National Renewable Energy Laboratory Wildland Fire Management Plan (August 2022–August 2025)

February–August 2022

Carol Rice

Wildland Resource Management

NREL Technical Monitor: Nicholas Bartlett

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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Subcontract Report
NREL/SR-1900-83565
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Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

List of Acronyms

AHJ	Authority Having Jurisdiction
BIOLV	Building Importance/Occupant Load/Value
BNA	Baseline Needs Assessment
CWPP	Community Wildlife Protection Plan
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
ESH&Q	Environment, Safety, Health, and Quality
EOC	Emergency Operations Center
ETIF	expanding thermal insulating foam
FACO	Fire Adapted Colorado
ICC	International Code Council
IWUIC	International Wildland Urban Interface Code
LBNL	Lawrence Berkeley National Laboratory
MVFPD	Mountain View Fire Protection District
NCAR	National Center for Atmospheric Research
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
NWCG	National Wildfire Coordinating Group
RAWS	remote automated weather stations
STM	South Table Mountain
USFS	U.S. Forest Service
WFMP	Wildland Fire Management Plan
WMFPD	West Metro Fire Protection District
WUI	wildland urban interface

Executive Summary

The National Renewable Energy Laboratory (NREL) is located in a moderate wildfire risk region (Colorado State Forest Service n.d.). The two main campuses for NREL are located on the Front Range of Colorado, which has experienced numerous wildland fires. One such fire, the Marshall Fire of 2021, threatened one of NREL's campuses and ultimately burned 1,084 structures and 6,026 acres, killing two people and injuring at least six. This threat serves to underscore the importance of a strong wildland fire management program at NREL.

Due to this exposure, wildland fire risk reduction and active vegetation management are paramount to protecting NREL assets and to ensure that continued scientific research activities are possible. This Wildland Fire Management Plan (WFMP) describes the means and methods by which NREL systematically works to reduce wildland fire risk, including topics such as fire prevention, fire suppression, and post-fire rehabilitation.

The goals of the WFMP are as follows:

1. Protect human health and safety
2. Protect NREL facilities and research
3. Enhance community protection
4. Diminish risk and consequences of wildland fires
5. Maintain the health of the ecosystem.

A robust fire prevention program is the first line of action to achieve the goals of the WFMP. When paired with comprehensive emergency management actions and swift fire department intervention, the wildland fire risk to NREL can be reduced significantly and managed effectively.

Several recommendations are presented at the end of this WFMP, with a focus on pre-incident planning for various scenarios that could impact NREL, such as:

- Major wind events during wildland fire
- Multi-event, major regional wildfire response for multiple ignitions starting on or near the NREL South Table Mountain Campus or Flatirons Campus.

Recommendations span:

- Enhanced community engagement
- Expanded defensible space and vegetation treatments
- Retrofitting vulnerable structures
- Improved signage to support emergency response
- Establishing procedures for notification and a process for evacuation.

This WFMP does not include NREL leased facilities, including Golden Warehouse (City of Golden), Building 16 (Lakewood, CO), Washington, D.C., Office, ReFuel (Denver, CO), and the Cold Climate Housing Research Center (Fairbanks, AK). It also does not include Camp George West, which was in the acquisition process during the development of this WFMP.

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1 Introduction

1.1 Purpose of the Plan

The Alliance for Sustainable Energy, LLC, manages and operates the National Renewable Energy Laboratory (NREL) on behalf of the U.S. Department of Energy (DOE). This plan was developed to comply with DOE Order 420.1C, *Facility Safety*; DOE-STD-1066-2016, *Fire Protection*; and the *Federal Wildland Fire Management Policy.* This plan reflects policies on the national level and details past policies still in force, partnerships developed, operations guidelines enacted, wildland fire hazard reduction treatments, and monitoring protocols developed.

This Wildland Fire Management Plan (WFMP) is intended to be used and implemented for NREL's two sites in Colorado. It will be reviewed by the NREL Fire Protection Engineers, with approval by DOE as required by DOE Order 420.1C.

The requirement within DOE Order 420.1C states, "An integrated site-wide wildland fire management plan, consistent with the *Federal Wildland Fire Management Policy*, must be developed, provided to DOE Head of Field Element for approval, and implemented in accordance with the relevant portions of [National Fire Protection Association] NFPA 1143, *Standard for Wildland Fire Management*" (DOE 2012, p. II-8). The purpose of NFPA 1143 is to specify management practices and policies necessary for a fire protection organization to develop a wildland fire management program (NFPA 2018).

The requirement for a wildland fire management plan is also established in the Federal Wildland Fire Management Policy by the statement, "Every area with burnable vegetation must have an approved Fire Management Plan. Fire Management Plans are strategic plans that define a program to manage wildland fires based on the area's approved land management plan" (U.S. Department of the Interior [DOI] 2009, p. 12).

1.2 Context

1.2.1 General Context

NREL's facilities in Colorado are split between two campuses in the greater Denver area. NREL has a workforce of over 2,900 individuals. The main site, the Golden Laboratories and Offices (also referred to as the South Table Mountain [STM] campus), is situated on approximately 327 acres of land (NREL n.d.[a]) in the high-altitude foothills of the City of Golden, most of which is covered with wildland vegetation. The STM Campus's permanent population is approximately 2,596 people daily (DOE 2022), including full-time and part-time scientists, engineers, support staff, and students, but this does not include the site's numerous visitors and guests (NREL n.d.[b]). The STM Campus includes services and amenities to benefit NREL's employees and work environment, such as a café, site security, parking facilities, and logistical services. NREL is operated for DOE by the Alliance for Sustainable Energy, LLC. NREL also leases four buildings not located on the STM Campus. These include the Golden Warehouse (located in the City of Golden), Building 16 (located in the City of Lakewood), ReFuel (located in the City of Denver), and the Cold Climate Housing Research Center (located in Fairbanks, Alaska). This

WFMP does not include an assessment of these leased facilities. Of these, the only known facility with a wildland urban interface exposure is the Cold Climate Housing Research Center. The STM Campus consists of 26 buildings (NREL 2021a) and a number of other structures that are used for a variety of purposes, including but not limited to offices, parking, storage, research laboratories and equipment, communication, educational and visitor centers, maintenance, and food services. The approximate replacement value of these buildings and structures (not including content value, fire cleanup, or rebuild costs), is approximately $465 million (NREL 2021a).

NREL's secondary Colorado site, the Flatirons Campus Laboratories and Offices, is situated on approximately 305 acres (NREL 2022) of land located in unincorporated Jefferson County, including 281.1 acres covered with wildland vegetation, roughly 25 miles north of the main NREL site in Golden. According to NREL's 2020 Baseline Needs Assessment (BNA), fewer than 200 people could be on the Flatirons Campus at a given time, including full-time and part-time scientists, engineers, and support staff. NREL has owned the Flatirons Campus facilities since the early 1990s. The Flatirons Campus facilities consist of approximately 40 structures (NREL 2021a) and buildings that are used for a variety of purposes, including but not limited to offices, parking, storage, research laboratories and various experimental and support equipment, a fire pump and tank, food services, and maintenance. The approximate replacement value of these buildings and structures (not including content value, fire cleanup, or rebuild costs), is approximately $98 million (NREL 2021a).

1.2.2 Fire Risk

NREL's Colorado sites are located in a region subject to intense and destructive wildland fires. The STM and Flatirons Campus vicinities are characterized by steep terrain, native and invasive vegetation, and extreme weather conditions (including drought, heavy rains, and fast-moving winds that either flow downslope under hot, dry conditions or from the north). Both campuses are located in a wildland urban interface (WUI), and each serve as a fuel break between the highly vegetated forests of Jefferson County and thousands of neighboring residences and businesses.

NREL's Flatirons Campus location is designated by the Colorado State Forest Service as a moderate wildfire risk zone, with moderate–high burn probability and low predicted fire intensity (per the Colorado State Forest Service's [n.d] Wildfire Risk Public Viewer). Meanwhile, most of the South Table Mountain location and its vicinity are designated by the same metric as presenting low wildfire risk, with some patches of moderate risk on the northern boundaries of the campus. Most of the immediate area is designated as presenting low to moderate burn probability, while the open space north of the campus is designated with moderate burn probability. Most of the STM Campus vicinity is predicted to burn with moderate fire intensity, with some small patches of highest intensity in the residential and commercial areas to the south of the facility and in the open space to the complex's north.

Figure 1. Map of the South Table Mountain (STM) Campus

Source: Wildfire Risk Public Viewer (Colorado State Forest Service n.d.)

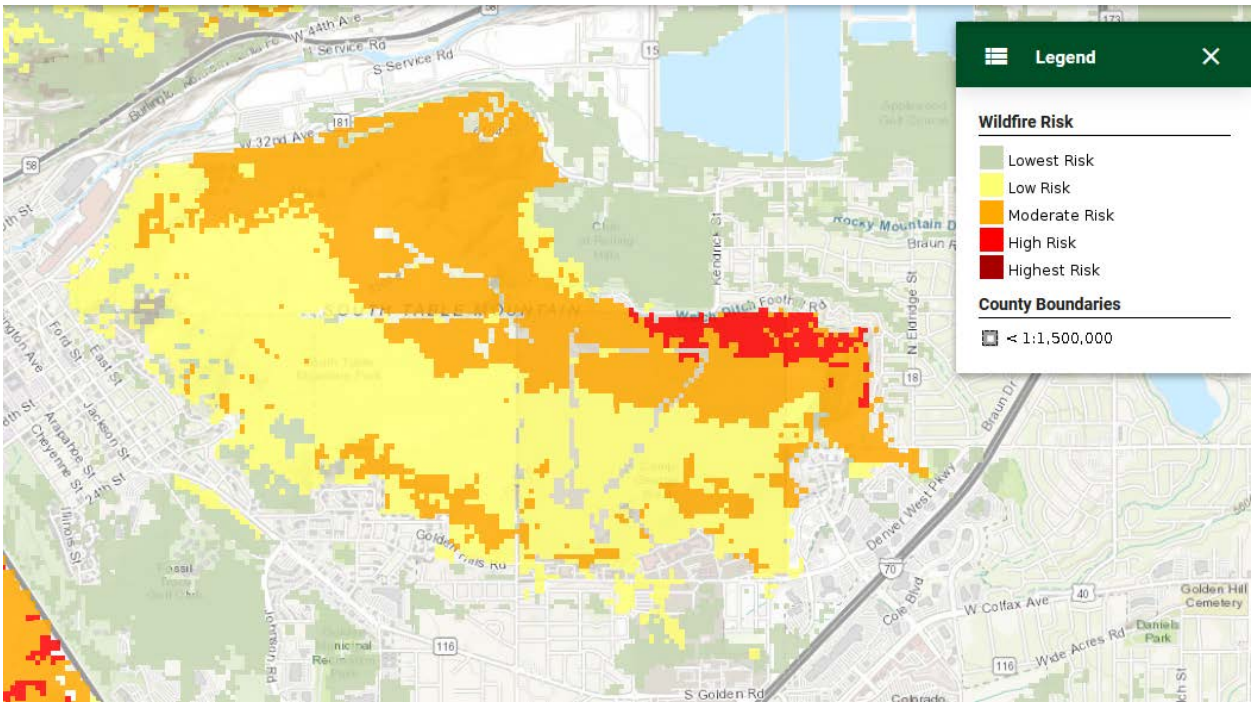

Figure 2. Map of wildfire risk in the STM Campus

Source: Wildfire Risk Public Viewer (Colorado State Forest Service n.d.)

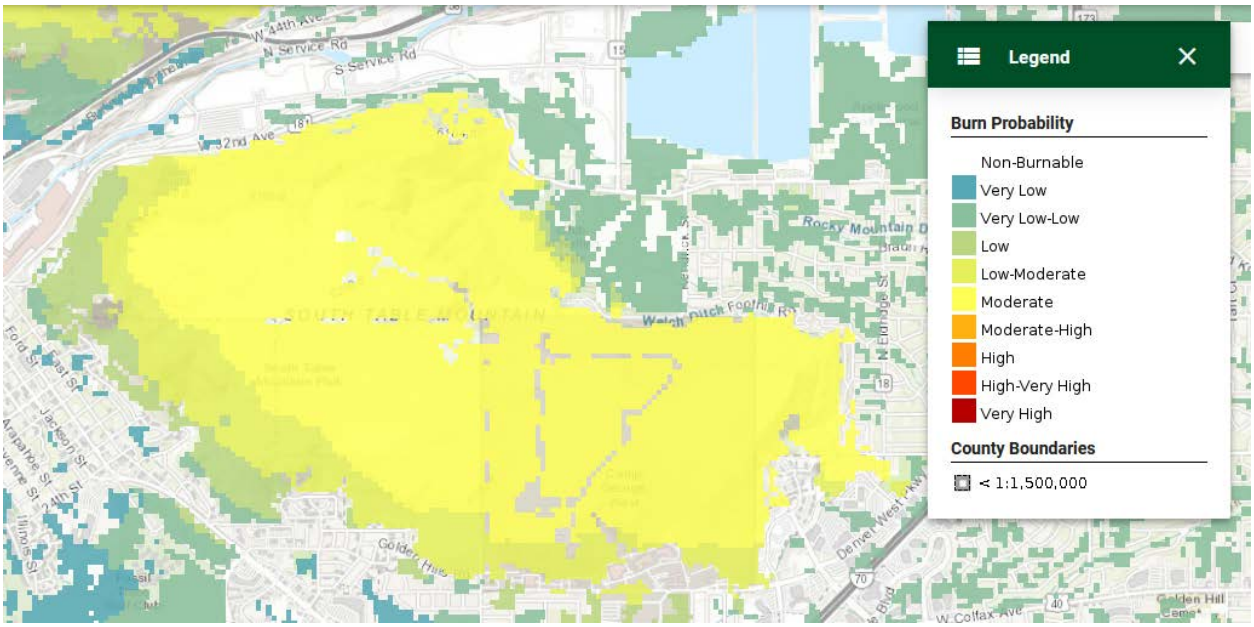

Figure 3. Map of burn probability in the STM Campus

Source: Wildfire Risk Public Viewer (Colorado State Forest Service n.d.)

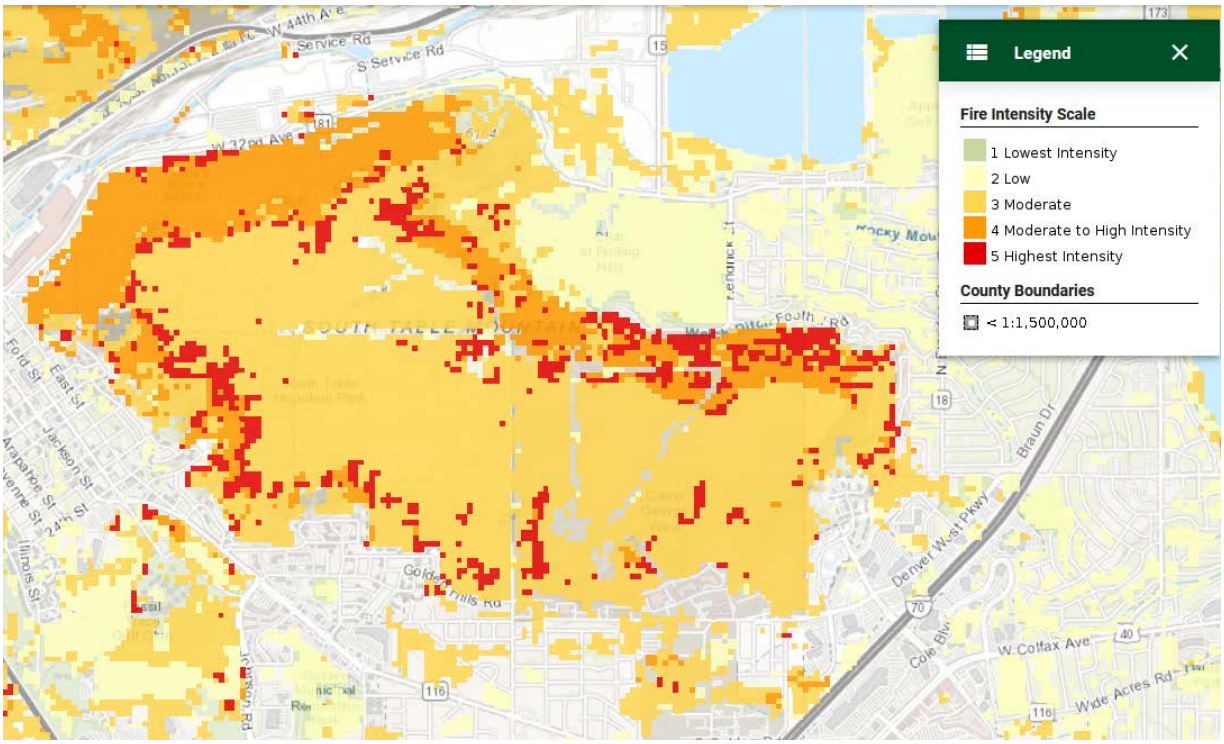

Figure 4. Wildfire intensity scale for the STM campus

Source: Wildfire Risk Public Viewer (Colorado State Forest Service n.d.)

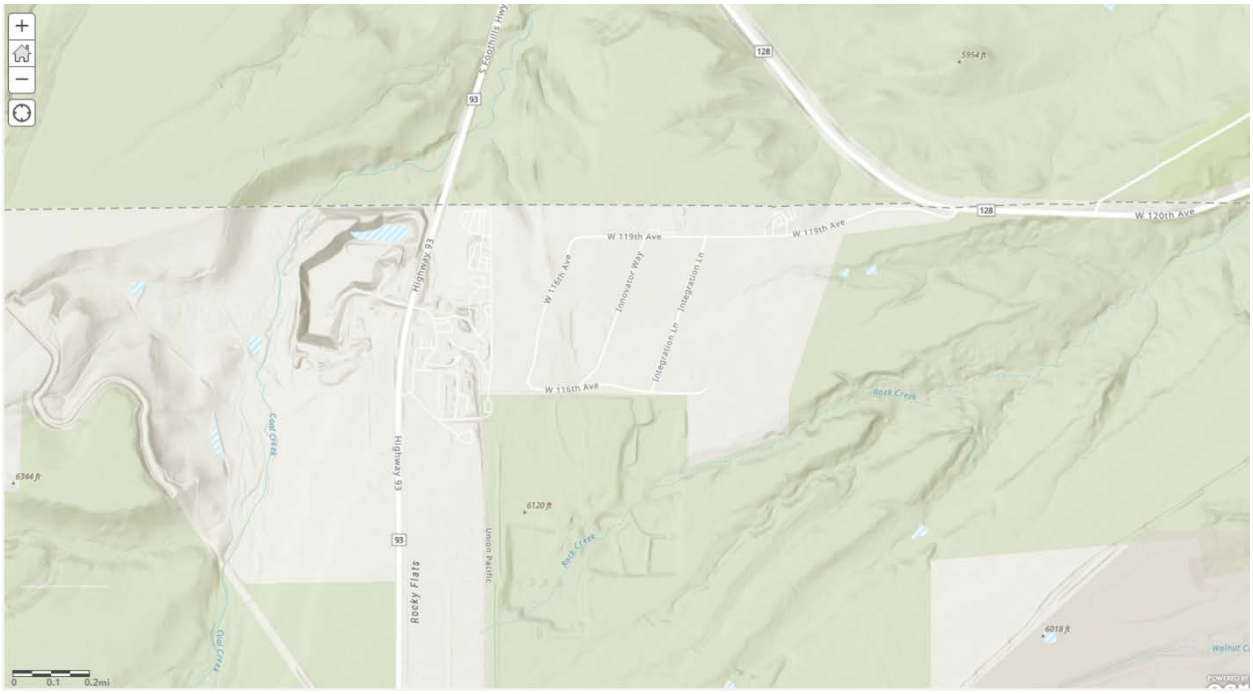

Figure 5. Map of the Flatirons Campus

Source: Wildfire Risk Public Viewer (Colorado State Forest Service n.d.)

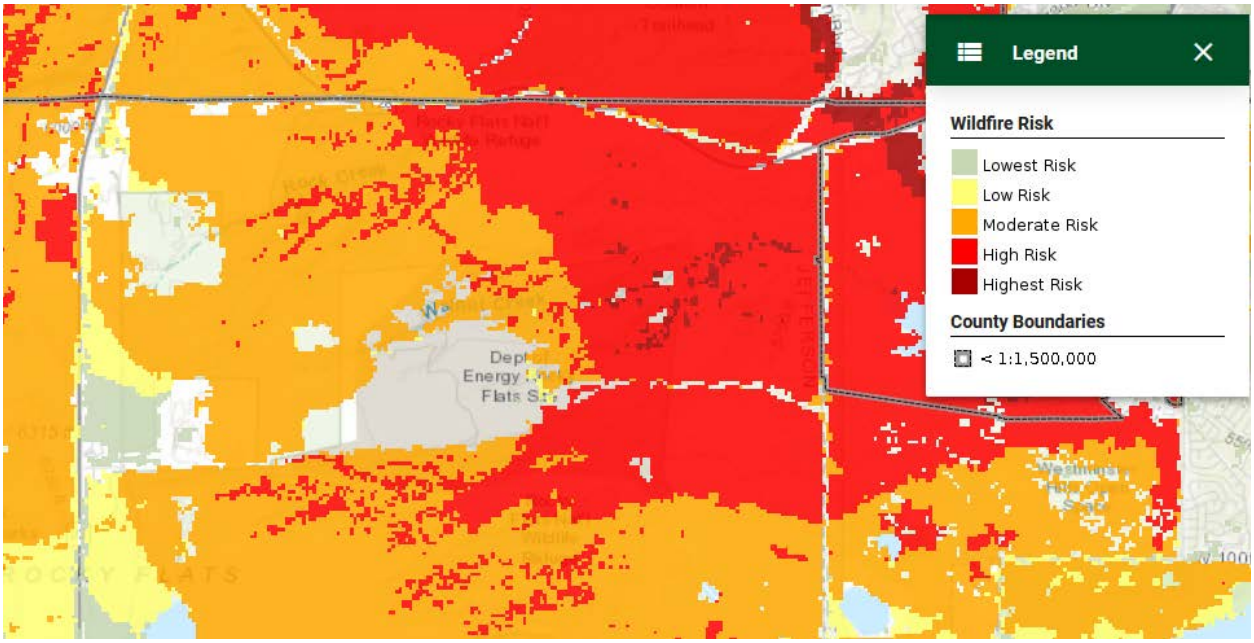

Figure 6. Map of wildfire risk in the Flatirons Campus

Source: Wildfire Risk Public Viewer (Colorado State Forest Service n.d.)

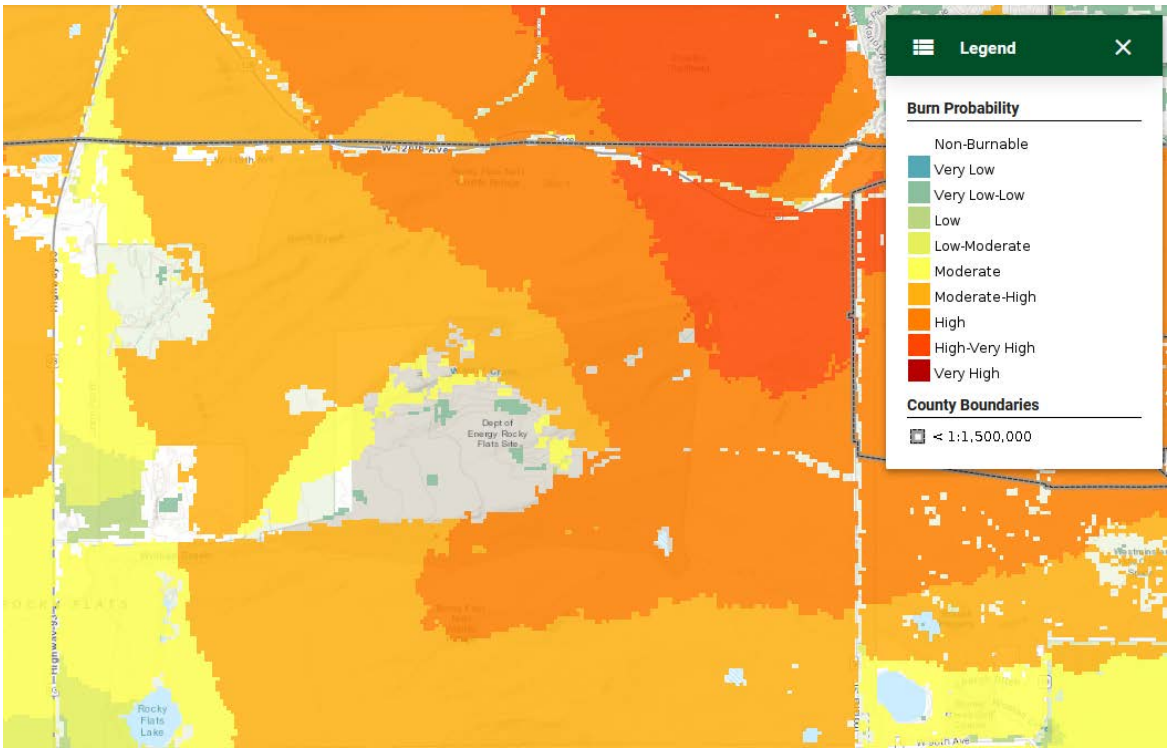

Figure 7. Map of burn probability in the Flatirons Campus

Source: Wildfire Risk Public Viewer (Colorado State Forest Service n.d.)

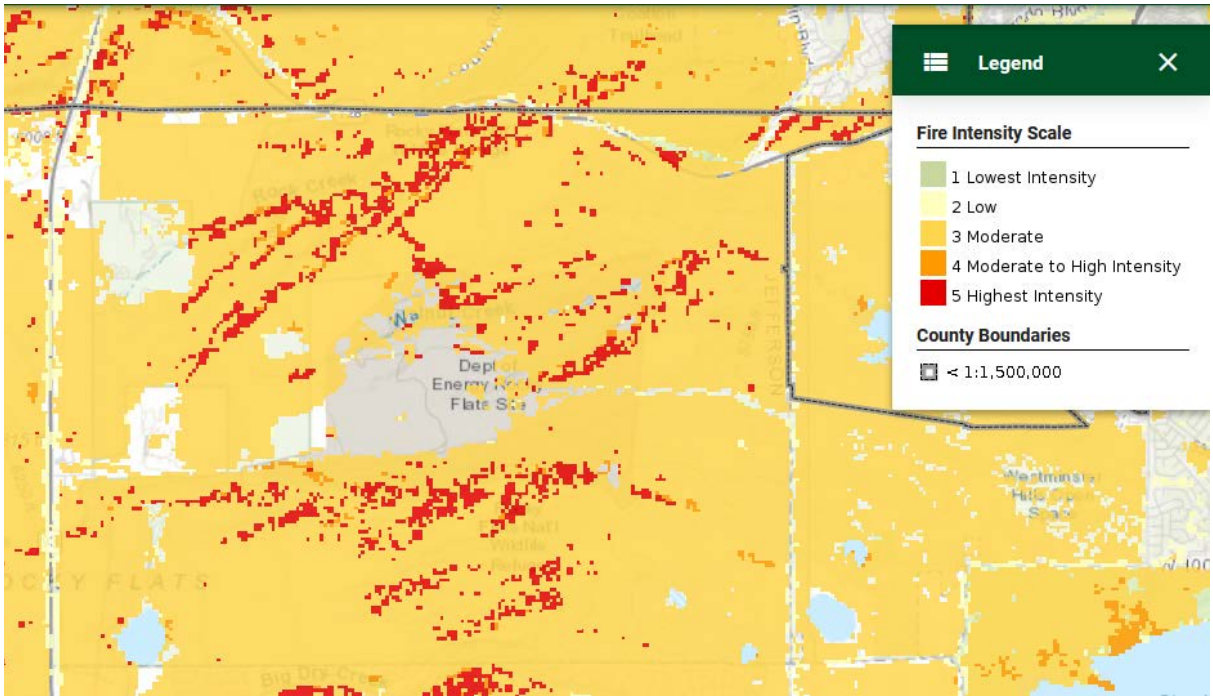

Figure 8. Wildfire intensity scale for the Flatirons Campus

Source: Wildfire Risk Public Viewer (Colorado State Forest Service n.d.)

1.2.3 Fire History

Wildfires occur with regular and growing frequency in Colorado, including several major fires in the greater Boulder-Denver area. Major historic wildfires in Boulder and Jefferson Counties include the 1989 Black Tiger Fire, the 1990 and 2009 Olde Stage Fires, the 2002 Hayman Fire, the 2003 Overland Fire, the 2010 Fourmile Canyon Fire, the 2016 Cold Springs Fire, the 2020 Cal-Wood and Lefthand Canyon Fires, the 2021–2022 Marshall Fire, and the two recent NCAR Fires (which burned in the area of the National Center for Atmospheric Research, or NCAR). While none of these fires burned on NREL property, the Marshall Fire burned just north of the Flatirons Campus, and all of the fires listed above were located within 30 miles of NREL's Flatirons Campus.

Wildfires usually occur from May to November; however, the Cal-Wood wildfire that burned in November 2020 near Jamestown (less than 30 miles north of the NREL Flatirons Campus) burned 10,000 acres and destroyed 28 structures. More recently, the Marshall Fire burned over 6,200 acres and 1,084 structures in Boulder County, less than 5 miles from the NREL Flatirons Campus, between December 30, 2021, and January 1, 2022. The fire risk during brief periods of the fall months is even more pronounced when strong winds, often called "Chinook winds," occur in the Colorado Front Range. These winds further desiccate fuel material and can drive fire fronts and fire brands at extreme speeds.

Several nonmajor fires have occurred even nearer to NREL facilities in the past 35 years. These include the March 2017 South Table Mountain Fire, the November 2016 Green Mountain Fire, the August 2016 South Table Mountain Fire, the February 2013 Rocky Flats Lake Fire, the September 2011 Indiana Fire, the August 2008 Green Mountain Fire, the April 2006 Rocky Flats Fire, the July 2005 North Table Mountain Fire, the September 1996 Labor Day Fire, and the September 1988 North Table Mountain Fire.

Some fires have been started on NREL facility grounds when conducting fuel management. In August 2016, a fire was ignited on the Flatirons Campus when mowing the grass near the Site 4.4 Siemens Data Shed in the facility's southeast. While the fire was self-extinguished approximately 5 minutes later and the fire burned just approximately 300 feet, the incident demonstrates the hazards associated with regular maintenance activities in dry fuel conditions.

Lightning strikes have been known to occur on South Table Mountain, some of which have caused wildfires. Luckily, these fires were extinguished prior to causing significant damage.

The following figure displays fire history, including year, location, and size, in the greater Denver area; this illustrates both the potential for wildfire ignition and resulting damage.

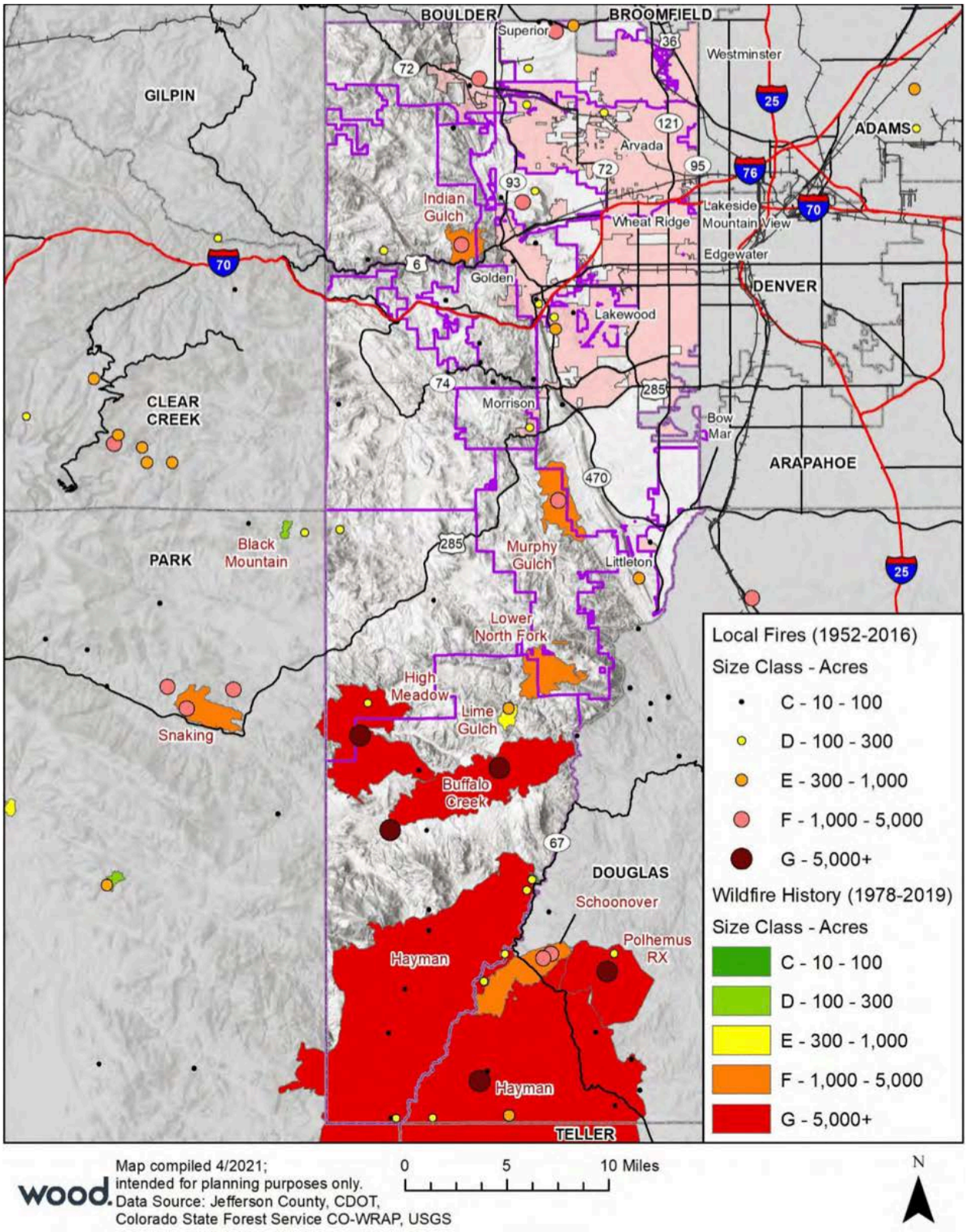

Figure 9. Fire history in the greater Denver area

Source: Jefferson County 2021 Hazard Mitigation Plan (Jefferson County 2021)

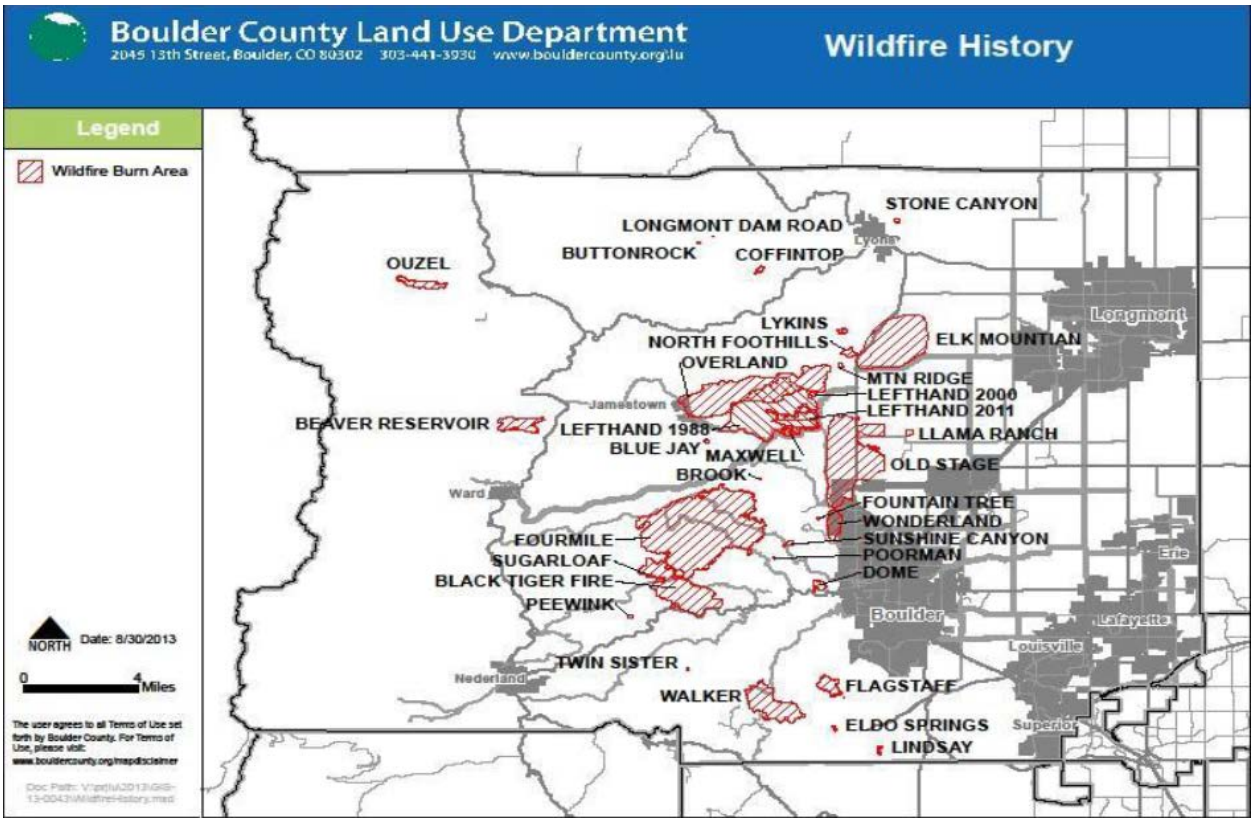

Figure 10. Fire history of Boulder County

Source: Boulder County Hazard Mitigation Plan (Boulder County Office of Emergency Management 2021)

1.3 Collaboration for Wildland Fire Risk Reduction

The Federal Wildland Fire Management Policy promotes interagency collaboration. It states, "Fire management planning, preparedness, prevention, suppression, fire use, restoration and rehabilitation, monitoring, research, and education will be conducted on an interagency basis with the involvement of cooperators and partners" (DOI 2009, p. 14). A clarifying statement within the Federal Wildland Fire Management Policy notes that the plan is to "promote interagency and intergovernmental planning" and to "encourage landscape scale planning across jurisdictional boundaries" (DOI 2009, p. 12). This policy document requires collaboration in wildland fire prevention activities by stating: "Agencies will work together and with their partners and other affected groups and individuals to prevent unauthorized ignition of wildfires" (DOI 2009, p. 14).

NREL has a history of partnerships and collaboration. This history serves as a record of how NREL is consistent with the Federal Wildland Fire Management Policy. NREL regularly participates in both external and internal wildfire management partnerships, including several interagency groups:

- West Metro Fire Rescue
- Mountain View Fire Department (formerly Rocky Mountain Fire Department)
- Arvada Fire Protection District

- U.S. Fish and Wildlife Service
- Rocky Flats Stewardship Council
- U.S. Environmental Protection Agency
- Colorado Forest Service
- City of Lakewood Office of Emergency Services
- City of Golden OES
- Jefferson County Sheriff's Office – Emergency Management, by Kenyon Shephard, Fire Management Officer
- U.S. Forest Service (USFS) Pike/San Isabel, by Joe Sean Kennedy, District Fire Management Officer
- Internal interdisciplinary planning teams, including
    - NREL Environment, Safety, Health, and Quality (ESH&Q) Fire Protection Engineers
    - NREL ESH&Q Environmental Program Staff, NREL Site Operations Personnel, NREL Point of Contact, NREL Laboratory Protection
- International Code Council (ICC), International Wildland Urban Interface Code work group
- Colorado Fire Commission – WUI Subcommittee
- Technical Committee Membership, NFPA 1140, *Standard for Wildland Fire Protection*.

1.3.1 Internal Interdisciplinary Planning Teams

Wildland fire management and risk reduction has involved many divisions and disciplines within NREL. These divisions and disciplines include NREL fire protection engineers, NREL ESH&Q environmental program staff, NREL Site Operations personnel, NREL ESH&Q field support staff, and NREL Laboratory Protection.

1.4 Regulatory Framework

Authority and guidance for implementing this plan are found in the following documents:

- Review and Update of the 1995 Federal Wildland Fire Management Policy: Provides a comprehensive federal fire policy. It relates fire management to land use policies.
- Department of Energy Order 420.1C, *Facility Safety*: Establishes facility and programmatic safety requirements for DOE facilities for fire protection, including the need for a comprehensive Wildland Fire Management Plan.

Additional standards and policies utilized for implementing the WFMP are referenced through this plan as applicable. For clarity, the most prominent of the standards and policies are noted below:

- DOE Order 1066-2016, *Fire Protection.* Provides methods and approaches for meeting DOE fire protection program and design requirements and to address special fire protection issues at DOE facilities.
- ICC, International Wildland Urban Interface Code (IWUIC).
- NFPA 1140, *Standard for Wildland Fire Protection.* Integrates a variety of wildland fire safety standards into a single document. Some of these include:

- NFPA 1143, *Standard for Wildland Fire Management.* Specifies management practices and policies necessary for a fire protection organization to develop a wildland fire management program.
- NFPA 1144 *Reducing Structure Ignition Hazards from Wildland Fire*. Provides a standard method for assessing fuel sources in the structure ignition zone for their potential to ignite structures and identifies possible mitigation measures to reduce the possibility of structure ignition.

2 Relationship to Land Management Planning and Wildland Fire Policy

This section of the document establishes the linkage between higher level planning documents, legislation and policies, and the actions described in the Wildland Fire Management Plan. This section identifies in broad programmatic terms the direction found in the land-use planning and management process, such as goals, objectives, and desired future condition, as they pertain to wildland fire management activities.

2.1 Reference to Planning and Documents

NREL integrates fire management into the DOE land-use planning process through its use of NFPA standards and ICC codes. NFPA 1140, *Standard for Wildland Fire Protection*, 2022 Edition, and the IWUIC, 2015 Edition, contain the applicable requirements. Integration is done primarily through the NREL Baseline Needs Assessment of Emergency Response Capabilities prepared in 2020, and through integrations with NREL Site Operations.

Building construction standards are integrated into fire management for planning purposes, primarily through the use of NFPA 1140 and the IWUIC. NFPA 1140 and the IWUIC are utilized as part of the Guide to Risk Ranking Characteristics for Wildland Fire Risk Reduction and Shelter-in-Place Building Selection (Appendix B). This assessment provides the direction for fuels management and wildland fire risk reduction. NFPA 1140 and the IWUIC are used for new construction projects to ensure wildfire-resistant building construction standards are met.

Planning at a particular site needs to fit within a context of regional planning, too. The following section reviews the variety of local plans that address wildfire in both Jefferson County and Boulder County, and more specifically within jurisdiction of the West Metro Fire Department and the City of Golden.

2.1.1 Local Plans and Policies

The STM Campus is situated within Golden city limits, while the Flatirons Campus is located in the town of Arvada, within the unincorporated portions of Jefferson County.

Jefferson County 2021 Hazard Mitigation Plan: Wildfires in Jefferson County are a significant concern. The geographic extent of the hazard is considered significant. The probability of future occurrences is considered likely, and the magnitude/severity for the event of record is critical. In addition, the hazard mitigation plan considers the hazard to have a high impact on the county. This equates to an overall impact rating of high.

The Indian Gulch Fire in 2011 near the STM Campus triggered a Fire Management Assistance declaration as a federal disaster. The Indian Gulch Fire occurred just west of Golden, between Clear Creek and Golden Gate Canyons from March 20 to 25. Strong winds coupled with very rugged terrain hampered firefighting efforts and allowed the wildfire to consume over 1,500 acres. Since 2000, four of the ten federal disaster declarations in Jefferson County were due to wildfire.

Boulder County Hazard Mitigation Plan: The Boulder County Hazard Mitigation Plan notes wildfire is high in overall significance, because it is:

- Significant in its geographic extent (impacting 10%–15% of the planning area)
- Highly likely (near 100% chance of occurrence in next year or happens every year)
- Critical in magnitude (25%–50% of property severely damaged, shutdown of facilities for at least 2 weeks, and/or injuries and/or illnesses result in permanent disability)
- Severe increased threat (highly likely to become more of a threat due to climate change).

Since 1969, Boulder County declared 24 federal disasters, of which 15 were from wildfire. Since 2000, there were nine wildfire-related federal disasters. Within Colorado, Boulder County has the highest number of residential structures within 500 miles of public wildland and ranks tenth overall in the west in terms of existing wildfire risk.

The closest fire near the Flatirons Campus resulting in a federal disaster declaration was the 2000 Walker Ranch/El Dorado fire (likely a human-caused fire), burning approximately 1,061 acres on September 15. No structures were lost, but more than 250 homes were threatened. Firefighting costs were estimated at $1.5 million. A Federal Emergency Management Agency Fire Management Assistance declaration was made to help cover firefighting costs. This area had previously undergone fuels treatment, which mitigated the severity of the fire.

West Metro Fire Department Community Wildfire Protection Plan (CWPP): The West Metro CWPP analyzed 12 communities within the West Metro jurisdiction. South Table Mountain, located east of the STM Campus itself, was identified as a WUI community and categorized as "high" in terms in the structural ignitability discussion.

This CWPP characterized South Table Mountain Park, just north of the STM Campus, as grass and shrub fuels, with some steep terrain and with high use. They suggested a public education program to raise awareness of wildfire hazards and to promote fire-safe use of the area. The CWPP stated, "These properties are kept in a natural condition, and no other recommendations regarding fuels, water supply, or operational factors are applicable."

