COLORADO STATE FOREST SERVICE
COLORADO STATE UNIVERSITY

2022 Colorado Wildfire Risk Assessment Update

Final Report

October 9th, 2023

technosylva

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1. PROJECT OVERVIEW

1.1 Introduction

This document is the final report for the 2022 update of the Colorado Wildfire Risk Assessment (CO-WRA) project. It is intended to provide a comprehensive description of the datasets, quantitative risk framework that was used, results, and findings for the assessment. Wildfire risk assessments are static models; a snapshot in time that are influenced by data, technology, the natural environment, and the social and cultural environment. All of these variables change and evolve over time.

1.2 Background of the Colorado Wildfire Risk Assessment

The initial statewide Colorado Wildfire Risk Assessment (CO-WRA) was published in February 2013 based on datasets current through 2012. This assessment was based on leveraging data and achievements of the West Wide Wildfire Risk Assessment (WWA) project, and tailoring these to reflect Colorado conditions, requirements and priorities. Certain data limitations existed in the 2012 assessment, although enhancements were implemented to focus on Colorado priorities. The Colorado State Forest Service (CSFS) developed the assessment with the best available data, science, and technology available at the time. The primary purpose of all assessments is to provide information that can be used by decision makers to address the risk of wildfire in Colorado. The project was funded and led by the Colorado State Forest Service (CSFS).

Once the 2012 CO-WRA was completed, the data were released to CSFS staff, CSFS partners and collaborators, and the public. The data were also made available through an interactive web mapping application called the Colorado Wildfire Risk Assessment Portal (CO WRAP). After the publication, some CO-WRA data layers were updated as new data became available.

In 2017, the CSFS embarked on a project to update the CO-WRA to reflect more current data and conditions describing Colorado's wildfire risk situation. This project focused on updating the key datasets, centered around the surface fuels data, and deriving new risk outputs that better reflected conditions at the time of publication. The project was also complimented by the development of a new CSFS website to host the web applications associated with CO-WRA; the previous CO WRAP website became the Colorado Forest Atlas (CFA; https://coloradoforestatlas.org/)

In 2022, with increasing severity of large and destructive fires occurring in Colorado since the 2017 assessment, there was a need to update the CO-WRA with more accurate and up-to-date data. Public information needs regarding wildfire have increased substantially, and with it an increased priority on identifying risk potential prior to wildfires occurring. The impacts and lessons learned from the Cameron Peak (2020), East Troublesome (2020) and Marshall Fire (2021), among other uncharacteristic fires resonate loudly with Colorado residents. It is hoped that with an increased detail in data accuracy that CO-WRA information can play a more active role in supporting proactive mitigation planning for municipalities, private landowners, commercial industry and the public.

The 2022 CO-WRA update represents a significant step forward with the accuracy and resolution of the input data and risk outputs. In addition, many new enhanced modeling approaches, leveraging robust, validated fire science along with machine learning methods, have been applied to increase the accuracy and usefulness of the risk results. These new models have been tested and validated across the Western

US over the past five years and have become the standard in California and surrounding states. The CSFS is excited to be able to leverage these achievements and put these new models and data to use for the State of Colorado.

The 2022 CO-WRA includes a comprehensive update of all input data, modeling approaches and risk outputs. As in 2017, the results are encapsulated in the **CSFS Colorado Forest Atlas Information Portal**, a web site to obtain information about forests for the State of Colorado. Interactive mapping applications are publicly available to review and query the 2022 CO-WRA data, to support wildfire mitigation and forest resiliency activities. Please refer to https://coloradoforestatlas.org/ (CFA) for more information and user support, provided by the CSFS Geospatial Data and Analysis and Wildfire Mitigation Programs.

Note that reference maps are shown throughout this report to help demonstrate the technical methods and outputs that were achieved. However, these are not intended to be comprehensive, and the reader is urged to visit the Colorado Forest Atlas web site which affords a rich suite of mapping tools to support detailed interrogation of the CO-WRA data.

1.3 Purpose of the Report

This report describes the datasets, methods and results of the updated risk assessment. It does not include a description of the fuels updating task or the CFA web site updating efforts. A separate CO-WRA Fuels Mapping Methods Report is available from the CSFS for those who desire more detailed information about the fuels data and methods used to derive this data.

This report is intended to provide the necessary background information so that CSFS staff, partners, Colorado landowners and stakeholders, and the public, can properly utilize the data and CFA web site for wildfire prevention and mitigation planning.

1.4 Project Technical Team

This project was completed by CSFS and Technosylva Inc. (La Jolla, CA). Technosylva is the contractor responsible for development, support and maintenance of the CO-WRA and CFA web site. To complete this project, CSFS and Technosylva employed a core team of subject matter experts in fuels mapping, fire behavior analysis, risk assessment, interactive web site development, wildfire prevention and mitigation planning, and outreach and communication. Readers are urged to visit the CSFS web site for more information at https://csfs.colostate.edu/.

