Currently, no fire test standard exists to evaluate ember intrusion, direct flame impingement, or thermal transmission of heat via convection or radiation from wildfires for bottom-of-wall to foundation joints. Though a variety of test standards for joints in interior building fire components exist, none are applicable to the fire conditions presented by wildfires. Because no test standards exist, this is unaddressed by current building codes. See also Section 5.2.6.

5.2.6. BOTTOM OF EXTERIOR WALL DETAILING

For residential homes, a minimum level of protection at the bottom of exterior walls is required by code for wood members to limit decay damage in certain locations. One of these locations is where wood siding, sheathing, and wall framing on the exterior of a building has a clearance of less than 6 inches from the ground or less than 2 inches vertical from concrete steps, porch slabs, and patio slabs. Similarly, horizontal surfaces exposed to weather are vulnerable to decay except where siding, sheathing, and wall framing are of naturally durable or preservative-treated wood. While this requirement is intended to increase protection against decay and termites, where the clearance is provided to avoid additional protection requirements, it also provides a degree of fire protection against surface fires because blown embers may ignite flammable materials that might burn at the base of a home, such as mulch. For wildfire protection, a minimum of 6 inches vertical from any horizontal surface is typically required regardless of the materials used for the wall siding or for the horizontal surfaces to limit embers from igniting flammable materials, leading to ignition of the siding material (where combustible) or penetrating behind the exterior cladding and into the interstitial spaces of the wall system.

In the field, the MAT observed that some homes appeared to have adequate clearance at the bottom-of-wall-to foundation to avoid additional protection requirements (Figure 45); however, this clearance was not consistently provided around the entire perimeter of the home, or at all for other homes.

Figure 45. Example of a home provided with adequate bottom-of-wall clearance.

There were two main "non-compliant" conditions that were frequently observed:

1. No clearance provided: Many homes did not have 6 inches of non-combustible bottom of wall clearance (Figure 46). The MAT was unable to verify if siding was of naturally durable or preservative-treated wood by visual inspection alone, so it is possible that some homes fell under this exception. Homes where this clearance is not provided are vulnerable to directly contacting accumulated embers at the base of the wall or exposed to surface fire caused by the embers that can burn up to the building perimeter and enter interstitial spaces in the exterior wall envelope.

Figure 46. Example of a home without adequate bottom-of-wall clearance.

2. Obstructions to clearance: Some homes were provided with the required clearance but had decorative elements covering the clearance area (Figure 47). The presence of these decorative features does not meet the original intent of the requirement, leaving the home vulnerable to surface fires.

Figure 47. Example of home provided with adequate bottom-of-wall clearance but with obstructions.

5.2.7. FOUNDATIONS

Foundations of homes were generally slabs-on-grade, basements, or walk-out basements. Most of the observed foundations were constructed of cast-in-place concrete though a few were constructed of reinforced concrete masonry units (CMU). Walk-out basements had window and door openings. Full basements appeared to have window wells and window openings. Window wells can provide places for debris to accumulate if they are not cleaned out regularly.

GEER conducted studies of building foundations during field data collection that was completed primarily during January 24–29, 2022. Additional data collection occurred in February and April 2022 and throughout the preparation of their report, which was released May 2022. The GEER team estimated the temperature foundations reached during the fire by comparing the colors of concrete provided by Hager (2014) to the foundation itself (GEER, 2022). The GEER team determined the homes burned at temperatures ranging from 300˚Celsius to 900°Celsius (GEER, 2022). Damaged or destroyed homes nearest to still-standing homes with minimal damage were exposed to temperatures on the lower end of the range. The GEER team also observed spalling of concrete on walkways which typically coincided with homes exposed to the higher temperature ranges. Firefighters indicated that some foundations exploded, which may have been the result of the concrete heating rapidly.

5.2.8. ATTACHMENTS

Attachments to homes are on the exterior of the structure and include decks, patios, porches, balconies, exterior stairways, and fences. Combustible attachments can act as “wicks” that allow fire to travel along it to where it is attached to the home, potentially igniting the home.

Patios, Decks, and Balconies

Almost every home that was observed had at least one combustible attachment—usually a combustible deck or patio. Combustible balconies did not appear to be common but were observed on some of the remaining houses so may have been present on some of the houses that burned.

Patios

Patios are often hardened open spaces that contain flammable materials such as furniture with cushions, grill propane tanks, and planters. These spaces can provide plenty of oxygen and fuel to spread a fire. Patios were observed adjacent to some of the houses in the Marshall Fire area. Back patios were usually attached to the house at or near grade and most often were constructed of concrete, brick, or stone, although a few used wood or composite materials. Patios that were observed generally had furniture, grills, and other temporary items (Figure 48) which can contribute to fire spread. Furniture made of metal was occasionally observed to survive but some of these items were misshapen, potentially by the heat of the fire.

Figure 48. Patios often contained furniture and grill propane tanks which are known to contribute to fire spread.

Decks

Decks attached to the house were often elevated above ground, in some cases by one story and appeared to be primarily constructed from wood and/or composite materials. Many of these elevated decks had exterior stairways leading to the ground level. Both decks and patios were observed to have combustible materials or other fuel sources stored on and under them, such as furniture, grill fuel, grill covers and decorative pieces. Elevated decks were also observed to frequently have combustible materials and other fuel sources stored beneath them, including furniture, firewood, lawnmowers, chairs, and other equipment (Figure 49).

Figure 49. Elevated decks and concrete patios attached to homes were commonly observed. Many elevated decks had combustible materials stored beneath them.

Combustible decks can pose a significant fire hazard in the event of a wildfire. Many existing decks are constructed of combustible materials such as wood and wood-plastic composite products that are vulnerable to under deck flame exposure in a wildfire event. One of the main concerns associated with decks is the large surface area they present for collecting embers that lead to ignition of materials located on the deck or the deck itself. Similar to eave overhangs, unique fire-induced flows can lead to the accumulation of embers and hot gases in the underside of elevated decks, potentially leading to ignition of the deck where combustible construction framing elements are exposed. Decks that are near grade level are susceptible to direct flame impingement from surface fuels and other adjacent vegetation (Figure 50). Anecdotally, a resident of the Sagamore neighborhood was an eyewitness to the wood decking of his neighbor's house (which was the first structure to ignite in the southern portion of Sagamore at the WUI) catching fire and immediately igniting the home.

Figure 50. Combustible decking directly attached to a single-family residence in Old Town in Superior, Colorado.

Balconies

Balconies have the potential to serve as ember collectors which can then ignite the home. Because they are elevated, balconies also can catch fire from below, increasing the potential of spreading the fire to upper portions of the house (Figure 51). While balconies did not appear to be common on single-family homes, a few upper level and rooftop balconies and terraces were observed.

Figure 51. Balconies can catch on fire from below, which can result in spreading fire to upper levels of the house.

Fences

Many homes and properties throughout the impacted areas had combustible (primarily wood) fences, serving as both property line separations and privacy barriers (Figure 52). In most cases, these wood fences were observed to frame directly into the exterior walls of a home and were oftentimes shared fences with neighboring homes (Figure 53).

Figure 52. Combustible fencing directly attached to a single-family residence in Rock Creek Ranch in Superior, Colorado.

Figure 53. Additional examples of combustible fencing attached directly to single-family residences in Louisville, Colorado.

Combustible fences can become hazardous in the event of a wildfire, particularly if they connect directly to a structure. Typical wooden post-and-board fences, particularly when old and weathered, can provide a "wick" leading directly to the structure. The bottom of fences can collect debris that, when combined with combustible fencing, can become a fuel source to carry fire directly to the structure and ignite the building through radiant heat, convective heat, or direct flame contact. Because fences are often just below the eaves of a residential structure or near other vulnerable components such as windows, there is the potential to carry the fire up to the eaves and thus to the roof or break the windows and let embers and flames in. Additionally, fences can also create access problems for fire crews attempting to enter a yard during a fire event. When coupled with other combustible fences (back-to-back), the potential fire load can be further exacerbated (NIST, 2022).

During site visits, the MAT observed numerous instances where wooden fences provided a major source of fire spreading either from wildland/open spaces (Figure 54) or from home-to-home (Figure 55). It is worth noting that the MAT observed a significant number of properties having timber property line fences and privacy fences reinstalled during rebuild.

Figure 54. Fences behind communities may have acted as wicks, drawing fire to the neighborhoods.

Figure 55. Sample evidence of combustible fencing attached directly to single-family residences in Louisville, Colorado, and serving as a fire pathway to an adjacent home.

5.2.9. SMOKE AND ASH INFILTRATION

The MAT did not enter any affected homes so information regarding smoke, ash, and soot could only be obtained through interviews. Many homes that were not burned by the fire still had to contend with smoke, soot, and ash infiltration. Smoke, soot, and ash damage cleanup and restoration can be expensive and often requires the removal of existing fiberglass batt insulation, porous materials, and replacement of damaged electronic equipment and fixtures that cannot otherwise be cleaned.

While there is no way to completely avoid smoke, soot, and ash infiltration, adding stronger door and window seals, shutting down air intakes, and using thicker insulation can help reduce the risk of infiltration. Such techniques can also make the home more energy efficient, but the flammability of sealants and non-fiberglass insulation must be examined to ensure code compliance and avoid increasing structural fire risk. For more information, refer to Marshall MAT document *Homeowner's Guide to Risk Reduction and Remediation of Residential Smoke Damage* (Appendix D).

5.2.10. ENERGY STORAGE SYSTEMS

Some parts of the U.S. are starting to see a shift to using systems that use non-traditional sources of power. In some instances, these systems can store their energy on site in Li-ion batteries. These batteries are known to pose an environmental and potential explosion hazard if they ignite. Though not widespread, the MAT observed evidence of the potential for some of these ESS to be present in commercial and residential facilities.

Firefighters indicated some firefighting priorities were determined based on the need to protect areas containing known Li-ion battery ESS, including rooftop solar arrays and battery backup systems for homes. While the location of all energy storage systems was not known, firefighters defended areas of known concentration of these systems (e.g., vehicle dealerships) due to concerns about potential environmental contamination, potential explosions, and to reduce the likelihood of re-ignitions.

An vehicle dealership in Superior was one location identified as having had multiple Li-ion batteries on-site in the vehicles for sale and service. Several homes were observed to have rooftop solar panels, which suggests that these homes may also have Li-ion battery storage systems on the property (though not common).

Li-ion battery ESS damaged by fire can exhibit thermal runaway, allowing battery units to ignite or re-ignite even after fire has been extinguished. Product enclosures, especially vehicle battery packs, prevent means for delivering extinguishing agents to cells in thermal runaway; this factor prevents the effectiveness of traditional automatic and manual fire suppression approaches. No singular best approach has been developed for extinguishing fires involving the ignition of Li-ion battery ESS. In addition, current model code fire safety provisions for installation and storage of ESS do not explicitly consider the potential risks associated with wildfire exposure. WUI codes and best practices for wildfire hazard-resistant construction may also contain gaps in protections for ESS. For example, wall-mounted ESS are at risk of ignition during a wildfire but are not prohibited by common defensible space standards.

Chapter 6: Conclusions and Recommendations

The MAT uses observations to draw conclusions and make actionable recommendations. The conclusions and recommendations presented in this report are based on the MAT's field observations; evaluation of relevant codes, standards and regulation; as well as information gathered from interviews with first responders and subject matter experts. They are intended to guide homeowners and building owners, community planners, design professionals, contractors, state, and local officials, building code professionals, and standards organizations. Some additional recommendations are directed to FEMA and other industry partners. Chapter 6 provides detailed information on the conclusions and recommendations, including a summary table. The recommendations have been summarized and grouped into overarching concepts here:

- Section 6.1 – Standardized Wildfire Terminology Recommendations
- Section 6.2 – Wildfire Hazard and Risk Recommendations
- Section 6.3 – Overall Community and Neighborhood/Subdivision Level Recommendations
- Section 6.4 – Parcel/Building Level Recommendations
- Section 6.5 – Summary of the Conclusions and Recommendations

The recommendations are presented as actionable guidance to the state, affected communities, and those who are involved with the design, construction, and maintenance of the built environment across the state. The state and the entities involved in reconstruction and mitigation efforts should consider these recommendations in conjunction with their existing priorities and resources when determining how they can or will be implemented.

Many of the conclusions and recommendations center on encouraging state and local governments to assess their code development and enforcement programs and implement a code and standards program that will withstand the elements over time. In addition, the conclusions and recommendations provide guidance on ensuring that the buildings provide robust systems to withstand fire events.

The MAT Conclusions and Recommendations are prioritized within each section as those that may be most important to implement by the state, community or interested party.

6.1. Standardized Wildfire Terminology and Public Education Recommendations

Conclusions and recommendations in this section generally fall under the Standardized Wildfire Terminology and Public Education concept.

Conclusion CO-1

Current WUI definitions do not accurately reflect the diversity of wildfire environmental settings and community designs that are prone to wildfire threats, including the area impacted by the Marshall Fire. The definition of “WUI” is not comprehensive enough in that it typically only describes environmental conditions such as vegetation and not explicitly the hazard, risk or vulnerabilities that is presents. This has led to the perception of “wildland” as sparsely populated, heavily wooded areas in rugged, mountain terrain with steep slopes.

Recommendation CO-1a

The NWCG, in coordination with FEMA and the United States Fire Administration (USFA), should update and expand upon the definition of “wildland-urban interface” to clarify that “wildland” includes a range of environments such as grasslands, shrublands and not just forests and trees. Guidance should be provided for local and state governments to adopt and adapt the NWCG’s definition to meet specific needs, such as defining “interface,” “intermix” and “occluded” space. For example, the definition of WUI published in the Federal Register on January 4, 2001, by the U.S. Forest Service, Bureau of Indian Affairs, Bureau of Land Management, Fish and Wildfire Service and National Park Service begins by using the definition, “The urban wildland interface community exists where humans and their development meet or intermix with wildland fuel.” It then identifies three categories of communities: interface, intermix and occluded. (See Section 1.3.2 for additional information.) Alternatively, develop additional terminology that reflects the different environments where catastrophic fires can occur so people who do not live in what is commonly perceived by the public as the “wildland” better understand their risk especially as the wildfire risk expands into urban areas.

Recommendation CO-1b

Local and state governments should raise awareness and provide educational programs for their citizens about the various local conditions that define the “WUI.” Communication regarding the definition should include categories of communities, types of natural and built environment fuels, and natural or man-made topographic features (such as ridgelines, steep slopes, drainage ditches etc.) that introduce fire flow paths into the community and increase wildfire behavior (e.g., intensity, rate of spread). Community education and understanding of the definition of “WUI” could support adoption of the IWUIC with local amendments, and integration of Colorado State fire hazard and risk maps into the development of local WUI maps.

6.2. Wildfire Hazard and Risk Recommendations

Conclusions and recommendations in this section generally fall under the Wildfire Hazard and Risk Considerations concept.

Conclusion CO-2

Though various forms of wildfire hazard and risk mapping layers have been developed by some state and federal agencies to address a variety of applications (e.g., land use management), a national, **consensus-based** wildfire risk mapping for community planning and building wildfire safety does not currently exist. The lack of such hazard delineation limits an understanding of wildfire "risk," with respect to both wildfire hazard severity levels and associated **return intervals at a national scale**, which are already provided for other hazards (e.g., wind, seismic, flooding). In turn, there is limited appreciation of how developing and adopting community wildfire planning, building codes and standards, and other wildfire programs can help mitigate WUI fire impacts to communities and structures.

Recommendation CO-2a

The USFA, NFPA, USFS and NIST should consider partnering with architectural and engineering standards development organizations to create a national, consensus-based wildfire hazard severity map that includes mean recurrence intervals for at-risk areas (i.e., wildfire "risk" map). The wildfire risk map should follow a similar structure to the ASCE 7-22 Basic Wind Speeds Maps or ICC-500 (2020) Design Wind Speeds for Tornadoes map for storm shelters. The intent is to provide a wildfire "risk" map akin to those provided for other hazards (e.g., seismic, flooding) such that national level policymakers can make risk-informed decisions using equivalent hazard risk mapping.

Recommendation CO-2b

The USFA should work with federal interagency and SLTT partners to explore development of national, consensus-based wildfire hazard severity zone maps with mean recurrence intervals that guide community and parcel-level decision making and trigger the use of fire safety requirements prescribed in the IWUIC or other model WUI, building or fire codes.

Recommendation CO-2c

Where wildfire hazard or risk maps already exist, local jurisdictions should consider using those maps for creating or updating local regulatory WUI maps. This effort should include an evaluation of the need to develop new or update existing WUI risk zones. Local jurisdictions should incorporate these WUI maps into their comprehensive plans, local hazard mitigation plans, zoning ordinances, and any local building and fire code requirements.

Conclusion CO-3

Current practices in assessing wildfire risks to the built environment are not based on risk-informed approaches analogous to other hazards (e.g., seismic, wind), where recurrence intervals and damage potentials are quantified at the national level. This limits cross comparisons for national level decision-making. There is no standard threshold for meeting building code requirements to reduce wildfire risk. For example, since 2000 there has been an average of over 70,000 wildfires per year in the U.S. impacting 7.0 million acres annually (Congressional Research Service, 2022). These fires have cost nearly $39 billion in suppression costs alone (National Interagency Fire Center, no date). The ten costliest wildfires in the U.S., nine of which have occurred since 2000, have resulted in estimated insured losses of an additional $44 billion (Insurance Information Institute, 2023). By comparison, five of the ten most expensive earthquakes to strike the U.S. have occurred since 2000 have resulted in approximately $14.4 billion in damages (Statista, no date).

Recommendation CO-3

Similar to the risk-informed approaches used for other hazards such as flood, wind, and earthquake, NFPA and ICC should consider working together to standardize development of acceptable wildfire risk thresholds based on risk-informed methods. Tie the risk levels that are developed to code requirements based on graduated levels of risk and importance. Identify other stakeholders that can contribute, such as insurance providers.

6.3. Community and Neighborhood/Subdivision Level Recommendations

Conclusions and recommendations in this section generally fall under the Holistic Wildfire Resiliency concept.

Conclusion CO-4

The Marshall Fire demonstrates how characteristics in the natural environment that markedly influence the behavior of wildfires (i.e., topography, weather, fuel) can interact with other natural hazards such as long-term drought and high wind to exacerbate the risk and behavior of a wildfire. Traditional hazard mitigation plans identify hazards as singular events and neglect the interactions between them.

Recommendation CO-4

AHJs in wildfire-prone areas should consider adopting approaches to wildfire mitigation that identify multi-hazard risks and collectively address risk reduction through land management and building mitigation practices. To be most effective, local hazard mitigation plan strategies should include the adoption and enforcement of hazard-resistant building codes (i.e., ICC model codes).

Conclusion CO-5

Historically, national- and state-level wildfire mitigation planning and preparedness have primarily targeted forest and woodland areas in the WUI. Many community plans, including the Boulder County Community Wildfire Protection Plan, focus on wildfire mitigation in forested and woodland landscapes within the WUI. However, a growing understanding of *wildland fire* risk calls for more wildfire mitigation strategies and programs targeting grasslands, shrublands and various man-made land uses and designs that interact with the natural environment (e.g., greenbelts, recreational spaces, flood control measures). For example, the Marshall Fire readily spread from wildlands to and within suburban and urban settings via undeveloped grasslands, open spaces, drainage channels and other flood control areas, and mostly unmanaged greenbelts.

Recommendation CO-5

Community planners should assess opportunities to apply landscape and parcel-level hazardous fuel maintenance and defensible space strategies to publicly owned outdoor, recreational, and open space, as well as undeveloped grassland and shrubland adjacent to the community. Comprehensive wildfire mitigation should address the different pathways for wildfire to spread through the landscape, including intermix and occluded zones and both natural and developed areas not traditionally understood or perceived to be associated with the WUI (e.g., grasslands, shrublands). This should include development of wildfire-specific land use planning, zoning restrictions, subdivision planning, and associated guidance, policies, and procedures to limit development in high-wildfire hazard areas without appropriate holistic wildfire risk assessment and mitigation planning.

Conclusion CO-6

While jurisdictions impacted by the Marshall Fire have taken steps to incorporate and coordinate multi-hazard planning, open space management, and community design into their wildfire risk assessments and mitigation strategies, these strategies are not yet consistent across all levels of planning and planning resources. The inconsistent and coordination-limited application of these strategies across all planning agencies, documents, and resources limits comprehensive strategy implementation and interagency coordination.

Recommendation CO-6

Community planners, building code and fire officials should consistently incorporate and coordinate comprehensive wildfire management strategies across all planning codes, standards, policy and guidance documents, including comprehensive or long-range planning, CWPP, hazard mitigation plans, building and fire safety codes/standards/local ordinances, energy codes, landscaping codes, forest, and open space plan. These plans should include all tiers of wildland fire mitigation, including landscape-level management, community planning, zoning, and parcel-level design.

Conclusion CO-7

During the Marshall Fire, water collection and diversion features (e.g., drainage ditches) and greenbelts overgrown with vegetation provided pathways for wildland fire to spread along the ground surface into urbanized areas. These “wildfire superhighways” have topographic features that channel and facilitate fire direction and flow. Dense vegetation provided additional fuel that led to more severe conditions. Although they currently have limited use in the Western U.S., parcel-level, vegetative fuel breaks have been demonstrated to be effective in impacting wind-driven fire behavior and providing time for residents to evacuate homes or structures during an impending fire.

Recommendation CO-7a

AHJs should consider requiring vegetated water collection and diversion features, greenbelts, parks and vegetated islands/bioswales that interact or interconnect wildland spaces with the built-environment in high fire prone areas to be regularly maintained through adoption of ordinances and provisions in maintenance contracts. Ordinances and maintenance contract provisions should indicate frequency of maintenance and time(s) of year that different techniques can be used. These ordinances and contracts also should require debris to be cleared from the banks of the water collection and diversion features and flood fringe areas.

Recommendation CO-7b

Local ordinances should require the use of diverse native, fire-resistant vegetation species in water collection and diversion features, greenbelts, parks and vegetated islands/bioswales that interact or interconnect wildland spaces with the built environment in high fire prone areas. The ordinances should address types and placement of species, as well as horizontal and vertical densities of species.

Recommendation CO-7c

State foresters should consider working with authorities having jurisdiction and other subject matter experts to evaluate the effectiveness of community and parcel-level vegetative fuel breaks and make recommendations for priority local areas to incorporate science-based vegetation management best practices. Create fuel management strategies such as vegetation breaks in greenbelts and grasslands adjacent to critical infrastructure (i.e., primary/secondary evacuation routes, communication systems, water supplies and associated equipment, electrical infrastructure) and populated areas to create defensible spaces. This may also include various integrated design (e.g., perimeter golf courses, agriculture belts, walkways) and “green” strategies (e.g., prescribed grazing), beyond traditional fuel breaks (e.g., mastication, prescribed burning) between these areas and populated areas. These breaks between communities and grasslands, shrublands and unmanaged open spaces can help to slow the spread of fire.

Conclusion CO-8

Current community and neighborhood level planning and design requirements in many high wildfire risk areas do not sufficiently incorporate wildfire safety considerations for landscaping. Local governments do not feature “approved” or “prohibited” plant lists or BMPs specific to local environmental settings and wildfire risks. Pervasive use of non-native, non-fire adapted, easily ignitable plants, ornamental vegetation, and inconsistent design and management practices (e.g., significant use of wood mulch, juniper bushes) contributed to the fire fuel hazard.

Recommendation CO-8a

AHJs should consider adopting zoning, codes and ordinances that integrate wildfire safety concepts into landscape planning, design, construction, long-term maintenance, and inspection. Requirements should address landscaping and residential planning concepts such as setback distances and having multiple entrances/exits to subdivisions for evacuation purposes.

Recommendation CO-8b

Local governments and community planners should coordinate with entities such as the Cooperative Extension Service, universities, and State forestry agencies to develop and socialize "approved" wildfire-resistant plant lists and landscaping strategies for use by developers, homeowners' associations, and homeowners.

Recommendation CO-8c

HOAs and local governments should consider partnering with wildfire education providers such as Firewise USA®, Wildfire Partners, IBHS Wildfire Prepared Home Program and Fire Adapted Communities Learning Network to educate landscapers and homeowners about ways to develop and implement mitigation strategies that decrease wildfire risk at the parcel and neighborhood level. The strategies that are developed should provide guidance on landscaping layouts, particularly with respect to the home ignition zone.

Conclusion CO-9

Local subdivision regulations do not include provisions that adequately address wildfire risk.

Recommendation CO-9a

AHJs in wildfire risk areas should consider working with their local fire departments to develop and adopt subdivision regulations that address wildland fire risk, including structure density in the WUI, appropriate access/egress capacity and separation, adequate water supply, requirements for fire protection and vegetation management plans, and procedures for subdivision evaluation and approval.

Recommendation CO-9b

AHJs should consider incorporating WUI terminology into local codes and ordinances to improve understanding of WUI concepts. This approach provides uniformity in messaging between communities, which can lead to a broader understanding of wildland fire risk and mitigation approaches.

Conclusion CO-10

The combined impact of natural hazards and weather conditions (e.g., high wind, combustible vegetation, and cold temperatures) can create disproportionate risks for at-risk communities. Several manufactured home communities in Boulder County sustained substantial damage or were permanently destroyed by high winds that accompanied the Marshall Fire ("Marshall Fire Recovery Milestones", n.d.). Rocky Mountain PBS also noted that residents of manufactured homes were vulnerable to cold temperatures when utility companies turned off electricity and natural gas to prevent ignition by power lines (Moore, 2022).

Recommendation CO-10

Communities with moderate to very-high wildfire risk should investigate and incorporate the vulnerabilities of at-risk communities (such as access to support recovery services) into multi-hazard wildfire mitigation planning, response, and recovery efforts.

Conclusion CO-11

Parcel/lot sizes in densely spaced neighborhoods may limit homeowners' abilities to satisfy best practices in defensible space. Because these lot sizes generally are fixed and cannot be changed, defensible space needs to be established at the neighborhood or community level.

Recommendation CO-11a

AHJs should consider working with fire departments, planning departments, and wildfire experts to develop local ordinances, standards and guidance documents for communal defensible space in overlapping ignition zones. Guidance documents should include audiences such as homeowners' associations and individual homeowners.

Recommendation CO-11b

AHJs should consider integrating and mainstreaming wildland fire safety concepts throughout the regulatory life cycle from planning and zoning to design and permitting to construction to long-term maintenance and inspection. This may include wildfire protection planning, environmental impact reports that include wildfire risks, zoning, general plans, landscaping codes, and safety elements. This may also include increasing structure separation distances in residential zoning ordinances in high wildfire risk areas.

6.4. Parcel/Building Level Recommendations

Conclusions and recommendations in this section generally fall under the Building Codes and Standards concept.

Conclusion CO-12

The current version of the IWUIC does not fully address needs at the building-, parcel- and community-levels.

Recommendation CO-12a

The ICC should consider working with the National Institute of Building Sciences (NIBS) and NIST to develop and include two performance objectives for the IWUIC—one for life-safety and one for structure survivability without the benefit of firefighting. Develop requirements to meet each of the performance objectives. This approach allows communities to understand and adopt a version of the IWUIC that most closely meets their needs.

Recommendation CO-12b

The ICC should consider revising the IWUIC to address wildfire planning and mitigation at different physical levels, including the building, parcel, neighborhood/subdivision, and community scales. Incorporating mitigation measures at different scales will provide a more comprehensive approach to addressing community wildfire risk.

Conclusion CO-13

Many of the current fire testing standards were not developed for wildland fire and therefore do not comprehensively address the risk of wildfire to structures.

Recommendation CO-13

The USFA should consider collaborating with ICC, fire testing laboratories, NIST, and other interested parties to develop wildfire-specific fire test standards for building construction and materials, exterior building components and details, exterior fire protection systems, interior suppression systems, etc. These fire test standards should consider the development of a standard wildfire exposure (including ember exposure), performance criteria, pre-fire testing weathering standards, the use of various exterior building construction materials, products, and systems on the exterior of buildings and suppression systems (both interior and exterior)

Conclusion CO-14

The I-Codes such as the IBC, IRC and the ICC lack a coordinated approach to addressing the risk of wildland fire to structures in the WUI. Some provisions in one of the I-Codes may not fully consider the risk of another hazard addressed by another of the International Codes.

Recommendation CO-14a

The ICC should consider evaluating exceptions in current codes and standards that allow fire spread, such as exceptions that allow for fire separation walls to not extend to the roofline. Identify which exceptions should be modified or eliminated to strengthen current codes and standards against the impacts of wildfire.

Recommendation CO-14b

The ICC should consider reviewing the intent of the different International Codes to ensure they address multiple hazards consistently. For example, consider the interrelationship between the fire codes, flood provisions of codes, and green construction codes with respect to insulation. Consider the flammability of different types of insulation having the same R-values and incorporate insulation requirements consistently across all codes.

Recommendation CO-14c

Similar to other language in the codes, AHJs should consider mandating that the more conservative, fire-resistant requirements must be followed if there is a conflict between other codes and fire-resistant codes and standards.

Conclusion CO-15

The timing of the ICC model code updates is not consistent with the evolution of best available science for wildfire hazard-resistant construction and WUI planning. AHJs with limited capacity and resources often rely on the ICC model codes to adopt and enforce the latest construction and design standards. As a result, local governments may not be knowledgeable of the most up-to-date best practices for wildfire resilient and hazard-resistant construction.

Recommendation CO-15

NIBS should consider collaborating with national organizations such as NIST, IBHS and UL Research Institutes and industry professionals to synthesize the best available science on WUI construction into short, digestible publications for local governments. The publication of these documents could be used to develop a threshold determined by a technical committee and the format could parallel FEMA flood map advisories.

Conclusion CO-16

Because many jurisdictions do not adopt the IWUIC and do not include WUI provisions in local codes and zoning requirements, structures in the WUI continue to be designed and built without incorporating wildland fire risk reduction measures. While the number of wildland fire events in the U.S. over the past several decades has remained fairly constant, the number of acres affected by wildfires in the U.S. has increased and likely will continue to do so. The average number of acres burned by wildfires annually since 2000 has more than doubled the average annual acreage burned in the 1990s (CRS, 2022), which is an indicator of increased wildfire severity (EPA, 2022).

Recommendation CO-16a

FEMA's Building Science Branch, in coordination with the USFA, should consider proposing a code amendment to incorporate the IWUIC into the IBC and IRC by reference for high wildfire risk areas similar to how ASCE 7 and ASCE 24 are incorporated by reference. This approach would require local jurisdictions to adopt local amendments to exclude IWUIC provisions, which could increase homeowner awareness of risks associated with wildland fire and mitigation measures that can be incorporated to address them.

Recommendation CO-16b

FEMA's Building Science Branch, in coordination with the USFA, should consider working with ASCE to develop a resistant design and construction standard incorporating wildland fire as a unique hazard rather than as part of "extraordinary events" because "extraordinary events" are defined as those having "low probability."

Conclusion CO-17

Adoption of stricter building code standards often compete with desires for local communities to quickly, efficiently, and affordably rebuild post-event or for long-term growth. This conflict in interests has resulted in jurisdictions adopting codes and ordinances that do not require adherence to IWUIC or wildland fire-resistant design principles, which can result in increased wildfire risk to residents.

Recommendation CO-17a

AHJs should carefully review all short-term financial, social, and other costs against long-term wildfire risks and mitigation benefits associated with decreased risk from improved codes when considering weaker or "opt-out" amendments for homeowners affected by the Marshall Fire. Where model code provisions are intended to safeguard public health and the safety of building occupants, consider reviewing and removing temporary exclusions to the codes.

Recommendation CO-17b

Local governments located in high wildland fire risk areas where WUI codes and standards are not mandated by the state or local governments should consider providing homeowner incentives for voluntary adoption of wildland fire-resistant design principles, such as tax incentives, rebate programs or "mini grants", and free chipping and hauling programs.

Conclusion CO-18

Adoption of different fire and building codes at the local government level can lead to gaps in fire protection of the built environment in adjacent communities. The State legislature recently followed the recommendation of the Colorado Fire Commission's 2022 Annual Report to create a Wildfire Resiliency Code Board, tasking it identifying and adopting model codes, requiring governing bodies with jurisdiction in an area within the wildland-urban interface to adopt codes that meet or exceed the standards set forth in the model codes, and making an appropriation.

Recommendation CO-18a

The State of Colorado should consider the adoption of a statewide unified building code and allow for jurisdictions to amend for more stringent requirements if needed. Establishing a minimum statewide building code would provide a standard basis when rendering mutual aid across jurisdictional boundaries. Taking this action is also consistent with updated guidance provided in FEMA's State Mitigation Planning Policy Guide, which requires building codes to be addressed in all standard plans and encourages states with enhanced plans to develop a strategy for statewide building code adoption and implementation. In the absence of a statewide building code, local jurisdictions should adopt the latest versions of the IBC, IWUIC, IRC, IEBC, and IFC.

Recommendation CO-18b

The State of Colorado should consider adopting the IEBC or enacting legislation that requires taking an all-hazards approach to building retrofits and incorporates different levels of hazard resistance based on the hazard. In the absence of a statewide requirement, local jurisdictions should consider requiring an all-hazards approach to building retrofits and, as appropriate, include amendments to improve the protections provided against certain hazards. Additionally, local jurisdictions should consider incorporating passive fire resistive measures from the WUI codes as they customize their adoption of the model IBC, IRC, and IEBC into their ordinances.

Conclusion CO-19

Above-code requirements may provide additional protections for townhouses and 2-family dwellings in wildland fire-prone areas.

Recommendation CO-19

Where not already required, AHJs should consider requiring a Class A fire rated roof cover installation to include materials and construction methodology, as well as the extension of the parapet above the tenant separation wall unless the roof deck is made of noncombustible materials, as defined by the 2021 IWUIC.

Conclusion CO-20

Local code exceptions and potential code enforcement gaps may have resulted in the use of some local building practices that decrease the fire resistance of homes, such as fire walls not extending fully through attics of townhouses.

Recommendation CO-20a

AHJs should review and implement ways to improve code enforcement, such as hiring additional code inspectors and providing additional or recurring training. In high wildland fire risk areas, ensure the training includes provisions in the codes and local amendments that specifically address risk to structures from wildfire. Consider obtaining or improving the community's Building Code Effectiveness Grading Schedule (BCEGS®) score.

Recommendation CO-20b

In areas with high to extreme wildfire risk, AHJs should consider adopting ordinances to require that common walls separating townhouse and 2-family dwelling units meet the

standards for exterior walls as described by the 2021 IWUIC Chapter 5 (Class 1 and 2 Ignition-Resistant Construction).

Conclusion CO-21

Local government agencies do not have adequate information, resources and/or training to effectively understand wildland fire risk, how to mitigate it, and methods to comprehensively regulate and enforce wildland fire safety provisions.

Recommendation CO-21a

FEMA, in coordination with the USFA, should consider providing additional information, resources, incentives, and training to assist state and local governments to better understand, adopt, regulate and enforce relevant wildland fire safety codes, standards and best practices. Some approaches may include completing updates to existing FEMA handbooks (e.g., P-737, P-754), developing regulatory guidance documents, updating Emergency Management Institute coursework, funding national level wildland fire risk mapping, including WUI in Building Code Adoption Tracking (BCAT) statistics, and partnering with wildfire organizations to promote and deliver wildland fire mitigation workshops at conferences and other similar events.

Recommendation CO-21b

FEMA, in coordination with the USFA, should explore working with Congress to extend the provisions of Section 1206 of the Disaster Recovery Reform Act of 2018 to provide funding for additional code inspectors for 365 days after a disaster (rather than 180 days as is currently stipulated).

Conclusion CO-22

Closely spaced houses (e.g., less than 15-foot setback) in medium- to high-density housing developments that were constructed in accordance with non-WUI codes and mitigation practices are more likely to be damaged by and contribute to structure-to-structure fire spread. Current building codes do not typically require fire resistance ratings for exterior walls for single-family residences, almost regardless of fire separation distances to adjacent properties or structures. This significantly increases the risk of structure-to-structure fire spread (or urban conflagration) particularly in a wind-driven wildfire incident.

Recommendation CO-22a

To reduce the likelihood of structure-to-structure fire spread, AHJs should consider if closely spaced homes (e.g., property line setback distances of less than 30 feet) in high wildfire risk areas should have a) one-hour or greater fire rated exterior walls b) either no windows, fire-rated opening-protection, or a specific lateral offset between windows on exterior walls facing adjacent buildings, as well as other provisions to reduce the likelihood of structure-to-structure fire spread. Consider partnering with engineers, code officials, firefighters, and wildfire experts to obtain multiple expert viewpoints.

Recommendation CO-22b

The ICC should consider updating national fire codes and standards (e.g., IFC, IRC, IWUIC, etc.) to require fire resistance ratings for exterior walls for single-family residences.

Conclusion CO-23

Planning, design, and construction professionals working in high wildfire risk areas lack adequate information and training regarding wildfire resilience practices at the building and neighborhood scales. Most homes in the impacted neighborhoods and adjacent neighborhoods had numerous well-known structural hardening and defensible space vulnerabilities, as well as lesser known vulnerabilities in the exterior building envelope. This included wildfire resilient designs and detailing at joints or interfaces of building components (e.g., a lack of proper detailing of bottom-of-wall to foundation joints, window-to-wall joints, wall-to-foundation joint, roof joints, wall-to-wall panel joints, edge of roof joints) throughout the exterior building envelope. These joints provided avenues for ember intrusion into the interstitial spaces, which are often constructed of combustible materials, leading to concealed fires and/or direct ignition of interior building contents.

Recommendation CO-23a

FEMA's Building Science Branch, in coordination with the USFA, should consider revising the internal Community Wildfire Resilience white paper collaboratively with IBHS and NIST and other fire science engineers as needed and make it publicly available.

Recommendation CO-23b

FEMA's Building Science Branch, in coordination with the USFA, should explore working with IBHS and NIST to identify construction joints and assemblies that are particularly susceptible to ember and/or flame intrusion. Based on this information, FEMA Building Science Branch should develop standard detailing guidance for particular construction joints and assemblies to improve the residential structure wildfire resistance.

Recommendation CO-23c

FEMA's Building Science Branch, in collaboration with the USFA, NIST, IBHS and other wildfire science engineers should consider designing and constructing a multi-hazard mitigation house to demonstrate how mitigation strategies can be incorporated to address

multiple hazards. Several other entities have constructed demonstration homes, including IBHS's Fortified home for hurricanes and wildfire, and Disney's partnership with the Federal Alliance for Safe Homes (FLASH) to develop the StormStruck exhibit at Epcot. FEMA could build upon and incorporate the concepts included in these demonstration homes to design and construct a multi-hazard-resistant demonstration home or smaller scale model.

Conclusion CO-24

Vent covering requirements in the IWUIC, while consistent with requirements in the other International Codes, are not consistent with recent research findings and recommendations from other building protection entities with respect to wildland fire mitigation, and as written provide for subjectivity on behalf of the code official for what is “approved.”

Recommendation CO-24

FEMA's Building Science Branch, in coordination with the USFA, should consider developing a code amendment proposal to the IWUIC to require 1/16-inch corrosion-resistant, noncombustible wire mesh openings instead of the current 1/4-inch requirement or “approved” design to prevent flame and ember penetration into the structure, where “approval” is determined by the designated code official. This amendment would make the IWUIC consistent with research findings from NIST and recommendations and requirements from other entities such as IBHS, NFPA, and California Building Code Chapter 7A. This amendment also would provide greater consistency in requirements across jurisdictions.

Conclusion CO-25

Vent openings in attics, roofs, walls, crawlspaces, and foundations that were not protected against wildfire provided pathways for embers to enter homes and structures.

Recommendation CO-25a

AHJs should consider adopting local ordinances to require vents made from noncombustible materials. Vents should be a maximum size of 144 square inches in conformance with IWUIC Section 504.10 and IBC Section 714.1.4 and provided with 1/8-inch to 1/16-inch, noncombustible mesh screens or ember resistant vent protection. Corrosion-resistant wire mesh should have openings 1/8-inch to 1/16-inch consistent with NFPA 1140 25.3.3(2) and California Building Code Chapter 7A Section 706A.2.2.1.

Recommendation CO-25b

For existing construction that includes gable-end vents, state and local AHJs should consider amending building codes and ordinances to require use of a wildfire-resistant gable vent that has passed ASTM E2886.

Recommendation CO-25c

AHJs in wildfire risk areas should consider adopting local ordinances to require decks, porches, and balconies to have walking surfaces constructed from noncombustible materials for at least 1 foot away from the home (NIST, 2022) for boards that are oriented parallel to the exterior wall. The rest of the attached structure should be constructed from fire-retardant-treated wood or noncombustible, ignition-resistant, or other materials having at least a 1-hour fire rating.

Conclusion CO-26

Single-pane windows, windows with aluminum or plastic framing and windows with plastic screens are vulnerable to wildfire exposures (e.g., cracking and fallout) due to radiant heat or large debris impact in high winds, fallout due to softening of aluminum or plastic framing, or ignition of plastic screens leading to ignition of combustibles in the interior. They are also susceptible to damage from high winds such as those that occurred during the Marshall Fire.

Recommendation CO-26

AHJs should consider adopting IWUI codes and standards. Alternatively, local jurisdictions can adopt local ordinances to require double-pane window systems (preferably with one tempered-laminated pane), metal or fiberglass screening, metal window frames or metal covering be used. Vegetation should also be excluded within 5–10 feet of glazed openings. New and existing structures should also consider high wind requirements when selecting new window systems. Ensure windows can demonstrate impact resistance via testing or ICC Evaluation Service approval.

Conclusion CO-27

Combustible fences, decks and patios attached to structures acted as wicks and helped to spread the fire from structure-to-structure. This is a well-known and codified wildland fire vulnerability, but was pervasive throughout the impacted neighborhoods, adjacent neighborhoods, and reconstructed locations, in part due to some requirements of local homeowners' associations.