This same CWPP described the topography, fuels, and structure ignition resistance of the STM Campus. It notes that topography is relatively flat on the southern side near Denver West Parkway; however, it becomes steeper to the north near the open space boundary. This report considers the Colorado State Patrol driving training track a possible ignition source.

It further notes that most buildings are of ignition-resistant construction, that access is excellent, and evacuation shouldn't be an issue in the event of a wildland fire.

Every CWPP requires recommended projects; this CWPP recommends that defensible space should be provided and maintained for buildings within 100 feet of natural fuels to prevent loss and provide safer access to firefighters. The CWPP includes a set of standards similar to those that appear in Appendix C. In contrast to the statement above, the CWPP recommends an interruption in the continuity of shrub fuels in the drainages running from the steeper terrain north of NREL buildings.

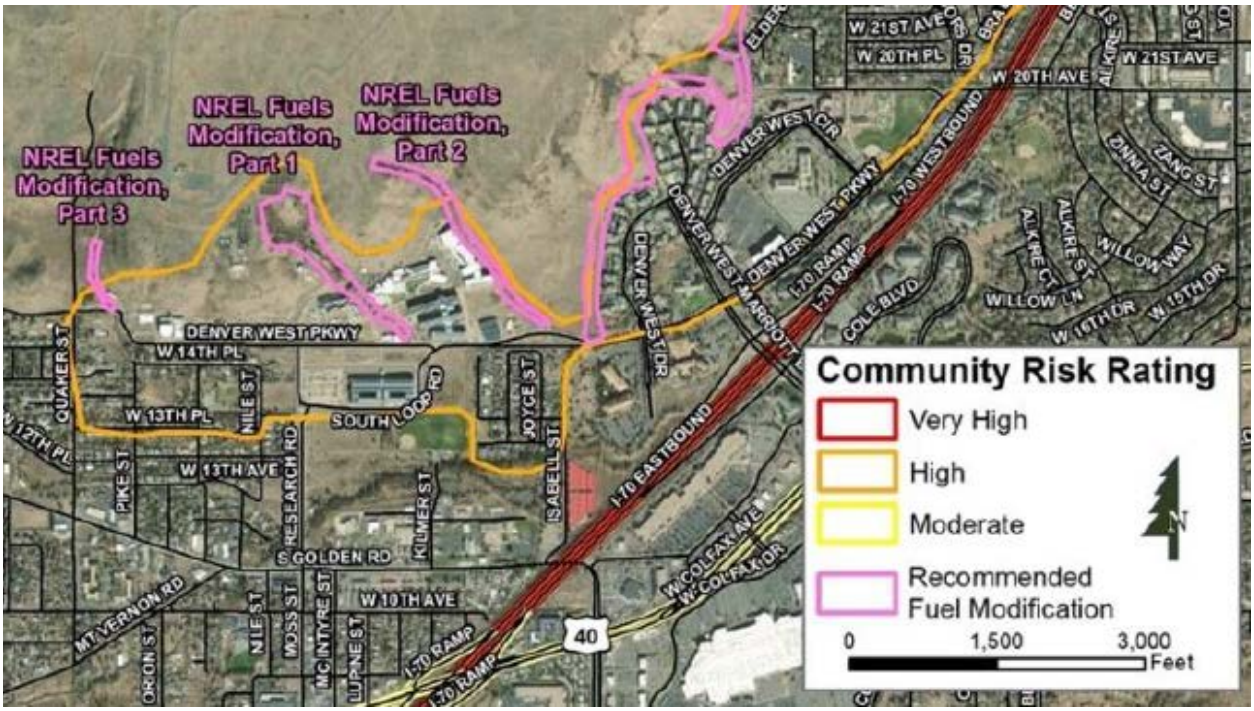

Figure 11. Locations of recommended fuel treatment to interrupt fuel continuity in drainages

City of Golden Fire Department CWPP: The City of Golden CWPP does not classify the NREL campus as an area of wildland, interface, or intermix, and it is not further addressed in the CWPP. This CWPP also identifies an area called South Table Mountain, but this is west of NREL.

The CWPP recommends that an evacuation pre-plan should be developed and reviewed annually for continued accuracy. The addition of signs at every junction should mark the route as a wildfire evacuation route. Primary and alternative roads should be inspected periodically at junctions to be sure they have reflective signage with at least 4-inch-tall characters.

Access road vegetation management similar to the roadside fuel management standards in Appendix C is recommended for primary and alternate access/evacuation routes. Limbing and thinning should be conducted in any section where fuels are found near the road.

The CWPP also considered criteria for shelter-in-place locations; in addition to those evaluated for the NREL buildings, the CWPP recommended shelter-in-place buildings have ventilation that can be easily shut down and isolated from the outside air to retard smoke infiltration.

3 Wildland Fire Management Goals and Strategies

Fires that burn natural vegetation on NREL's campuses are considered wildland fires. Fires will receive immediate fire suppression actions to minimize the area burned and ensure safety of the lab population. Wildland firefighting operations are based on fuels, weather, and topography.

Actions are taken to accomplish the specific suppression objectives for that individual fire, and its specific conditions. In addition to fire response, a crucial wildland fire management strategy will be used to emphasize pre-fire mitigating actions: ignition prevention, attentive fuel management, and fire response preparedness.

3.1 Wildland Fire Management Goals

Wildland fire management planning and wildland fire prevention includes sitewide considerations, interagency partnerships, regional strategies, and collaborative processes that are incorporated in wildland fire management strategies.

The primary goals of the NREL wildland fire management program are as follows:

1. Protect human health and safety
2. Stabilize the incident to reduce future impacts
3. Protect NREL facilities and research
4. Enhance community protection
5. Diminish risk and consequences of wildland fires
6. Maintain the health of the ecosystem.

To accomplish these goals, NREL will use four tools: fire prevention, fire suppression, emergency management, and recovery. Wildland fires that occur will be managed through suppression.

Wildland fire management goals provide the programmatic direction for the wildland fire program and are accordingly included within the context of the approved land-use planning and management process direction. These goals are intended to provide safe and effective implementation of the fire management plan.

The NREL fire management goals consider the site, institutional, and customer (DOE) needs. Since the NREL site is situated in both a wildland and suburban setting, fire management goals are focused on wildland/urban interface fire management. The objectives of wildland/urban interface fire management are: (1) to facilitate fire prevention and protection and minimize fire loss and damage to structures, other human development, and wildland resources; (2) to prevent a structure fire from spreading into wildland fuels; and (3) to encourage property owners (while NREL owns the STM and Flatirons Campuses, it leases several other buildings[1] and has

[1] This was true as of December 2020 and reflected in current maps of the South Table Mountain Campus (also called the Golden Campus).

numerous neighboring properties) to take an active role in establishing and maintaining their own fire prevention and safety measures in the wildland/urban interface.

3.1.1 Sitewide Assets at Risk

The NREL STM and Flatirons Campuses include many different types of assets that need to be protected against wildland fires, the most important of which are the employees and visitors on the site. Additional assets include long-term research projects of national interest, unique facilities, and infrastructure that provides support to NREL and partnering scientific organizations. Environmental considerations such as protection of "ancient soils" and the jumping mouse are also included as valuable assets.

NREL physical assets and their respective susceptibility to damage or loss by fire are discussed in depth in Appendix B.

Table 1. List of buildings With and Without Wildland Exposure

South Table Mountain (STM) Campus Buildings or Structures With Direct Wildland Urban Interface (WUI) Exposure	
• Bulk Storage Building	• High-Flux Solar Furnace (Mesa Top)
• Education Center	• Solar Industrial Mesa Test Area (Mesa Top)
• Energy Systems Integration Facility (ESIF)	• Solar Radiation Research Laboratory (Mesa Top)
• ESIF Hydrogen Pad	• Thermal Test Facility
• Ethanol Storage Tank (near the Integrated Biorefinery Research Facility)	• Vehicle Testing and Integration Facility
• Facilities Maintenance Building	• Waste Handling Facility
STM Campus Buildings With No Direct WUI Exposure	
• Café	• Research Support Facility
• Field Test Laboratory Building	• Science and Technology Facility
• Integrated Biorefinery Research Facility	• Shipping and Receiving
• Outdoor Test Facility	• Solar Energy Research Facility
• Parking Garage	
Flatirons Campus Buildings or Structures With Direct WUI Exposure	
• Building #101 Site Entrance Building	• Building #254 Structural Test Lab
• Building #152 Fire Pump House	• Building #255 2.5-MW Dynamometer Spin Test Facility
• Building #248 Trailer 126250	• Building #256 Model Test Laboratory
• Building #249 Trailer 126251	• Building #257 Trailer 12652
• Building #249 Trailer 126253	• Building #258 5-MW Dynamometer Spin Test Facility
• Building #251 Administration and Engineering	• Building #260 Composites Manufacturing Education and Technology
• Building #252 Small Switchblade Test Facility	• Controllable Grid Interface
• Building #253 Switchgear Building	• M-1A Met Equipment Storage
• Building #253A Old Switchgear Building	• Research Operations Facility

3.1.2 Adjacent Properties at Risk

Risk to properties adjacent to the STM and Flatirons Campuses reinforces the need for immediate containment in the event of a wildfire. The STM Campus is bounded to the southeast by the Richard Heights residential neighborhood of single-family homes and the Denver West Office Park development; to the east by a narrow section of South Table Mountain Park, two apartment complexes, and additional office buildings that are part of the Denver West Office Park; to the north by South Table Mountain Park and beyond that The Club at Rolling Hills golf facility; to the southwest by single-family residential developments and an office building occupied by the Colorado State Forest Service; and to the south by the Jefferson County-owned

Camp George West Park. The open space to the north and south of the STM Campus presents a significant wildfire hazard.

The Flatirons Campus is bounded to the south and east by the Rocky Flats National Wildlife Refuge, operated by the U.S. Fish and Wildlife Service; to the west by two functioning industrial facilities (a mining equipment services provider and a concrete batch plant) and a remnant stone materials provider where no buildings are currently located; and to the north by undeveloped land and open space owned by the City of Boulder. Near the site to the south and southwest are two stone quarries and a number of industrial, storage, and restaurant buildings. The unimproved and undeveloped land to the north, south, and east of the Flatirons Campus would present a significant wildfire hazard.

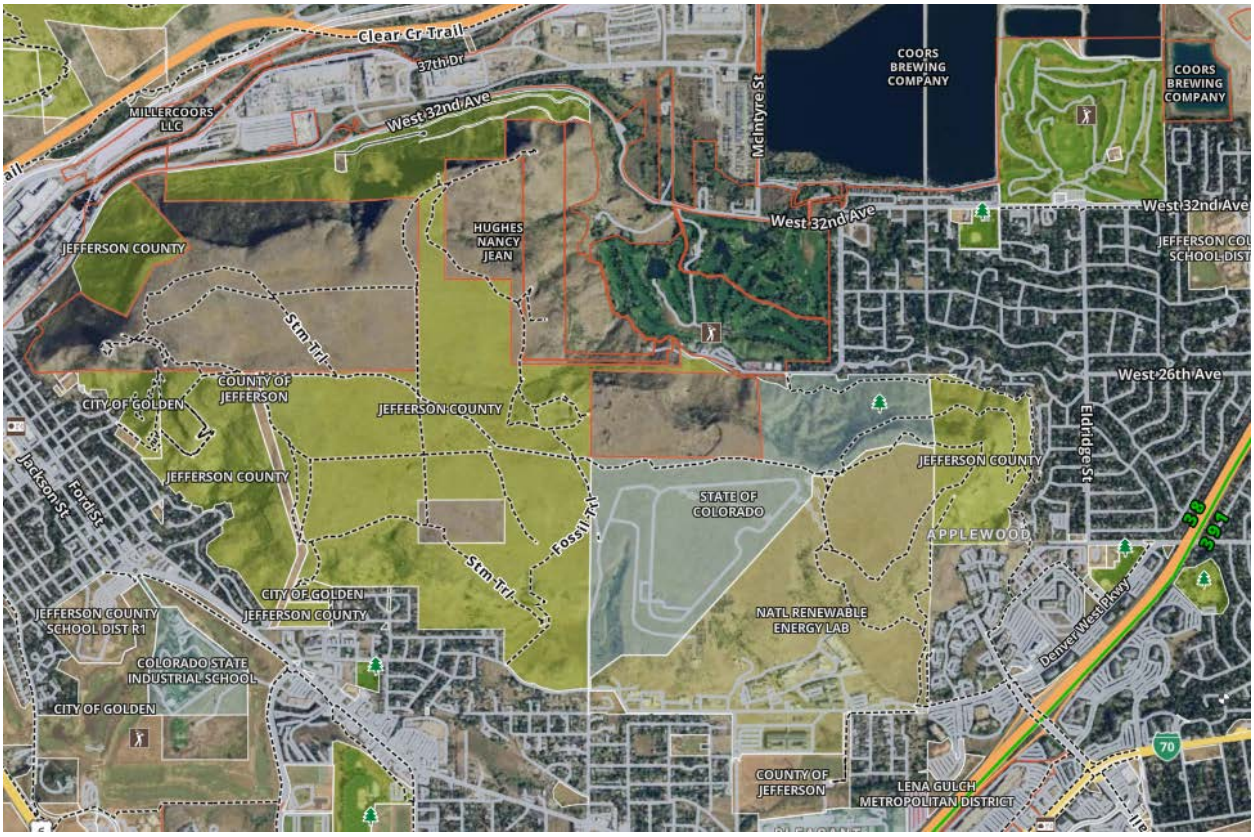

Figure 12. Context of NREL showing adjacent land ownership of the STM Campus

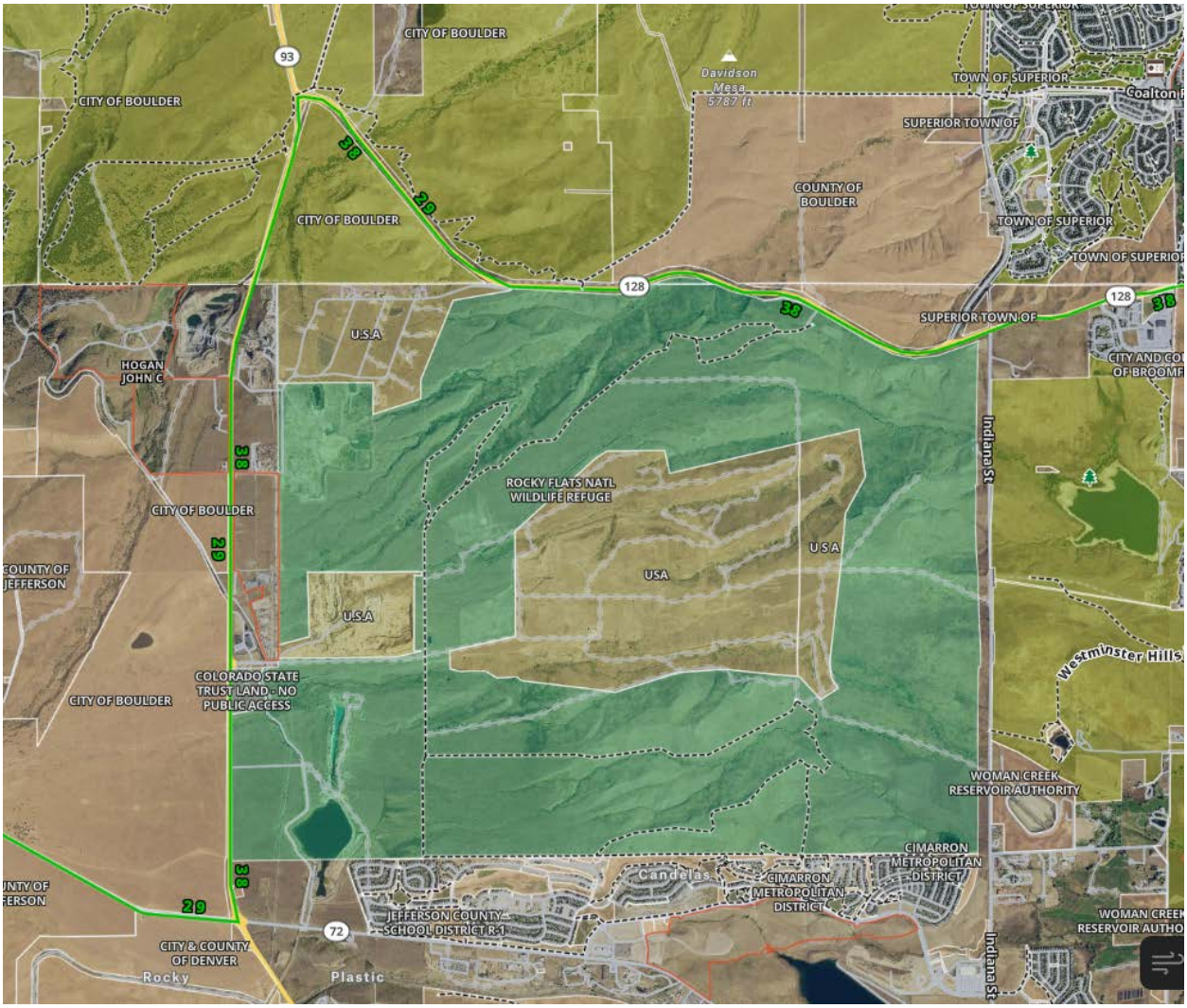

Figure 13. Context of NREL showing adjacent land ownership of the Flatirons Campus

3.2 Wildland Fire Management Strategies

To support the wildland fire management goals, a strategy to manage fuels to limit wildland fire intensity and spread is necessary and critically important. This strategy serves to protect lives and property when fires burn on the NREL site and when a widespread fire burns in the near vicinity. During a catastrophic fire, fire suppression forces may be committed to residences and life-safety concerns outside NREL facilities.

An additional strategy is to prevent wildland fires from penetrating and igniting buildings through managing vegetation so that it produces at most a 2-foot flame length in a wildfire. This allows for suppression of low-intensity, slow-moving wildfires with minimal emergency response.

Lab areas of highest priority for treatment in support of these strategies include:

- Areas next to buildings

- Major egress and emergency ingress routes
- Areas of crown fire potential.

4 Wildland Fire Program Components

The components of NREL's wildland fire program include four core activities: fire prevention, fire suppression, emergency management, and recovery.

4.1 General Information

The following background information supplements the four main activities.

4.1.1 Range of Potential Fire Behavior

Wildland fire involving on-site or off-site vegetative fuels presents a risk to NREL facilities. The impact of fire involving vegetative fuels includes:

- Fuels which, when burned, produce enough heat to make firefighting untenable, shatter windows and/or ignite building exteriors
- Embers, which may number in the thousands, each potentially starting new fires—these are lofted and land on ignitable grass and congregate in building crevices
- Highly flammable ("flashy") fuels such as dry grass, and rabbit brush which are likely to start numerous new fires from embers and act as to spread fire to less ignitable fuels.

As part of this plan, wildfire behavior modeling quantified the worst-case fire behavior, and this information is included in Section 4.1.1.2.

4.1.1.1 Fire Modeling: Background Information

The NREL Colorado campuses and immediate vicinities are characterized by a diverse range of existing vegetation cover, which is defined as percent canopy cover by life form. The classes of vegetation occurring on the STM Campus and the Flatirons Campus range from high-intensity developed areas to dense herb, shrub, and tree cover, as depicted in Figures 14 and 15, and as outlined in Tables 2 and 3, respectively.

The STM Campus is dominated by two classes of vegetation: 11%–49% shrub cover, which characterizes 43% of the total campus area, and 12%–70% herb cover, which characterizes 35% of the total campus area. The core of the STM Campus facilities, located in the southern edge of the campus area, is primarily medium- and high-intensity developed areas, with some patches of development characterized by upland shrubland and upland herbaceous vegetation cover. The northeastern buffer area is primarily developed with upland deciduous forest cover, while the northwestern and western buffer zone is primarily large swaths of low shrub and high herb (i.e., grass) cover; the southwestern and southeastern buffer zones are a mix of low-intensity developed areas and developed areas with upland evergreen forest cover.

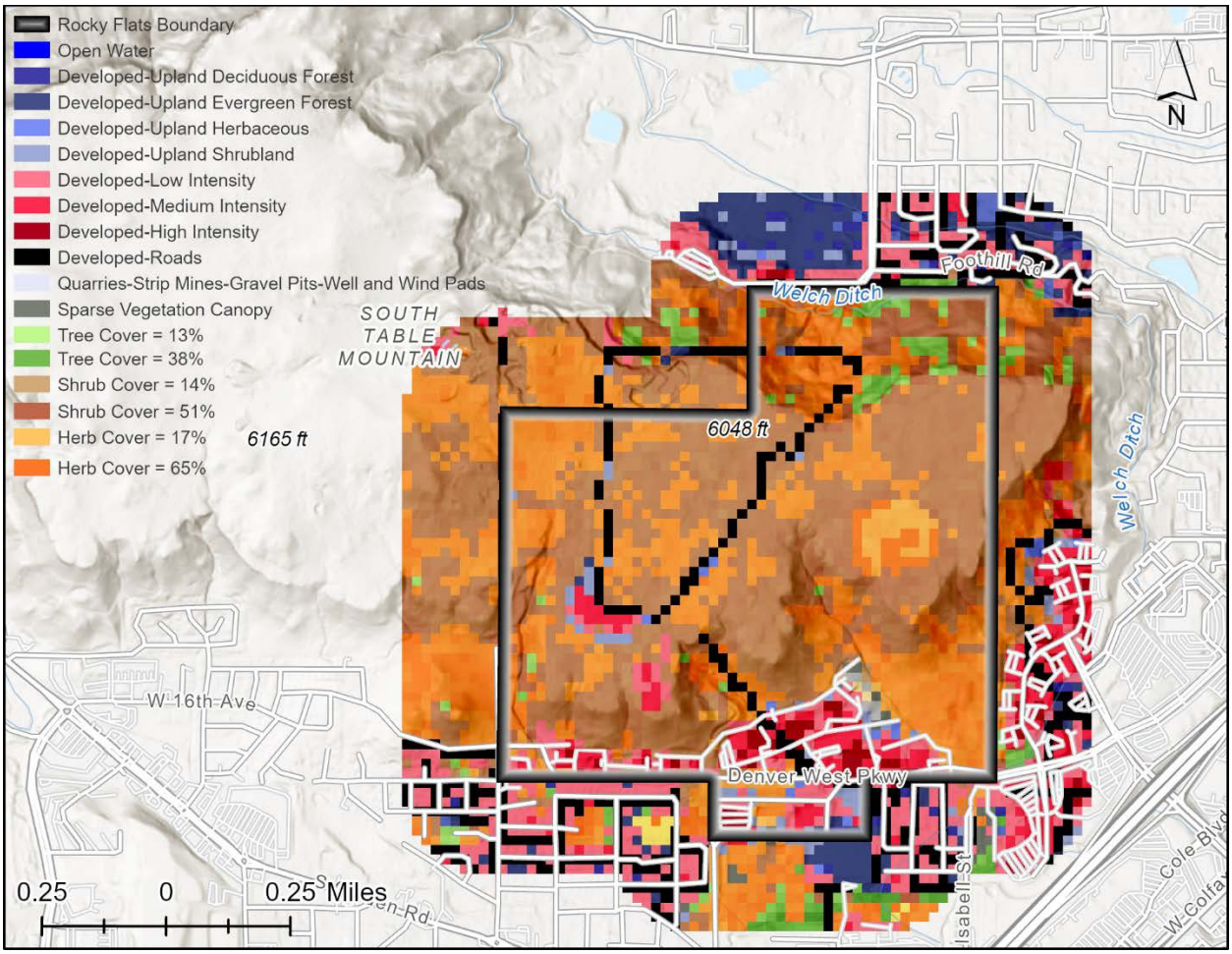

Figure 14. Map of existing vegetation cover on the STM Campus

Source: LandFire (2016)

Table 2. Existing Vegetation Cover on the South Table Mountain Campus

Existing Vegetation Cover Class	Acres	Percent
Developed-High Intensity	10.0	2%
Developed-Low Intensity	27.8	5%
Developed-Medium Intensity	24.5	4%
Developed-Roads	29.7	5%
Developed-Upland Deciduous Forest	0.9	0.2%
Developed-Upland Evergreen Forest	4.0	1%
Developed-Upland Herbaceous	2.4	0.4%
Developed-Upland Shrubland	11.6	2%
Herb Cover = 12%–70%	202.3	35%
Shrub Cover = 11%–49%	252.2	43%
Tree Cover = 18%–38%	14.2	2%
Sparse Vegetation Canopy	1.9	0.3%
National Agricultural Statistics Service–Wheat	0.5	0.1%
Barren	1.4	0.2%

The Flatirons Campus is dominated overwhelmingly by 17%–60% herb cover (i.e., grassland), representing 80% of the total campus area. The northern core of the Flatirons Campus is characterized by high- and medium-intensity development with some small patches of developed areas covered by upland shrubland and upland herbaceous vegetation. The western buffer is characterized by a mix of high-, medium-, and low-intensity development, developed areas with upland shrubland vegetation cover, developed roads, dense herb cover, and mixed-density shrub cover. The northern, eastern, and southeastern buffer zones, like the majority of the campus area, is dominated by mixed-density herb cover (grassland), with some patches of mixed-density shrub cover and some stretches of tree cover abutting the campus' southeastern edge. The southwestern buffer transitions from mixed-intensity developed areas to a patch of open water and a barren quarry vegetation type.

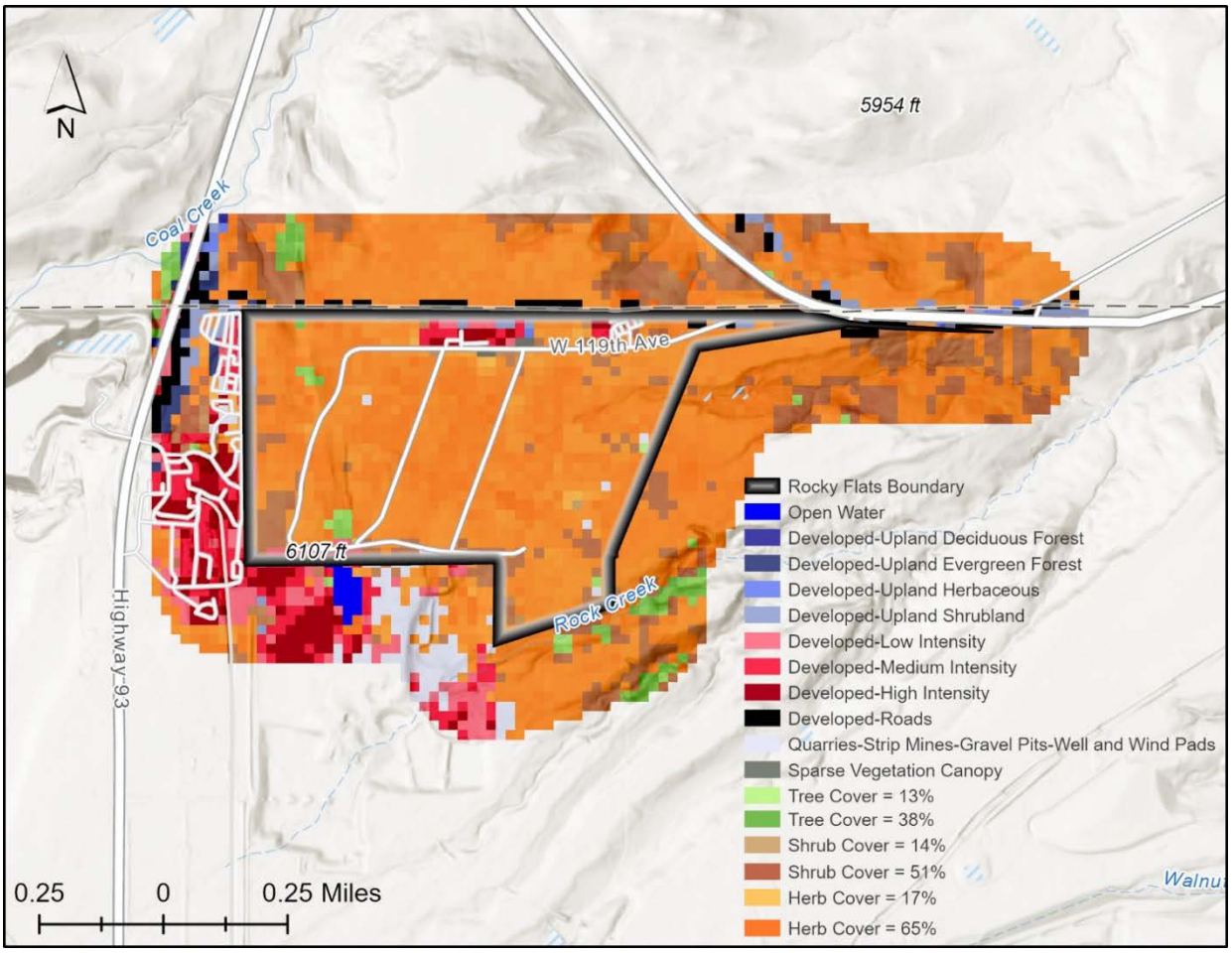

Figure 15. Map of existing vegetation cover on the Flatirons Campus

Source: LandFire (2016)

Table 3. Existing Vegetation Cover on the Flatirons Campus

Existing Vegetation Cover Class	Acres	Percent
Developed-High Intensity	3.3	1%
Developed-Low Intensity	8.5	3%
Developed-Medium Intensity	5.0	2%
Developed-Roads	4.3	1%
Developed-Upland Evergreen Forest	0.7	0.2%
Developed-Upland Herbaceous	0.7	0.2%
Developed-Upland Shrubland	4.5	1%
Herb Cover (17%–60%)	247.2	80%
Shrub Cover (14%–51%)	26.1	8%
Tree Cover (13%–34%)	3.8	1%
Sparse Vegetation Canopy	0.9	0.3%
Quarries-Strip Mines-Gravel Pits-Well and Wind Pads	3.1	1%
Open Water	0.5	0.2%

A quantitative method for predicting fire behavior based on mathematical models that require descriptions of fuel properties as inputs was performed as part of the development of the WFMP. These models mapped both the wildland fuel characteristics and vegetation types, incorporating much of the existing vegetation cover data discussed above. Wildland fuel characteristics include the site's surface fuel and canopy fuel properties. The collections of fuel properties have become known as fuel models. Surface fuel models describe the vegetation in terms of fuels that might carry a fire near the ground, and do not include foliage or other fuels in the tree canopy (canopy fuels). A National Wildfire Coordinating Group (NWCG) document, *Aids to Determining Fuel Models for Estimating Fire Behavior*, was used in combination with professional judgment to select surface fuel models (Anderson 1982). Another NWCG document, *How to Predict the Spread and Intensity of Forest and Range Fires*, provided guidance on appropriate customization of the models and appropriate fire environmental inputs (Rothermel 1983).

As with the existing vegetation cover data discussed above, both surface and canopy fuel characteristics for the area were obtained from LandFire, a national mapping effort by the U.S. Forest Service that characterizes both vegetation and fuels on a 30-meter resolution. The LandFire files also included vegetation and terrain data (slope, aspect, and elevation).

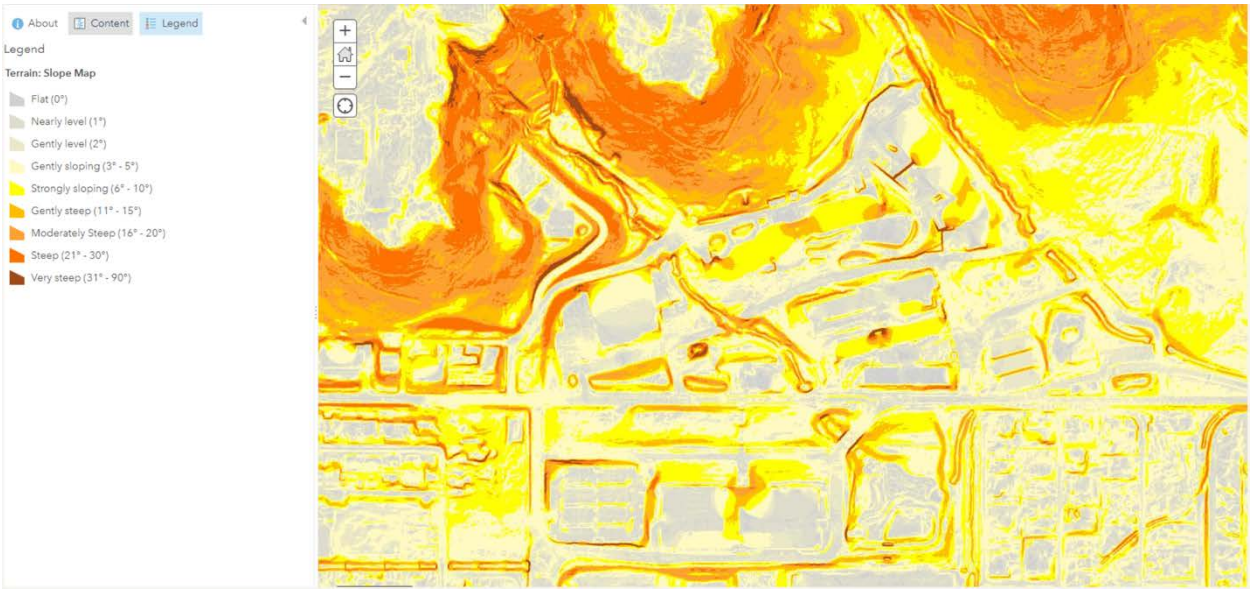

Figure 16. Slope map of the STM Campus

Source: LandFire (2016)

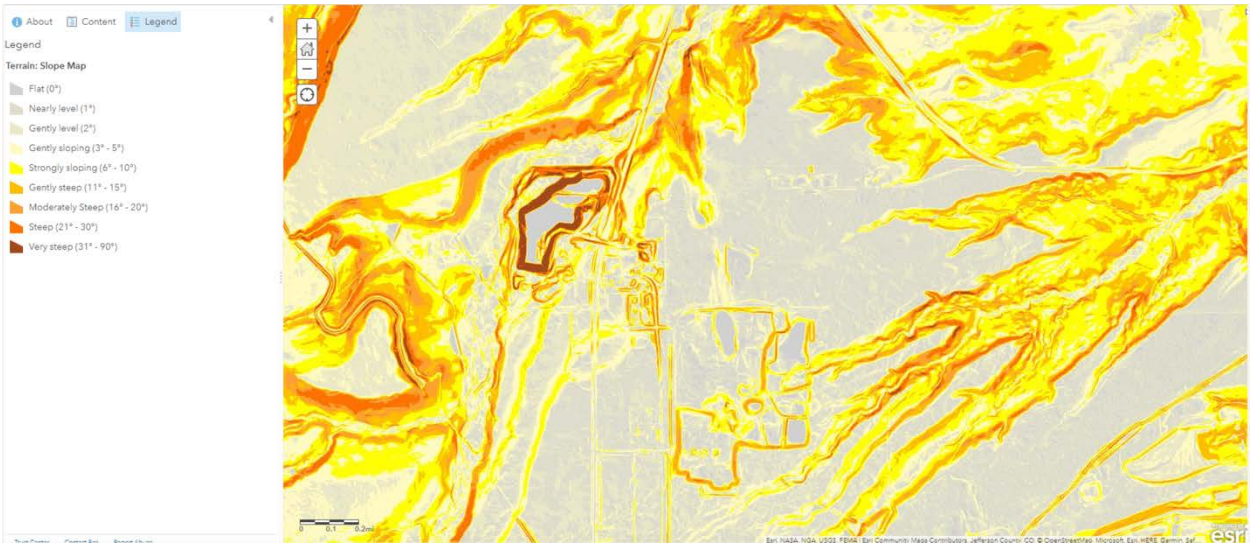

Figure 17. Slope map of the Flatirons Campus

Source: LandFire (2016)

Weather conditions that closely mimicked the Marshall Fire were selected for fire behavior prediction. FAMWEB data tracking actual weather observations from the nearest remote automated weather stations (RAWS; MesoWest n.d.) to each NREL campus (Corral Creek and Pickle Gulch) during the period from Jan. 1, 2015, to March 31, 2022, were used as inputs for the fire behavior modeling program (FlamMap).

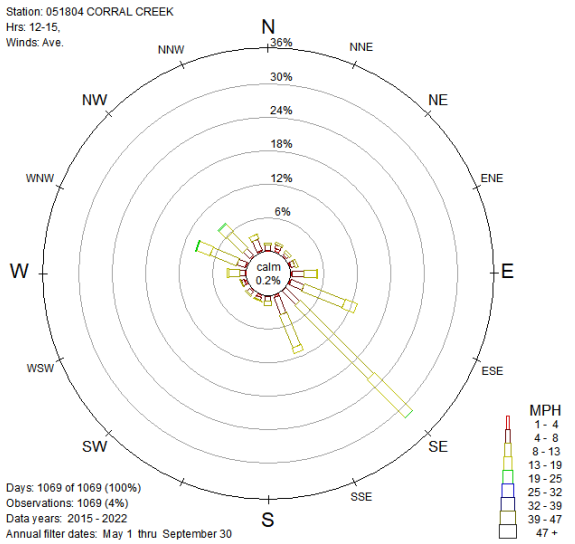

Figure 18. Wind behavior in the NREL vicinity per Corral Creek RAWS station, as used in fire behavior modeling

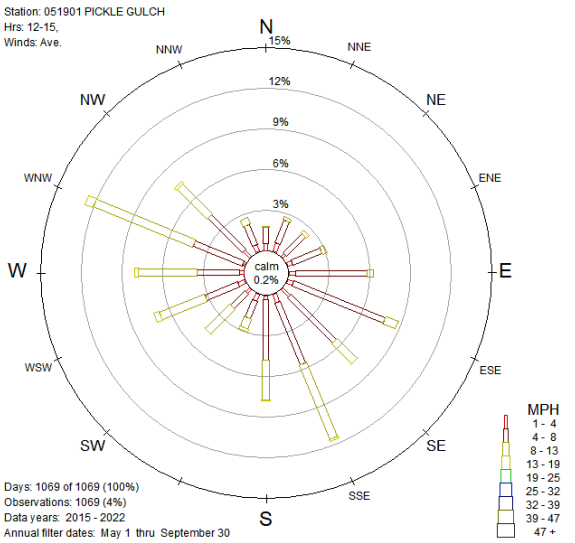

Figure 19. Wind behavior in the NREL vicinity per Pickle Gulch RAWS station, as used in fire behavior modeling

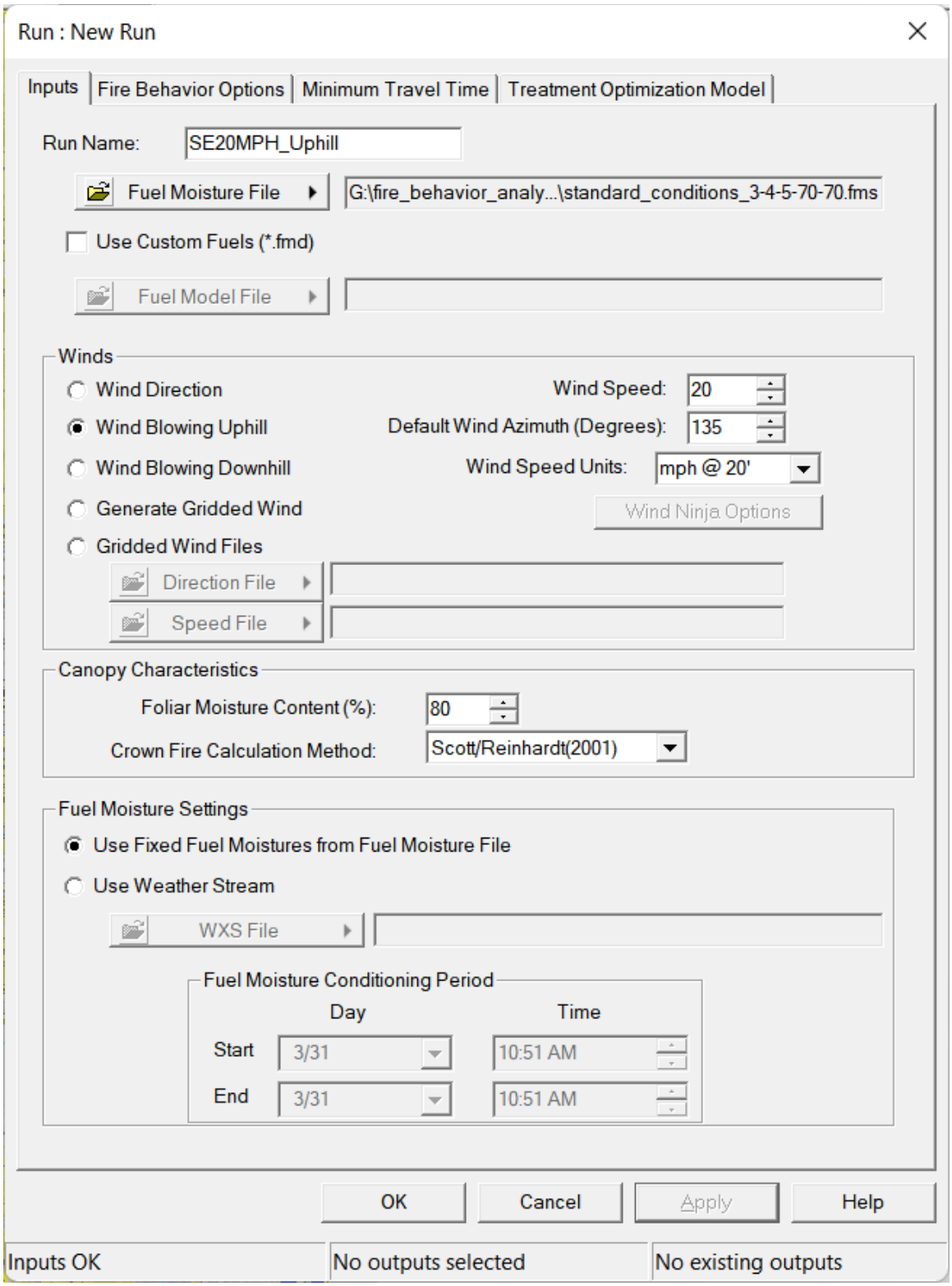

Figure 20. Wind conditions and foliar moisture content data inputs for fire behavior modeling

The vegetation types and surface fuel models on NREL's two Colorado campuses are given in Tables 4 and 5:

Table 4. South Table Mountain Campus Acres by Fuel Model and Vegetation Type

Fuel Model Code	Fuel Model Name	Fuel Model Description	Acres	Percent
NB1	Urban/Developed	Modeled as unburnable	92.8	16%
NB3	Agricultural	Unburnable	0.5	0%
NB9	Bare Ground	Unburnable	3.3	1%
GR1	Short, Sparse Dry Climate Grass	Short, sparse dry climate grass is short, naturally or heavy grazing, predicted rate of fire spread and flame length low	1.4	0.5%
GR2	Low Load, Dry Climate Grass	Low load, dry climate grass primarily grass with some small amounts of fine, dead fuel, any shrubs do not affect fire behavior	272.4	87%
GR3	Low Load, Very Coarse, Humid Climate Grass	Very coarse grass, grass height about 2 feet; spread rate high, flame length moderate	180.2	31%
GS1	Low Load, Dry Climate Grass-Shrub	Low load, dry climate grass-shrub shrub about 1 foot high, grass load low, spread rate moderate and flame length low	25.6	4.4%
GS2	Moderate Load, Dry Climate Grass-Shrub	Moderate grass load, dry climate grass-shrub shrub 1–3 feet high, grass load moderate, spread rate high and flame length moderate	251.5	43%
SH7	Very High Load, Dry Climate Shrub	Very heavy shrub load dry climate shrub, woody shrubs and shrub litter, fuel bed depth about 4–6 feet spread rate high and flame very high	1.7	0%
TL2	Low Load Broadleaf Litter	Low load, compact; spread rate very low, flame length low	0.9	0%
TL3	Moderate Load Conifer Litter	Moderate load conifer litter; spread rate very low, flame length low	4.0	1%
TL5	High Load Conifer Litter	High load conifer litter, light slash or mortality fuel; spread rate low, flame length low	12.3	2.1%
Total Acres			**583.0**	

Table 5. Flatirons Campus Acres by Fuel Model and Vegetation Type

Fuel Model Code	Fuel Model Name	Fuel Model Description	Acres	Percent
NB1	Urban/Developed	Modeled as unburnable	24.2	8%
NB9	Bare Ground	Unburnable	2.8	1%
GR1	Short, Sparse Dry Climate Grass	Short, sparse dry climate grass is short, naturally or heavy grazing, predicted rate of fire spread and flame length low	1.4	0.5%
GR2	Low Load, Dry Climate Grass	Low load, dry climate grass primarily grass with some small amounts of fine, dead fuel, any shrubs do not affect fire behavior	272.4	87%
GS1	Low Load, Dry Climate Grass-Shrub	Low load, dry climate grass-shrub shrub about 1 foot high, grass load low, spread rate moderate and flame length low	4.3	1%
GS2	Moderate Load, Dry Climate Grass-Shrub	Moderate grass load, dry climate grass-shrub shrub 1–3 feet high, grass load moderate, spread rate high and flame length moderate	4.5	1%
SH7	Very High Load, Dry Climate Shrub	Very heavy shrub load dry climate shrub, woody shrubs and shrub litter, fuel bed depth about 4–6 feet spread rate high and flame very high	1.4	0.5%
TL3	Moderate Load Conifer Litter	Moderate load conifer litter; spread rate very low, flame length low	0.9	0.3%
Total Acres			**311.9**	

Mowed grass and unburnable areas were by far the most common surface fuel models on the lab's site.

