

Mitigation Assessment Team Report

Marshall Fire

Building Performance, Observations, Recommendations, and Technical Guidance

FEMA P-2320 / June 2023

FEMA

All photographs and figures used in this report were taken by the Mitigation Assessment Team or developed for this report unless stated otherwise.

All documents were prepared with accessibility and compliance with Section 508 of the Rehabilitation Act of 1973 in mind. For further information or clarification regarding items such as technical drawings or maps, please contact the FEMA Building Science Helpline at FEMA-BuildingScienceHelp@fema.dhs.gov or 866-927-2104.

Authors and Members of the Mitigation Assessment Team

FEMA Building Science Disaster Support Manager and MAT Lead:

Daniel Bass, RA, CFM
FEMA HQ

Task Order Manager:

Stacy Franklin Wright, AICP, PMP, CFM
Atkins

FEMA Building Science Marshall Fire MAT Points of Contact:

Christina Aronson, PE, SE
FEMA HQ

Sean McGowan, PE
FEMA Region 8

MAT Members

Stuart Adams, Stantec
Faith Berry, USFA
Julia Cuendet, Jensen Hughes
Erica Fischer, PhD, PE, Oregon State University
Brad Gillespie, Jensen Hughes
Meagan Joy, Jensen Hughes
Nicole LaRosa, USFA
Abbie Liel, PhD, PE, University of Colorado, Boulder
Laurel McGinley, PE, PMP, Dewberry
Tony Mendes, FEMA
Deborah Mills, CFM, Dewberry
Amelia Pludow, Jensen Hughes
Cameron Ramey, Stantec
Michael Riemer, PE, Atkins
Darlene Rini, PE, Jensen Hughes
John Squerciati, PE, CFM, Dewberry
Brad Wham, PhD, University of Colorado, Boulder

Internal Support

Technical Editor:
Corina Coulas, Stantec

Graphic Artist:
Susanne Dunleavy, Stantec

This page intentionally left blank

Table of Contents

This page intentionally left blank

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. 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 codes and standards, as well as design,

> 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.

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

construction, land-use planning, and defensible space practices can be improved to increase community wildfire resilience, particularly as the risk to landscape due to climate change 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 due to climate change. 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 due to climate change.

    - **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

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

within suburban communities. Mitigation strategies for this (and other future) events require a multi-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 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.

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 climate, 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 as the impacts of climate change are resulting in environmental conditions (e.g., increases in drier, warmer weather, longer droughts, insect infestation) that increase the likelihood of wildfire ignitions (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

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

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.

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

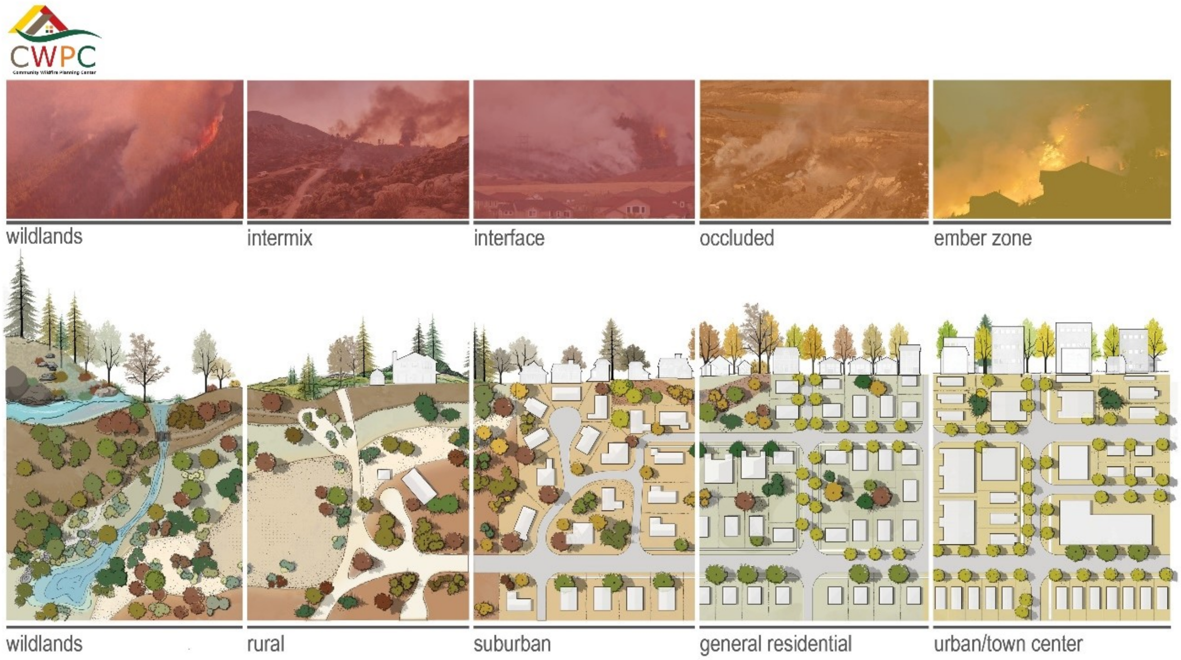


Figure 1. Communicating a continuum of environmental conditions will allow planners, engineers, community officials, and residents to better understand their wildfire risk (Image courtesy of Community Wildfire Planning Center).

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

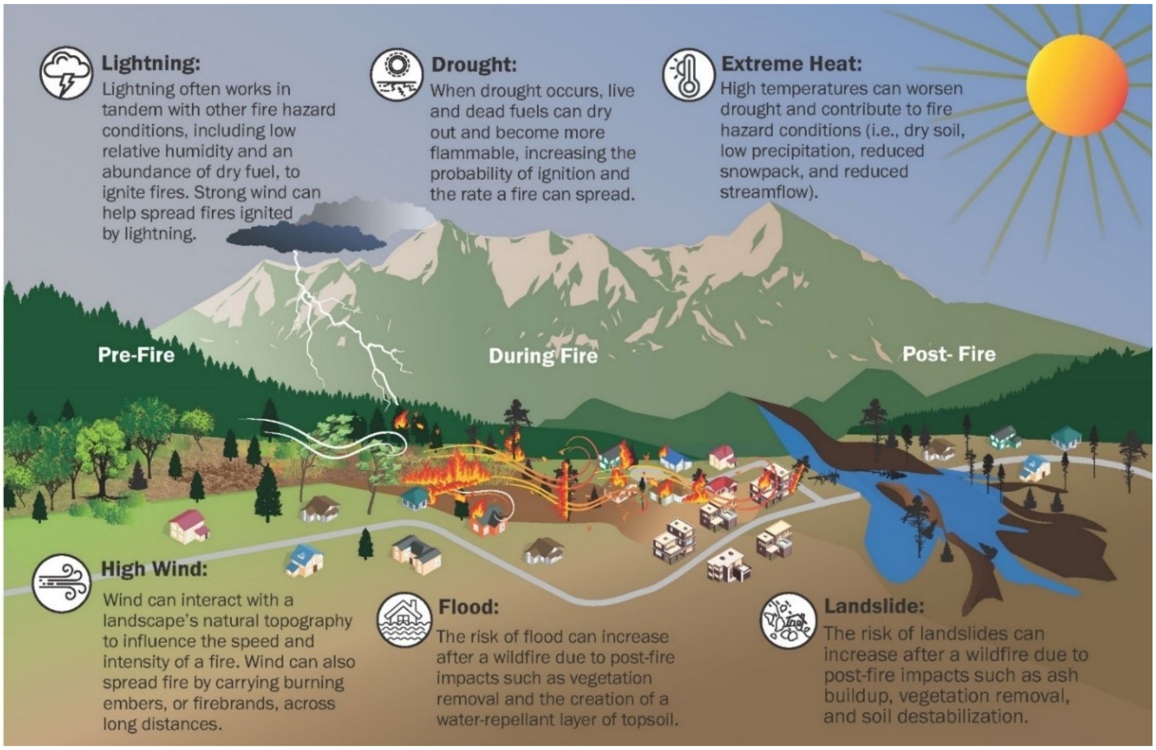


Figure 2. Multiple hazards can contribute to or result from wildfires.

Wildfire mitigation strategies are evolving to keep pace with a changing climate 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).