Recommendation CO-27

AHJs should consider adopting WUI codes and standards. Alternatively, local jurisdictions and homeowners' associations can partner to adopt local ordinances that require a) new and refurbished decks and patios to be constructed of noncombustible materials; b) all fences (regardless of height) connected to homes/structures be constructed of noncombustible materials at least within the first 5 feet from the structure; and c) all fences (regardless of height) parallel to and within 10 feet of homes/structures should be constructed from noncombustible materials. Parallel fences along property lines separating two pieces of property should be disallowed, as NIST research has shown that this configuration is highly combustible (NIST, 2022).

Conclusion CO-28

Building owners do not understand measures they can take to decrease the impacts of smoke, soot, and ash from wildland fires on their structures, which can result in extensive damage and expensive clean up.

Recommendation CO-28a

Local governments should consider working with insurance companies, restoration contractors, and local fire departments to develop guidance for building owners on how to prepare their buildings to reduce the risk of smoke and ash infiltration, such as shutting down HVAC systems and taping door and window seals shut. Additionally, building owners need to be made aware of the potential contents damage and health risks associated with not addressing smoke and ash infiltration.

Recommendation CO-28b

Homeowners and contractors should make efforts to minimize the risk of contamination entering the actual living spaces of the house. When remediating against existing smoke and ash damages, homeowners should consider using techniques to reduce the risk of future smoke, soot, and ash damage, such as improving door and window sealants and replacing fiberglass batt insulation with thicker sprayed foam/closed cell insulation. Such techniques can also make the home more energy efficient, but the flammability of sealants and non-fiberglass insulation must be examined to ensure code compliance and avoid increasing structural fire risk.

Conclusion CO-29

Systems that store energy in Li-ion batteries pose an environmental and fire hazard if ignited. NFPA 855 and the 2021 International codes provide fire separation standards for some Li-ion battery systems, but additional protections against wildfire may be needed as this technology becomes more prevalent.

Recommendation CO-29a

AHJs with moderate to high wildland fire risk areas should adopt the latest published editions of the IRC, IFC, and IBC that provide expanded protections for battery storage systems and solar arrays.

Recommendation CO-29b

NFPA, in coordination with the USFA and ICC, should consider collaborating with a recognized fire testing laboratory (e.g., UL, Southwest Research Institute, Intertek) to evaluate provisions in the International Codes that provide mandatory protection for energy storage systems and augment as appropriate to provide protection against damage and ignition of these systems resulting from wildfire.

Conclusion CO-30

Current building codes and standards do not adequately address protection of photovoltaic systems and Li-ion battery storage systems in high wildfire risk areas. While NFPA 855 addresses the storage of Li-ion batteries in a stationary situation, it does not specifically consider wildland fire risk.

Recommendation CO-30

FEMA, in coordination with the USFA, should consider proposing code changes to the ICC and NFPA to require special safety provisions for photovoltaic and Li-ion battery storage systems in high wildfire risk areas. The provisions should consider not only stationary situations but also Li-ion batteries in vehicles operating in high wildland fire risk areas.

Conclusion CO-31

Li-ion batteries damaged by fire pose the risk of igniting or reigniting even after the fire has been extinguished. No approved method has yet been developed for extinguishing fires involving Li-ion battery ESS. The ignition and re-ignition potential of Li-ion batteries was cited during interviews as one factor in determining firefighting priorities.

Recommendation CO-31

The NFPA and the Occupational Safety and Health Administration (OSHA), in coordination with the USFA, should consider developing a placard or adopt and modify as appropriate the current OSHA Li-ion storage placard and make it available to vendors of products that include Li-ion battery storage systems. Homeowners with Li-ion battery storage systems should be encouraged to post these placards in their windows or other places on their houses to enable firefighters to recognize the presence of such a system in the home. This will allow firefighters to take appropriate actions with respect to such battery storage systems.

6.5. Summary of Conclusions and Recommendations

Table 16 is a matrix listing the conclusions and recommendations cross-referenced to the sections of the report that describe the supporting observations.

Table 16. Summary of Conclusions and Recommendations

Observations	Conclusions	Recommendations	Suggested Agency Lead
Section 1.3.2	**CO-1:** Current WUI definitions do not accurately reflect the diversity of wildfire environmental settings and community designs that are prone to wildfire threats, including the area impacted by the Marshall Fire. The definition of "WUI" is not comprehensive enough, in that it typically only describes environmental conditions such as vegetation and not explicitly the hazard, risk or vulnerabilities that is presents. This has led to the perception of "wildland" as sparsely populated, heavily wooded areas in rugged, mountain terrain with steep slopes.	**CO-1a:** The NWCG, in coordination with FEMA and USFA, should update and expand upon the definition of "wildland-urban interface" to clarify that "wildland" includes a range of environments such as grasslands, shrublands and not just forests and trees. Guidance should be provided for local and state governments to adopt and adapt the NWCG's definition to meet specific needs, such as defining "interface," "intermix" and "occluded" space.	NWCG
		CO-1b: Local and state governments should raise awareness and provide educational programs for their citizens about the various local conditions that define the "WUI."	Local and state governments
Section 1.3.2	**CO-2**: Though various forms of wildfire hazard and risk mapping layers have been developed by some state and federal agencies to address a variety of applications (e.g., land use management), a national, consensus-based wildfire risk mapping for community planning and building wildfire safety does not currently exist. The lack of such hazard delineation limits an understanding of wildfire "risk," with respect to both wildfire hazard severity levels and associated return intervals at a national scale, which are already provided for other hazards (e.g., wind, seismic, flooding).	**CO-2a:** The USFA, NFPA, USFS and NIST should consider partnering with an architectural and engineering standards development organizations to create a national, consensus-based wildfire hazard severity map that includes mean recurrence intervals for at-risk areas (i.e., wildfire "risk" map).	USFA, NFPA, USFS and NIST
		CO-2b: The USFA should work with federal interagency and SLTT partners to explore development of national, consensus-based wildfire hazard severity zone maps with mean recurrence intervals that guide community and parcel-level decision making and trigger the use of fire safety requirements prescribed in the IWUIC or other model WUI, building or fire codes.	USFA
		CO-2c: Where wildfire hazard or risk maps already exist, local jurisdictions should consider using those maps for creating or updating local regulatory WUI maps.	Local governments
Section 1.3.2	**CO-3:** Current practices in assessing wildfire risks to the built environment are not based on risk-informed approaches analogous to other hazards (e.g., seismic, wind), where recurrence intervals and damage potentials are quantified at the national level.	**CO-3:** Similar to the risk-informed approaches used for other hazards such as flood, wind, and earthquake, NFPA and ICC should consider working together to standardize development of acceptable wildfire risk thresholds based on risk-informed methods.	NFPA and ICC

Observations	Conclusions	Recommendations	Suggested Agency Lead
Section 1.3.3 Section 2.2 Section 4.3	**CO-4:** The Marshall Fire demonstrates how characteristics in the natural environment that markedly influence the behavior of wildfires (i.e., topography, weather, fuel) can interact with other natural hazards such as long-term drought and high wind to exacerbate the risk and behavior of a wildfire. Traditional hazard mitigation plans identify hazards as singular events and neglect the interactions between them.	**CO-4:** AHJs in wildfire-prone areas should consider adopting approaches to wildfire mitigation that identify multi-hazard risks and collectively address risk reduction through land management and building mitigation practices.	AHJs
Section 4.1 Section 4.2 Section 5.1.1	**CO-5:** Historically, national- and state-level wildfire mitigation planning, and preparedness have primarily targeted forest and woodland areas in the WUI. Many community plans, including the Boulder County Community Wildfire Protection Plan, focus on wildfire mitigation in forested and woodland landscapes within the WUI.	**CO-5:** Community planners should assess opportunities to apply landscape and parcel-level hazardous fuel maintenance and defensible space strategies to publicly owned outdoor, recreational, and open space, as well as undeveloped grassland and shrubland adjacent to the community.	Local governments and community planners
Section 3.5 Section 4.1	**CO-6:** While jurisdictions impacted by the Marshall Fire have taken steps to incorporate and coordinate multi-hazard planning, open space management, and community design into their wildfire risk assessments and mitigation strategies, these strategies are not yet consistent across all levels of planning and planning resources.	**CO-6**: Community planners, building code and fire officials should consistently incorporate and coordinate comprehensive wildfire management strategies across all planning codes, standards, policy and guidance documents, including comprehensive or long-range planning, CWPP, hazard mitigation plans, building and fire safety codes/standards/local ordinances, energy codes, landscaping codes, forest, and open space plan.	Local governments and community planners
Section 2.2 Section 4.1 Section 4.2	**CO-7:** During the Marshall Fire, water collection and diversion features and greenbelts overgrown with vegetation provided pathways for wildland fire to spread along the ground surface into urbanized areas.	**CO-7a:** AHJs should consider requiring vegetated water collection and diversion features, greenbelts, parks and vegetated islands/bioswales that interact or interconnect wildland spaces with the built-environment in high fire prone areas to be regularly maintained through adoption of ordinances and provisions in maintenance contracts.	AHJs
Section 4.2		**CO-7b:** Local ordinances should require the use of diverse native, fire-resistant vegetation species in water collection and diversion features, greenbelts, parks and vegetated islands/bioswales that interact or interconnect wildland spaces with the built environment in high fire prone areas.	AHJs

Observations	Conclusions	Recommendations	Suggested Agency Lead
Section 4.1 Section 4.3		**CO-7c**: State foresters should consider working with authorities having jurisdiction and other subject matter experts to evaluate the effectiveness of community and parcel-level vegetative fuel breaks and make recommendations for priority local areas to incorporate science-based vegetation management best practices.	State Foresters
Section 4.1 Section 4.2	**CO-8**: Current community and neighborhood level planning and design requirements in many high wildfire risk areas do not sufficiently incorporate wildfire safety considerations for landscaping.	**CO-8a**: AHJs should consider adopting zoning, codes and ordinances that integrate wildfire safety concepts into planning, design, construction, long-term maintenance, and inspection.	AHJs
Section 4.1		**CO-8b:** Local governments and community planners should coordinate with entities such as the Cooperative Extension Service, universities, and State forestry agencies to develop and socialize “approved” wildfire-resistant plant lists and landscaping strategies for use by developers, homeowners’ associations, and homeowners.	Local governments and community planners
Section 3.1.3 Section 4.1 Section 4.2		**CO-8c:** Homeowners’ associations and local governments should consider partnering with wildfire education providers such as Firewise USA®, Wildfire Partners, IBHS Wildfire Prepared Home Program and Fire Adapted Communities Learning Network to educate landscapers and homeowners about ways to develop and implement mitigation strategies that decrease wildfire risk at the parcel and neighborhood level.	Homeowners’ associations and local governments
Section 3.2 Section 4.1 Section 4.2	**CO-9:** Local subdivision regulations do not include provisions that adequately address wildfire risk.	**CO-9a:** AHJs in wildfire risk areas should consider working with their local fire departments to develop and adopt subdivision regulations that address wildland fire risk, including structure density in the WUI, appropriate access/egress capacity and separation, adequate water supply, requirements for fire protection and vegetation management plans, and procedures for subdivision evaluation and approval.	AHJs
Section 1.3.2 Section 3.2		**CO-9b:** AHJs should consider incorporating WUI terminology into local codes and ordinances to improve understanding of WUI concepts.	AHJs
Section 2.3	**CO-10:** The combined impact of natural hazards and weather conditions (e.g., high wind, combustible vegetation, and cold temperatures) can create disproportionate risks for at-risk communities.	**CO-10:** Communities with moderate to very-high wildfire risk should investigate and incorporate the vulnerabilities of at-risk communities (such as access to support recovery services) into multi-hazard wildfire mitigation planning, response, and recovery efforts.	Local governments

Observations	Conclusions	Recommendations	Suggested Agency Lead
Section 5.1	**CO-11:** Parcel/lot sizes in densely spaced neighborhoods may limit homeowners' abilities to satisfy best practices in defensible space. Because these lot sizes generally are fixed and cannot be changed, defensible space needs to be established at the neighborhood or community level.	**CO-11a:** AHJs should consider working with fire departments, planning departments, and wildfire experts to develop local ordinances, standards and guidance documents for communal defensible space in overlapping ignition zones.	AHJs
Section 5.1		**CO-11b:** AHJs should consider integrating and mainstreaming wildland fire safety concepts throughout the regulatory life cycle from planning and zoning to design and permitting to construction to long-term maintenance and inspection.	AHJs
Section 3.1 Section 3.2	**CO-12:** The current version of the IWUIC does not fully address needs at the building-, parcel- and community-levels.	**CO-12a:** The ICC should consider working with the NIBS and NIST to develop and include two performance objectives for the IWUIC—one for life-safety and one for structure survivability without the benefit of firefighting.	ICC
Section 3.1 Section 3.2		**CO-12b:** The ICC should consider revising the IWUIC to address wildfire planning and mitigation at different physical levels, including the building, parcel, neighborhood/subdivision, and community scales.	ICC
Section 3.3	**CO-13:** Many of the current fire testing standards were not developed for wildland fire and therefore do not comprehensively address the risk of wildfire to structures.	**CO-13:** The USFA should consider collaborating with ICC, fire testing laboratories, NIST and other interested parties to develop wildfire-specific fire test standards for building construction and materials, exterior building components and details, exterior fire protection systems, interior suppression systems, etc.	USFA
Section 3.1 Section 3.2 Section 5.1.3	**CO-14:** The I-Codes such as the IBC, IRC and the ICC lack a coordinated approach to addressing the risk of wildland fire to structures in the WUI. Some provisions in one of the I-Codes may not fully consider the risk of another hazard addressed by another of the International Codes.	**CO-14a:** The ICC should consider evaluating exceptions in current codes and standards that allow fire spread, such as exceptions that allow for fire separation walls to not extend to the roofline.	ICC
Section 2.2 Section 3.1 Section 3.2		**CO-14b:** The ICC should consider reviewing the intent of the different International Codes to ensure they address multiple hazards consistently.	ICC
Section 3.1 Section 3.2		**CO-14c:** Similar to other language in the codes, AHJs should consider mandating that the more conservative, fire-resistant requirements must be followed if there is a conflict between other codes and fire-resistant codes and standards.	AHJs

Observations	Conclusions	Recommendations	Suggested Agency Lead
Chapter 3	**CO-15:** The timing of the ICC model code updates is not consistent with the evolution of best available science for wildfire hazard-resistant construction and WUI planning.	**CO-15:** NIBS should consider collaborating with national organizations such as NIST, IBHS and UL Research Institutes and industry professionals to synthesize the best available science on WUI construction into short, digestible publications for local governments.	NIBS
Chapter 3	**CO-16:** Because many jurisdictions do not adopt the IWUIC and do not include WUI provisions in local codes and zoning requirements, structures in the WUI continue to be designed and built without incorporating wildland fire risk reduction measures.	**CO-16a:** FEMA's Building Science Branch, in coordination with the USFA, should consider proposing a code amendment to incorporate the IWUIC into the IBC and IRC by reference for high wildfire risk areas similar to how ASCE 7 and ASCE 24 are incorporated by reference.	FEMA's Building Science Branch
Chapter 3		**CO-16b:** FEMA's Building Science Branch, in coordination with the USFA, should consider working with ASCE to develop a resistant design and construction standard incorporating wildland fire as a unique hazard rather than as part of "extraordinary events" because "extraordinary events" are defined as those having "low probability."	FEMA's Building Science Branch
Section 3.2	**CO-17:** Adoption of stricter building code standards often compete with desires for local communities to quickly, efficiently, and affordably rebuild post-event or for long-term growth.	**CO-17a:** AHJs should carefully review all short-term financial, social, and other costs against long-term wildfire risks and mitigation benefits associated with decreased risk from improved codes when considering weaker or "opt-out" amendments for homeowners affected by the Marshall Fire.	AHJs
Section 3.1 Section 3.2		**CO-17b:** Local governments located in high wildland fire risk areas where WUI codes and standards are not mandated by the state or local governments should consider providing homeowner incentives for voluntary adoption of wildland fire-resistant design principles, such as tax incentives, rebate programs or "mini grants" and free chipping and hauling programs.	Local governments
Chapter 3	**CO-18:** Adoption of different fire and building codes at the local government level can lead to gaps in fire protection of the built environment in adjacent communities. The State legislature recently followed the recommendation of the Colorado Fire Commission's 2022 Annual Report to create a Wildfire Resiliency Code Board, tasking it identifying and adopting model codes, requiring governing bodies with jurisdiction in an area within the wildland-urban interface to adopt codes that meet or exceed the standards set forth in the model codes, and making an appropriation.	**CO-18a:** The State legislature should follow the recommendation of the Colorado Fire Commission's 2022 Annual Report to create a Wildland-Urban Interface Code Board.	Colorado State Legislature
Chapter 3		**CO-18b:** The State of Colorado should consider the adoption of a statewide unified building code and allow for jurisdictions to amend for more stringent requirements if needed.	State of Colorado
Chapter 3		**CO-18c:** The State of Colorado should consider adopting the IEBC or enacting legislation that requires taking an all-hazards approach to building retrofits and incorporates different levels of hazard resistance based on the hazard.	State of Colorado

Observations	Conclusions	Recommendations	Suggested Agency Lead
Section 2.5 Section 3.2 Section 5.2.1	**CO-19:** Above-code requirements may provide additional protections for townhouses and 2-family dwellings in wildland fire-prone areas.	**CO-19:** Where not already required, AHJs should consider requiring a Class A fire rated roof cover installation to include materials and construction methodology, as well as the extension of the parapet above the tenant separation wall unless the roof deck is made of noncombustible materials, as defined by the 2021 IWUIC.	AHJs
Chapter 3 Chapter 5	**CO-20:** Local code exceptions and potential code enforcement gaps may have resulted in the use of some local building practices that decrease the fire resistance of homes, such as fire walls not extending fully through attics of townhouses.	**CO-20a:** AHJs should review and implement ways to improve code enforcement, such as hiring additional code inspectors and providing additional or recurring training.	AHJs
Section 5.1.3 Section 5.2.7		**CO-20b:** In areas with high to extreme wildfire risk, AHJs should consider adopting ordinances to require that common walls separating townhouse and 2-family dwelling units meet the standards for exterior walls as described by the 2021 IWUIC Chapter 5 (Class 1 and 2 Ignition-Resistant Construction).	AHJs
Section 5.1 Section 5.2	**CO-21:** Local government agencies do not have adequate information, resources and/or training to effectively understand wildland fire risk, how to mitigate it, and methods to comprehensively regulate and enforce wildland fire safety provisions.	**CO-21a:** FEMA, in coordination with the USFA, should consider providing additional information, resources, incentives, and training to assist state and local governments to better understand, adopt, regulate and enforce relevant wildland fire safety codes, standards and best practices.	FEMA
Section 5.1 Section 5.2		**CO-21b:** FEMA, in coordination with the USFA, should explore working with Congress to extend the provisions of Section 1206 of the Disaster Recovery Reform Act of 2018 to provide funding for additional code inspectors for 365 days after a disaster (rather than 180 days as is currently stipulated).	FEMA
Section 5.1 Section 5.2	**CO-22:** Closely spaced houses (e.g., less than 15-foot setback) in medium- to high-density housing developments that were constructed in accordance with non-WUI codes and mitigation practices are more likely to be damaged by and contribute to structure-to-structure fire spread. Current building codes do not typically require fire resistance ratings for exterior walls for single-family residences, almost regardless of fire separation distances to adjacent properties or structures. This significantly increases the risk of structure-to-structure fire spread (or urban conflagration) particularly in a wind-driven wildfire incident.	**CO-22a:** To reduce the likelihood of structure-to-structure fire spread, AHJs should consider if closely spaced homes (e.g., property line setback distances of less than 30 feet) in high wildfire risk areas should have a) one-hour or greater fire rated exterior walls b) either no windows, fire-rated opening-protection, or a specific lateral offset between windows on exterior walls facing adjacent buildings, as well as other provisions to reduce the likelihood of structure-to-structure fire spread.	AHJs
Section 5.1.3 Section 5.2		**CO-22b:** The ICC should consider updating national fire codes and standards (e.g., IFC, IRC, IWUIC, etc.) to require fire resistance ratings for exterior walls for single-family residences.	ICC

Observations	Conclusions	Recommendations	Suggested Agency Lead
Section 4.1 Section 4.2 Section 5.1 Section 5.2	**CO-23:** Planning, design, and construction professionals working in high wildfire risk areas lack adequate information and training regarding wildfire resilience practices at the building and neighborhood scales.	**CO-23a:** FEMA's Building Science Branch, in coordination with the USFA, should consider revising the internal Community Wildfire Resilience white paper collaboratively with IBHS and NIST and other fire science engineers as needed and make it publicly available.	FEMA's Building Science Branch
Section 5.2		**CO-23b:** FEMA's Building Science Branch, in coordination with the USFA, should explore working with IBHS and NIST to identify construction joints and assemblies that are particularly susceptible to ember and/or flame intrusion.	FEMA's Building Science Branch
Section 1.3.3 Section 2.2		**CO-23c:** FEMA's Building Science Branch, in collaboration with the USFA, NIST, IBHS and other wildfire science engineers should consider designing and constructing a multi-hazard mitigation house to demonstrate how mitigation strategies can be incorporated to address multiple hazards.	FEMA's Building Science Branch
Section 2.3.2 Section 5.2	**CO-24:** Vent covering requirements in the IWUIC, while consistent with requirements in the other International Codes, are not consistent with recent research findings and recommendations from other building protection entities with respect to wildland fire mitigation, and as written provide for subjectivity on behalf of the code official for what is "approved."	**CO-24:** FEMA's Building Science Branch, in coordination with the USFA, should consider developing a code amendment proposal to the IWUIC to require 1/16-inch corrosion-resistant, noncombustible wire mesh openings instead of the current 1/4-inch requirement or "approved" design to prevent flame or ember penetration into the structure, where "approval" is determined by the designated code official.	FEMA's Building Science Branch
Section 5.2	**CO-25:** Vent openings in attics, roofs, walls, crawlspaces, and foundations that were not protected against wildfire provided pathways for embers to enter homes and structures.	**CO-25a:** AHJs should consider adopting local ordinances to require vents made from noncombustible materials.	AHJs
Section 5.2		**CO-25b:** For existing construction that includes gable-end vents, state and local AHJs should consider amending building codes and ordinances to require use of a wildfire-resistant gable vent that has passed ASTM E2886.	AHJs
Section 5.2.11		**CO-25c:** AHJs in wildfire risk areas should consider adopting local ordinances to require decks, porches, and balconies to have walking surfaces constructed from noncombustible materials for at least 1 foot away from the home (NIST, 2022) for boards that are oriented parallel to the exterior wall.	AHJs

Observations	Conclusions	Recommendations	Suggested Agency Lead
Section 5.2.7	**CO-26:** Single-pane windows, windows with aluminum or plastic framing and windows with plastic screens are vulnerable to wildfire exposures (e.g., cracking and fallout) due to radiant heat or large debris impact in high winds, fallout due to softening of aluminum or plastic framing, or ignition of plastic screens leading to ignition of combustibles in the interior. They are also susceptible to damage from high winds such as those that occurred during the Marshall Fire.	**CO-26:** AHJs should consider adopting IWUI codes and standards. Alternatively, local jurisdictions can adopt local ordinances to require double-pane window systems (preferably with one tempered-laminated pane), metal or fiberglass screening, metal window frames or metal covering be used.	AHJs
Section 5.2.11	**CO-27:** Combustible fences, decks and patios attached to structures acted as wicks and helped to spread the fire from structure-to-structure.	**CO-27:** AHJs should consider adopting WUI codes and standards. Alternatively, local jurisdictions and homeowners' associations can partner to adopt local ordinances that require a) new and refurbished decks and patios to be constructed of noncombustible materials; b) all fences (regardless of height) connected to homes/structures be constructed of noncombustible materials at least within the first 5 feet from the structure; and c) all fences (regardless of height) parallel to and within 10 feet of homes/structures should be constructed from noncombustible materials.	AHJs
Section 5.2.13	**CO-28:** Building owners do not understand measures they can take to decrease the impacts of smoke, soot, and ash from wildland fires on their structures, which can result in extensive damage and expensive clean up.	**CO-28a:** Local governments should consider working with insurance companies, restoration contractors, and local fire departments to develop guidance for building owners on how to prepare their buildings to reduce the risk of smoke and ash infiltration, such as shutting down HVAC systems and taping door and window seals shut.	Local governments
Section 5.2.13		**CO-28b:** Homeowners and contractors should make efforts to minimize the risk of contamination entering the actual living spaces of the house.	Homeowners
Section 5.2.4 Section 5.2.14	**CO-29:** Systems that store energy in Li-ion batteries pose an environmental and fire hazard if ignited. NFPA 855 and the 2021 International codes provide fire separation standards for some Li-ion battery systems, but additional protections against wildfire may be needed as this technology becomes more prevalent.	**CO-29a:** AHJs with moderate to high wildland fire risk areas should adopt the latest published editions of the IRC, IFC, and IBC that provide expanded protections for battery storage systems and solar arrays.	AHJs
Section 5.2.4 Section 5.2.14		**CO-29b:** NFPA, in coordination with the USFA and ICC, should consider collaborating with a recognized fire testing laboratory (e.g., UL, Southwest Research Institute, Intertek) to evaluate provisions in the International Codes that provide mandatory protection for energy storage systems and augment as appropriate to provide protection against damage and ignition of these systems resulting from wildfire.	NFPA and ICC

Observations	Conclusions	Recommendations	Suggested Agency Lead
Section 5.2.4 Section 5.2.14	**CO-30**: Current building codes and standards do not adequately address protection of photovoltaic systems and Li-ion battery storage systems in high wildfire risk areas. While NFPA 855 addresses the storage of Li-ion batteries in a stationary situation, it does not specifically consider wildland fire risk.	**CO-30:** FEMA, in coordination with the USFA, should consider proposing code changes to the International Code Council and NFPA to require special safety provisions for photovoltaic and Li-ion battery storage systems in high wildfire risk areas.	FEMA
Section 5.2.4 Section 5.2.14	**CO-31:** Li-ion batteries damaged by fire pose the risk of igniting or reigniting even after the fire has been extinguished. No approved method has yet been developed for extinguishing fires involving Li-ion battery ESS.	**CO-31:** The NFPA and the Occupational Safety and Health Administration (OSHA), in coordination with the USFA, should consider developing a placard or adopt and modify as appropriate the current OSHA Li-ion storage placard and make it available to vendors of products that include Li-ion battery storage systems.	NFPA and OSHA

Appendix A: Acknowledgements

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Appendix C: Glossary

- **Community** – A group of people living in the same locality and under the same government, or a political subdivision of a state or other authority that has zoning and building code jurisdiction over a particular area.

- **Communal Defensible Space** – The area or space around a collection of properties where the minimum defensible space distances (30–100 feet) is achieved by the sharing of vegetation management and fuel treatments across neighboring property lines. This is in lieu of individual property owner's ability to achieve the requisite defensible distances for setbacks and defensible space within their own parcel. Also known as overlapping ignition zones.

- **Communal or Common Space** – Land or space that is intended for common ownership or use by the residents of surrounding dwelling units.

- **Community Wildfire Protection Plan** (CWPP) – A plan developed in the collaborative framework established by the Wildland Fire Leadership Council and agreed to by state, tribal, and local government, local fire department, other stakeholders and federal land management agencies managing land in the vicinity of the planning area. A CWPP identifies and prioritizes areas for hazardous fuel reduction treatments and recommends the types and methods of treatment on Federal and non-Federal land that will protect one or more at-risk communities and essential infrastructure and recommends measures to reduce structural ignitability throughout the at-risk community. A CWPP may address issues such as wildfire response, hazard mitigation, community preparedness, or structure protection or all of the above.

- **Conflagration** – A large destructive fire that causes substantial destruction (NFPA 101®, Life Safety Code Handbook).

- **Critical infrastructure** – The systems, networks, and assets, whether physical or virtual, that are so essential that their continued operation is required to ensure the security of the state, nation, its economy, and the public's health and/or safety.

- **Defensible space** – The area around a structure where the location, selection, and maintenance of vegetation and other combustible materials are managed to reduce the structure's exposure to radiation (heat), direct flame impingement and spot fires from embers, which are considered the three principal mechanisms leading to structure ignition. (Bell et al., 2007).

- **Ember** – Smoldering or flaming particles of vegetation from tree branches, pieces of chaparral shrubs, or other combustibles (such as structures) that ignite and burn during a wildfire and are carried by winds in front of the wildfire at varying distances. Flaming or glowing fuel particles that can be carried naturally by wind, convection currents, or by gravity into unburned fuels.

- **Exposure** – The people, property, systems, or functions that could be lost to a hazard.
- **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.
- **Fire resistance** – The fire resistance of a building element characterizes its ability to confine a fire or to continue to perform a given structural function, or both.
- **Fire-resistance rating –**The period of time a building element, component or assembly maintains the ability to confine a fire, continues to perform a given structural function, or both, as determined by fire tests or methods based on fire tests.
- **Fire-resistant joint system –** An assemblage of specific materials or products that are designed, tested and fire-resistance rated in accordance with a standard fire test to resist for a prescribed period of time through joints made in or between fire-resistance rated assemblies (IBC).
- **Fire-resistive construction –** Fire-resistive construction is construction that has been designed and tested to withstand a certain amount of fire exposure. Fire-resistive construction is typically given a fire-resistance rating as determined by fire tests or methods based on fire tests.
- **Firestopping Product** – Firestopping is a component of a firestop system, which is designed to seal an opening into or through a fire-resistance rated assembly. These products help to reduce the amount of smoke and embers that could potentially penetrate walls (Knott, 2019).
- **Fuel** – A material that will maintain combustion under specified environmental conditions. A material used to produce heat or power by burning (NFPA).
- **Fuel break** – A natural or manmade change in fuel characteristics which affects fire behavior so that fires burning into them can be more readily controlled.
- **Fuel loading** – The amount of fuel present expressed quantitatively in terms of weight of fuel per unit area. This may be available fuel (consumable fuel) or total fuel and is usually dry weight.
- **Fuel management** – Act or practice of controlling flammability and reducing resistance to control of wildland fuels through mechanical, chemical, biological, or manual means, or by fire, in support of land management objectives.
- **Fuel modification** – Manipulation or removal of fuels to reduce the likelihood of ignition and/or to lessen potential damage and resistance to control (e.g., lopping, chipping, crushing, piling, and burning). *Synonym: Fuel treatment*

- **Fuel treatment** – Manipulation or removal of fuels to reduce the likelihood of ignition and/or to lessen potential damage and resistance to control (e.g., lopping, chipping, crushing, piling, and burning). *Synonym: Fuel modification*

- **Hazard** – A natural or human-caused act or phenomenon that has the potential to produce harm or other undesirable consequences to a person or thing.

- **Intensity** – A measure of the energy expected from a wildfire. It is largely a condition of the vegetative landscape and vegetative fuel available to burn.

- **Interface** – The interface community exists where structures directly abut wildland fuels.

- **Intermix** – The intermix community exists where structures are scattered throughout a wildland area.

- **Likelihood** – The annual probability of an event occurring in a specific location.

- **Membrane-penetration firestop system** – An assemblage consisting of a fire-resistance-rated floor-ceiling, roof-ceiling or wall assembly, one or more penetrating items installed into or passing through the breach in one side of the assembly and the materials or devices, or both, installed to resist the spread of fire into the assembly for a prescribed period of time.

- **Mitigation** – Modifying the environment, structures, or human behavior to reduce potential adverse impacts from a natural hazard.

- **Neighborhood** – The region near some place; an adjoining or surrounding district; a more immediate vicinity.

- **Occluded** – The occluded community generally exists in a situation, often within a city, where structures abut an island of wildland fuels (e.g., park or open space).

- **Open space** – Undeveloped land, a naturally landscaped area, or formal or man-made landscaped area that provides a connective link or buffer between other resources. In Colorado, each community defines open space in its own way, but generally open space is set aside for preservation with the idea that it will not be developed.

- **Passive Fire Protection** – A series of built-in fire-resistant features such as firewalls and fire doors to limit the spread of fire, heat, and smoke by containing it in a single compartment in its area of origin.

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

- **Risk** – The chance of fire starting as determined by the presence and activity of causative agents.
- **Through-penetration firestop system** – An assemblage consisting of a fire-resistance-rated floor, floor-ceiling, or wall assembly, one or more penetrating items passing through the breaches in both sides of the assembly and the materials or devices, or both, installed to resist the spread of fire through the assembly for a prescribed period of time.
- **Undeveloped land** – A vacant area without any utilities, infrastructure, or buildings.
- **Vulnerability** – Susceptibility to injury, harm, damage, or economic loss.
- **Wildfire** – An unplanned, unwanted fire burning in a natural area.
- **Wildland** – A natural environment that has not been significantly modified by human activity.
- **Wildland-Urban Interface** (WUI) – The line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetation fuels.

Appendix D: Homeowner's Guide to Risk Reduction and Remediation of Residential Smoke Damage

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Marshall Fire Mitigation Assessment Team: Homeowner's Guide to Risk Reduction and Remediation of Residential Smoke Damage

Revised April 2025

FEMA

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The approaches provided in this document can reduce but not eliminate all contaminants from wildfire smoke and ash.

Environmental testing is recommended after post-cleanup to ensure contaminants from wildfire smoke are safe for long-term occupancy. An operational air purifier after cleanup can further reduce contaminants from wildfire smoke until environmental testing indicates the home is safe for long-term occupancy.

1. Introduction

On December 30, 2021, a wind-driven wildfire affected over 2,000 residential structures and several commercial facilities in unincorporated Boulder County, the City of Louisville, and the Town of Superior, Colorado. Data gathered after the fire indicates that a significant number of additional residential structures experienced damage from smoke and ash infiltration.

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

The purpose of this document is to provide recommendations to homeowners for pre-wildfire measures to help reduce the risk of smoke damage and do-it-yourself (DIY) steps that homeowners can take to remediate light to moderate smoke damage. This document also includes recommendations for selecting and monitoring a professional cleaning services contractor for heavy smoke damage.

3. Key Issues

- **What is Smoke?** Smoke is a mixture of gases including carbon monoxide, carbon dioxide, and other chemicals as well as particulate matter. When smoke from a wildfire dissipates, many of the gases are absorbed into the surrounding air and porous materials, while the particulate matter carried by the smoke settles to the ground and other surfaces as soot and ash. Soot is the remains of incomplete combustion and is composed of small, dark-colored particles measuring 0.1 micrometer in diameter. Ash is the solid remains of a fire and is composed of larger, light-colored particles measuring 1 to 10 micrometers in diameter.

- **What are the Consequences of Smoke Damage?** Smoke can cause significant physical damage as well as health issues, even if the home is not destroyed or burned by fire. Although smoke does do not result in the complete loss of structures, contents, or landscaping, it can still result in devastating impacts (e.g., costly cleaning, repair or replacement of materials, displacement of residents, disruption of businesses, health issues). Examples of smoke, soot and ash damage include soot and ash deposition, unpleasant odors, metal corrosion, plastic deterioration, and staining of materials. If not removed from surfaces in a timely manner, fire residue can permanently etch metal surfaces due to its extreme levels of alkalinity or acidity. Soot and ash can damage porous materials such as upholstery and clothing, making them nearly impossible to clean. Additionally, smoke, soot and ash can lead to a range of health impacts, including respiratory irritation, shortness of breath, worsening of asthma, potential exposure to carcinogens, and other short-term and long-term medical conditions.

- Levels of damaging smoke infiltration into the residence may be reduced if precautions are taken prior to a fire event. Many of the mitigation measures that can be implemented to reduce ember ignition also are effective at reducing smoke and ash infiltration (see Marshall Fire MAT document *Wildfire Resilient Detailing, Joint Systems and Interfaces of Building Components*). Additionally, the impacts of smoke damage can be reduced if timely and effective measures are employed by homeowners after the actual fire danger has passed.

- Although it is nearly impossible to completely eliminate the risk of smoke damage, there is evidence to suggest that homes that are tightly sealed against ember intrusion may also be more effective at limiting smoke damage.

4. Pre-Event Smoke Risk Reduction Measures

This section focuses on short-term measures to reduce the risk of smoke infiltration in the hours prior to a wildfire. You can take additional actions well in advance of a wildfire to protect against ember and hot gas intrusion that also can help protect against smoke, soot and ash infiltration. See Marshall Fire MAT document *Wildfire Resilient Detailing, Joint Systems and Interfaces of Building Components* for additional information.

4.1. Recommended Measures

If a fire evacuation notice is issued, use the Pre-Event Wildfire Evacuation Checklist below to ensure you have packed essential items and confirmed transportation to evacuate. Once this is done, the following specific pre-event measures should be taken within 1 hour of an impending fire or evacuation notice if time and circumstances allow to reduce the risk of smoke infiltration:

- Shut down the heating, ventilation, and air conditioning (HVAC) system by switching off the power at the breaker panel.

- Shut all windows, doors, skylights, and other openings, but leave them unlocked.

- Seal openings like "pet doors" and vents where possible.

- Consider spraying metal fixtures in the bathrooms and kitchen with moisture-displacing lubricant such as WD-40 to prevent flash corrosion due to high / low pH soot residues.

- Cover or move outdoor furniture indoors to protect against smoke, soot and ash.

Pre-Event Fire Preparedness Checklist

In addition to pre-event measures listed above for reducing the risk of smoke and ash infiltration, the following pre-event preparedness checklist is recommended for use within 24 hours of a fire evacuation notice. **Start by getting a notebook or binder and begin a journal of your actions and conversations surrounding this event.** Keeping a log of dates, times, and names of individuals spoken to can be invaluable if your property should become damaged. If you need to file an insurance claim, remember that documentation describing the "who, what, where, when, and why" of activities that support your decisions can be just as important as damage photographs and receipts.

- ☐ Identify two or more safe places for evacuation that are well outside the area of potential fire spread.
- ☐ Fill vehicles with fuel or fully recharge, or secure transportation to evacuation site.
- ☐ Withdraw cash for purchases in the days following the fire.
- ☐ Charge cellphones, laptops, other critical electronics, and purchase and charge power banks.
- ☐ Pre-pack prescription medications and other valuable items (cash, jewelry).
- ☐ Identify and pack critical documents (passports, birth records, insurance binders, social security information). Keep emergency cash with these documents and take it with you.
- ☐ Take digital photographs to document valuables and other contents of every drawer, closet, storage container, freezer, and refrigerator.
- ☐ Take digital photographs to document the exterior of the house with attention to the roof, yard vegetation around the house, and neighbor's structures.
- ☐ Consider packing perishable foodstuffs as wildfires can result in power outages for extended periods of time.
- ☐ Consider preparing an Initial Assessment Kit, as described in the text note below, including proper clothing to conduct the assessment (i.e., long-sleeved shirt, long pants, and boots).

5. Steps to Remediate Smoke Damage

5.1. Initial Assessment

Before trying to remediate smoke damage, it is important to conduct an initial assessment of the level of fire and smoke damage to determine what resources will be needed to remediate or repair your home. Once you are allowed by local officials (e.g., fire department, building department, and utility providers) to return to your home and have assembled the necessary items for an Initial Assessment Kit (see side note), perform an assessment as follows:

Initial Assessment Kit – Items to Bring

- Cell phone
- Camera or cell phone camera
- Flashlight
- Goggles
- Dust masks (N95 or better)
- Rubber gloves
- Hand cleaning wipes
- Box of alcohol wipes
- First aid kit
- Small, clear plastic zip lock bags
- Permanent marker
- Phone numbers for your insurance agent, local utility providers, and contractors (electrician, HVAC, and restoration)

1. Wear personal protective equipment (PPE) and clothing to protect yourself – including goggles, an N95 or P100 respirator, gloves, long pants, long sleeve shirt, and closed toe shoes.
2. Walk exterior of home and look for obvious signs of fire and smoke damage. Focus particular attention on damaged roofs, overhangs, windows and doors, electrical service and equipment, and damaged HVAC components. Check for signs of smoke and ash buildup on the exterior siding, doors, and windows.
3. If you have found damage to roof, overhang, wall, windows and/or doors, make a note, photograph these areas, and document them for your insurance carrier prior to undertaking any remediation or restoration efforts. Contact a contractor to seal any penetrations as soon as possible to prevent further damage.
4. If any visible damage is noted to electrical service or wiring, or if you suspect a gas leak, do <u>not</u> touch the damaged part, contact your utility company immediately or your electrician. If it is safe to enter the home, turn off the main breaker in your electric panel (see Steps 5 and 6 for details).
5. If any visible damage is noted to your outdoor HVAC components, contact your HVAC contractor. If it is safe to enter the home (i.e., there is no visible fire or smoke damage), turn off the main breaker in your electric panel (see Step 6 for details). If you are unfamiliar with the location and operation of your electric panel, contact an electrician.
6. Enter the home if it is safe to do so wearing PPE (goggles, N95 or P100 respirator, gloves) and check utilities:

- **Electricity:**
    - If the power is on, be aware of any noises (sizzling or crackling) and burning odors as you turn on lights and use devices. If you notice any of these conditions, shut off the device immediately and call an electrician.
    - If the power is off, and the outside electric service is not visibly damaged, go to your electrical panel and shut off your main breaker and all other breakers. Turn on the main breaker first. One by one, turn on each breaker. If the main breaker or any individual breaker trips, leave that breaker off and contact your electrician.
- **Natural Gas:**
    - Check with the gas utility to determine whether gas service has been restored and pilot lights have been re-lighted. If it has not been restored, or if pilot lights on gas appliances need to be re-lighted, contact your gas utility company.
    - If a gas leak is detected or suspected, leave, and call 911 immediately, and contact your utility company as soon as possible.
- **HVAC:**
    - If the air handling system is operating, shut it down until you determine the condition of the home.
    - If the air handling system is not operating, shut off all breakers related to the HVAC system and contact your HVAC contractor.

7. Although not directly related to smoke damage, check refrigerators and freezers for spoiled food from power outages. Remove from the home to minimize odor problems that could mask smoke odors and photo document for possible insurance claim.