Moderate load dry climate grass-shrub is the most common fuel type on the STM Campus, followed by low load very coarse humid climate grass. These grassland and grass-shrub fuel types are associated with extremely fast-moving, moderate-intensity fires, as discussed below.

The Flatirons Campus, meanwhile, is overwhelmingly dominated by low load dry climate grass, representing 87% of the total campus area. This grassland fuel type is associated with low-intensity but extremely fast-moving fire behavior, as discussed below.

Figures 21 and 22 display the various fuel types across the landscapes of the two NREL campuses. These were used as an input to the fire model.

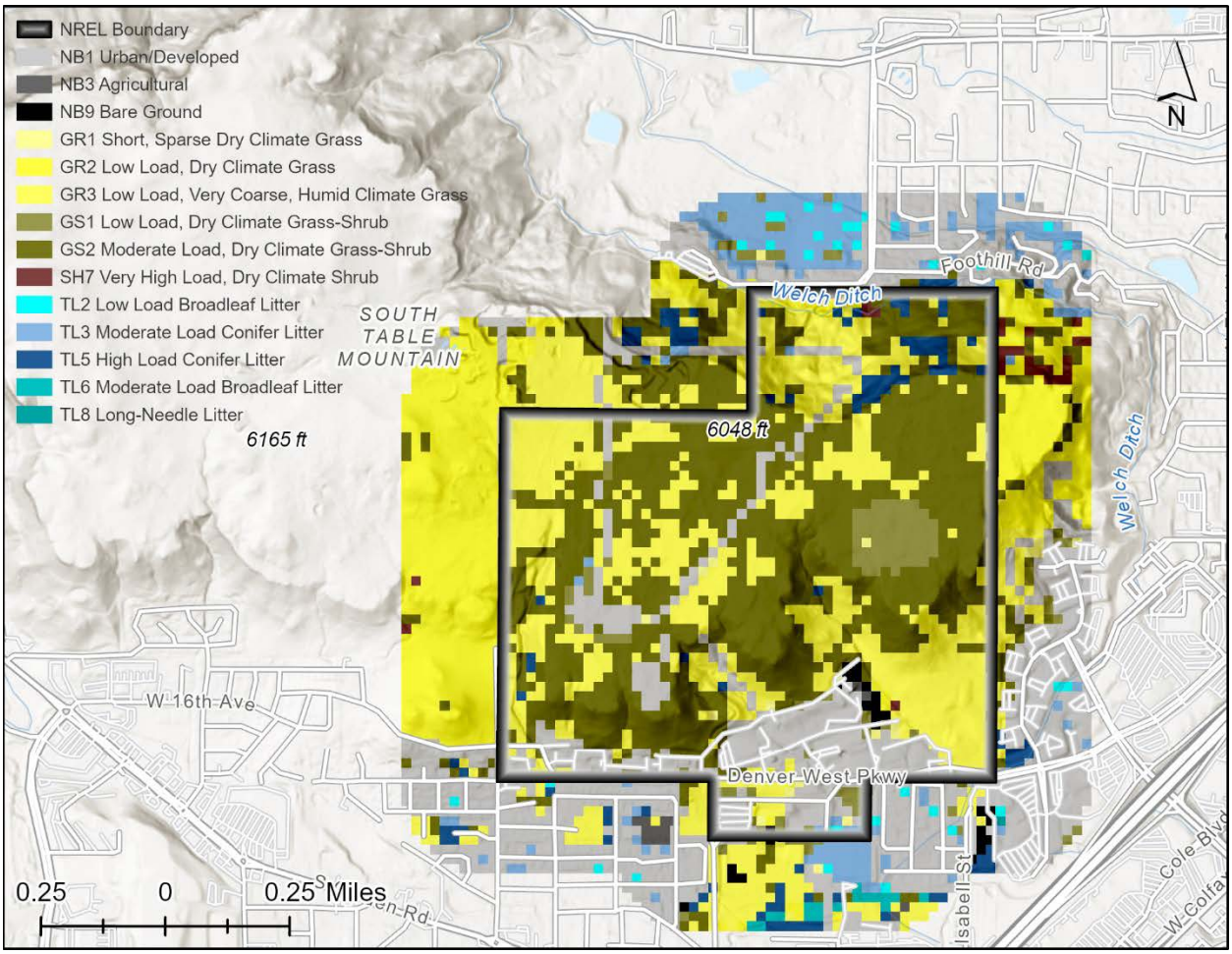

Figure 21. Fuel characteristic map of the STM Campus

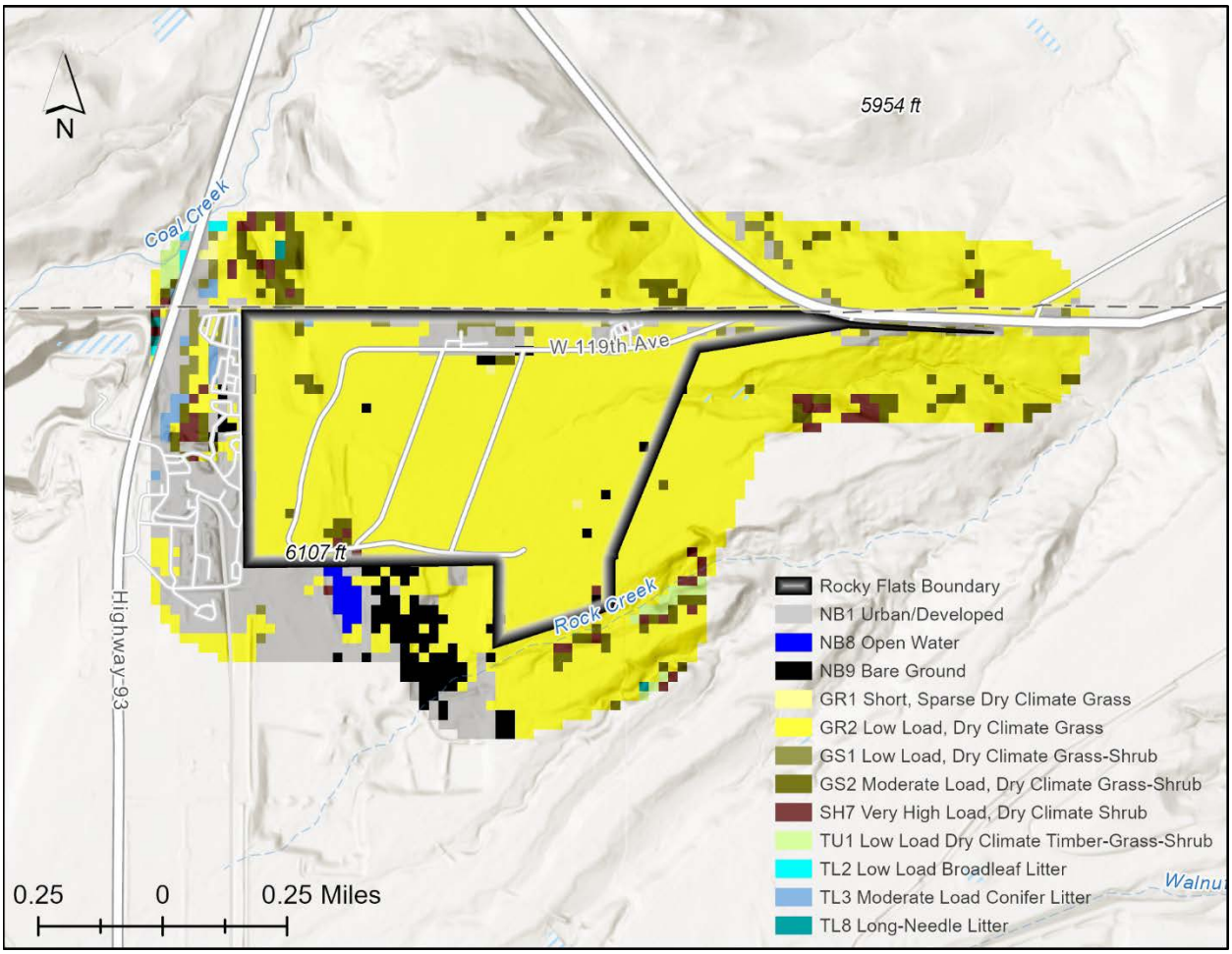

Figure 22. Fuel characteristic map of the Flatirons Campus

4.1.1.2 Fire Modeling: Results

This section reports the results of wildland fire behavior prediction simulation, in terms of flame lengths, rates of fire spread, and crown fire potential. In both campuses, the flame lengths were generally moderately high and the spread rates were fast, both reflective of fire behavior in a grassy fuel type. Similarly, because few trees are present, torching is rare and crown fire is nonexistent.

Flame Length

Flame length is often correlated to the ability to control a fire. A flame length of 4 feet is the limit of what can be attacked with hand crews or other forms of direct attack, and 8 feet is usually considered a cutoff point for strategic firefighting decisions on whether to attack the fire directly, or instead attempt control through indirect methods. Attacking the fire directly involves efforts to slow the flaming front at its head—where it is advancing fastest—or "anchor, flank, and pinch" fire control efforts along the fire's flanks. Indirect attack involves fire control methods well ahead of the fire (using backfires or retardants).

Flame lengths are often used as a proxy for fire intensity because they are highly correlated to higher natural resource impacts. Flame length is the result of one other fire prediction output: fireline intensity times a constant. Fireline intensity is the result of two fuel model inputs (heat yield or the British thermal units [BTU] per pound of fuel and the weight of available fuel) along with one other fire prediction output (rate of spread). Flame length, reported in feet, is the numerical characteristic that encompasses the flaming front of a fire and its interaction with wind and the fire's radiation and convection heat transfer to adjacent fuel (U.S. Forest Service 2018).

Figures 23 and 24 are maps of the expected fire behavior on NREL's STM and Flatirons Campuses, respectively. Forty-one percent of the STM Campus, mainly those portions of the campus dominated by grass-shrub fuels, is predicted to burn with flame lengths between 4 and 8 feet, with significant patches of dry climate grass along the campus' western edge and southeastern corner (amounting to 40% of the total campus area) predicted to burn with flame lengths between 8 and 12 feet. The more developed areas on the southern edge of the campus and within its northern and southern boundaries are either not predicted to burn at all or would burn with flame lengths less than 4 feet, although a narrow swath of very high dry climate shrub to the campus' northeast and tiny parcels of mostly high load conifer litter dotting the southern buffer area that are predicted to burn with flame lengths greater than 20 feet.

The overwhelming majority of the Flatirons Campus—90% of the total campus area—is dominated by dry climate grass that is predicted to burn with flame lengths between 4 and 8 feet. Small patches of very high dry climate shrub in the campus' northwest and eastern buffer areas are predicted to burn with flame lengths greater than 20 feet, which could confound the best fire suppression efforts. However, most of these patches of severe predicted fire intensity in the campus' western buffer area abut developed areas that are not predicted to burn, mitigating the potential fire hazard.

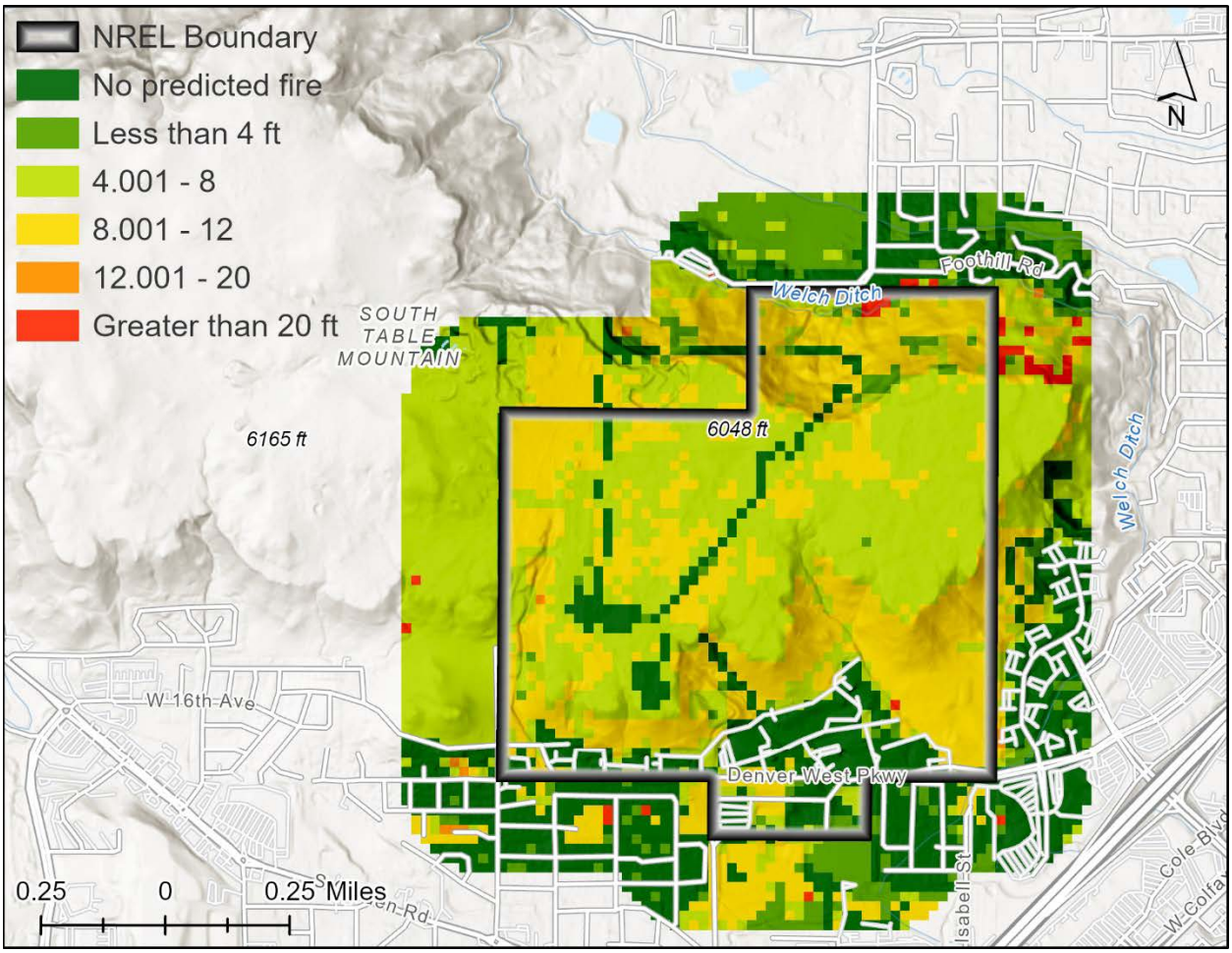

Figure 23. Map of flame length distribution showing context of the STM Campus

Table 6. Predicted Flame Lengths for the STM Campus

Flame Length Category	Acres	Percent
No predicted fire	96.6	17%
<4 feet	14.2	2%
4–8 feet	237.7	41%
8–12 feet	231.8	40%
12–20 feet	0.2	0.04%
>20 feet	2.6	0.4%
Total Acres	583.2	

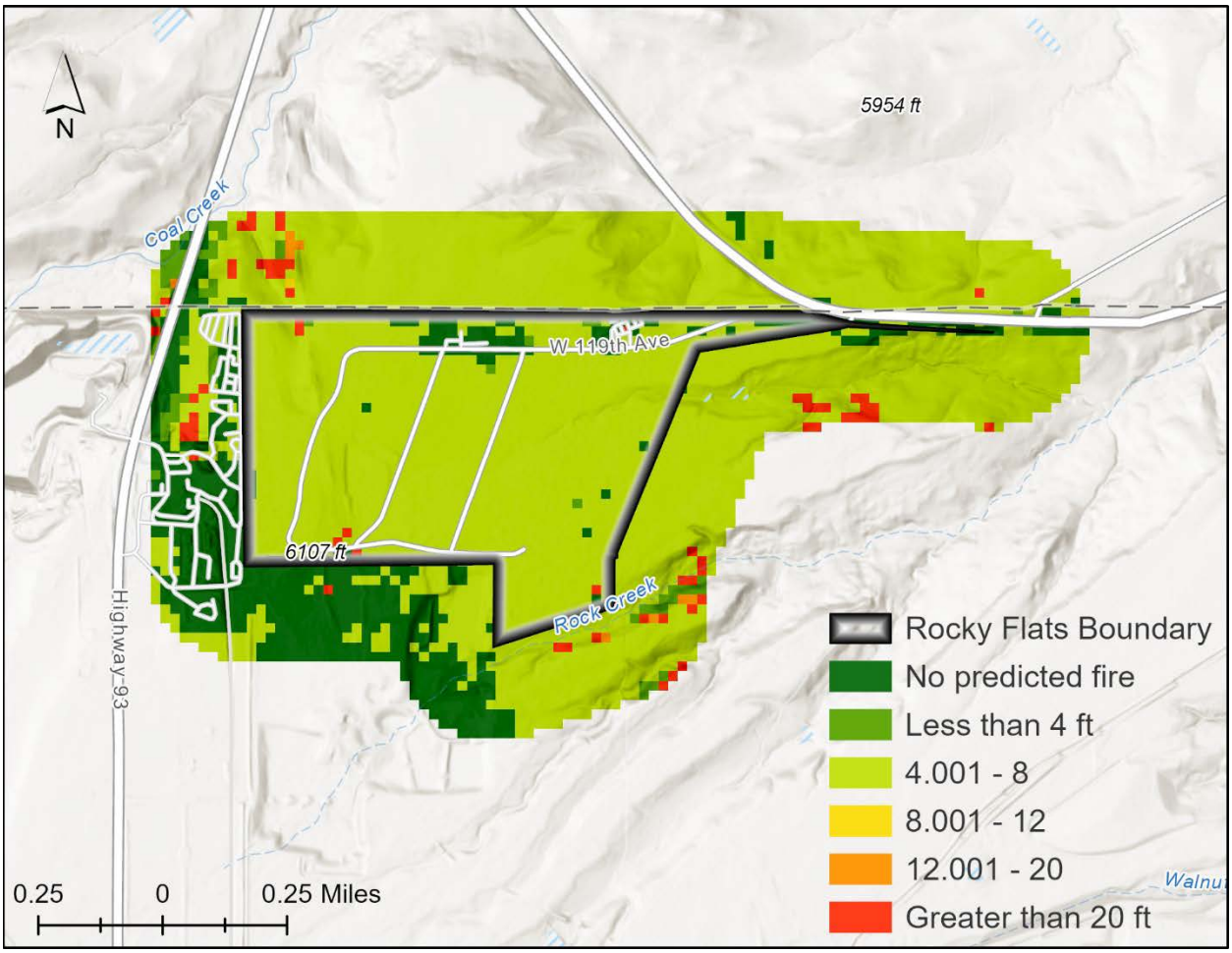

Figure 24. Map of flame length distribution showing context of the Flatirons Campus

Table 7. Predicted Flame Lengths for the Flatirons Campus

Flame Length Category	Acres	Percent
No predicted fire	27.1	9%
<4 feet	2.4	0.8%
4–8 feet	280.7	90%
8–12 feet	0.0	0%
12–20 feet	0.0	0%
>20 feet	1.9	0.6%
Total Acres	312.0	

Rate of Spread

Rate of spread, or the rate at which a fire moves across a specific fuel bed, is a much more complicated parameter to determine. Factors used to determine rate of spread include energy released from the fuel wind and slope factor, density of the fuel bed, heat of pre-ignition (i.e., amount of heat required to ignite 1 pound of fuel), a heat source, and a heat sink along with other propagating ratios and coefficients (U.S. Forest Service 2018). The wildland fire behavior predictions generally underpredict the rate of fire spread with extremely fast wind speeds. Recent research offers an easy and more accurate prediction with simply multiplying the current windspeed by 0.2 (Cruz, Alexander, and Fernandes 2022).

Rate of spread is the measurement of how fast the head (or leading front) of a surface fire advances. The metric of rate of spread is of concern when considering fire containment, response times, and evacuation. A slow-moving fire (for example, slower than 1/8 mile per hour, or 11 feet per minute) might be easily contained, whereas fast-moving fire (a fire moving faster than 1 mile per hour, or 88 feet per minute) challenges containment and has the potential to move into high-value sensitive areas before containment can occur. While an extreme rate of spread does not necessarily result in a problematic fire, a fast-moving fire coupled with high flame lengths cannot be suppressed with a hand crew.

Predicted rates of spread for both the STM and Flatirons Campuses—as mapped in Figures 25 and 26, respectively—are overwhelmingly high. While most (but not all) of the developed core of the STM Campus in the southern sector of the campus is not predicted to burn, fully three quarters of the total campus area is predicted to burn with fast rates of spread over 40 feet per minute (slightly less than 1/2 mile per hour). These areas are entirely dominated by dry climate grass and dry climate grass-shrub. Most of the STM Campus' similarly vegetated buffer zone to the west, northwest, and east is also predicted to burn with extreme rates of spread, though some coniferous-dominated patches in the northern buffer zone are expected to burn with comparatively low rates of spread between 1 and 10 feet per minute.

Almost the entirety of the Flatirons Campus is predicted to burn with equally extreme rates of spread, with nearly 90% of the campus area modeled with rates of spread over 40 feet per minute. This is primarily due to the dry climate grass that dominates almost the entirety of the campus area. Only the most developed areas in the campus' north are not predicted to burn. Most of the grassland-dominated buffer zone to the campus' north and southeast are predicted to burn with very fast rates of spread (greater than 44 feet per minute), although much of the developed areas to the campus' immediate west are not predicted to burn.

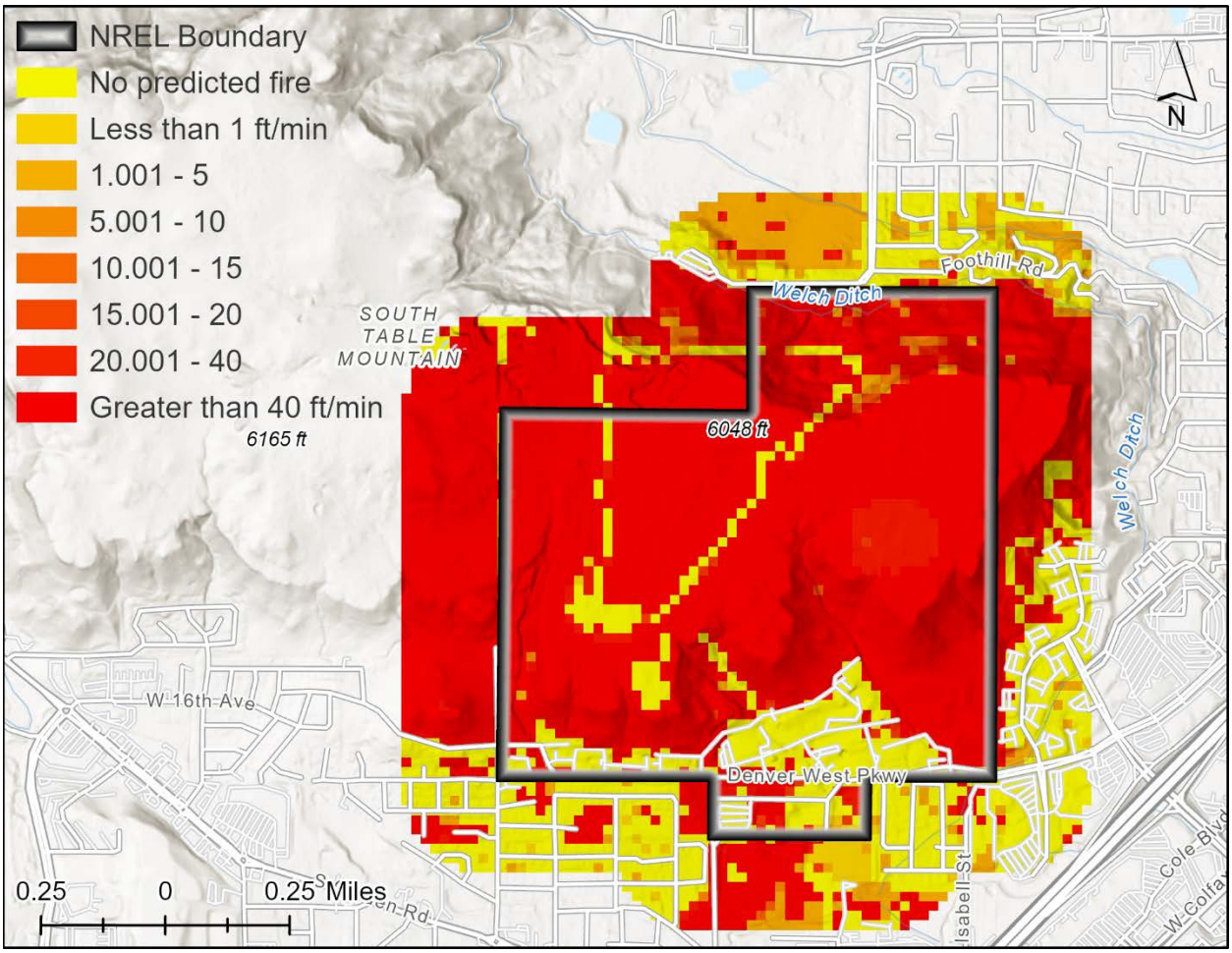

Figure 25. Map of rate of spread distribution showing context of the STM Campus

Table 8. Predicted Rates of Spread for the STM Campus

Rate of Spread Category	Acres	Percent
No predicted fire	96.6	17%
<1 foot/minute	3.3	0.6%
1–5 feet/minute	4.5	0.8%
5–10 feet/minute	3.3	0.6%
10–15 feet/minute	1.9	0.3%
15–20 feet/minute	4.3	0.7%
20–40 feet/minute	28.5	5%
>40 feet/minute	440.7	76%
Total Acres	583.2	

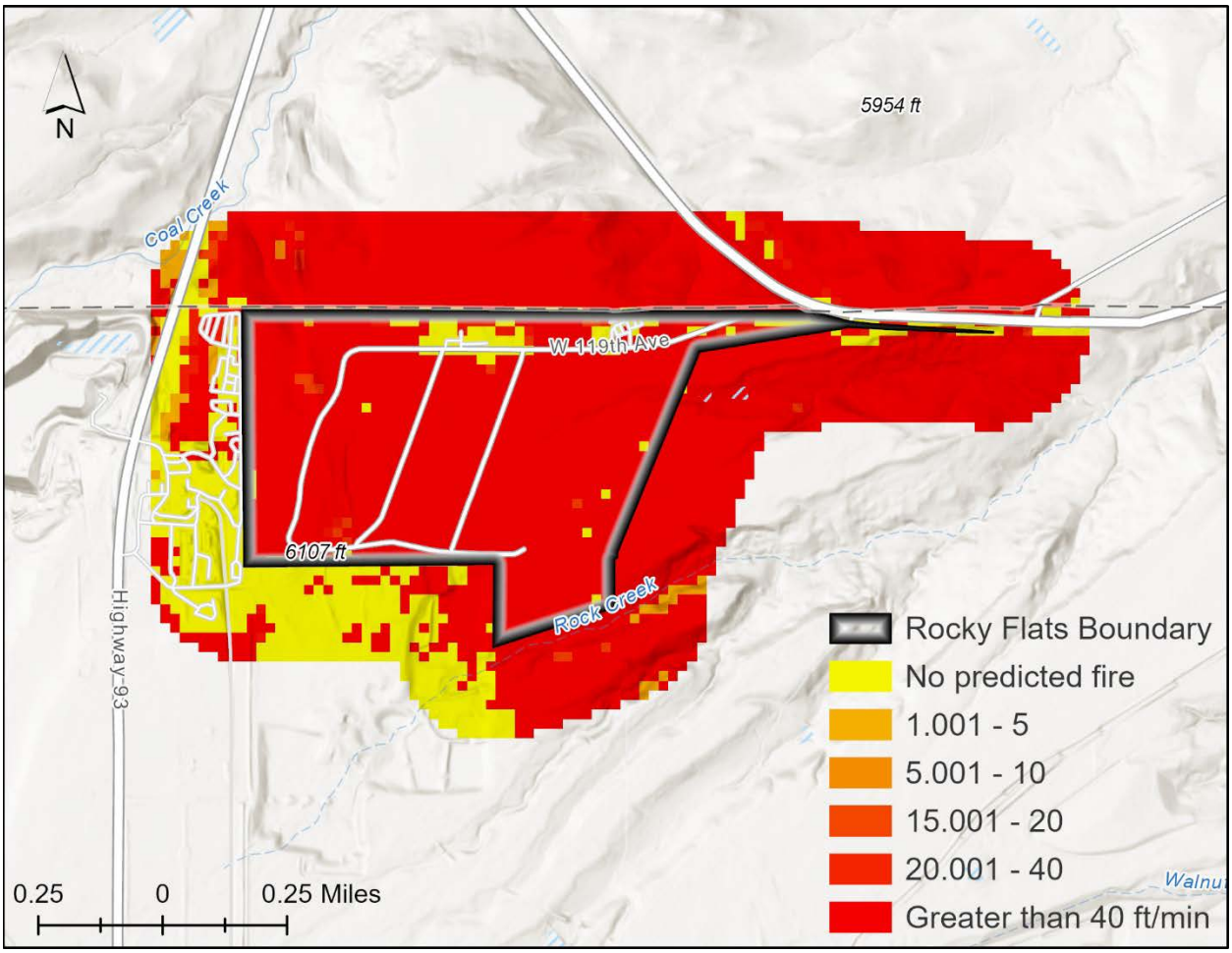

Figure 26. Map of rate of spread distribution showing context of the Flatirons Campus

Table 9. Predicted Rates of Spread for the Flatirons Campus

Rate of Spread Category	Acres	Percent
No predicted fire	27.1	9%
<1 foot/minute	0.0	0%
1–5 feet/minute	0.9	0.3%
5–10 feet/minute	0.0	0%
10–15 feet/minute	0.0	0%
15–20 feet/minute	3.1	1%
20–40 feet/minute	4.7	2%
>40 feet/minute	276.2	89%
Total Acres	312.0	

Crown Fire Activity

The description of crown fire activity includes four possible model outputs: crown fire, torching fire, surface fire, or no predicted fire. Crown fire indicates locations where fire is expected to spread into and possibly consume the canopy of trees or shrubs.

Modeling how a surface fire makes the transition to some form of crown fire is based on the fireline intensity, canopy base height, and foliar moisture content. This transition is known as torching, or "passive crown fire." Fire spread from tree crown to tree crown is considered "active crown fire," and is based on rate of fire spread, the density of the tree crown, and wind speed. Surface fires are limited to fire burning in grass, short shrubs, and the understory of a treed environment, or locations with tall shrubs.

It is important to keep in mind that crown fires and torching can occur only where there are trees and tall shrubs. Short shrub stands can burn intensely and still not torch.

When a fire burns through trees or tall shrub crowns, countless embers are produced and are distributed, sometimes at long distances. These embers can start new fires called "spot fires," which can each grow and confound the finest fire suppression forces. "Spotting potential" or "crowning potential" describes the propensity of vegetation to create and disperse embers that have the potential to start new fires well in advance of the main fire. In terms of ecological effects, prediction of torching or crown fire is highly correlated with fire severity and greater environmental impact.

While grass fires do not produce torching or crown fires, they can still produce embers, posing a risk to structures and other valuable resources. Hence, while the spotting potential of grass fires—such as is predicted to occur on most of the NREL campus grounds—is significantly less than that of tree- or shrub-dominated fuel types, embers from grass fires are still hazardous.

As represented in Figures 27 and 28, neither of the NREL campuses are predicted to produce crown fires, as both campuses are dominated by grassland and/or grass-shrub fuels that do not facilitate crown fire behavior.

Torching fire behavior is only predicted in small patches of the STM Campus, amounting to 2% of the total campus area, primarily in more coniferous-vegetated areas in the campus' northeastern corner along with nearby buffer areas. The roads within the STM Campus area are not predicted to burn, nor is most of the developed core of the facility in the south of the campus area and its adjacent buffer zone. The dry climate grass and dry climate grass-shrub-dominated majority (82%) of the STM Campus area is predicted to burn with surface fires, as is the public park just south of the campus boundary beyond South Loop Road.

Torching is only predicted in tiny patches of very high shrub in the Flatirons Campus' northwestern and southwestern edges, amounting to just 0.4% of the total campus area. Fully 91% of the Flatirons Campus and the entirety of its northern and southeastern buffer zone is predicted to burn with surface fires, corresponding with the overwhelmingly grassland vegetation in those areas. The most developed portion of the facility in the campus' north is not predicted to burn, nor are the developed area in the campus' western and southwestern buffer zone and the swath of bare ground in the southern buffer.

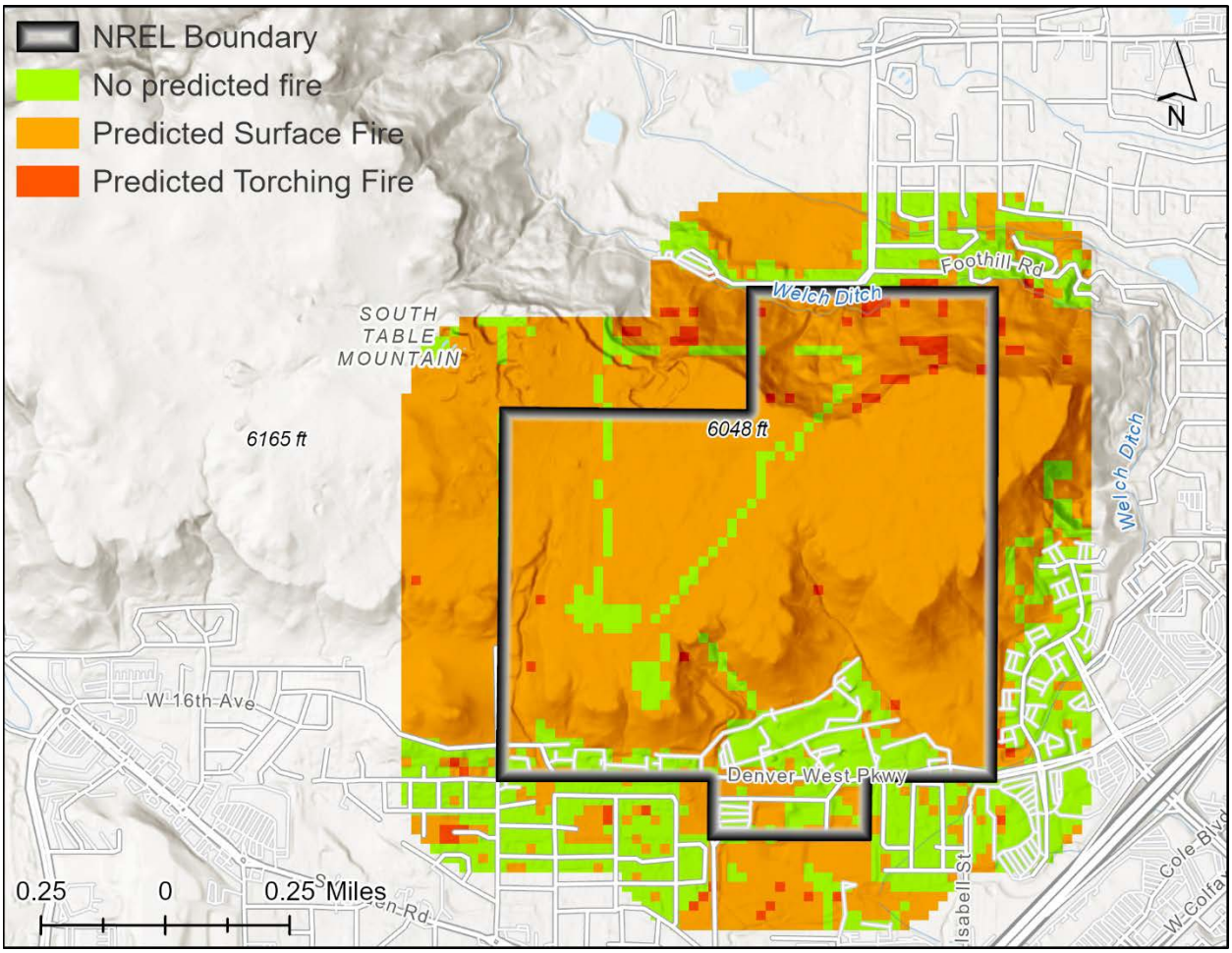

Figure 27. Map of crown fire activity showing context of the STM Campus

Table 10. Predicted Crown Fire Activity for the STM Campus

Crown Fire Activity Category	Acres	Percent
No predicted fire	97	17%
Surface fire (1)	477	82%
Torching fire (2)	10	2%
Active crown fire (3)	0	0%
Total Acres	583.2	

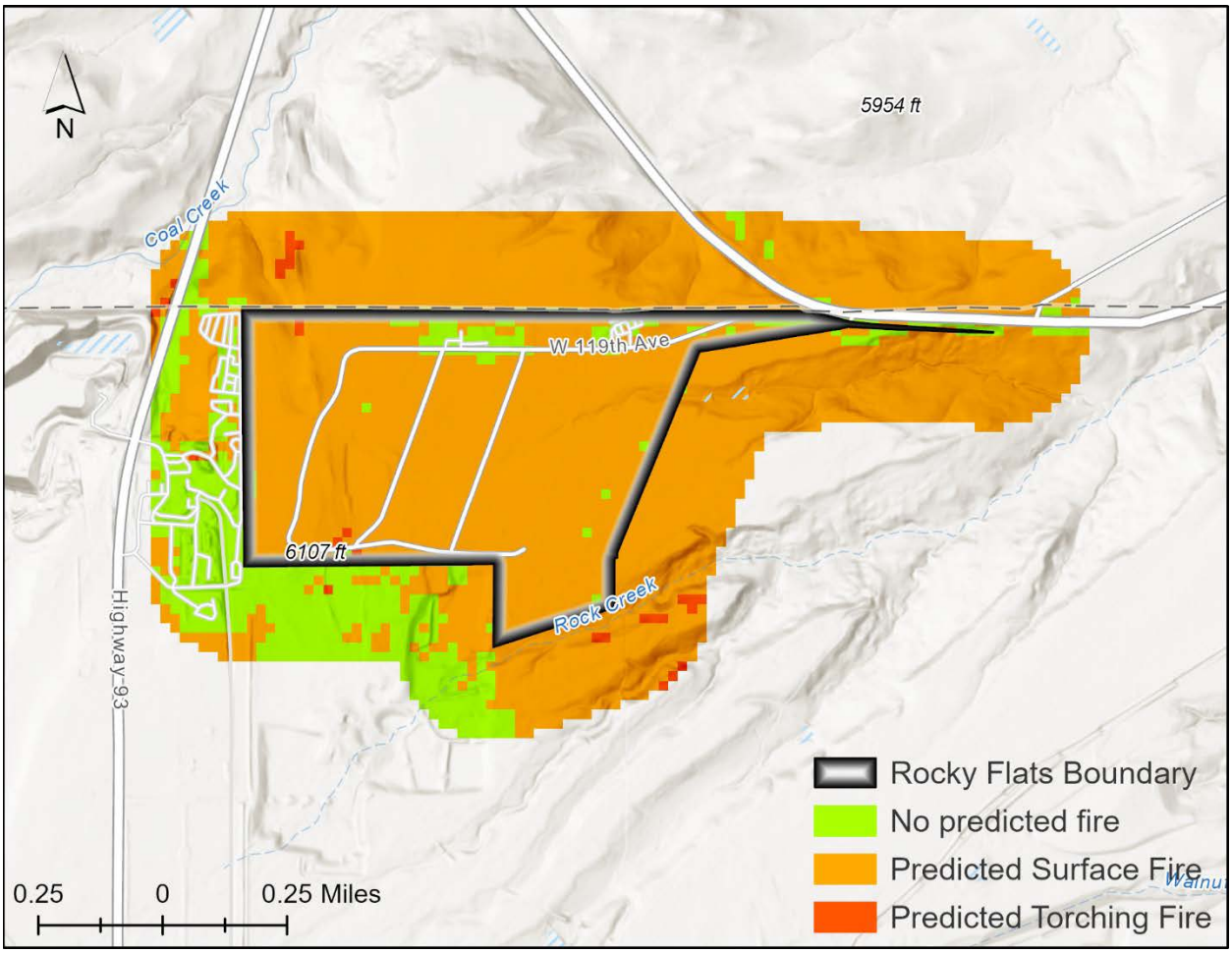

Figure 28. Map of crown fire activity showing context of the Flatirons Campus

Table 11. Predicted Crown Fire Activity for the Flatirons Campus

Crown Fire Activity Category	Acres	Percent
No predicted fire	27	9%
Surface fire (1)	284	91%
Torching fire (2)	1	0.4%
Active crown fire (3)	0	0%
Total Acres	312.0	

4.1.2 Development of a Comprehensive Building Risk Assessment

The NREL Fire Protection Group determined that a risk assessment was necessary to identify the most vulnerable structures as it pertains to wildland fire, and to guide overall wildland fire risk reduction strategies. In a financially constrained environment, a comprehensive risk assessment can assist with prioritizing which buildings to focus on to provide the greatest risk reduction.

As part of the development of this WFMP, NREL performed an assessment of structures on both campuses for their vulnerability to wildland fire. A complete guide to the comprehensive risk assessment is located in Appendix B. The section below provides an abbreviated summary of that document.

The assessment includes an evaluation of the construction characteristics of each building based on staff knowledge in wildland fire, building construction, a review of available NREL building and engineering documentation, and legacy internal knowledge. The evaluation also included building attributes to enhance asset prioritization, above and beyond construction characteristics. These attributes include occupant load, monetary fire loss potential, and the mission importance of each structure.

The assessment was performed in accordance with NFPA 1140, (2022 Edition), *Standard for Wildland Fire Protection*, Chapters 24–26 (formerly known as NFPA 1144, *Standard for Reducing Structure Ignition Hazards from Wildland Fire*). Additional guidance on performing wildland fire structure assessments was utilized, as described in DOE-HDBK-1224-2018, *Hazard and Accident Analysis Handbook*. The structures were evaluated for seven different construction characteristics and three different non-construction-related attributes. The attributes are listed below, and expanded definitions are located in Appendix B. In general, characteristics are aligned with construction requirements in NFPA 1140 and the International Wildland Urban Interface Code. Although these construction requirements are not retroactive, they are useful for benchmarking an existing building's vulnerability to wildland fire.

- The materials and construction used for the building siding
- The materials and construction used for the building roofs
- The materials and construction used for the building windows and skylights
- The presence of, and materials used for, building eaves and other projections
- The location, size, and type of screening at ventilation openings
- The presence of adjacent wood structures such as decks, stairways, and ramps
- The environment surrounding the building and its potential for exposing the building to adjacent flames. The surrounding environment included trees, vegetation, adjacent buildings, and adjacent slopes.

As previously mentioned, three additional attributes were considered:

- Building occupant load
- Building replacement value
- Building mission criticality.

Each building is scored against each attribute. The scores are weighted. This is known as a weighted matrix. The weights associated with each score associated with each attribute were determined based on consensus from NREL Fire Protection Group and against precedence established via similar methods at other DOE national laboratories. The weights are as follows:

Table 12.Scoring Categories and Points

Category	Points	Category Point % of Total
Structure Ignition	60	40
Topography	40	26.7
Importance/Occupants/Value	50	33.3
Total	150	100

After each building was scored, the scores can then be used for a variety of purposes, including:

- Binning each building as extra-high, high, medium, or low risk
- Identifying buildings for which retrofit should be considered
- Identifying potential buildings for use as a possible shelter-in-place location.

A complete guide to this framework and the scoring is shown in Appendix B. This novel framework for risk assessment and asset prioritization was developed by another DOE national laboratory (Lawrence Berkeley National Laboratory [LBNL]) and was presented to the wildland fire community by LBNL at the 2021 International Association of Wildland Fire 16th International Wildland Fire Safety Summit. Working with LBNL, NREL has adapted this methodology for its campuses.

4.1.2.1 Risk Assessment Results

Based on the risk assessment, no buildings were identified as extra-high or high risk. In general, such buildings represent those that possess a combination of attributes, which are typically high wildfire ignition vulnerability, high occupant load, high replacement value, and being mission critical. Risk binning is discussed in detail in Appendix B. However, no structures on either NREL site meet the criteria for high or extra-high risk.

NREL buildings are generally well constructed and do not have significant slope or vegetation exposures that would heighten wildfire risk, producing very low risk assessment point values for most buildings on both campuses. Additionally, the majority of the buildings on both NREL sites have low occupant loads, and only a few buildings between the two campuses are mission-critical, contributing to the relatively low risk assessment point values across the board.

Nearly all of the buildings on both NREL campuses are low risk, with only six buildings between the two sites earning a medium risk evaluation. Of 150 total available risk assessment points between the three assessment categories, the Solar Energy Research Facility building on the STM Campus scored the highest with 65 points, placing it at medium overall risk.

All of the NREL buildings on both campuses are medium and low risk; the Integrated Biorefinery Research Facility on the STM Campus received 25 points (medium risk), the worst score for building construction among NREL buildings. NREL will construct a modification plan for the Integrated Biorefinery Research Facility and four other buildings whose construction could be modified to reduce its risk bin from medium to low. To provide a path to mitigate wildfire risk to the most ignition-prone buildings, risk reduction recommendations are offered in Section 7, Recommendations.

Based on the assessment, five buildings on the STM Campus were identified as suitable shelter-in-place candidates: the Field Test Laboratory Building, Solar Energy Research Facility, Science and Technology Facility, Research Support Facility, and Café. The High-Flux Solar Furnace is identified as a suitable shelter-in-place candidate at the mesa top area. Importantly the High-Flux Solar Furnace at Mesa Top (the shelter-in-place building), has no features that require retrofitting. These designations are discussed in Section 7. Buildings designated as shelter-in-place candidates are buildings with higher occupancy loads and greater ignition resistance.