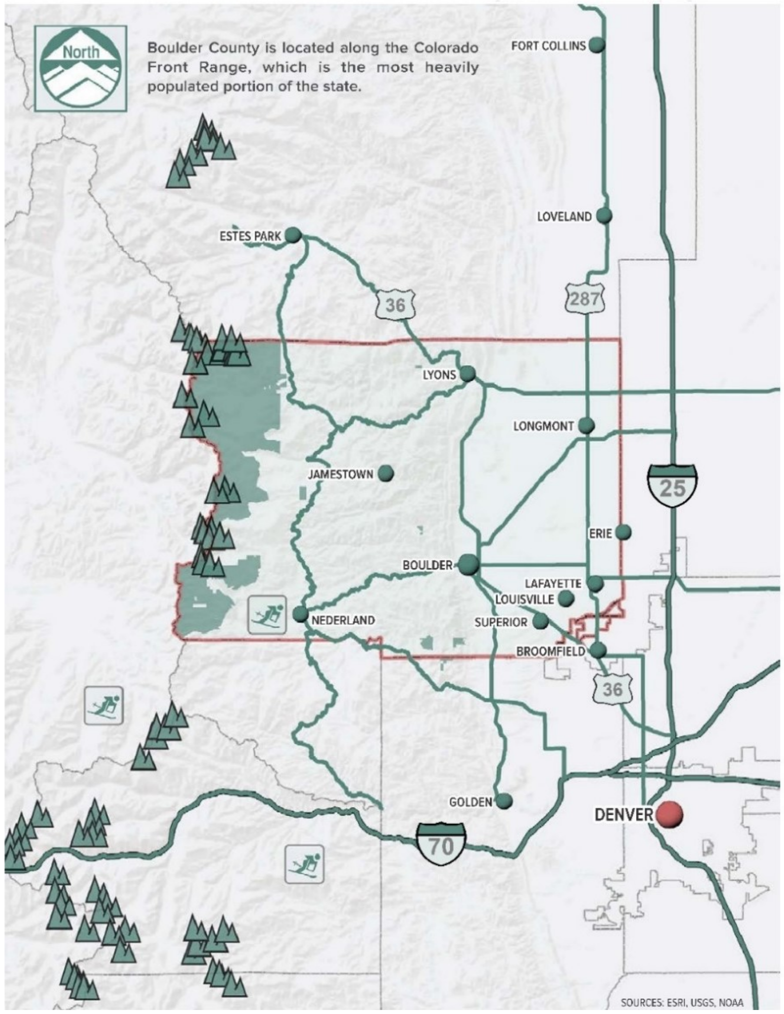


Figure 3. Boulder County Location Map (Boulder County Comprehensive Plan, 2020).

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

Event Date	Event Name	Cause	Weather Conditions	Foothills or Flatlands	Number of Acres Burned	Impacts
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.

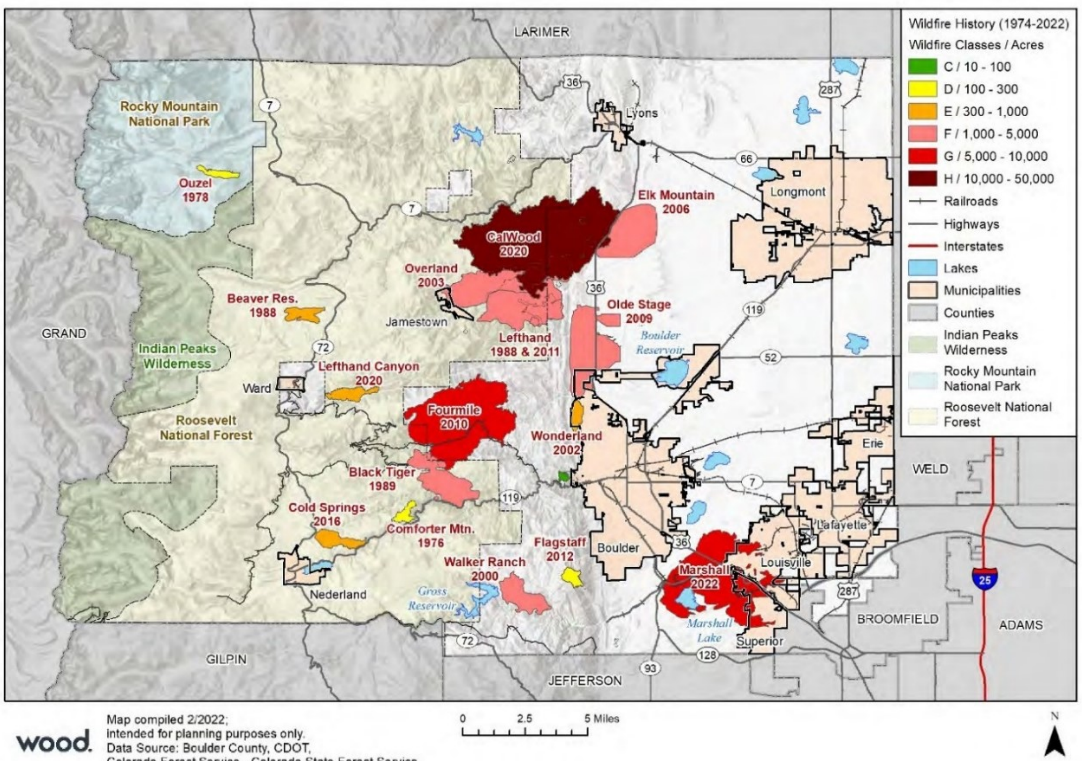


Figure 4. Historical Wildfires in Boulder County (Boulder County Hazard Mitigation Plan, 2022).

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 climate change, 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.

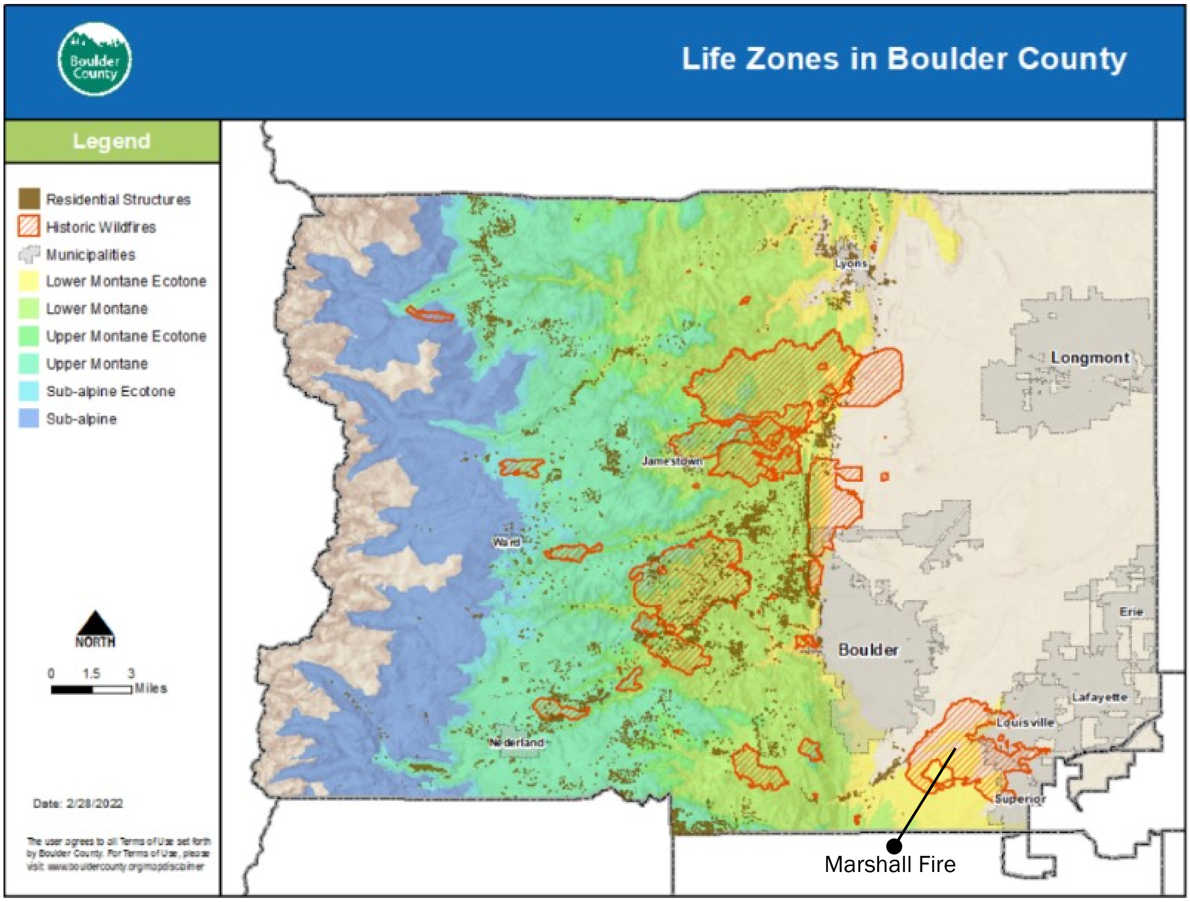


Figure 5. Life zones across Boulder County with past fire history overlay (Boulder County).

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.