8. Walk the entire home and determine the smoke, soot and ash condition of each room.

    - **Smoke:** To check for the presence of smoke, simply "follow your nose". If there is a noticeable smoke odor, then you likely have some level of smoke damage.

    - **Soot and Ash:** To check for the presence of soot and ash, check horizonal surfaces for presence of soot and ash by using a wipe test. To conduct a wipe test, put on a clean pair of gloves and open a small, prepackaged alcohol wipe to wipe a horizontal surface that is unfinished (such as unpainted and unvarnished wood), then check the wipe for the presence of soot and ash. The wipe test will help decide where and how much soot and ash is present, if this is a cleaning project that you can undertake yourself, or if a professional cleaning service will be needed.

    Table 1 provides the categories of soot and ash conditions based on a wipe test and provides a recommended restoration approach. After classifying the soot and ash condition in each room, using Table 1, consider placing each wipe sample in a clear plastic zip lock bag, then label each bag with the date and room where the sample was collected before sealing it.

9. Document all rooms and wipe test results with notes and digital photographs to give to your insurance company. Be sure to keep all original notes and photographs for your file. Consider keeping test wipe samples as well.

Table 1. Categories of Smoke, Soot and Ash Conditions and Smoke Remediation Recommendations

Category	Description of Smoke, Soot and Ash Conditions	Smoke Remediation Recommendation
None	No visible soot or ash on horizontal surfaces, no visible airborne particulate, and no noticeable smoke odor. Wipe test can be used to confirm no soot/ash.	No smoke remediation by homeowner is necessary.
Light	No visible soot or ash on horizontal surfaces and no airborne particulate, but noticeable smoke odor. Wipe test confirms no soot/ash. (No visible soot/ash on exterior siding or windows.)	Homeowner can undertake simple steps to clean the home
Moderate	Presence of light soot and ash on horizontal surfaces (see Figure 1), visible airborne particulate, and noticeable smoke odor. Soot Wipe test shows a light amount of soot/ash. (Soot/ash may be visible on exterior siding and/or windows.)	Homeowner can undertake detailed steps to clean the home if simple cleaning steps are unsuccessful.
Heavy	Presence of heavy soot and ash on horizontal surfaces and floors (see Figure 2), visible airborne particulate, and noticeable smoke odor. Wipe test shows a heavy amount of soot/ash. (Soot/ash likely visible on exterior siding and/or windows.)	Retain a professional cleaning/restoration service contractor if detailed steps to clean the home are unsuccessful.
Other	Visible fire damage to structural elements or contents.	Do not enter home until cleared by the fire department, then keep professional contractor(s) to address structural fire damage and smoke damage.

5.2. Light Smoke, Soot and Ash Damage: Recommended Restoration Steps

For light smoke, soot and ash damage (i.e., where there is only an odor of smoke, but no visible presence of soot or ash), the homeowner can undertake the following four basic restoration steps:

1. **Aerate/Ventilate.** Open all windows and doors to air out the interior of the home. Note: This first step should be avoided if heavy smoke and particulates remain in the air outside.
2. **Filter.** Install a new air filter in your air handling unit with a Minimum Efficiency Reporting Value (MERV) rating of MERV 11 or higher to help filter smoke particles and operate the unit using constant fan mode.

3. **Absorb.** Place activated charcoal bags or containers throughout the home to absorb smoke odors. These bags/containers can be found at most home improvement stores or available online. Avoid the use of odor masking products or perfume-based odor counteractants. These products are not effective at eliminating smoke orders and may result in new odors that are difficult to identify.

4. **Clean.** If the odor is particularly strong in one or more rooms of the home, consider cleaning all absorbent materials in that room(s), such as linens and other fabrics.

If the smoke odor is not removed after completing these four steps, then a deeper cleaning of the residence will most likely be required. After coordinating with your insurance company, review and apply the necessary restoration steps and techniques for moderate smoke, soot and ash damage in the next section for deeper cleaning.

5.3. Moderate Smoke Damage: Recommended Restoration Steps

For moderate smoke, soot and ash damage, where there is a light level of soot on horizontal surfaces and visible airborne particulates (see Figure 1), in addition to a noticeable smoke odor, the homeowner can undertake the following six detailed restoration steps:

Figure 1. Photos of light soot levels associated with moderate smoke and ash damage. (Photos provided by John DiMenno of Romualdi Davidson & Associates and used with permission.)

1. **Protect Yourself.**

- Wear PPE, including safety goggles and an N95 or P100 respirator, to protect your eyes and lungs from irritation by smoke and ash. Additionally, dress in long-sleeved shirts, long pants, close toe shoes and socks to minimize skin contact.
- Use extreme caution when cleaning electrical devices and appliances. Make sure to turn off power to these items prior to cleaning, and do not over-wet the devices. Shut down all electronics (televisions, computers, printers, etc.), then HEPA vacuum rather than wet clean surfaces; follow manufacturer's recommended methods and products.
- Contact your doctor or medical provider about cleaning and use of affected medications and medical equipment. You may need to contact your medical equipment provider for additional assistance.

2. **Stop the Spread.**

- Keep in mind that if soot and/or ash is visible on hard flooring surfaces, then it is present on carpeted surfaces. Therefore, avoid walking through the home excessively, prior to cleaning, as this will only spread and further embed the soot into the flooring surfaces.

- Do <u>not</u> turn on the air handler for your HVAC system until the bulk of the soot/ash has been removed (see Step 6.) Operating the air handler prior to removing the bulk of the soot/ash throughout the home will only result in spreading the particulate and re-contaminating surfaces that have already been cleaned.

3. **Initial Cleaning.**

- Start by removing any visible soot/ash or debris from exterior siding and windows. Use a pressure nozzle attached to a garden hose to wash off light soot or ash off exterior siding; consider using a pressure washer to remove any stubborn soot or debris. Clean exterior windows with a gentle mixture of dish soap and water applied with a microfiber towel and be sure to carefully separate clean towels from dirty ones already used.
- Move to the interior and start by cleaning all hard floor surfaces using a damp cloth or cleaning pad sweeper. Note that several passes may be needed to remove all the soot from hard floors.
- Next, clean all carpets using a high-efficiency particulate air (HEPA) filtered vacuum. As with hard floor surfaces, several passes may be needed to remove all soot from carpets.
- Use a clothes washer to clean all bedding, towels, and clothes that have visible soot on the surfaces.
- Clean all soft goods such as couches, mattresses, pillows, pet beds, and plush toys with a HEPA filtered vacuum. Note that several passes may be needed to remove all soot from various soft surfaces.

4. **Detailed Cleaning.**

- First, damp wipe ceilings and walls using water and a mild detergent or all-purpose cleaner. Start by cleaning high surfaces then work your way downward. Use caution when working on ladders. Prior to cleaning, test clean a hidden area of a ceiling or wall to ensure that the surface will not be damaged by the water and/or cleaner. Note it may be necessary to clean the surfaces multiple times.
- Next, damp wipe hard contents and furniture using water and a mild detergent or all-purpose cleaner. As with ceilings and walls, test clean a hidden area before proceeding to make sure that the surface will not be damaged by the water and/or cleaner. Also note that it may be necessary to clean the items multiple times.
- All dishes, utensils, glasses, which have visible soot can be cleaned in the dishwasher or hand washed using dish soap and warm water. Additionally, you may have to clean items in cabinets, depending on the extent and severity of the soot deposition.
- Use caution when damp cleaning framed and unframed photos and wood furniture as they can easily be damaged by water and cleaning products.
- Most un-opened boxed and canned pantry items can be wiped clean.

5. **Discard Unsalvageable Items.**

- Food items left open or in partially opened containers such as cereal boxes should be discarded. Photo document all discarded items.

- Consider replacement of baby items, especially pacifiers and baby bottles, as well as medical devices such as oxygen and continuous positive airway pressure (CPAP) masks and tubing instead of cleaning.

6. **Clean HVAC System.**

- Wipe all HVAC register covers. Be sure to tape a lightweight fabric, such as cheesecloth, over the register prior to starting the air handler.
- Once most of the soot has been removed in the previous steps, install a new air filter in your air handler with a Minimum Efficiency Reporting Value (MERV) rating of MERV 11 or higher to help filter smoke particles, and operate the unit on constant fan mode.
- It is recommended to have all ducts and the furnace professionally cleaned.

5.4. Heavy Smoke Damage: Recommended Restoration Steps

For heavy smoke, soot, and ash damage where there is a heavy amount of particulate on horizontal surfaces as well as visible airborne particulates, in addition to a noticeable smoke odor, the homeowner should take the following six steps to retain a professional cleaning service to conduct the restoration.

1. **Make the Call.** Contact your insurance company and let them know that you will be retaining a professional cleaning service. Your insurance company may have a list of companies from which you can choose.

2. **Select a Contractor.** Research the cleaning companies in your area using the checklist with tips for selecting a professional cleaning service contractor provided below. Using local companies is generally best. Be cautious when working with out-of-town companies, especially after a major disaster.

Checklist for Selecting a Professional Cleaning/Restoration Service

Given the high cost of smoke, soot and ash restoration, it is strongly recommended that you follow this checklist when selecting a professional cleaning/restoration service contractor.

- ☐ **Get References.** Ask for the names of past customers. Call those customers and ask relevant questions on how their project went. Confirm that the contractor is licensed by the state or county to do the work and has the necessary bonding and liability insurance coverage.

- ☐ **Discuss Insurance.** Ask the contractor if they work with your insurance company. Call your insurance agent and ask them if they have worked with the prospective contractor.

- ☐ **Request Certifications.** Ask the contactor for company and employee certifications, such as from the Institute of Inspection Cleaning and Restoration Certification (IICRC) and the Restoration Industry Association (RIA).

- ☐ **Get an Estimate.** The contractor must provide you with an estimate. Do <u>not</u> begin work on the project without an estimate.

- ☐ **Review the Contract.** The contractor must provide you with a contract that includes the ***project amount, as well as a start and completion date***. Do not work a contractor who will not provide specific cost and schedule information written into the contract. Make sure to review and understand the terms of the contract and what is required by you, such as payment of your homeowner's insurance deductible.

3. **Sign and Start.** Once a professional cleaning service contractor is selected and the contract is reviewed (see contractor selection checklist), you and the contractor must sign the contact to start the work. *Do not allow the contractor to begin work on the project without a contract signed and dated by both parties*.
4. **Work with Insurance.** Know who your insurance adjuster is and how to contact them (cell phone, e-mail). Keep in constant contact with the adjuster, as well as your insurance agent, who are your advocates. Be sure you understand how the insurance company will pay for the services rendered by the contractor. Claims are typically paid in installments or with partial payments based on achieving specific milestones. Note that contractors may request a partial payment prior to the start of work on the project. Make sure to discuss this issue with your adjuster prior to paying any funds. Do not pay the contractor in full until the project is complete to your satisfaction (see step 6).
5. **Monitor Contractor Performance.** Ask who the project manager will be for the restoration work, and obtain that person's contact information, including cell phone and e-mail. Find out the planned working hours of the crew. Many restoration crews typically work weekday shifts from 8 am to 5 pm. Monitor what days the crew worked, how many crew members worked, and the names of the crew members when possible. Be sure to communicate with the project manager on a regular basis during the project. If restoration work requires removal and replacement of insulation or other work that requires a building permit, check to be sure the project manager understands the local permitting requirements. When an issue arises where an aspect of the restoration work is either not in accordance with contract terms or not to your satisfaction, contact the project manager immediately to discuss the situation as well as plan to resolve the issue.
6. **Finish the Job.** When the work conducted by the restoration contractor is completed to your satisfaction and in accordance with the contract requirements, contact your insurance adjuster and tell them that the project is complete. This will aid the carrier with issuance of final payment as well as closing their file.

6. Resources and Useful Links

FEMA Technical Fact Sheet Series FEMA P-737: *Home Builder's Guide to Construction in Wildfire Zones*. https://defensiblespace.org/wp-content/uploads/2021/01/FEMA_2008_P-737-Home-Builders-Guide-to-Construction-in-Wildfire-Zones.pdf

American Industrial Hygiene Association (AIHA). Technical Guide for Wildfire Impact Assessments for the OEHS Professional. Edited by Enrique Medina. 2018. https://online-ams.aiha.org/amsssa/ecssashop.show_product_detail?p_mode=detail&p_product_serno=1558

Centers for Disease Control and Prevention (CDC). Preparing for Wildfires webpage. https://www.cdc.gov/disasters/wildfires/beforefire.html

EMSL Analytical, Inc. Fire & Smoke Damage Testing Pocket Guide. https://emsl.com/

International Environmental Standards Organization (IESO)/Restoration Industry Association (RIA) Standard 6001. Evaluation of Heating. Ventilation and Air Conditioning (HVAC) Interior Surfaces to Determine the Presence of Fire-Related Particulates as a Result of a Fire in a Structure. 2012 Edition.

Restoration Industry Association (RIA). https://www.restorationindustry.org/

Reviewed.com Article: How to Clean Smoke Damage, Ash and Soot from Your Home. https://www.reviewed.com/cleaning/features/how-clean-smoke-damage-ash-and-soot-your-home

Appendix E: Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire

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Marshall Fire Mitigation Assessment Team: Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire

Revised April 2025

FEMA

DR-4634

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1. Introduction

On December 30, 2021, a wind-driven wildfire affected over 2,000 residential structures and several commercial facilities in unincorporated Boulder County, the City of Louisville, and the Town of Superior, Colorado. Data gathered after the fire highlighted that homes were vulnerable to ignition at various features including the exterior envelope of the structure and associated attachments.

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 provides homeowners with steps they can take now to decrease the likelihood their homes will ignite due to direct flame contact, ember intrusion, or hot gases from wildfires at various physical vulnerabilities throughout the exterior envelope of the house. Specifically, it provides information about some measures that homeowners can take to address vulnerabilities at joints, gaps, vents, and attachments such as decks and fences.

3. Key Issues

> Note: This document uses the term “embers” to refer to both “firebrands” and “embers.” Sometimes scientific literature distinguishes between the two terms where “embers” are “any small, hot, carbonaceous particle” and “firebrands” are embers that are “airborne and carried for some distance on an airstream” (Babrauskas, 2018).

- When components and assemblies of homes such as walls, roofs, windows, doors, and siding systems are connected they leave exposed surfaces, form joints or spaces at the connection points. These joints and spaces help accommodate building movements and construction tolerances. They also are places where vegetative debris (e.g., leaves, needles, grass clippings, twigs, branches, etc.) tends to accumulate. While current building codes do require fire-resistant construction, homes constructed following older codes may have exterior walls that are susceptible to fire depending on the construction and/or materials used to construct them.

Single-family homes typically do not have exterior walls that are built to resist wildfire, which means they have the potential to allow surfaces to be exposed to embers, flames, and hot gases or enter the home through the exterior envelope (Figure 1).

- Vents in roofs, walls, and crawl spaces provide the air circulation needed to minimize moisture buildup that can lead to significant damages over time. These vents, if not sealed, provide a pathway for embers to enter the house, resulting in possible ignition inside the structure.

- Current research indicates that decks, porches, balconies, and exterior stairs are often constructed of non-fire-resistant materials which embers can ignite. Vegetative debris can accumulate on or under these structures. These structures can ignite when directly exposed to embers or direct flaming. Because they are often adjacent or attached to the vulnerable components (e.g., glass doors and windows) of the house, once they ignite, fire can spread to the house itself.

- Fences constructed from combustible materials and having joints or spaces between components (such as post-and-board fences) can allow embers to collect in the joints and gaps. Flames can travel horizontally along combustible fences when ignited, acting as a "wick." When the fence is attached to the home, these flames can then ignite the house itself. Fences within the first five feet of the house pose the greatest risk of flames igniting combustible siding or embers and flames igniting the under-eave area and the roof edge.

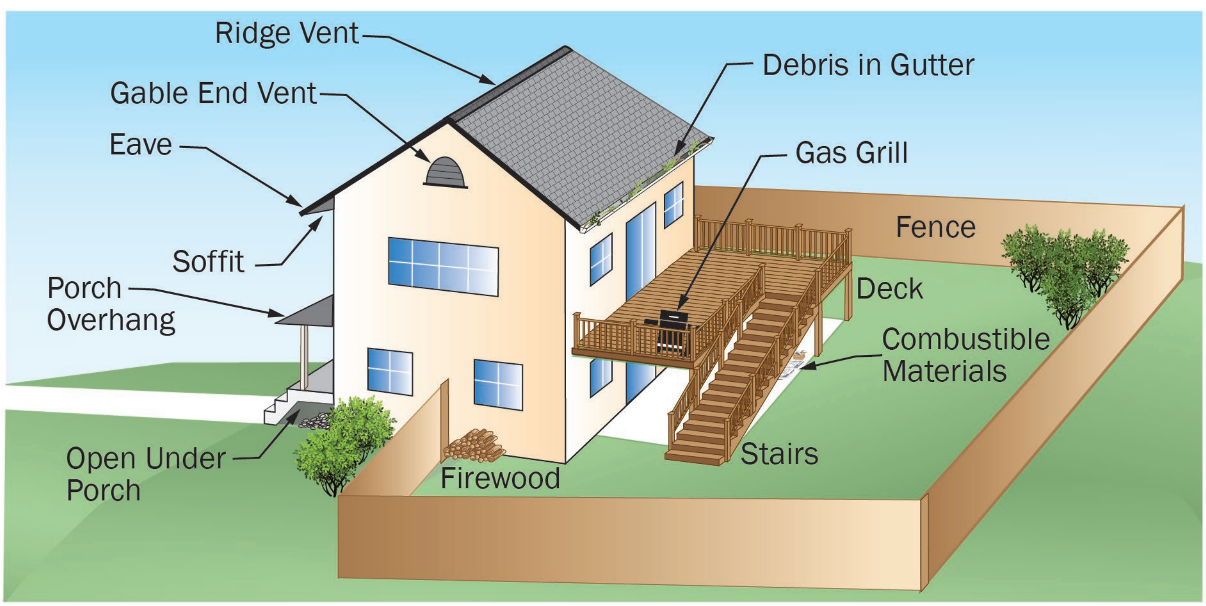

Figure 1. Many components of a home can be susceptible to ember and hot gas intrusion from a wildfire, which can result in the home igniting.

DEFINITIONS

Fire resistance – The property of materials or their assemblies that prevents or retards the passage of excessive heat, hot gases, or flames under conditions of use. (International Building Code (IBC), 2021)

Fire-retardant-treated wood – Wood products that are treated with chemicals so that the treated wood does not support combustion, and its burning rate is limited when flame is applied. (Minnesota Department of Labor and Industry, no date)

Ignition-resistant building material – A type of building material that resists ignition or sustained flaming combustion sufficiently to reduce losses from wildland-urban interface conflagrations under worst-case weather and fuel conditions with wildfire exposure of burning embers and small flames. (IWUIC, 2021; ASTM E84; ASTM E2786)

Noncombustible (building material) – Material of which no part will ignite and burn when subjected to fire; any material conforming to ASTM E136 meets this requirement. Also includes material having a structural base of noncombustible material as defined previously with a surfacing material not over 1/8-inch thick, which has a flame spread index of 50 or less. (IWUIC, 2021)

4. Vents and Openings (including soffits, ridges, crawl spaces and gables)

Vents help create proper air flow in interior unoccupied building spaces such as attics and crawl spaces, which help to reduce moisture and hence moisture-related problems such as mold (Figure 2). They also provide an exit for exhaust from heating, ventilation, and air conditioning (HVAC), and plumbing systems. In wildfire conditions, these openings can provide an entrance for embers and hot gases to be blown or pulled into the house, which can result in the ignition of interior contents.

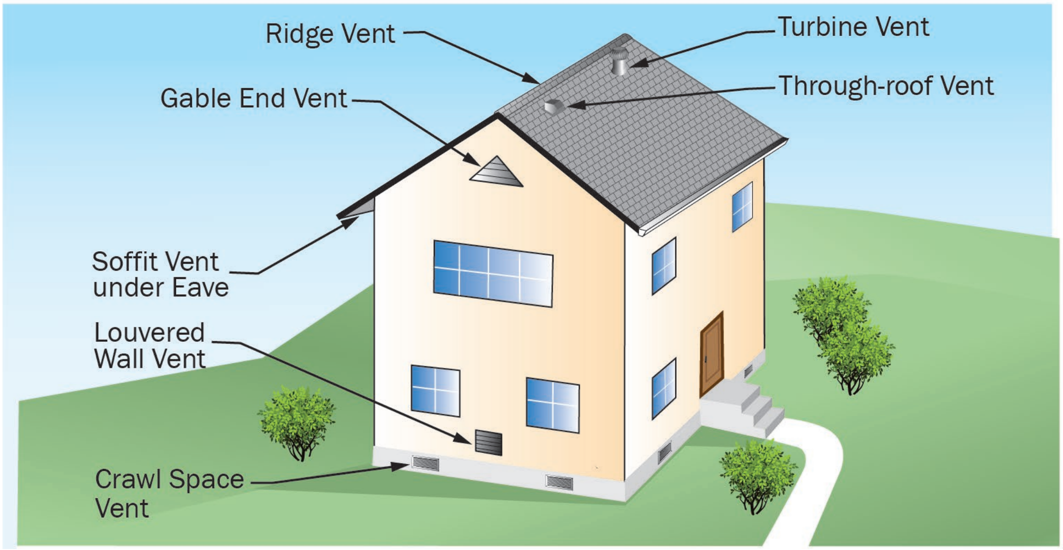

Figure 2. Vents can provide an entrance for embers to enter a house.

Vents containing metal mesh with 1/8-inch or less openings can help reduce the possibility of embers entering the house through the vent. Metal mesh with 1/16-inch openings is acceptable but will more easily accumulate debris so it needs to be cleaned more often than vents with larger openings; however, all vents should be cleaned regularly. Taking the following measures can help reduce the likelihood of embers and hot gases entering the house through vents.

- Check the flashing around vents on the roof. Replace missing, loose, or corroded flashing using noncombustible screening materials. Seal using a fire-resistant caulk, non-combustible mortar, or fire-rated expanding foam. Online videos can provide additional guidance or use a roofing contractor to secure the flashing around the vents.

- Turbine vents can help keep embers out, however, it is important to attach a piece of 1/8-inch mesh to the bottom of the roof sheathing at the opening for the vent (IBHS/NFPA, 2022).

- Consider replacing existing exterior wall, crawl space, and foundation vents with noncombustible flame- and ember-resistant vents (Figure 3). The California Department of Forestry and Fire Protection (CalFire) Building Materials Listing Program maintains a Wildland Urban Interface (WUI) Products Handbook online (https://osfm.fire.ca.gov/media/5e4drz1r/2021-sfm-wui-listed-products-handbook-12-14-2021.pdf) that contains a listing of products that meet the State's Building Code requirements for "vents for WUI." Many of these products and materials included in the listing are appropriate for use outside of California, as are recommendations included in their Low-Cost Retrofit List (https://osfm.fire.ca.gov/media/p0elt0sp/low-cost-retrofit-list-update-2_17_22.pdf).

- Add a layer of 1/8-inch or 1/16-inch opening corrosion-resistant metal wire mesh behind or in front of the vent opening in existing exterior vents.

- Replace existing non-fire-rated louvered wall vents such as those for clothes dryers with fire-rated, noncombustible, or fire-resistant wall louver vents minimize the entry of embers from entering through the vent. Be sure louvers open and close properly. Do not use mesh in louvered dryer vents.

- When replacing or reinstalling vents, use a fire-resistant caulk to seal around the edges of the vent to prevent water and ember intrusion between the vent and the exterior wall.

- This video from Fire Safe Marin shows how to repair or replace foundation vents. (https://www.youtube.com/watch?v=kEZPdnwdmGY)

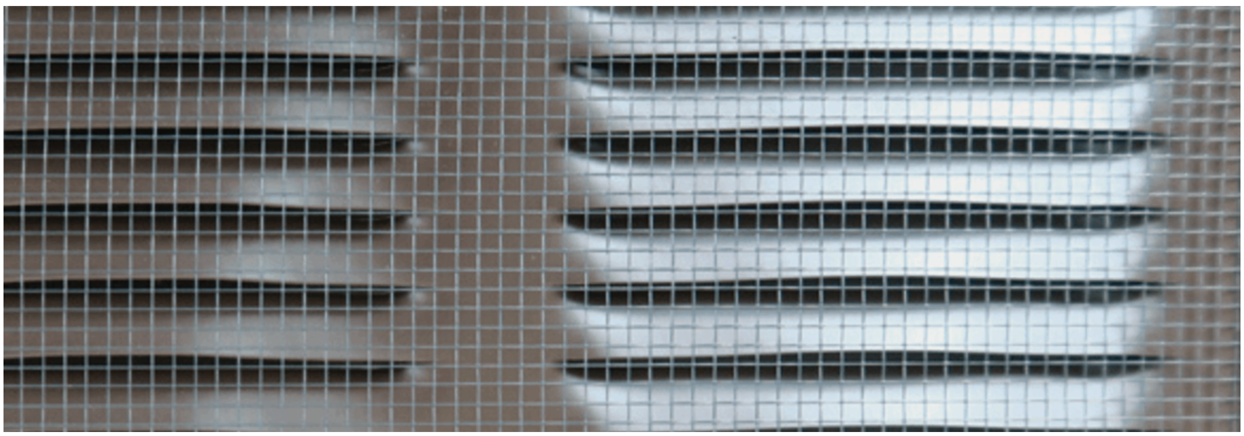

Figure 3. Installing 1/8-inch noncombustible mesh screening over exterior vents will help reduce the likelihood of ember intrusion. (IBHS, no date)

5. Gaps at Joints and Interfaces

Detailing at joints and interfaces of building components throughout the exterior envelope of a home, such as joints between skylights and roofs, gutters and roofs, windows and walls, and siding and foundations often leave exposed surfaces and can result in gaps or spaces where the two components join together. The exposed surfaces and gaps can leave these areas vulnerable to ember and flame intrusion as well as smoke, soot and ash infiltration. Embers entering through these spaces can become trapped between the outside and inside walls of the house, allowing the fire to spread in this space between walls. In addition, combustible debris such as dried vegetation can accumulate along linear joints and in gaps and pose an additional fire threat. Using the following measures can help reduce the likelihood of embers, hot gases, smoke, soot and ash entering the house through joints and gaps.

- Cover exposed edge surfaces of combustible material with a non-combustible material to minimize the chance of direct exposure to excessive heat, embers, or flame. An example would be to wrap the exposed edges of roof, wall, or floor sheathing material with corrosion-resistant (galvanized) metal flashing and seal with intumescent caulk, which swells when heated to seal gaps.

- Use a fire-resistant sealant, caulk, or expandable foam to seal the gaps between wall and frame joints around skylights, windows, doors, and garage doors. This helps to protect against entry of embers, hot gases, smoke, soot and ash.

- Multiple opportunities exist to reduce the exposure of roofs to ember intrusion and ignition. Homeowners might prefer to work with a contractor to implement these strategies, some of which are listed below.

    - Confirm that corrosion-resistant metal flashing is installed around chimneys. If flashing is not present, is not corrosion-resistant, or is in poor condition, install, repair, or replace the flashing.

    - Where there are gaps in roof-to-roof joints (ridges), seal the roof ridges at their terminations. Generally, a mortar mix is easy to use in these locations for tile or other roofing material where mortar is appropriate.

    - Install corrosion-resistant metal flashing at the roof edges and where exterior walls meet roofs. For profile-tiled roof edges, install bird stops or mortar at the open ends of tiles.

    - Install noncombustible gutters. If gutter guards are used to minimize the accumulation of leaves and debris in the gutters, they should be noncombustible.

- At wall expansion joints and where roof expansion joints are visible, verify the joint protection and flashing are in good condition. Consider replacing combustible expansion joints with noncombustible materials.

- Verify weather stripping around doors and operable windows is in good condition and provides a weather-tight seal. Consider replacing existing combustible weather stripping with fire-rated weather stripping to help protect against entry of embers, hot gases, smoke, soot and ash.

- Block gaps in siding with firestopping materials such as mineral wool or fire-resistant caulking/sealants
(Figure 4).

Figure 4. Homeowners should block gaps between siding and foundations (such as the one pictured here) using firestopping materials such as mineral wool or fire-resistant sealants to prevent embers, hot gases, and flames from entering and becoming trapped.

6. Decks, Porches, and Balconies

Existing decks, porches and balconies may be constructed from a variety of materials, including but not limited to softwoods, hardwoods, plastic composites, and aluminum. They usually are directly attached to the exterior walls of the house and, if constructed from combustible materials, can provide a pathway for fire to ignite the house. In traditional construction, the boards that form the walking surface of these structures are usually spaced about 1/8-inch apart. Gaps between the planks and between the structure and the house will trap embers. Decks, porches, and balconies are often elevated above ground, which makes them susceptible to wildfire from both above and below. The upper surface can ignite from ember exposure while the under-surface can ignite as a result of flame exposure. Homeowners can take steps to improve the fire-resistance of decks, porches, and balconies to protect their homes.

- If the existing deck frame is structurally sufficient, consider removing the existing deck boards and installing new decking using ignition-resistant building materials such as aluminum, steel, autoclaved aerated concrete, noncombustible tile, or fire-retardant treated wood. Composite deck boards should be used only if the manufacturer provides documentation that they are noncombustible. Some decking such as metal can be installed without gaps, decreasing the circulation of oxygen that feeds the fire. If new surfaces are installed with gaps between the boards, the gaps should be ¼-inch.

- If the existing decking will not be completely replaced, remove and replace combustible deck boards that are parallel to and within one foot of the adjacent exterior wall of the house with noncombustible deck boards having the same thickness as the rest of the decking (Maranghides et. al., 2022) (Figure 5).

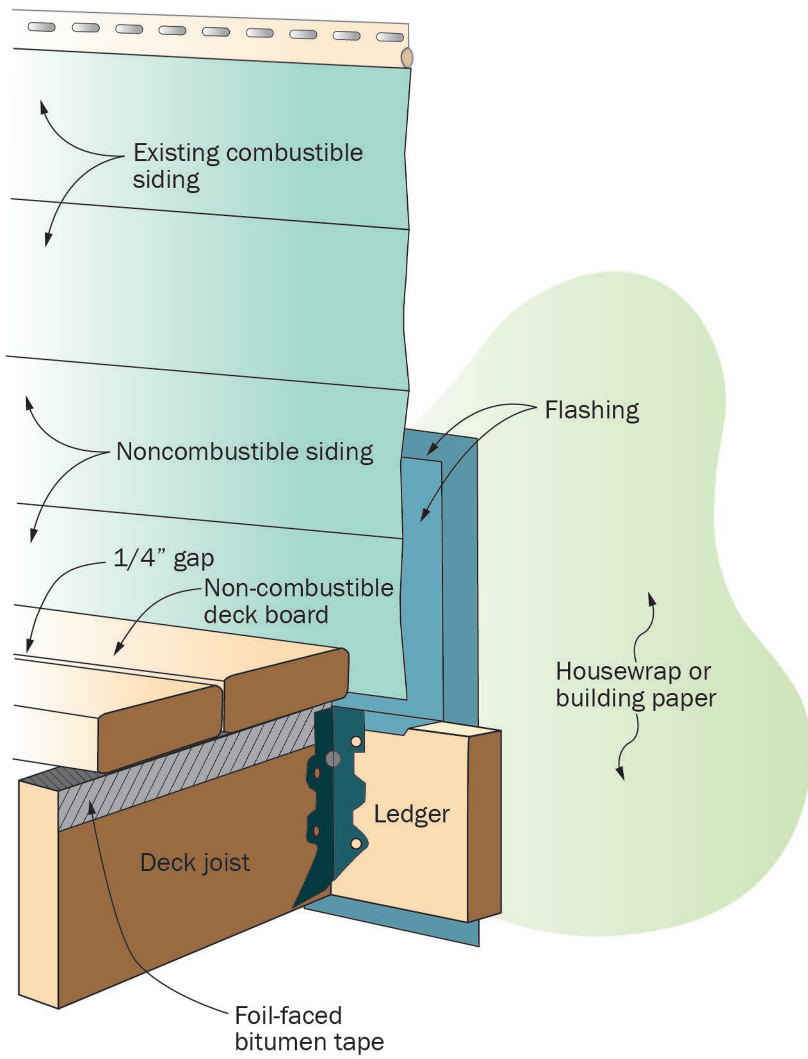

Figure 5. Replacing two to three courses/rows of combustible materials with noncombustible materials where a deck adjoins a house will help protect a house against ember ignition. Attaching foil bitumen tape at the joints between deck joists and deck boards and installing with a 1/4-inch gap between deck boards will also increase the ember resistance of decks.

- If the existing deck is constructed from combustible materials and the surface decking is being replaced, apply foil-faced self-adhering bitumen along the length and tops of the joists supporting the deck (Figure 5). Position the tape on each side of the joist near the top where the deck boards are attached.

- If existing siding is combustible, remove the bottom two to three courses of siding and replace them with noncombustible siding (Figure 5). If this is not possible or desirable, install a metal flashing strip approximately 18 inches tall extending from the top of the deck over the existing siding. Be sure to tuck the top of the flashing behind the siding to prevent water from seeping between the flashing and the siding.

- Replace combustible railings with railings constructed from noncombustible materials.

- Ignition-resistant building materials need to maintain their performance after they have weathered. Obtain information from the materials’ manufacturer regarding fire performance after weathering. Replace deteriorated components before they lose their fire-resistance.

- Enclose open spaces beneath elevated decks and stairways using ignition-resistant or noncombustible materials. Enclosures should extend the full height of the structure all the way to the ground surface, except when the deck is constructed over a descending slope greater than 10%, in which case the space should be enclosed to within six inches of the ground. To prevent a build-up of moisture that could result in decay, install ember and flame-resistant vents to avoid moisture degradation issues in the under-deck area (e.g., corrosion of metal fasteners and fungal decay in wood members).

7. Fences

Privacy fences are often constructed so they attach perpendicular to the home and extend to follow property lines. They can be constructed from a variety of materials and can include different designs. Soft woods such as cedar and redwood are often used for their aesthetic and ease of installation and maintenance; however, these types of wood can ignite easily when exposed to radiant or convective heat or embers. Hard woods are more ignition-resistant than soft woods but can still catch fire. Plastic or composite materials also are more ignition-resistant than soft woods but are susceptible to melting during a wildfire or grass fire. Regardless of the fence material, vegetative debris can accumulate along the bottom of fences, providing an additional source of fuel for fires. Debris and embers also can get trapped between slats in fences, resulting in ignition of the fence. In areas susceptible to wildfires and grass fires, fences constructed from combustible materials can inadvertently act as sources of fuel and “wicks” that draw the fire to the house. Homeowners can take steps to reduce the likelihood of home ignition from adjacent fences (Butler, Johnsson, et. al., 2022).

- Construct fences using noncombustible materials. At a minimum, use noncombustible materials for the first five feet of the fence that is in contact with the home (Figure 6). Fences parallel to the home should be constructed of noncombustible materials if a single fence is within 10 feet of exterior walls. Stone, decorative block, brick, precast concrete, and steel are all materials that can be used to construct visually pleasing fences that are also noncombustible.

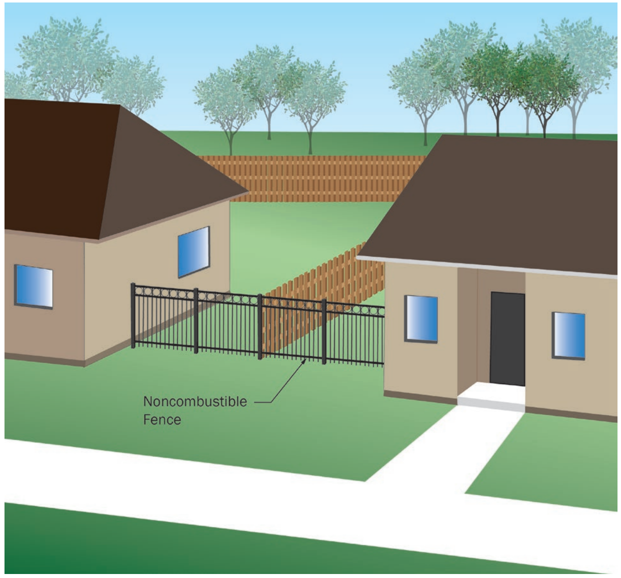

Figure 6. Noncombustible materials should be used to construct at least the first 5 feet of a fence attaching to a home.

- Back-to-back fences along either side of a property line should not be used, as fire intensity and the spread of the fire along the fence is significantly increased using this configuration.
- Keep combustible landscaping at least five feet away from (combustible) fences. Instead, use ignition-resistant materials such as stone near fences constructed from combustible materials. (See Marshall Fire MAT document "*Homeowner's Guide to Defensible Space*" for additional information.)

8. Maintenance

Homeowners should perform regular maintenance on their homes to protect against wildfire. There are several actions they can take to reduce the likelihood of embers and hot gas from entering their houses.

- Regularly remove vegetative and other debris from roofs, gutters, joints, where the foundation meets the ground surface, and along fences. Debris is a combustible fuel easily ignited by embers and often found directly on or next to the house, which increases the chances of home ignition.
- Clean vents periodically to remove debris so that each vent can perform its moisture management function properly.
- Do not store flammable materials in attics, on or under decks, under porches, or in crawl spaces.
- Remove vegetation near vents, exterior stairs, overhanging roofs and balconies, fences, and other places within five feet of the house (see the Marshall Fire MAT document *Homeowner's Guide to Reducing Wildfire Risk Through Defensible Space* for additional information).

9. Renovations and Significant Retrofits

When undertaking a renovation or significant replacement such as a new roof, windows, exterior doors, or deck, ask the contractor about using ignition-resistant or noncombustible materials. This is particularly important when structures are in proximity, which can cause ignition through radiation. See Marshall Fire MAT document *Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire* for additional information.

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Appendix F: Homeowner's Guide to Reducing Wildfire Risk Through Defensible Space

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Marshall Fire Mitigation Assessment Team: Homeowner's Guide to Reducing Wildfire Risk Through Defensible Space

Revised April 2025

FEMA

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1. Introduction

On December 30, 2021, a wind-driven wildfire affected over 2,000 residential structures and several commercial facilities in unincorporated Boulder County, the City of Louisville, and the Town of Superior, Colorado. Data gathered after the fire highlighted several vulnerabilities in the Home Ignition Zone (HIZ), particularly with respect to defensible space principles, that likely played a significant role in spreading fire from the wildland and open spaces to the built environment.

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.

1.1. Purpose

This document provides homeowners with steps they can take now to protect their homes from loss or damage from wildfires due to vulnerabilities introduced by surrounding landscaping and other exterior features (e.g., outbuildings, sheds, furniture, and trash bins) within the homeowner's property. The goal is to increase homeowner's awareness of the key mechanisms and characteristics of WUI fires that can result in home ignition, and to provide homeowners with guidance and various options to assist in the following:

1. Limit the ability of a fire to spread uninterrupted from adjacent wildlands and open spaces directly to the home (via direct contact from flames, exposure to hot gases or heat from radiation)
2. Limit the likelihood of embers igniting receptive fuel beds and other combustible items within the homeowner's property leading to home ignition (via heat from radiation, direct contact from flames, exposure to hot gases or additional embers created by vegetative and non-vegetative features (fuel)

These mechanisms, summarized in Figure 1, not only spread fire from wildlands, open spaces, greenbelts, and communal spaces to structures, but can also lead to the spread of fire from structure-to-structure and other items in the built environment. This is known as an urban conflagration.

This document provides homeowners with practical information, resources, and methods to better reduce or mitigate key vulnerabilities within their property from the home outward. This includes:

1. Creating and maintaining fire-adapted landscaping in terms of selection, location, and management of vegetation on the property
2. Increasing the home's chance to survive a fire whether firefighting resources are available or not available
3. Implementing additional wildfire-resiliency measures when property-line setbacks or defensible space are insufficient or unavailable which includes suggestions for how a homeowner can routinely check and evaluate the vulnerability of their home

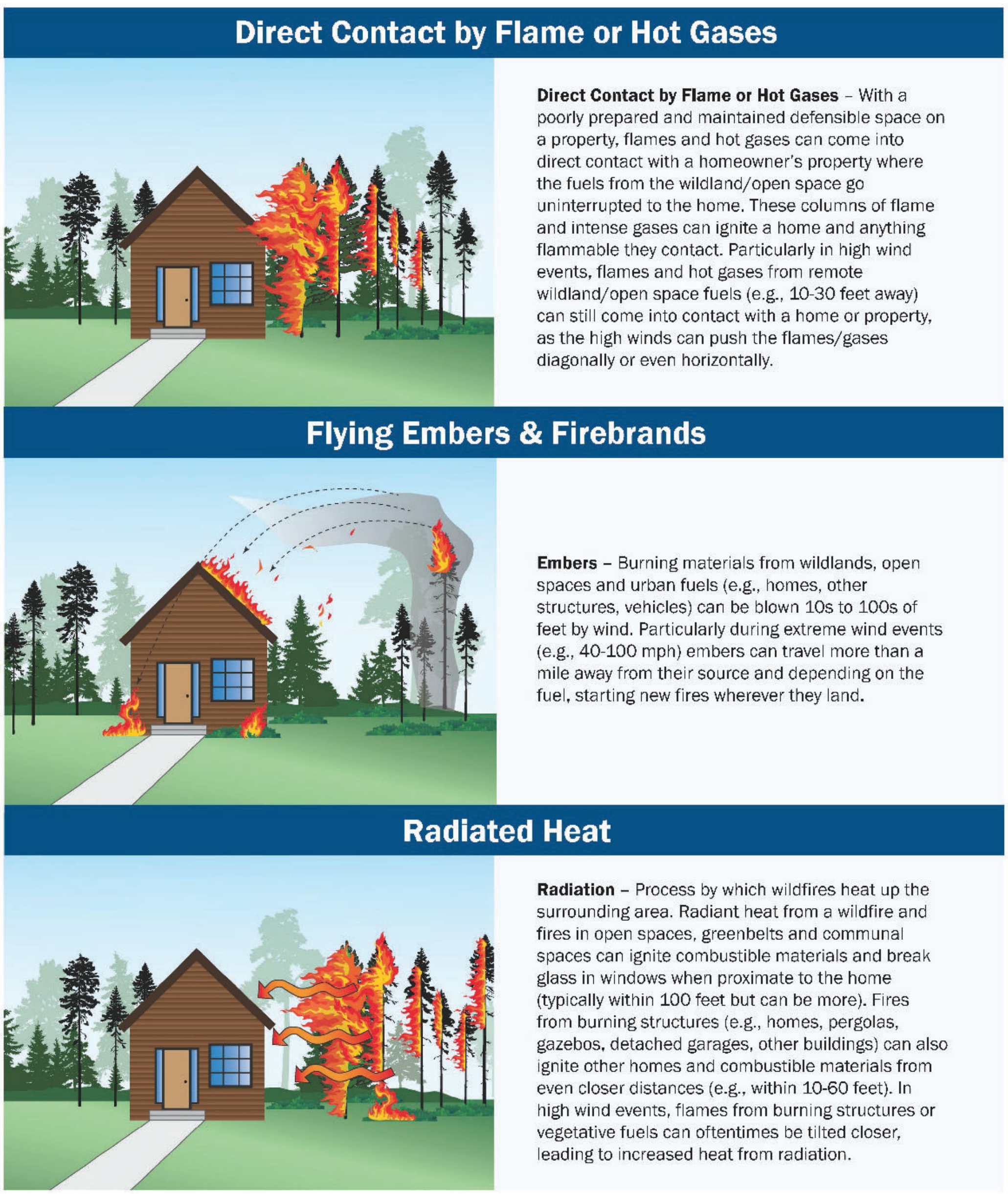

Figure 1. Key Mechanisms for Wildfires Leading to Property Damage and Loss.