One building on the Flatirons Campus, Building 251, was deemed worthy to serve as a shelter-in-place site. The final selection of buildings shall be determined in coordination with NREL Laboratory Protection.

4.1.3 Fire Season Start and Stop Criteria

The Colorado State Forest Service declares the start and stop of wildfire season. While wildfires are a natural part of Colorado's landscape, the fire season in Colorado and across the West is starting earlier and ending later each year; in fact, in recent years, and particularly within fuel types that characterize the NREL sites, the fire season in practice is year-round. Climate change is considered a key driver of this trend. Warmer spring and summer temperatures, reduced snowpack, and earlier spring snowmelt create longer and more intense dry seasons that increase moisture stress on vegetation and make forests more susceptible to severe wildfire. For example, the historically dry season spanning 2021–2022 was noted as a contributing cause to the Marshall Fire.

4.1.4 Wildland Fire Weather and Fire Danger Rating

Per MesoWest, the nearest RAWS to the STM and Flatirons Campuses are the Corral Creek and Pickle Gulch RAWS. The weather data can be checked regularly via a public website, the Measurement Instrumentation Data Center, to determine on-site conditions. The equipment is maintained as a joint effort between the NREL Metrology and Sensing & Predictive Analytics groups. The status of red flag conditions may be obtained from local data in conjunction with National Weather Service information. These RAWS stations measure weather in a manner consistent with National Fire Danger Rating System reporting. In addition to these RAWS stations, both the STM and Flatirons Campuses host on-site weather dashboards with real-time information available; however, these weather stations do not provide observations consistent with the inputs for fire danger assessments.

4.1.5 National Fire Danger Rating System Indices

Wildland fire management actions are primarily informed by wildland fire danger levels. These levels are determined through the use of the National Fire Danger Rating System. Actions include fire prevention activities, staffing and initial response complement, fire suppression activities on large wildland fires, and prescribed fire.

NREL utilizes the National Fire Danger Rating System to alert all employees and visitors to the current fire danger on campus. This is accomplished using fire danger warning signs at each entrance. This system uses five different color-coded levels to describe fire potential. Those levels are: low, moderate, high, very high, and extreme. The fire danger is assigned by the USFS,

and the ratings are published daily on the USFS website. NREL Laboratory Protection updates the signs on campus to align with the USFS ratings.

The regionally accepted trigger for short-term changes in staffing and operations is the determination of a "red flag warning" or a "high wind warning." The National Oceanic and Atmospheric Administration has established weather conditions that merit a red flag warning designation. The outlook and designation of a red flag warning can be found at the following websites:

- National Weather Service (Denver/Boulder area)
- National Interagency Fire Center (Rocky Mountain area)

A red flag warning is issued when the combination of dry fuels and weather conditions support extreme fire danger. The criteria for the Denver/Boulder area include:

- No wetting rain (greater than 0.10 inch in the previous 24 hours) AND
- Wind gusts of 25 miles per hour or greater AND
- Relative humidity of 15% or less (National Interagency Fire Center 2021) OR
- More than 15% coverage of dry lightning (i.e., as part of a thunderstorm with no wetting rain) in an area.

In addition to the basic criteria above, a combination of other factors may result in red flag conditions:

- Haines index of 5 or 6, indicating a moderate or high potential for large, plume dominated fire growth
- Wind shifts associated with frontal passages
- First significant lightning event (wet or dry) after an extended hot and dry period
- Poor relative humidity recovery overnight (relative humidity remaining at 40% or lower) OR
- Any combination of weather and fuel moisture conditions, which, in the judgment of the forecaster, would cause extensive wildfire occurrences (National Weather Service n.d.).

In the last 10 years (2011 to 2021), 1,411 red flag warnings were issued by the National Weather Service for the state of Colorado. In 2022, 138 red flag warnings were issued before June 1. Within Zone 239 alone (National Weather Service 2022a), which includes the NREL Colorado sites, 33 red flag warnings have occurred between 2017 and 2020. This demonstrates a significant increase in the frequency of severe fire weather events.

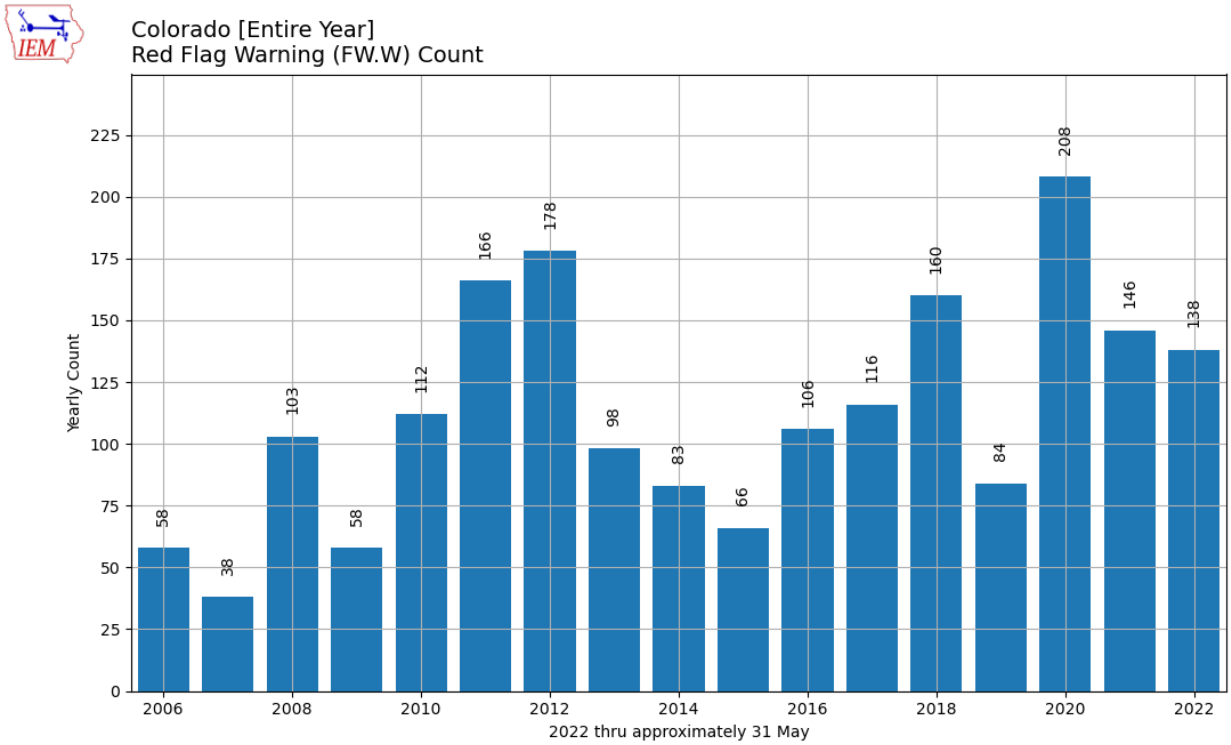

Figure 29. Number of red flag warnings from 2006 to May 31, 2022

Source: Iowa Environmental Mesonet (Iowa State University 2022)

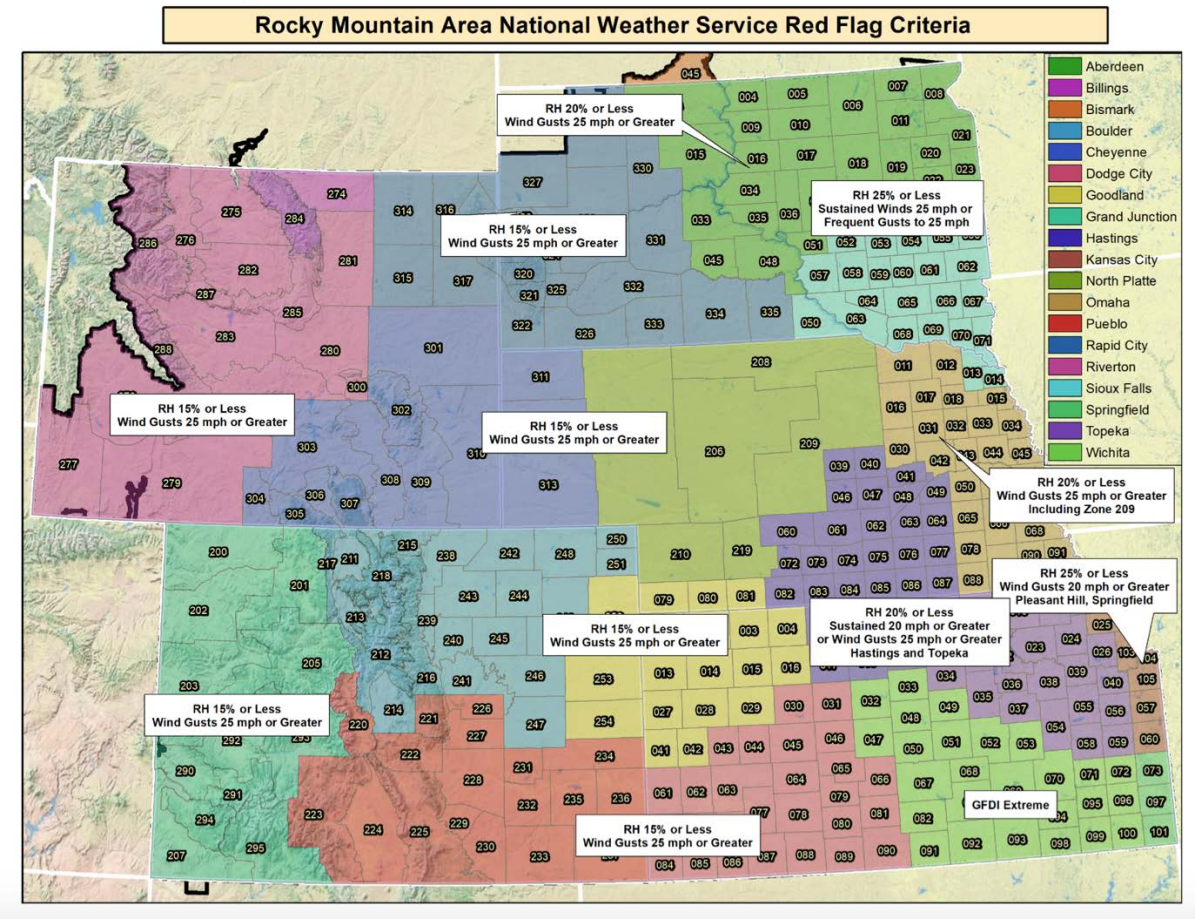

Figure 30. Map of red flag warning criteria in Colorado and adjacent states

Source: Rocky Mountain Area Fire Weather Annual Operating Plan (National Interagency Fire Center 2021)

Due to increasing levels and frequencies of red flag days, the National Weather Service has begun using an elevated level of red flag conditions identified as "extreme red flag" (Serna and Rong-Gong 2019), when especially strong winds are sustained for more than a day and humidity is particularly low. In past extreme red flag days, relative humidity has dipped to 1% and wind speeds faster than 70 miles per hour have been sustained for days.

As evidenced by the Marshall Fire, catastrophic losses coincide with wildfires burning under extremely strong winds.

NREL Fire Protection Group and NREL Laboratory Protection monitor weather reports, local weather station data, National Weather Service red flag declarations (National Weather Service 2022b), and Jefferson County fire restrictions and bans (Jefferson County Sheriff's Office 2022) during fire season to determine if a red flag warning has been declared. On days when red flag (fire weather) warnings are issued, employees and contractors are instructed to terminate any exterior hot work and any exterior work that could produce sparks and/or fire. This includes mowing, chainsaw operations, excavation, and driving in grasslands. Outdoor hot work permits are suspended, as are barbecues. An email notification is sent to laboratory employees notifying them of the fire weather conditions, the prohibitions, and to use extreme caution for any

activities that could start a fire. The red flag warning condition is rescinded when the National Weather Service cancels the warning.

4.1.6 Other General Wildland Fire Considerations

The NREL campuses are unique, requiring specific management and operational considerations that affect both wildland fire prevention and suppression. These include cultural resources, protected habitats, gas lines and utilities, and a variety of special hazards including industrial gases that are stored outside.

4.1.6.1 Cultural Resources

NREL is subject to provisions of both the National Historic Preservation Act and the Archeological Resource Protection Act, which require NREL to "identify, evaluate and protect historical and archeological sites eligible for listing in the National Register of Historic Places."

The former Camp George West Amphitheater on the northwestern side of the STM Campus is recognized as a significant historical site. Other than this amphitheater, no structures or lands on either NREL campus have been identified as holding historical or cultural significance. NREL's scientific research mission is the primary, albeit intangible, cultural resource on site. It would be directly threatened by widespread wildfire and the resultant damage to invaluable facilities.

Fixed constraints include areas afforded special status or protection prescribed by law or policy.

4.1.6.2 Protected Habitats

A small patch of critical habitat for the Preble's meadow jumping mouse (*Zapus hudsonius preblei*) occurs on the southeastern corner of the Flatirons Campus.

The Rocky Flats National Wildlife Refuge has several locations near the Flatirons Campus, including the Lindsay Ranch buildings, but none are situated on NREL property or located directly adjacent to the campus area.

Conserved areas are present on both the STM Campus and the Flatirons Campus. Most of the STM site (to the north and west of the primary developed facilities) is covered by an extensive conservation easement, in addition to a trail easement controlled by Jefferson County (Figure 31). Several conservation management areas are present on the Flatirons Campus, with ancient soils and wetlands including the Wet Meadow headwater occurring along the eastern edge of the campus (Figure 32). The western edge of the Flatirons Campus includes a wind fetch area and the large Western Conservation Area in the northwest corner of the property.

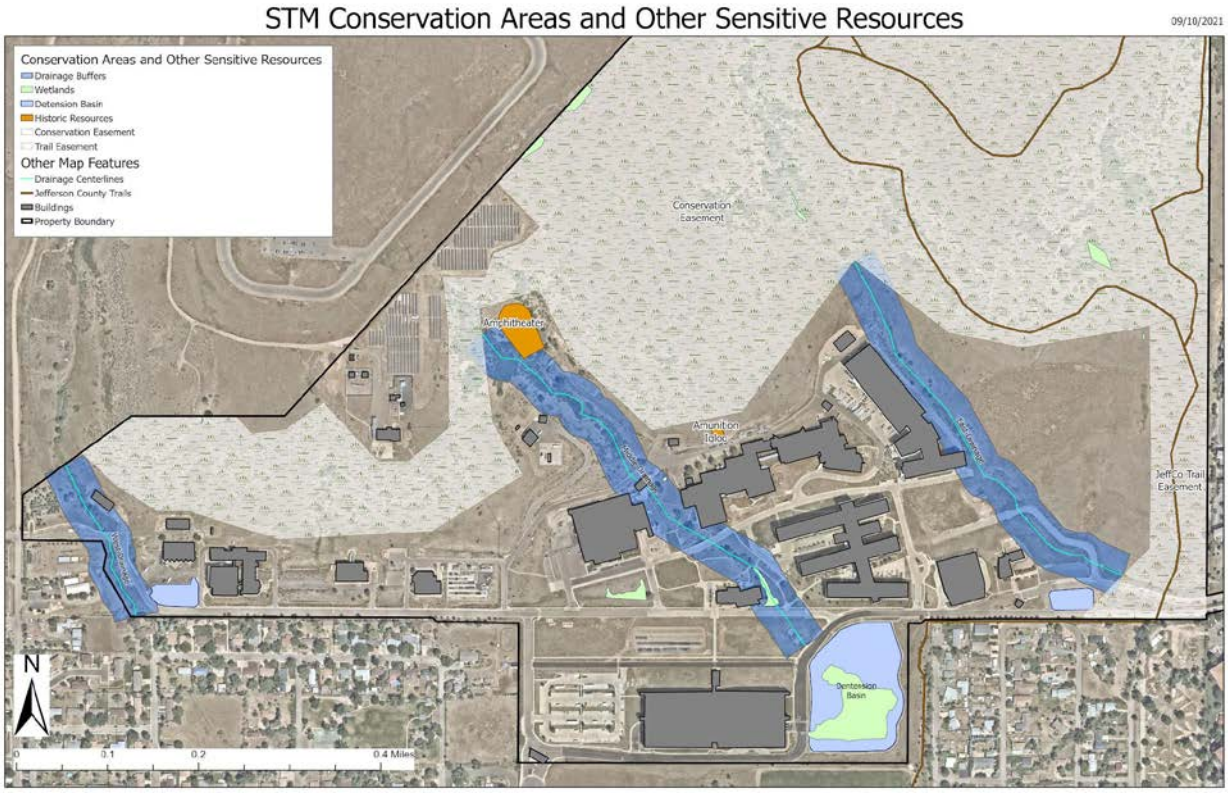

Figure 31. Map of sensitive resources on the STM Campus property

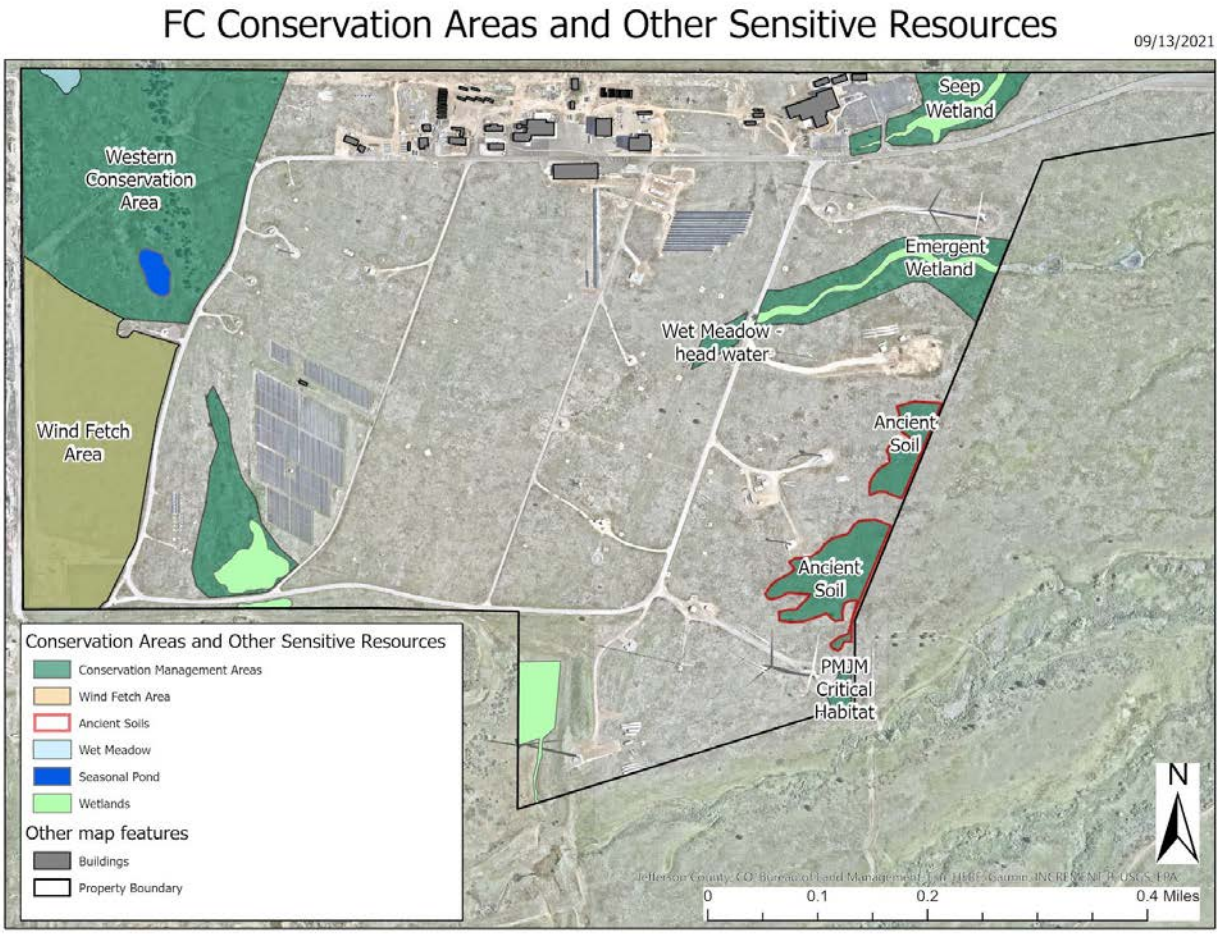

Figure 32. Map of sensitive resources on the Flatirons Campus property

4.1.6.3 Special Hazards

Both of NREL's Colorado facilities have numerous special hazards that require safety considerations. With the exception of experimental equipment and other externally stored hazardous materials covered in Section 4.1.7.5, most of these hazards are common to wildland firefighting in the wildland urban interface. Unique infrastructure hazards include compressed gas cylinders, hydrogen dispensing stations, and outdoor battery storage systems. For example, hydrogen supplies are stored on the back of the Energy Systems Integration Facility. Natural hazards on both campuses include wide swaths of open space on site and on adjacent properties, and the STM Campus is also characterized by steep slopes. Wildfire suppression activities are also limited by the following considerations:

- Accessibility to certain areas by vehicles due to steep terrain on the STM site
- Limited water resources at the Flatirons Campus
- Firelines must be rehabilitated and stormwater controls implemented to avoid unnecessary erosion and habitat fragmentation.

Sites impacted by fire suppression or by fire will be rehabilitated as necessary, based on an approved course of action for each incident.

Ignition locations include storage yards, exterior hazardous materials storage, container-based experiments, vehicles, temporary portable buildings, solar arrays, wind turbines and other exterior apparatus. External structures such as experimental and operational solar arrays, equipment platforms and specialized test equipment are present.

According to the 2020 BNA, the laboratory buildings range in potential hazard from an emergency response perspective; these hazards may become relevant should a wildfire spread to the facility in question. Those dedicated to testing or monitoring-type activities present little additional hazard that is typical of commercial use. These types of facilities include the Mesa Top buildings, the Outdoor Test Facility, Vehicle Testing and Integration Facility and the Thermal Test Facility. In contrast to the previously listed buildings that do not contain hazardous materials, larger laboratory buildings and some of their support buildings often use or store sizeable quantities of hazardous materials and other chemicals, Those buildings include the Science and Technology Facility, Solar Energy Research Facility, Field Test Laboratory Building, and Waste Handling Building. These hazardous materials could magnify the intensity and hazard of a wildfire if burned.

The Energy Systems Integration Facility contains primarily electrically related research, introducing potential high-voltage/high-amperage hazards to moderate levels of chemical use. These locations could pose an additional risk of ignition; however, ample noncombustible surfaces surround the possible ignition sites. The Integrated Biorefinery Research Facility contains a sizeable brewery/distillery to evaluate ethanol production capabilities (the distilling tower is currently out of service, and it is not anticipated to be put back in operation). The Renewable Fuel Heat Plant contains an experimental wood-fired boiler system, and the biomass offers additional fuel for a wildland fire.

Wind turbines such as those present on the Flatirons Campus present a particular fire hazard: while the relative occurrence of wildfires in wind turbines is low, in the event of a wildfire or direct ignition of a wind turbine by lightning, equipment malfunction, or hot work, wind turbines may cause secondary fires far ahead of an existing wildfire by tossing combustion byproducts across significant distances.

In addition, the electric vehicle charging stations, located adjacent to wildland fuels, present another potential ignition source. The electrical distribution line on Denver West Parkway has the potential to cause wildfires, and to spread a vegetation fire to nearby residences.

The BNA notes, “The site’s location represents a wildland fire hazard due to the open space located primarily to the north. While there is some very limited development on South Table Mountain, established by NREL and the Colorado State Patrol, the vast majority of the mesa and surrounding lands are public park (Jefferson County). As well, there is additional open space to the south of the Research Support Facility and Parking Garage areas, which is also public park lands operated by Jefferson County as part of the Camp George West development.”

While there are obviously a range of concerns with the facilities and campus, overall, the STM Campus would be considered low hazard by DOE standards, since there is no use of radiological/nuclear materials (beyond source quantities), high explosives or nontraditional hazardous materials. With respect to the local community, there are a number of facilities with

similar hazards in the surrounding area (e.g., Coors brewery, CoorsTek ceramics research, Ball Metal Packaging production, etc.), resulting in emergency service providers that are well acquainted with the types of hazards and concerns at the STM Campus (NREL 2020).

The BNA acknowledges that there is a significant wildland fire hazard at the Flatirons Campus. In addition to the wind turbines discussed above, large dynamometers, solar arrays, high-voltage electricity, and large battery systems present the most significant hazards should a wildland fire spread to those areas. There are some limited hazardous materials hazards; however, the majority of the work is considered nonhazardous to those responding to a wildland fire. The BNA did not note additional ignition risks due to operations; however, the adjacent facilities to the west (a mining equipment services provider, concrete batch plant, and stone materials provider) are deemed a limited fire exposure risk, but the unimproved lands around the facilities raise the potential for a wildland fire initiation and spread.

4.1.6.4 Major Utilities Lines or Easements

Available data do not indicate any high-voltage above-ground transmission lines or easements passing through either NREL campus. However, an electrical distribution line is located on the southern boundary of the STM Campus, on Denver West Parkway, between Pike Street and Research Road.

4.1.6.5 Hazardous Materials Stored in Exterior Locations

A potential hazard may be posed from hazardous materials that are stored in exterior locations on both NREL campuses if a wildfire were to approach and spread into the location where the hazardous materials are stored.

The Flatirons Campus is host to only limited qualities of hazardous materials, with the majority of Flatirons Campus research involving nonhazardous materials from an emergency response perspective per the 2020 BNA. However, the BNA notes that in addition to the facilities themselves, the STM Campus has other hazards that would be of concern to emergency responders. The STM Campus hosts a wide variety of hazardous materials in exterior storage, including but not limited to pressure vessels, pressurized cylinders of various gases, and hydrogen tube tanks. These include the variety of research and production solar arrays (electrical hazards) and external hazardous materials storage facilities (e.g., pressure vessels, pressurized cylinders of various gases, hydrogen tube tanks). The latter can contain hazards such as energy storage systems, hydrogen fuel cell experiments, and similar operations that might be hazardous to responders, and a potential accelerant to a wildland fire. Various experimental trailers, vehicles, or containers are occasionally brought onto the campus for evaluation. These temporary hazards include energy storage systems, hydrogen fuel cell experiments, and other operations that might present hazards to emergency responders.

Figure 33. Approximate locations of hazards identified in the Baseline Needs Assessment and in this WFMP

Hazards are mitigated for fuel storage tanks on NREL property through integrated tank design, ongoing maintenance, and vegetation clearing. Tank design safety features include, for example, double-wall containment (to prevent leaks) and explosion vents. Tanks are inspected annually in accordance with NFPA 30, *Flammable and Combustible Liquids Code*, and the Steel Tank Institute SP001, *Standard for Inspection of Aboveground Storage Tanks.* Tank locations, documented inspection protocols, and pertinent controls are identified in the Laboratory-Level Procedure 625-12, *Aboveground Storage Tank Management*.

4.2 Fire Prevention

The goals of the NREL Fire Protection Program, administered by the NREL Fire Protection Group through the Environment, Health, Safety, & Quality Division (NREL 2021b), are to:

- Minimize the likelihood of a fire-related event
- Minimize the consequence of fire-related events affecting the public, workers, environment, property, and lab mission
- Prevent unacceptable damage or loss of function to critical process safety controls, safety significant and safety class systems, structures, and components as established by facility safety analyses
- Provide a level of safety protection consistent with “highly protected risk” class of industrial risks.

These goals are achieved through the oversight of design, construction, and maintenance of government-owned, government-leased, and contractor-leased facilities used for DOE mission purposes. These goals are also achieved through the development and implementation of policies on emergency response, facility fire protection assessments, wildland fire, and a multitude of other specific fire protection program criteria, some of which will be described in more detail in the following sections.

The objective of wildland fire prevention is to reduce the likelihood of wildland fire ignition on NREL property and to reduce the severity and impact of any wildland fires. NREL shall make every attempt to accomplish this in a safe, efficient, and cost-effective manner, through appropriate planning and coordination.

Fire prevention efforts that contribute to wildland fire risk reduction include:

- Community education and involvement
- Design review, work planning, and control, and facility fire inspections
- Hot work program
- Oversight of inspection, design, and maintenance of fire protection systems and equipment (including but not limited to sprinkler systems, detection system, fire extinguishers, etc.)
- Vegetation management
- Staff training, including training for wildland fire prevention, detection, reporting, and response.

4.2.1 Community Education and Involvement

Through open town halls and strategic communications, the NREL Fire Protection Group provides education and outreach specifically on the topic of wildland fire. This includes a description of the wildland fire issue, what NREL is doing to reduce wildland fire risk, and how the members of the NREL community can prepare themselves and their homes for the next wildland fire.

NREL's staff works with local fire departments (implemented through Automatic Aid and Mutual Aid Agreements) and other state and local emergency preparedness agencies with fire management and public safety responsibilities. NREL staff work with West Metro Fire Protection District (WMFPD), Mountain View Fire Protection District (MVFPD), U.S. Fish and Wildlife Service, Arvada Fire Protection District, Golden Fire Department, Jefferson County Sheriff's Office Emergency Management and Fire Management units, and others, to establish common protocols and procedures, identify training needs, conduct joint training, and develop strategies for safer and more efficient fire management operations. These regional efforts provide a consistent message to the public and lab employees, provide consistent training to many organizations in an efficient manner, and offer a consistent strategy that can be customized when needed.

4.2.2 Design Review, Work Planning and Control, and Facility Fire Inspections

4.2.2.1 Design Review

Modifications related to buildings and their infrastructures must be reviewed and approved by NREL's Fire Protection Group. While most construction is done in the interior of structures and is not a source of ignition for wildland fire, the same process applies to design and construction aspects that affect wildland fire hazards.

During a project, the Fire Protection Group provides design oversight (and serves as Authority Having Jurisdiction) for matters regarding fire and life safety. This includes ensuring compliance with fire and life safety codes, including but not limited to DOE, ICC, and NFPA codes and standards.

During project construction, staff inspect the project to ensure compliance with the approved design documents. Any deficiencies require correction prior to certificate of occupancy. Upon construction completion, the Fire Protection Group witnesses the testing and commissioning of the relevant building systems and fire protection systems. Any deficiencies found during inspections or testing are identified to the project in writing. Upon completion and verification of deficiencies, the fire marshal then signs off on the project.

New construction is required to comply with the latest construction standards pertaining to wildland fire. This includes the International Wildland Urban Interface Code and NFPA 1140, *Standard for Wildland Fire Protection.*

4.2.2.2 Work Planning and Control

As part of the work planning process for experiments at NREL, principal investigators, managers, and supervisors are required to consider what environment, health, and safety hazards, risks, and concerns are present, and to implement appropriate controls using the Integrated Safety Management System approach. Policies and procedures governing this include Laboratory-Level Program 625-5, *Safe Conduct of Work*, and Laboratory-Level Procedure 600-2, *Hazard Identification and Control.* Work Planning and Control is currently implemented via the Worksafe system. An effort is currently underway to completely renovate the Work Planning and Control process. This effort has an expected completion date of September 2023. The current process involves pertinent stakeholders identifying hazards and implementing necessary administrative and engineering controls. The NREL Fire Protection Group participates in the Work Planning and Control process for certain hazards.

4.2.2.3 Facility Fire Inspections

As required by the Department of Energy Order DOE 420.1C, *Facility Safety*, structures are inspected at minimum every three years. Some structures, depending on hazard or value, require annual fire inspections.

These fire inspections ensure that building infrastructure and operations are continually maintained to meet the minimum standards of fire and life safety. As part of these inspections, vegetation surrounding structures is inspected in accordance with the defensible space recommendations in this WFMP, as well as NFPA 1140 and the IWUIC.

Where issues are observed, the Fire Protection Group works closely with the NREL facilities managers, research operation Managers, Researchers, EHS&Q Points of Contacts (POC), and others, to resolve issues. Findings are logged in a database maintained by the Fire Protection Group called File Maker Pro. Where vegetation is found to be hazardous and noncompliant with required regulations, work orders are submitted and processed accordingly by NREL Site Operations.

Collectively, the facility fire inspections serve to reduce the likelihood of a fire occurring in a building and limit any impact through automatic suppression and containment, should one occur. These efforts directly correlate to a reduction in the likelihood that a fire starting in an NREL structure would spread to wildland areas. They also serve to reduce the likelihood of ignition of vegetation surrounding buildings, and the severity of a wildland fire event, through the previously mentioned defensible space inspections. During facility fire inspections, building exteriors are also inspected for hazardous conditions, ranging from vegetation, combustible debris, hazardous materials, dumpsters, and other conditions that could lead to an exterior fire, which could serve as a wildland fire ignition source.

4.2.3 Hot Work Operations

In accordance with DOE Order 420.1C and International Fire Code, hot work performed at NREL must be performed under a Hot Work Permit in accordance with NFPA 51B *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work,* issued by the NREL Fire Protection Group or authorized designees, such as facility managers. The work is authorized by the NREL fire protection AHJ or designee only after meeting with the requestor and inspecting the site regarding equipment, location, condition scope, and duration of the work. Hot work policy is captured in Laboratory-Level Procedure 600-42, *Fire Safety*.

Hot work encompasses welding and allied processes, heat treating, grinding, thawing pipe, powder-driven fasteners, hot riveting, torch-applied roofing, and similar operations producing a spark, flame, or heat.

The hot work permit must be posted at the site before and during any hot work. The requestor must assure that the conditions of the permit are addressed before starting work and do not change as the work progresses. If the work or conditions do change, the requestor must stop and contact the NREL Fire Protection Group or designee for a review/reinspection and possible modification of the permit for reissuance. Permits may extend to multiple days, up to 30 days. The area of the permit is inspected daily by the requestor.

A fire watch is required during the permitted operation and for at least one-half hour after the operation ceases, as determined by the permit. The length of time the fire watch is required will not only be marked on the permit but also verbally communicated to the requestor.

The area of hot work will be noncombustible, fire-resistive construction, essentially free of combustibles and flammables, suitably segregated from adjacent areas, equipped with fire extinguishers, and inspected and approved by the Fire Protection Group or their designated representative.

4.2.4 Fire Protection Systems and Equipment

Automatic fire sprinkler systems are provided in structures consistent with DOE requirements and applicable codes. These sprinkler systems help prevent fires in buildings from developing to become an ignition source to wildlands. Additional suppression systems have been provided where warranted by existing hazards. These suppression systems include dry chemical, wet chemical, high-expansion foam, or deluge. Each building is also equipped with portable fire extinguishers. The size, type, and location are based on applicable codes. The majority of buildings are also equipped with partial or complete fire detection systems. These systems serve to detect fires originating within buildings. For those systems with air handling units with a capacity of over 2,000 cubic feet per minute, smoke detection in the units will cause the units to shut down upon sensing smoke from a wildland fire. This will reduce the amount of wildfire smoke dispersion throughout a building.

Building fire alarm systems warn building occupants automatically as well as summon the fire department in the event of a fire. Upon activation of any fire suppression or detection system, a signal is sent using auto-dialers to the central monitoring station and either the WMFPD or the MVFPD responds. This notice dispatches firefighters from the fire station nearest NREL. These stations are continuously staffed. Local panels and notification devices are provided with secondary power and remain functional for 24 hours upon loss of power.

The NREL Fire Protection Group provides oversight on the design and continued maintenance of fire protection systems and equipment. As it pertains to maintenance, fire detection and suppression systems are tested, inspected, and maintained as per the requirements of the applicable NFPA standards, The NREL Fire Protection Group provides oversight of inspection, testing, and maintenance of fire extinguishers. Site Operations provides monthly inspections, and required maintenance is contracted out. Site Operations is responsible for inspection, testing, and maintenance of fire detection and suppression systems, including the following:

- Diesel-engine-driven water supply pumping systems
- Water storage tanks
- Automatic sprinkler systems
- Pre-action sprinkler systems
- Deluge sprinkler systems
- Standpipe and Fire Department connections
- Fire hydrants
- Aqueous film-forming foam systems
- High-expansion foam systems
- High-sensitivity smoke detection systems
- Clean agent extinguishing systems
- Dry-chemical systems (detection and annunciation only)
- Wet-chemical systems (detection and annunciation only)
- Heat detectors, smoke detectors, and building fire alarm systems
- Proprietary site-wide fire alarm monitoring systems.

The testing program is not specific to wildland fire. The inspection and testing and maintenance are done year-round, and not in specific preparation for the wildfire season.

4.2.5 Vegetation Management

4.2.5.1 General Information

As previously outlined, defensible space inspections are part of regular fire inspections performed by NREL Fire Protection Group staff. This section expands upon the efforts put forth to reduce the wildfire risk at the lab through selective vegetation management.

Vegetation management may be performed by either in-house personnel or contractors. In 2014, the Defensible Space Management Plan was created through an interdisciplinary work group led by the NREL Fire Protection Group to provide a framework for in-house personnel to manage site vegetation around the STM laboratories and offices in a holistic and comprehensive manner. This guide was initially created to resolve a gap identified in the Federal Wildland Fire Management Plan, which was to have a site vegetation plan that includes ecosystem sustainability as one of its objectives. This new plan places a cognizant focus on wildfire risk reduction. It provides guidance on when, where, and how to prune, mow, and otherwise manage vegetation on the STM Campus in a wildfire-conscious manner (see Figures 34 and 35 for maps of ongoing and proposed vegetation management on the STM Campus). Due to staffing concerns, much of the vegetation management at NREL must be contracted out. A similar plan for the Flatirons Campus was not developed; regardless, vegetation treatment was performed over the years to minimize wildfire hazards (see Figure 36 for maps of proposed vegetation management on the Flatirons Campus). The proposed vegetation management maps have been developed based on the results of this WFMP, including site-specific fire modeling, nationally recognized codes and standards, site visits, a risk assessment, and best practices garnered from experience in wildland fire prevention.

Sitewide reviews of wildland fuels is performed at least annually by personnel with a background in landscape architecture. Trees that are noted in need of thinning or removal are entered into the annual scope of work for contractors. Funds for any identified treatments and inspections are then requested for consideration and approval by management.

Additionally, NREL commits annual funds to address wildland fire risks via regular programs such as vegetation management for defensible space.

Figure 34. Approximate locations of wildland-urban interface on the STM Campus requiring regular inspection and maintenance

Source: 2014 Wildland Fire Defensible Space Plan (FP2Fire 2014)

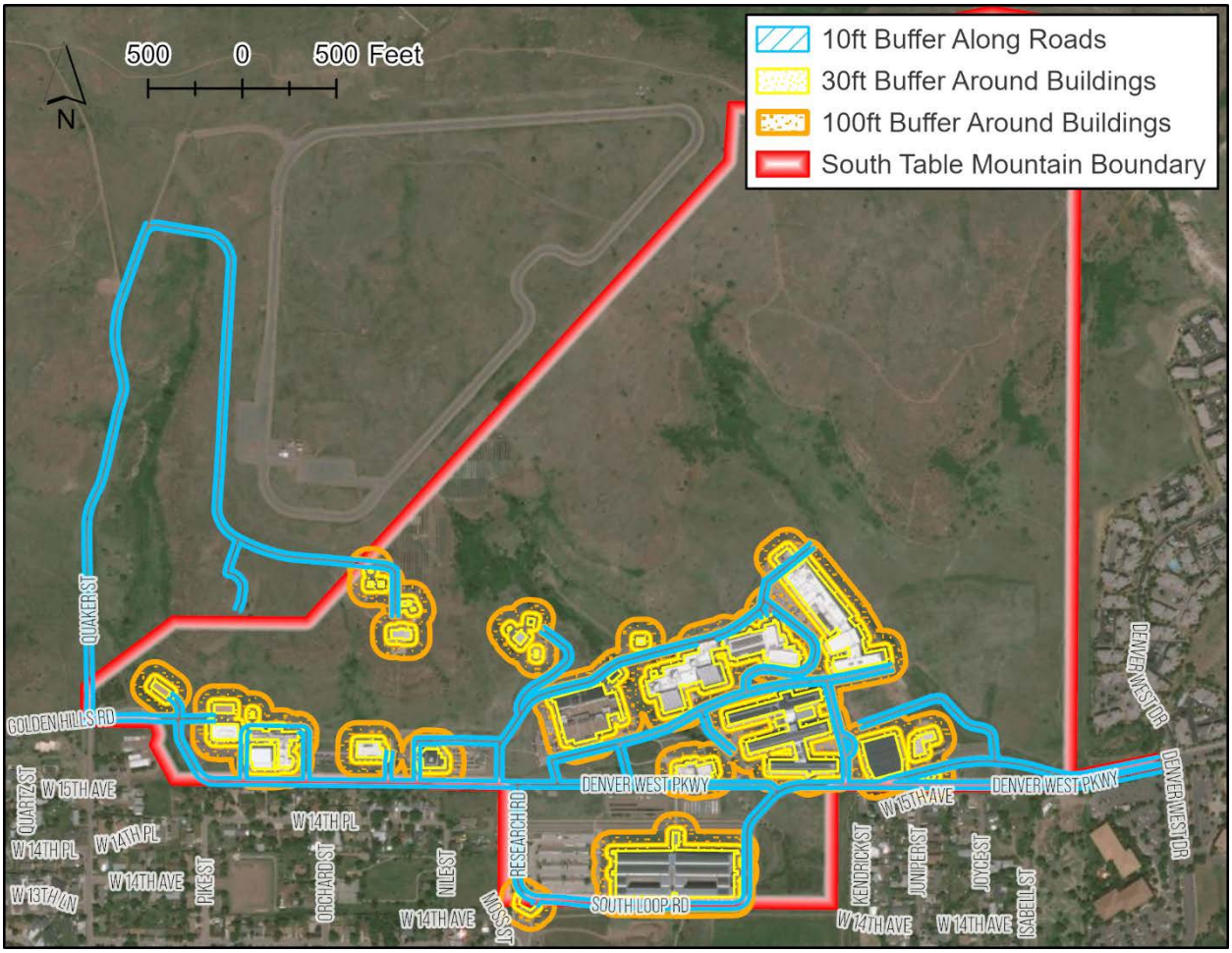

Figure 35. Proposed vegetation treatment locations on the STM Campus. Blue indicates a 10-foot-wide treatment along roads, which includes mowing and tree trimming; mowing is to occur within 30 feet of each building, and defensible space extends to 100 feet where trees are limbed of lower branches and shrubs are thinned and grouped.

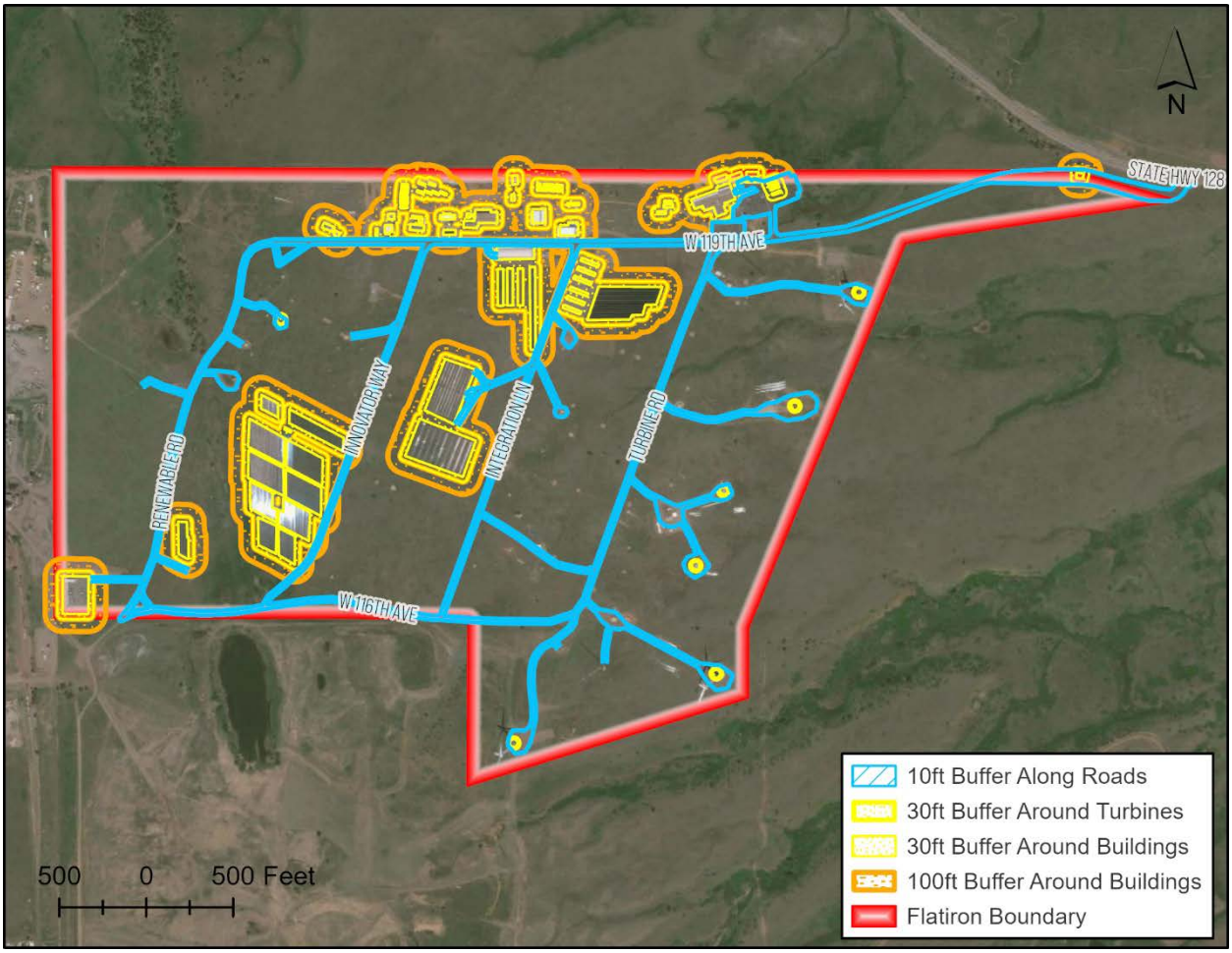

Figure 36. Proposed vegetation treatment locations on the Flatirons Campus. Blue indicates a 10-foot-wide treatment along roads, which includes mowing and tree trimming; mowing is to occur within 30 feet of each building, and defensible space extends to 100 feet where trees are limbed of lower branches and shrubs are thinned and grouped.