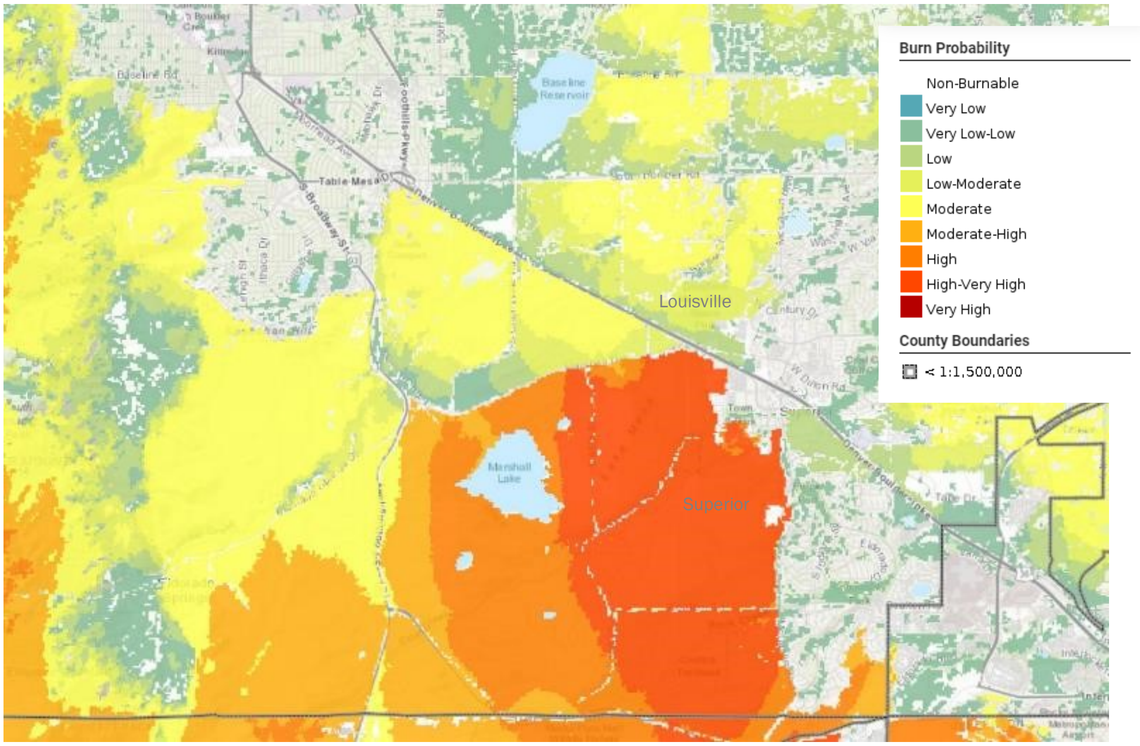


Figure 7. Relative burn probability across Boulder County (Colorado Forest Atlas).

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

[7] https://climate.colostate.edu/normals_stn_select.html

locally, with an average dry bulb temperature of 72°Farenheit. However, temperatures in excess of 85°Farenheit can occur from June through September.[8]

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."

[8] https://www.weather.gov/wrh/climate?wfo=bou

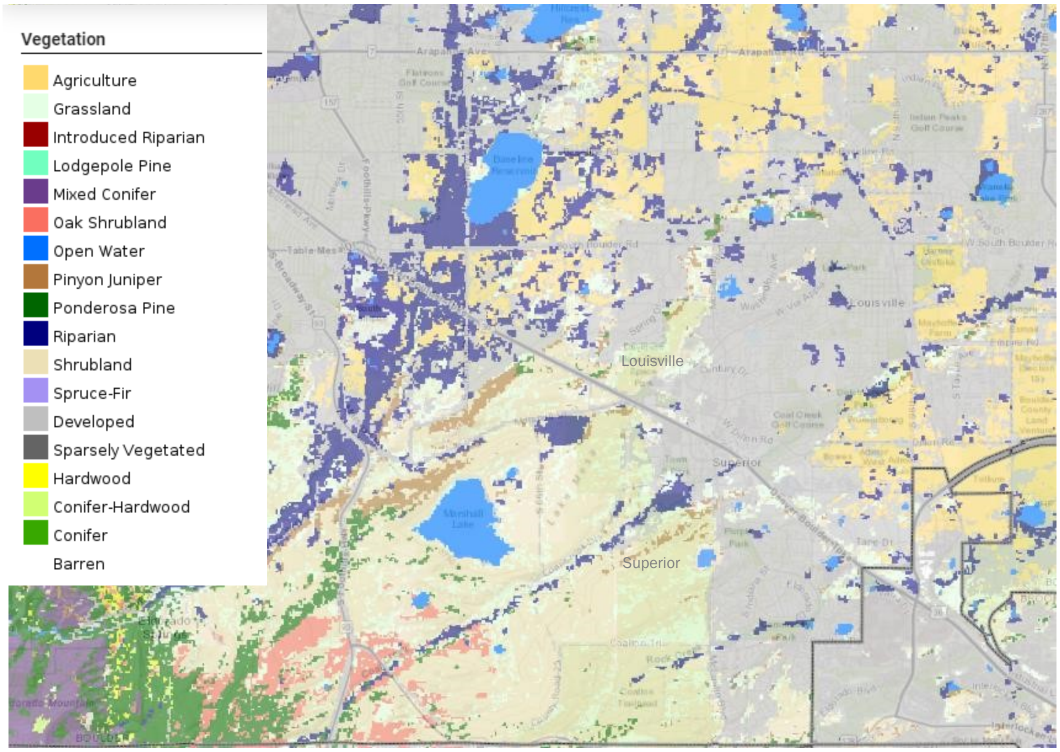


Figure 8. Vegetation map in and around the impacted communities of the Marshall Fire (Colorado Forest Atlas).

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).

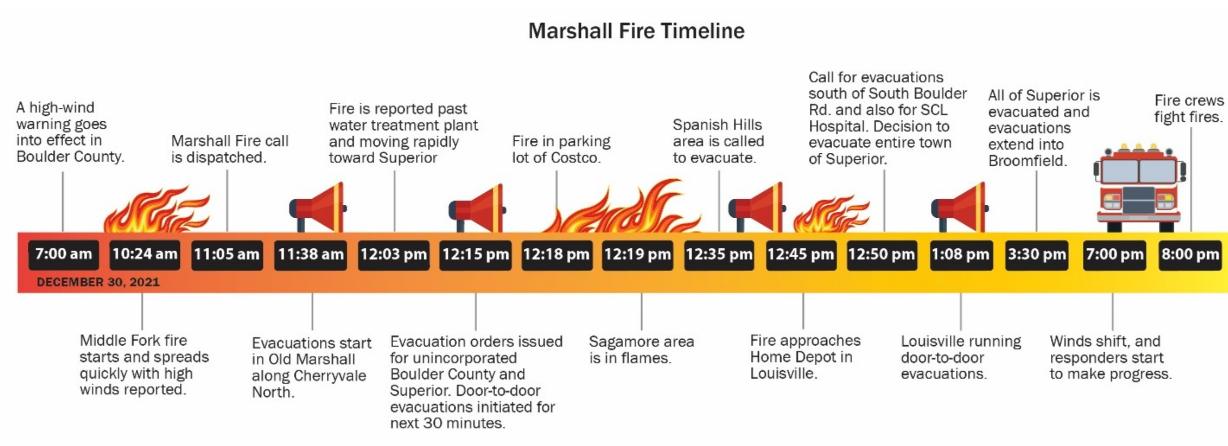


Figure 9. Marshall Fire Timeline Overview.

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.

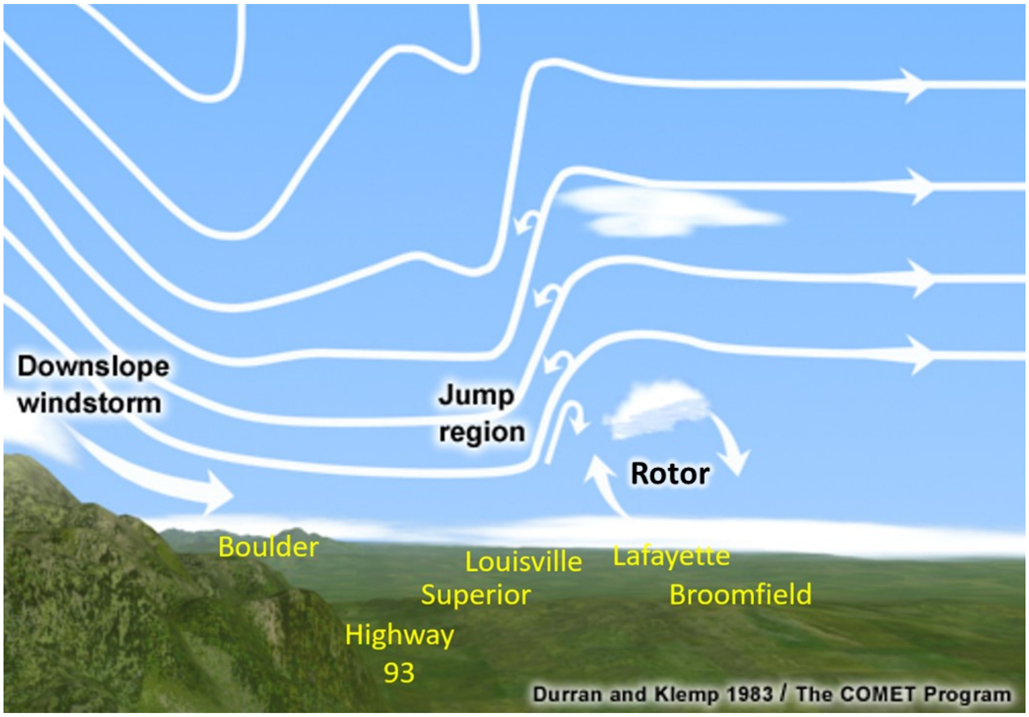


Figure 10. Conceptual model of a mountain wave (NWS, 2022).