Note: This document focuses on increasing wildfire resiliency in the defensible space around a home. Marshall Fire MAT document *Homeowner’s Guide to Reducing Risk of Structure Ignition from Wildfire* provides actionable items for increasing wildfire resiliency for the home itself such as the building materials, components, assemblies, and attachments throughout the exterior envelope (i.e., structural hardening) from the top of the roof down to the foundation.

1.2. Key Issues

Defensible space is intended to provide a buffer between the building and the wildland or open spaces that surround it. It should be developed and maintained so that if vegetative or non-vegetative components ignite, they will not threaten the home from generated embers, radiant heat, or direct flames. During a major wildfire event, first responders will likely be unable to actively defend individual homes, so it is essential for homeowners to take proactive measures, so their homes and yards survive with or without defensive actions by first responders (i.e., "survivability "). That said, properly developed and maintained defensible space will also create a place of relative safety that may increase the likelihood of first responders to defend a property. Ultimately, the responsibility of developing and maintaining defensible space, fire-resilient landscapes, and monitoring parcel-level wildfire vulnerabilities lies with homeowners, Information in this report highlights key opportunities for homeowners to reduce their wildfire risk.

Fires rapidly spread via various flow paths that can lead to ignition of structures throughout communities. Structure ignitions can be caused by one or multiple mechanisms, building materials and features, site conditions, or adjacent environmental settings (Figure 2), including:

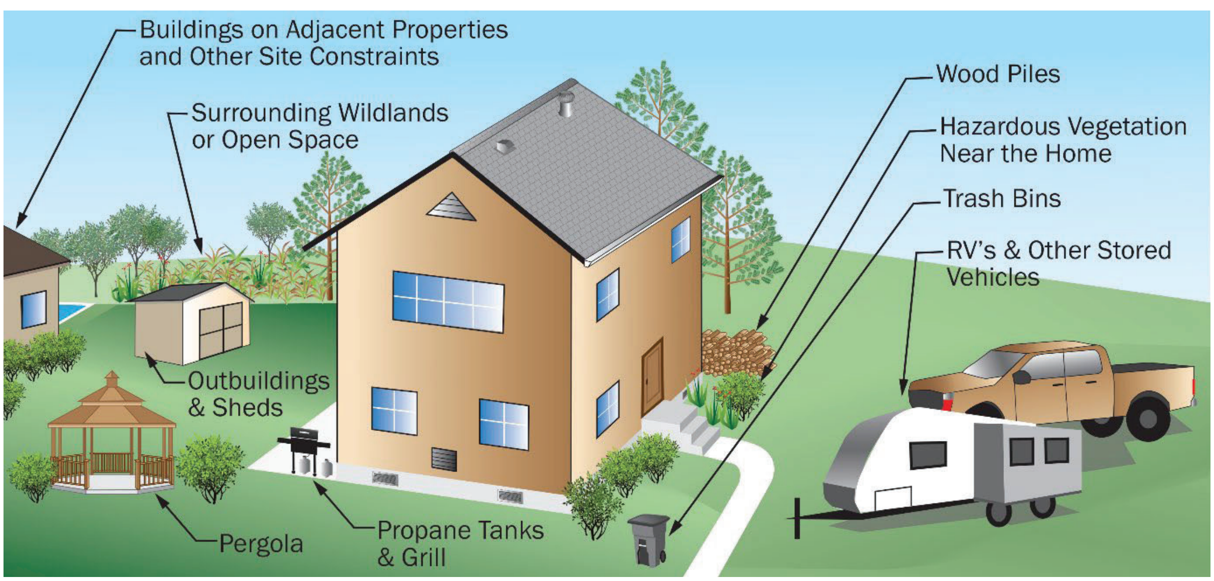

Figure 2. Key Wildfire Vulnerabilities Near a Home.

- **Wildland and Open Space Vegetation (e.g., grasses, shrubs, and trees)** – Fires in these spaces, whether intermixed or next to a community or home, can present a significant risk due to the intensity and rate-of-spread they are often characterized by (particularly in severe fire weather conditions). Large and uninterrupted open spaces or wildlands that border or mix with communities and neighborhoods, if not managed or considered in city or community land-use planning, can easily ignite homes and community assets through elevated radiative exposures, convective heat, and embers.

- **Landscape Vegetation** – Landscaping can consist of a wide range of managed vegetation types (e.g., trees, shrubs, flowers, grasses), plant characteristics and arrangements (e.g., height, growth type and extent, native vs. non-native, tendency for dead material accumulation), landscape purposes (e.g., food, shade, recreation), fire ecology attributes, and quality of ongoing maintenance. These 'man-made' landscape environments can be just as combustible as wildland vegetation and can provide a pathway for fire to spread from wildlands, open spaces, and greenbelts to the home both horizontally through surface fuels or vertically as ladder fuels from grasses and other low-lying vegetation and accumulated debris.

> While some plants are marketed and described as "firesafe" or "fire resistant", all plants will burn under the right conditions. The environment plants grow in and how they are maintained will generally have more influence on the flammability of the plant than its inherent characteristics.
> (CAL FIRE, 2022)

- **"Approved" and "Prohibited" Plants** – Many areas have compiled lists of both "approved" and "prohibited" plants to guide homeowners in landscaping design. The ability or inability to resist ignition is based on the physical characteristics of the plant. While these lists are beneficial to homeowners, they can be incomplete or misleading and can provide a false sense of security. These lists are highly dependent on a variety of local factors that may not be relevant to other locations. Numerous factors (e.g., plant species, plant structure, plant products such as resins, setting, surface mass, branching patterns, foliage size, density, litter production and retention, maintenance practices, placement, weather, weather history, etc.) influence whether a plant should be considered "hazardous" or "approved". Of these factors, maintenance is crucial, and any plant can become a hazard if not maintained properly. Homeowners are encouraged to consult with local fire departments or plant ecologists to evaluate plant "safety" due to the variety and nuances of plant flammability. Even "approved" plants will burn.

- **Embers** – Embers are responsible for the majority of wildfire structure ignitions (estimated to be at least 2/3 of ignitions, Maranghides 2009). Embers can be produced from burning vegetative fuels; other combustible materials such as buildings and contents; and other fuels such as vehicles, and waste bins in the area surrounding the built environment. Embers can be carried by high winds in front of the wildfire at varying distances (e.g., 1/2–2 miles). This creates a wind-driven fire hazard that is unique to wildfire incidents. See Figure 3.

Figure 3. Embers are the primary driver for rapid spread of wildfires into communities. (Valachovic, et al. 2021).

- **Site Constraints and Limited Setbacks** –Site constraints and limited setbacks to adjacent properties restrict a homeowner’s ability to achieve 30–100 feet of defensible space. These constraints can oftentimes mean that homeowners must contend with additional hazards e.g., adjacent unmanaged vegetation, vacant lots, structure-to-structure fire spread, that are mostly outside of their control. Alternative methods, such as common defensible space with neighbors and other structural hardening measures, are needed to address these increased risks.

- **Other Fuels in the Built Environment** – There are a wide range of other types of combustible fuels that homeowners may have stored adjacent to the primary structure, which may ignite due to a wildfire and present an additional fire hazard to homes. This can include firewood piles, sheds, outdoor grills, propane tanks, outdoor furnishings, lawnmowers, trash bins, vehicles, and decorative landscaping (e.g., artificial grass/turf). The type, quantity, and characteristics of these other fuels range dramatically and can present additional challenges in predicting fire behavior (e.g., fire severity, rate of spread, burning characteristics) and damage loss potential in the WUI (Society of Fire Protection Engineers WUI Handbook, 2023).

1.3. Definitions

- **Approved or Recommended plants** – “Recommended” or “approved” plants are generally based on characteristics that allow for a more fire-resistant landscape. Common characteristics include drought-resistance, high moisture content, low levels of volatile oils and other readily flammable chemicals, noninvasive, slow, and low growing, low litter production and bark shedding, and able to grow and thrive without supplemental fertilization.

- **Defensible space** – The area around a home where the location, selection, and maintenance of vegetation and other combustible materials are managed such that a fire or wind-blown embers are less likely to ignite the structure. This managed area provides a "defense" against the fire to reduce the structure's exposure to radiation (heat), direct flame contact and ignition from embers, which are considered the three principal factors of ignition in a wildfire. (Bell et al. 2007).

- **Defensibility** – The level and degree of wildfire mitigation measures that are provided for a structure such that it can be safely defended by firefighting resources in a wildfire but may not survive if firefighting is unavailable.

- **Embers (a.k.a. firebrands)** – Smoldering or flaming particles of vegetation from tree branches, leaves, shrubs, grass, chaparral, or other urban combustibles (such as building components, fences, sheds) that ignite and burn during a wildfire and are carried by winds in front of the wildfire at varying distances. Embers are sometimes also referred to as firebrands.

- **Fire-Adapted Plants** – Plants that have adapted to survive and live in environments with fire. Plant species can typically be classified into five different categories based on their adaptations, although some fit into more than one category. These categories include resisters (i.e., survive moderate to low-intensity fires), sprouters (i.e., endure fire and resprout from their roots), seeders (i.e., evade fire by shedding lots of seeds that sprout after a fire such as serotinous cones of lodge pole pine), invaders (i.e., take over recently burned areas) and avoiders (i.e., grow in areas where fire does not normally occur) (BLM, 2010).

- **Fire-Resistant Landscapes** – This type of landscape uses fire-resistant plants that are strategically planted and maintained to resist the spread of fire to your home. (CAL FIRE, 2019)

- **Hazardous or "Prohibited" Plants** – "Hazardous" or "prohibited" plants are generally based on characteristics that increase ignitability and introduce fire hazards in the landscape. Common characteristics include blade-leaf or needle-leaf evergreens; stiff, woody, small or fine, lacey leaves; leaves and wood containing volatile waxes, fats, terpenes, or oils. Other traits include gummy or resinous sap; plentiful fine, twiggy, dry, or dead materials, loose or papery bark, or produce a large amount of vegetative debris or duff. These types of "hazardous" plants typically flame when preheated and ignited (Fire Safe Marin, 2022).

- **Home Ignition Zone (HIZ)** – The HIZ consists of three zones around a structure including the immediate or ember-resistant zone, the intermediate zone, and the extended or reduced fuel zone (Figure 4). Different names and numbering may be given to these zones by different agencies and organizations.

- **Survivability** – The level to which a structure has the potential to withstand wildfire without being defended.

2. What is Defensible Space?

Defensible space, coupled with home hardening, is essential to increasing your home's likelihood of surviving a wildfire. It is the space that provides a buffer between your home and potential fires in adjacent open spaces or wildland areas comprised of grasses, shrubs, and trees. This buffer is needed to slow or stop the progression of wildfire, and it helps protect your home from damage or loss. Maintaining defensible space includes specific actions for vegetative and non-vegetative objects (e.g., trash cans, fencing and sheds) around a home generally up to 100 feet from the structure (IWUIC, 2021). Defensible space is generally subdivided into three zones, whereby the highest priorities and most restrictive measures are required for the area closest to the structure. The National Fire Protection Association® (NFPA) defines the three zones as follows (see Figure 4):

- **Zone 0**, "Immediate Zone", "Ember-Resistance Zone", or "Noncombustible Zone" (0–5 feet). Zone 0 is considered the most important and includes areas immediately surrounding a structure, as well as areas under any attached decks or overhangs.

- **Zone 1**, "Intermediate Zone", or "Lean, Clean and Green" (5–30 feet). Zone 1 adds a defensible zone that extends from Zone 0 to Zone 2. The goal of this area is to reduce the connectivity between garden beds, shrubs, and trees; removing lower branches of trees and shrubs; and creating areas of irrigated and mowed grass or hardscape between lush vegetation islands so that wildfire does not burn to the house or into the crown of trees. Plants should be properly irrigated and maintained to remove dead/dry material (Valachovic, et al., 2021). This designation also applies to the area within 10 feet of driveways, access roads, or public roads adjacent to the property.

- **Zone 2**, "Extended Zone" or "Reduce Fuel Zone" (30–100 feet+). The goal of Zone 2 is to create a fuel break that interrupts the continuous vegetative fuel path of a wildfire, minimize flame length, and keep fires on the ground by reducing ladder fuels and crown clustering.

Figure 4. Before (upper) and after (lower) implementation of the three-zone defensible space strategy. While this figure shows a forested setting, the same concepts apply to other vegetation types (e.g., grass- and shrub-lands) and residential settings (Valachovic, et al. 2021).

Many federal, state, and local resources provide a range of information, guidance, and recommendations specific to each zone. See the Reference section for details. Note: Homeowners are encouraged to refer to their local fire department, other local government agencies (e.g., planning department), and other community groups (e.g., HOAs, Firewise communities, fire safe councils, and non-profits) for additional requirements and/or guidance specific to their area. Local ordinances and guidance documents can often provide more tailored and nuanced information for the region or area, and in some cases more stringent requirements.

3. Fire-Resistant Landscapes

Reducing or eliminating hazardous fuels (vegetative or non-vegetative) and maintaining the landscape within the HIZ of a structure can greatly increase its survivability. This helps not only reduce potential sources of embers, but also reduces the likelihood of wildland fuels, landscaping and other materials directly surrounding the structure or below the structure to serve as ember receptors.

3.1. "Recommended" or "Approved" Plant Lists

Jurisdictions often provide "approved" or "recommended" plant lists with recommendations on vegetation that has more fire-resistant characteristics given the specific climate, topography, and ecological systems in the local area. Some general characteristics of plants included on "approved" lists are (Kuhns, 2019):

- Drought-resistant
- Contain more moisture
- Contain low amounts of volatile oils and other readily flammable chemicals
- Noninvasive
- Slow growing
- Produce less litter and dead material
- Low growing
- Able to grow and thrive without supplemental fertilization

While these "approved" or "recommended" plant lists provide a starting point for creating a fire-resistant landscape, it is critical that homeowners know how to properly locate, care, and maintain their landscape. All plants, even recommended plants, shrubs, and trees, will burn given the right conditions and have the potential to become fuel during a wildfire. Also, some plants are difficult to maintain because of the amount of maintenance they require. Homeowners should understand the amount of care and maintenance required for their landscape and verify that this aligns with their available resources. Refer to best management practices below for more details.

Colorado State University Cooperative Extension Service has developed a comprehensive list of fire-resistant plant, shrub, and tree species list. These plants are available at many nurseries which, when combined with defensible space landscaping management practices, can reduce fire risk. The list includes many species attractive in suburban settings like iris, penstemon, beebalm, maples, plum, river birch, mountain ash, and lilac. (Colorado Extension Service, 1999).

Additionally, the Colorado State University Cooperative Extension Service and the Colorado Forest Service have developed plant, shrub, and tree recommendations for Colorado's wildfire environments through the Firewise program which are appropriate to Boulder County's wildfire risk and Wildland Urban Interface (WUI) conditions (Colorado State University Extension. Fire-Resistant Landscaping Fact Sheet 6.303 06303.pdf (colostate.edu)).

See a sample list of references provided in the box below.

Federal, State, And County Best Management Practices of Defensible Space

National Non-Government

- International Wildland-Urban Interface Code (IWUIC). (2021).
- National Fire Protection Association (2022). Firewise USA®. https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Firewise-USA
- NFPA 1140, 2022 Edition: Standard for Wildland Fire Protection
- NIST. (2022). WUI Structure/Parcel/Community Fire Hazard Mitigation Methodology. https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2205.pdf

Federal

- USDA Forest Service. (2022). Urban and Community Forestry Program: Tree Pruning Guide. https://www.arborday.org/trees/tips /

State

- Colorado State University (CSU). (2010): Front Range Tree Recommendation List. https://extension.colostate.edu/docs/pubs/garden/treereclist.pdf
- Colorado State Forest Service. (2021). The Home Ignition Zone: A guide to preparing your home for wildfire and creating defensible space. https://coloradoforestatlas.org/customers/colorado/information/2021_CSFS_HIZGuide_Web.pdf
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County

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- Boulder County. (2017). Your Defensible Space Slideshow. https://assets.bouldercounty.gov/wp-content/uploads/2017/02/defensible-space-slideshow.pdf

3.2. Hazardous or "Prohibited" Plant Lists

Many communities within high wildfire-prone areas have a list of common plants that are considered "hazardous" or "prohibited" for use. Specific guidance has not been developed for Boulder County, Colorado. However, observed highly-flammable tree types common to eastern Boulder County include species in arborvitae (cedars), Juniperus (junipers), Pinus (pines), Douglas fir, spruce, cypress, and yew. Flammable shrubs include Tamarisk, Russian Olive, sagebrush, rosemary, bitterbush and scotch broom. Ground covers such as pampas grass are also extremely flammable in dry conditions. Plants like junipers, Italian cypress, feather and fountain grasses, and ice plant are often considered hazardous due to the amount of maintenance required to manage dead thatch inside or under a green surface layer (Figure 5). Other plants like eucalyptus, palms and some manzanitas are also typically not recommended in medium- to high-wildfire risk areas due to the shedding of dry bark, leaves, fronds, and other duff that can readily ignite and spread fire (UCANR, 2022).

Common characteristics of wildfire vulnerable vegetation include:

- Low moisture content
- Volatile resins and oils, generally aromatic when crushed
- Narrow leaves or long, thin needles
- Waxy or fuzzy leaves
- Accumulates dead leaves and twigs on and/or under the plant
- Loose or papery bark
- Invasive species


Figure 5. Junipers (left) are among the least fire-resistant plants commonly used in landscaping. Their leaf structure and the volatile oils they contain make them highly flammable. Cheatgrass (right), a non-native species, is a flashy fuel meaning that it is highly flammable and can burn rapidly to spread fire and ignite other fuels.

The following publications provide general guidance and considerations for identifying hazardous or "prohibited" plants. For more site and neighborhood-specific guidance, homeowners are encouraged to reach out to their local fire department, their county forester, landscape architects, nurseries, cooperative extension agents, or other fire ecology/fire safety professionals to evaluate their landscaping design.

References for Restricted Invasive Plants (Boulder County, Colorado)

- Boulder County. (2021). Boulder County Invasive Plants 2021 Yearly Report.
- Boulder County, Colorado. https://assets.bouldercounty.gov/wp-content/uploads/2020/05/weeds-annual-report.pdf
- Typical invasive trees within Boulder County include: Trees of Heaven, Russian Olive, and Tamarix.
- Other plants that are on Boulder County's List A Watch list include: Mediterranean Sage, Rush Skeletonweed, Myrtle Spurge, Purple Loosestrife, Hairy Willow-herb, Orange Hawkweed, Spotted Snapweed, Yellow Flag Iris, Garden Loosestrife, Yellow Toadflax, Leafy Spurge, and Japanese Knotweed (Boulder County, 2021).

3.3. Landscape Design and Layout – Make Wildfire Resiliency Attractive

A homeowner's landscape can be tailored to reduce the likelihood of ember ignition, fire intensity, and spread of fire to a home. Methods such as mosaic planting and fuel breaks can greatly reduce radiative exposures, high-severity fires proximate to the home, and ultimately increase the probability that a structure will survive a wildfire. When done well, landscaping around a home can be both fire-resistant and achieve a variety of other goals (e.g., aesthetics, soil retention, healthy and native ecosystems, temperature control, flood control). See Figure 6.

Figure 6. Examples of Fire-Resistant Landscapes, including Mosaic Design Features. (Left Photo Credit: CALFIRE, 2022b)

From a fire-prevention perspective, reducing connectivity or continuity of vegetation by creating islands of vegetation or mosaic patterns by increasing spacing between trees and shrubs can limit the spread of fire (Valachovic et al. 2021). Clustered trees and shrubs that are continuous over large areas provide an uninterrupted path, which enables wildfire to gain intensity and spread rapidly. In a WUI setting, this can potentially increase wildfire exposure to homes in intermix zones, and into the developed parts of a community. Landscape designs can also incorporate fuel breaks using pavers and other noncombustible materials. In addition to general spacing, homeowners should reduce the amount of ladder fuels in their landscaping. Ladder fuels are low-growing vegetation such as tall grasses, shrubs, and tree branches, both living and dead that can more readily ignite in a wildfire and lead to ignition of taller vegetation.

Figure 7 illustrates some of the concepts used in successful defensible space development. See the References section for more information. Additional site-specific landscape design guidance is available from the local fire department, county forester, landscape architects, cooperative extension agents or other fire ecology/fire safety professionals.

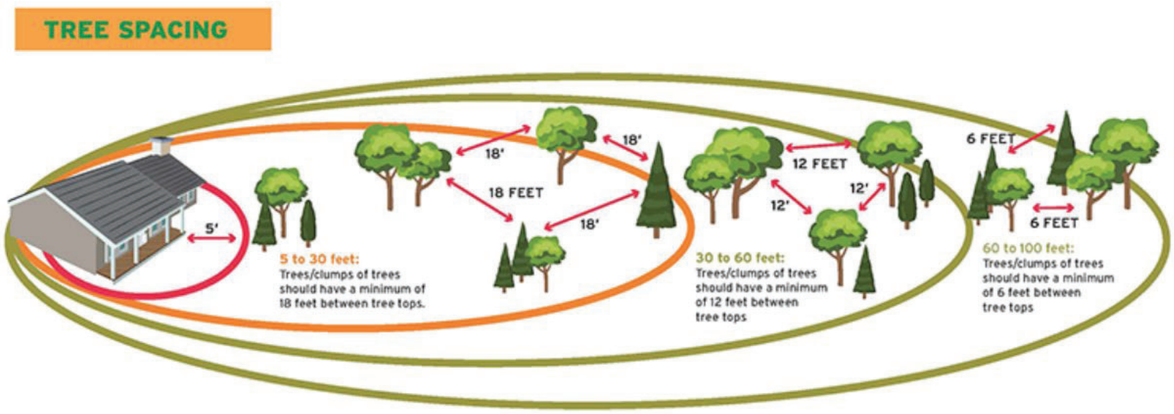

Figure 7. Prescriptive Tree Spacing Guidance (Reproduced from NFPA's website, ©NFPA 2022).

3.4. Best Management Practices – Any Plant Can Burn!

Choosing appropriate plants for landscaping will still require maintenance throughout the HIZ. Plants require water, trimming, and sometimes removal to reduce the hazard that vegetative fuels pose during a wildfire. Best management practices, even for the same species of plant, can vary depending on site topography and local weather and climate conditions (Figure 8). Strategies used by residents and landscapers to alter influences on flammability (e.g., pruning and plant establishment methods), impacts to plant vigor versus flammability, and other landscaping objectives still need development and industry standardization.

Due to the large variety and detailed nuances of plant flammability, homeowners are encouraged to reach out to local experts (e.g., fire departments, local universities, landscape architects and local fire ecologists) to evaluate their vegetative landscape and how best to manage the vegetation surrounding their home.

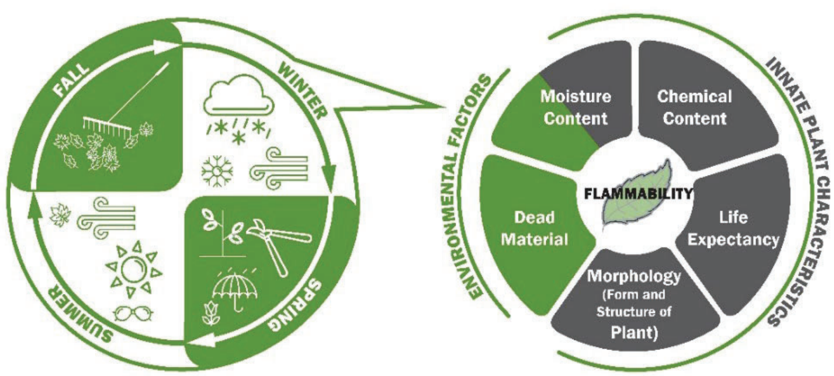

Figure 8. Factors to consider throughout seasons in the year for maintaining defensible space (Sustainable Defensible Space, 2022).

4. How to Increase Home Survivability Without Firefighters

During a major wildfire incident, firefighters and other first responders will likely be unable to “defend” most residential properties. As seen during and after the Marshall Fire (and most major wildfires in the U.S.), the severity and scale of the incident limited the opportunity and safety of first responders to contain or suppress the wildfire let alone defend threatened structures and neighborhoods. Therefore, homeowners are encouraged to develop and maintain appropriate defensible space and structural hardening provisions to ensure that their home and property have a greater chance of survival without relying on the presence of firefighting interventions.

Remember to implement the following methods to protect your home from wildfire:

- Develop and maintain defensible space or alternative risk mitigations where site restrictions exist
- Work with adjacent property owners to develop and maintain “communal defensible space”
- Select, locate, and maintain recommended fire-resistant plants, shrubs, and trees throughout your property
- Develop and maintain a fire-resistant landscape (e.g., tree/shrub spacing, mosaic design), and where necessary, consult a local wildfire specialist, fire department personnel, fire ecologist or fire landscape architect
- Monitor and evaluate your home ignition zone annually and prior to core fire season(s)
- Ask your local fire department, fire safe council or other local wildfire resiliency organization such as Wildfire Partners (https://wildfirepartners.org/) to inspect your home and property
- Develop and maintain structural hardening provisions (see Marshall Fire MAT document *Homeowner’s Guide to Reducing Risk of Structure Ignition from Wildfire*)

5. What if Your Property Has No Space?

As was observed in the Marshall Fire and numerous WUI fires in recent years, significant damage and loss of property can result from fire spreading from structure–to–structure and not necessarily from the wildlands or open space to the structure. Structure-to-structure fire spread (or urban conflagration) increases in likelihood when homes are closely spaced (e.g., within 60 feet of another structure). This is already recognized in building codes and standards in fire separation requirements. However, most existing codes provide exceptions that allow residential homes to be within 5 feet from a property line (or roughly 10 feet to another home). In some high wildfire jurisdictions, local wildland/WUI fire ordinances have been adopted that require 20 or 30 feet of separation from the primary home to the property line to limit structure–to–structure fire spread, in addition to the typical defensible space requirements described earlier. While this may be possible for new construction, for most existing properties achieving 30 feet of separation let alone the 100 feet of defensible space is not possible, leaving homeowners unable to achieve prescriptive defensible space measures or optimum wildfire resiliency. The following provides homeowners with guidance on approaches to take to where building setbacks, property line constraints or other practical challenges limit the ability to achieve 100 feet of defensible space or 20–30-foot setbacks to the property line.

5.1. Where 100 Feet of Defensible Space is Limited

Where 100 feet of defensible space next to wildlands, open space, or adjacent properties is not available, homeowners are encouraged to consider the following strategies:

1. Work with neighbors and other adjacent property owners to ensure that common defensible space considerations are implemented between and adjacent to structures on both properties within Zones 0–2 within their own property lines (Figure 9).

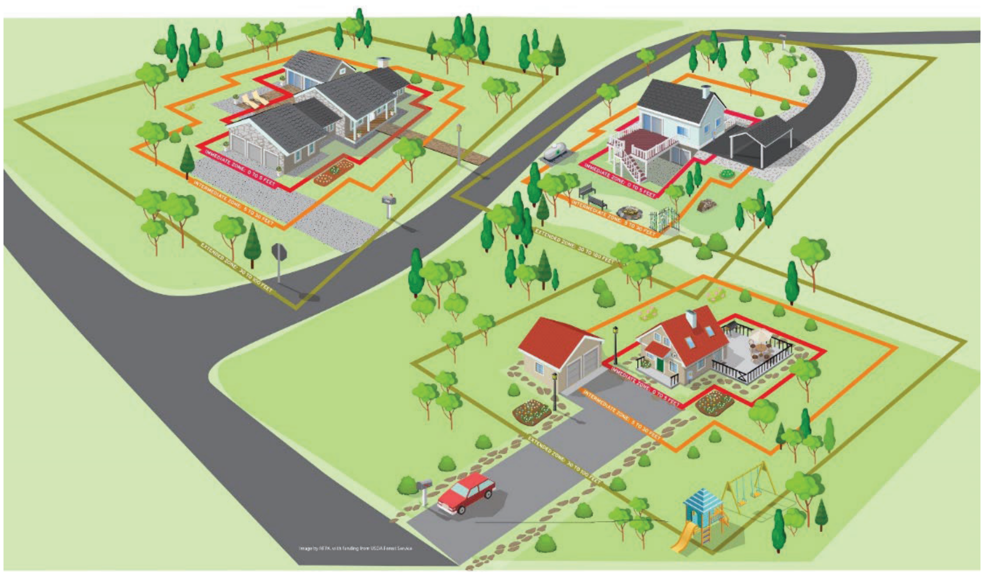

Figure 9. Communal defensible space boundaries.
(Reproduced from NFPA's website, ©NFPA 2022)

2. Prioritize localized structural hardening measures on the sides of the home with insufficient separation to adjacent properties, such as:

- Replace existing vent covers with 1/16-inch wire mesh or an approved ember and flame-resistant vent. Some jurisdictions have "pre-approved" products such as CALFIRE's Building Materials Listing Program (https://osfm.fire.ca.gov/divisions/fire-engineering-and-investigations/building-materials-listing/bml-search-building-materials-listing/). Local building and/or fire officials have discretion to approve products.

- Replace combustible siding with non-combustible or ignition resistant materials (e.g., fiber cement, stucco).

- Replace combustible decking with non-combustible decking.

- Remove all combustible non-vegetative features (e.g., ornamental grass, trash bins, sheds, pergolas, gazebos, wood piles, vehicles).

- Replace single-pane window with double-paned or tempered-laminated glazing.

- Replace combustible fences with non-combustible materials (e.g., concrete, masonry, metal), particularly for fences that attach to a neighbor’s combustible fence.

3. Provide structural hardening measures for the entire home (e.g., upgrading to a Class A roof). Refer to Marshall Fire MAT document *Homeowner’s Guide to Reducing Risk of Structure Ignition from Wildfire*.
4. Prioritize the reduction of receptive fuel beds around the entire home from ember attack. Refer to Fire Resistant Landscapes section above.

Hardening structures and parcels to reduce risk of ember exposure and mitigating the major fire pathways that lead wildfire toward residences can be the most important way to protect high-density communities (Maranghides et all, 2022). See *Marshall Fire Mitigation Assessment Team: Mitigation Strategies to Address Multi-Hazard Events*. Refer also to other federal, state, and local references for more details.

5.2. Where 30 Feet of Property Line Setback is Limited

Where 30 feet of setback to the property line is not possible for practical reasons (e.g., parcel dimension or size, topographic limitations, or other easements), homeowners are encouraged to provide additional fire-safety enhancements to their home to reduce the likelihood of structure-to-structure fire spread. The following are potential options (Figure 10):

- Install a six-foot, solid, noncombustible property line wall or fence (e.g., brick, masonry, or concrete masonry unit walls) to minimize ember transmission, radiation, and other forms of heat transfer from adjacent properties. Note: This is more effective for grass and shrubland landscapes.

- Install five to ten feet of noncombustible material (e.g., pavers, gravel) horizontally around the home. Where there is significant hardscaping around the home, additional measures may be needed to limit potential drainage or flooding issues.

- Prioritize localized structural-hardening measures on the side of the structure with less than 30 feet of setback (e.g., replace combustible siding with non-combustible siding). Refer to bullet point 2 in the above section.

- Provide additional structure hardening such as installing or upgrading exterior walls, windows, vents, and under-eaves areas of the home to be fire-resistance rated (e.g., 1-hour rated).

Homeowners may need to contact a licensed contractor or design professional for assistance. Refer to Marshall Fire MAT document *Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire* for details.

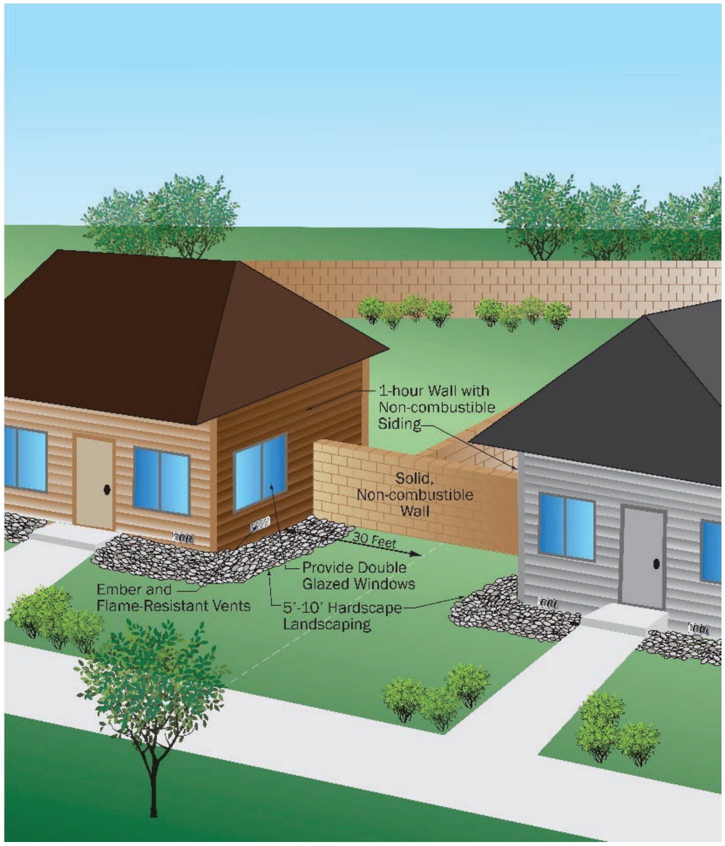

Figure 10. Examples of additional structural hardening and defensible space features where 30 feet of setback to the property line is not feasible.

6. Monitor and Evaluate Your HIZ

In addition to the measures described above, it is critical that homeowners periodically monitor and evaluate the defensible space and structural hardening provisions in their property's HIZ. A thorough HIZ assessment identifies potential wildfire vulnerabilities that could result in damage or total loss of a structure. These assessments should be performed by the property owner in consultation with wildfire/fire safety professionals (e.g., fire engineers, fire department prevention officers) or other trained individuals (e.g., Firewise USA®), members of the local fire safe council, Wildfire Partners (https://wildfirepartners.org/) or those who have taken a recognized HIZ assessment course, such as NFPA®: Assessing Structure Ignition Potential from Fire). The reference section highlights resources which outline best practices for conducting HIZ assessments for defensible space, including the Colorado State Forest Service's Home Ignition Zone Checklist.

There are numerous best management practices (BMPs) for parcel and community-level vegetation management available at the Federal, State, and County levels. For example, the Colorado State

Forest Service has published recommendations for homeowners to prepare the HIZ of their property for wildfire.

Best Practices for Conducting HIZ Assessments for Defensible Space

- NIST WUI Structure/Parcel/Community Fire Hazard Mitigation Methodology. https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2205.pdf
- NFPA 1140, 2022 Edition: Standard for Wildland Fire Protection
- NFPA® "Assessing Structure Ignition Potential from Wildfire" training.
- Fire Adapted Communities Learning Network. https://fireadaptednetwork.org/
- Colorado State Forest Service Home Ignition Zone Checklists. https://csfs.colostate.edu/wildfire-mitigation/home-ignition-zone-checklists/
- IBHS, How to Maintain Your Home's Defensible Space. https://wildfireprepared.org/article/how-to-maintain-your-homes-defensible-space/
- Society of Fire Protection Engineers: Virtual WUI Handbook. https://www.sfpe.org/wuihandbook/home#about-handbook

FEMA Fact Sheets for Defensible Space in The Home Ignition Zone

FEMA Technical Fact Sheet Series FEMA P-737: *Home Builder's Guide to Construction in Wildfire Zones*. https://defensiblespace.org/wp-content/uploads/2021/01/FEMA_2008_P-737-Home-Builders-Guide-to-Construction-in-Wildfire-Zones.pdf

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Appendix G: Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire

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Marshall Fire Mitigation Assessment Team: Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire

Revised April 2025

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Table of Contents

1. Introduction

On December 30, 2021, a wind-driven wildfire affected over 2,000 residential structures and several commercial facilities in unincorporated Boulder County, the City of Louisville, and the Town of Superior, Colorado. Data gathered after the fire highlighted the importance of preventing or slowing down structure-to-structure fire spread. Such prevention begins with the selection of appropriate building systems and spacing between buildings. Foundations, roofing, siding, windows, and doors, and building configuration and siting all play into slowing or eliminating the ability of a fire to spread from an adjacent structure, shed, or fence.

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

During a fully developed fire, temperatures can reach above 1,000° Celsius (about 1,800° Fahrenheit) which can lead to significant structural degradation of building structural systems. This degradation can lead to loss of capacity for structural elements and could potentially lead to life safety concerns in structures that remain standing. The purpose of this document is to provide recommendations to contractors and designers on new building construction that may prevent or slow the spread of a fire from structure-to-structure in densely-spaced neighborhoods.

3. Key Issues

Structure-to-structure fire spread is typically caused by one or both of the following:

- **Vulnerable building components**: Roof systems, composite siding, and single pane, or large glass panel windows can propagate fires due to radiant heat causing them to break and allow them to spread faster. Other combustible building components, such as attached structures (e.g., decks, balconies, fences), can ignite from embers or direct flame contact and spread fire to the building.

- **Building configuration, siting, and spacing**: Buildings with complex shapes can allow embers to collect on rooftops and cause fires to spread more rapidly to other buildings. Buildings sited along ridgetops or placed closely together in densely-developed areas can ignite one another by direct flame contact or radiant heat.

Debris from various household and outdoor items surrounding a building can act as wicks to spread the fire hazard from one structure to another. Such items may include propane tanks, firewood, outbuildings, vehicles, and filled dumpsters too close to a structure. To address the issue of debris, refer to Marshall Fire MAT document *Homeowner's Guide to Reducing Wildfire Risk Through Defensible Space*.

In a widespread or intense wildfire there may be limited firefighting resources available to defend structures to prevent the spread of fire between them. Homeowners, designers, and contractors in high wildfire risk areas should consider using fire-resistant and noncombustible construction materials and techniques to increase the likelihood a home will withstand a wildfire if firefighting resources are limited.

4. Vulnerable Building Components

Vulnerable building components that contribute to structure-to-structure fire spread through combustion or other means typically include one or more of the following:

- Roofing systems
- Wall system assemblies
- Vent protection
- Glazing systems
- Attachments

In addition, landscaping and vegetation surrounding the building can contribute to structure-to-structure fire spread. (Refer to Marshall Fire MAT document *Homeowner's Guide to Reducing Wildfire Risk Through Defensible Space* for more information on this topic.)

The following sections describe the conditions observed and recommended migration strategies for each component listed above.

4.1. Roofing Systems

Although there were no direct observations of roofing systems resulting in structure-to-structure fire spread during the Marshall Fire, residential roofing systems are a key area of known wildfire vulnerability. Many homes during a fire hazard event burn from the top down when roofing materials or combustible roof decking are ignited by embers that generated from other structures, the flame front (the wave of the fire heading toward a structure) or when embers enter through roof vents or other openings in the roof.

Recommended mitigation strategies for roofing systems include:

- Select tested roofing systems that meet ASTM E108 or UL 790 Class A requirements should be used. Systems include, but are not limited to, asphalt shingles, concrete, brick, or masonry tiles (with bird stops), or metal panel/shingles. Note that Class A roof systems include the entire roofing assembly and not just the roof covering.
- Avoid materials such as wood and fiberglass when selecting new or replacement building roofing systems.
- Use metal valley flashing to avoid debris accumulation between and below tiles and add an underlying mineral surface cap sheet into assemblies that use metal valley flashing.
- Limit the number of joints and elevation changes in the roof design. Use proper flashing at the joints between walls and porch roofs/lower roofs and roof edges. Use noncombustible materials to construct roof expansion joints. Refer to the Marshall Fire MAT documents *Guide to Reducing Risk of Structure Ignition from Wildfire* and *Wildfire Resilient Detailing, Joint Systems, and Interfaces of Building Components* for additional information.
- Use metal gutters and downspouts. Install corrosion-resistant noncombustible drip edge flashing from the roof to the gutter, tightly fitting the flashing against the gutter. Use gutter covers made from noncombustible materials to prevent debris from accumulating in gutters.
- Use enclosed soffits or appropriate vent screens and batts in soffits.
- Provide bird-stops or mortar at open ends of tiles on profile-tiled roof edges. For other types of roof edges, provide underlayment that is continuous to the roof edge and metal flashing at the roof edge.
- Install spark arresters on chimneys.