4.2.5.2 Prescribed Fire

Currently fire hazard reduction activities do not involve prescribed fire. A program of using prescribed fire is not considered in this plan due an abundance of caution surrounding the risks involved, and because lands surrounding the STM Campus that would be suitable for prescribed burning are being considered for a transfer of ownership.

4.2.5.3 Non-Fire Ground-Level Fuels Removal

Ground-level wildfire fuel reduction treatments are planned for and carried out by the NREL Site Operations as well as contracted crews, with additional input and oversight by the NREL Fire Protection Group Treatments currently consist of hand labor crews to cut grass, mowing, and pruning trees and shrubs.

Historical Context

Laboratory safety procedures at NREL have historically attempted to mitigate wildland fire hazards through fuel management and other procedures. NREL's fuel management strategies were significantly updated with the adoption of the NREL Wildland Fire Defensible Space Plan in 2014, which integrated up-to-date interpretations of the WUI that emphasized a zoned approach to increased mitigation closer to structures in lieu of widespread clearing to produce "firebreaks." Future vegetation management is addressed in Section 7, Recommendations.

Ongoing management of NREL facilities over the years has targeted the grasslands and shrub vegetation that dominates the STM and Flatirons Campuses and surrounding areas, with more recent fuel management practices adopting the zoned approach to bare ground or concrete perimeters followed by mowed areas in close proximity to buildings and other structures.

The 2020 BNA states, "NREL has an active and aggressive program to address wildland hazard either through engineered controls (ranging from building design to use of noncombustible landscaping materials around areas or items of concern) and administrative controls (e.g., mowing operations, smoking zones, vehicle access limitations, etc.). The program has a supporting plan in place, and areas of concern that are not yet fully addressed are scheduled. This program is a key part of wildland fire mitigation, given that wildland fire control [relies] as much on strong prevention and physical mitigation actions as it does on suppression capabilities."

Fire breaks on the Mesa Top are created by roads and parking lots only. The same is true on the main campus, but to a much larger and most expansive extent. Response in the area has traditionally been aggressive to preclude expansion to NREL buildings or adjoining developed areas.

4.2.5.4 Fuel Reduction: Mowing

NREL implements its fuel reduction program by mowing selected locations. Activities at the STM Campus have been guided by a Wildland Urban Interface Defensible Space Plan. Mowing using hand-held string mowers is performed in locations near buildings. Additional mowing may occur if regrowth occurs in late summer or in the fall; however, in most years, mowing using riding mowers will likely have to occur throughout most of the summer. Particular attention is paid to areas that expose NREL and the surrounding community to the greatest chance of fire and greatest potential damage.

String mowing is typically completed by the beginning of April. The treatments around buildings and electrical substations are considered part of general cleanup activities.

4.2.5.5 Fuel Breaks via Roadside Mowing

The roadways at NREL serve as important fuel breaks for incoming wildland fires. The roadways within the complex also serve to slow fire spread between regions of the laboratory. However, roadways are also the most common place for ignitions. Therefore, NREL maintains many roadways clear of vegetation and mows grass within 10 feet of roadway. Such mowing should be extended to the vegetation along roadways.

4.2.6 Prevention Training and Qualifications

The NREL Fire Protection Group staff is thoroughly trained in all areas of fire prevention. This training allows them to successfully implement the various fire prevention tasks discussed in this section of the WFMP. Sample certifications for staff include:

- ICC Fire Inspector I, II, and Plans Examiner
- State of Colorado Fire Inspector III: Plans Examiner
- Professional Engineer: Fire Protection
- National Fire Academy Training: Fire Inspections and Hazardous Materials
- National Fire Academy Training: "Wildland Urban Interface: Fire Adapted Communities"
- NFPA Training: Assessing Structure Ignition Potential From Wildfire.

Staff also participate in ongoing training on a wide variety of fire prevention topics. Ongoing training activities augment and reinforce the skills and knowledge base of NREL Fire Protection Group staff.

NREL Fire Protection Group staff also participate in regional and national code development pertaining to wildland fire. This allows NREL to keep abreast of potential code changes that could impact NREL's approach to wildland fire. It also allows NREL to contribute to code development in a manner that favorably impacts the needs of NREL as well as the region. Involvement includes:

- Technical Committee Member, NFPA 1140, *Standard for Wildland Fire Protection*
- Participant, Colorado State Fire Commission, Wildland Urban Interface Subcommittee (responsible for developing a Colorado State Wildland Urban Interface Code)
- Participant, ICC Fire Code Action Committee, Wildland Urban Interface Code Committee.

4.3 Fire Suppression

4.3.1 Attack Types

An initial attack is a response that does not exceed one operational period, occurs when the fire does not threaten persons or property off-site, does not require more than fire agencies located in the immediate vicinity of the NREL site, and generally does not involve an Incident Action Plan (NWCG 2013). An extended attack would involve a wildland fire incident that is not contained through initial attack, continues more than one operational period, and would require fire agency response via state master mutual aid agreements. Wildland fire response will be initiated by fire suppression personnel and equipment based on the initial dispatch; requests for additional personnel and equipment from surrounding fire stations will be made by the incident commander or via mutual aid.

The WMFPD is responsible for wildfire suppression at the STM Campus and has been since the merger of the former Lakewood and Bancroft Fire Protection Districts in 1995.

West Metro Fire Department Station #5, located at 14055 West 20th Avenue in Golden, is the nearest fire station to the STM Campus and is situated ~1.2 miles (a 4-minute drive) northeast of

the main campus. Station #5 is staffed 24 hours a day with a minimum of five firefighters (one captain, one engineer, and two firefighters, with at least two of them being paramedics) (West Metro Fire Protection District 2020); fire engines are expected to take 3–7 minutes to get to the main STM Campus or 12–17 minutes to the Mesa Top facilities in the event of a fire. Station #5 specializes in responding to events involving hazardous materials and operates one hazardous materials response apparatus in addition to at least one medical vehicle and at least one fire engine. This station houses an engine, ambulance, and a hazmat vehicle. For wildland fire response, West Metro utilizes engines operating from roadways until brush apparatus or all-wheel-drive engines can arrive from nearby stations (e.g., Brush 6 from Station 6, Brush 58 from Arvada Fire Protection District Station 58, Engine 32 and Brush 32 from Fairmount Fire Protection District Station 32, etc.). An extensive discussion of WMFPD capabilities, mutual aid agreements, and other considerations are expanded upon in the 2020 NREL Baseline Needs Assessment (NREL 2020).

The MVFPD is responsible for wildfire suppression on the Flatirons Campus and has been since its 2021 merger with the Rocky Mountain Fire Protection District.

Mountain View Fire Department Station #9 (formerly Rocky Mountain Fire Department Station #6), located at 4390 Eldorado Springs Drive in Boulder, is the nearest fire station to the Flatirons Campus and is situated 5.5 miles northwest of the campus; fire engines are expected to take 10–15 minutes to get to the Flatirons Campus in the event of a fire. Station #9 is staffed 24 hours a day with a minimum of three firefighters and houses an all-wheel-drive engine, a tender, and a brush/wildland apparatus. Additional wildland resources would come from Jefferson County and Boulder County's Sherriff's Office Fire Management units, Coal Creek Canyon Fire Protection District, Fairmount Fire Protection District, Boulder Fire Rescue Department, and Arvada Fire Protection District. Full details on wildland fire apparatus and capabilities at the closes stations for each department are described in full detail in the 2020 BNA (NREL 2020).

4.3.1.1 Information Used To Set Initial Attack Priorities

Initial attacks will commence with at least one Engine Company and at least three firefighters. Decisions regarding where to focus attack efforts will be based on location of the fire, weather conditions, topography, exposures, and other tactical considerations determined by the incident command.

4.3.1.2 Criteria for the Appropriate Response

Every wildfire will be suppressed as quickly as possible, with consideration for the extremely high values of assets at risk and the sensitivity of those assets to damage from wildfire. The appropriate response is generally aimed at effective and efficient suppression, prioritizing life safety, and protection of buildings and research.

Extended Attack

Extended attacks, like all phases of a wildfire event, will be managed using the National Incident Management System under a Unified Command and would require activation of the lab's Emergency Operations Center (EOC).

In the event of an extended attack, the NREL EOC will coordinate with the responding agencies as necessary.

4.3.2 Training and Preparedness

The contract fire suppression provider is required to comply with applicable DOE and NFPA Standards. This is validated through the NREL Baseline Needs Assessment.

WMFPD is certified as an Insurance Services Office (ISO) Class 1 department. MVFPD is certified as an ISO Class 2 department for properties within 1,000 feet of a fire hydrant and Class 3 where residences are beyond 1,000 feet of a hydrant. Employees dispatched or assigned to wildland fires will be qualified, unless assigned as trainees.

Fire personnel involved in federal fire management activities must meet the fitness standards established by their agency. Both the WMFPD and the MVFPD use the National Fire Protection Association's Standard 1500, Occupation Health and Safety Program. This includes an annual physical and stress test. ISO certification also includes evaluation against NFPA 1500.

Both the WMFPD and the MVFPD establish and maintain a program of issuance, use, accountability, and maintenance of personal protective equipment for wildland firefighting, in accordance with nationally recognized standards, and as required by the Federal Wildland Management Policy and DOE-STD-1066-2016.

In addition, the NREL staff participate in regional training exercises such as a Table-Top Exercise prepared by the Rocky Flats National Wildlife Refuge Fire Management. In this instance, NREL staff observe and learn as fire management teams from the area discuss their step-by-step plans and response to a simulated fire scenario that could theoretically occur at Rocky Flats National Wildlife Refuge. At the conclusion of the response exercise, observers will be invited to bring forward any questions they may have pertaining to the scenario.

4.3.2.1 Annual Training

Firefighters are on duty throughout the year, and their qualifications need to be maintained at all times. Wildland fire skills are updated annually. The State of Colorado implements the training and framework used by the NWCG. Qualification cards are tracked and administered by the Colorado Division of Fire Prevention and Control. The NWCG system of qualification includes standards that either directly implement NFPA standards or provide equivalent levels of qualification under national accreditation approaches.

4.3.3 Minimum Impact Suppression Tactics Requirements

Attempts to minimize impacts to natural resources from suppression activities will be made, where possible. The Incident Commander has the authority to commit resources and determine the suppression strategy and tactics, The NREL EOC may inform the Incident Commander of sensitive habitats for protected species, erosive soils that may preclude the use of heavy equipment, and other considerations that can reduce the effects of fire suppression. Final decisions on suppression activities are determined by the Incident Commander.

4.4 Emergency Management

To align wildland fire management and emergency management goals, this plan will ultimately align with Emergency Management Plan. The NREL Emergency Management Plan is currently under development as of the publication of this WFMP. The following items will be covered by the Emergency Management Plan and pertain to both wildland fire and emergency management.

- Sitewide emergency preparedness and sheltering procedures
- Employee emergency reporting procedures
- The Emergency Response Organization and its support for wildland fire suppression operations.

4.5 Emergency Rehabilitation and Restoration

4.5.1 Emergency Stabilization

A large wildfire on or near the NREL properties may cause detrimental effects on the environment and present a health and safety risk to laboratory personnel. Such an event may or may not reach the level where it could be declared an Operational Emergency under DOE Order 151.1D. Regardless, response and post-wildfire actions may be needed to minimize the threat to life and health and prevent unacceptable degradation to natural and cultural resources.

If a wildfire does pose a threat to life and health and to prevent degradation to natural and cultural resources, an Operational Emergency will be declared to coordinate and support response efforts. In the post-event phase, the EOC Emergency Director could be authorized by the Laboratory Director to appoint the Recovery Manager, if one is needed, and to hand-off emergency response activities to the recovery phase of the event cycle. The Recovery Manager would then follow the recovery plan to return the lab to a state of normalcy.

4.5.2 Burned Area Rehabilitation

Similar to immediate post-wildfire actions, applicable post-wildfire burned area rehabilitation actions may be needed to repair or improve wildfire-damaged lands that are unlikely to recover naturally, or minor facilities damaged by the fire. Burned areas will be assessed to determine suitable and effective emergency stabilization and rehabilitation needs to meet current and anticipated environmental conditions (DOI 2009).

DOE Order 151.1D requires that termination and recovery planning efforts include dissemination of information to federal, state, and local organizations regarding the emergency and possible relaxation of protective actions; planning for decontamination actions, if necessary; and reporting requirements and criteria for resumption of normal operations (DOE 2016). Recovery planning is event-specific and requires input from Site Operations personnel for utility and infrastructure issues, and from ESH&Q Division personnel for safety guidelines and potential air, land, water, and personnel monitoring if the event involves a hazardous materials release.

Where a fire affects NREL property, outside consultants will be brought in to assess watershed conditions and determine if any actions are necessary to restore the watershed and prevent damage to other ecosystems. ESH&Q will coordinate these activities in conjunction with Site Operations.

4.6 Implementation

The degree to which the components of this plan are implemented dictate if the goals and desired conditions of the WFMP are achieved. The implementation mechanisms may include NREL institutional tracking mechanisms or other means developed by the NREL Fire Protection Group.

5 Wildland Fire Risk Mitigation: Prioritization, Budget, and Organization

5.1 Budget

5.1.1 Vegetation Management

The primary expense pertaining to wildland fire risk reduction is vegetation management. Vegetation management expenses are covered institutionally as overhead within NREL Site Operations via the NREL Landscaping Maintenance budget. This typically consists of the following:

- Mowing: Mowing is performed by a subcontractor. Annual mowing expenses vary but are approximately $450,000. Mowing is not solely for wildland fire risk reduction. Mowing scope includes both campuses and includes targeted wildland risk reduction per mowing maps, native grass maintenance, general landscaping, and miscellaneous tasks and projects requiring mowing.
- Tree Work: Tree work is performed by a subcontractor. Annual trimming expenses vary but are approximately $25,000. Tree work is done by a certified arborist. The arborist performs an annual site survey to assess tree health and needs. Included in this assessment is an evaluation of trees that may be dead or dying and trees that are too close to buildings, both of which may pose a wildland fire risk. The subcontractor's full scope includes items such as removing trees (dead trees or removal for other purposes), planting new trees, replanting or moving trees, trimming trees, thinning trees, and tree irrigation.

5.1.2 Infrastructure

Wildland fire risk reduction expenses related to infrastructure have historically been covered by both the NREL Landscaping Maintenance budget, and NREL ESH&Q one-time "end-of year" funds. Infrastructure expenses have included adding rock skirts around buildings to provide for a noncombustible, ignition-resistant zone adjacent to buildings. Table 13 presents an inexhaustive summary of recent projects and associated expenses:

Table 13.Summary of Expenses on Recent Landscape Maintenance Projects

Date	Location[a]	Work	Cost	Budget Source
August 2014	RSF, ESIF, Café	Installed Rock	-	Overhead – Landscape Maintenance
August 2014	Flatirons – Hydrogen Tanks	Installed Rock	$10,000	Overhead – Landscape Maintenance
September 2014	RSF – Around Drainage	Installed Rock	-	Overhead – Landscape Maintenance
May 2015	S&TF – Around Drainage	Installed Rock	$2,000	Overhead – Landscape Maintenance
May 2015	Shipping & Receiving	Installed Rock	$1,600	Overhead – Landscape Maintenance
August 2015	ESIF – East Side	Installed Rock – 5-foot Strip	$2,000	Overhead – Landscape Maintenance
February 2016	VTIF	Installed Rock – 5-foot Strip	-	Overhead – Landscape Maintenance
May 2016	ESIF – Hydrogen Pad	Installed Rock	$3,200	Overhead – Landscape Maintenance
August 2016	Propane Tank, Diesel Tank, All Electrical Boxes	Installed Rock	$4,000	Overhead – Landscape Maintenance
August 2016	TTF – North Side	Installed Rock – 5-foot Partial Strip	$2,800	Overhead – Landscape Maintenance
September 2017	Bulk Storage	Install Rock – 5-foot Strip		ESH&Q
September 2017	Facilities Maintenance	Install Rock – 5-foot Strip		ESH&Q
September 2017	Waste Handling	Install Rock – 3-foot strip		ESH&Q
September 2017	SRRL	Install Rock – 2-foot Strip		ESH&Q
May 2018	TTF – North Side	Installed Rock + Retaining Wall	$2,000	Overhead – Landscape Maintenance

[a] RSF = Research Support Facility; ESIF = Engineering Systems Integration Facility; S&TF = Science & Technology Facility; VTIF = Vehicle Testing & Integration Facility; TTF = Thermal Test Facility; SRRL = Solar Radiation Research Laboratory

Future funding for infrastructure-related items will continue to be provided by either Landscape Maintenance overhead, or ESH&Q one-time funding. Projects requiring funding will be selected using a risk-based approach. Example projects that may require funding include retrofitting vents, siding, roofing, or windows. See the recommendations section of the WFMP for more details. Additional funding mechanisms, such as including retrofits as scope on planned small or large capital projects, should be considered.

5.2 Organization Chart Supporting Wildland Fire Management Plan Implementation

There are many areas and levels of responsibility for implementation of the wildland fire management program. There may be instances that the same person functions in multiple areas of responsibility. The WFMP defines areas of responsibility, provides direction and accountability, and furthers the development of a responsive fire management program.

The Department of Energy Head of Field Element, known as the Golden Field Office, is the Authority Having Jurisdiction for fire protection. This is formally described in DOE Order 42.01C, Change 2, *Facility Safety*, and DOE-STD-1066-2016, *Fire Protection*, Section 1.5 (refer to definition of Authority Having Jurisdiction [AHJ]). The Head of Field Element can choose to assign this responsibility. The Golden Field Office formally assigned this responsibility to the NREL ESH&Q Office on August 19, 2010.[2] This responsibility was further assigned to the NREL Fire Protection AHJ within the ESH&Q Office on January 28, 2022.[3]

The responsibility for implementing the NREL WFMP resides primarily with the NREL Fire Protection AHJ, Fire Protection Group, and the Maintenance/Grounds Office. Line management plays an important role in supporting these endeavors. Specific responsibilities are described as follows:

Golden Field Office

- Provides ultimate oversight for NREL fire protection program
- Delegates authority for day-to-day management of the fire protection program
- Approves the sitewide wildland fire management plan, per DOE Order 42.01C, Chapter II, Section 3.g.

Chief Operating Officer

- Supports implementation of the WFMP as necessary at management level to support the NREL mission
- Delegates authority for the fire protection program to the NREL Fire Protection AHJ.

Maintenance & Operations Supervisor

- Maintains contracts with emergency response agencies

[2] Letter from Steve Scott to Dr. Dan E. Arvizu, August 19, 2010. SUBJECT: Delegation of Authority
[3] Letter from Julie Baker to Nicholas Bartlett dated January 28, 2022. SUBJECT: Assignment of Fire Protection Authority Having Jurisdiction Responsibility

- Coordinates mowing and tree trimming to meet wildland fire management goals, in collaboration with Fire Protection AHJ and other entities
- Coordinates maintenance related infrastructure upgrades pertaining to wildland fire risk reduction.

Fire Protection Group

- Owns the NREL WFMP
- Implements the NREL fire protection program
- Oversees the NREL fire protection program and ensures coordination with research projects, facility management, grounds maintenance, and other NREL programs
- Responsible for short- and long-range planning and implementation of the WFMP
- Conducts reviews of fires as specified in this plan
- Assists in the investigation of fires on NREL property
- Develops fire protection staff qualifications
- Provides for the development of employee fire qualifications
- Manages equipment assigned to the fire protection program
- Monitors weather and forecast fire danger rating, collaborating to issue lab-wide red flag warnings or other weather-related information as necessary
- Prepares annual fire program funding proposals
- Communicates with area and regional wildland fire managers.

Director, Laboratory Protection

- Coordinates weather-monitoring activities within Laboratory Protection
- Issues lab-wide red flag warnings and other wildland fire related weather alerts
- Coordinates with emergency response personnel in the event of a wildland fire
- Coordinates the EOC
- Implements sitewide evacuation protocol
- Conducts wildland fire evacuation drills.

5.3 Cooperative Agreements and Interagency Contacts

Interagency cooperation is vital to the full realization of NREL's fire management program objectives. The ability of a single agency to implement a fire management program of any complexity is limited without coordination with and assistance from other organizations. Interagency cooperation and the coordination of shared resources and common activities are critical to the success of the fire management program.

5.3.1 Cooperative Agreements

Fire protection districts (such as WMFPD and MVFPD serving NREL) have primary responsibility for controlling wildfires in their jurisdiction (Jefferson County 2018). In the event of complex or extended wildland fire incidents, agencies responding to a wildland fire on or near NREL property may require assistance from other fire departments and government agencies. It is the responsibility of fire protection districts and other jurisdictional agencies (such as the USFS) to maintain and update their mutual aid agreements (Jefferson County n.d.). The 2018

Jefferson County Annual Operating Plan (Jefferson County 2018) highlights terms and conditions of these mutual aid agreements.

5.3.2 Memoranda of Agreement and Emergency Response Contracts

Memoranda of agreement and contracts with off-site agencies outline the emergency support services that each provides to NREL when requested. Contracts with WMFPD and MVFPD are maintained by Site Operations. Requests for additional assistance may be initiated by the NREL Laboratory Protection Director or the EOC Emergency Director. Requests for federal assistance for either NREL campus can be initiated through the Golden Field Office.

5.4 Equipment Rental Agreements

No equipment rental agencies for the purposes of fire suppression are under subcontract with NREL.

6 Monitoring and Evaluation

Monitoring of the wildland fire program consists of a system to report wildland fires and to evaluate the effects of fuel management. Monitoring is performed through a self-survey appraisal system with targeted measurements of fuel management effects.

6.1 Reporting of Wildland Fires

An occurrence report for any wildland fire or other fire outside the facility that has the potential to threaten the facility must be submitted to DOE within the time constraints prescribed in DOE Order 232.2A, *Occurrence Reporting and Processing of Operations Information.* NREL implements DOE Order 232.2A through Laboratory-Level Program 625-18 (*Management of Environment, Safety, Health, and Quality Issues*). The required notifications for fire incidents, per DOE Order 232.2A (Attachment 2, Section 4) are:

- Activation of an automatic fire-suppression system by fire
- An unplanned fire that takes longer than 10 minutes to extinguish following the initiation of firefighting efforts by the emergency response organization
- Any fire that disrupts normal operations in the facility for more than 4 hours
- Any wildland fire or other fire outside a DOE facility that has the potential to threaten the facility.

Fires occurring on NREL property for which a fire department responds to are also reported by the applicable fire department to the Colorado Fire Incident Reporting System. The Colorado Fire Incident Reporting System is used for all incident types, including fires, rescue, and hazmat. This system releases data to the National Fire Incident Reporting System, which. NFIRST is a standard national reporting system used by fire departments in the United States to report fires and other incidents that they respond to and to maintain records of incidents in a uniform manner.

At NREL, employees are trained to report fires (building fires or wildland fires) immediately to 911 or to the NREL Central Monitoring Station.

6.2 Monitoring Fuel Management Effects

Fuel monitoring is performed in an ongoing manner at NREL. This is primarily due to the unpredictable weather patterns. Late or off-season rain may result in renewed vegetation growth that could necessitate additional mowing efforts. Fuel monitoring consists of monitoring the height of grasses throughout the year to determine if mowing is necessary. Should grazing occur, it includes active, continuous monitoring of livestock to ensure grass heights get to no shorter than 4 inches to maintain soil health, prevent erosion, and minimize the chance of invasive grass proliferation.

In addition to monitoring of grasses and grazing, an annual survey is conducted by a certified arborist. This survey assesses the status of trees at both NREL campuses and determines if treatments are necessary. Monitoring is the basis for adaptive management, a best practice that continually improves treatments.

Monitoring of mowing and fuel management is also accomplished as part of the routine, year-round inspections performed by the NREL Site Operations. As part of the Facility Assessment program, the Fire Protection Program assesses the building—considering fuel management—on a triannual basis, with the exception of the Engineering Systems Integration Facility (and its surroundings), which is looked at every year.

7 Recommendations

7.1 South Table Mountain Campus Recommendations

7.1.1 Community Engagement

Because NREL's STM Campus is located within the city of Golden, with developed property on three sides of its border, community engagement is important, as wildfire spreads easily across borders, both to and from the STM Campus.

Fire Adapted Colorado (FACO) provides a statewide platform for information sharing and forward-thinking discussion as related to wildfire issues. FACO acts as a connecting force that works with a collective voice, aimed at creating safer and more resilient communities living with the threat of wildfire. FACO provides educational and networking opportunities for communities, groups, and individual stakeholders focused on reducing the negative impacts of wildfires in the state. More locally, West Metro Fire Rescue Firewise Community participates in FACO in order to learn from others and implement best practices.

NREL should create and distribute materials regarding wildland fire preparedness aimed at adjacent neighborhoods, with attention to the apartments to the east, (Denver West Apartments LLC) and the single-family homes to the south, along Juniper and Kendrick Streets, the Marriott Hotel, and the Jefferson School District immediately south of the NREL eastern gate. If the neighborhoods (both the apartments and single-family homes) have a unifying organization, such as a homeowner's association, a presentation is suggested. This presentation could describe the way NREL addresses wildland fire, and what they can do to reduce fire hazards and be more prepared. Presentations in conjunction with the West Metro Fire Department are recommended.

Internally to the STM Campus, NREL could prepare and present messages about wildfire spanning appropriate behavior for ignition prevention, wildfire detection procedures, ongoing programs within NREL (possibly including the development of a WFMP), evacuation procedures, and future plans for retrofitting buildings (if any). Guidance developed by West Metro Fire Department about pre-fire actions by employees at home could be distributed.

There are many programs that should continue; employee training regarding proper use of a fire extinguisher is one of those programs.

7.1.2 Defensible Space/Vegetation Treatments

Adopt fuel management standards per Appendix C. Figure 37 shows fuel treatment boundaries for the STM Campus.

Mow according to grass growth within 30 feet of structures—6 inches would trigger mowing. Expect and plan for at least two mowings per year.

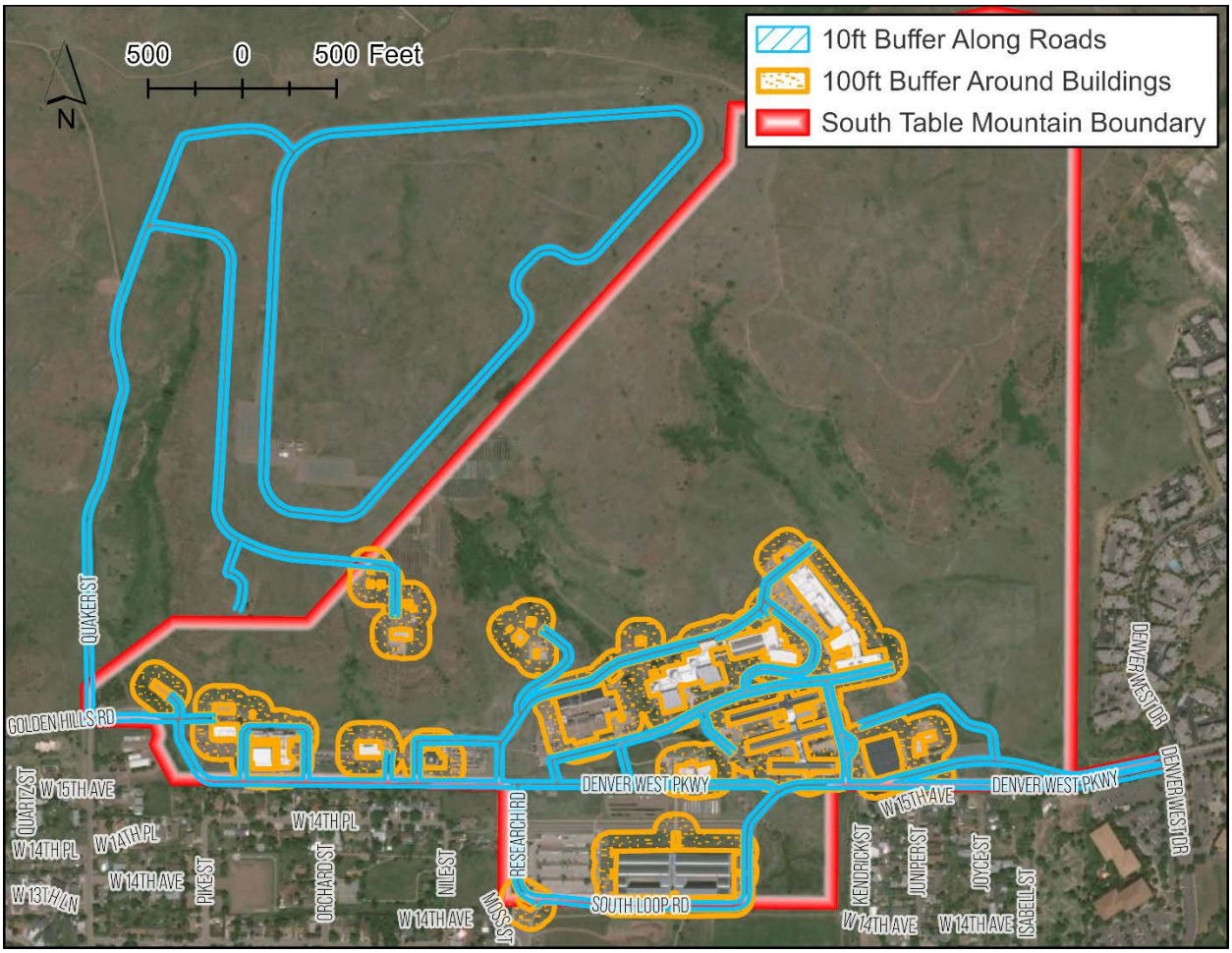

Figure 37. Vegetation management boundaries at the STM Campus

7.1.3 Structure Retrofit

Retrofit buildings per priority ranking; however, schedule low-cost retrofitting activities that have a high impact (vents). The retrofitting recommendations fall into three activities:

- Replace vents to be ember resistant.
- Replace single-paned windows, based on the ranking system. In some locations, such as the Maintenance Building, windows adjacent to the wildlands should be prioritized for retrofitting. Consider National Institute of Standards and Technology (NIST) Technical Note 2205 (Maranghides et al. 2022) when scheduling partial retrofit activities.
- Coat the external foam thermal insulation with a fireproof coating, based on risk ranking. This will entail repeated coatings over time, depending on the product used.

The following prioritization of retrofitting is recommended, based on the relative importance of the building and the greatest benefit for the lowest cost:

For the STM Campus,

1. Start with the buildings with the highest importance/occupant/value score.

2. Those buildings with the highest score AND a rating of "Medium" should be addressed first.

These include:

- Solar Energy Research Facility (Building Importance/Occupant Load/Value [BIOLV] score of 65 and medium wildfire risk)
- Field Test Laboratory Building (BIOLV score of 55 and medium wildfire risk)
- Research Support Facility (BIOLV score of 55 and medium wildfire risk)
- Energy Systems Integration Facility (BIOLV score of 50 and medium wildfire risk)
- Integrated Biorefinery Research Facility (BIOLV score of 50 and medium wildfire risk).

Of these, consider replacing the vents on buildings that have substandard vents. These are:

- Solar Energy Research Facility
- Research Support Facility
- Integrated Biorefinery Research Facility.

Then, coat any buildings that have expanding thermal insulating foam (ETIF) covering, such as the Integrated Biorefinery Research Facility.

Once the five buildings that are rated as medium wildfire risk, other buildings with ETIF could be coated to protect them from wildfire. Other buildings with ETIF are:

- Thermal Test Facility
- Education Center
- Shipping and Receiving.

Then, replace single-paned windows with double-paned. The Facilities Maintenance Building is the only building (other than the Integrated Biorefinery Research Facility, which would have already been retrofitted) that would benefit from this type of retrofitting construction.

7.1.4 Wildland Fire Response

Continue to host West Metro Fire Department pre-fire as a way to familiarize first responders with the campus. Include Jefferson County Sheriff's Office in such familiarization. Visits to Mesa Top are particularly important because this location has no water availability, and no buildings have emergency fire suppression sprinklers. Thus, structure ignition resistance and defensible space are paramount. Quick response, along with early detection and notification will be a necessary compensation for the lack of water.

7.1.5 Evacuation

NREL should establish procedures for notification and processes for evacuation. This would include:

- A notification system that specifies the means of notification, the people to be notified, the trigger for notification, the destination for evacuees, and the directions/procedure for evacuation.

- The notification system should be a public announcement notification system within buildings. Any notification system should be tested at the beginning of the fire season and monthly during the fire season.
- Triggers for evacuation will be informed by a fire growth simulation, based on two combinations of ignition locations and wind direction. The simulations indicate that a fire burning from the north with a northerly wind spreads fastest in the area at the top of the STM Campus, and that the golf course and developed areas directly north of NREL constrain fire growth to the campus. Thus, evacuation caused by fire from the north is not a major concern. In comparison, a fire from the west spreads quickly and can impact Mesa Top rapidly. Fires from the west and with a westerly wind will also move into the campus proper. In this scenario, fires will also impact neighboring residents. Fortunately, Denver West Parkway is affected later in the fire growth simulation, thereby allowing evacuation prior to the fire reaching the road. Evacuation should go to the NREL East Gate.
    - Evacuation should begin if a fire reaches an area between Highway 6 and Highway 58 when winds are higher than 20 miles per hour.
    - While the area south of the NREL campus does not contain very much wildland fuel, should a wildfire spread through Lena Gulch with a southerly wind, the parking garage could be impacted, thereby hindering evacuation.
    - The NREL staff should work with the West Metro Fire Department to refine the evacuation triggers; however, the recommendation would be to initiate evacuation if a fire were to start south of the campus with a southerly wind, if it spreads into the area encompassed by South Golden Rd.
- Because access to Mesa Top crosses an area of wildlands and the access itself is poor, it is recommended staff should evacuate well before a fire spreads to the east of South Golden Road. However, any staff remaining at that point should shelter in place in the High-Flux Solar Furnace building.
- Similarly, the campus would consider shelter-in-place in lieu of evacuation if
    - The Parking Garage is threatened or
    - The fire has reached the NREL East Gate or
    - The fire has spread to Quaker St. or
    - The fire has spread to the Colorado State Patrol Academy Track.
- Evacuation drills should be performed at least yearly. This should include both evacuation and shelter-in-place scenarios. The time it takes to evacuate should be recorded and used to inform triggers for the initiation of evacuation during a real event. Operations, such as making all possible lanes available for exit should be evaluated and implemented in the various drills.
- A check-in procedure to ensure all are evacuated should be developed. Laboratory Protection may be the appropriate department within NREL to develop this.

7.2 Flatirons Campus Recommendations

7.2.1 Community Engagement

The Flatirons Campus should work with the Mountain View Fire Department to become an active member of Boulder County's Fire Adapted Community through its Wildfire Partners

program (Wildfire Partners n.d.). NREL could utilize Fire Adapted Colorado for this purpose. See Section 7.1.1 for more details on Fire Adapted Colorado.

The Flatirons Campus is more remote than the STM Campus; nevertheless, it has a community that should act together in wildfire preparedness. The Flatirons Campus should engage with Mountain View Fire Department and neighbors to be a fire adapted community. These neighbors include three private landowners: Old Thyme Lumber (John Sainsbury); Bill Hogan Living Trust, John C. Hogan, TRNLWB LLC; and American Contract Miners, Inc. (American Mine Services). In addition, a few public landowners should be included in the community engagement process. This is especially important, as it may facilitate the development of additional evacuation routes that would travel through neighboring properties. This includes the Rocky Flats U.S. Fish and Wildlife Refuge and the City of Boulder and County of Boulder staff that manage the nearby parkland.

NREL should create and distribute materials regarding wildland fire preparedness aimed at bolstering detection, notification, and evacuation response. Presentations could describe the way NREL addresses wildland fire and what neighbors can do reduce fire hazards and be more prepared, especially regarding alternate evacuation routes. Presentations in conjunction with the Mountain View Fire Department are recommended.

Internally to the Flatirons Campus, NREL could prepare and present messages about wildfire spanning appropriate behavior for ignition prevention, wildfire detection procedures, ongoing programs within NREL (possibly including the development of a WFMP), evacuation procedures, and future plans for retrofitting (if any). Guidance developed by the Mountain View Fire Department about pre-fire actions by employees at home could be distributed.

There are many programs that should continue; employee training regarding proper use of a fire extinguisher is one of those programs. Similarly, labwide messages communicating wildfire evacuation and possible shelter-in-place protocols should continue and be expanded.

7.2.2 Defensible Space/Vegetation Treatments

Buildings should be surrounded with at least 5 feet of noncombustible materials (Appendix C); the noncombustible zone around the substation should extend to 30 feet (due to a long response time and assets at risk).

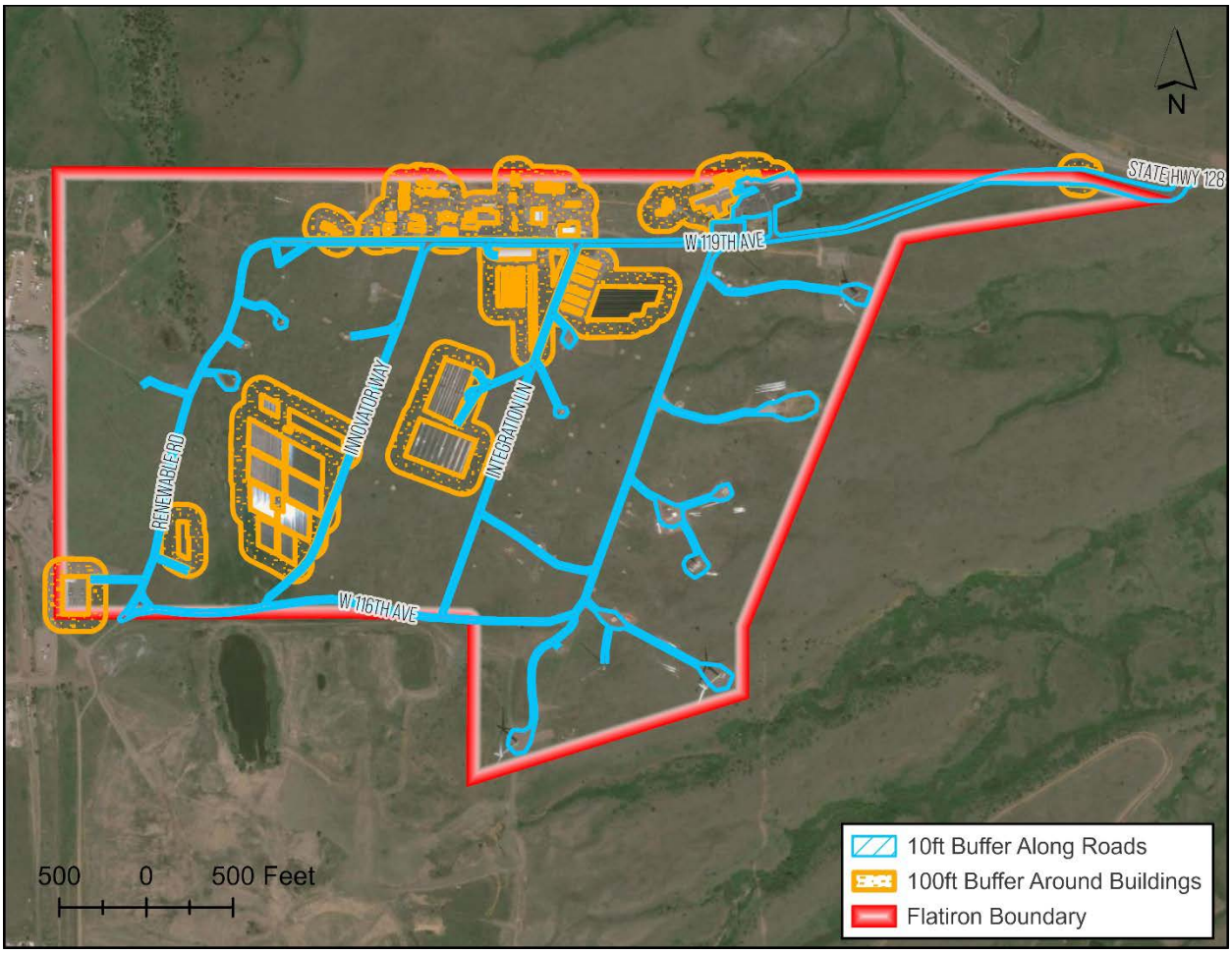

Figure 38. Vegetation management boundaries at the Flatirons Campus

The areas to be mowed yearly should be revised to include areas within 10 feet of roadways (including W 116th Ave., Innovator Way, and Integration Lane).

Grass within 100 feet of buildings should be shorter than 4 inches during the fire season. Because grazing is compatible with wildland fire hazard reduction, and because there is a local cattle-grazer who can graze the area with portable fencing and offered to return to sites as needed, this operation should be explored. The cattle grazing arrangement should include specifications for fencing, number of animals in any one area, the length of time the animals stay, based on the residual dry matter or grass height, and the trigger for return if the grass regrows (likely to be grass height). The map shown in Figure 38 should be vetted with campus leadership and research partners, with boundaries adjusted yearly, as needed. During the initial stages of the program, areas east of Turbine Rd should not be included in area to be grazed, in order to avoid Ancient Soils, Emergent Wetland, PMJM Critical Habitat and wetlands, as identified on the FC Conservation Areas and Other Sensitive Resources map.

Contracts with research partners should be reviewed and potentially revised to identify the fuel conditions in the research area. For example, the contractor (research partner) should ensure conditions under the solar panels should be such that it will not carry fire and make clear which

entity is responsible for ensuring this condition, the inspection process, and the consequences for noncompliance. Current contractors have agreed to the responsibility to ensure low fuel height under solar panels.

Mowing should not occur under such solar panels, and cattle or other grazing animals will need to be kept clear of the area in order to avoid disturbing electrical cables or other features critical to the research.

7.2.3 Structure Retrofit

For the Flatirons Campus, the highest priority for retrofitting is Building 251 as well as the nearby trailers (Buildings 248, 249, and 250). Building 251 is the sole designated shelter-in-place location, and the close proximity of the trailers may jeopardize the safety of Building 251. The vents in Building 251 should be protected with 1/8-inch screen or a UL-listed vent that prevents ember intrusion. The single-paned windows in the trailers should be replaced with double-paned windows to minimize the chance of breakage during a wildfire.

Retrofit buildings per priority ranking; however, schedule low-cost retrofitting activities that have a high impact (vents). The retrofitting recommendations fall into three activities:

- Replace vents to be ember resistant.
- Replace double-paned windows, based on the raking system. Some locations, such as Buildings 248–250, should be prioritized for retrofitting because they are adjacent to the one building identified as a shelter-in-place location. Windows on both sides of the buildings should be double-paned: on one side, there is exposure to wildlands, and on the other side, there is a possible threat to Building 251. Consider NIST Technical Note 2205 (Maranghides et al. 2022) when scheduling partial retrofit activities.
- Coat the Composites Manufacturing Education and Technology Facility with fireproof coating. This will entail repeated coatings over time, depending on the product used.

7.2.4 Wildland Fire Response

Continue to host tours for the Mountain View Fire Department throughout the year as a way to familiarize first responders with the campus; include firefighters and engines. Incorporate Jefferson County Sherriff's Office Fire Management personnel into tours of both campuses to facilitate their familiarity of both NREL sites.

7.2.5 Evacuation

The Flatirons Campus should develop additional exits to facilitate emergency evacuation. These exits should provide passage to routes remote form each other and offer entry to different highways leading to different locations.

- Work with neighbors to the west (ARCOSA Lightweight) to develop an exit on the west side to Highway 93. Currently, barriers stop contractors from entering the campus. The route would enable evacuation through the current gate or replacement of such gate to a dirt/gravel road that would be maintained.
- Evaluate gate exit (the entry was newly replaced):
    - Explore the feasibility of a breakaway gate at the main gate and/or

    - Create the default position of the gate such that when there is no power, the gate is up (power outage is likely during a wildfire)
    - Enable both the entry and exit to be open during evacuation to expedite the process.

NREL should establish procedures for notification, and process for evacuation. This would include:

- A notification system that specifies the means of notification, the people to be notified, the trigger for notification, the destination for evacuees and the directions/procedure for evacuation. For the Flatirons Campus, this would entail expanding protocols from current evacuation for wind. Security will lead the drill for the Flatirons Campus.
- The Flatirons Campus should explore a notification system that leverages the current outdoor warning siren, potentially with a hi-log frequency to differentiate the emergency of wildfire from tornado. The notification system will need to be discussed with the Mountain View Fire Department and the Office of Emergency Services for both Jefferson and Boulder Counties. This should be in conjunction with a public announcement notification system within buildings. Any notification system should be tested at the beginning of the fire season and monthly during the fire season.
    - Triggers for evacuation will be informed by a fire growth simulation, based on two combinations of ignition locations and wind direction.
    - The simulations indicate that a fire burning from the north with a northerly wind spreads evenly across the landscape heading to the Flatirons Campus and is constrained by Highway 93, but easily crosses Highway 128. A fire starting near the southern extent of South 66th St. under these conditions without fire suppression would be expected to reach the campus and block the main exit in 3 hours.
    - A fire growth simulation assuming an ignition west of the campus with a westerly wind indicates that Highway 93 is an effective barrier to fire spread for some time; however, wildfire does block Highway 93 in 2.5 hours from ignition and Highway 128 (and the main entrance) several hours later.
    - Evacuation should use the main gate if a fire starts west of Highway 93 with a westerly wind; Evacuation through the proposed southwestern exit should take place if a fire starts north of Highway 128 with a northerly wind.
    - Evacuation should begin if a fire spreading with a northerly wind reaches the drainage known as Old Dirty Bismark at the end of South 116th St. Similarly, evacuation should begin if a wildfire spreading with a westerly wind crossed the Community Ditch Trail.
    - NREL staff should work with the Mountain View Fire Department to refine the evacuation triggers.
- Similarly, the campus should consider shelter in place in lieu of evacuation if a wildland fire reaches Highway 93 with a westerly wind or Highway 128 with a northerly wind. The only approved shelter-in-place building is Building 251.
- Evacuation drills should be performed at least yearly. This should include both evacuation and shelter-in-place scenarios. The time it takes to evacuate should be recorded and used to inform triggers for the initiation of evacuation during a real event.