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.

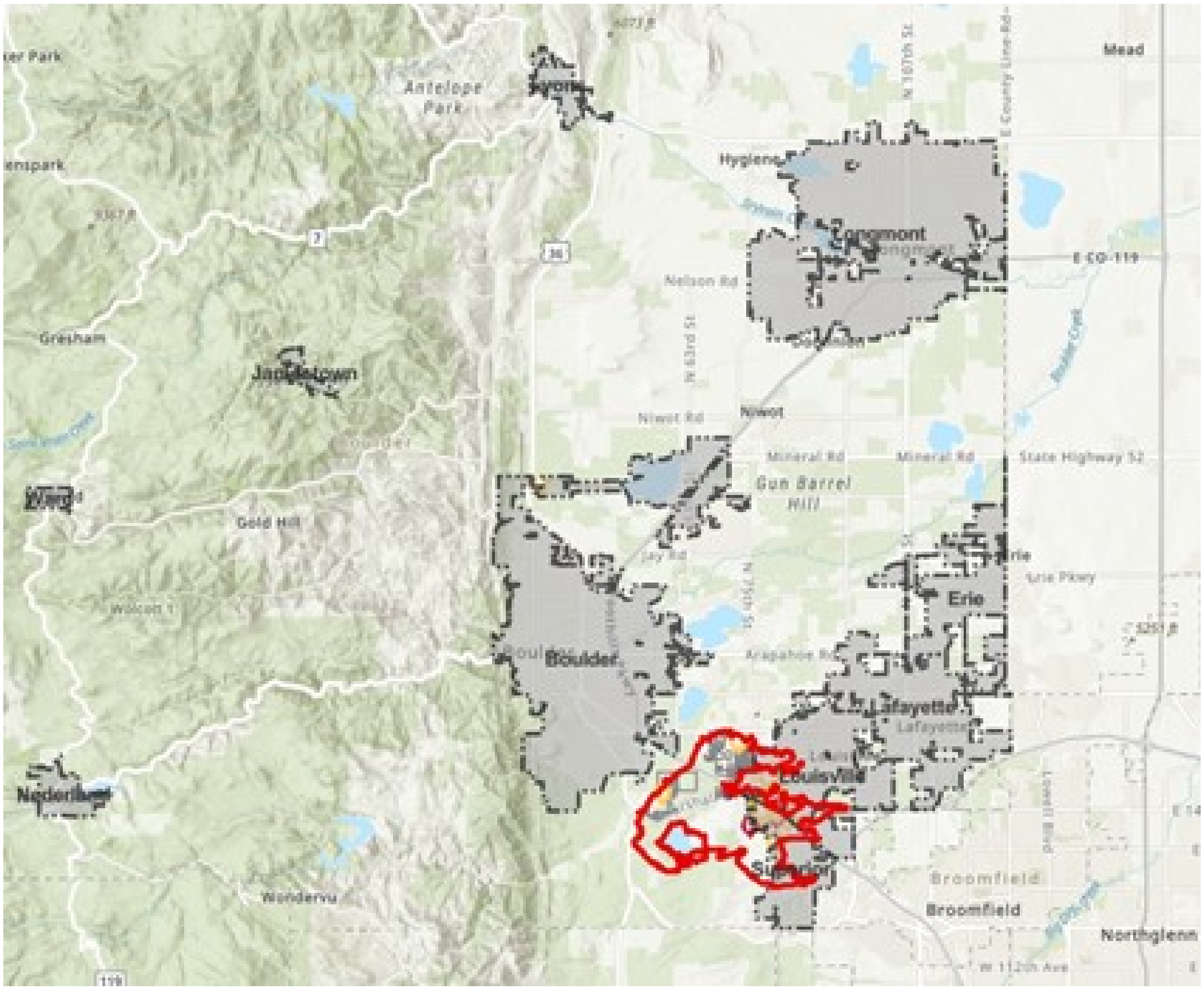


Figure 11. Marshall Fire Extent in Boulder County (Boulder County, 2023).

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).

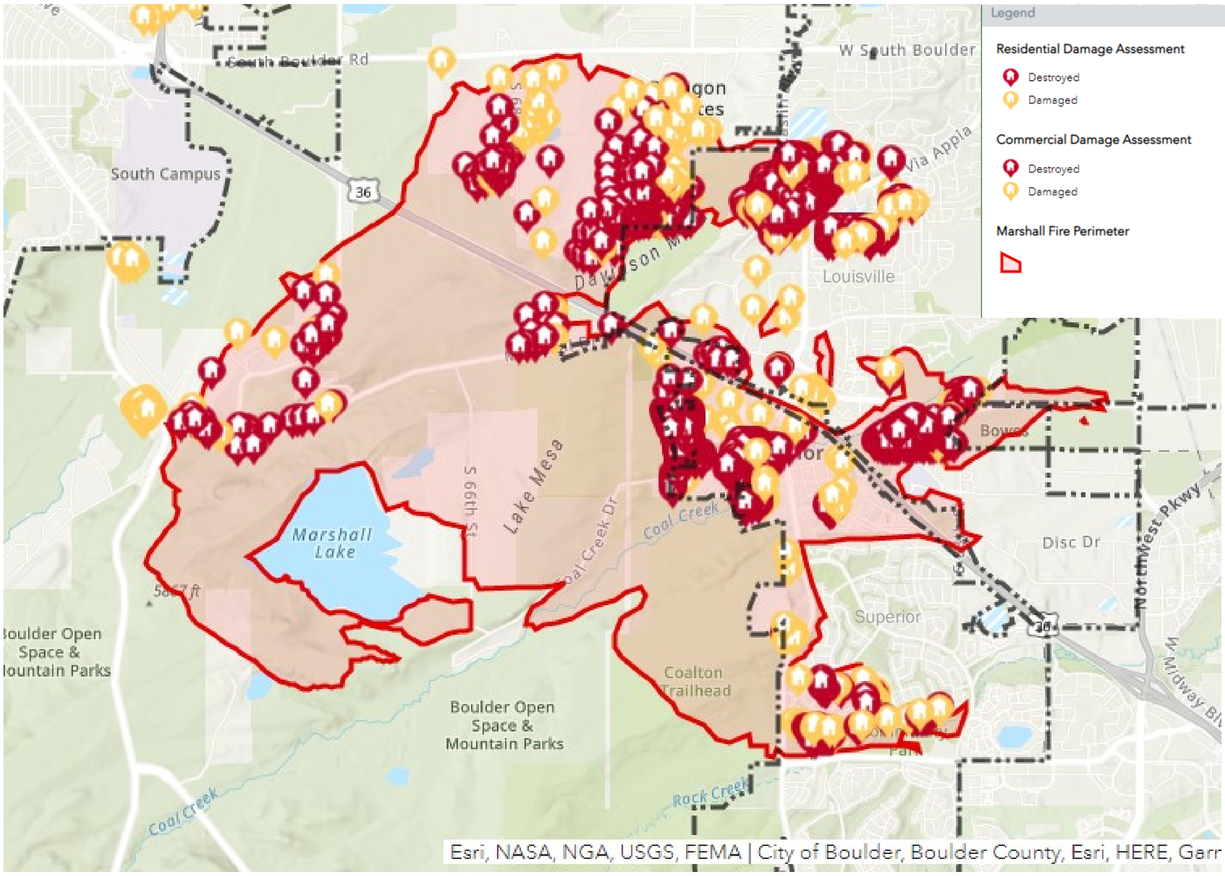


Figure 12. Destroyed (red) and damaged (yellow) structure locations in the Marshall Fire Perimeter (Boulder County, 2022).

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). Boulder County has developed an Equity Map to identify residents in need of additional recovery aid due to racial or socioeconomic disparity.

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.

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

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

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 electric 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

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

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 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 an electric 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 electric 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.