4.2. Wall System Assemblies

Residential construction consisted of mainly wood-frame building systems with either brick or stone veneer and vinyl or fiber cement exterior siding. Siding and veneers appeared to be built over wood framing, with plywood or oriented-strand-board (OSB) sheathing and building paper (Figure 1).

Figure 1. Examples of damaged wall assemblies.

Recommended mitigation strategies for wall system assemblies include:

- Provide additional layers of exterior gypsum (5/8-inch thick type X) board sheathing to create a fire-resistant wall assembly that can slow fire propagation and structure-to-structure fire spread (Figure 2).

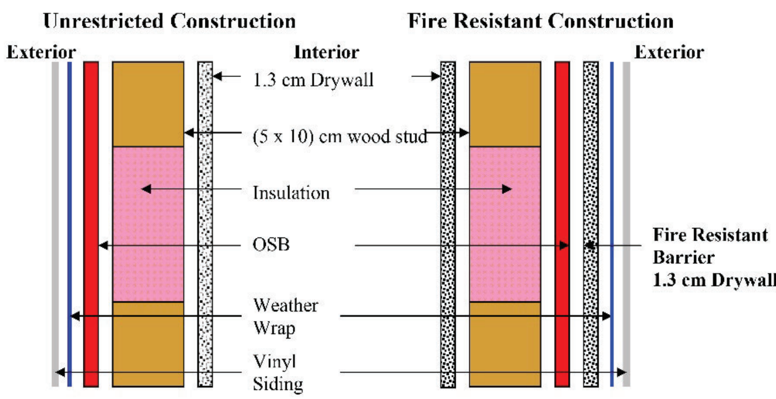

Figure 2. Fire-resistant wall assembly cross-section (NIST, 2008).

- Use non-combustible cement board cladding, masonry construction or veneer, stucco exterior or a combination of these three options, especially at head-of-wall locations.
- Designers should consider adding fire-resistant walls on sides of the building where fire hazards are within 25 to 50 feet to reduce or prevent fire spread (Figure 3).

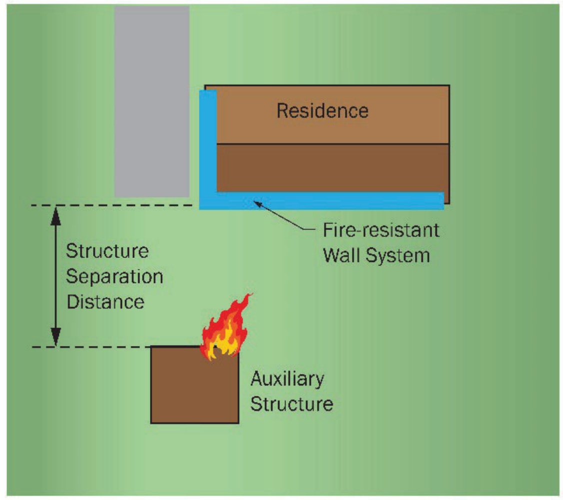

Figure 3. Fire-resistant wall system recommendations when desired structure separation distance (SSD) cannot be achieved (NIST, 2022).

- Use ignition-resistant fiberglass batt insulation inside wall cavities or ensure exterior walls are flashed/sealed with fire resistant caulk completely to prevent embers and hot gasses from entering the structure.
- Provide proper detailing at wall joints and interfaces along the base of the wall and the base of the roof to prevent gaps. Refer to the Marshall Fire MAT document *Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire* for additional details on addressing gaps at joints and interfaces.

4.3. Vent Protection

Plumbing and attic vents on existing construction did not appear to have proper screening to prevent ember intrusion into most of the observed structures. Soffit vents with opening sizes of more than 1/8-inch square mesh can allow embers to enter an attic that could cause a fire to propagate or continue. Crawlspace vents are typically covered with mesh screening that is 1/4-inch square to prevent rodents from getting in, but this can still allow embers to pass through and contribute to fire spread.

Recommended mitigation strategies for vent protection include:

- Cover all plumbing stacks, attic, crawlspace, soffit, and ridge vents with non-combustible mesh having opening sizes no larger than 1/8-inch square for new or retrofit construction (Figure 4).

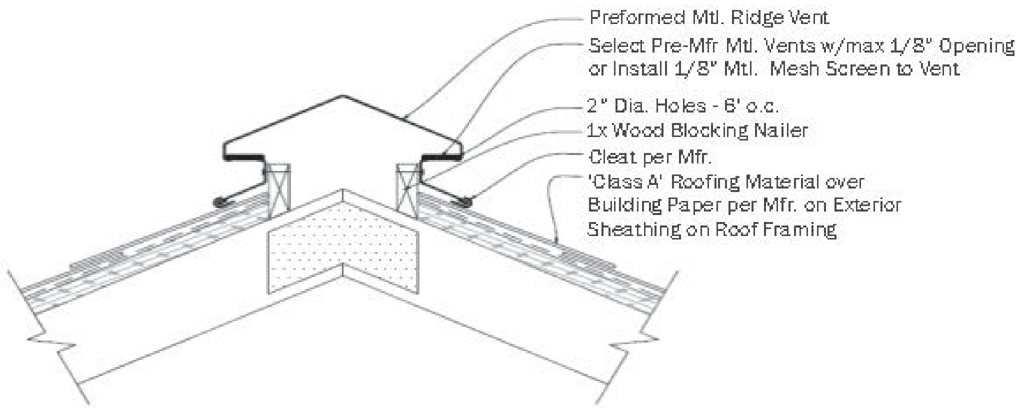

Figure 4. Example of ridge vent drawing with proper screening (Note: confirmation of proper attic ventilation by code still required) (City of Colorado Springs Fire Department, 2020).

Refer to the Marshall Fire MAT document *Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire* for additional details on protecting vents and other openings.

4.4. Glazing Systems

Glazing systems can break due to radiant heat or breakage from debris of single pane windows allow embers to enter and cause ignitions at the interior of a structure (Figure 5). Both single pane and multi-pane glazing systems were observed. In some cases where multi-pane glazing was present, the outer pane of glass was observed to be damaged.

Single-pane glazing will crack and fall out under intense heat and allow ember and flame spread into the structure and propagate the fire, especially if the window is located below or next to burning material or burning vegetation.

Figure 5. Example of glazing system failures.

Recommended mitigation strategies for glazing systems include:

- Use tempered-glass and double-pane glazing systems for windows and doors with glazing.
- Install aluminum coverings or use metal framing for window and door frames.
- Use fiberglass or metal screening on windows.

4.5. Attachments

In some cases, attachments such as decks, patios, porches, and balconies acted as "wicks" that, once ignited from embers or direct flame contact, provided a direct vehicle to igniting the home. Decks can provide a large surface area where embers can collect, which can lead to ignition of materials on the deck or of the deck itself. Many decks were observed to have materials stored on or underneath them that could - and in some cases did - provide fuel for ignition. See Marshall Fire MAT document *Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire* for more guidance on mitigating fire risk posed by attachments.

Recommended mitigation strategies for attachments include:

- Use noncombustible materials for deck framing, walking surfaces, railings, and stairs. All metal components must be corrosion resistant.
- Space deck boards with 1/4-inch gap. As an alternative, consider installing a solid walking surface, such as lightweight concrete, or use aluminum decking without gaps.
- For decks four feet or less above the ground, enclose the space under the deck from the walking surface to the ground using corrosion-resistant metal mesh having openings 1/8-inch or less (IBHS, 2023). Alternatively, fully enclose the space using noncombustible materials. If the deck is over a 10% or greater slope, the enclosure should stop within 6 inches above the ground surface to allow for drainage.
- Install metal flashing between or on top of the deck surface and the adjacent exterior wall. Extend the flashing at least 18 inches up the wall and tuck it in behind the lap joint (Fire Safe Marin, 2023).
- See Marshall Fire MAT document *Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire* for additional details.

5. Building Configuration, Siting and Spacing

The following sections describe the building configuration, siting and spacing conditions observed and recommended mitigation strategies for each.

5.1. Building Configuration

Although there were no direct observations of building configuration leading to structure fires, complex building geometries can lead to debris collecting at roof valleys and re-entrant corners, allowing embers to spread fire between structures (Figure 6). Structural overhangs are also a possible location for debris and embers to collect and hot gases to enter the building.

Recommended mitigation strategies related to building configuration include:

- Limit re-entrant corners on building designs to eliminate locations where debris could build up.
- At roof dormers, limit areas where debris could collect.

- Enclose the underside of structural projections from buildings with ignition resistant material to reduce the likelihood of fire spread in these areas.

5.2. Building Siting

Although there were no direct observations of siting issues (including set back) leading to structure fires, building siting plays an important role in preventing structure-to-structure fires. Orientation and location of buildings can help slow or prevent the spread. Understanding how topography can influence fire hazard behavior will allow designers to aid property owners in site selection to reduce the potential of fire hazard spread.

Recommended mitigation strategies related to building siting include:

- Avoid selecting a construction site in or adjacent to a topographic saddle or narrow mountain pass.
- Avoid constructing a home adjacent to or on a mild or steep slope. If a building is to be constructed at a ridgetop, the structure should be set back 50 feet from vegetation on the downslope side (Figure 7).

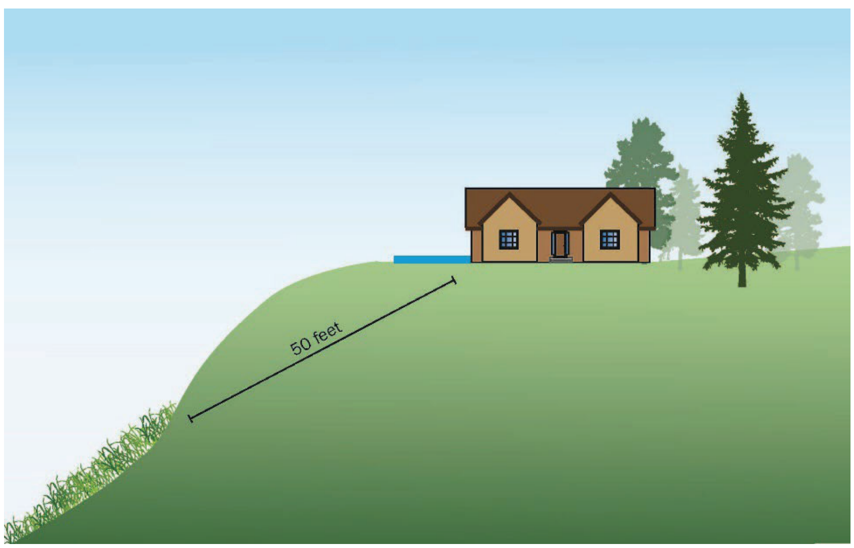

Figure 7. Example of recommended setback from a ridgetop (FEMA, 2008).

- Orient the narrowest wall of a structure toward the likely path of a fire hazard spread to minimize the risk of ignition. Orient the building based on prevailing wind and fuel sources nearby so that embers do not accumulate next to building walls.
- Pay close attention to building orientation with respect to inside corners and other offset walls.
- Refer to the Marshall Fire MAT document *Best Practices for Wildfire-Resilient Subdivision Planning* for additional details on building siting.

5.3. Building Spacing

Observations from the Marshall Fire indicated that the average spacing between buildings likely played a role in structure-to-structure fire spread (Figure 8). Although clustering homes together within a subdivision surrounded by community defensible space is generally considered beneficial for reducing wildfire risk, increasing the separation distance between individual buildings can help slow or prevent structure-to-structure fire spread. Note that increasing spacing between properties can drive up costs and impact affordability. This approach also may not be possible in more densely developed areas.

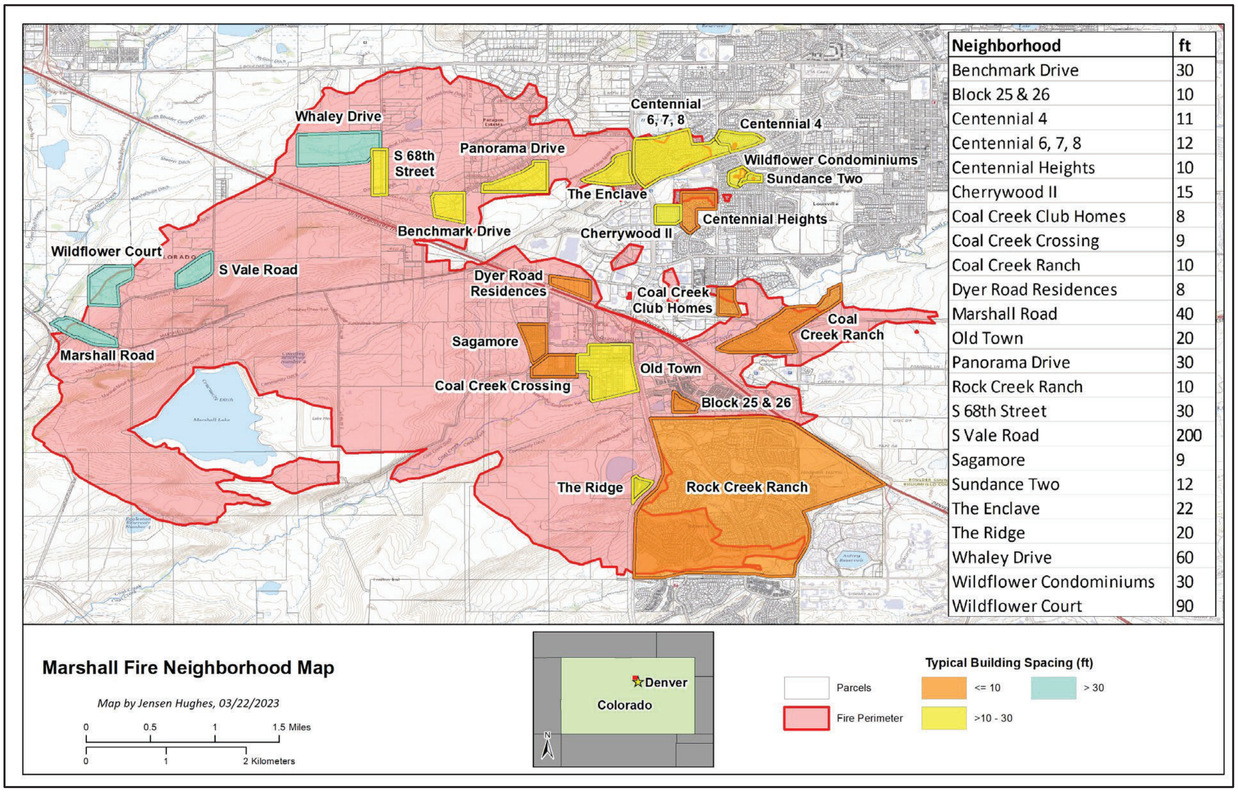

Figure 8. Typical building spacing in Superior and Louisville, Colorado, neighborhoods impacted by the Marshall Fire.

Recommended mitigation strategies related to building spacing include:

- Provide a minimum spacing of 30 feet between structures when possible.
- Buildings in high-risk wildfire areas that are spaced within 30 feet of each other should be constructed with Class A roof systems and fire-resistant exterior wall assemblies. Placement of vegetation, fences, decks, vehicles, and outbuildings in areas where construction is close together can also contribute to structure-to-structure fire spread. Refer to the Marshall Fire MAT document *Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire* for more information on reducing risk of structure ignition from wildfires.
- Refer to the Marshall Fire MAT document *Best Practices for Wildfire-Resilient Subdivision Planning* for additional details on density of development.

6. Resources and Useful Links

City of Colorado Springs Fire Department. 2020. "Ignition Resistant Construction Design Manual"

Federal Emergency Management Agency. 2008. FEMA P-737: *Home Builder's Guide to Construction in Wildfire Zones.* Available at: https://basc.pnnl.gov/library/fema-p-737-home-builders-guide-construction-wildfire-zones-technical-fact-sheet-series

Fire Safe Marin. 2023. *Fire-Resistant Decks, Patios, & Porches*. Available at: https://firesafemarin.org/harden-your-home/fire-resistant-decks-patios-porches/

National Institute of Standards and Technology. 2022. WUI Structure/Parcel/Community Fire Hazard Mitigation Methodology. NIST Technical Note 2205. Available at: https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2205.pdf

Institute for Building and Home Safety. 2023. *Wildfire Prepared Technical Standard.* Available at: https://wildfireprepared.org/wp-content/uploads/WFPH-Standard-2022-Final.pdf

International Wildland Urban Interface (IWUI) Code, 2021.

Maranghides, A. and Erik Lewis Johnsson. 2008. "Residential Structure Separation Fire Experiments." National Institute of Standards and Technology (NIST) Technical Note 1600. Available at: .https://www.govinfo.gov/content/pkg/GOVPUB-C13-61ebeb4a9065a1584c3a9b0561bbb525/pdf/GOVPUB-C13-61ebeb4a9065a1584c3a9b0561bbb525.pdf

National Fire Protection Association® (2022). NFPA 1140, 2022 Edition: Standard for Wildland Fire Protection

Quarles, Stephen and Standohar-Alfano, Christine. 2018. Wildfire Research Ignition Potential of Decks Subjected to Ember Exposure. *Institute for Building and Home Safety.* Available at: https://ibhs.org/wp-content/uploads/member_docs/Ignition-Potential-of-Decks-Subjected-to-an-Ember-Exposure_IBHS.pdf

Society of Fire Protection Engineers and SFPE Foundation. "WUI Virtual Handbook for Property Fire Risk Assessment & Mitigation." SFPE.org. 2023. Available at: https://www.sfpe.org/wuihandbook/home

Appendix H: Mitigation Strategies to Address Multi-Hazard Events

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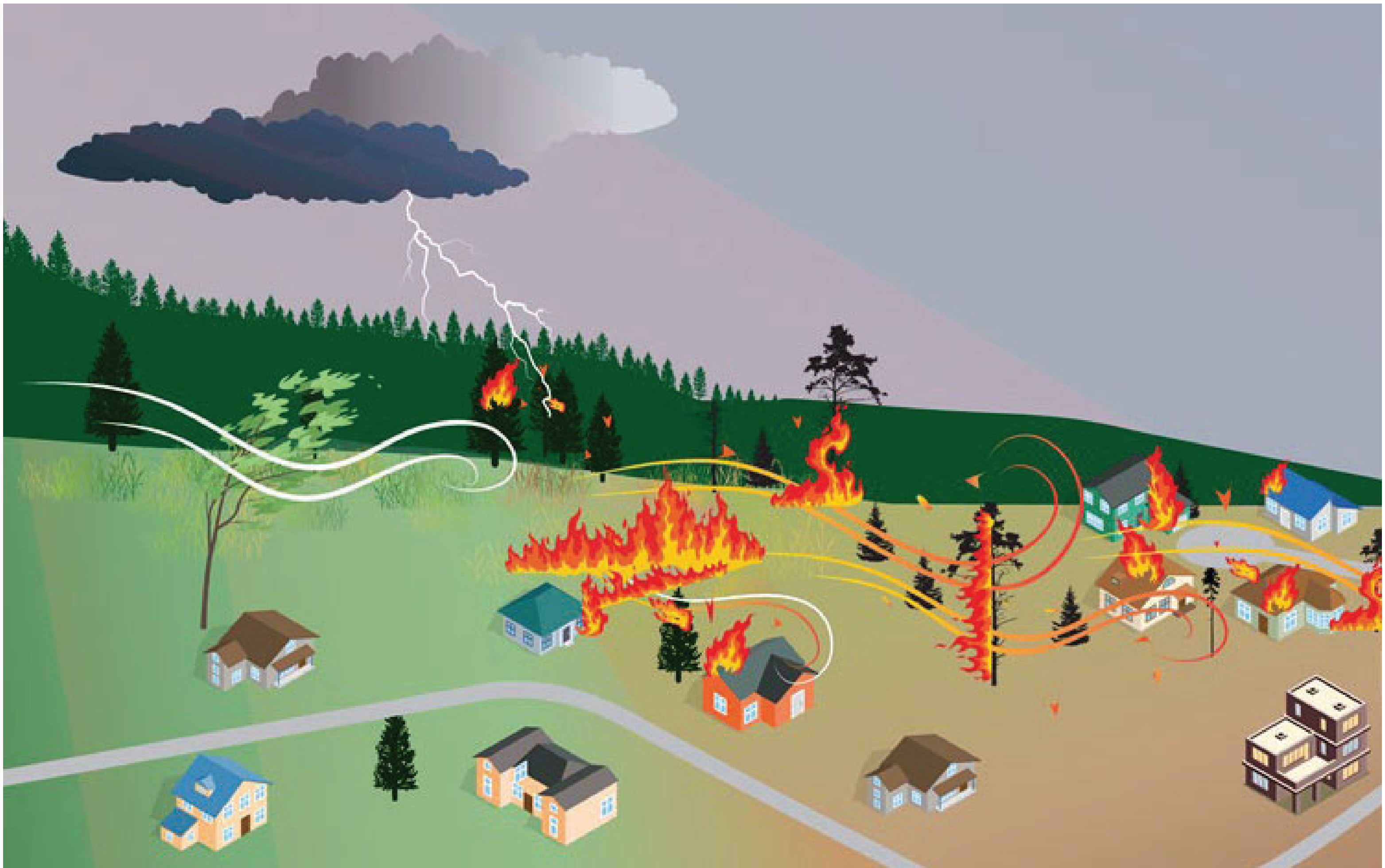

Marshall Fire Mitigation Assessment Team: Mitigation Strategies to Address Multi-Hazard Events

Revised April 2025

FEMA

DR-4634

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Table of Contents

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.

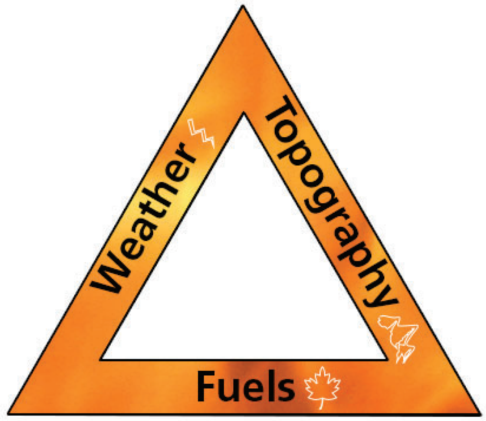

Figure 1. Topography, fuel, and weather are the three fire hazard conditions that are most influential on the growth and behavior of a wildfire (NPS/C. Boehle).

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.

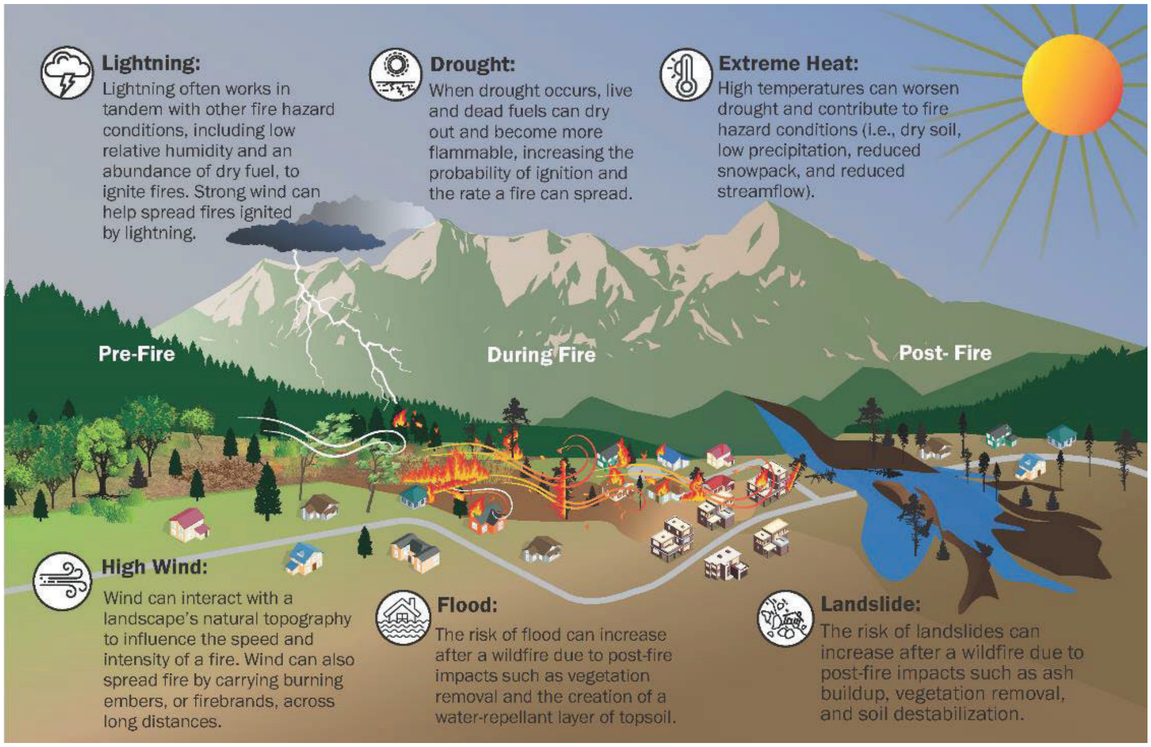

Figure 2. Hazards that contribute to or result from wildfires.

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

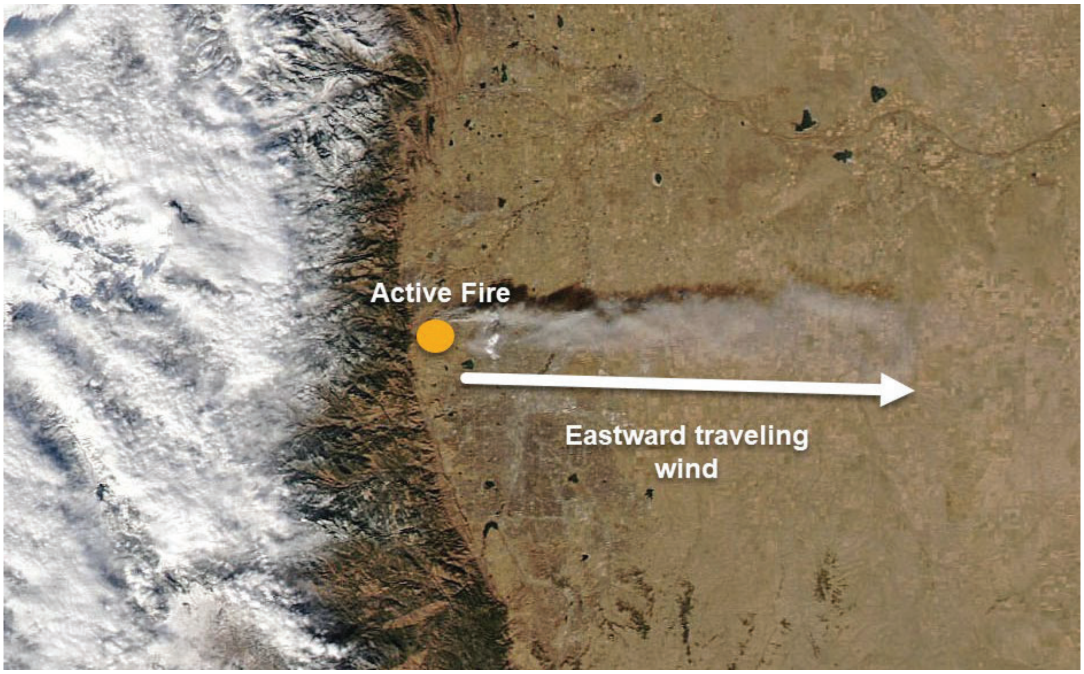

Figure 3. Wind gusts measuring 115 mph travelled east down the slope of the Rocky Mountains spreading the fire across grass and brush into unincorporated Boulder County, Louisville and Superior. Wind-driven embers landed on and helped ignite structures (NASA Earth Observatory, Dec 30, 2021).

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

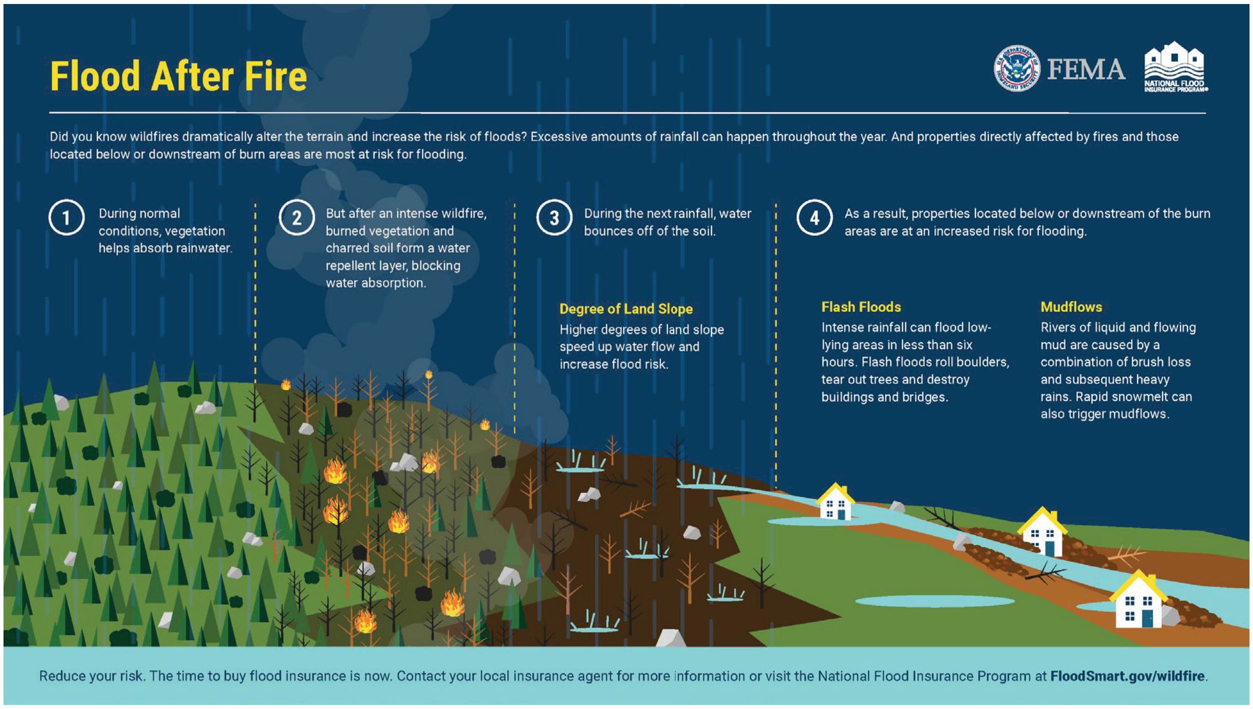

Figure 5. The risk of flood and mudflows can increase after a wildfire due to post-fire impacts such as ash buildup, vegetation removal, soil destabilization and the creation of hydrophobic soil.

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.

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

6.1. Grasslands & Outdoor Spaces

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.

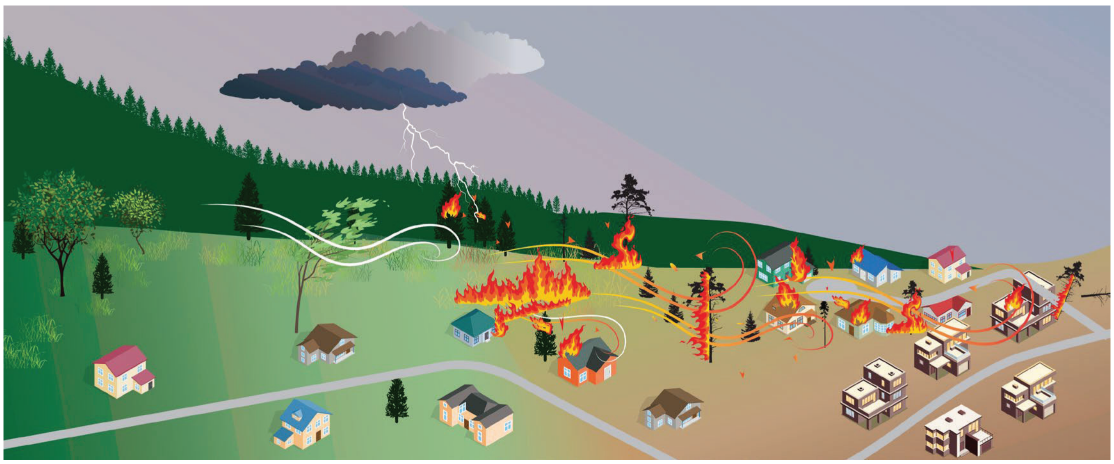

Figure 6. Grasslands and outdoor spaces can become avenues where wildfire is able to burn rapidly and spread to residential areas.

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.

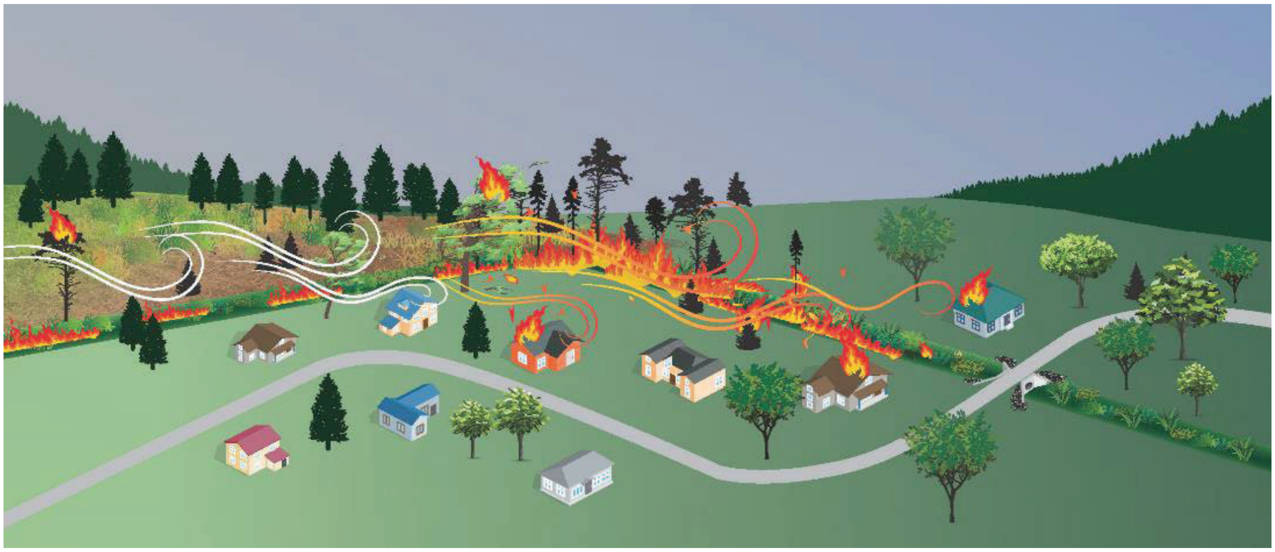

Figure 7. When fire ignites in stream corridors and drainage ditches, the abundance of dry fuel creates a superhighway for fire to spread through grassland to developed areas.

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.

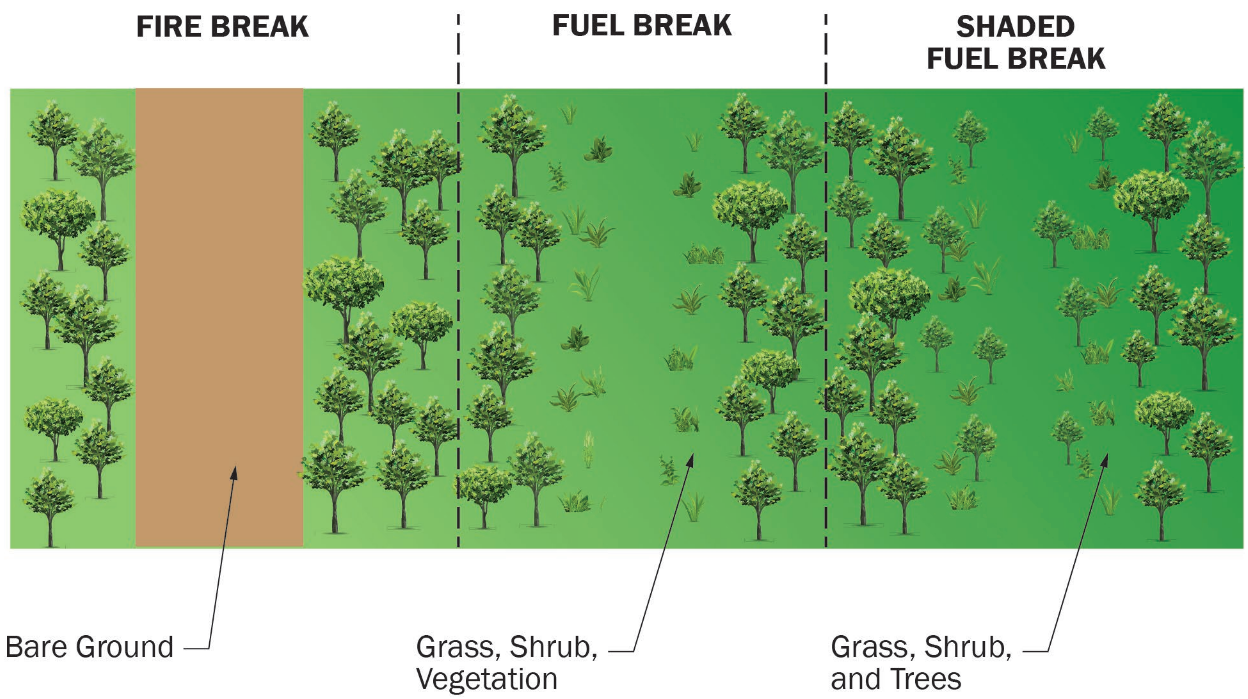

Figure 12. Fire breaks and fuel breaks can be used by homeowners and community planners to prevent or slow the progress of fire.

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.

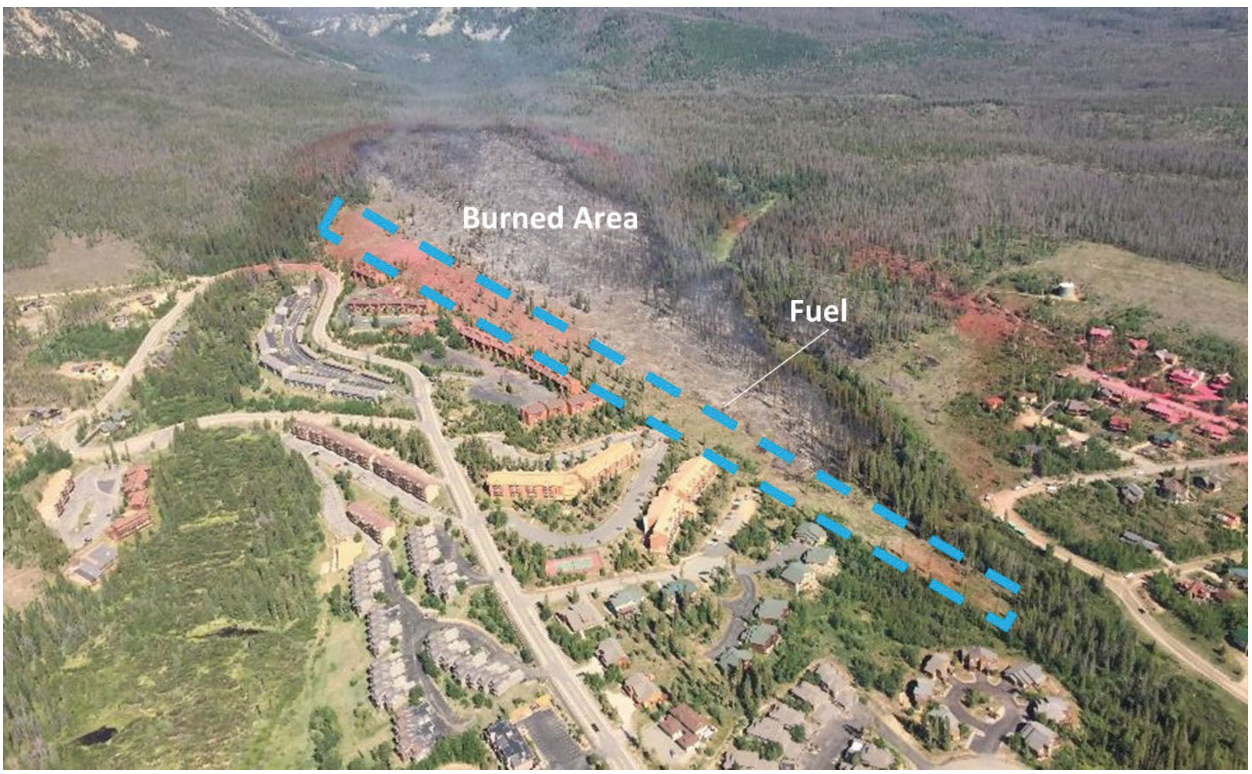

Figure 13. Fuel breaks (the blue line between the homes and forested area) played an important role protecting homes during the 2018 Buffalo Fire in Summit County (U.S. Forest Service).

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].