Operations such as making all possible lanes available for exit should be evaluated and implemented in the various drills.
- Consider inviting staff from the neighboring federal wildlife refuge to evacuation drills.
- Consider inviting neighbor ARCOSA Lightweight to the evacuation drills because employees would be crossing their property.
- Consider inviting the Jefferson County Sheriff (Patrol and Office of Emergency Management Staff), Golden Emergency Management, and other law enforcement entities that would be expected to assist in evacuation; the Jefferson County Sheriff participated in the 2022 Rocky Flats Training Exercise.

7.3 NREL-Wide Recommendations

Develop training on wildland fire for employees—this could take the form of newsletters, monthly communications to employees, or web-based training.

Send out emails to both NREL campuses regarding fire weather and red flag prohibitions. Red flag conditions will be based on notification from the National Weather Service, potentially through the iNWS app. Encourage employees to download this app and other notification and awareness apps.

7.3.1 Defensible Space/Vegetation Treatments

Every time machinery is used, a fire watch should be in place, especially when winds exceed 7 miles per hour. Mowing is to start by sunrise, and end by 10 a.m., as is current practice. This specification should be in all contracts, with clauses for repercussion if the practice is not followed, even if no fire occurred.

This set of standards focuses on vegetation spacing and appropriate standards for landscaping maintenance. Landscaping should comprise low-fire-hazard/fire-safe species and, more importantly, be established in appropriate spacing such that the continuity of landscaping will not promote fire spread horizontally or vertically. A list of firewise plants recommended by the Colorado State Forest Service can be found in their FireWise Plant Materials publication (Dennis 2012).

The fuel management standards for the STM Campus should be considered for NREL-wide application.

7.3.2 Wildland Fire Response

Participate in interagency training exercises. NREL should participate in a yearly, or twice-yearly emergency exercise, which should include:

- Jefferson/Boulder Counties Offices of Emergency Services, including the Sheriff's Offices Patrol and Operations for both counties
- Nearby landowners as described earlier
- West Metro and Mountain View Fire Protection Departments
- Other organizations that could respond under mutual aid.

Improve signage:

- Ensure buildings have lighted/reflective signs of at least 4-inch stroke
- Ensure street names have lighted/reflective signs
- Remove signs that are not appropriate:
    - Sign indicating hydrogen on the H1 trailer at Flatirons Campus
- Replace signage indicating empty diesel tank where tanks have been emptied with a sign that indicates it is empty and out of service
- Install a wildfire danger sign at entry points at both campuses. This will entail monitoring fire weather, and physically adjusting the indicator as it changes.

An NREL representative should be designated as a resource advisor or agency liaison; this could be a member of the Emergency Management Team so that when a fire does occur, this individual can communicate within the incident command system and advise the responders about specific hazards and areas to avoid placing heavy equipment. This individual would be aware of those hazards and would have specialized equipment (such as hydrogen detectors) and maps of sensitive areas (e.g., ancient soils in the Flatirons Campus). Each campus should produce a map of the area to be protected from fire suppression impacts. The campus should supply maps (digitally in a geo-referenced PDF and as an analog map) to West Metro and Mountain View Fire Departments. The map can indicate other sensitive areas, marked as "avoid as necessary."

The installation of an advanced wildfire detection system could be explored. The existing camera at Mesa Top, which can detect visual light bands at the STM Campus, has a limited view and distance and is currently monitored by Laboratory Protection. A similar type of camera could be installed at the same location with a wider view and hosted by the Weather Stem or Alert Wildfire network (ALERT Wildfire n.d.[a]). This location has the greater view of the STM Campus. A similar type of camera could be installed on the weather tower at Flatirons Campus. ALERT Wildfire is a consortium of The University of Nevada, Reno, University of California San Diego, and the University of Oregon providing fire cameras and tools to help firefighters and first responders:

1. Discover, locate, and confirm fire ignition
2. Quickly scale fire resources up or down
3. Monitor fire behavior during containment
4. Help evacuations through enhanced situational awareness
5. Observe contained fires for flare-ups.

There is currently one such camera in Colorado at the Harvey Gap location west of Glenwood Springs (ALERT Wildfire n.d.[b]).

Other cameras with an infrared sensor are also being tested in California. Such a camera could be tied to an alarm system to alert NREL of an incident nearby.

Glossary

The source for many of the following definitions are the National Fire Protection Agency (NFPA) and the National Wildfire Coordinating Group (NWCG) Glossary of Wildland Fire (NWCG 2022). These definitions are provided so that common terminology is used as appropriate in DOE wildland fire management planning.

Term	Definition
Fire protection	All measures taken to reduce the burden of fire on the quality of life. Source: NFPA
Fuel	All combustible materials, including but not limited to vegetation and structures (NFPA 2022).
Fuel ignition	Pyrolysis of combustible material through either natural or human action.
Fuel treatment	Manipulation or removal of fuels to reduce the likelihood of ignition and/or to lessen potential damage and resistance to control (i.e., lopping, chipping, crushing, piling, and burning).
Hazard	Any real or potential condition that can cause injury, illness or death of personnel, or damage to, or loss of equipment or property (NWCG 2022).
Hot work	Work involving burning, welding, or a similar operation that is capable of initiating fires or explosions (NFPA 2019).
Incident	An occurrence, either human-caused or a natural phenomenon, that requires action or support by emergency services personnel to prevent or minimize loss of life or damage to property and/or natural resources. Source: NFPA
Land-use planning and management process	A process examining the environmental impact, consequences and recommended practices for DOE land use and stewardship, prepared in conformance with applicable DOE orders and federal requirements and guidance (see DOE Order 430.1B, *Real Property Asset Management*).
Preparedness	Activities that lead to a safe, efficient, and cost-effective fire management program in support of land and resource management objectives through appropriate planning and coordination. Source: NWCG
Prescribed fire	A wildland fire originating from a planned ignition in accordance with applicable laws, policies, and regulations to meet specific objectives. Source: NWCG

Term	Definition
Prevention	Activities, including public education, law enforcement, personal contact, and reduction of fuel hazards, directed at reducing the incidence of fires.
Topography	The land surface configuration. Source: NFPA
Treatment	See Fuel treatment.
Wildland	Land in an uncultivated, more or less natural state and covered by timber, woodland, brush, and/or grass. Source: NFPA
Wildland fire	A fire that originates in or extends to vegetative fuels and that can involve structures or other combustible materials. Source: NFPA
Wildland/urban interface	A geographical area where structures and other human development meet or intermingle with wildland or vegetative fuels, resulting in the potential for ignition of the structures within the area from flames or firebrands of a wildland fire. Source: NFPA

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Appendix A. Documentation of FlamMap Input Files

Spatial Input Files

The spatial data inputs to FlamMap characterize the terrain, weather, and fuels on the site with 11 different data layers. The combined files build landscape files, usable in FARSITE and FlamMap.

The spatial input data files are described in Table A-1.

Terrain

The three files that describe terrain were taken from LandFire Data. The original data is in a 10-meter resolution, resampled to 3 meters. The digital elevation model data provided elevation, aspect, and slope steepness.

Surface Fuel Models

Surface fuel models describe the volume, arrangement, density, moisture, and chemistry from the ground to an approximately 6-foot height. These characterize different types of grass, shrubs, and trees. Surface fuel models were described via the Standard 13 fuel models (Anderson 1982) via LandFire, which was a nationwide program that collected and interpreted fuels in 2005.

Surface fuel models for the area within NREL were mapped via Google Earth.

Custom fuel models were developed to describe conditions that were not included in the Standard 13 fuel models. One custom fuel model was used, which was mowed or grazed grass. This fuel model characterizes most of the surface fuels on lab property.

Canopy Cover

Canopy cover describes the percent of the ground surface that is covered by tree foliage. Canopy cover was categorized into percentage classes via LandFire. As with surface fuels, resolution of this data is 10 meters.

Height to Live Crown (or Crown Base Height)

Height to live crown is the average height of the lowest extent of the tree crown. The height to live crown was mapped in feet into via LandFire. See Appendix A for the metadata about layers obtained from LandFire. As with surface fuels, the original resolution of these data was 10 meters and was resampled to be 3-meter resolution.

Typically, height to live crown is quite high, around 20 feet in areas where eucalyptus and pines have been managed, while trees in unmanaged areas typically have a crown base height of 4–6 feet. The canopy cover for the area inside the lab was mapped via Google Earth.

Weather

The effects of weather on fire behavior are expressed in two ways in the FARSITE fire behavior modeling system. The first is through a time stream of weather variables, wind, and weather files. The second is through designating the moisture of the fuels at the outset of the modeling time. For shorter simulations, the fuel moisture designation is very important, potentially more important than the weather (but not wind) inputs.

The weather files were taken from a day in October that was similar to the condition in which the Marshall Fire burned.

The moisture of the fuel is designated for each fuel model and within each fuel model, for each size class (>1/4 inch, 1/4–1 inch, 1–3 inches), and for woody/live fuel components. The values were consistent with those thought to be present during the Marshall Fire. These are 2, 3, 7, and 70 for the size class and woody/live fuel components, respectively.

Adjustment File

Since FARSITE uses winds that are constant, not buffeting and changing direction, the rates of spread are known to be higher than observed. The adjustment file allows users to decrease the rate of spread for each fuel type independently. Generally, the windier the condition, the more the adjustment file. The adjustment file is kept standard at 0.9 for all fuel models.

Table A-1. Spatial Input Files

Level	Purpose
Elevation (feet above sea level)	This is necessary for adiabatic adjustment of temperature and humidity between elevations and for conversion of fire spread between horizontal and slope distances.
Slope (percent of inclination from the horizontal)	Slope is used to compute steepness effects on fire spread and solar irradiance.
Aspect (azimuth values degree clockwise from north)	Aspect is used to compute effects on fire spread and solar irradiance.
Fuel Model	Fuel models, organized and described as Fire Behavior Prediction System in terms of fuel volume, structure, and chemistry.
Canopy Cover	Canopy cover is necessary to compute shading and wind reduction factors. Canopy cover was mapped for the LandFire Program.
Tree Height	Tree height is used to compute spotting distance and crown fire characteristics.
Crown Base Height or Height to Live Canopy	Crown base height is an important parameter for determining the transition from surface fire to crown fire. This value incorporates the effects of ladder fuels in increasing vertical continuity and assisting transition to crown fire.
Weather and Wind	Weather is important to determine environmental conditions during the simulation. The weather data theme describes the maximum and minimum temperature and relative humidity, and the time in which the maximum and minimum temperature occurs in order to dry and moisten fuels accordingly.

Appendix B. Risk Assessment Results

Guide to Risk Ranking Characteristics for Wildland Fire Risk Reduction and Shelter-in-Place Building Selection

B.1 Purpose

The purpose of this document is to describe the attributes used to assess NREL buildings and describe the outcomes of the assessments. The assessments can be used to inform:

- Binning of NREL buildings for wildland fire structure ignition potential
- Identifying candidate buildings for retrofit to reduce structure ignition potential
- Identifying NREL shelter-in-place buildings for shelter-in-place orders during wildland fire.

The document describes what each attribute is, why it is important, and how many points each attribute contributes to the overall score. This is known as a weighted matrix. As such, certain attributes are assigned more value than others. The document describes the subsequent data mining process to identify risk bins, retrofit candidates, and shelter-in-place buildings.

B.2 Outline

The ranking attributes are contained within three main groups:

1. Building Construction Characteristics
2. Topography
3. Building Importance, Value, and Occupant Load.

Every attribute is evaluated for each building. Points are assigned based on how the building conforms to the attribute criteria. Building construction and topography points were assigned by NREL personnel, in conjunction with an industry expert in wildland fire, based on visual inspections and documentation, where available.

This document utilizes structure assessment methodologies presented in NFPA 1140, *Standard for Wildland Fire Protection* and DOE-HDBK-1224-2018, *Handbook and Accident Analysis,* Section 4.6.8.2.

B.3 Available Points

The total number of points from all three groups is 150.

B.4 Building Construction Characteristics

Description: The construction characteristics of a building may increase or decrease its susceptibility to ignition from wildland fire. The primary mechanisms of fire spread from vegetative fuel to a building are radiant heat, embers, and direct flame impingement. The International Wildland Urban Interface Code (IWUIC) and NFPA 1140 (*Standard for Wildland Fire Protection*) provide acceptable construction methods intended to reduce the risk of building ignition from wildland fire. The following attributes are based on requirements contained in these documents. Construction means and methods that do not comply with these documents score poorly. Building construction characteristics make up 40% of the total available points (60 out of 150 points).

B.4.1 Siding

Description: Exterior siding is susceptible to radiant heat and direct flame impingement. In addition, embers can land in cracks, ledges, and corners in siding. If exterior siding ignites, a fire may propagate to the remainder of the structure. Exterior siding materials vary widely. Treatments to protect against ignition include smooth designs that do not allow embers to ledge, and ignition-resistant materials such as stucco, cementitious materials, and other materials permitted by IWUIC and NFPA 1140.

Maximum Points: 5

Point Percentage: Siding represents 3.3% of the overall score and 8.3% of the allowable points within Building Construction Characteristics.

Points:

0: Noncombustible/fire-resistive/ignition-resistant. Complies with NFPA 1140 and/or the IWUIC. Examples include stucco, masonry, concrete, and metal wall panels.

5: Combustible siding. Examples include vinyl siding, batten and board, shingles, or other combustible materials.

B.4.2 Roofing

Description: Roofing is primarily susceptible to ignition via ember due to its large horizontal surface area, although radiant heat ignition is possible from nearby vegetation. Roof types vary widely in their susceptibility to ignition.

Maximum Points: 10

Point Percentage: Due to its large surface area and the fact that is a common building ignition point, roofing represents 6.6% of the overall score and 16.6% of the allowable points within Building Construction Characteristics.

Points:

0: Class A roof (NFPA 1140, 2022 ed., Section 25.3.1); noncombustible roof membrane.

10: Any roof material or assembly that is not Class A or noncombustible; assign 10 points where roof construction is unknown.

B.4.3 Eaves

Description: Eaves may serve as an initial building ignition point. There are different types of eaves. Two common types are "boxed" (in which the eave is enclosed) and "unenclosed." Eaves most frequently ignite because they physically trap heat and flame. If vegetation is adjacent to the structure, and the eave is combustible, it may ignite. Unboxed eaves that ignite can rapidly spread fire to the roof assembly and remainder of the building. Boxed eaves, no eaves, or ignition-resistant eaves are preferable. Vinyl gutters, where present, can ignited eaves or roofs.

Maximum Points: 5

Point Percentage: Eaves represent 3.3% of the overall score and 8.3% of the allowable points within Building Construction Characteristics.

Points:

0: No eaves; enclosed with fire-retardant treated wood, ignition-resistant materials, or noncombustible (NFPA 1140, 2022 ed., Section 25.4).

5: Unboxed eaves. Eaves that do not comply with the requirements for zero points.

B.4.4 Windows

Description: Windows may break due to radiant heat or direct flame impingement and fire can spread directly to a structure's interior. Studies show that multiple windowpanes, with at least one tempered glass pane, are more resistant to failure. Untempered glass expands with heat, while the casing constrains the space, causing cracks and failure.

Maximum Points: 10

Point Percentage: Windows represent 6.6% of the overall score and 16.6% of the allowable points within Building Construction Characteristics.

Points:

0: Dual pane with at least one tempered pane (NFPA 1140, 2022 ed., Section 25.7.1); no windows.

10: Unknown window material; windows not dual pane with at least one tempered pane.

B.4.5 Vents

Description: Vents create openings in buildings to allow for ambient air flow. They are typically located near the roof or foundation. Testing has shown that vents are a common ignition point for a building. Embers generated from a wildland fire are carried by winds and may enter a structure via its vent openings. These embers are typically undergoing smoldering combustion; when they land on a combustible object, they may ignite that object and start a new fire. This event is

regarded as one of the most common causes of building ignition. Reducing screen size, or installing vents tested to ASTM standards, have proven effective in limiting building ignition.

Maximum Points: 10

Point Percentage: Due to vents being a common building ignition point, vents represent 6.6% of the overall score and 16.6% of the allowable points within Building Construction Characteristics.

Points:

0: No vents; screened vents with a mesh opening size 1/8 inch or less (NFPA 1140, 2022 ed., Section 25.3.3).

10: Vents are uncovered; screened vents with a mesh size greater than 1/8 inch.

B.4.6 Deck/Balcony/Patio

Description: Decks, balconies, and patios that are connected to structures represent another ignition point for a structure due to their large horizontal surface. Frequently, they may contain spaces between boards, cracks, and at corners, which allow for lodgment of embers. Once ignited, a fire in these areas can spread to the main structure. This category also includes stairs, platforms, landings, and other ancillary exterior attachments to structures. Acceptable materials are typically ignition resistant, noncombustible, or fire-treated wood.

Maximum Points: 10

Point Percentage: Decks, balconies, and patios are a common building ignition point, and frequently have a large surface area. This category represents 6.6% of the overall score and 16.6% of the allowable points within Building Construction Characteristics.

Points:

0: Structure does not have deck/balcony/patio; materials are fire-retardant treated lumber, noncombustible material, or ignition resistant (NFPA 1140, 2022 ed., Section 5.4).

10: Item does not meet the requirements for zero points (this could include non-fire-retardant treated lumber, plastic composite materials that are not ignition resistant, etc.).

B.4.7 Deck Underside

Description: The underside of a deck is susceptible to accumulation of vegetation and general combustible storage. If items underneath a deck ignite, a fire may spread from the deck to the main structure.

Maximum Points: 10

Point Percentage: Deck undersides frequently have combustible vegetation or combustible storage underneath them. Ignition of these items via wildland fire is a common initiator for a structure fire. This category represents 6.6% of the overall score and 16.6% of the allowable points within Building Construction Characteristics.

Points:

0: No deck; deck is constructed of fire-retardant treated wood; deck is noncombustible; deck is ignition resistant (NFPA 1140, 2022 ed., Section 25.2).

10: Deck does not meet the requirements for zero points (decks could be constructed of non-fire-retardant treated lumber, plastic composite materials that are not ignition resistant, etc.).

B.5 Topography

General Description: The topography surrounding a structure can have a significant impact on whether structure ignition occurs during a wildland fire. For this risk assessment, topography includes slope and vegetation. Steep slopes and the presence of nearby combustible vegetation have been demonstrated to greatly increase the risk of building ignition. As such, this category represents 26.7% of the overall maximum points.

B.5.1 Slope

Description: A wildfire occurring on an upward slope will spread at a faster rate than a fire on a flat surface or a downslope. One reason is that flame lengths on an upslope preheat and ignite upslope vegetation via radiation, convection, and conduction. Steep slopes near buildings place a building at higher risk of ignition.

Maximum Points: 20

Point Percentage: Slope represents 13.3% of the overall score.

Points:

0: Does not meet the requirements for 20 points.

20: An upward slope toward a building of greater than 20% within 30 feet of a structure.

B.5.2 Vegetation

Description: Vegetation near a structure can ignite the structure via radiant heat or direct flame impingement. The region within 5 feet (“near zone”) of a structure is required to be free of combustible vegetation. The region between 5 and 30 feet (“midzone”) of a structure is required to be maintained in a manner to limit overall combustibility and thus reduce the risk of structure ignition (NFPA 1140, 2022 ed., Section 26). The Authority Having Jurisdiction shall have the authority to interpret the intent of these vegetation requirements.

Maximum Points: 20

Point Percentage: Vegetation represents 13.3% of the overall score.

Points:

0: Near zone is free of combustible vegetation that could ignite a structure. Midzone is maintained in an approved manner that reduces overall risk of fire spread to a structure.

10: Near zone and midzone are largely maintained but contain small amounts of combustible vegetation that could present a risk for structure ignition.

20: Does not comply with the criteria for zero or 10 points. Combustible vegetation in near zone and midzone.

B.6 Importance, Value, and Occupant Load

General Description: This category describes building attributes that are not related to structure ignition risk. These attributes are important for overall risk ranking.

B.6.1 Mission Critical

Description: Mission-critical buildings include those housing utility systems, facilities storing nuclear materials, user facilities, emergency response facilities, facilities housing communication systems and utilities, and support facilities necessary for performing operations associated with mission-essential functions.

Maximum Points: 20

Point Percentage: Mission critical represents 13.3% of the overall score.

Points:

0: Building is not considered mission critical.

20: Building is considered mission critical.

B.6.2 Building Value

Description: The building value is the replacement value of the building in the event of a fire leading to total building loss. This includes the value of the building contents, the replacement value of the building structure and its systems, the cost of upgrading to recent codes due to new construction, the cost for design work, and the cost of environmental cleanup. The building value monetary thresholds are based on guidance provided in DOE Order 420.1C, *Facility Safety.*

Maximum Points: 10

Point Percentage: Building value represents 6.6% of the overall score. This represents 20% of the Importance/Occupant Load/Building Value category. A lower value was chosen compared to the other two attributes in this category as this does not have life safety implications (occupant load), nor does it have a significant impact on lab operations (as in mission critical).

Points

0: Calculated building value is less than $5.7 million.

5: Calculated building value is more than $5.7 million but less than $177 million.

10: Calculated building value is more than $177 million.

B.6.3 Occupant Load

Description: Occupant load is an important consideration for both wildland fire risk and shelter in place building designation. Buildings with high occupant loads are more suitable as shelter in place buildings as they are able to accommodate large quantities of individuals to shelter in place. Buildings with a high number of occupants may also need to be prioritized wildfire risk reduction. Occupant load is based on the NREL FIMS Occupancy report.

Maximum Points: 20

Point Percentage: Occupant load represents 13.3% of the overall score.

Points:

0: Less than 20 occupants.

10: Between 20 and 100 occupants.

20: More than 100 occupants.

B.7 Risk Binning

Risk binning is useful in the context of wildland fire for asset prioritization. Buildings that are more susceptible to ignition (due to a combination of construction characteristics and topography), as well as buildings with high occupant loads, that are mission critical, or have a high replacement value, will be placed in higher risk bins. Table B-1 lists the risk bins and associated points:

Table B-1. Risk Bins and Points

Risk Bin	Points
Extra High	112.5–150
High	75–112.5
Medium	37.5–75
Low	0–37.5

Based on these bins, all buildings at NREL are either low or medium risk. Risk reduction efforts should be focused first on the medium-risk buildings. Risk reduction can be achieved through either reducing nearby combustible vegetation or retrofitting the building to be more ignition resistant. It should be noted that some buildings may score well as it pertains to building construction and vegetation/topography but are classified as medium risk due to their mission criticality, occupant load, and value. A good example of this is the Engineering Systems Integration Facility.

Table B-2. NREL Building Risk Bin Designations

Building	Risk Bin
Engineering Systems Integration Facility	Medium
Mesa Top (Solar Radiation Research Laboratory)	Medium
Field Test Laboratory Building	Medium
Solar Energy Research Facility	Medium
Research Support Facility	Medium
Integrated Biorefinery Research Facility	Medium

B.8 Shelter-in-Place Buildings

Candidate shelter-in-place buildings are those buildings that score low as it pertains to ignition risk and can house a significant number of occupants. Shelter-in-place buildings must meet both of the following criteria:

- Building construction points: 20 or less (out of 60)
- Occupant load: at least 20 or more occupants.

Using the criteria above, the following are candidate shelter-in-place buildings:

- Engineering Systems Integration Facility
- Field Test Laboratory Building
- Solar Energy Research Facility
- Science & Technology Facility
- Research Support Facility
- Building 251 (Flatirons Campus).

Table B-3. NREL Scores for Structure Risks

	BUILDING CONSTRUCTION CHARACTERISTICS								TERRAIN			Building Importance/Occupant					
Building	Siding	Roof	Eave	Window	Vents	Deck/Balcony/ Patio	Underside of Deck	Building Construction Sum	Slope	Vegetation	Sum Including Terrain	Mission Critical	Occupant Load	Building Value	Total Score	Shelter In Place?	Wildfire Risk Bin
South Table Mountain Campus																	
Bulk Storage Building	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
Facilities Maintenance Building	0	0	0	10	10	0	0	20	0	0	0	0	0	0	20	FALSE	LOW
Thermal Test Facility (TTF)	5	0	0	0	0	0	0	5	0	0	0	0	0	5	10	FALSE	LOW
Vehicle Testing and Integration Facility (VTIF)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
Waste Handling Facility (WHF)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
Energy Systems Integration Facility (ESIF)	0	0	0	0	0	0	0	0	0	0	0	20	20	10	50	TRUE	MEDIUM
ESIF Hydrogen Pad	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
IBRF Alcohol Tank	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
Education Center	5	0	0	0	0	0	0	5	0	0	0	0	0	0	5	FALSE	LOW
Solar Radiation Research Laboratory (SRRL, on Mesa T	0	0	0	0	10	0	0	10	0	10	10	0	0	0	20	FALSE	LOW
Solar Industrial Mesa Test Area (SIMTA, on Mesa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
High-Flux Solar Furnace (HFSF, on Mesa Top)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
Shipping & Receiving	5	0	0	0	0	0	0	5	0	0	0	0	0	5	10	FALSE	LOW
Integrated Biorefinery Research Facility (IBRF)	5	0	0	10	10	0	0	25	0	10	10	0	10	5	50	FALSE	MEDIUM
Outdoor Test Facility (OTF)	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	FALSE	LOW
Field Test Laboratory Building (FTLB)	0	0	0	0	0	0	0	0	0	10	10	20	20	5	55	TRUE	MEDIUM
Solar Energy Research Facility (SERF)	0	0	0	0	10	0	0	10	0	10	10	20	20	5	65	TRUE	MEDIUM
Science & Technology Facility (S&TF)	0	0	0	0	0	0	0	0	0	0	0	20	10	5	35	TRUE	LOW
Research Support Facility (RSF)	0	0	0	0	10	0	0	10	0	0	0	20	20	5	55	TRUE	MEDIUM
Café	0	0	0	0	0	0	0	0	0	0	0	0	20	0	20	TRUE	LOW
Parking Garage																	
Flatirons Campus																	
Bldg #101 Site Entrance Building	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
Bldg #152 Fire Pump House	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
Bldg # 248 Trailer 126250	0	0	0	10	0	0	0	10	0	10	10	0	0	0	20	FALSE	LOW
Bldg #249 Trailer 126251	0	0	0	10	0	0	0	10	0	10	10	0	0	0	20	FALSE	LOW
Bldg #249 Trailer 126253	0	0	0	10	0	0	0	10	0	10	10	0	0	0	20	FALSE	LOW
Bldg #251 Admin & Engineering	0	0	0	0	10	0	0	10	0	0	0	0	10	5	25	TRUE	LOW
Bldg #252 Small Switchblade Test Facility	0	0	0	0	0	10	0	10	0	0	0	0	0	0	10	FALSE	LOW
Bldg #253 Switchgear Bldg	0	10	0	0	0	0	0	10	0	0	0	0	0	0	10	FALSE	LOW
Bldg #253A Old Switchgear Bldg	0	10	0	0	0	0	0	10	0	0	0	0	0	0	10	FALSE	LOW
Bldg #254 Structural Test Lab STI	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	FALSE	LOW
Bldg #255 MW-Dynamometer Spin Test Facility	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	FALSE	LOW
Bldg #256 Model Test Laboratory	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
Bldg #257 Trailer 12652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
Bldg #258 5MW Dynamometer Spin Test Facility	0	0	0	0	10	0	0	10	0	0	0	0	0	5	15	FALSE	LOW
Bldg #260 COMET	5	10	0	0	10	0	0	25	0	0	0	0	0	0	25	FALSE	LOW
ROF Research Operations Facility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
CGI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
M-1A Met Equipment Storage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW
SW on Row1 Substation Control Bldg	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	FALSE	LOW
3.0 Grid Integration Research Pads	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FALSE	LOW

Appendix C. Fuel Management Standards

The following vegetation treatments are required to create sufficient defensible space within the fuel management zones described in this section. Fuel treatments for areas in proximity to structures include: the Campus Perimeter Zone, the Noncombustible Zone, the Landscaping Zone, and the Roadway Zone. The plant communities present determine the management actions required. Four general plant community type are addressed in this plan because of their presence in the fuel management zones. The community types provide specifics for treatment standards for grasslands, shrub, conifer, and riparian woodland, as defined further below.

In circumstances where slope, vegetation cover, building materials of existing buildings, or other circumstances beyond the control of NREL, the width of the relevant fuel management zone may be expanded to address increased risk factors. In such cases, strategies other than vegetation removal, such as "structure hardening," should also be considered and incorporated to the extent feasible.

Table C-1. Fuel Management Zone Specifications

	Fuel Management Zone	Zone Area
1	Campus Perimeter Zone	Site boundaries within 100 feet of adjacent structures
2	Noncombustible Zone	5 feet from structures
3	Landscaping Zone	Entire landscaped area
4	Roadway Zone	10 feet from pavement
5	Grassland Zone	30 feet from structures
6	Shrub Zone	100 feet from structures
7	Conifer Zone	100 feet from structures
8	Riparian Woodland Zone	20 feet from top of creekbank

C.1 Noncombustible Zone: To a Distance of 5 Feet From Structures

Figure C-1. Excellent example of a noncombustible zone

Hardscape surfaces (such as patios, gravel, and bare soil), and landscape materials (such as lawn and succulent herbaceous plants) are examples of noncombustible surfaces. Wood mulch is not considered noncombustible. Maintenance staff and landscape architects are encouraged to make liberal use of hardscaping within 5 feet of structures. Care should be taken in the design phase to ensure there is adequate room for such treatments.

Figure C-2. Noncombustible zones should also extend 5 feet from equipment that may ignite

Figure C-3. Keep shrubs from this zone, especially adjacent to unprotected vents

C.2 Landscaping Zone: Within Entire Campus Landscaped Area

Ornamental landscaping often results in large amounts of shrubby flammable vegetation being planted near structures. Many commonly used landscape plants, such as conifers, flammable woody shrubs, and tall ornamental grasses, should be avoided because they may create a fire threat to a building that would otherwise be fire safe. In some areas of the campus the landscape is aged, with dead and dying plants that need to be removed or rejuvenated. Plant material that is removed from the landscaping must be composted or removed and disposed of properly.

The spacing between landscaping plants and volume of landscaping biomass should mimic the conifer zone. Landscaping zone should be maintained according to the standards in the mixed conifer zone (see Figure C-4).

Figure C-4. Approved landscaping must be designed and maintained to minimize flammability. This landscape is compatible with wildland fire safety.

C.3 Roadway Zone: 10 Feet From Edge of Roadway Pavement

The roadway zone is important to create space for safe passage and to provide a location where firefighters can travel and engage in fire response. Treatment standards correspond to vegetation type along the roadway:

- Grassland, and the understory of treed vegetation should be mowed within 10 feet from the pavement edges, according to the standards in the grassland zone.

Figure C-5. Roadsides should be mowed for a width of 10 feet from road edge

Figure C-6. No trees were present that would require pruning over the road

- Tree branches extending over roadway surfaces should be pruned to ensure 15 feet of vertical clearance. Whenever possible, healthy overhanging branches higher than 15 feet should be left in place to shade roadway areas and thereby reduce weed and understory growth.
- Ensure that every structure has a dedicated fire hydrant and a hammerhead or other safe turnaround for fire equipment access. Maintain vegetation around these facilities to ensure visibility and access. Vegetation must be cleared 3 feet around each fire hydrant.

Maintain both 15 feet vertical and horizontal clearance at the hammerhead or other turnaround for fire equipment.

Figure C-7. Hydrants were generally kept clear of vegetation that would prevent their use in a wildfire; however, shrubs should be trimmed on right

C.4 Annual Grassland Zone: To a Distance of 30 Feet From Structures

Because annual grasslands dry and become flammable at the start of every summer, grassland areas will need annual attention, typically by mowing prior to the beginning of each summer. By mowing in late spring, perennial native grasses and wildflowers are retained and may contribute in a lower-hazard condition. Invasive, non-native species such as acacia, French broom, poison hemlock, and thistles must be completely removed annually in the treated areas.

- Within 30 feet from structures, annual grassland areas should be mowed in early summer to maintain a minimum height of 4 inches during the summer. A second mowing may be needed if late rains allow the annual grass to continue to grow.
- Native perennial grasses and wildflower stands should not be mowed more frequently than every 60 days, ideally shortly after they have set seed. This may require a delayed mowing schedule in wetter years to maintain their density.
- Shrub species growing within the grassland zone should be cut or removed. Islands of shrubs should present less than 30% cover and be well spaced in the grasslands. Select invasive species, common species, and aged shrubs for treatment to achieve desired spacing.

Figure C-8. Grass is generally mowed to appropriate heights, as pictured

Figure C-9. Not all structures currently have grass mowed within 30 feet of the building edge

Figure C-10. Annual grassland zones (or unirrigated lawns) must be mowed at least once annually in late spring or early summer

Figure C-11. Grassland within 30 feet of structures or campus perimeter should be mowed every year shortly after it cures

C.5 Shrub Zone: To a Distance of 100 Feet From Structures

This vegetation type burns with great intensity, and it poses a high fire hazard to adjacent structures both on and off campus. Many shrub species growing within shrub habitat will stump-sprout vigorously when cut or burned, so shrub zones will need to be retreated on a regular basis. In this vegetation type, defensible space is created by maintaining well-spaced shrubs with succulent young vegetation, and no dead branches.

Figure C-12. All shrubs within shrubs must be thinned or mowed within 100 feet of structures

Figure C-13. Reducing fuel volume from shrubs is especially important when structures are located above the wildlands

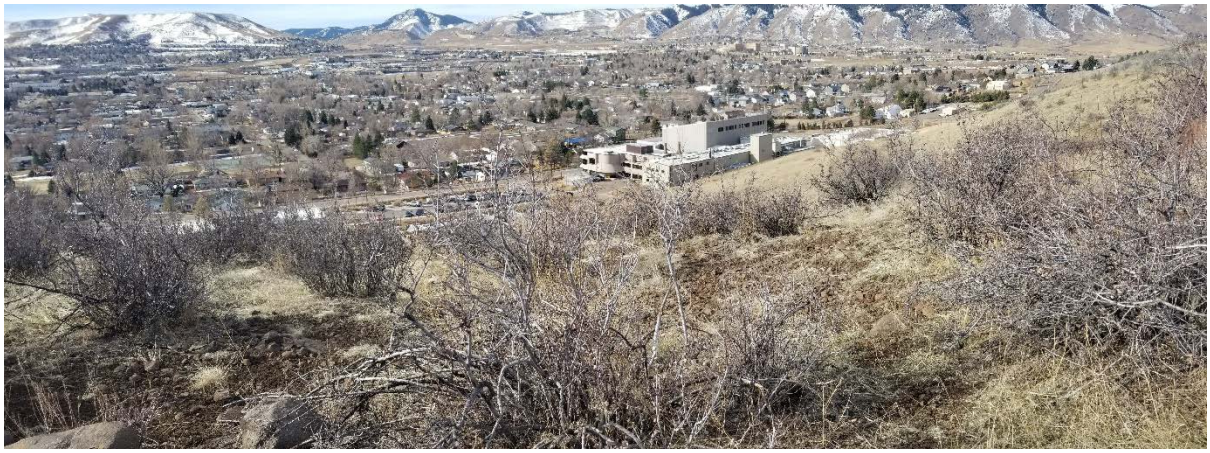

Figure C-14. Maintain shrub masses to be discontinuous groups of shorter, younger, more succulent shrubs

- In open areas away from trees, within 100 feet of structures, change the mass of shrubs into discontinuous groups of shorter, younger, more succulent shrubs and ensure the distance between groups of shrubs is at least 2 times the height of the shrub patch.

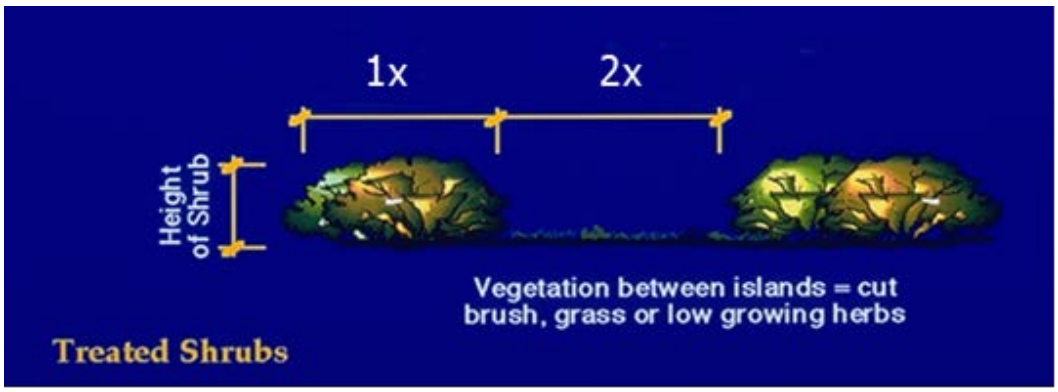

Figure C-15. Create shrub groupings to provide horizontal separation between shrubs. Each group of shrubs should be no wider than 2 times its height, or less than 120 square feet in area. The space between shrub groups should be at least 2 times the height of the shrubs, or a distance of 10 feet, whichever is greater.

- If many shrub species are present, target removal of the most common shrubs first.
- It is not necessary to eliminate all shrubs within the fuel management zone. Instead, change the pattern into discontinuous groups of shorter, younger, more succulent shrubs.
- Remove all dead branches from less-flammable desirable shrubs.
- Healthy trees should be retained. As trees increase in size and number, they provide a long-term reduction in shrub cover and fire hazard.

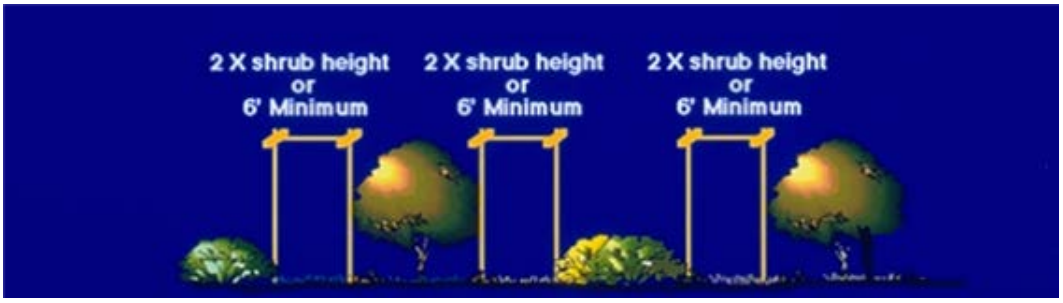

Figure C-16. Create horizontal spacing between trees and shrubs by removing shrubs from around trees within a radius that extends 3 feet from the tree's drip line. For trees taller than 6 feet, remove shrubs within a distance of 6 feet from the tree's drip line.

- Trees growing within this zone should be encouraged by removing shrubs from within an area around the tree.
    - When the tree is shorter than 6 feet, all shrubs should be removed from within a distance of 3 feet from the tree's drip line.
    - When a tree is taller than 6 feet, all shrubs should be removed from within a distance of 6 feet from tree crown edge.

C.6 Conifer Zone: To a Distance of 100 Feet From Structures

Figure C-17. In the conifer zone, annual grass must be mowed, understory plants must be kept short, and small lower tree branches must be removed

Figure C-18. The conifer zone should also be applied to the occasional hardwoods on the campus

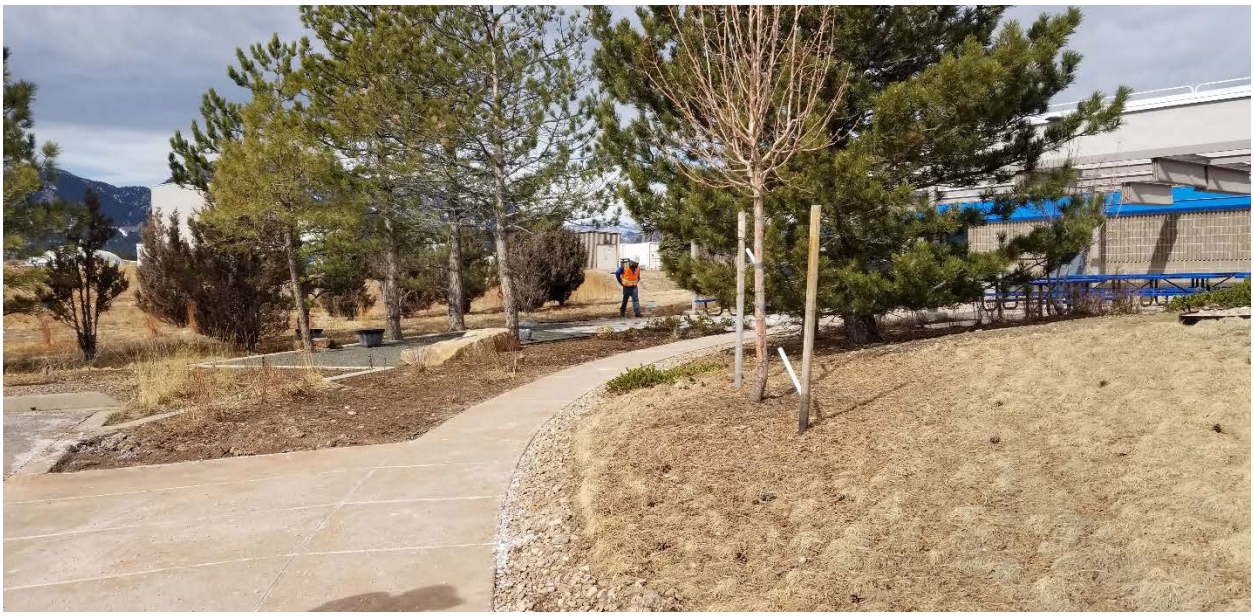

Figure C-19. In the conifer zone, annual grass must be mowed, understory plants must be kept short, and small lower tree branches must be removed

Figure C-20. Ladder fuels should be eliminated by pruning lower branches and/or removing adjacent trees that form vertical continuity

Figure C-21. Branches on the lower third of the tree height hsould be removed if the tree is shorter than 24 feet

The understory of conifer zone habitat includes short shrubs and grasslands. The goal of this standard is to maintain a zone with a short-statured understory of herbaceous plants and shrubs, and a tree canopy at least 8 feet above the ground. An initial treatment will be required to prune smaller branches of trees up to 8 feet above the ground and to reduce density and stature of understory shrubs. After the initial treatment, annual maintenance will be needed to cut back shrub sprouts in order to maintain a maximum height of 2.5 feet.

C.6.1 Prescriptions for Grass Mowing in Conifer:

Mowing annual grass under and around trees reduces fire intensity and rate of spread of fire to an acceptable level and diminishes the possibility that fire can climb into the tree canopy. Pruning the small lower tree branches will reduce the possibility that fire can spread into the tree crowns. Invasive species must be completely removed annually.

- Within 30 feet of structures, grassland areas should be mowed in early summer to a height of four inches, according to the standards in the grassland zone.
- Within 100 feet of structures, grass growing under trees, out to 6 feet beyond the driplines of trees, should be mowed in early summer to a height of 4 inches.
- Within 30–100 feet of structures (depending on slope and other factors), grass growing in the open, away from trees, does not need to be mowed.

C.6.2 Prescriptions for Removing Dead Wood on the Ground:

- Throughout the fuel management zones, remove all dead branches or larger logs on the ground smaller than 8 inches in diameter.
- Large dead material may be removed or relocated. Dead limbs larger than 8 inches in diameter in the fuel management zones should remain on the site if isolated from dead material that is smaller than 4 inches in diameter, if not under a tree canopy, or if moved at least 100 feet from the structure. Large woody material by itself does not ignite readily and does not produce long flames. Retaining these features in open areas serves a beneficial purpose of retaining soil moisture and supports important wildlife, including native pollinators. Once dead logs become rotted through and friable, they should be removed or scattered in the general area to avoid a concentration of lighter fuels.

C.6.3 Prescriptions for Understory Maintenance:

- Within 30 feet from structures, at the beginning of each summer, ensure that the herbaceous understory is maintained at a maximum height of 4 inches.
- Understory vegetation should not be completely removed. Instead, selectively remove flammable species remove dead branches from less-flammable desirable species.
- Native understory shrubs are to be kept free of dead branches and no more than 2.5 feet in height. Taller shrubs may be retained in areas where there is no tree canopy cover.
- Keep leaf litter depth no greater than 4 inches.
- Remove undesirable trees.

C.6.4 Prescriptions for Tree Pruning:

- Remove all branches, living or dead, less than 3 inches in diameter and less than either 8 feet from the ground or 3 times the height of any understory shrubs, whichever is greater.