Interview Date	Interviewee	Key Findings
		▪ 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.
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 electric 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

Interview Date	Interviewee	Key Findings
		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.
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.

[12] https://coloradoforestatlas.org/

- Allows the technical advisory panel that evaluates the proposals for forest restoration and wildfire risk mitigation grants to scale up and down in size.
- 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

---

[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

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]

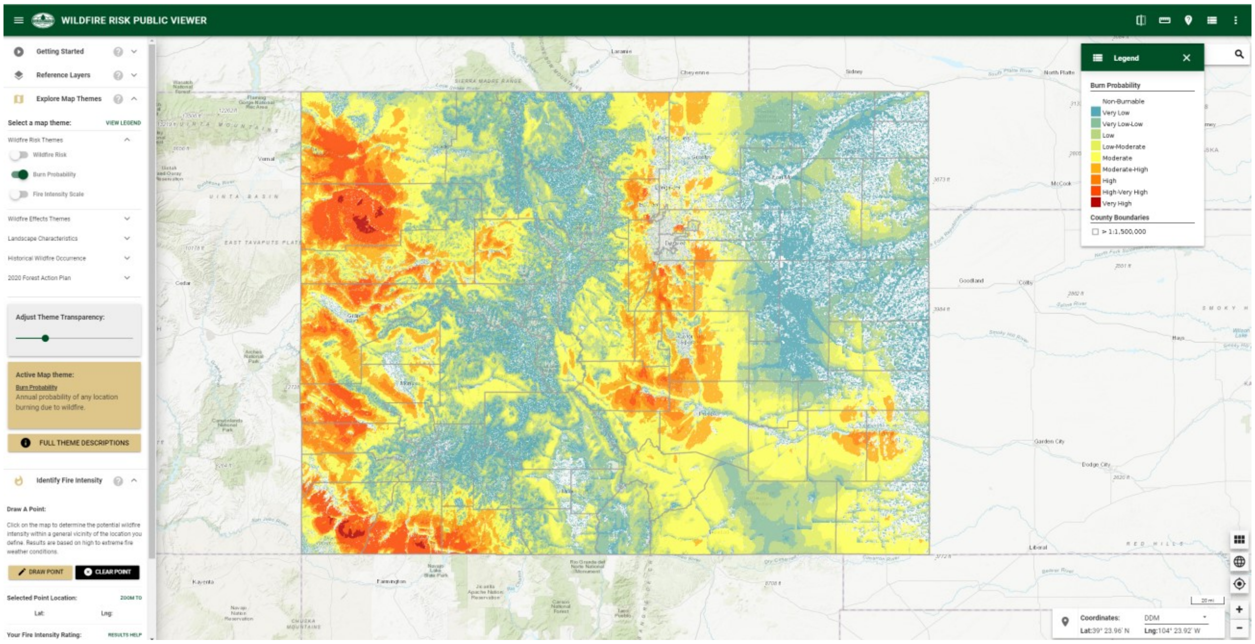


Figure 13. Colorado Forest Atlas Wildfire Risk Public Viewer (Colorado State Forest Service, 2022).

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

[16] https://coloradoforestatlas.org/
[17] https://wildfirepartners.org/
[18] https://realfire.net/

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 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]

---

[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/.

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 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.

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.

[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/ .

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 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.

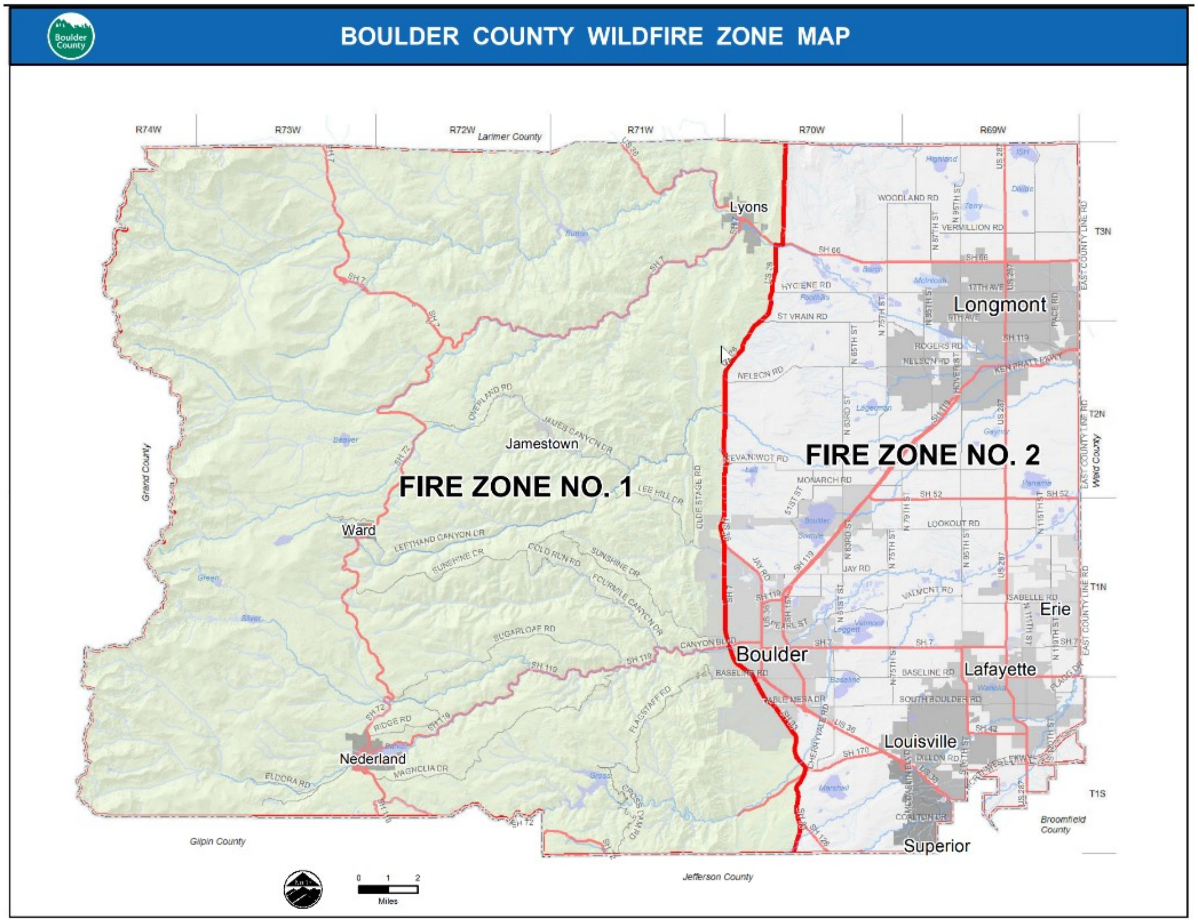


Figure 14. Boulder County is divided into two Wildfire Zones (Boulder County).

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 greenhouse gas 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, which sets standards for energy efficiency, waste management, and water conservation. 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 renewable energy and electric-vehicle 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 due to climate change. 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.

Wildfire-Specific Risk Control Measures	Identified Gap
	▪ 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 equitable and inclusive 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.

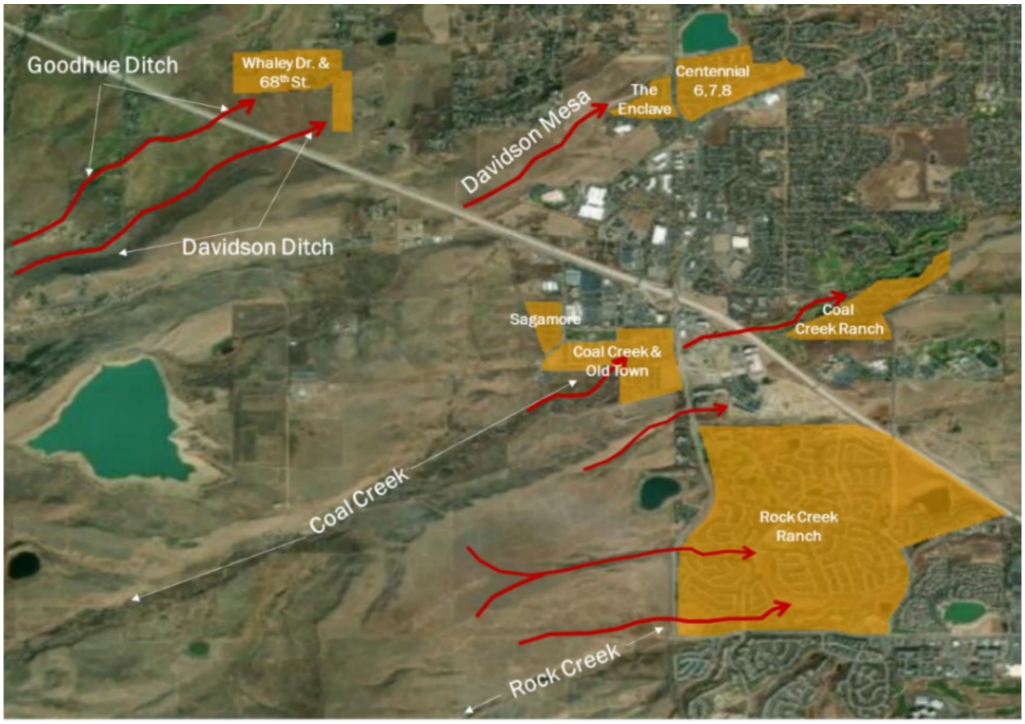


Figure 17. Neighborhoods with homes damaged/destroyed by fire spreading (red arrows) along observed drainage ditches & greenbelts.