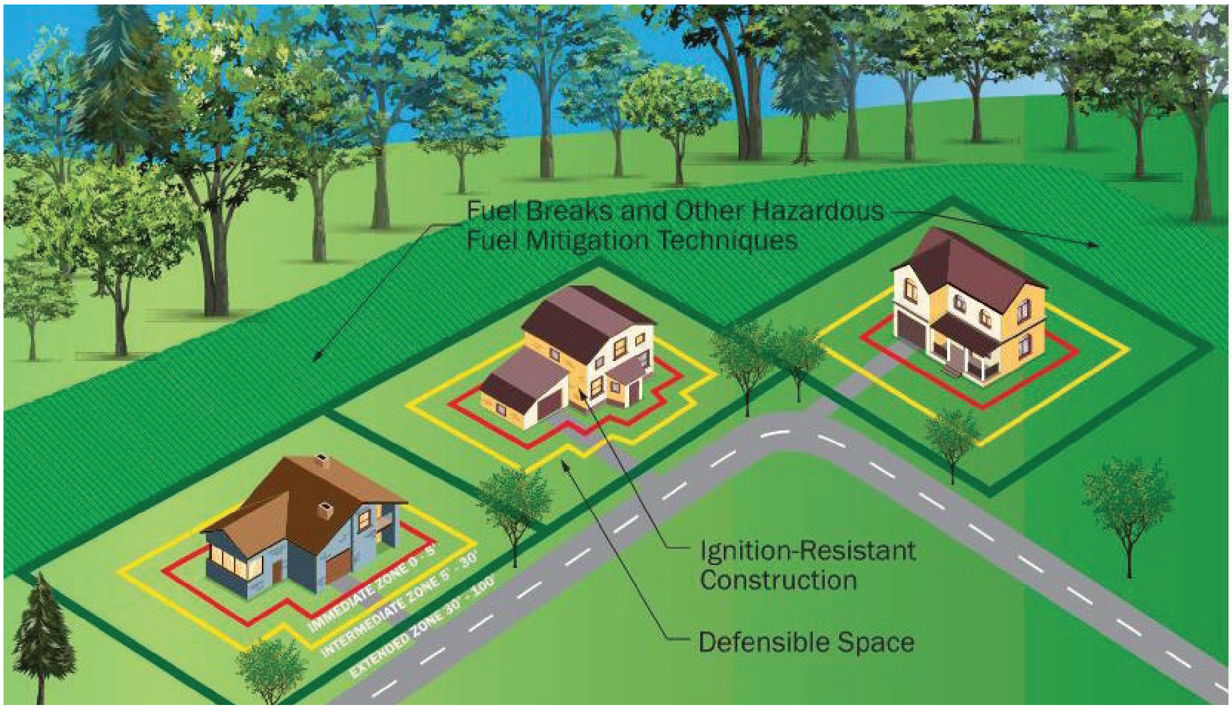

Figure 14. Property-level defensible space and ignition-resistant construction can be combined with community fuel breaks and fuel maintenance to create comprehensive wildfire protection for a subdivision or neighborhood.

[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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Appendix I: Best Practices for Wildfire-Resilient Subdivision Planning

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Marshall Fire Mitigation Assessment Team: Best Practices for Wildfire-Resilient Subdivision Planning

Revised April 2025

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1. Introduction

On December 30, 2021, a wind-driven wildfire impacted residential and commercial structures in the City of Louisville, the Town of Superior, and unincorporated Boulder County, Colorado. Evidence gathered after the fire highlighted several vulnerabilities in subdivision planning and in the management of proximate or intermixed communal open spaces, greenbelts, and wildland spaces that likely played a significant role in the spread of fire. This document provides builders/contractors, planning professionals, homeowner associations (HOAs), and local land resource managers with information about subdivision/community planning and open space management to reduce the risk of loss or damage to residential and commercial structures in future wildfire incidents.

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 conflagration directly and indirectly impacting several communities and the 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, particularly as the risk to landscape due to changing weather patterns is continuously evolving and putting more communities at risk.

1.1. Purpose

This document provides builders/contractors, planning professionals, HOAs, and local land resource managers with information about wildfire resiliency planning and open-space management policies, best practices, and procedures at subdivision- and neighborhood-scales. The intent is to prevent or limit the risk of wildfire exposures and impacts through various regulatory and policy approaches during planning and entitlement phases (e.g., fire risk assessments, wildfire impact studies, zoning, wildfire-protection planning), such that wildfire hazards and risks are appropriately considered early in the planning-design-construction life cycle of future developments. Also included are approaches for holistic, ongoing management of communal open spaces, greenbelts, and proximate wildland spaces as integrated features of neighborhood-, subdivision- and community-scale wildfire resiliency of new and existing residential and commercial developments.

Note: This document should also be read in conjunction with the *Marshall Fire Mitigation Assessment Team: Mitigation Strategies to Address Multi-Hazard Events*.

1.2. Key Issues

In the U.S., the resistance of structures to wildfires in the built environment is typically addressed through the application of building and fire codes at the individual building or parcel level, and not usually at the neighborhood-or community-scale. The level, degree, and even presence of building-level wildfire safety requirements depends on the adoption and enforcement of these regulations at state and/or local levels. In some locations, wildfire safety requirements for buildings are based on where a structure or development is located relative to fire hazards, which can be defined in fire hazard maps (e.g., Fire Hazard Severity Zone (FHSZ) maps produced by the state in California[1], Colorado Springs Fire Department's Wildfire Risk Map)[2]. In locations where state and/or local building and fire code regulations are triggered by the fire-hazard classification, design features to improve wildfire/fire resiliency may be required and can include specific building materials, forms of construction, fire-rated or fire-resistive elements, components or assemblies (e.g., vents, exterior walls, windows, roofs, decks), defensible space requirements, minimum levels of access/egress, and water supplies. However, most states and local jurisdictions across the U.S. have limited or no wildfire-safety building codes, standards, guidance documents, programs, tools, and/or resources (FEMA, 2021)[3] to assist designers, engineers, planners, contractors/builders, and other professionals in wildfire resiliency. Even if a state or local jurisdiction has adopted a model WUI building code or local ordinances such as International Wildland-Urban Interface Code (IWUIC) and National Fire Protection Association (NFPA) 1140, these requirements are often limited to individual buildings and mostly residential occupancies, and there is often no information available for the neighborhood, community, city, or regional scales (FEMA, 2021) particularly during the planning phase of a development. Some best practice guidance is detailed throughout the rest of this document.

The following is a list of key issues for neighborhood- and community-scale wildfire resiliency planning and development (see also Figure 6 later in this document):

- Wildfire Hazard and Risk Mapping – A range of 'official' and 'unofficial' wildfire hazard and risk maps exist at local, state, and national levels (e.g., West Wide Wildfire Risk Assessment, CALFIRE's Fire Hazard Severity Zone maps, wildfirerisk.org) (FEMA, 2021). However, most available wildfire hazard and risk maps are not explicitly designed to inform land-use planning, zoning, building design codes and standards, or other wildfire resiliency construction practices at the local, neighborhood, or individual home scale, or during a development's life cycle (e.g., planning/entitlement phase to design/construction to long-term management and operations). California is one example where state-extent FHSZ maps are referenced in the California Building

[1] California Department of Forestry and Fire Protection (CAL FIRE). Forestry and Fire Protection's Fire and Resource Assessment Program (FRAP). https://frap.fire.ca.gov/mapping/pdf-maps/

[2] Colorado Springs Fire Department. Wildfire Risk Map. https://gis.coloradosprings.gov/Html5Viewer/?viewer=wildfiremitigation

[3] Rini, D et al. (2021). *Community Wildfire Resilience: Landscape Analysis* (Volume 1) White Paper. FEMA.

and Fire Codes (CBC, 2021)[4], and ultimately all buildings constructed in specific FHSZs (since 2008) are required to have wildfire-specific risk mitigation provisions. However, most states and local jurisdictions have limited or no available wildfire hazard and risk maps to trigger planning and building safety provisions. This means that numerous buildings and developments are potentially being planned, designed, and constructed in high fire risk areas without appropriate building fire safety provisions. Additionally, there are countless existing building stock and developments that may not currently be in a high wildfire prone area but could be at risk in the future due to ongoing changes in the wildfire risk landscape and other factors. Understanding this potential change in the risk landscape is a major challenge that is not currently considered in land use planning.

- Siting of Structure or Development – The location of a development or subdivision on the general landscape is a major driver of its wildfire risk. Wildfire severity and rate-of-spread of fire increase at specific topographic features such as saddles, ridge lines, drainages, canyons, and steep slopes (Figure 1). This can present a significant threat to homes or developments in those locations, such as for a property located mid-slope, which cannot be more easily mitigated using standard defensible space, setback, and structural hardening provisions (described in other Marshall Fire MAT products). Some jurisdictions provide additional siting requirements (e.g., minimum setbacks, additional defensible space requirements, additional structural hardening measures, development of a fire protection plan) for buildings and developments located in higher hazard topographies. However, this is not consistently provided in most local jurisdictions. In addition, most jurisdictions do not have neighborhood-, community- or regional-level planning, or wildfire zoning requirements that introduce limitations on new developments in very high-risk landscapes.

[4] California Building Standards Code. (2022, July 1). Chapter 7A *California Building Code (CBC)*. https://www.osha.gov/coronavirus/safework

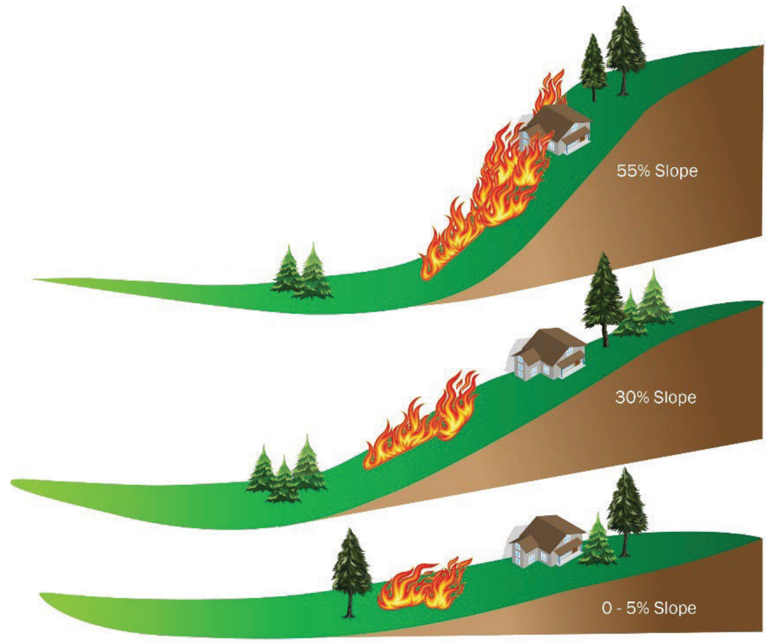

Figure 1. Wildfire intensity and rate-of-spread increases as slope increases.

- Structure Density – Current building fire safety regulations typically do not require structure-to-structure fire separations for single family residences (e.g., Type VB, R-3 buildings) unless the home is within 5 feet of the property line. In some cases, where automatic sprinkler protection is provided per NFPA 13D (NFPA 13D, 2016), fire-separation distances for residential homes can decrease to 3 feet or even 0 feet to the property line (IRC Table R302.1(2)). For most other occupancies and construction types, exterior fire-rated walls are typically required where buildings are within 10 feet of a property line in addition to limits on the presence of, or protection required for openings (e.g., windows). Existing fire separation requirements were designed to limit urban conflagration, originating from a single interior building fire (not wildfires or multiple structure fires occurring simultaneously). Under these assumed conditions, firefighters typically have sufficient resources to control and suppress a single-family home fire.

  However, under extreme wildfire conditions, where fires are simultaneously occurring in both the wildland and the built environment, firefighting resources are often overwhelmed and unable to limit structure-to-structure fire spread (particularly under severe fire weather). For typical parcel sizes and residential structure separations (e.g., 5–10 feet), the effects of radiation, direct flaming, and ember exposures from a home on fire are likely sufficient to ignite an adjacent structure, particularly under high-wind conditions (Figure 2). The parcel centric nature of existing codes, in which parcels are considered independently despite the impact they have on one another, leads to minimal structure separation distances (National Institute of Standards and Technology (NIST) Technical Note 2205). Additional wildfire zoning, planning, structural hardening, and other fire-safety features are likely needed to reduce structure-to-structure fire spread.

Figure 2. Typical residential building separations (10–20 feet) are vulnerable to structure-to-structure fire spread under extreme wildfire conditions, as most single-family residences have non-fire rated exterior walls.

- Access, Egress, and Evacuation Planning – Recent wildfires have highlighted the critical need for properly planning and designing safe paths of egress and access during a major wildfire incident. Many residents and first responders have been placed in dangerous situations, often at night and with limited time to either safely evacuate or respond to an approaching wildfire.

  Current building codes and standards are primarily focused on mitigating interior building fires for single parcels or buildings. However, access and egress requirements to safely manage people (e.g., number, separation of, and capacity of exits) are aimed at getting people out of buildings. There currently is not an equivalent fire safety code, standard, or consensus document that requires provisions for people management during wildfire events at neighborhood-, community- or regional-scales. This means that most existing and new developments may not have a sufficient number, arrangement, or capacity of egress routes to evacuate all residents to a relative place of safety during a major wildfire incident or allow for sufficient access for first responders (Figure 3).

Figure 3. Wildfire evacuations place considerable stress on residents, first responders, resources, and transportation infrastructure. Few neighborhoods, communities- or cities- have properly planned for timely and safe egress from a fire.

Both infrastructure and evacuation planning are key components at the neighborhood- and community-scales in high wildfire-prone settings, such that people are able to safely and quickly evacuate before being endangered by fire, smoke, or hot gases, and first responders can safely and effectively conduct emergency operations.

- Subdivision Landscaping and Vegetation Management – The location and vegetative make-up of open spaces within and adjacent to a development can increase risk of wildfire intensity and spread at the WUI and provide pathways for wildfire to enter a community like a wick. Common spaces, greenbelts, and other types of open spaces can lead to high-risk vegetative conditions (e.g., non-fire adaptive plants, high fuel load due to presence of creek bed or other water features, no fuel management, more flammable vegetation types, proximity to structures) which, in combination with high fire hazard topographic features (e.g., slopes, drainages), can further exacerbate intermix/interface wildfire hazards and risks (Figure 4 and Figure 10).

Figure 4. Unmaintained open space adjacent to the Sagamore neighborhood in Superior CO pre- and post-Marshall Fire. This unmanaged open space likely played a role in the rapid spread and subsequent ignition of the proximate neighborhood.

- Protecting Critical Infrastructure - Though there are some regulations and guidance on mitigating wildfire risks for electrical infrastructure (e.g., vegetative management around poles and lines), other types of critical infrastructure (e.g., communication systems, road networks, power supplies, water supplies) at various scales have few codes, standards and/or guidance documents for wildfire resiliency, or post-wildfire hazards particularly at the subdivision planning scale. As most critical infrastructure is designed and managed at city and regional scales, most developers, contractors, engineers, and planners have little influence over the wildfire safety provisions for those large-scale systems. Recent and past wildfires have resulted in significant short- and long-term impacts to critical infrastructure (e.g., loss and/or damage of water tanks and associated pumps, post-fire debris flows and landslides washing out transit networks) that have resulted in greater financial losses, increased downtime, extended recovery and rebuilding periods, and general disruption to social capital in communities (Figure 5). Understanding what risks wildfire threats present to critical infrastructure (during and post-incident) in a subdivision, and what types of measures are necessary to protect these assets (pre-, during and post-incident) is critical, particularly where a developer, contractor or designer has control over the protection of those lifeline services (Figure 6).

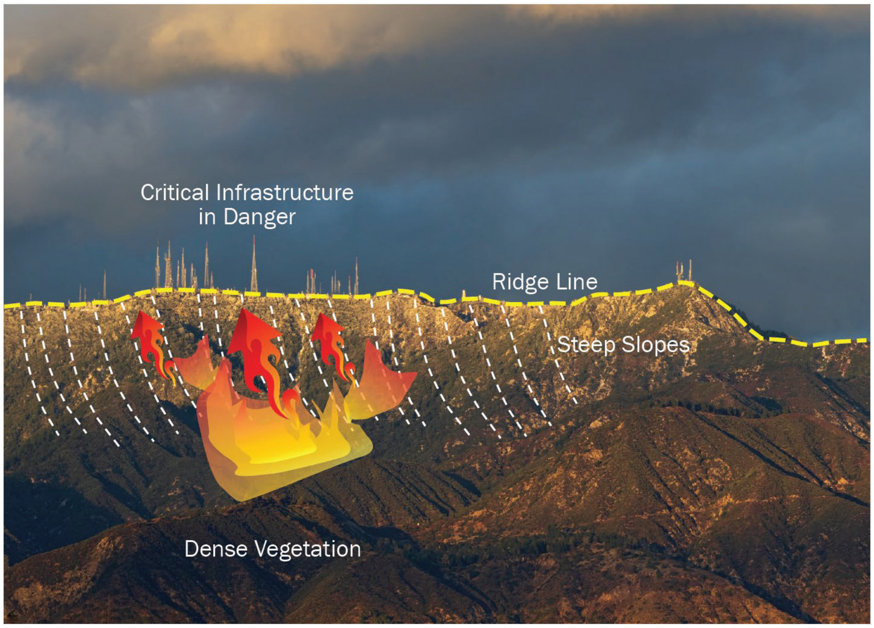

Figure 5. Critical infrastructure is often located in settings with severe wildfire risk (e.g., along ridge lines, on steep slopes, in remote settings with dense vegetation).

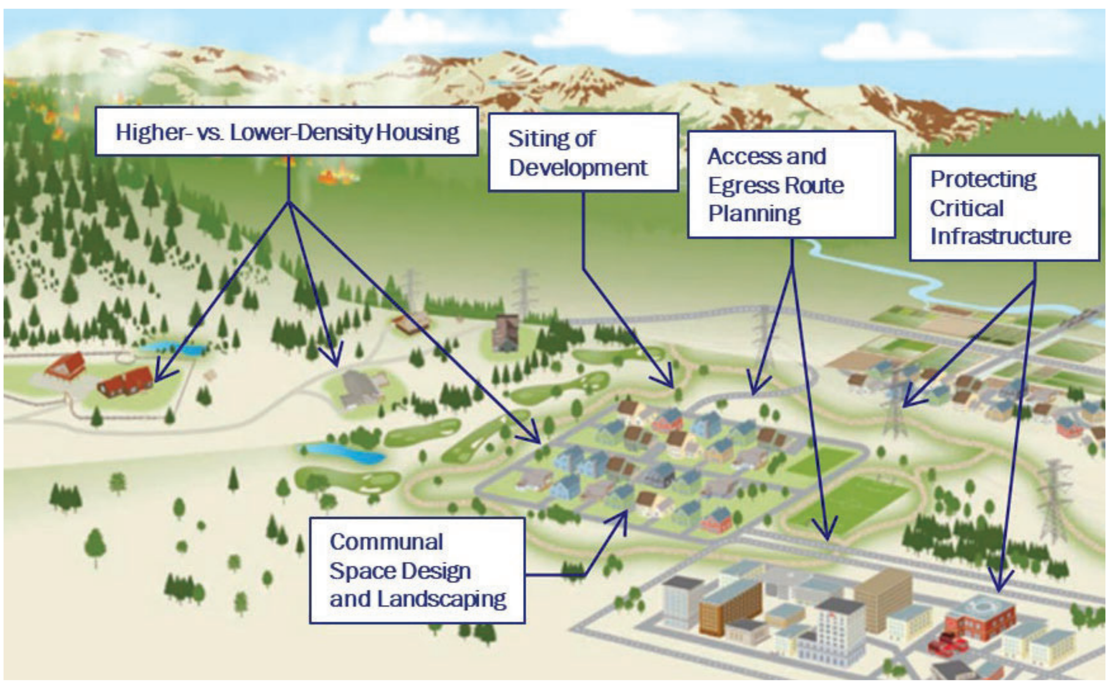

Figure 6. Multiple key issues at the subdivision, neighborhood, and community scales all influence the overall wildfire risk of structures (adapted from Wildfire Planning International, 2016).

1.3. Definitions

Approved or recommended plants – "Approved" or "recommended" plants are generally based on characteristics that allow for a more fire-resistant landscape. Common characteristics include drought-resistance, high moisture content, low levels of volatile oils and other readily flammable chemicals, pest-resistance, noninvasive, slow, and low growing, low litter production and bark shedding, and will grow without supplemental fertilization.

Communal defensible space – The area or space around a collection of properties where the minimum defensible space distances (30–100 feet) is achieved by the sharing of vegetation management and fuel treatments across neighbor property lines. This is in lieu of individual property owner's ability to achieve the requisite defensible distances for setbacks and defensible space within their own parcel. This is related to the concept of "overlapping ignition zones."

Communal or common space – Land or space that is intended for common ownership or use by the residents of surrounding dwelling units.

Community scale –A large area within a community or, in some cases, the whole community (i.e., an entire town or county) (adapted from NFPA, 2013).

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 a place of relative safety to conduct firefighting operations (e.g., control or suppression fire, search-and-rescue) during a wildfire or urban conflagration.

Greenbelt – A belt of parkways, parks, or farmlands that encircles a community (Merriam-Webster, 2022).

Interface WUI – The area where developed/settled areas abut wildland vegetation (Radeloff et al., 2018).

Intermix WUI – The area where houses and wildland vegetation directly intermingle (APA, 2018a).

Neighborhood or subdivision – An area composed of a collection of residential structures (APA, 2018a) that are typically part of a defined subdivision or large Planned Unit Developments (PUDs), particularly when applications for major new developments are submitted for planning or permitting. These are smaller areal units of residential or commercial use that do not cover an entire community, city, or county (Adapted from APA, 2018a and NFPA, 2013).

Vegetation management – Tree thinning, spacing, limbing, and trimming; removal of any vegetation growing under tree canopies (typically referred to as "ladder fuels"), surface vegetation removal, and brush clearance; vegetation conversion, fuel modifications, and landscaping (NFPA, 2013).

Wildfire hazard assessment – Hazard assessment identifies areas based on natural factors such as fuel/vegetation, slope, and weather patterns that increase the likelihood of wildfire occurring (NFPA, 2013).

Wildfire risk assessment – Risk assessment identifies where wildfire is most likely to threaten something of community value, such as human life, property, natural/historic resources, or other features or resources of local value. Risk assessment often includes other risk factors, such as existing roof types, road access, water supply, location and density of structures, and likelihood of post-fire flood damage. A high hazard rating in an area with a low-risk rating (i.e., a wildfire in an undeveloped area) may therefore result in low risk (NFPA, 2013).

2. Subdivision Wildfire Planning

Neighborhood-level codes, standards, and guidelines for planning and design of subdivisions do not currently exist or are very limited. However, because subdivision regulations address a range of conditions on parcels, there are elements of subdivision planning that are critical for reducing wildfire risk (Figure 7). Planning at the subdivision scale can also be an effective tool for addressing several issues of concern for communities in the WUI. Important areas of consideration include:

- Wildfire hazard and risk assessment
- Siting of development
- Housing density considerations
- Access, egress, and evacuation planning
- Water sources for fire fighting
- Subdivision landscaping and vegetation management
- Protecting critical infrastructure & lifeline services

Note: Structural hardening and defensible space provisions at the building/parcel level are the subject of separate Marshall Fire Mitigation Assessment Team products including Marshall Fire MAT document *Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire* and Marshall Fire MAT document *Guide to Reducing Wildfire Risk Through Defensible Space*.

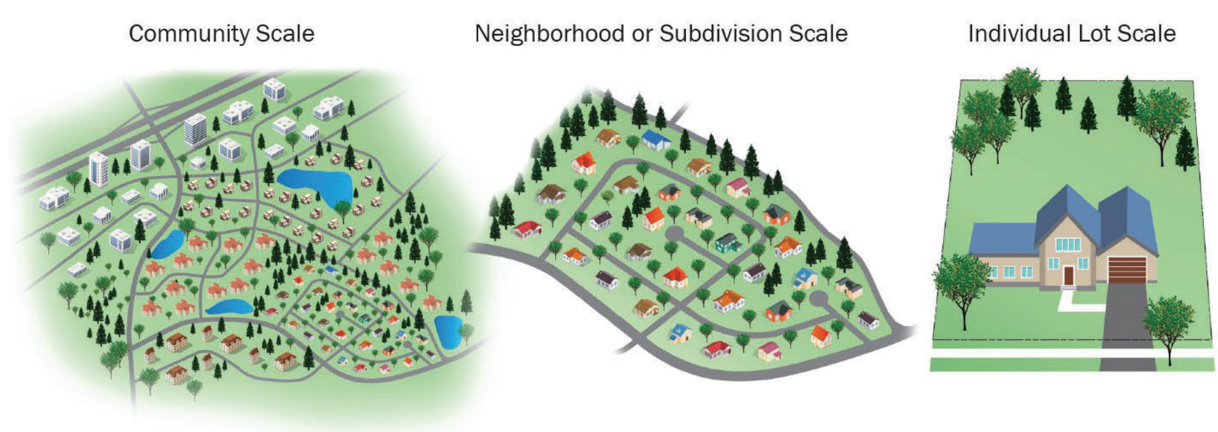

Figure 7. Schematic illustrating scale differences critical for holistic wildfire resiliency planning (adapted from UCANR 2020).

2.1. Wildfire Hazard Assessment

The effective use of wildfire hazard information (e.g., wildfire hazard and risk maps, local wildfire/fire safety ordinances, zoning restrictions, wildfire safety elements in general plans) in the early planning or entitlement phases of new developments including subdivisions is critical. Such information can help to avoid the placement of new developments in very high fire-hazard areas as well as understand site- and neighborhood-specific wildfire vulnerabilities and risks, allowing communities to more comprehensively plan for and design against potential loss of life, property, or other assets. It is fundamental that the evaluation of wildfire hazard conditions is not only conducted at the parcel-level, but also at the subdivision and community-scales. Contractors, developers, design professionals, and planners should undertake the following tasks to understand wildfire hazards during the planning process:

- Evaluate all relevant state and local wildfire hazard and risk maps. Wildfire hazard and risk maps at the state level are typically provided by the State Fire Marshall's office, State Forestry Department, or equivalent state fire agency (e.g., Colorado Forest Atlas, CALFIRE FRAP resources, Texas Wildfire Risk Explorer). At the local level, wildfire hazard and/or risk maps are typically provided by County or Local fire agencies, office of emergency services (OES), or other local government agencies. Local level fire maps (e.g., Colorado Springs wildfire risk maps, Boulder County Fire Zone maps, Local Responsibility Area maps in California) may supersede state level information. The availability and recency of wildfire hazard and/or risks maps will vary depending on the state and local jurisdiction.

- Most available wildfire hazard and "risk" maps only capture the potential severity of a wildfire due to local environmental settings (e.g., topography, vegetation, and weather). Although sometimes called "risk" maps, these maps often do not encompass the risk a wildfire may pose to community values or assets (e.g., life safety, property protection, environmental protection) or any existing or planned vulnerabilities in the neighborhood and community (Figure 8), such as:

    - Occupant characteristics (e.g., age, income, limited English proficiency, limited mobility)

    - High-risk land uses or occupancies (e.g., large assembly, hazardous facilities, schools, hospitals)

    - Availability of fire safety resources (e.g., access/egress, water supplies, power distribution, communications)

    - Construction practices (e.g., pre-WUI code building practices, combustible construction)

- As "risk" is a function of hazard, exposure, and vulnerability; a high-density housing development without WUI code construction and transit-dependent senior care facilities in a medium wildfire hazard zone may experience greater overall risk than a high-end construction, residential subdivision with golf courses and manicured greenbelts in a very high-fire-hazard zone. Given this, the contractor, designer, and/or planning professional will need to evaluate not only site-specific hazards, but also potential risks to the proposed development (see next bullet point).

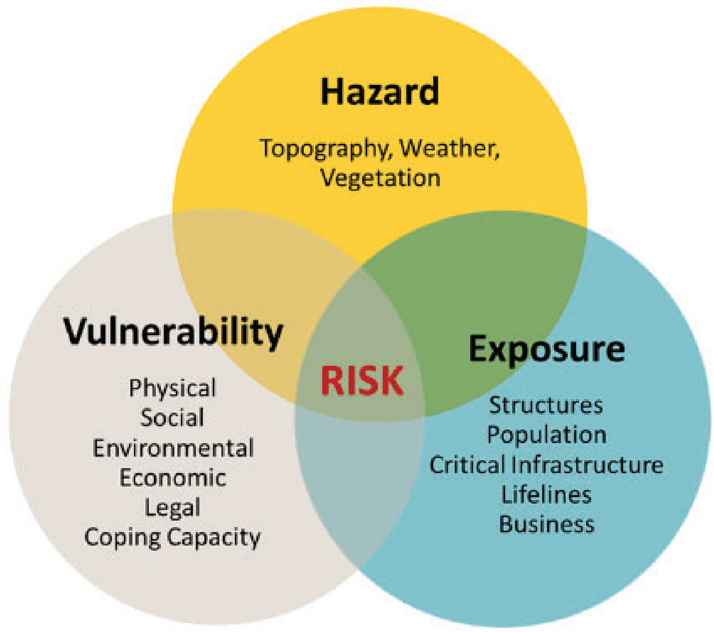

Figure 8. Wildfire risk identifies where wildfire is most likely to threaten a community value (e.g., human life, property) and is defined by the combination of hazard, exposure, and vulnerability.

- Determine if an environmental review (e.g., National Environmental Policy Act or California Environmental Quality Act) is required as part of the planning phase. The objectives of environmental reviews may conflict with the objectives of wildfire hazard and risk-reduction measures, so consultation with both a wildfire/fire safety specialist and an environmental protection specialist should be undertaken to appropriately address and balance public safety and environmental concerns.

- Evaluate all relevant local level community planning documents, plans, and maps. This may include, but is not limited to the following:

  - Community Comprehensive Plans at county, city, and local levels
  - General plans, master plans, form-based plans, zoning requirements, and land-use planning
  - Community Wildfire Protection Plans (CWPPs)
  - Hazard Mitigation Plans (HMPs) (e.g., All-Hazard Mitigation Plans, Multi-Jurisdictional HMPs). Reference *Marshall Fire Mitigation Assessment Team: Mitigation Strategies to Address Multi-Hazard Events* for additional guidance
  - Emergency operational plans and procedures
  - Unit Strategic plans or other fire department planning documents

  The existence of and detail in these documents varies widely between jurisdictions. In best-case scenarios, these plans should provide hazard mapping for the area, indicate overlap between natural hazards and vulnerable community assets, detail structural vulnerabilities, and list concerns about post-wildfire impacts (APA, 2018).

- Consult state and locally adopted wildfire safety building and fire codes, ordinances, and other relevant regulatory documents. Where the state or local jurisdiction have not adopted any wildfire-specific safety regulations, refer to the 2021 International WUI Code (Table 502.1 and/or Appendix C: Fire Hazard Severity Form) for general guidance around analyzing the fire hazard of a specific site.
- Consult with the local fire department to understand any local requirements, additional guidance documents, wildfire planning processes and reviews, and existence of any mutual aid agreements and/or alternative mitigation initiatives appropriate to the area.

2.2. Siting of Development

The location of a development or subdivision on the landscape is a major driver of its wildfire risk. Local site conditions (e.g., topography, vegetative characteristics, vegetative maintenance, proximity of fuels and other developments, weather, and orientation of a site) can markedly influence site-specific wildfire hazards and exposures not typically captured by the federal, state, and local level wildfire hazard and risk maps discussed in the previous section. The following paragraphs include recommended best practices to consider during planning for siting a development in the WUI:

Consult existing state and local wildfire hazard and risks maps, as well as other wildfire related planning documents described in the previous section for a general understanding of “landscape” level fire hazards. Where state or local hazard maps are nonexistent, out-of-date, or of low spatial resolution, consider contracting a specialist to complete a project-specific wildfire hazard and risk assessment. A project-specific assessment will provide a higher level of granularity of anticipated wildfire behavior, will highlight any vulnerabilities due to the presence of local topographic conditions (e.g., hilltops, ridges, steep slopes), and will show potential fire flow paths from neighborhood- or community-level features such as greenbelts, open spaces, or drainages (Figure 9). In recent fires, such as the Marshall fire in Colorado, drainages and other communal open spaces provided an avenue for wildfire to spread into the more developed urban/suburban environments. This type of detailed analysis may be particularly prudent if your development will be in an interface or intermix WUI or in an occlusion zone (Figure 10).

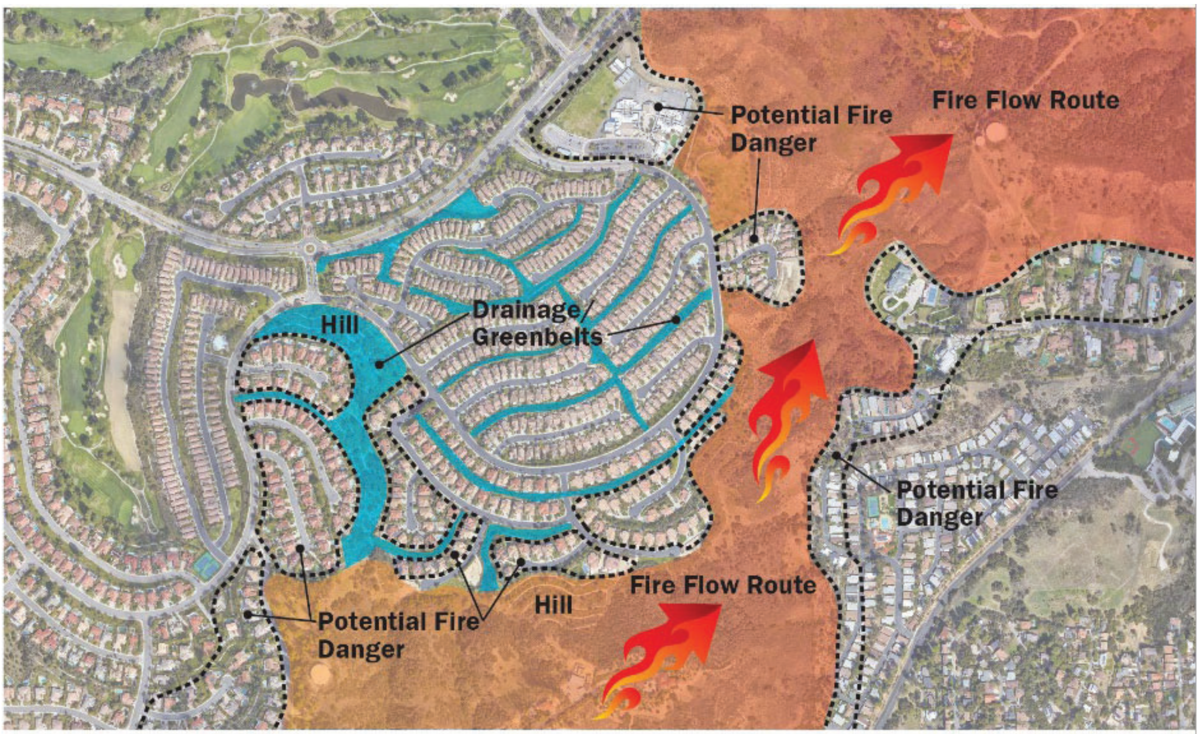

Figure 9. Drainages and greenbelts in or adjacent to communities can provide access for fire to flow into the urban/built environment.

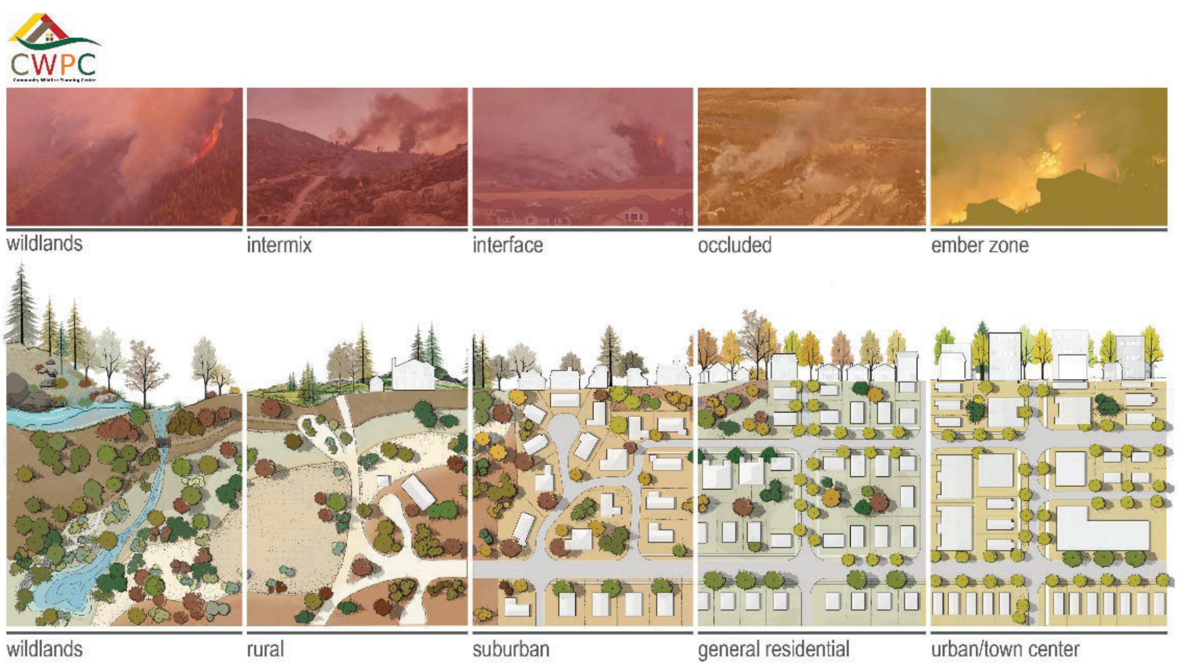

Figure 10. The spatial relationship between vegetation and development changes along a continuum from wildland to urban. Intermix, interface, and occluded/urban forest WUI often have the highest wildfire hazard (Image courtesy of Community Wildfire Planning Center).

If a detailed wildfire hazard assessment is not available or feasible, the following general guidance for siting a subdivision or development can help reduce wildfire risk:

- Avoid selecting a construction site along a gully or in a narrow canyon
- Avoid selecting a construction site in or adjacent to a saddle or narrow mountain pass
- Avoid constructing a new development adjacent to or on a steep slope. If a ridgetop site is selected, consider the following:
    - Choose an area that allows for a minimum 30–100-foot setback from wildland vegetation on the downslope side (see Figure 11). Increase the setback at sites with heavier fuels such as in a forested environment. Implement the measures in Marshall Fire MAT document *Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire* and Marshall Fire MAT document *Homeowner's Guide to Reducing Wildfire Risk Through Defensible Space*.

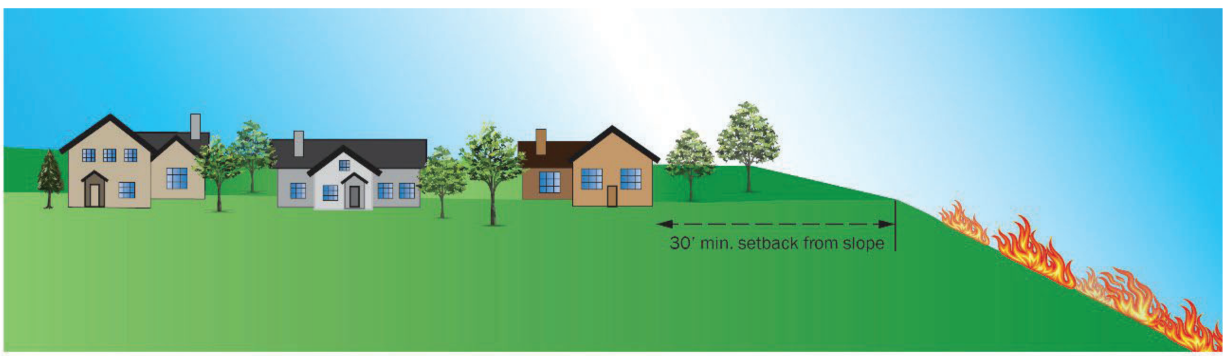

Figure 11. Topographic features, such as slopes, may increase wildfire risk. Appropriate mitigation actions, such as slope setbacks, should be undertaken.

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    - Develop a fuel modification and long-term vegetation management plan for the steep slopes proximate to the development site (if within your control) (Figure 12). Given the specific topographic and vegetative conditions more than 100 feet of defensible space will likely be needed. Consult with the local fire department or other authority having jurisdiction for site-specific guidance and/or local ordinance requirements. In some jurisdictions, this can be as much as 200+ feet (e.g., Los Angeles County, Orange County in California). See vegetation management section below. Refer to the *Marshall Fire Mitigation Assessment Team: Homeowner's Guide to Reducing Wildfire Risk Through Defensible Space* as well as additional guidance documents in the references section.

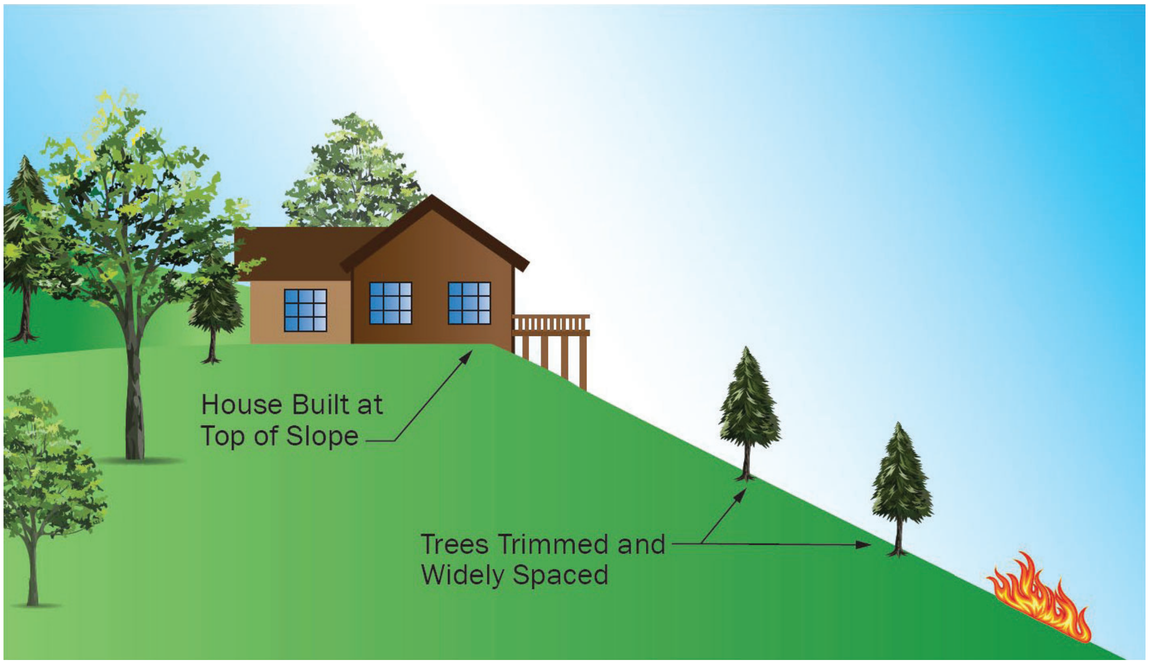

Figure 12. Topography and vegetation influence wildfire risk. Where 50-foot setback to steep slopes is not feasible, provide a minimum of 100–200 feet of fuel modifications along the proximate slope.