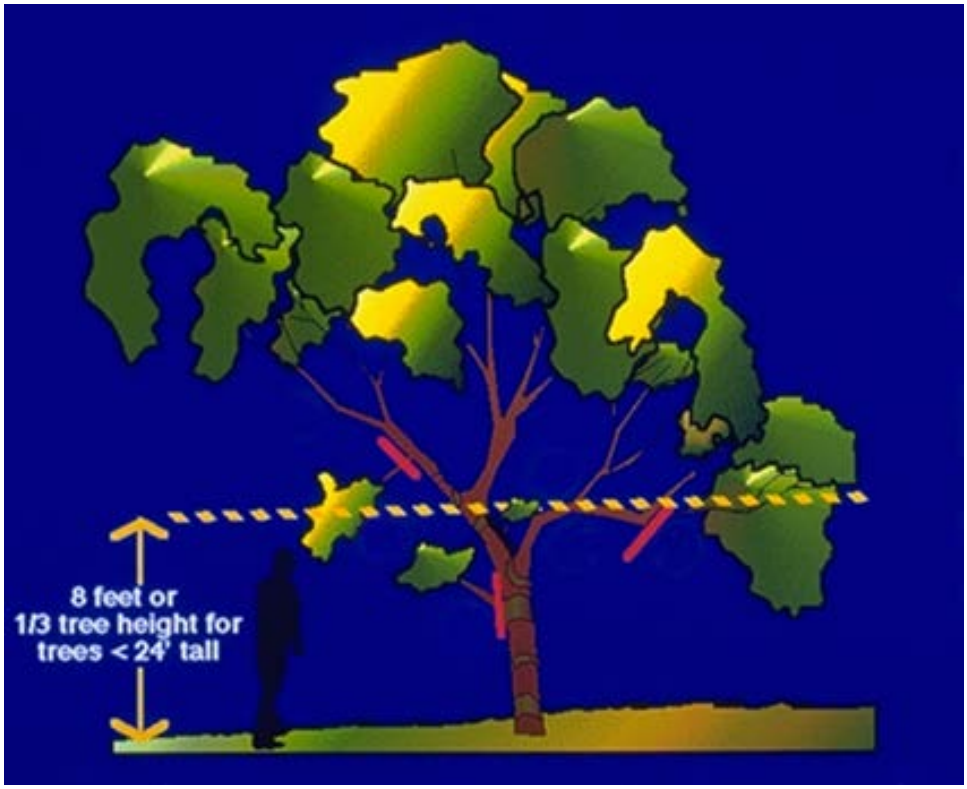

Figure C-22. Create vertical spacing under lower tree branches by removing small tree branches from the bottom 8 feet of the tree, or from the bottom one-third of the tree, whichever is less

- Living branches that are greater than 3 inches in diameter but lower than 8 feet in height can be retained, provided that the area within the dripline of trees is maintained clear.
- Dead limbs located less than 8 feet in height from the ground shall be removed.
- In landscaped areas, healthy tree branches less than 3 inches in diameter or 8 inches diameter if split or diseased, should be removed to provide vertical clearance of 3 times the height of the understory plants, or 8 feet above understory plants, whichever is greater.

- For trees shorter than 24 feet in height, remove lower 1/3 of branches smaller than 3 inches in diameter, or alternatively, treat as a shrub grouping.
- Once initial pruning is accomplished, tree pruning is likely to be needed infrequently, on an interval of about once every 3 to 5 years.
- Do not thin, or unnecessarily prune, the tree canopy, as this will promote more understory shrub growth as well as growth on lower parts of the tree and will result in increased risk that fire will spread to the tree canopy. Maintain canopy closure where possible.
- Sometimes small trees may need to be cut to the ground in order to achieve the separation of the ground level from the tree canopy, or because mowing equipment cannot avoid the small trees.

C.7 Riparian Woodland Zone: Within 20 Feet From Top of Creekbank

The riparian zone is the area 20 feet either side of the top of bank and within the banks of the creek bed. Riparian woodland is designated as a sensitive habitat by the Colorado Fish and Wildlife Conservation Office. In these areas special care should be taken not to trample riparian vegetation or alter the creek alignment or banks.

No fuel management should be performed inside the bank of the creek. Hand labor must be used to treat fuels within 20 feet of the top of bank of the creek.

Treatments for fire safety in the riparian woodland zone are limited by concerns for wildlife habitat. Fortunately, foliage of vegetation in this area generally has higher moisture and can act to dampen fire intensity and spread. Fire management treatments that concentrate on dead material can enhance fire safety without compromising wildlife habitat.

Figure C-23. Hand labor would need to be used in this area within 20 feet of the creekbank (willow trees indicate riparian area)

The following actions are to be taken in the riparian woodland zone:

- Remove dead vegetation, vines, and dry fuels such as dead lower branches of trees.
- Remove all invasive non-native plants such as acacia, French broom, yellow star thistle, and Italian thistle.
- Living trees and shrubs may not be removed or pruned.

C.8 Areas of Concern: Electrical Charging Station

Figure C-24. Areas around the electric charging should be mowed

C.9 Additional Areas: Power Poles

Tree branches should be trimmed away from the line carrying power, and per the standards in the conifer zone. This is so that any ignition along the road or from faulty equipment will be prevented from traveling to tree crowns and distributing embers.

Similarly, grasses should be mowed within 10 feet of the roadside, and within a 10-foot radius from poles with transformers.

Figure C-25. Example of location where trees should be trimmed and grass mowed

Figure C-26. While the tree is not tall enough to merit trimming from the top, the grass should be mowed at the base of this pole with a transformer

C.10 Schedule of Vegetation Management

The first priority for the schedule of vegetation management actions is life safety. Focus vegetation management first on the:

- Noncombustible zones, starting from each building exit and working around the building to maintain a 5-foot zone that reduces the chance of ignition immediately adjacent to buildings.
- Roadways zones 15 to 30 feet from the edge of pavement to support access by first responders and evacuation of employees.

After life safety, property protection is second in priority.

- Develop defensible space for each building with the landscaping zone and landscape type up to 100 feet from the structures.
- Complete perimeter treatments where adjacent homes' defensible space is within the campus boundary.

The final priority is natural resource protection that treats the vegetation to reduce the potential for ignition and overall fuel load. Natural resource protection treatments not only protect the natural landscape, but also reduces the chance of uncontrolled wildfire across the campus.

Appendix D. Fire Growth Simulations

Several fire behavior prediction software applications have been developed by the U.S. Forest Service. These include a wide variety of applications designed to specifically meet firefighting or fire prevention needs. For the analysis comparing fire growth with possible evacuation triggers for evacuation, we used FARSITE, which has recently merged into one software package (FlamMap version 6.0).

FARSITE predicts fire growth across a landscape. It allows the analyst to compare fire behavior potential across an entire landscape. FARSITE predictions do **not** include fire suppression action. In this aspect, the results do not portray realistic growth after a few hours from ignition, since suppression actions will slow fire growth and modify its spread pattern. However, FARSITE does show potential fire spread and its associated fire intensity. It also shows us the likely spread direction of a fire. The fire growth analysis that FARSITE allows does not allow for the direct comparison of one fire over another because of the difference with ignition start, terrain, weather, and other parameters. FARSITE provides information that helps determine fire risk and hazard, in addition helps land managers determine what fuel modifications would best change potential fire behavior, and especially in this case, when evacuation might be initiated.

FARSITE computes wildfire growth and behavior for fairly long time periods under heterogeneous conditions of terrain, fuels, fuel moistures, and weather. (https://www.firelab.org/project/flammap)

Two separate predictive scenarios were developed for each campus. Tables D-1 and D-4 on the following pages show a scenario matrix for the STM Campus and the Flatirons Campus, respectively, with the FARSITE inputs for each scenario. There are several fire behavior outputs that the fire behavior software can generate. The Scenario Matrix details which outputs were selected and reviewed for this assessment. In this analysis, the output selected was:

1. Time of Arrival
2. Perimeters
3. Flame length
4. Rate of fire spread.

D.1 South Table Mountain Scenario Matrix

Table D-1. Inputs for the FARSITE Simulation for the South Table Mountain Campus

Scenario Num	STM1	STM2
Scenario Description	330 deg wind at 20mph	270 deg wind at 20mph
LCP	LCP_LF2021_FBFM40_210_CONUS.lcp	LCP_LF2021_FBFM40_210_CONUS.lcp
FMS	standard_conditions_3-4-5-70-70.fms	standard_conditions_3-4-5-70-70.fms
FMD	n/a	n/a
WXS	STM1 Extreme Weather 330 deg max 20mph.wxs	STM2 Extreme Weather 270 deg max 20mph.wxs
IGN PT	483,576.85; 4,401,763.78	482,588.19; 4,399,633.17
PERIMETER RESOLUTION	30 meters	30 meters
DISTANCE RESOLUTION	30 meters	30 meters
TIME STEP	30 minutes	30 minutes
EMBER SPOT PROBABILITY	0.05	0.05
MINIMUM SPOT DISTANCE	30 meters	30 meters
BACKGROUND SPOTTING GRID RESOLUTION	15 meters	15 meters
FOLIAR MOISTURE CONTENT	100	100
CROWN FIRE CALCULATION	Scott/Reinhardt (2001)	Scott/Reinhardt (2001)
FUEL MOISTURE CONDITIONING DAY	10/1 1300	10/1 1300
	START DATE/TIME	END DATE/TIME
Burn Period 1	10/2 1000	10/2 1800
Burn Period 2	n/a	n/a
Burn Period 3	n/a	n/a
OUTPUTS:		
Arrival Time	Yes	Yes
Perimeters	Yes	Yes
Flame Length	Yes	Yes
Rate of Spread	Yes	Yes
Crown Fire Activity	Yes	Yes

Maps and Tables

For the inputs detailed in scenario matrix in Table D-1, the following fire growth is predicted for a period of 8 hours and assumes no fire suppression takes place. Please note, in all models presented in this appendix, buildings are not considered fuel, and fire growth or potential are not predicted where they exist.

D.1.1 STM1

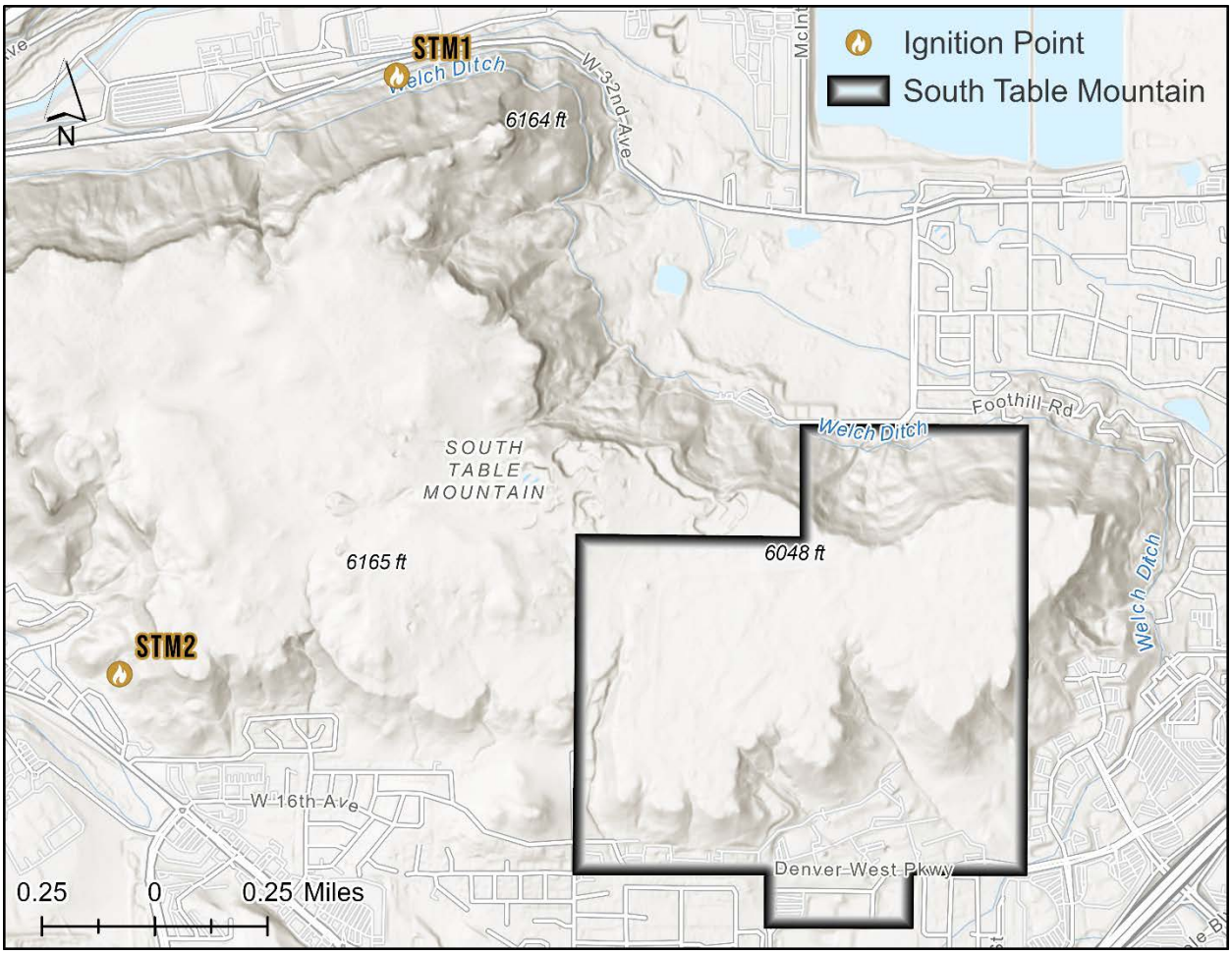

Figure D-1. Area of analysis for the fire growth simulations

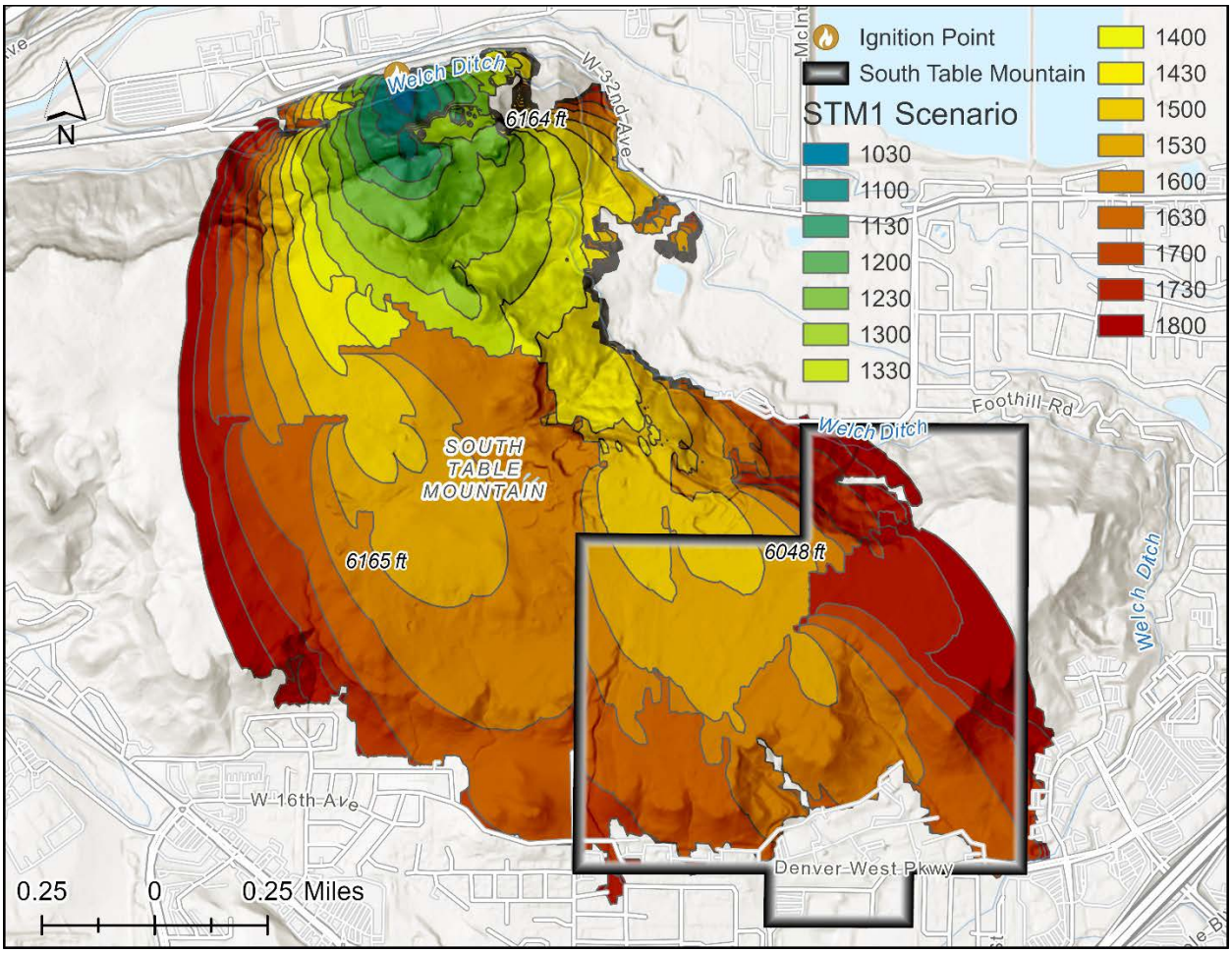

Figure D-2. Visual representation of the results of fire simulation STM1 indicating the time of arrival

This simulation indicates that a fire burning from the north with a northerly wind spreads fastest in the area at the top of the STM Campus, and that the golf course and developed areas directly north of NREL constrain fire growth to the campus. In this scenario, evacuation caused by fire from the north is not a major concern.

Table D-2. Table of Time of Arrival and Number of Fires Produced in Each Time Step for Simulation STM1

Elapsed (DD HH:mm)	Current (MM/DD HH:mm)	Fires	Enclaves	Total Acres	Time Step Acres
00 00:30	10/02 10:30	3	0	2.74	2.74
00 01:00	10/02 11:00	4	0	10.66	7.92
00 01:30	10/02 11:30	6	1	22.17	11.52
00 02:00	10/02 12:00	10	0	34.20	12.03
00 02:30	10/02 12:30	5	0	64.52	30.32
00 03:00	10/02 13:00	10	8	111.10	46.58
00 03:30	10/02 13:30	14	6	160.81	49.71
00 04:00	10/02 14:00	17	6	205.22	44.41
00 04:30	10/02 14:30	28	8	267.10	61.87
00 05:00	10/02 15:00	20	9	382.23	115.14
00 05:30	10/02 15:30	22	14	578.50	196.27
00 06:00	10/02 16:00	25	21	880.28	301.78
00 06:30	10/02 16:30	35	32	1104.24	223.96
00 07:00	10/02 17:00	38	36	1207.10	102.86
00 07:30	10/02 17:30	37	35	1305.05	97.95
00 08:00	10/02 18:00	39	37	1378.51	73.46

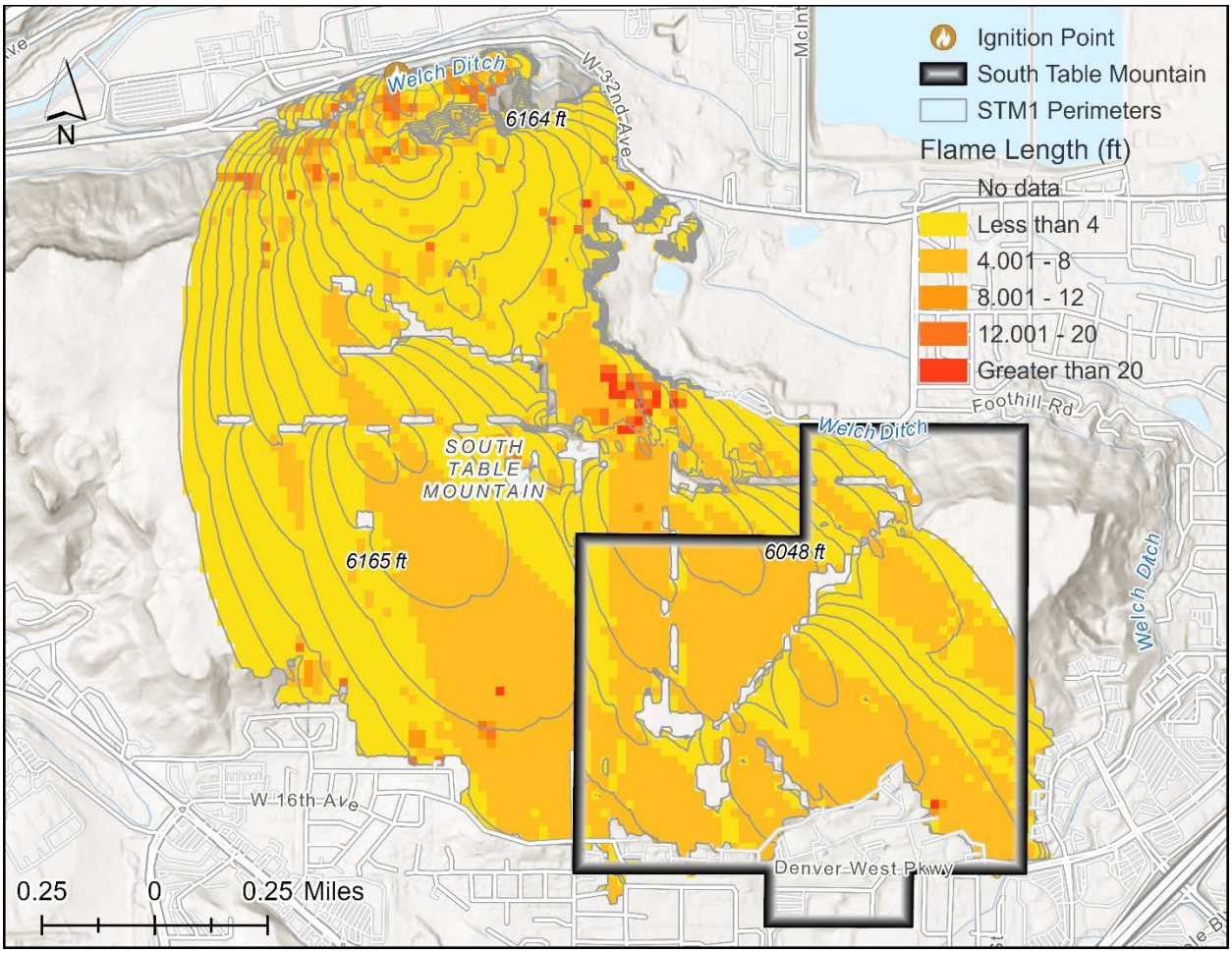

Figure D-3. Visual representation of the results of fire simulation STM1 indicating flame lengths

In this scenario, almost all areas burned with flames shorter than 8 feet, consistent with an area with light, flashy fuels. A small location of longer flame lengths is located immediately east of built portion of the campus. Generally, the areas where flame lengths are predicted to be within 4–8 feet are on the western portion of the campus.

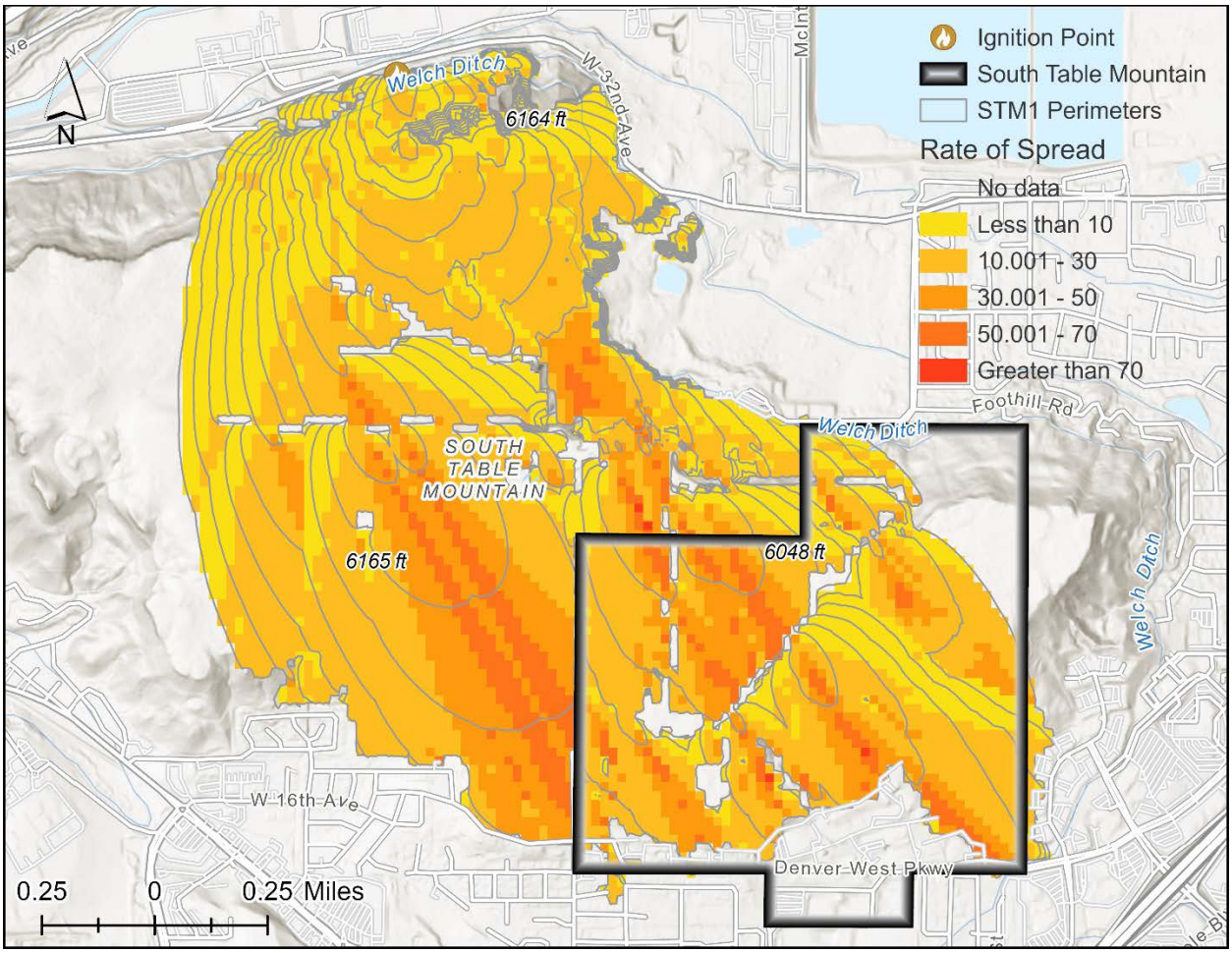

Figure D-4. Visual representation of the results of fire simulation STM1 indicating rates of fire spread

Fire spread rates within the STM Campus are highest in the drainages north of the built environment. Fire spread rates are moderately fast, consistent with grassy fuel types and strong winds.

D.1.2 STM2

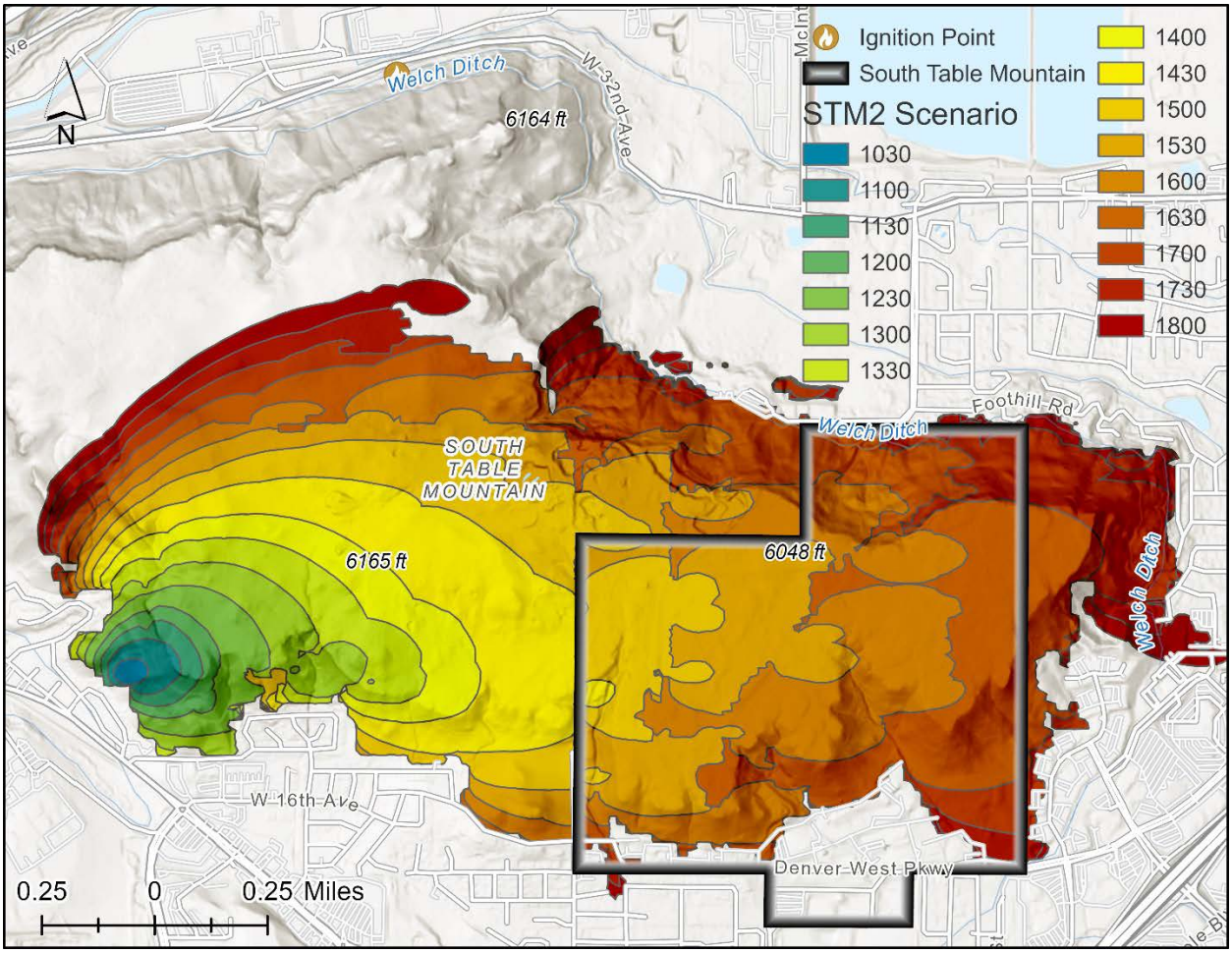

Figure D-5. Visual representation of the results of fire simulation STM2 indicating the time of arrival

In this simulation a fire from the west spreads moderately quickly and can impact Mesa Top within 4 hours (without effective fire containment). Fires from the west and with a westerly wind will also move into the campus proper. In this scenario, fires will also impact neighboring residents. Fortunately, Denver West Parkway is affected later in the fire growth simulation, thereby allowing evacuation prior to the fire reaching the road. All evacuation should go to the NREL East Gate.

Table D-3. Table of Time of Arrival and Number of Fires Produced in Each Time Step for Simulation STM2

Elapsed (DD HH:mm)	Current(MM/DD HH:mm)	Fires	Enclaves	Total Acres	Time Step Acres
00 00:30	10/02 10:30	1	0	2.21	2.21
00 01:00	10/02 11:00	1	0	9.64	7.42
00 01:30	10/02 11:30	1	0	19.42	9.78
00 02:00	10/02 12:00	1	0	32.29	12.88
00 02:30	10/02 12:30	3	1	61.42	29.12
00 03:00	10/02 13:00	3	1	100.07	38.65
00 03:30	10/02 13:30	4	3	145.37	45.30
00 04:00	10/02 14:00	3	2	200.41	55.04
00 04:30	10/02 14:30	4	3	335.43	135.02
00 05:00	10/02 15:00	7	6	487.81	152.38
00 05:30	10/02 15:30	15	14	662.57	174.76
00 06:00	10/02 16:00	25	23	878.95	216.38
00 06:30	10/02 16:30	47	40	1142.92	263.97
00 07:00	10/02 17:00	56	48	1264.71	121.79
00 07:30	10/02 17:30	58	46	1323.08	58.37
00 08:00	10/02 18:00	50	42	1373.20	50.12

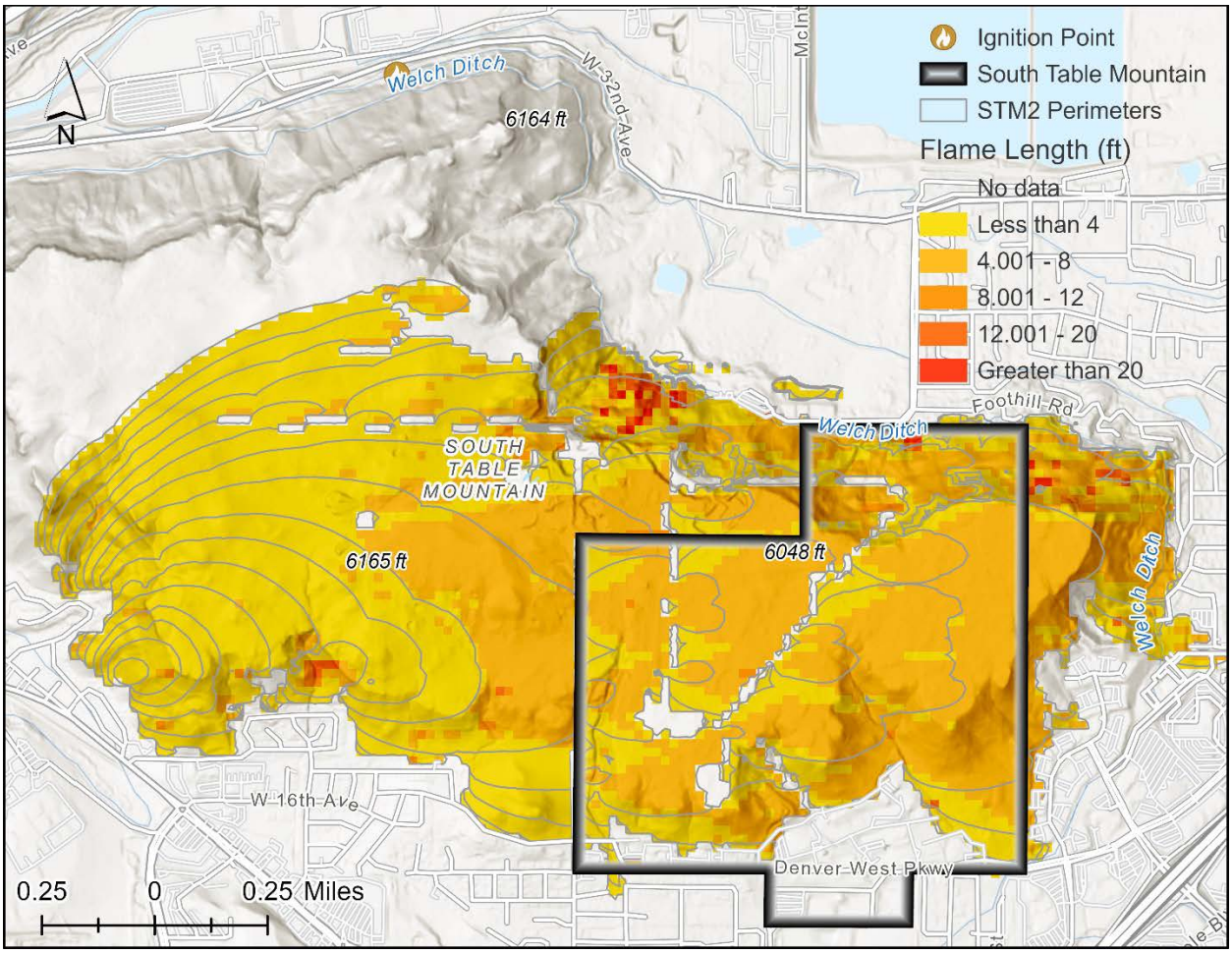

Figure D-6. Visual representation of the results of fire simulation STM2 indicating the flame lengths

Similar to the previous simulation, most of the flame lengths are shorter than 8 feet; almost the entire area within the STM Campus burns with flames between 4 and 8 feet in length. The same small location on the eastern side of the built environment on the STM Campus is predicted to burn with a longer flame length, likely due to heavier fuels in that location.

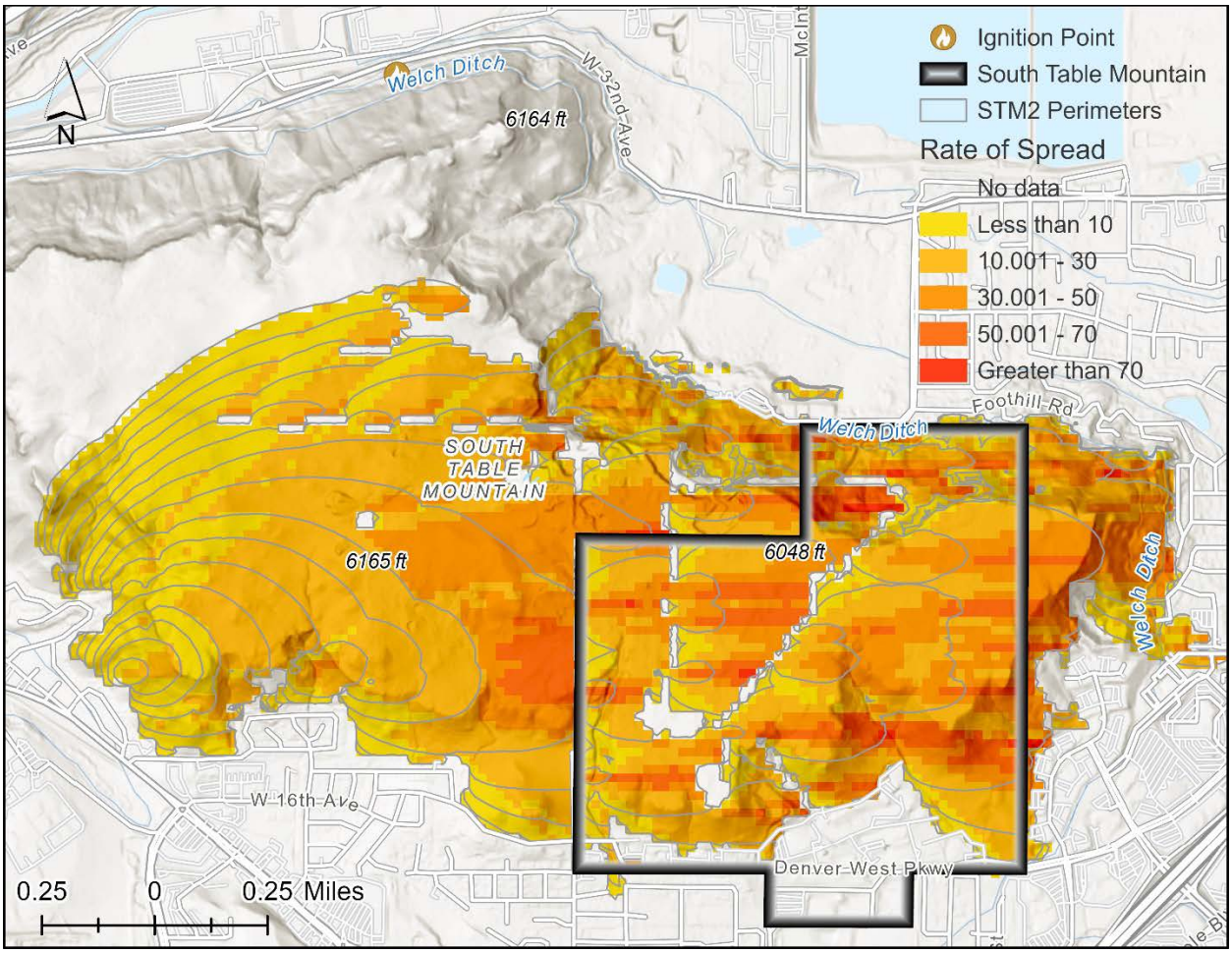

Figure D-7. Visual representation of the results of fire simulation STM2 indicating the rate of fire spread

This simulation indicates that spread rates accelerate as the fire spreads to the east. Fire spread north of the built environment in the STM Campus is highest and is fairly rapid throughout the area of interest.

D.2 Flatirons Campus Scenario Matrix

Table D-4. Inputs for the FARSITE Simulation for the Flatirons Campus

Scenario Num	FLT1	FLT2
Scenario Description	300 deg wind at 20mph (sustained)	30 deg wind at 20mph (sustained)
LCP	LCP_LF2021_FBFM40_210_CONUS.lcp	LCP_LF2021_FBFM40_210_CONUS.lcp
FMS	standard_conditions_3-4-5-70-70.fms	standard_conditions_3-4-5-70-70.fms
FMD	n/a	n/a
WXS	FLT1 Extreme Weather 300 deg max 20mph.wxs	FLT2 Extreme Weather 30 deg max 20mph.wxs
IGN PT	478,276.12; 4,419,279.38	481,680.59; 4,420,356.72
PERIMETER RESOLUTION	30 meters	30 meters
DISTANCE RESOLUTION	30 meters	30 meters
TIME STEP	30 minutes	30 minutes
EMBER SPOT PROBABILITY	0.05	0.05
MINIMUM SPOT DISTANCE	30 meters	30 meters
BACKGROUND SPOTTING GRID RESOLUTION	15 meters	15 meters
FOLIAR MOISTURE CONTENT	100	100
CROWN FIRE CALCULATION	Scott/Reinhardt(2001)	Scott/Reinhardt(2001)
FUEL MOISTURE CONDITIONING DAY	10/1 1300	10/1 1300
	START DATE/TIME	END DATE/TIME
Burn Period 1	10/2 1000	10/2 1800
Burn Period 2	n/a	n/a
Burn Period 3	n/a	n/a
OUTPUTS:		
Arrival Time	Yes	Yes
Perimeters	Yes	Yes
Flame Length	Yes	Yes
Rate of Spread	Yes	Yes
Crown Fire Activity	Yes	Yes

Maps and Tables

For the inputs detailed in scenario matrix in Table D-4, the following fire growth is predicted for a period of 8 hours and assumes no fire suppression takes place. Please note, in all models presented in this appendix, buildings are not considered fuel, and fire growth or potential is not predicted where they exist.