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

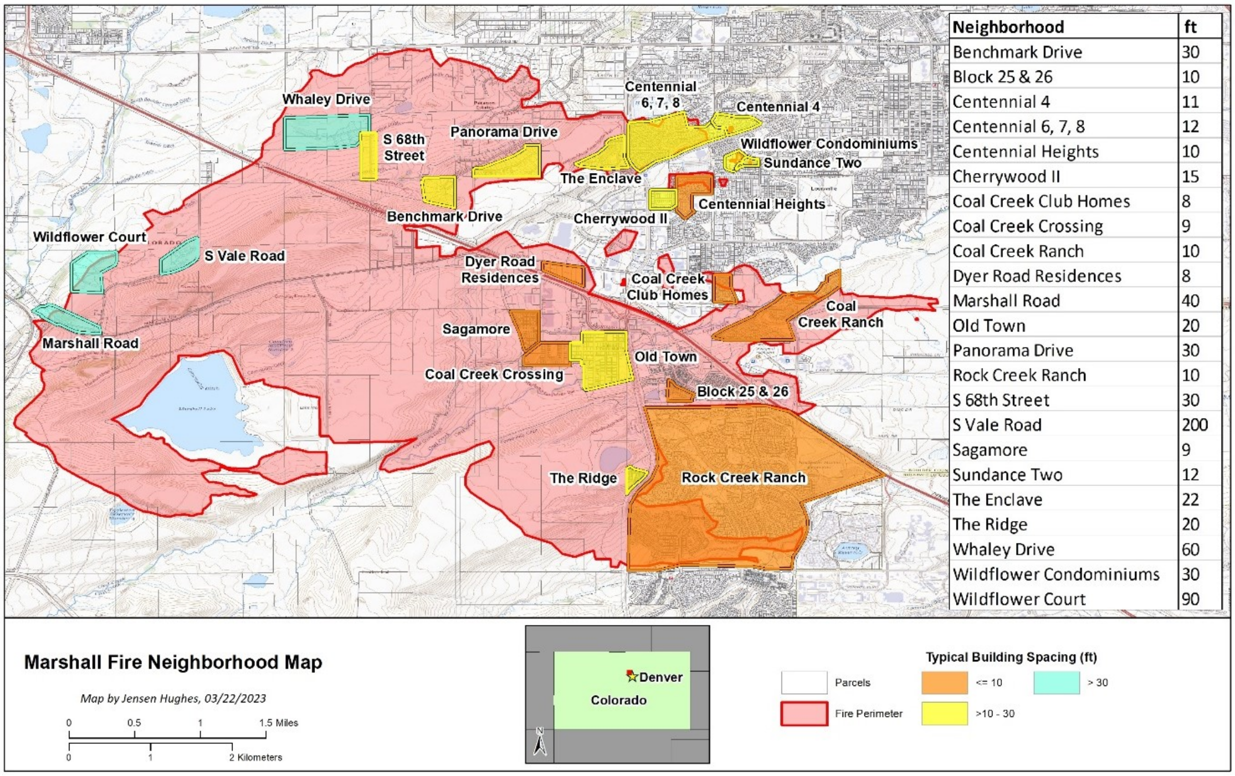
Many of the communities impacted by the Marshall Fire featured structures and buildings that were densely spaced with limited fire separation distances (i.e., less than 30 feet of separation). At the time of the fire, local planning, building and fire codes did not recognize most of these communities 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

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).

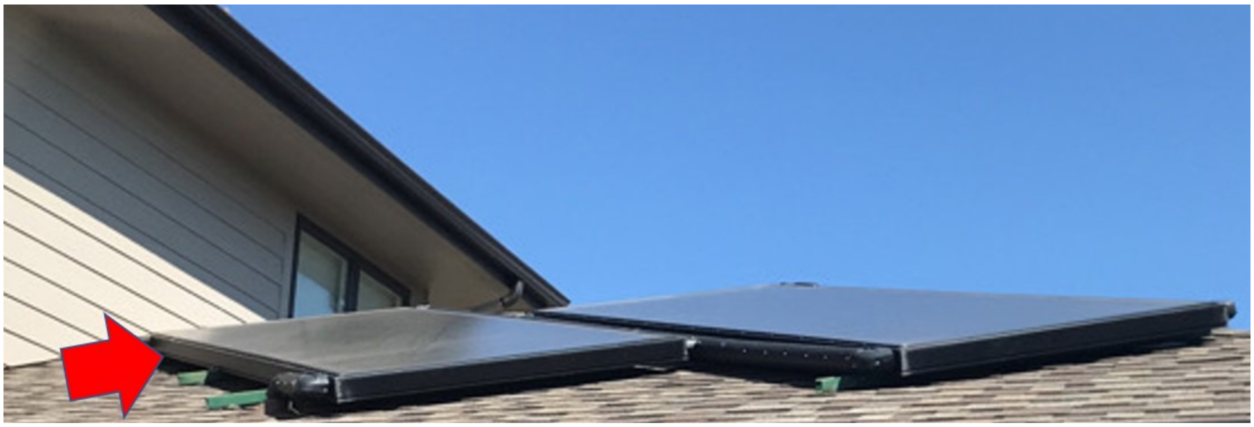


Figure 29. Example of observed unprotected solar panel installation.

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.

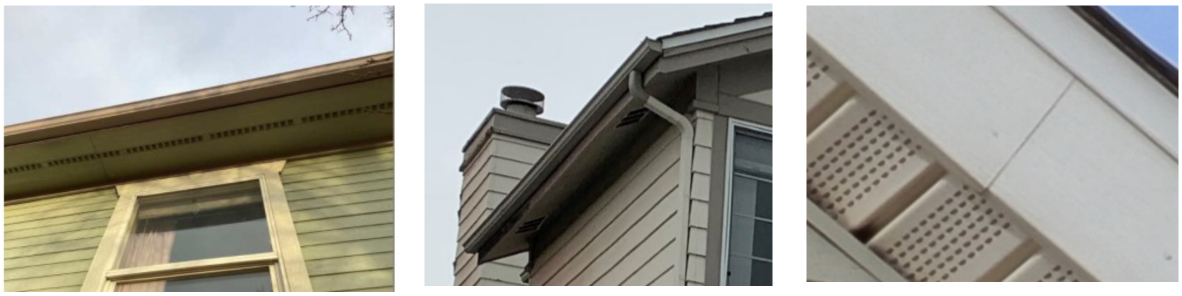


Figure 37. Observed vent protection for soffit eave vents in Superior and Louisville, Colorado.

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.

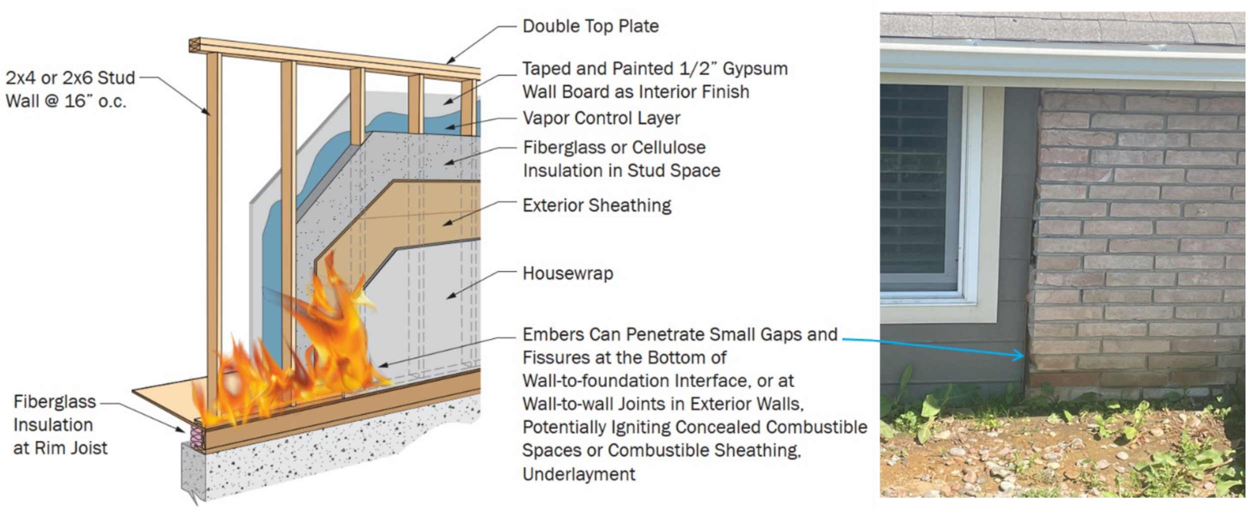


Figure 44. Example of gaps in common exterior wall construction (e.g., interfaces of wall systems, butt joints between siding, bottom-of-wall to foundation details) that can lead to ember penetration, and potential fire in combustible interstitial spaces. Note: At butt joints of exterior siding, embers 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 some systems that are less reliant on fossil fuels, such as solar power and electric vehicles. 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, electric vehicles, 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., electric vehicle dealerships) due to concerns about potential environmental contamination, potential explosions, and to reduce the likelihood of re-ignitions.