- Avoid constructing a new development adjacent to an unmanaged open or wildland space where 50 to 100 feet of defensible space cannot be provided on the proposed site. If a site is selected that is proximate to an unmanaged open or wildland space, consider the following design features:

  – Integrate inherent fuel breaks such as fruit orchards, irrigated landscaping/greenbelts, golf course or other similar low-wildfire hazard features (Figure 13).

  – In addition, or where achieving perimeter defensible space is infeasible, consider providing increased structural hardening measures for structures proximate to the open or wildland space such as 6-foot non-combustible perimeter walls or 1-hour fire-resistant exterior walls and protected openings (Figure 13).

  – Refer to 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*.

  – Refer to Marshall Fire MAT document *Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire* for additional siting recommendations at the building-scale (e.g., building orientation relative to fire flow paths, debris and ember accumulation, window number, and orientation.

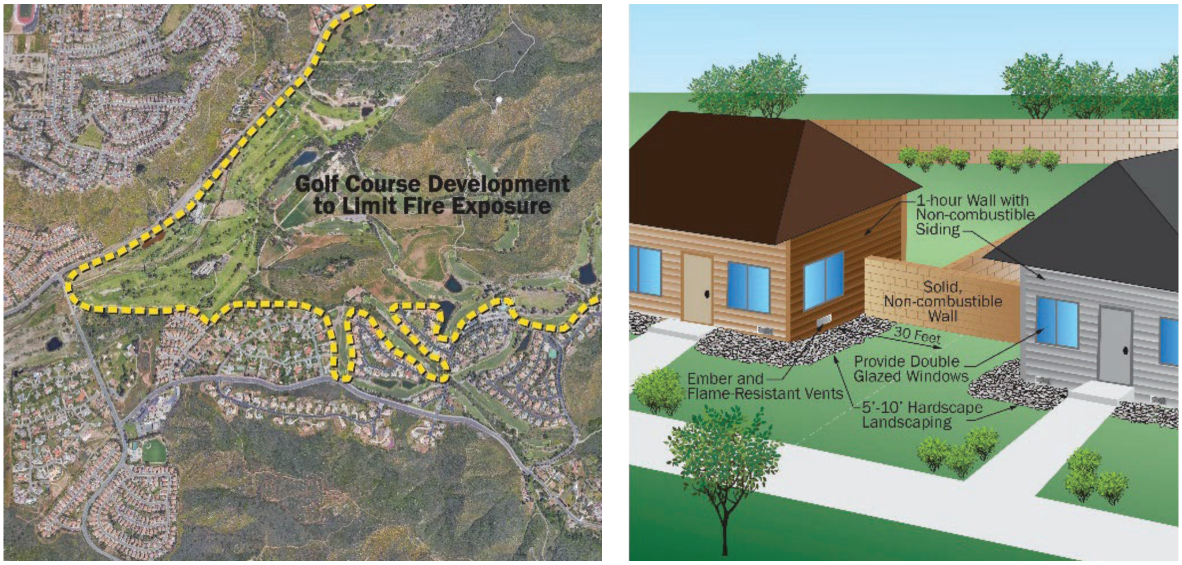

Figure 13. Example of golf course placement around a development to limit wildfire exposure (left) and fire-resistant construction techniques (right).

In recent catastrophic wildfire incidents (e.g., 2017 Camp Fire, 2021 Marshall Fire), fire spread rapidly not only via wildlands and other open spaces, but also from structure to structure (via direct flame contact, hot gases, radiation, and embers). Given the devastating influence nearby subdivisions can have during a wind-driven fire incident, developers and planners should consider the extent and proximity of surrounding developments and their influence on fire behavior. The following provides general guidance for siting a subdivision or development relative to other existing or future developments:

- Avoid construction sites proximate to an existing or future development in a high or very high fire hazard severity zone, where a minimum 30-foot setback to the property line cannot be provided. Where this cannot be avoided, consider integrating design features, such as fuel breaks and increased structural hardening measures, like those described for sites proximate to unmanaged open or wildland space (see section above).

- If there will be any hazardous land uses on the site that could potentially exacerbate risk (e.g., storage of combustible materials, fuel storage facilities) and which cannot be restricted, consider providing additional mitigation measures (APA, 2019), such as larger setbacks and defensible space areas, secondary emergency water supplies and associated emergency power, increasing exterior wall fire resistance rating (e.g., 1-hour to 2-hour). Consult with a fire-safety engineer, design professional, or local fire department for guidance, as needed.

2.3. Housing Density Considerations

When planning a new housing development, there are various options and considerations in selecting the density of houses and structures, both across multiple lots and on a single lot. These decisions are generally guided by local regulations and zoning, economic and financial needs of the developer, and preferences of homeowners/buyers. In WUI areas, an additional consideration must be reducing wildfire risk. There may be conflict between guidance and best practices for wildfire risk mitigation with residential development needs and preferences.

Currently, there is limited formal guidance to assist developers, design professionals and planners in providing appropriate wildfire safety provisions given the range of housing density and layout considerations in practice (see NIST Technical Note 2205 and UCANR 8680 for additional detail). Development planning provides a unique opportunity to mitigate wildfire risk at a neighborhood scale, rather than at the individual lot scale, which forms the basis of current building and fire code requirements. This document provides general guidance given two different housing density designs: (A) "Clustered" or High-Density and (B) "Traditional" or Low-Density, as shown in Figure 14.

Figure 14. Conventional, or traditional, development with low-density houses (A) versus clustered development with several high-density clusters of structures (B) (UCANR, 2020).

The following sections provide potential fire safety design considerations given "clustered" or high-density designs vs. "traditional" or low-density design options.

2.3.1. "CLUSTERED" OR HIGHER DENSITY HOUSING

Clustering homes together within a subdivision can reduce the expansion of development in high-wildfire hazard areas while also minimizing the overall number of houses on a site. This design strategy can also help limit impacts to environmental services, ecological needs, and recreational goals for open spaces, while also reducing the distribution of firefighting resources during a major wildfire incident (APA Multihazard Planning Framework for Communities in the WUI, 2018; UCANR, 2020).

However, higher-density designs may increase structure-to-structure ignitions due to the closer arrangement of buildings, and therefore require additional fire safety mitigations to offset reduced fire separations (e.g., fire-rated exterior walls, non-combustible construction materials, ember resistant vent protection). These include:

- Provide vent covers with 1/16-inch wire mesh or an approved ember and flame-resistant vent. Some jurisdictions have "pre-approved" products such as CALFIRE's Building Materials Listing Program[5] . Local building and/or fire officials have discretion to approve products.
- Provide combustible siding with non-combustible or ignition resistant materials (e.g., fiber cement, stucco).
- Provide combustible decking with non-combustible decking.
- Provide noncombustible materials for non-vegetative features (e.g., ornamental grass, sheds, pergolas, gazebos) or design any combustible elements in surrounding landscape (e.g., trash bins, wood piles, vehicles) to be more than 30 feet away from homes or structures or to be enclosed in non-combustible construction.
- Provide double-paned or tempered-laminated glazing. Recommend reducing the number of openings (i.e., windows, glazed doors, vents) on the aspect where exterior walls are in close proximity to other buildings.
- Use noncombustible materials (e.g., concrete, masonry, metal), particularly for fences that attach to adjacent homes or structures.
- Provide structural hardening measures for the entire home (e.g., upgrading to a Class A roof). Refer to Marshall Fire FS-2 "*Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire*".

Given the increased structural hardening measures and other fire safety features, higher-density designs, can be viewed as one large "building" or development, where prescriptive requirements for

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[5] https://osfm.fire.ca.gov/divisions/fire-engineering-and-investigations/building-materials-listing/bml-search-building-materials-listing/

achieving 100 feet of defensible space is provided around the perimeter of the entire development site, while also considering the following integrated design features:

- Provide a minimum 100-foot inherent fuel breaks around the entire development such as fruit orchards, irrigated landscaping/greenbelts, golf courses, roads, or other similar low-wildfire hazard features. See vegetation management section below for further discussion of this topic.

- Concentrate housing on inner side of roadways and away from vegetation (UCANR, 2020).

Although high-density development can efficiently create vegetative buffers (e.g., green belts, golf courses, orchards) and allow for fire department response, additional risks are involved when structures are closely spaced. See Marshall Fire MAT document *Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire* for information on mitigating risk for high-density neighborhoods and subdivisions. Additionally, reference Marshall Fire MAT document *Homeowner's Guide to Reducing Wildfire Risk Through Defensible Space*. Marshall Fire MAT document *Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire* for information on protecting structures within high-density developments. and "Traditional" or lower-density housing.

2.3.2. "TRADITIONAL" OR LOWER DENSITY HOUSING

Traditional housing developments, with lower density designs, allow each individual home/structure to directly integrate wildfire safety provisions (e.g., structural hardening measures and defensible space) prescribed in wildfire codes and standards for each individual building or home. However, as shown in Figure 15, lower-density housing, collectively, requires a higher amount of land area dedicated to defensible space compared to higher-density designs, which can have negative impacts to environmental services and other ecological goals of the community. Lower density developments can also result in the need to disperse firefighting resources and suppression activities in the event of a major wildfire incident, given the larger spread of development. (UCANR, 2020).

Be aware that unplanned subdivisions or structures on adjacent lots may not have been designed to meet an equivalent level of safety as described in this document, therefore, the fire risk they can present to surrounding properties is uncertain. Thus, the guidance in this document is intended to mitigate this uncertainty by recommending fire safety measures at the neighborhood level during planning and development specific to subdivisions, such as communal defensible space or high-density vs low-density design options.

In the event that the low-density housing development still is unable to meet 100 feet of defensible space on all sides of an individual structure, contractors should ensure that communal defensible space considerations and structural hardening measures on all affected properties are implemented as described in the *Marshall Fire Mitigation Assessment Team: Homeowner's Guide to Reducing Wildfire Risk Through Defensible Space*. Refer also to this fact sheet, where 30 feet of setback from property lines is not feasible.

2.4. Access, Egress and Evacuation Route Planning

Both road infrastructure and evacuation planning are key components at the neighborhood- and community-scales in high wildfire prone settings, such that people are able to evacuate during a major wildfire safely and quickly along primary and secondary routes, and first responders can effectively gain access to conduct emergency operations. This includes providing sufficient number, arrangement, and capacity of road networks, as well as meeting specific roadway standards, and understanding the impact of new development on the regional road network. The following guidance provides recommendations for planning appropriate wildfire access/egress for new subdivisions:

Figure 15. Access roads should have sufficient separation.

- Separation of Access/Egress Routes (Remoteness of exits) – Emergency access/egress to or from a neighborhood is necessary to protect life safety in the case of evacuation and fire responder activities. Access/egress routes should be spaced sufficiently so that both routes are not blocked during a wildfire emergency event. Where two access/egress roads are required (e.g., developments of one- or two-family dwellings where the number of dwelling units exceeds 30), they should be separated by a distance not less than one-half the length of the maximum overall diagonal dimension of the area to be served (IFC Appendix D) (Figure 15). The ease of separating access will depend on site setting and surrounding terrain and may require consultation with the local fire authority. (Planning for Wildfires; APA Zoning Practice 9, 2018).

- Subdivision or Neighborhood Wildfire Access/Egress Capacity and Dead-End Conditions

    - All roads should provide a minimum of two 10-foot traffic lanes, not including shoulder and striping. These traffic lanes should provide for two-way traffic flow to support emergency vehicle and civilian egress unless other standards or additional requirements are mandated by Local Jurisdictions or local subdivision requirements.

- Where one-way roads are provided, they should provide a minimum of one 12-foot traffic lane, plus shoulders. One-way roads should connect to a road with two traffic lanes providing for travel in different directions and provide access to an area currently zoned for no more than 10 Residential Units. Avoid providing one-way roads in excess of 2,640 feet in length. Where one-way roads are provided, turnouts should be placed and constructed at approximately the midpoint of each one-way road.

- All lengths should be measured from the edge of the road surface at the intersection that begins the road to the end of the road surface at its farthest point. Where a dead-end road crosses areas of differing zoned parcel sizes requiring different length limits, the shortest allowable length should apply.

- Fire Apparatus Access – Fire codes, local ordinances, and standards for roads, driveways, and bridges to ensure access by fire department apparatus and emergency services equipment should be followed and may be more restrictive than the following suggestions. These include minimum road width, maximum grade, number of turnarounds/turnouts, and load limits. Note: The following guidance provides minimum suggestions. Consult with local fire and other authorities having jurisdiction where requirements may be more restrictive.

    - Fire apparatus access roads should have a minimum width of 20 feet, and a minimum clear height of 13 feet 6 inches. Dead-end roads more than 150 feet in length should have turnarounds. A driveway which does not meet the requirements of a fire access road should not serve more than five residences (IWUIC 2021). Consult the local fire department for jurisdiction-specific requirements.

    - Grades for all roadways and driveways should not exceed 16% or as limited by the local fire department. Consult the local fire department for confirmation.

    - Driveways in excess of 150 feet in length should be provided with turnarounds. These turnarounds should have an inside turning radius of not less than 30 feet and an outside turning radius of not less than 45 feet (IWUIC 2021). Road intersections should accommodate similar turn requirements.

    - Driveways in excess of 200 feet in length and less than 20 feet in width should be provided with both turnarounds and turnouts. Turnouts should be an all-weather road surface and not less than 10 feet wide and 30 feet long (IWUIC 2021).

    - Roads should be designed and maintained to support the imposed load of fire apparatus weighing 75,000 pounds and provide an aggregate base. Consult the local fire department for jurisdiction-specific requirements.

  - Road signs should be uniform and meet visibility requirements. Any locked gates should have a Knox box installed for emergency responder access (APA Zoning Practice 9, 2018; PAS 594).

- **Protection of Primary and Secondary routes** – Planning for fire-adapted landscaping and/or fuel treatments such that a minimum of 10 feet on either side of all major access/egress routes within the subdivision should be considered (Figure 16). Consult with a wildfire specialist, landscape architect or other design professional for detailed guidance and best management practices.

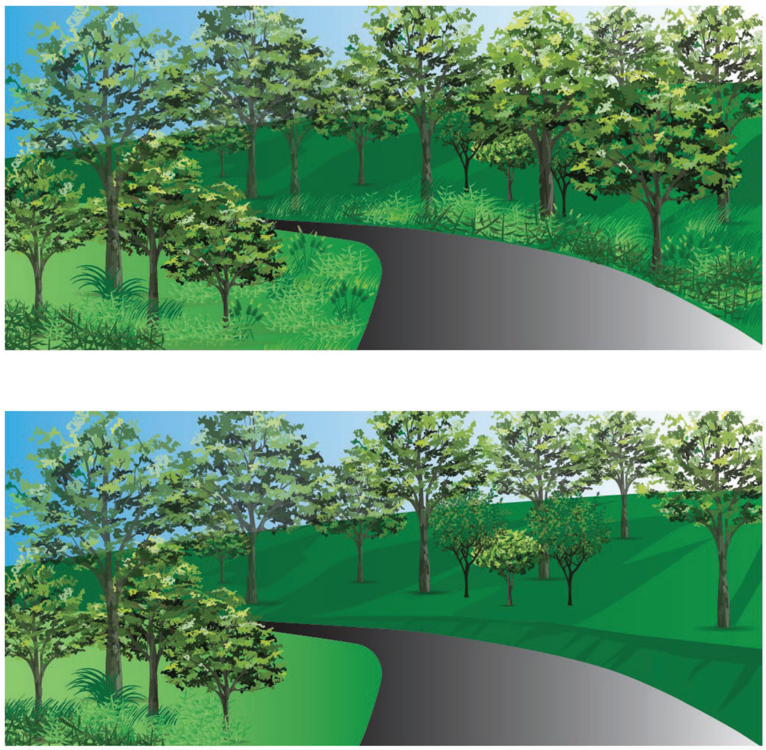

Figure 16. A minimum of 10-feet of fuel modification should be maintained around primary and secondary egress routes. This distance may increase where an access road is in high hazard topography (e.g., steep slopes, ridgelines, drainages, canyons).

- **Community Scale Wildfire Evacuation Capacity** – The planning process for new developments (particularly large developments) in very high fire hazard areas should consider undertaking a wildfire evacuation analysis to consider various likely wildfire scenarios, assess how a new development will impact the broader community road network during an evacuation, and undertake comprehensive evacuation modeling and planning that considers the specific needs of the local population. Standard roadway designs do not explicitly consider large scale emergency evacuations. A wildfire evacuation often results in larger egress flows which exceed typical roadway design flow assumptions, whether employing phased or total evacuation strategies. Wildfire-specific analysis and consideration is crucial to prepare for sufficient evacuation capacity or alternative people management strategies. Consult with the local planning and fire department for local guidance and requirements.

2.5. Subdivision Landscaping and Vegetation Management

Most subdivisions will include various common open spaces (e.g., parks, play areas, undeveloped lots, road medians, trails). Careful consideration needs to be given to planning these areas with fire-adaptive landscape design features. In addition to initial design and planning, long-term maintenance plans must be developed and implemented. The placement of open spaces within a development, specific types of plants to use and avoid, and ongoing maintenance are all important planning elements. Specific topics to consider and recommendations include:

- Place open spaces within the development site with consideration to underlying wildfire hazard and risk. This may include designating areas of high wildfire hazard as permanently conserved open spaces (with ongoing fuel reduction treatments), thereby reducing the introduction of people and property in higher-hazard areas. An added benefit of this technique may be conserving useful habitat for native plants and animals (UCANR, 2020; APA, 2018a).

- Consider the different types of open space which may exist or be built within the development. Small, landscaped, and manicured open spaces have a lower risk profile than large spaces with non-native, and possibly more flammable, vegetation. Surround larger spaces with defensible space and plan for them to burn periodically (UCANR, 2020). The outside perimeter of a development is a good place to locate walkways and trails, to reduce fuel loading adjacent to structures.

- Design vegetated open spaces so that relatively high-water content is maintained in leaves, which makes plants less likely to ignite. This requires consideration of both plant selection, irrigation systems, and a regular maintenance schedule (UCANR, 2020).

- Consider placement of vegetation within each open space. Recommended separation distances will vary by community and vegetation type (Figure 17). Reference recommendations and requirements for tree spacing based on the slope and location of the property.

  - Select specific plant types based on fire-resistance. There may be an approved or recommended plant list for your location. Also be aware of plants to avoid specific to your local area. Be aware that native plants may not be fire resistant and some may be extremely flammable.

  - In addition to initial vegetation and landscape planning, ongoing vegetation management and maintenance is crucial (Figure 18). This includes all areas with vegetation in the development—both heavily landscaped open spaces and those dominated by native vegetation. Regular fire mitigation over the long-term should be required or performed (APA, 2019).

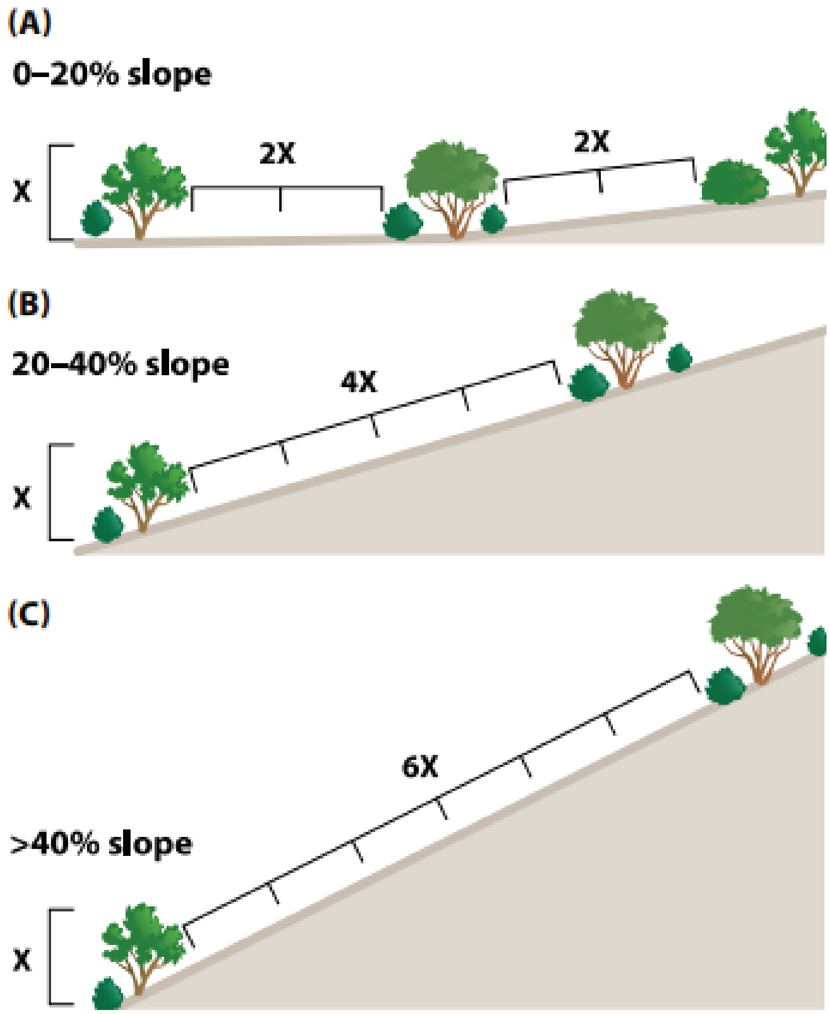

Figure 17. As slope increases, recommended distance between vegetation also increases. Steeper slopes should have widely spaced vegetation (UCANR 8695).

Figure 18. Before (left) and after (right) fuel reduction thinning treatment (California Climate Investments, 2022).

2.6. Protecting Critical Infrastructure

The protection of critical infrastructure (e.g., access/egress routes, communication systems, water supplies/infrastructure, electrical power infrastructure) from wildfire hazards, as well as limiting the potential source of wildfire ignitions due to some of these features, is an important planning consideration where relevant to a new development or subdivision. Currently, there are limited codes, standards, and guidance documents for protecting certain types of critical infrastructure from wildfire, but also ensuring that certain types are not sources of wildfire ignitions themselves at the subdivision or development scale.

The following guidance and best practices should be considered where a new development requires the design and installation of critical infrastructure. Refer also to FEMA's *Home Builder's Guide to Construction in Wildfire Zones Technical Fact Sheet No. 16* for additional details.

2.6.1. GENERAL GUIDANCE

- Critical infrastructure may span across multiple jurisdictions and may have multiple responsible entities (e.g., public utilities, city, county). Coordinate with all responsible parties. Infrastructure should be inventoried and assessed to determine vulnerability. Mitigation strategies, such as the removal of hazardous vegetation, may be part of an existing CWPP or HMP. If a critical infrastructure plan exists separately, planners should seek connections between these plans (APA, 2019).

- Consider hiring a fire protection engineer or wildfire safety specialist to evaluate and recommend wildfire safety provisions, protection measures, etc.

2.6.2. ELECTRICAL UTILITIES AND EXTERIOR EQUIPMENT

- Where possible, place all electrical distribution equipment in conduit underground.

- Where underground distribution equipment is infeasible, consult any relevant state and local fire safety ordinances for adequately designing overhead electrical distribution lines and associated equipment (e.g., transformers) to reduce the likelihood of this equipment providing a source for wildfire ignitions. Consideration should be given not only to the hardening of the equipment, but also in providing adequate vegetation clearance, appropriate plant selection such that fall-in, grown-in and lean-in of vegetation is minimized, and long-term management.

- Where state or local guidance is not available, Chapter 17 of NFPA 1 provides some limited and general guidance on clearance of brush and vegetation growth around electrical lines. This includes a combustible free zone around poles and towers of not less than 10 feet in each direction (Figure 19). For distribution lines, vegetation clearances are defined as a function of line voltage and time of trimming (e.g., a 4160V line requires a minimum of 4 feet clearance, so trimming requirements are triggered when vegetation is 4 feet from the line and must be trimmed to 6 feet clearance, to allow for growth in between trimming cycles).

Figure 19. A minimum of 10 feet of clearance should be maintained around utility equipment.

- Regular vegetation maintenance should be planned to maintain appropriate clearances, and should take into consideration species' growth rates, trim cycle, and line sway (NFPA 1, Chapter 17).

2.6.3. ACCESS/EGRESS ROUTES

Refer to the "Access, Egress and Evacuation Planning" section above for details.

2.6.4. FUEL-RELATED UTILITIES

- Fuel tanks (e.g., propane) can present a significant hazard to both structures and first responders if they start off-gassing or explode during a wildfire. Exposed, fuel lines can also be vulnerable to wildfire damage (see NFPA 58).
- Bury or shield fuel lines to protect them from the effects of radiation, direct flaming, and ember exposure.
- Bury pressurized fuel-storage vessels underground, where possible.
- Where fuel storage tanks are stored or installed above ground, the following guidance should be considered:
    - Install tanks a minimum of 30 feet from habitable structures
    - For cylindrical tanks, use vertical tanks (e.g., Figure 20) or orient horizontal tanks so that the circular ends are pointed away from residences or structures since the ends are weaker than the tank body
    - Install tanks on and surrounded by noncombustible surfaces
    - Provide a non-combustible masonry wall enclosure, where possible

- Avoid installing tanks near high-risk topographic features (e.g., steep slopes, drainages)
- Maintain at least 10 feet of clearance from other combustibles
- Avoid installing tanks in proximity to primary or secondary egress routes (APA, 2019)
- Ensure pressurized storage tanks have a pressure-relief valve and that the valve/vent is directed away from residences and structures

- Provide signage or other form of notification of type and location of fuel-related utilities, where concealed or inconspicuous.

2.6.5. FIRE-PROTECTION EQUIPMENT

- Critical fire-protection equipment (e.g., water tanks, water supply pumps, pump houses) may necessitate fire-hazard reduction measures to protect this infrastructure from being damaged or lost during a wildfire incident.
- As a minimum, 30 feet of brush clearance should be maintained around critical fire protection equipment (Figure 20). This distance may vary pending review and discussion with local fire authorities. Refer to NFPA 1 and local ordinances for detail.

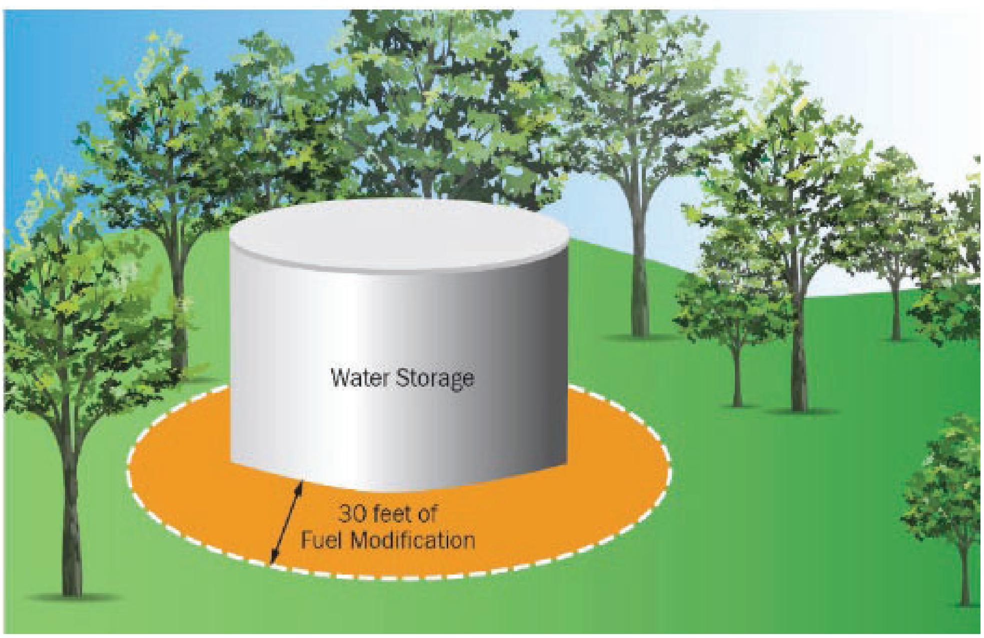

Figure 20. A minimum of 30 feet of fuel modification should be maintained around water storage tanks.

- Water supply and water storage, including on-site storage, are components of critical infrastructure within a development. Minimum water storage requirements should be applied to provide protection for dwellings and other structures where adequate public/private water supply is not available.

- Developers should coordinate with local fire departments to determine water supply requirements and hydrant placement (APA, 2018a). Many fire authorities provide specific requirements for their jurisdiction on water storage requirements and equipment (e.g., hose adapter).

2.6.6. COMMUNICATION TOWERS

- Consider providing 30 feet of hardscaping or brush clearance around communication towers and associated equipment. Consult with local fire authorities for any local requirements, guidance, and best practices. Where no local guidance is provided, consult NFPA 1, NFPA 1140 or IWUIC.

3. Additional Resources and Useful Links

Design Guidance for New Construction

While the recommendations in this Recovery Advisory focus on existing residential structures, several resources are available with design guidance for new homes.

- International Wildland Urban Interface (IWUI) Code, Section 603
- NFPA 1140, 2022 Edition: Standard for Wildland Fire Protection
- SFPE & SFPE Foundation WUI Virtual Handbook for Property Fire Risk Assessment & Mitigation

Guidance for Wildfire Vulnerability Assessments

- NFPA 1140, 2022 Edition: Standard for Wildland Fire Protection
- NFPA “Assessing Structure Ignition Potential from Wildfire" training. https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone?gclsrc=aw.ds&?order_src=G076&gclid=Cj0KCQjw1vSZBhDuARIsAKZlijT7pqdYOPLrprSJ0_ZdMy3IYD3yT6Z521MfTaXnFcW8gYI4etDRGPcaAogJEALw_wcB&gclsrc=aw.ds
- Fire Adapted Communities Learning Network. https://fireadaptednetwork.org/

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FEMA: Protect Your Property from Wildfires: https://www.fema.gov/sites/default/files/2020-11/fema_protect-your-property_wildfire.pdf

FEMA: Technical Fact Sheet – Home Builder's Guide to Construction in Wildfire Zones https://wildfiretoday.com/documents/FEMA_home_builders_guide_wildfire_zones.pdf

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Appendix J: Wildfire-Resilient Detailing, Joint Systems, and Interfaces of Building Components

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Marshall Fire Mitigation Assessment Team: Wildfire-Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components

Revised April 2025

FEMA

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1. Introduction

On December 30, 2021, a wind-driven wildfire affected over 2,000 residential structures and several commercial facilities in unincorporated Boulder County, the City of Louisville, and the Town of Superior, Colorado. Data gathered after the fire highlighted several vulnerabilities at the interfaces and joints of exterior building components, that likely provided an avenue for embers, flames, and hot gases to penetrate the interior spaces of homes leading to significant damage or total loss. This document provides builders, contractors, and other design professionals with information on design strategies and construction practices to reduce the risk of home ignition due to vulnerabilities at the joints and interfaces of exterior building components.

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 provides information on ways to reduce the vulnerability of residential structures to wildfire ignition due to windborne embers, hot gases, and flames penetrating common detailing joints and building component interfaces that exist throughout the exterior envelope of a building. This document provides information on measures that builders, contractors, and other design professionals can take to “seal” gaps at joints and retrofit building components and interfaces on the exterior surfaces. While the primary focus of this document is to provide guidance on retrofitting existing residential homes, many of the recommendations for increasing wildfire resiliency of common details, joint systems, and building component interfaces would also be applicable to new construction and commercial buildings.

3. Key Issues

Buildings are comprised of a combination of elements, components, and built-up assemblies (e.g., foundation, columns, walls, roofs, windows, doors, floor systems, façade systems) that, when connected, result in joints or spaces at the interfaces to accommodate construction tolerances and building movements. For interior building components, fire-resistive joint systems (such as blocking in a wall cavity) are typically provided to protect the joints or spaces within or between components from interior fire and smoke spread. However, for most residential construction (e.g., single-family housing, low- and medium-density housing), the exterior envelope of the building is not typically required to achieve a fire-resistance rating unless the fire separation distance to an adjacent lot or building is five feet or less. Additional allowances are permitted where the residential buildings or subdivisions are (interior) sprinklered[1].

This section highlights key issues with current wildfire safety design and construction practices at the joints and interfaces of building components throughout the exterior building envelope.

3.1. Presence of Gaps at Joints and Interfaces

Detailing at joints and interfaces of building components throughout the exterior envelope of a building or residence (e.g., foundation-to-wall siding interface, window-to-wall joints, skylight-to-roof joints, chimney-to-roof joints, joints at roof valleys) often have gaps or spaces at the interfaces between them, leaving these areas vulnerable to ember accumulation or intrusion.

Gaps in the exterior envelope of the building can lead to embers penetrating into combustible interstitial spaces of exterior walls and roof systems (see Figure 1). These spaces do not typically contain any kind of fire detection to notify building occupants of a fire or suppression systems to extinguish a fire. As such, a fire in combustible interstitial spaces due to ember intrusion can go unnoticed for long periods, allowing the fire to grow to uncontrollable levels before being detected.

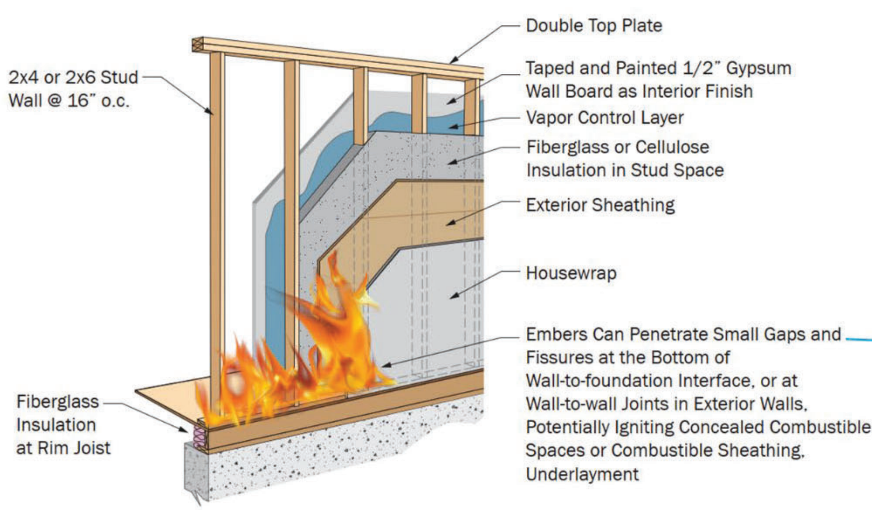

Figure 1. Example of gaps in common exterior wall construction (e.g., interfaces of wall systems, butt joints between siding, bottom-of-wall to foundation details) that can lead to ember penetration, and potential fire in combustible interstitial spaces. Note: At butt joints of exterior siding, embers may penetrate these joints leading to ignition of exterior combustible cladding before burning into the wall cavity.

[1] Refer to the International Residential Code with local amendments for details.

The gaps created by joints also create spaces for combustible debris to accumulate (e.g., leaf litter, dust) over time, creating a fuel source within the interstitial spaces, gaps, or joints. These gaps can be in areas that are not easily accessible, which make it easier for combustible debris to accumulate unnoticed. During a wildfire event, embers can penetrate the gaps, readily igniting any combustible debris that may have accumulated. This could lead to ignition of the exterior cladding (where combustible) before burning into the interior wall cavity. Note: Even in joints or gaps where combustible debris does not readily accumulate (e.g., vertical gaps/joints), embers can still become lodged in the gaps and provide a potential source of ignition where combustible cladding or other combustible construction materials are present.

Similarly, gaps in the exterior envelope of various roof components and details (e.g., edge of roof, around fire-rated or protected vents, open eave rafter, or joist blocking details) can lead to embers penetrating combustible attic spaces (see Figure 2). Attics spaces can typically contain large amounts of combustible surfaces and stored goods, accumulated dust and debris, and other materials that can readily ignite from embers if they penetrate gaps, joints, or interfaces at the roof-attic envelope. In addition, attics in residential homes do not typically contain fire detection or suppression systems even if the home is provided with a residential sprinkler system. In the event an interior building fire ignites in the attic space due to ember intrusion, the fire will typically go unnoticed and potentially lead to total building loss.

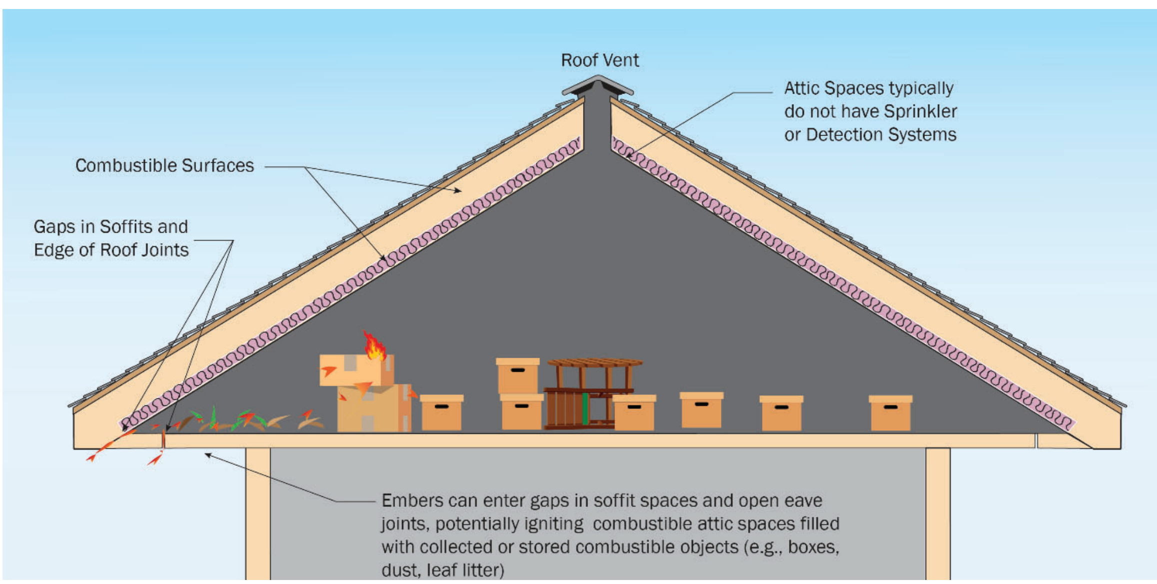

Figure 2. Example of gaps in open eaves, soffit spaces and edge of roof construction leading to ember penetration and potential ignition of various combustible surfaces, collected materials or storage goods common in attic spaces.

3.2. Combustible Debris and Ember Accumulation at Joints and Interfaces

Certain types of joints and interfaces (e.g., door-to-wall, window-to-wall, wall-to-wall, roof-to-roof joints), in particular combustible or non-fire rated joints, create areas where vegetative debris and embers can accumulate (see Figure 3) potentially leading to ignition of surrounding combustible building components. Door-to-wall and window-to-wall joints are often comprised of combustible materials where debris and embers can collect. In the event embers collect or get lodged at these joints (whether horizontal or vertical joints) ignition of vegetative debris or surrounding combustible trim, cladding or other construction materials is possible, and can eventually lead to ignition of interior wall cavities. For roof-to-roof joints, where the roof system is not fire-rated or Class A (such as for wood shingle roofs), debris and ember accumulation can lead to ignition of the roof covering itself and potentially any combustible underlayment, which may eventually lead to fire penetrating into the roof or attic space.

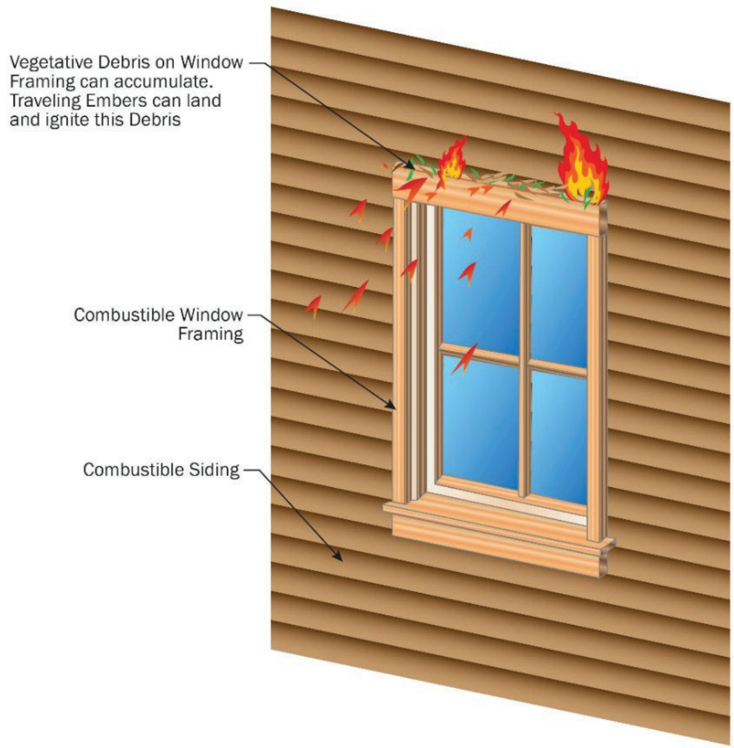

Figure 3. Vegetative debris (e.g., pine needles) and embers can accumulate at window-to-wall joints, as well as other joints throughout the exterior envelope of a home.