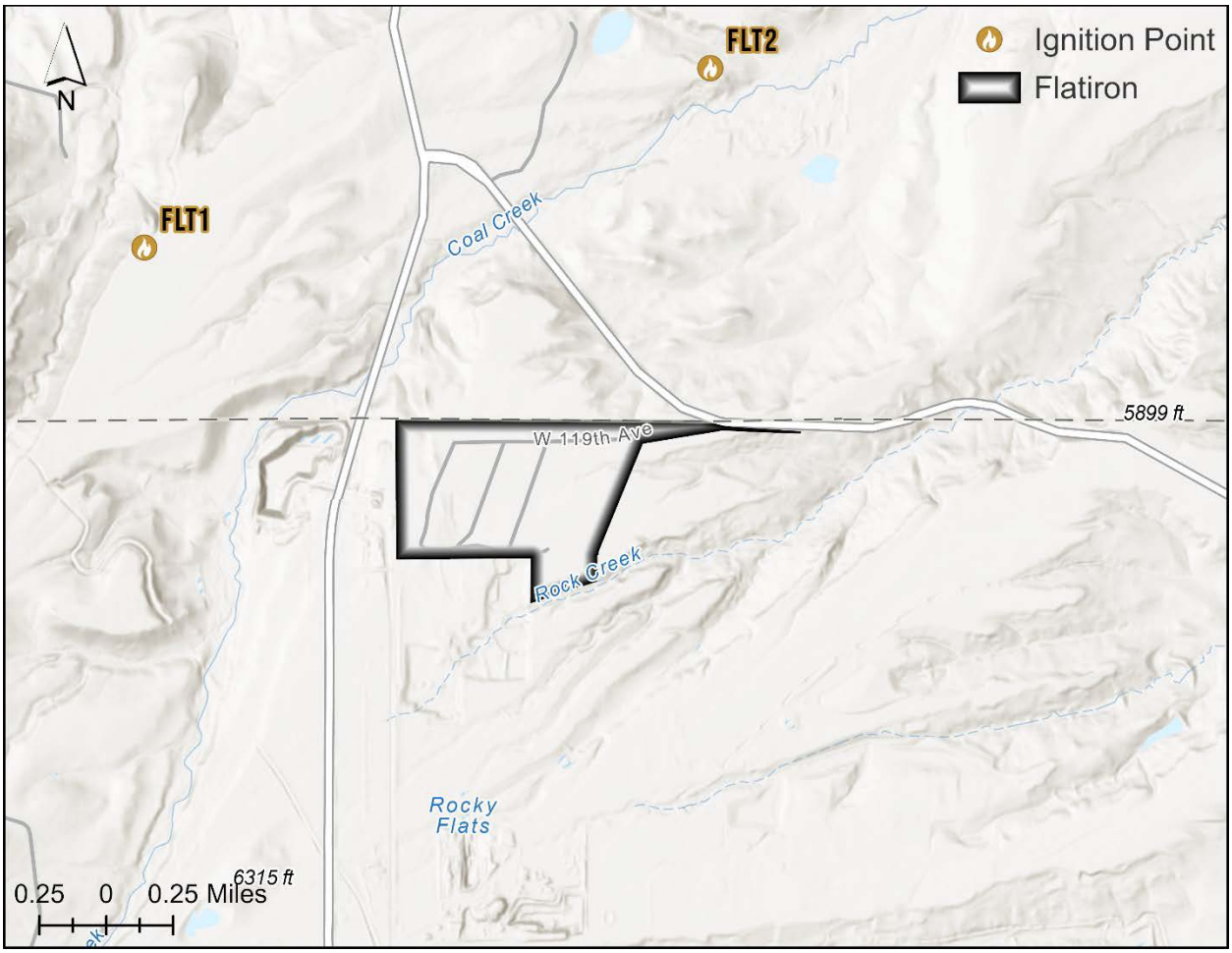

Figure D-8. Area of analysis for the fire growth simulations for the Flatirons Campus

D2.1 FLT1

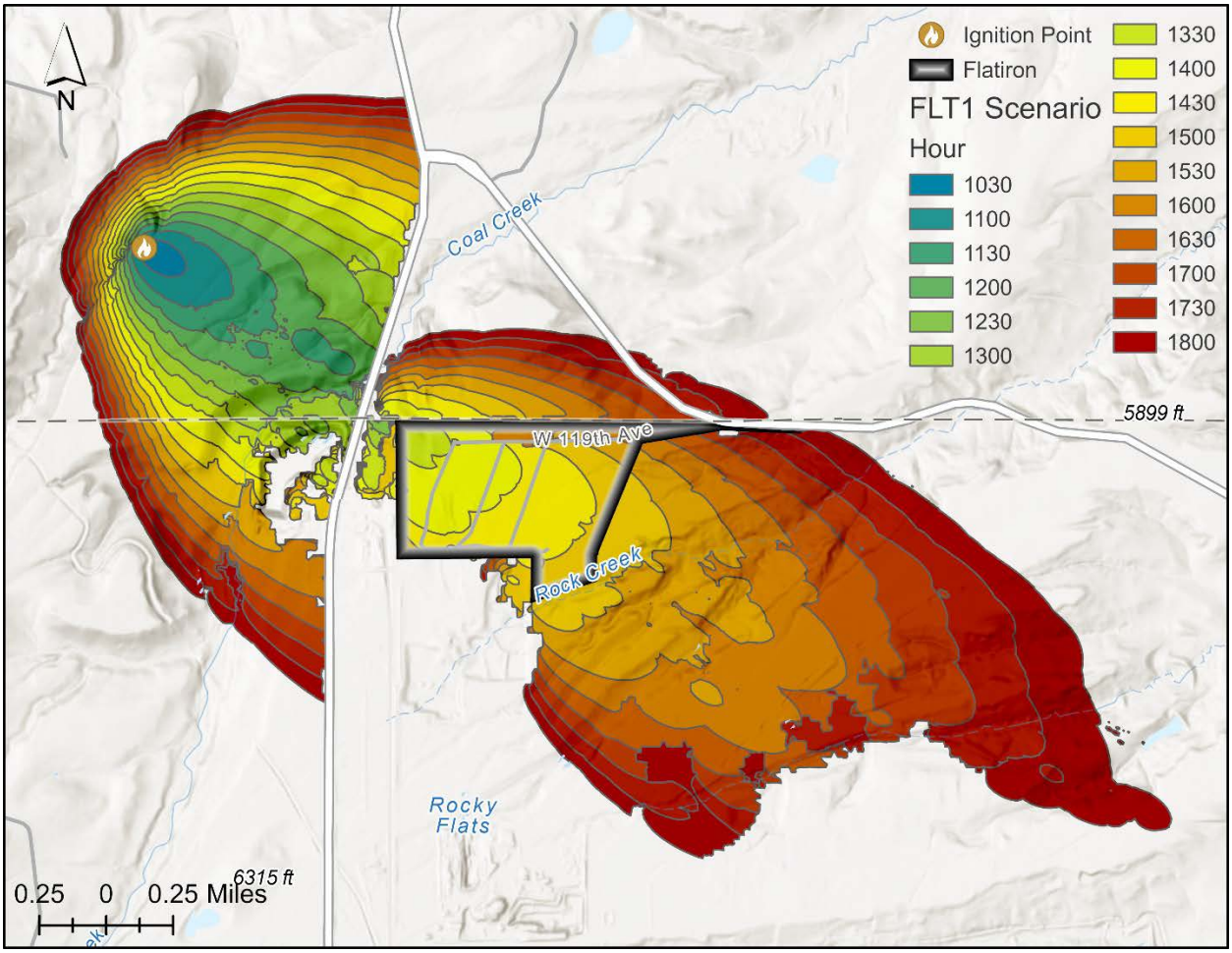

Figure D-9. Visual representation of the results of fire simulation FLT1 indicating the time of arrival

A fire growth simulation assuming an ignition west of the campus with a westerly wind indicates that Highway 93 is an effective barrier to fire spread for some time; however, wildfire does block both Highway 93 in 2.5 hours from ignition and Highway 128 (and the main entrance several hours later.

Table D-5. Table of Time of Arrival and Number of Fires Produced in Each Time Step for Simulation FLT1

Elapsed (DD HH:mm)	Current(MM/DD HH:mm)	Fires	Enclaves	Total Acres	Time Step Acres
00 00:30	10/02 10:30	1	0	11.40	11.40
00 01:00	10/02 11:00	4	0	49.39	37.99
00 01:30	10/02 11:30	26	0	128.75	79.37
00 02:00	10/02 12:00	15	2	271.49	142.74
00 02:30	10/02 12:30	21	2	349.64	78.15
00 03:00	10/02 13:00	13	6	449.76	100.12
00 03:30	10/02 13:30	17	7	552.03	102.26
00 04:00	10/02 14:00	15	10	712.94	160.91
00 04:30	10/02 14:30	18	12	895.95	183.01
00 05:00	10/02 15:00	29	20	1120.56	224.61
00 05:30	10/02 15:30	46	40	1426.04	305.48
00 06:00	10/02 16:00	43	35	1821.34	395.30
00 06:30	10/02 16:30	35	28	2141.80	320.45
00 07:00	10/02 17:00	32	29	2452.66	310.87
00 07:30	10/02 17:30	42	37	2808.39	355.73
00 08:00	10/02 18:00	50	38	3212.15	403.76

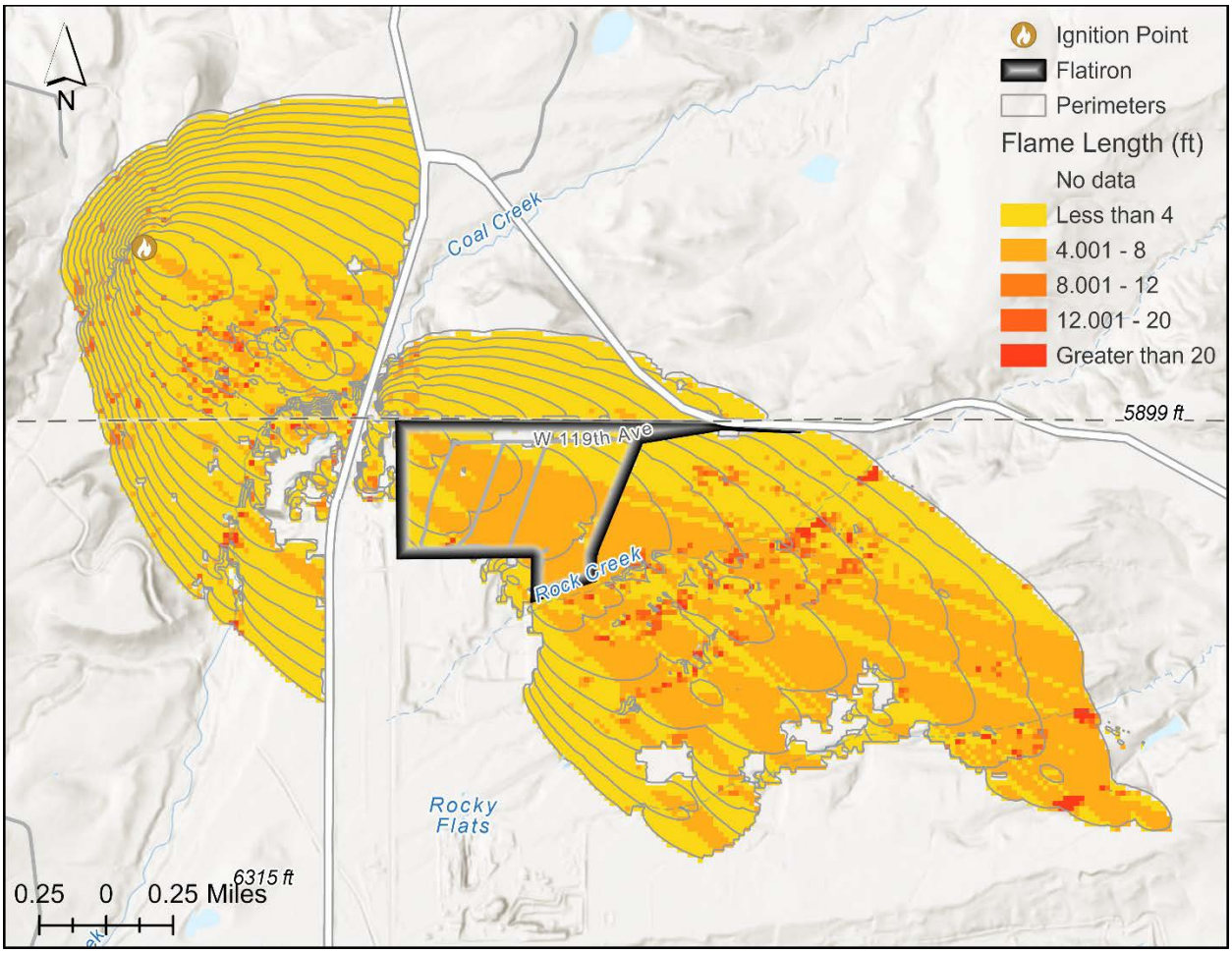

Figure D-10. Visual representation of the results of fire simulation FLT1 indicating the flame lengths

The vast majority of the area is predicted to burn with flame lengths shorter than 8 feet. Almost the entirety of the Flatirons Campus is likely to burn with flames between 4 and 8 feet in length. Longer flames are predicted in scattered areas outside the Flatirons Campus, likely due to increased fuel volumes and topographic conditions.

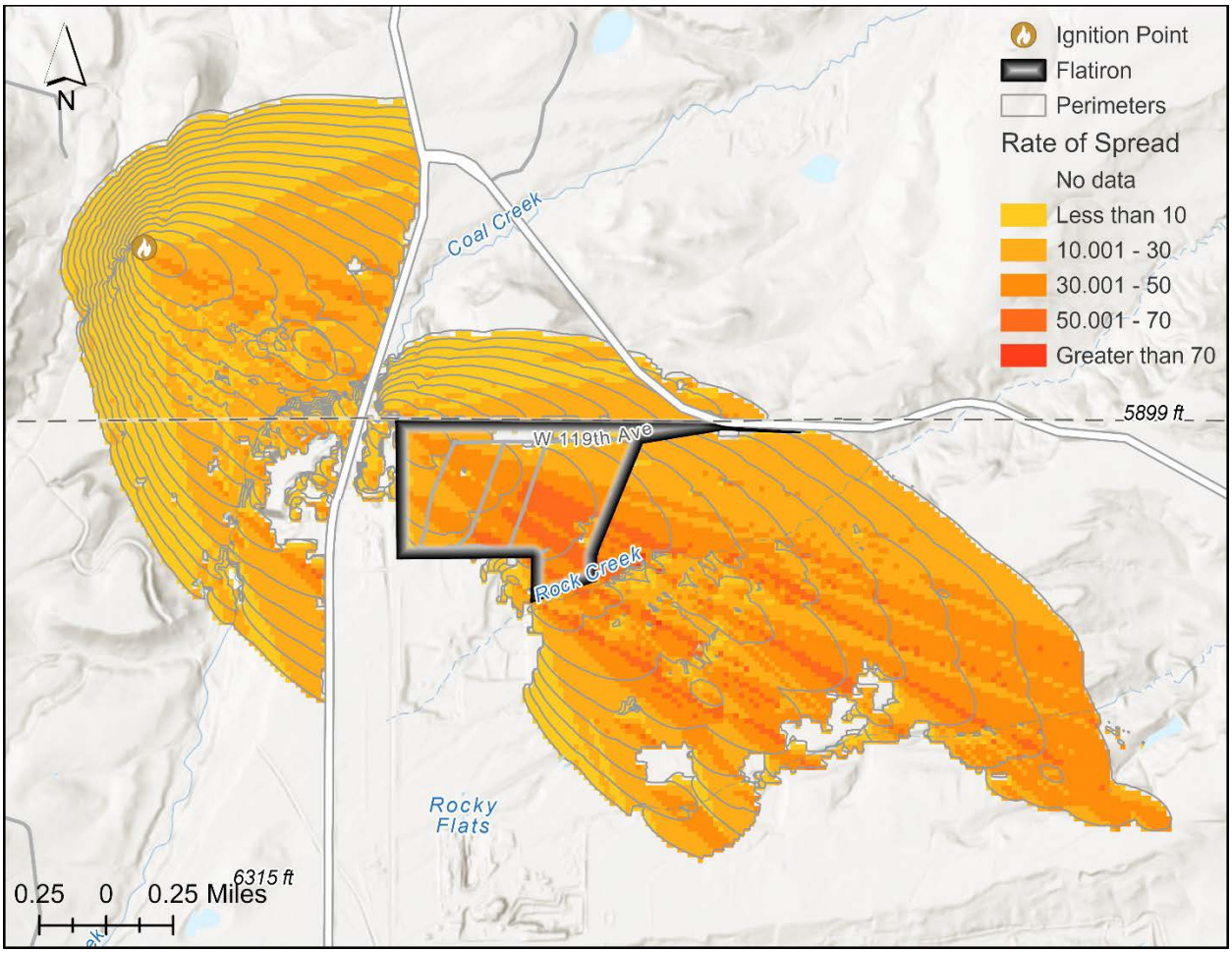

Figure D-11. Visual representation of the results of fire simulation FLT1 indicating rates of fire spread

Fast-spreading fires are the rule, based on the outputs of this simulation. The Flatirons Campus is expected to experience very fast fire spread rates, particularly on the southeast portion of the campus. This is to be expected due to the light flashy fuels on site and strong unblocked winds.

D.2.2 FLT2

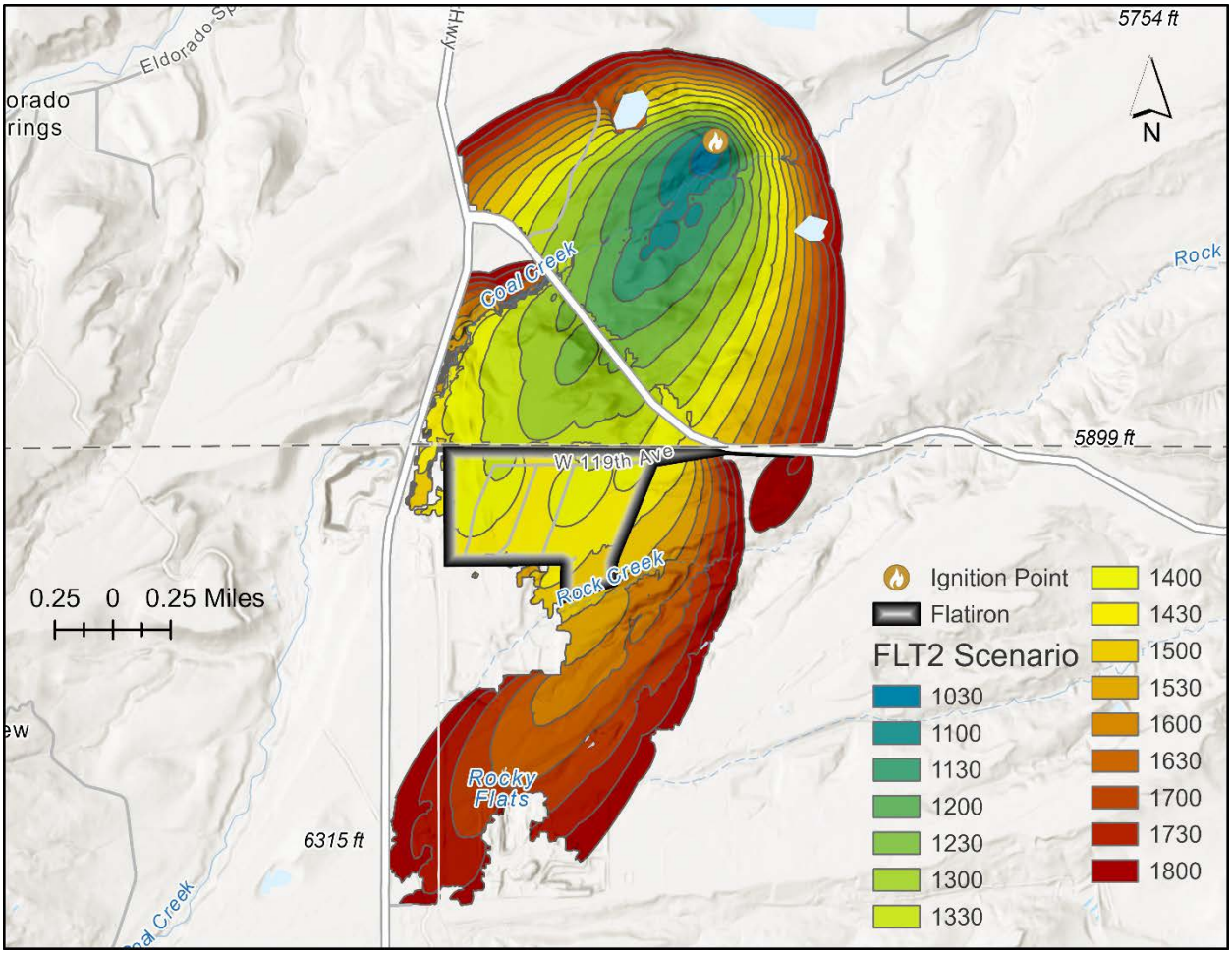

Figure D-12. Visual representation of the results of fire simulation FLT2 indicating the time of arrival

The simulations indicate that a fire burning from the north with a northerly wind spreads evenly across the landscape heading to the Flatirons Campus, and is constrained by Highway 93 but easily crosses Highway 128. A fire starting near the southern extent of South 66th St. under these conditions without fire suppression would be expected to reach the campus and block the main exit in 3 hours.

Table D-6. Table of Time of Arrival and Number of Fires Produced in Each Time Step for Simulation FLT2

Elapsed (DD HH:mm)	*Current(MM/DD HH:mm)*	*Fires*	*Enclaves*	*Total Acres*	*Time Step Acres*
00 00:30	10/02 10:30	1	0	11.34	11.34
00 01:00	10/02 11:00	5	1	58.90	47.56
00 01:30	10/02 11:30	10	6	149.40	90.50
00 02:00	10/02 12:00	6	5	257.90	108.50
00 02:30	10/02 12:30	6	4	402.74	144.83
00 03:00	10/02 13:00	14	13	628.08	225.34
00 03:30	10/02 13:30	14	13	825.44	197.37
00 04:00	10/02 14:00	24	19	1078.41	252.97
00 04:30	10/02 14:30	29	26	1353.76	275.35
00 05:00	10/02 15:00	39	33	1526.68	172.92
00 05:30	10/02 15:30	41	34	1673.79	147.11
00 06:00	10/02 16:00	40	37	1847.60	173.82
00 06:30	10/02 16:30	45	42	2073.16	225.56
00 07:00	10/02 17:00	39	36	2295.78	222.61
00 07:30	10/02 17:30	43	40	2550.48	254.70
00 08:00	10/02 18:00	41	38	2789.07	238.59

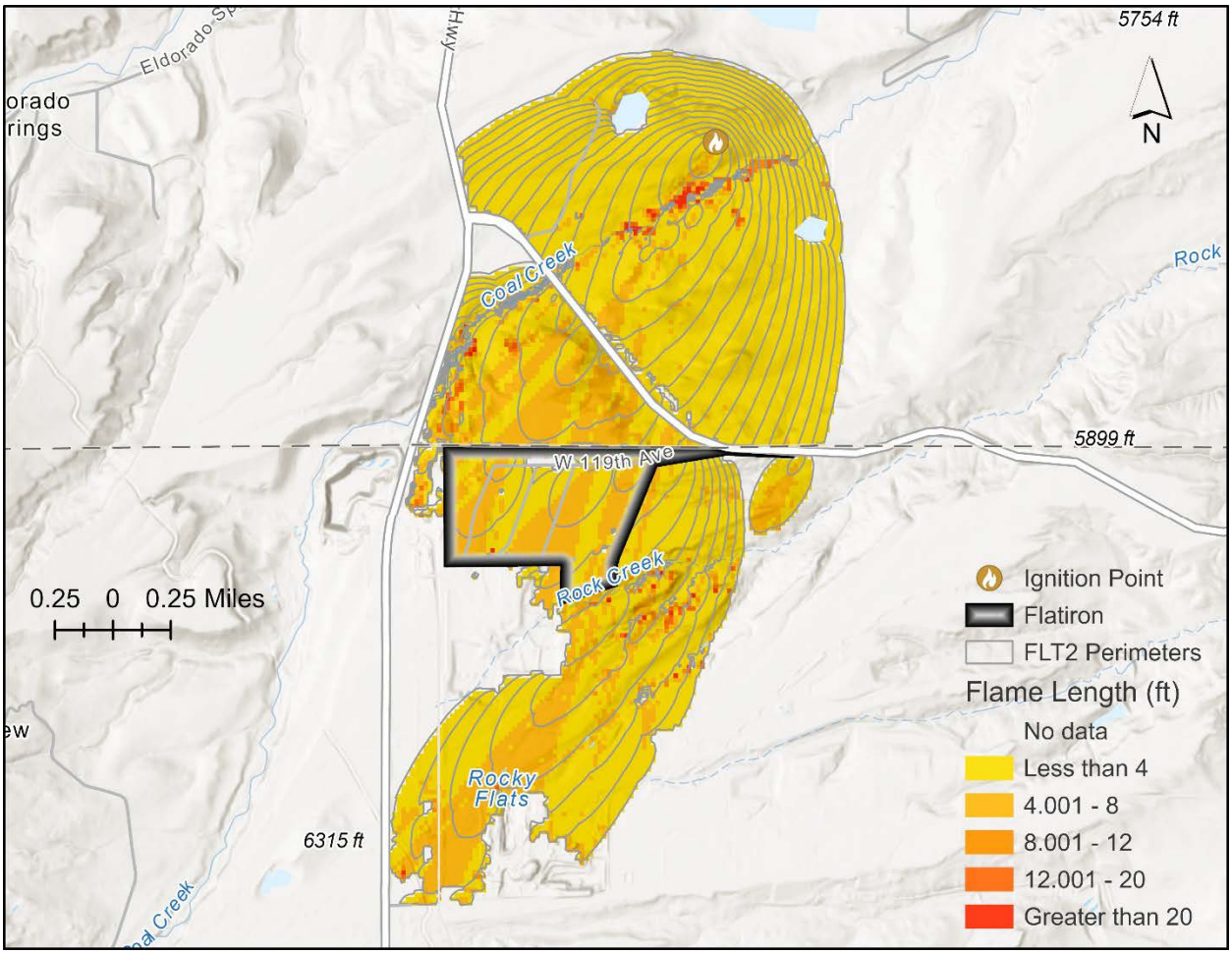

Figure D-13. Visual representation of the results of fire simulation FLT2 indicating flame lengths

As in all other simulations of the NREL campuses, the area is expected to burn with flames lengths shorter than 8 feet. The same locations on the Rocky Flats Refuge as in FLT1 simulation burn with longer flame lengths. Longer flame lengths can also be expected between Highway 93 and the Flatirons Campus, and in the Coal Creek drainage.

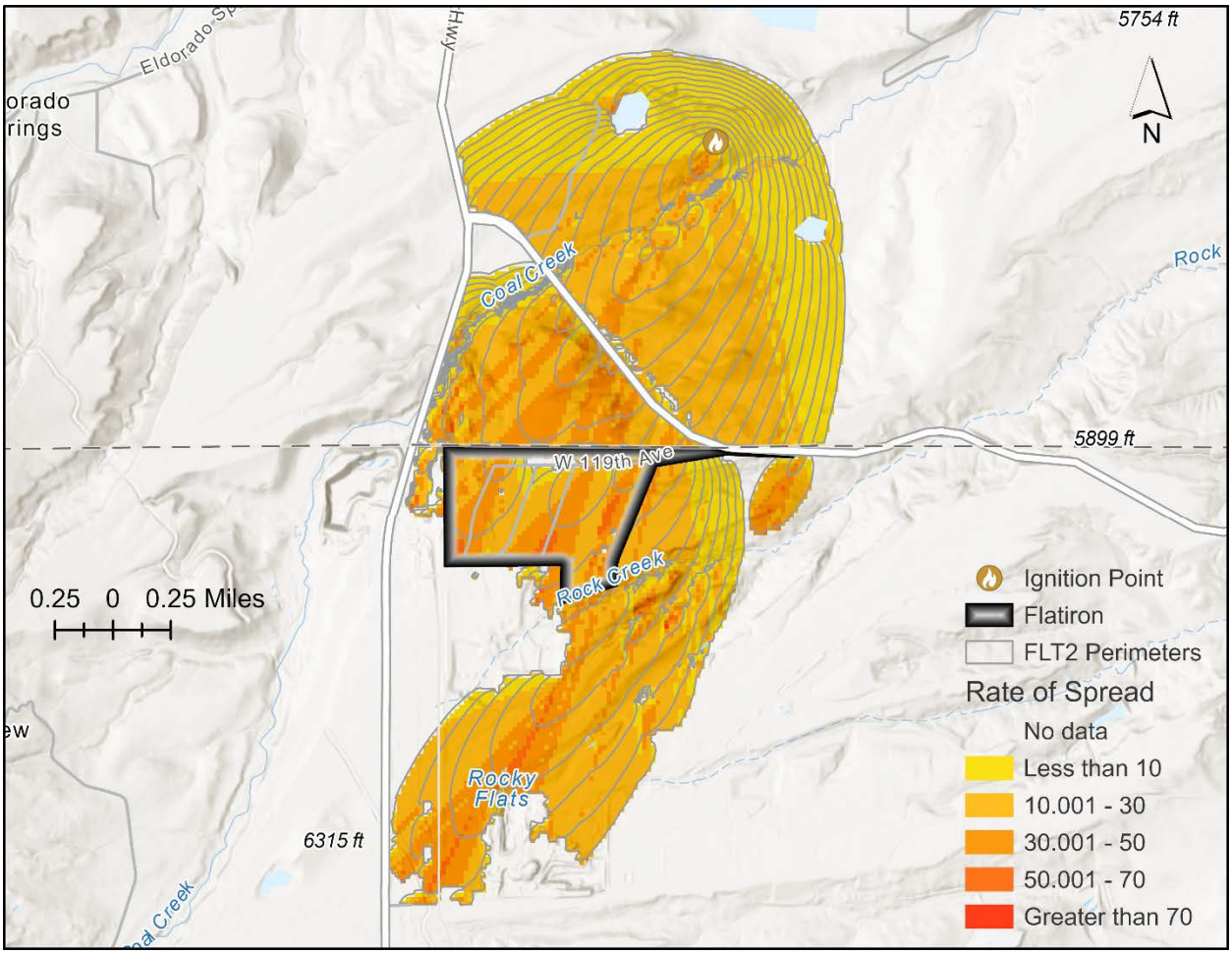

Figure D-14. Visual representation of the results of fire simulation FLT2 indicating the rate of fire spread

With winds from the north, fire spread rates are not as constant as with a fire from the west. A wildfire on the Flatirons Campus could be expected to burn fastest along the roads leading to research sites.

Appendix E. Federal Wildland Fire Management Plan and Implementation Plan Gap Analysis

2001 Federal Wildland Fire Management Policy Gap Analysis							
Section	***Text***	***DOE 1066-2016 Section***	***DOE Guidance (1066-2016)***	***Does Section Apply? (Yes, or N/A)***	***Is Requirement Met? (Yes, No, or N/A)***	***Comments***	***Implementation Plan Action Item***
1 - Safety	Firefighter and public safety is the first priority. All Fire Management Plans and activities must reflect this commitment.	8.4.2	DOE wildland fire activities should reflect a commitment to firefighter and public safety as the first priority. DOE site management contractors should: (a) Establish procedures for issuance, use, and accountability of personal protective clothing and equipment; (b) Ensure that training, use, appropriate employee medical surveillance programs, and maintenance and storage of the protective equipment comply with applicable standards; (c) Provide 4 hours of annual wildland fire safety refresher training to personnel directly involved with such activities; and, (d) Ensure that work supervisors are responsible for the safety of employees engaged in wildland fire management activities.	Yes	Yes	(a) West Metro Fire Department and Mountain View Fire Department coordinate, issue, use, and maintain accountability for all PPE. (b) West Metro Fire Department and Mountain View Fire Department provide medical surveillance as well as maintenance and storage of PPE. (c) West Metro Fire Department and Mountain View Fire Department provide regular annual wildland fire refreshers. (d) West Metro Fire Department and Mountain View Fire Department establish line management in accordance with nationally recognized fire management Standards.	Action 1, 2, 3
2 - Fire Management and Ecosystem Sustainability	The full range of fire management activities will be used to help achieve ecosystem sustainability, including its interrelated ecological, economic, and social Fire, as a critical natural process, will be components.	8.4.3	See DOE Order 436.1, Departmental Sustainability	Yes	Yes	The new NREL Wildland Fire Management Plan has been developed in concert with NREL ESH&Q Site Sustainability and the new WFMP identifies the applicable fire response units Environmental Staff.	Action 4
3 - Response to Wildland Fire	integrated into land and resource management plans and activities on a landscape scale, and across agency boundaries. Response to wildland fires is	8.4.4	DOE site management contractors should: (a) Identify the applicable Fire Management Unit; and (b) Coordinate wildland fire response as agreed with other agencies adjacent to the DOE site.	Yes	Yes	a) The new WFMP identifies the applicable fire response for each site b) The new NREL WFMP has been developed in collaboration with regional wildland response agencies. In addition, the new WFMP identifies adjoining property owners for both sites, and provides recommendations to enhance engagement. NREL collaborated with U.S. Fish & Wildlife in the development of the new WFMP.	Action 5, 6
4 - Use of Wildland Fire	Wildland fire will be used to protect, maintain, and enhance resources and, as nearly as possible, be allowed to function in its natural ecological role. Use of fire will be based on L/RMP and associated Fire Management Plans and will follow specific prescriptions contained in operational plans.	8.4.5	DOE sites should integrate fuel management and fire management programs in support of the following resource management objectives. (a) Use an interdisciplinary approach to integrate fuel management planning into all appropriate activities. (b) Identify, through economic analysis, the most cost-efficient fuel profile to meet resource management direction. Consider a full range of fuel management alternatives, including no treatment. Fuel management activities should be responsive to long-term site productivity, utilization opportunities, and air quality considerations. (c) Where a management activity, such as timber sales, thinning, or road construction, contributes to an unacceptable fuel profile, modify that activity to reduce its incremental contribution to the fuel profile. (d) On lands where repetitive management activities will occur, evaluate the projected fuel profile to determine the most cost-efficient time(s) of entry and the level of treatment(s). (e) Manage fuel in accordance with fire management direction in the site land-use planning and management process.	Yes	Yes	(a) NREL works collaboratively to integrate fuel management planning into Site Operations. (b) The new WFMP considers all potential fuel management possibilities. NREL utilizes the most cost-effective methods, taking into consideration risks and benefits. (c) N/A (d) NREL works to minimize the frequency of treatments by performing treatments at appropriate times. (e) The new WFMP provides overarching fuel management guidance. NREL ESH&Q and Site Operations collaborate to ensure this is taken into account in land use planning on projects.	Action 7

2001 Federal Wildland Fire Management Policy Gap Analysis							
Section	***Text***	***DOE 1066-2016 Section***	***DOE Guidance (1066-2016)***	***Does Section Apply? (Yes, or N/A)***	***Is Requirement Met? (Yes, No, or N/A)***	***Comments***	***Implementation Plan Action Item***
5- Rehabilitation and Restoration	Rehabilitation and restoration efforts will be undertaken to protect and sustain ecosystems and public health and safety, and to help communities protect infrastructure.	8.4.6	The following post-fire activities (for prescribed, operational, and wildfires) should be accomplished at the earliest opportunity. (a) Sites should conduct an immediate assessment of watershed conditions following the fire. (b) Sites should determine if emergency watershed rehabilitation efforts are required to restore watershed functions and minimize damage to soil resources. (c) Sites should initiate post-fire rehabilitation treatments as necessary (e.g., sediment reduction, channel treatments, check dams) to stabilize biotic communities, address safety concerns, and to prevent degradation of critical known natural and cultural resources. (d) Sites should monitor the effectiveness of rehabilitation treatments to determine if additional treatments are required.	Yes	Yes	See Action 4	See Action 4
6 - Protection Priorities	The protection of human life is the single, overriding priority. Setting priorities among protecting human communities and community infrastructure, other property and improvements, and natural and cultural resources will be done based on the values to be protected, human health and safety, and the costs of protection. Once people have been committed to an incident, these human resources become the highest value to be protected.	8.4.7	In general, DOE field elements are responsible for developing, implementing, and overseeing protection programs for individuals and assets under their cognizance. This includes protecting assets from internal structural fire damage and from the conflagration potential associated with the external wildland fire. A Wildland Fire Management Program comprises the full range of activities and functions necessary to plan, prepare, and respond to potential fires and rehabilitate undeveloped lands following a fire. DOE should observe the following fire management priorities on all fires: (a) Ensure firefighter, worker, and public safety. (b) Protect mission property and natural and cultural resources based on the relative values to be protected.	Yes	Yes	Both a) and b) are defined as goals in the new WFMP.	Action 8, 9
7 - Wildland Urban Interface	The operational roles of federal agencies as partners in the Wildland Urban Interface are wildland firefighting, hazard fuels reduction, cooperative prevention and education, and technical assistance. Structural fire suppression is the responsibility of tribal, state, or local governments. Federal agencies may assist with exterior structural protection activities under formal Fire Protection Agreements that specify the mutual responsibilities of the partners, including funding. (Some federal agencies have structural protection authority for their facilities on lands they administer and may also enter into formal agreements to assist state and local governments with structural protection).	8.4.8	The zone where structures and other human development meet or become intermingled with undeveloped wildland is referred to as the wildland/urban interface. The objectives of wildland/urban interface fire management are to facilitate fire prevention and protection and minimize fire loss and damage to structures, other human development, and wildland resources; to prevent a structure fire from spreading into wildland fuels; and to encourage property owners to take an active role in establishing and maintaining their own fire prevention and safety measures in the wildland/urban interface. The following recommendations are applicable to this category. (a) Document DOE wildland fire protection and suppression assistance in mutual aid agreements with all emergency response organizations engaged in such activities; (b) Collaborate with outside emergency response organizations to establish and update cooperative agreements that recognize the jurisdictional protection responsibilities and assistance capabilities of the respective cooperators; (c) Educate wildland firefighters about safe operational procedures in the wildland/urban interface and provide training in safe wildland firefighting operations for structural firefighters who respond to wildland/urban interface fires; (d) Provide education to adjoining property owners on fire risks and hazards and on fire prevention responsibilities and actions to minimize losses and damage to structures and lands in the wildland/urban interface;	Yes	Yes	(a) The new WFMP identifies emergency response organizations and addresses mutual aid agreements. (b) The new WFMP discusses cooperative agreements. (c) Responding agencies provide training for firefighters. (d) Education of adjoining property owners is a recommendation and will be fully address via Fire Adapted Communities. (e) The new WFMP addresses fire prevention and collaboration with various entities. (f) The new WFMP is a collaborative effort between NREL ESHQ & Site Operations. Wildland fire requirements such as fuel treatments, landscaping, and requirements for structures are incorporated into all projects. (g) NREL has an active fuel management program, including mowing and tree trimming. (h) NREL adopts and enforces the IWUIC and NFPA 1140, and this is codified in the NREL fire protection program and the new NREL WFMP.	Action 10, 11

2001 Federal Wildland Fire Management Policy Gap Analysis							
Section	***Text***	***DOE 1066-2016 Section***	***DOE Guidance (1066-2016)***	***Does Section Apply? (Yes, or N/A)***	***Is Requirement Met? (Yes, No, or N/A)***	***Comments***	***Implementation Plan Action Item***
			(e) Assess, analyze, and plan for fire prevention and protection in conjunction with other Federal, tribal, state, county, and local government entities and with community and citizen groups; (f) Integrate wildland/urban interface considerations in the DOE land-use planning and management process, as well as in program project and plans; (g) Implement fuel modification projects to mitigate fire hazards; (h) Adopt special building construction requirements in wildland/urban interface areas, such as the construction requirements of NFPA 1144; and (i) Implement other practices that reduce wildland fire risks.			(i) NREL has developed a risk assessment for wildland fire. All aspects pertaining to wildland fire risk reduction are covered in the new WFMP.	
8 - Planning	Every area with burnable vegetation must have an approved Fire Management Plan. Fire Management Plans are strategic plans that define a program to manage wildland fires based on the area's approved land management plan. Fire Management Plans must provide for firefighter and public safety; include fire management strategies, tactics, and alternatives; address values to be protected and public health issues; and be consistent with resource management objectives, activities of the area, and environmental laws and regulations.	8.4.9	Preparedness planning provides for timely recognition of approaching fire management situations and for setting priorities, deploying resources, and considering other actions to respond to those situations. Wildland fire preparedness planning should include the following: (a) The purpose of preparedness plans and reviews is to ensure the timely recognition of and appropriate response to fire management situations and to provide the basis for ensuring program accountability. Preparedness planning requires (1) an intelligence system, (2) an analysis and decision-making process, and (3) identified actions to be taken at increasing levels of fire severity and activity (preparedness level). Preparedness plans should be documented in a site mobilization guide or other appropriate document. (b) When developing preparedness plans, consider the following: (1) Actions for responding to fire preparedness levels (National Interagency Mobilization Guide, NFES 2092); (2) Preparedness levels and actions addressing the full range of anticipated fire danger and activities; (3) Documented processes to coordinate actions among cooperating agencies and to transmit decisions promptly to all affected organizations, including adjacent units and cooperators; (4) Preparation of a Fire Management Plan documenting the fire management program that most effectively achieves land use planning and management process direction; (5) Preparation of a Site Fire Plan, to be reviewed and revised at least once every three years, for any activities that increase wildland fire risk or constitute a wildland fire hazard, such as land clearing, timber harvesting, mining, and power line or highway construction; and (6) Triennial review and update of all cooperative wildland fire agreements.	Yes	Yes	(a) Preparedness is documented in the new WFMP, as well as applicable Emergency Management documents. The new WFMP was developed in concert with NREL Lab Protection, which administers preparedness, action plans, and other pertinent documents. (b) NREL Lab Protection is responsible for preparedness. In addition, the fire protection program works with Lab Protection to coordinate wildland fire exercises. The new WFMP and existing Lab Protection policies and procedures serve to satisfy this requirement.	Action 12

2001 Federal Wildland Fire Management Policy Gap Analysis							
Section	***Text***	***DOE 1066-2016 Section***	***DOE Guidance (1066-2016)***	***Does Section Apply? (Yes, or N/A)***	***Is Requirement Met? (Yes, No, or N/A)***	***Comments***	***Implementation Plan Action Item***
9 - Science	Fire Management Plans and programs will be based on a foundation of sound science. Research will support ongoing efforts to increase our scientific knowledge of biological, physical, and sociological factors. Information needed to support fire management will be developed through an integrated interagency fire science program. Scientific results must be made available to managers in a timely manner and must be used in the development of land management plans, Fire Management Plans, and implementation plans.	8.4.10	No specific action recommended.	Yes	Yes	NREL uses fire modeling as part of the new WFMP. NREL strives to participate in fire science, planning, and code development. This is detailed in the new WFMP. The fire modeling, and new WFMP include lidar data on vegetation, wind speed data, and topography.	Action 13
10 - Preparedness	Agencies will ensure their capability to provide safe, cost-effective fire management programs in support of land and resource management plans through appropriate planning, staffing, training, equipment, and management oversight.	8.4.11	DOE site management contractors should: (a) Establish and document the need for developing agreements with other federal, state, local, and nongovernmental resources; (b) Relay the need for these agreements to the DOE Head of Field Element (or designee) so that DOE may pursue these agreements; (c) Assist DOE, as requested, in developing agreements with other federal, state, local, and nongovernmental resources; and (d) Identify and address staffing, equipment, and training needs based on the wildland fire threat as determined by the BNA.	Yes	Yes	See Action 5	See Action 5
11 - Suppression	Wildland fires are suppressed at minimum cost, considering firefighter and public safety, benefits, and values to be protected, consistent with resource objectives.	8.4.12	Wildland fire suppression is intended to safely suppress wildland fires at minimum cost, consistent with land and resource management objectives and fire management direction as stated in fire management plans. Expectations or actions to take in the event of a wildland fire include the following. (a) Ensure that suppression planning, operations, and personnel comply with the wildland fire suppression principles and practices that are set out in the DOE Wildland Fire Management Program and associated procedures. (b) Conduct fire suppression in a timely, effective, and efficient manner, giving the first priority to firefighter and public safety. (c) Decide how to organize and conduct suppression operations (suppression strategies). Line managers should minimize both suppression cost and resource loss consistent with the resource management objectives for the values to be protected. (d) Consider fire behavior, the availability of suppression resources, the value of natural resources and property at risk, direction in the site land-use planning and management process, and the potential cost of suppression. (e) Consider using a wildland fire situation analysis to document suppression strategy	Yes	Yes	Mutual aid agreements are discussed thoroughly in the NREL Baseline Needs Assessment. (a) Suppression activities are coordinated by responding agencies. NREL will coordinate to assist responding crews. (b) All fires are to be put out in a timely manner. Firefighter safety is the first priority and is discussed in the WFMP. (c) NREL contracts out fire response activities, N/A. (d) NREL contracts out fire response activities. (e) NREL contracts out fire response activities.	Action 14, 15

2001 Federal Wildland Fire Management Policy Gap Analysis							
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12 - Prevention	Agencies will work together and with their partners and other affected groups and individuals to prevent unauthorized ignition of wildfires.	8.4.13	The objective of wildland fire prevention is to avoid the costs and risks associated with wildland fire suppression activities. A DOE site's wildland fire prevention program should be: (a) Coordinated with local stakeholders to encourage planning and analysis of stakeholder lands in accordance with wildland fire prevention programs; and (b) Coordinated with other agencies where risks affect other jurisdictions.	Yes	Yes	See Actions 1 through 14. NREL has engaged with local stakeholders in the development of the new NREL WFMP.	See Actions 1 through 14
13 - Standardization	Agencies will use compatible planning processes, funding mechanisms, training and qualification requirements, operational procedures, values-to-be- protected methodologies, and public education programs for all fire management activities.	8.4.14	No specific action recommended. This Standard provides DOE's standard approach.	Yes	Yes	NREL participates in exercises with U.S. Fish and Wildlife and other regional partners. The exercises serve to promote standardization and common understanding of operations in the event of a wildland fire. NREL has collaborated with multiple agencies in the development of the new NREL WFMP.	Action 16
14 - Interagency Cooperation and Coordination	Fire management planning, preparedness, prevention, suppression, fire use, restoration and rehabilitation, monitoring, research, and education will be conducted on an interagency basis with the involvement of cooperators and partners.	8.4.15	Each site's Fire Management Plan should: (a) Contain or reference all cooperative agreements and interagency contacts. (b) Describe or reference the interagency coordination needed to implement the wildland fire management plan. (c) List or reference key interagency contacts by function. (d) Discuss local agreements that are in place. Include major cooperators, such as state and other Federal agencies, as well as local volunteer fire companies.	Yes	Yes	See Actions 1 through 16	See Actions 1 through 16
15 - Communication and Education	Agencies will enhance knowledge and understanding of wildland fire management policies and practices through internal and external communication and education programs. These programs will be continuously improved through the timely and effective exchange of information among all affected agencies and organizations.	8.4.16	Each site's wildland fire management plan should address: (a) The overall wildland fire prevention and community education and assistance programs for the site, (b) A description of the typical human-caused wildland fire, and (c) The main activities of the site related to wildland fire prevention.	Yes	Yes	(a) The new NREL WFMP provides recommendations on community education. (b) The new NREL WFMP discusses some causes of wildland fires, including a human-caused mowing fire. (c) This is covered in detail in the new NREL WFMP.	Action 17, 18
16 - Agency Administrator and Employee Roles	Agency administrators will ensure that their employees are trained, certified, and made available to participate in the wildland fire program locally, regionally, and nationally as the situation demands. Employees with operational, administrative, or other skills will support the wildland fire program as necessary. Agency administrators are responsible and will be held accountable for making employees available.	8.4.17	Every DOE site where wildfire risk exists is expected to: (a) Provide training adequate to meet fire management needs, and (b) Ensure that cognizant DOE and contract employees meet standards for training, experience, and physical fitness before they are certified for wildland fire organization positions. Site management should adhere to the qualification standards established by the NWCG, NFPA and state or local laws or regulations.	Yes	Yes	(a) Response agencies provide requisite firefighter training. NREL provides wildland fire education and conducts wildland fire evacuation drills. (b) The contracted response agency requirements are met and detailed in the Baseline Needs Assessment.	Action 19, 20, 21

2001 Federal Wildland Fire Management Policy Gap Analysis							
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17 - Evaluation	Agencies will develop and implement a systematic method of evaluation to determine effectiveness of projects through implementation of the 2001 Federal Fire Policy. The evaluation will assure accountability, facilitate resolution of areas of conflict, and identify resource shortages and agency priorities.	8.4.18	DOE site management contractor should provide periodic reviews of wildland fire management planning consistent with Section 3.2.2 of this Standard.	Yes	Yes	The new NREL Wildland Fire Management Plan will be reviewed and updated triennially. This will be tracked internally by ESH&Q.	