An electric 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 due to climate change.

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, unit strategic plans, 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 disadvantaged 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). Boulder County has developed an Equity Map to identify residents in need of additional recovery aid due to racial or socioeconomic disparity.

Recommendation CO-10

Communities with moderate to very-high wildfire risk should investigate and incorporate the vulnerabilities of disadvantaged 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. Adoption of modern building codes and standards is consistent with the National Initiative to Advance Building Codes.

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

Photovoltaic energy systems, electric vehicles, and other 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 electric 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 such as solar PV arrays and electric vehicles 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
Section 1.3.2		**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
Section 1.3.2		**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
Section 1.3.2		**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, unit strategic plans, 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 disadvantaged communities.	**CO-10:** Communities with moderate to very-high wildfire risk should investigate and incorporate the vulnerabilities of disadvantaged 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

Observations	Conclusions	Recommendations	Suggested Agency Lead
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
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:** Photovoltaic energy systems, electric vehicles, and other 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

The Federal Emergency Management Agency (FEMA) would like to acknowledge and heartily thank the many people whose countless contributions enabled the Marshall Fire Mitigation Assessment Team (MAT) to develop this Report and associated documents, as well as provide numerous briefings, training, and outreach efforts in supporting the affected areas impacted by the Marshall Fire. Below is our attempt to list as many individuals by name as possible, with regret to those we may have missed.

Katherine Baum, FEMA Region 8

Faith Berry, U.S. Fire Administration

Anne Cope, PhD, PE, Institute for Building and Home Safety

Zach Corcoran, J.D., Stantec

Erica Fischer, PhD, PE, Oregon State University

Karl Fippinger, CEM, PMP, International Code Council

Faraz Hedayati, PhD, Institute for Building and Home Safety

Matthew Holland, PE Stantec

Nicole LaRosa, U.S. Fire Administration

Hussam Mahmoud, PhD, Colorado State University

Robert MacKay, PE, FEMA Region 8

Brian Metzger, U.S. Fire Administration

Molly Mowery, AICP, Community Wildfire Planning Center

Andrew Notbohm, CO-CEM, Pikes Peak Regional Office of Emergency Management

Stephen Quarles, PhD, Institute for Building and Home Safety

Peter Reinhardt, CFM, FEMA Region 8

Tim Reinhold, PhD, Stantec

Mark Thompson, State of Colorado

Yana Tukvachinski, FEMA Region 2

Brad Wham, PhD, University of Colorado, Boulder

Appendix B: References

Bell, C.E., J.G. Gonzales, V.J. Mellano, M. Nakamura, S.L. Quarles, T.P. Salmon, and D.A. Shaw. 2007. Wildfire Preparedness and Recovery in San Diego County: A Review and Analysis White Paper of Data and Research Studies Relevant to Wildfire. Farm and Home Advisor's Office, University of California Cooperative Extension, County of San Diego. San Diego, CA.

Bernard, A. 2020. Home Rule Governance in Colorado. Legislative Council Staff Issue Brief Number 20-16. Available at: https://leg.colorado.gov/publications/home-rule-governance-colorado-20-16

Boulder County Community Planning and Permitting Department. 2017. Boulder County Building Code Amendments: Resolutions 2015-104 & 2016-96: Amendments to Boulder County Building Code Effective January 1, 2016.

Boulder County Community Planning and Permitting Department. 2022. Boulder County Building Code Amendments: Resolutions 2015-104, 2016-96 and 2022-040 Amendments to Boulder County Building Code Effective June 6, 2022. Available at: https://assets.bouldercounty.gov/wp-content/uploads/2017/03/building-code-2015.pdf

Boulder County Land Use Department. 2017. Boulder County BuildSmart Code. Available at: https://assets.bouldercounty.gov/wp-content/uploads/2017/03/buildsmart-code-2015.pdf

Boulder County Land Use Department. N.d. Fire Sprinkler System Plan. Available at: https://assets.bouldercounty.gov/wp-content/uploads/2017/03/b44-fire-sprinkler-system-plan.pdf)

Boulder County Office of Emergency Management. 2022. 2022 – 2027 Boulder Hazard Mitigation Plan. Available at: https://assets.boulderoem.com/wp-content/uploads/2020/12/hazard-mitigation-plan.pdf

Boulder County. 2011. Boulder County Community Wildfire Protection Plan. Available at: https://bouldercounty.gov/disasters/wildfires/mitigation/community-wildfire-protection-plan/

Boulder County. 2018. Boulder County Environmental Sustainability Plan. Available at: https://assets.bouldercounty.gov/wp-content/uploads/2018/08/2018-sustainability-plan.pdf

Boulder County. 2020. Boulder County Comprehensive Plan. Available at: https://assets.bouldercounty.gov/wp-content/uploads/2018/10/bccp-boulder-county-comprehensive-plan.pdf

Boulder County. 202. Boulder County Hazard Mitigation Plan. Available at: https://assets.boulderoem.com/wp-content/uploads/2020/12/hazard-mitigation-plan.pdf

Boulder County. N. d. *Wildfire Mitigation FAQ*. Available at: Wildfire Mitigation FAQ - Boulder County

Bowman et. al. 2009. *Fire in the Earth System*. Science, vol. 324, no. 5926

Building Energy Codes. N.d. Colorado Energy Office. Available at: https://energyoffice.colorado.gov/climate-energy/energy-policy/building-energy-codes

Building in Bushfire-prone Areas. N.d. South Australia County Fire Service. Available at: https://www.cfs.sa.gov.au/plan-prepare/building-planning/building-in-bushfireprone-areas/

City, Boulder County Continue to Make Progress on Fire Mitigation Efforts. 2022. City of Louisville. Available at: https://www.louisvilleco.gov/Home/Components/News/News/6218/

City of Louisville. N.d. Ignition Resistant Construction Guide. Available at: https://www.louisvillefire.com/wp-content/uploads/2022/05/Guide-4.27.22.pdf

City of Louisville. N.d. Strategic Planning Framework 2023-2024. Available at: https://www.louisvilleco.gov/home/showpublisheddocument/22025/638095618431500000

City of Louisville. 2022. Ordinance No. 1824. Available at: https://www.louisvilleco.gov/home/showpublisheddocument/34312/637821560275770000

City of Louisville. 2022. Ordinance No. 1838. Available at: https://www.louisvilleco.gov/home/showpublisheddocument/36317/637989298617570000

City of Louisville. 2022. Recovery Plan for Marshall Fire. Available at: https://www.louisvilleco.gov/home/showpublisheddocument/34565/637844998923630000

Colorado Division of Fire Prevention and Control. 2022. Facilitated Learning Analysis. Available at: https://storymaps.arcgis.com/stories/83af63bd549b4b8ea7d42661531de512

Colorado Forest Atlas. Available at: https://coloradoforestatlas.org/

Colorado State Forest Service. (1999). Fire-Resistant Landscaping. https://extension.colostate.edu/docs/pubs/natres/06303.pdf

Community Planning & Permitting Department. 2022. *Boulder County Land Use Code.* Available at: https://assets.bouldercounty.gov/wp-content/uploads/2017/02/land-use-code.pdf

Community Planning & Permitting Department. 2022. *Marshall Fire Rebuilding and Repairs in Unincorporated Boulder County.* https://assets.bouldercounty.gov/wp-content/uploads/2022/02/m1-marshall-fire-rebuilding.pdf

Country Fire Authority. N.d. Landscaping for Bushfire. Available at: https://www.landcarevic.org.au/assets/Uploads/landscaping-for-bushfire.pdf

Federal Emergency Management Agency. 2021. *Community Wildfire Resilience- Landscape Analysis Volume 1.*

Federal Emergency Management Agency. 2021. *Community Wildfire Resilience- White Paper Volume 2.*

Fourmile Canyon Fire Maps. N.d. Boulder County. Available at: https://bouldercounty.gov/disasters/wildfires/fourmile-canyon-fire-maps/