3.3. Combustible Debris and Ember Accumulation Adjacent to Roof-to-Wall Siding Interfaces

Various roof-to-wall joints and interfaces in the roof envelope oftentimes create areas where vegetative debris and embers accumulate creating major sources of ignition vulnerability (see Figure 4). Most roof joints and interfaces proximate to dormers and other wall systems (at roof level) accumulate vegetative debris throughout the year (see Figure 3). During a fire event, embers will also accumulate in these locations oftentimes leading to ignition of the vegetative debris and potential ignition of adjacent combustible dormer or wall siding. As shown in Figure 4, both images depict a Class A roof comprised of fire rated asphalt composition shingles, where vegetative debris has collected in close proximity to a non-fire rated dormer or wall system. In a fire event, embers can readily ignite the debris, and while unlikely lead to breach of the fire rated roof system, will result in a flaming exposure to the adjacent non-fire rated siding, potentially leading to ignition of not only the cladding but also the interior wall assembly.

Figure 4. Vegetative debris (e.g., pine needles) and embers can accumulate at roof valleys (left, Source: NFPA®) and at the base of the wall on the roof of this split-level house (right, Source: Stephen Quarles).

3.4. Lack of Fire Test Standards for Joint Systems exposed to Wildfires

Currently, there are no standardized fire tests for joint systems or interfaces of exterior building components, assemblies or "systems" exposed to a "standard wildfire" exposure. Existing fire test standards for joint systems found in building and fire codes are limited to ASTM E119 (Standard Test Methods for Fire Tests of Building Construction and Materials) exposure conditions, which is characteristic of interior building fires primarily comprised of cellulosic materials. While the ASTM E119 standard fire exposure is considered severe (i.e., reaching 1000°Fahrenheit in 5 minutes, 1700° Fahrenheit in 1 hour and so on), it does not consider the direct effects of embers on performance of tested components, assemblies, or systems. Note: Some performance criteria in ASTM E119 permit small fissures and gaps in wall and floor assemblies provided they do not result in ignition of a cotton pad on the unexposed (non-fire) side of the testing apparatus. The cotton pad test was designed for assessing small, intermittent flames, which may not be equivalent to the fire-flow mechanisms that embers can introduce when penetrating membranes.

3.5. Lack of Wildfire-Resistive Joint Systems Products

Several catalogs (e.g., Underwriters Laboratory, Gypsum Association) of "listed" fire resistive joint systems, products, and fire-rated assemblies are available for various interior building components, systems, and assemblies. These catalogs provide homeowners, builders, building officials, and design professionals with options for achieving fire resistive construction. No equivalent set of catalogs at the national level exist for exterior building components and associated joints, detailing or interfaces exposed to wildfires in combination with weathering pre-tests (Note: California has state-approved WUI products, but there are limited joint and other interface detailing products specific to WUI). This limits the ability for design professionals, contractors, and homeowners to select and properly install building components, products, and systems that can reliably achieve fire resistance to wildfire exposures.

3.6. Limited access for Joint Inspections and Maintenance

Joint systems and construction details at component interfaces throughout the exterior envelope of a building are often difficult to physically access (e.g., roof joint systems) and visually inspect, particularly when systems or components are hidden behind exterior coverings, weather systems, and other architectural features. This can make enforcement, inspections, and long-term maintenance of joint systems and interface detailing particularly challenging. These instances, where joints and interfaces are inaccessible and difficult to maintain on an annual basis to reduce accumulation of vegetative debris or prevent ember accumulation, are some of the critical areas of a building envelop where non-combustible or fire-resistant surfaces and joints systems should be prioritized.

Definitions

- **Fire-resistance rating** –The period of time a building element, component or assembly maintains the ability to confine a fire, continues to perform a given structural function, or both, as determined by fire tests or methods based on fire tests.
- **Fire-resistant joint system** – An assemblage of specific materials or products that are designed, tested and fire-resistance rated in accordance with a standard fire test to resist for a prescribed period of time through joints made in or between fire-resistance rated assemblies (IBC).
- **Fire-resistive construction** – Fire-resistive construction is construction that has been designed and tested to withstand a certain amount of fire exposure. Fire-resistive construction is typically given a fire-resistance rating as determined by fire tests or methods based on fire tests.
- **Firestopping Product** – Firestopping is a component of a firestop system, which is designed to seal an opening into or through a fire-resistance rated assembly. These products help to reduce the amount of smoke and embers that could potentially penetrate walls (Knott, 2019).
- **Membrane-penetration firestop system** – An assemblage consisting of a fire-resistance-rated floor-ceiling, roof-ceiling or wall assembly, one or more penetrating items installed into or passing through the breach in one side of the assembly and the materials or devices, or both, installed to resist the spread of fire into the assembly for a prescribed period of time.
- **Through-penetration firestop system** – An assemblage consisting of a fire-resistance-rated floor, floor-ceiling, or wall assembly, one or more penetrating items passing through the breaches in both sides of the assembly and the materials or devices, or both, installed to resist the spread of fire through the assembly for a prescribed period of time.

4. Detailing at Joints and Interfaces

While wildfire-specific fire test standards and associated "listed" WUI building products are still limited, there are actions that still can be taken based on best practices to increase wildfire resiliency of joints and other building component interfaces throughout the exterior envelope of a building. The guidance below targets new construction and retrofits to existing buildings, detailing various actions for key building components that are commonly found in residential construction. See Figure 5 for an overview of building envelope locations.

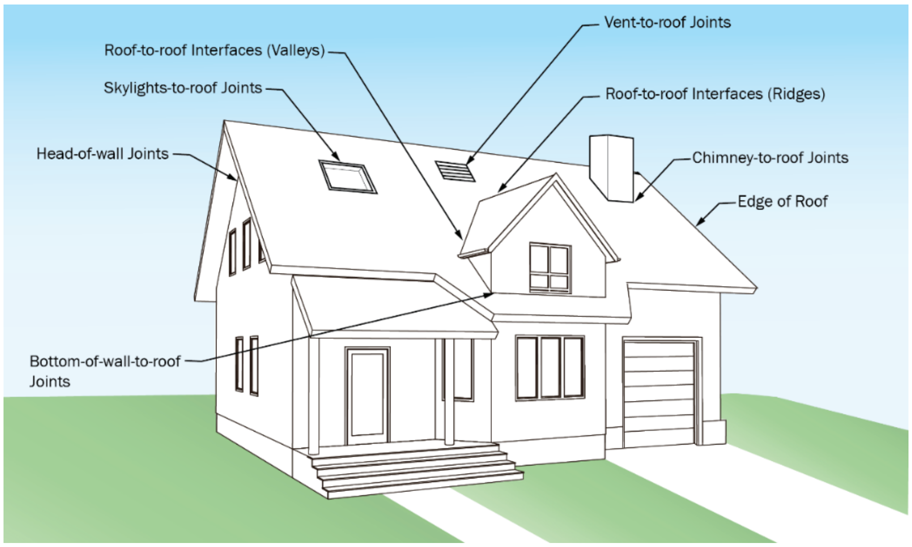

Figure 5. Various locations of vulnerable joints, penetrations, and interfaces throughout the exterior envelope of a residential structure to wildfires.

4.1. Roof Joints and Detailing Considerations

4.1.1. ROOF JOINTS AT THROUGH PENETRATIONS – CHIMNEYS, SKYLIGHTS, ROOF VENTS

Roof assemblies for residential buildings incorporate a range of construction features that introduce through-membrane penetrations of the entire roof assembly (e.g., chimneys, skylights, vents). The following are recommended details for improving the resiliency at the joints of through-membrane penetrations of roof systems.

Where chimneys are constructed with an exterior chase comprised of combustible siding or other combustible materials (see Figure 6), install noncombustible metal flashing and counter flashing that protects the roof-to-chimney chase joint for at least 6 vertical inches above the roof surface. The metal flashing should be lapped above the roof covering material extending vertically up along the exterior side of the chimney chase before being "let in" behind the chase siding at the lap joint with combustible siding kept 4–6 inches above the roof surface (see Figure 6). Corrosion-resistant metal flashing is one material that might be used to accomplish this. Alternatively, "local" replacement of siding (i.e., chase area only) with non-combustible materials would also be acceptable.

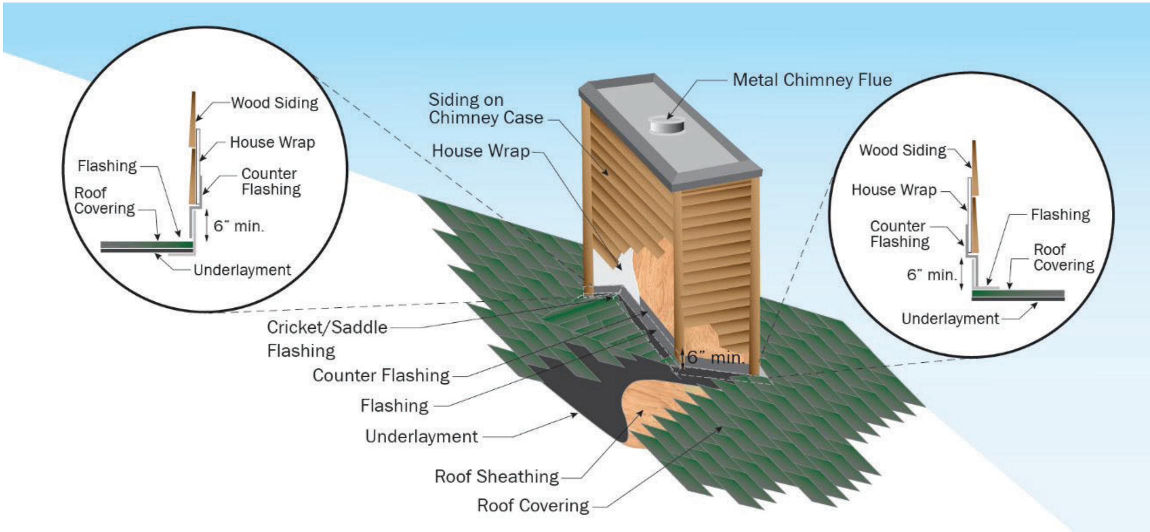

Figure 6. Example of fire-resistant caulking and non-combustible underlayment at the chimney-to-roof joint.

Where metal valley flashing is used for chimney chases, incorporate an underlying mineral surfaced cap sheet. Be sure to consult with the roofing manufacturer to confirm that the installation of the cap sheet does not void the roofing manufacturer's warranty.

For other types of roof penetrations (e.g., vents, skylights), ensure the joint at the penetration and the roof assembly is well sealed to minimize the entry of embers (see Figure 7 for example of skylight-to-roof interface). Roof penetrations should be sealed per manufacturer's instructions, where available. Where no instructions are available, this can be achieved with fire-resistant caulk, noncombustible mortar, compressed mineral wool, fire-rated expanding foam, or metal flashing. For enhanced protection, use a rated exterior penetration firestop system. Special considerations should be taken when considering the installation of a rated exterior penetration firestop system, such as ensuring the system installed is listed for use in the appropriate type of roof system.

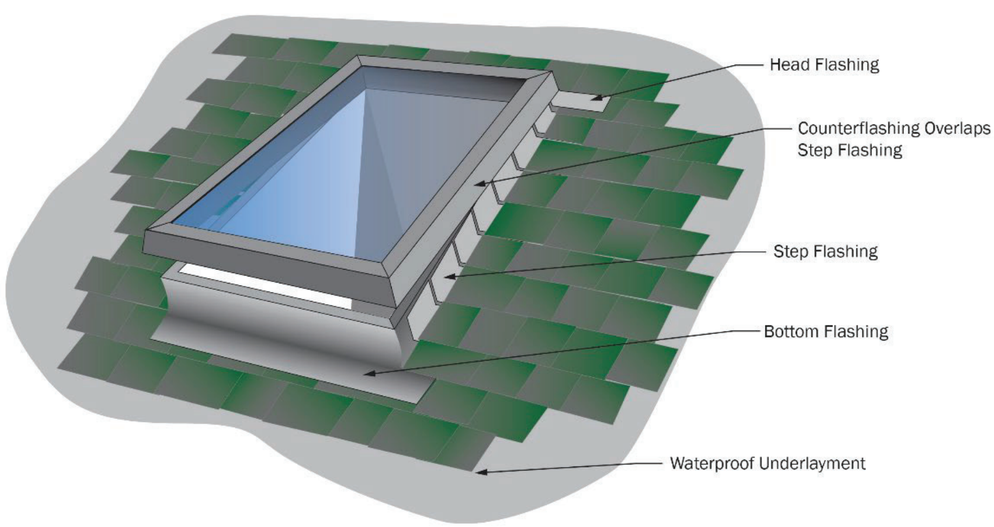

Figure 7. Example of flashing details for skylight-to-roof joint.

For retrofits, replace existing vulnerable roof penetrations and surrounding shingles. When replacing penetrations, follow manufacturer's recommendations for sealing the gaps that might be created by the installation (see Figure 8).

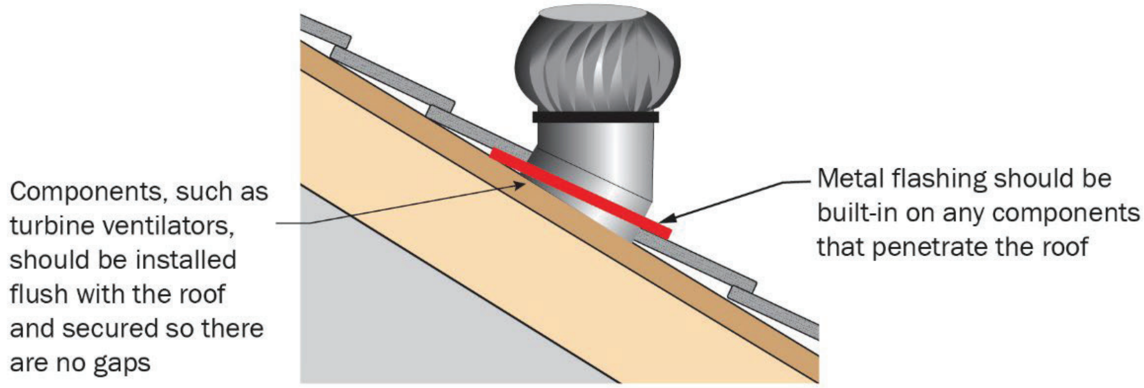

Figure 8. Example of a through penetration detail at the roof.

4.1.2. ROOF CONSTRUCTION DETAILING – UNDERLAYMENT AND DECKING DETAILING

As embers can be blown under steep-slope roof coverings, an enhanced underlayment such as a mineral-surface cap sheet rated for use in a Class A rated assembly should be installed. For metal shingles or panels, the metal should not bear directly on the cap sheet due to corrosion concerns (SFPE WUI Handbook, 2023).

Similarly, where roofing material is installed over furring strips to create an airspace under the roof covering above a combustible deck, consider installing a cap sheet complying with ASTM D3909 under the entire roof deck. See NFPA 1140, 2022 Edition, Section 25.3.5 for more information, plus local code criteria for roof system requirements.

Most homes have roof decks comprised of wood (e.g., plywood or oriented strand board). For more protection, a layer of fiberglass gypsum panelized product between the decking and the roof covering should be installed. Where fiberglass gypsum board is installed, ensure that the joints between the gypsum and wood sheathing panels are staggered (UCANR, 2023), as shown in Figure 9. This strategy is particularly useful where roof coverings have a gap between the covering and the roof deck (i.e., barrel-style and some metal coverings).

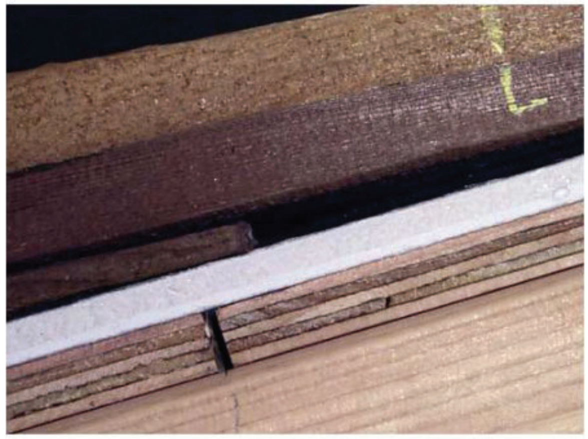

Figure 9. Vertical cross-section through Class A rated roof assembly consisting of exterior-rated, fire-retardant treated wood shakes and underlying fiberglass gypsum board (in white). The joints between the wood sheathing (below) and gypsum are staggered. (Credit: Stephen Quarles)

As most low-slope roofs will have a layer of insulation, the insulation can be comprised of a range of materials anywhere from highly combustible to noncombustible. Noncombustible insulation provides the most fire-resistant properties. However, polyisocyanurate roof insulation could be used provided a 5/8-inch layer of gypsum roof board per ASTM C1177 is installed immediately below the roof covering. The strategy listed in the above paragraph is also applicable (FEMA Home Builder's Guide to Construction in Wildfire Zones, 2008).

4.1.3. ROOF-TO-ROOF INTERFACES – RIDGES

Roof ridges can oftentimes have roof caps that create additional surfaces and gaps leading to ember accumulation and/or entrapment of vegetative debris, which can ignite during a wildfire. In addition, roof ridge edges can also be susceptible to having large gaps that are vulnerable to the collection of vegetative debris and ember intrusion. As these areas are difficult for homeowners to keep clear of debris or inspect annually, various wildfire detailings are recommended to reduce wildfire vulnerabilities. For roof caps that also serve as attic ventilation (e.g., underlying ridge vents), ensure that these ridge vents are provided with ember and flame-resistant vent protection. Where roof caps do not serve as attic ventilation, ensure that any gaps are sealed. For roof ridge edges or terminations, ensure any gaps are filled with a noncombustible material (see Figure 10). Typically, a mortar mix is easier to use in these locations.

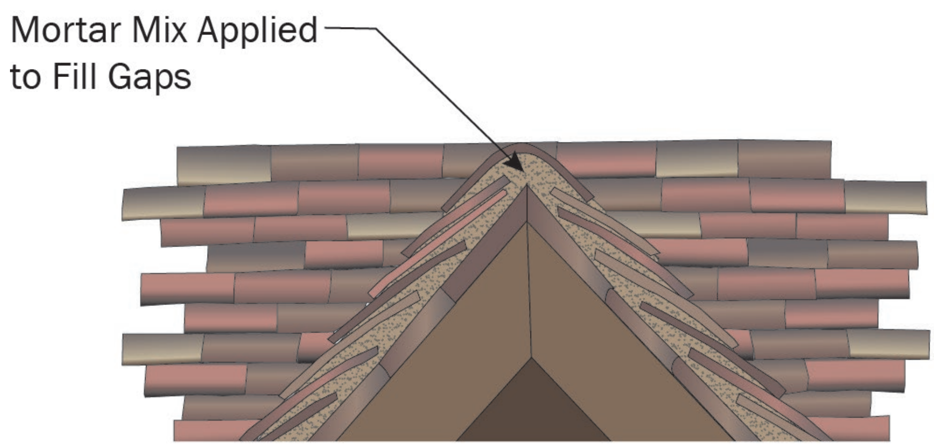

Figure 10. Example of mortar mix used to seal gaps at roof ridge edges.

4.1.4. ROOF-TO-ROOF INTERFACES – VALLEYS

Provide roof valley joints with metal valley flashing with an underlying mineral surfaced cap sheet incorporated into the assembly. See manufacturer's guidelines for properly installing the underlayment (see Figure 11 for an example).

Where Class A asphalt composition shingles are used, use of metal flashing can be avoided by interweaving the shingles. One method that can be used to accomplish this is to install a cut valley.

Limit the number of complex roof designs and elevation changes.

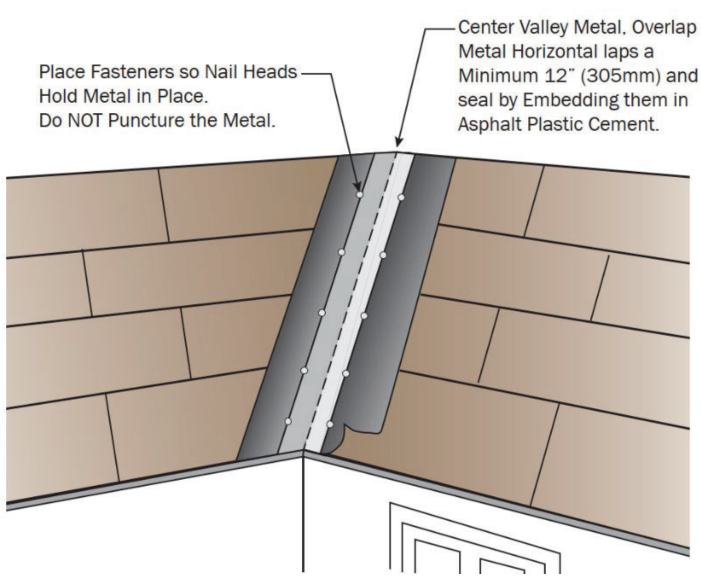

Figure 11. Example showing roof valley flashing installation.

4.1.5. EDGE-OF-ROOF JOINTS

Plug gaps at the roof edge. The methods used to do this are similar to strategies used for roof ridges (see above). For roof coverings that create gaps at open ends of tiles, provide bird-stop or mortar to plug the gap. For other types of roof edges, provide metal flashing at the roof edge. A cap sheet should be installed under the metal flashing.

Install a metal drip edge or flashing to protect the roof edge (particularly at all rake and eave edges) to minimize ember entry to the attic via materials burning in a rain gutter or wind-blown embers impinging on the area at the edge of the roof (see Figure 12).

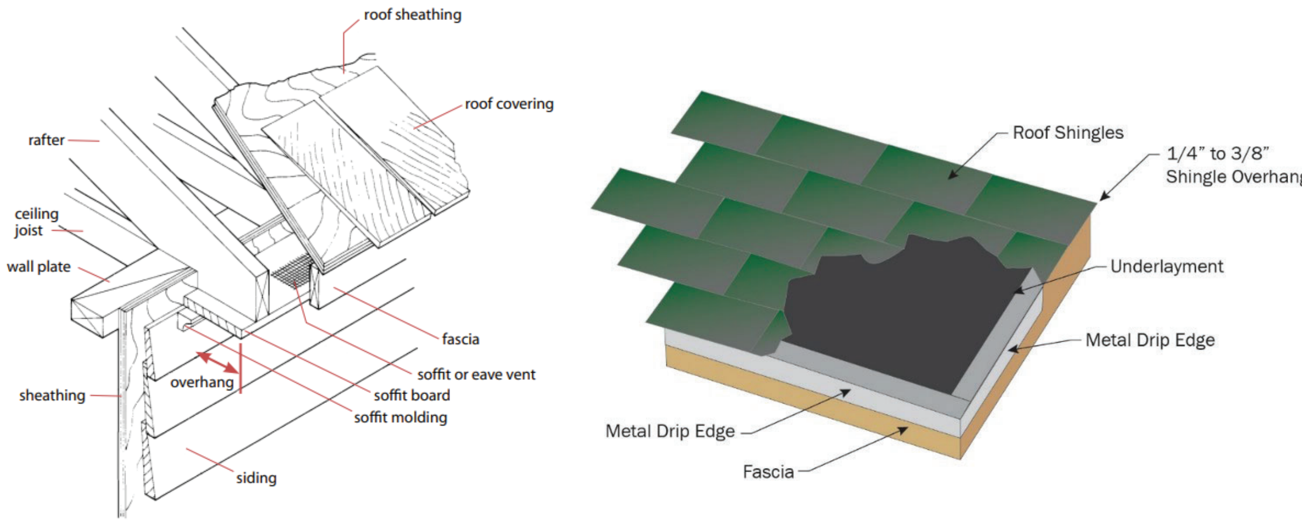

Figure 12. Schematic of the edge of roof detail (left) (adapted from Sherwood and Stroh, 1989) Use of metal drip edge to limit embers from entering gaps at the roof edge, particularly at the fascia where gutters are attached (right) (adapted from SFPE WUI Handbook, 2023).

4.1.6. HEAD-OF-WALL JOINTS

Provide fire-resistant caulking at any gaps at the joint between the head-of-wall and roof or ceiling. Use noncombustible construction where possible (in both new construction & retrofits). Protect exterior walls with 2-inch nominal solid blocking between exposed rafters at all roof overhangs, under exterior wall coverings on sides exposed to native vegetation (see Figure 13). For more information, see NFPA 1140, 2022 Edition, Section 25.6.2.

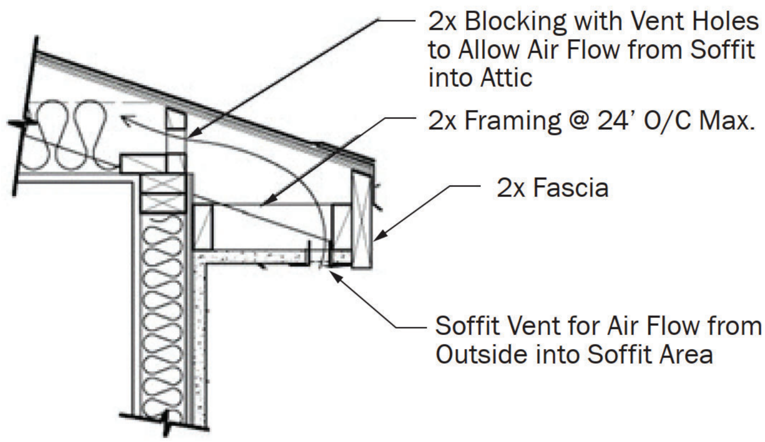

Figure 13. Diagram of construction details that allow air to flow from the soffit into the attic (adapted from UCANR, 2010).

4.1.7. BOTTOM-OF-WALL-TO-ROOF-JOINTS

Provide fire-resistant caulking at any gaps at the joint between the bottom-of-wall-to roof joint. Where the wall siding is comprised of combustible materials install noncombustible metal flashing and counter flashing that protects the roof-to-wall joint for at least 6 vertical inches above the roof surface. The metal flashing should be lapped above the roof covering material extending vertically up along the exterior side of the wall siding before being "let in" behind the siding at the lap joint, with combustible siding kept 4–6 inches above the roof surface (see Figure 14). Corrosion-resistant metal flashing is one material that might be used to accomplish this. Alternatively, "local" replacement of siding with non-combustible materials would also be acceptable.

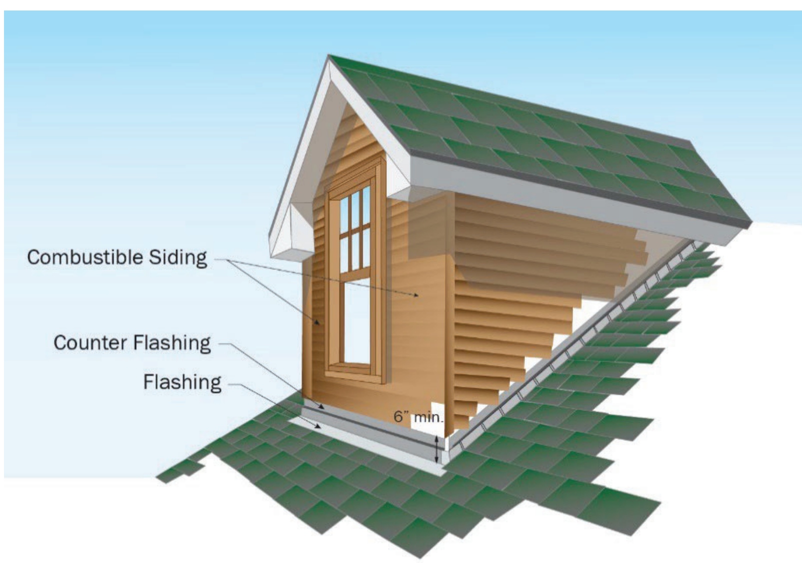

Figure 14. Example of metal flashing installation at bottom-of-wall-to-roof joint.

4.2. Wall Joints, Penetrations, and Detailing Considerations

The guidance below targets new construction and retrofits to existing buildings, describing various actions for wall joints, penetrations, and detailing that are commonly found in residential construction. See Figure 15 for an overview of building joint locations.

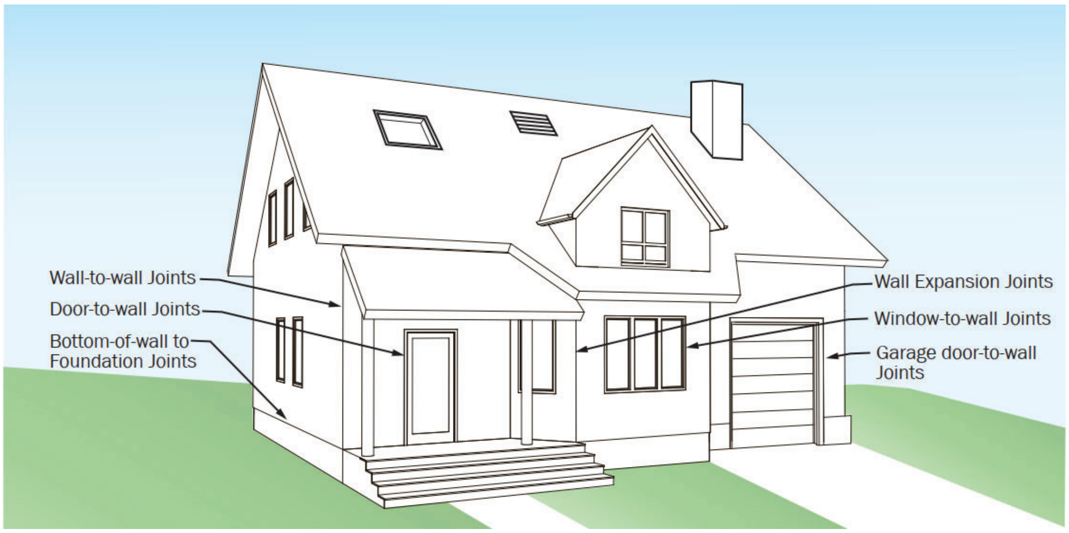

Figure 15. Various locations of vulnerable joints, penetrations, and interfaces throughout the interior of a residential structure to wildfires.

4.2.1. WALL-TO-WALL JOINTS

Seal gaps in wall joints with fire-resistant firestopping products. For wood stud construction with composite panel siding (e.g., fiber cement siding), consider incorporating metal flashing with an underlying mineral surfaced cap sheet into the assembly. (Refer to Figure 7 and Figure 14 for metal flashing installation examples). For concrete-to-concrete wall construction, consider installing recessed polyethylene backer rods compressed into the joint with fire sealant flush to exterior wall surfaces (see Figure 16).

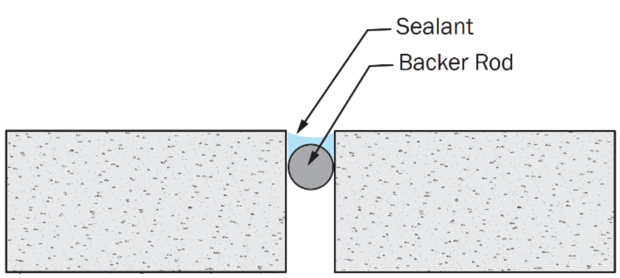

Figure 16. Plan view cross-section of exterior wall joints, where a backer rod is placed to fill joint (adapted from Armacell, 2017).

4.2.2. WINDOW-TO-WALL JOINTS

Ensure the space between the window and the framing is well sealed. Where possible, incorporate the use of rigid cap flashing at the bottom-of-wall-top-of-window joint between the underlayment and wall siding (see Figure 17). Replace vinyl window frames with frames comprised of noncombustible materials (e.g., metal clad wood, aluminum).

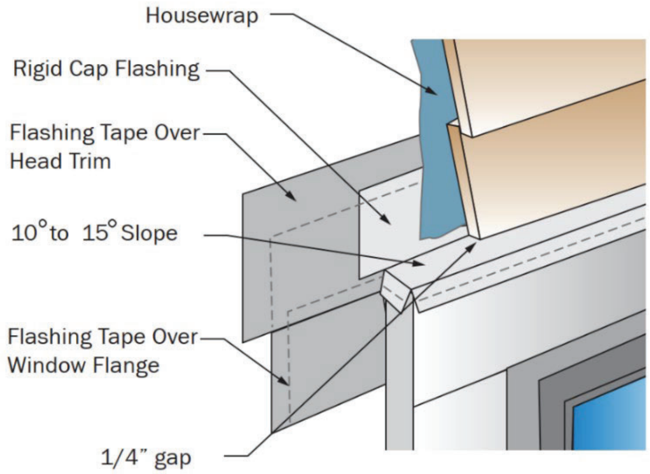

Figure 17. Example of rigid cap flashing installation at window-to-wall joints (adapted from Fine Homebuilding).

4.2.3. DOOR-TO-WALL JOINTS

Ensure the space between the door and the framing is well sealed. Where possible, incorporate the use of rigid cap flashing at the wall-to-door interface, between the underlayment and wall siding (see Figure 18).

Figure 18. Examples of door-to-wall joints. Where openings in the plane of a door exist, such as dog doors or windows, the gaps around the openings should be filled caulking, mineral wool, or similar non-combustible material. In addition, the opening itself should be protected from ember intrusion that can be deployed during a wildfire incident (e.g., provide a noncombustible shutter).

4.2.4. GARAGE-DOOR-TO-WALL JOINTS

Where gaps are present, utilize appropriate weatherstripping, firestopping and/or penetration materials/products as needed. Figure 18 above demonstrates some gaps that may be appropriately filled with firestopping materials.

Make sure the space between the garage door, framing, and concrete slab is well sealed to minimize the entry of embers. Ensure weather sealing is provided and in good condition. Where possible, incorporate the use of rigid cap flashing around the joint of the wall-to-garage door frame interface, between the underlayment and wall siding (see Figure 19).

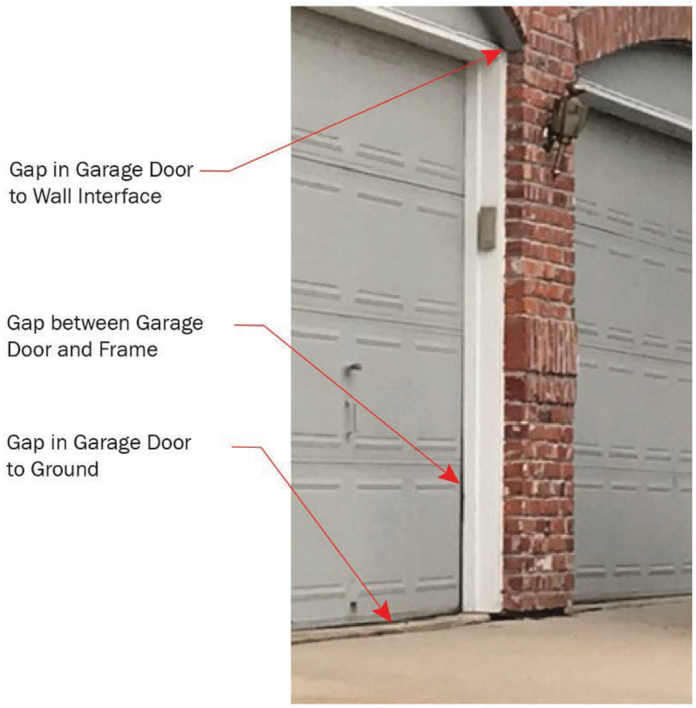

Figure 19. Example of gaps at garage-door-to-wall joint.

4.2.5. WALL EXPANSION JOINTS.

Where possible, use or replace existing expansion joints with noncombustible materials.

4.2.6. BOTTOM-OF-WALL-TO-FOUNDATION JOINTS

Block gaps in siding with firestopping materials (e.g., mineral wool, fire caulking, and fire-rated sealants). Where possible, install a minimum of 6-inch noncombustible vertical separation where horizontal surfaces meet the wall. Please note that this 6-inch minimum assumes very minimal combustibles in the near-home zone (0–5 feet), which should be kept free of combustibles. This could be a separation created by noncombustible materials, or metal flashing, as demonstrated in Figure 20.

Figure 20. Examples of noncombustible separation at bottom-of-wall-to-foundation joints (Left: noncombustible separation, right: metal flashing).

4.3. Floor-to-Wall Joints and Detailing Considerations

Balconies, decks, and porches interface with the exterior wall envelope. At these interfaces, embers can accumulate, leaving them susceptible to ignition. Some measures can be taken to protect these joints:

- Install metal flashing on ledger boards that are attached without gaps (see Figure 21).
- Seal gaps with appropriate firestopping and fire caulking.

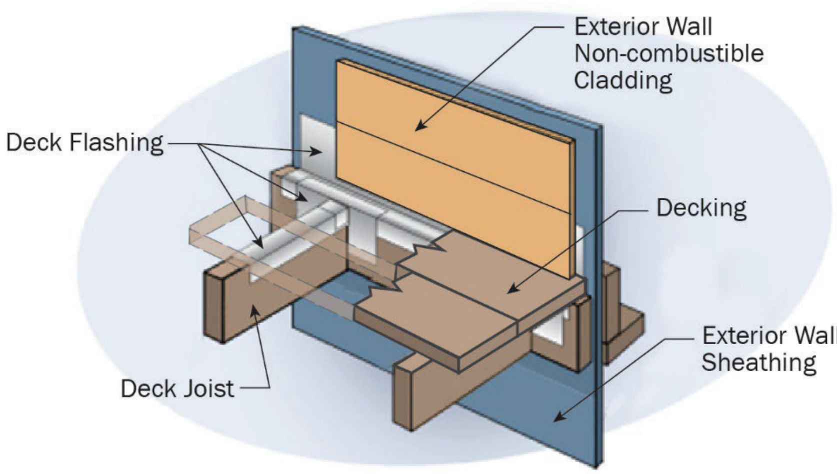

Figure 21. Example installation of metal flashing on ledger boards.

5. Fire-Listed Products and Assemblies

While most exterior building envelope components and associated joints, interfaces and penetrations do not have nationally established WUI fire test standards or product lists, the California Office of the State Fire Marshal (CA SFM) currently provides a list of WUI products that satisfy CA SFM WUI codes and test standards. Many SFM Test Standards have been converted to

ASTM (national) standards, however, are not broadly referenced by most building and fire codes outside of California. While these products meet state-specific requirements, they may be a good starting point for jurisdictions where WUI fire test standards are not adopted[2].

The contractor is also advised to consult other recognized (approved) fire-testing laboratories (e.g., UL Solutions, Intertek, Southwest Research Institute, FM Global) or nationally recognized wildfire/fire research entities (e.g., IBHS, NIST, ATF) as WUI fire test standards, custom product testing, and the latest research in building fire safety are constantly evolving. Each of the fire testing agencies keep databases of products that have been listed by their agency and can be accessed online via their respective websites. In addition, each of the national fire research organizations have dedicated websites for the latest wildfire building research and testing. Refer to the ‘Resources and Useful Links’ section for details.

6. Fire Testing for Wildfire Conditions

Where “listed” wildfire joint systems, products, or assemblies are not available or do not satisfy the performance goals of the project, custom fire testing may be a reliable option (albeit expensive). Prior to conducting any custom fire tests, the contractor or builder should consult with a wildfire behavior specialist, fire engineer, or other fire safety design professional (e.g., architect) to evaluate site-specific wildfire hazards and risks, and project specific building construction detailing to understand the specific fire safety needs and performance objectives. A custom fire test specification will likely need to be developed in collaboration with the local fire department and accredited fire testing laboratory to identify a “standard” wildfire exposure, need for pre-fire weathering tests, acceptance criteria, and reporting requirements. Development of a “wildfire tested” joint system or product should also include installation, inspection, and long-term maintenance protocols.

[2] https://osfm.fire.ca.gov/divisions/fire-engineering-and-investigations/building-materials-listing/bml-search-building-materials-listing/

7. Resources and Useful Links

Full-Scale Research on Wildfire Resiliency of Joints and Building Detailing

- Insurance Institute for Business & Home Safety (IBHS) Full-Scale Fire Testing https://ibhs.org/risk-research/wildfire/
- Fire Safety Research Institute (FSRI) https://fsri.org/about
- National Institute of Standards and Testing (NIST) https://www.nist.gov/fire

Codes and Standards for Fire Resistant Joint Systems for Interior Building Fires

- International Code Council (ICC) Codes, International Building Code https://www.iccsafe.org/
- National Fire Protection Association® (NFPA) Codes and Standards, NFPA 5000 https://www.nfpa.org/

Codes and Standards for General Protection of Structures in the Wildland Urban Interface

- International Code Council (ICC) Codes, International Wildland Urban Interface Code https://www.iccsafe.org/
- National Fire Protection Association® (NFPA) Codes and Standards, NFPA 1140 https://www.nfpa.org/

Design Guidance for New and Existing Construction

- SFPE Foundation Virtual Handbook on WUI Risk Assessments https://www.sfpe.org/wuihandbook/home
- University of Nevada, Reno Wildfire Home Retrofit Guide https://extension.unr.edu/publication.aspx?PubID=3810
- Maranghides, A., et al, WUI Structure/Parcel/Community Fire Hazard Mitigation Methodology https://www.nist.gov/el/fire-research-division-73300/wildland-urban-interface-fire-73305/hazard-mitigation-methodology-1

Databases for Fire-Listed Products and Assemblies

- FM Approvals, Approval Guide https://www.approvalguide.com/
- Intertek Directory of Building Products https://bpdirectory.intertek.com/pages/DLP_Search.aspx
- UL Product iQ https://productiq.ulprospector.com/en
- CAL FIRE Building Materials Listings https://osfm.fire.ca.gov/divisions/fire-engineering-and-investigations/building-materials-listing/bml-search-building-materials-listing/

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