Geotechnical Extreme Events Reconnaissance Association. 2022. The 2021 Marshall Fire, Boulder County, Colorado. Available at: https://geerassociation.org/index.php/component/geer_reports/?view=geerreports&layout=build&id=103

Green Building Program. N.d. Town of Superior. Available at: https://www.superiorcolorado.gov/departments/building-department/green-building-program

Halford, M. (2023, January 30). *Boulder County Community Wildfire Protection Plan* [PowerPoint slides]. City of Louisville. Available at: https://www.louisvilleco.gov/home/showpublisheddocument/37591/638112735305830000

Hedayati, F., Quarles, S., and Standohar-Alfano, C. 2022. Evaluating Deck Fire Performance – Limitations of the Test Methods Currently Used in California's Building Codes. Available at: https://www.mdpi.com/2571-6255/5/4/107

Insulation Replacement. N.d. City of Louisville. Available at: https://www.louisvilleco.gov/local-government/government/departments/building-safety/rebuilding-resources-following-marshall-fire/insulation-replacement

Knott, E. "Common firestop code violations". February 2019. https://www.iccsafe.org/building-safety-journal/bsj-technical/common-firestop-code-violations-2/

Land Use Tool: Building Codes. N.d. Planning for Hazards. Available at: https://planningforhazards.com/building-code#:~:text=Building%20code%20regulations%20in%20Boulder%20County%20were%20first,loss%2C%20and%20have%20continued%20to%20evolve%20since%20then.

Louisville, Colorado Code of Ordinances. Municode. Available at: https://library.municode.com/co/louisville/codes/code_of_ordinances

Louisville Fire Protection District. N.d. Louisville Fire Protection District 2021-2026 Strategic Plan. Available at: https://www.louisvillefire.com/wp-content/uploads/2021/08/Louisville-Fire-Protection-District-Strategic-Plan-2021-2026-FinalV1.pdf

Majority of Permitted Rebuilds in Superior Choose Energy Efficiency. 2023. Town of Superior. Available at: https://www.superiorcolorado.gov/Home/Components/News/News/4132/17?backlist=%2fcommunity%2fsuperior-recovers

Marshall Fire Finances and Rebates. N.d. Boulder County. Available at: https://bouldercounty.gov/finances-and-rebates/

Marshall Fire Recovery Milestones. N.d. Boulder County. Available at: https://bouldercounty.gov/marshall-fire-recovery-milestones/

Marshall Fire Use Tax Credit Program. N.d. City of Louisville. Available at: https://www.louisvilleco.gov/local-government/government/departments/building-safety/rebuilding-resources-following-marshall-fire/marshall-fire-use-tax-credit-program

Miller, Blair. National Weather Service analysis identifies factors that caused Marshall Fire to spread so quickly. January 12, 2022. https://www.thedenverchannel.com/news/marshall-fire/national-weather-service-analysis-identifies-factors-that-caused-marshall-fire-to-spread-so-quickly

National Fire Protection Association. 2021. *NFPA 101®,* Life Safety Code Handbook. Available at: https://catalog.nfpa.org/NFPA-101-Life-Safety-Code-Handbook-P15695.aspx?icid=W003

National Institute for Standards and Technology. 2022. Wind-Driven Fire Spread to a Structure from Fences and Mulch. https://www.nist.gov/publications/wind-driven-fire-spread-structure-fences-and-mulch

National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI), U.S. Billion-Dollar Weather and Climate Disasters, 2022. https://www.ncei.noaa.gov/access/billions/

National Weather Service. 2022. *Marshall Fire and High Wind on December 30, 2021.* Available at: https://www.weather.gov/bou/MarshallFire20211230

National Wildfire Coordination Group (2019) *Wildland Urban Interface Wildfire Mitigation Desk Reference Guide* Permit Fees and Tax Rates. N.d. Town of Superior. Available at: https://www.superiorcolorado.gov/departments/planning/marshall-fire-community-planning-and-rebuilding-effort/permit-fees-and-tax-rebates

Phillips, Noelle. (2022). “Marshall fire destroyed 1,084 homes worth a combined half-billion dollars, new assessment shows”. Denver Post. January 6, 2022. Available at: https://www.denverpost.com/2022/01/06/marshall-fire-damage-estimates/

Rebuilding Better. N.d. Boulder County. Available at: https://rebuildingbetter.org/

Rocky Mountain Fire Protection District. 2010. Rocky Mountain Fire Community Wildfire Protection Plan. Available at: https://static.colostate.edu/client-files/csfs/documents/RockyMountainFPDCWPP_2010.pdf

Schmidt, L. 2023. The Science of Fire Behavior: Training Fire Analysts in a Time of Rapidly Changing Forests. Rocky Mountain Research Station. https://www.fs.usda.gov/research/rmrs/news/featured/science-fire-behavior-training-fire-analysts-time-rapidly-changing-forests

Scott, Michon. Wet, then dry extremes contributed to devastating Marshall Fire in Colorado. January 7, 2022. https://www.climate.gov/news-features/event-tracker/wet-then-dry-extremes-contributed-devastating-marshall-fire-colorado

Stein, Andy. "Marshall fire explained: How we got 115 mph winds in Boulder County on a December winter day". Denver Post. December 31, 2021." Available at: https://www.denverpost.com/2021/12/31/marshall-fire-explained-firestorm-colorado-weather/#:~:text=The%20Marshall%20Fire%20continues%20to%20burn%20out%20of,60%20to%20100-plus%20mph%20at%20times%20on%20Thursday.

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

Superior, Colorado Code of Ordinances. Municode. https://library.municode.com/co/superior/codes/municipal_code

Texas A&M Forest Service. 2022. State Fire Assistance for Hazard Mitigation 2022 Vegetative Fuel Break Grant Application. Available at: https://tfsweb.tamu.edu/uploadedFiles/TFSMain/Preparing_for_Wildfires/Prepare_Your_Home_for_Wildfires/Contact_Us/2022%20Vegetative%20Fuel%20Break%20GrantApplication.pdf

Town of Superior. 2012. Town of Superior Comprehensive Plan. Available at: https://www.superiorcolorado.gov/home/showpublisheddocument/32/635548384058770000

Town of Superior. 2021. Town of Superior Parks, Recreation, Open Space and Trails Master Plan. Available at: https://shapesuperior.com/parks-recreation-open-space-trails-master-plan

Town of Superior. 2022. Information for Meeting of the Superior Board of Trustees. Available at: https://townofsuperior.granicus.com/MetaViewer.php?view_id=4&clip_id=2095&meta_id=100082

Town of Superior. 2022. Ordinance No O-2. Available at: https://www.superiorcolorado.gov/home/showpublisheddocument/20253/637820007978330000

Town of Superior. 2022. Ordinance No. O-3. Available at: https://townofsuperior.granicus.com/MetaViewer.php?view_id=4&clip_id=2013&meta_id=96260

Town of Superior. 2022. Ordinance No. O-5. Available at: https://library.municode.com/co/superior/ordinances/municipal_code?nodeId=1153315

Town of Superior. 2022. Ordinance No. O-7. Available at: https://www.superiorcolorado.gov/home/showpublisheddocument/20830/637928760251900000

Town of Superior. 2022. Ordinance No. O-8. Available at: https://www.superiorcolorado.gov/home/showpublisheddocument/20585/637892544871670000

Town of Superior. 2022. Ordinance No. O-13. Available at: https://www.superiorcolorado.gov/home/showpublisheddocument/20872/637945203903776352

Town of Superior. 2023. Majority of Permitted Rebuilds in Superior Choose Energy Efficiency. Available at: https://www.superiorcolorado.gov/Home/Components/News/News/4132/17?backlist=%2fcommunity%2fsuperior-recovers

Town of Superior. N.d. Permits for Insulation Replacement. Available at: https://www.superiorcolorado.gov/departments/planning/marshall-fire-community-planning-and-rebuilding-effort/permits-for-insulation-replacement

University of California Agriculture and Natural Resources (UCANR). (2022a). Landscape Restoration. https://ucanr.edu/sites/fire/Recovery/Revegetation/

U.S. Global Change Research Program. 2018. National Climate Assessment 4 Vol II: Impacts, Risks, and Adaptation in the United States.

Westerling and Bryant. 2008. Climate change and growth scenarios for California wildfire. Climatic Change. 109 (Suppl 1): S445 S463.

What's New with Parks and Open Space. 2022. Town of Superior. Available at: https://www.louisvilleco.gov/Home/Components/News/News/6131/ (louisvilleco.gov)

Windows Have Impact-Rated Glass, Fire-Resistant Glass, or Protective Coverings. 2022. U.S. Department of Energy. Available at: https://basc.pnnl.gov/resource-guides/windows-have-impact-rated-glass-fire-resistant-glass-or-protective-coverings

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.