The CO-WRA core team consisted of:

- Amanda West Fordham, CSFS, Associate Director, Science and Data Division
- Nic Kotlinski, CSFS, Geospatial Data and Analysis Program Manager
- Dan Beveridge, CSFS, Fire, Fuels and Watershed Manager
- Chad Julian, CSFS, Wildfire Mitigation Program Specialist
- Todd Ruffner, CSFS, Wildfire Mitigation Program Specialist
- Jason Zumstein, Technosylva, Project Manager
- Kate Sabourin, Technosylva, Senior Software & Data Analyst
- Adrián Cardil Forradellas, Technosylva, Senior Fuels & Fire Scientist
- David Buckley, Technosylva, Senior Advisor
- Joaquin Ramirez, Technosylva, Technical Senior Advisor

The team is a complement of skills and knowledge, incorporating local Colorado landscape fuels and wildfire field experience along with leading edge technical fuels mapping, fire behavior, and risk assessment expertise. For the fuels update (details in separate fuels report available from CSFS), the core team also consulted with:

- Scott Ritter, Colorado Forest Restoration Institute, Warner College of Natural Resources, Colorado State University
- Camille Stevens-Rumann, Forest and Rangeland Stewardship Department and Colorado Forest Restoration Institute, Warner College of Natural Resources, Colorado State University
- Boyd Lebeda, Colorado Department of Public Health and Environment
- Bradley Pietruszka, USDA Forest Service
- Rocco Snart, Colorado Division of Fire Prevention and Control

In addition to the core team, Technosylva employed a team of technical analysts and subject matter experts to conduct the processing and development of final results. The technical team leads consisted of:

- Santiago Monedero, Technosylva, Chief Scientist & Modeler
- Francisco José Diez Vizcaíno, Technosylva, Lead GIS Analyst
- Carmen Robles Hernandez, Technosylva, Lead GIS Analyst
- Humberto Diaz, Technosylva, Lead Software Developer

Lastly, there are a large number of internal CSFS and external advisors who provided input and feedback during the fuels mapping and evaluation of risk metrics. They include:

Internal (CSFS Staff)

- John Twitchell, Supervisory Forester (CSFS-Steamboat Springs)
- Zack Wehr, Supervisory Forester (CSFS-Granby)
- Adam Moore, Supervisory Forester (CSFS-Alamosa)
- Dan Allen, Forester (CSFS-Boulder)
- Ben Pfohl, Supervisory Forester (CSFS-Boulder)
- John Grieve, Supervisory Forester (CSFS-Canon City)
- Max Erikson, Supervisory Forester (CSFS-Fort Collins)
- Paul Branson, Supervisory Forester (CSFS-La Veta)
- Andy Schlosberg, Supervisory Forester (CSFS-Woodland Park)
- Jodi Rist, Supervisory Forester (CSFS-Montrose)
- Kamie Long, Supervisory Forester (CSFS-Grand Junction)
- Mike Taratino, Supervisory Forester (CSFS-Gunnison)
- Josh Kuehn, Forester (CSFS-Salida)
- JT Shaver, Lead Project Forester (CSFS-Salida)
- Carolina Manriquez, Forester (CSFS-Steamboat Springs)
- Damon Lange, SW Area Manager (CSFS-SW Area Manager)
- Derek Sokoloski, SE Area Manager (CSFS-SE Area Manager)
- Ron Cousineau, NW Area Manager (CSFS-NW Area Manager)
- Allen Gallamore, NE Area Manager (CSFS-NE Area Manager)

External Advisors

- Michael Caggiano, Wildland Fire Decision Support Program Manager (USFS)
- Mike Battaglia, Research Silviculturist (USFS-Rocky Mtn. Research Station)
- Peter Brown, Director (Rocky Mtn. Tree Ring Research, RMTRR)
- Rob Addington, Forest/Fire Program Manager (TNC)
- Ashley Garrison, Colorado-Gunnison-Yampa-White/Green Basins Grant Manager (Colorado Water Conservation Board-DNR)
- Nick Stremel, Forestry-Fire Planning (Boulder County)
- Chris Wanner, Vegetation Stewardship Supervisor (City of Boulder)
- Nathaniel Goeckner, Extension Agent (Colorado State University-Extension Service)

1.5 Definition of Terms

The following table provides a definition of terms as they apply to this project. This reflects terms or acronyms that have specific implied meaning for use in a technical or subject matter context.

Table 1. Definition of terms

Term/Acronym	Definition
Burn probability (BP)	The probability of a wildfire burning a specified point or area. Burn Probability is the combination of numerous individual fire growth potential simulations to create an overall fire growth potential map. This is a key component for deriving risk outputs in the quantitative risk framework.
Calibration	The technical process to refine and/or enhance data or methods to result in a more accurate dataset that depicts actual landscape conditions. Calibration typically involves modifying or correcting existing data rather than re-creating or replacing data.
CFA	Colorado Forest Atlas Information Portal - https://coloradoforestatlas.org/
Characteristic Output	The term characteristic is applied to represent the combination of outputs for a specific analysis, such as fire behavior Rate of Spread, into a single composite output. For CO-WRA, this term is used to represent the development of a single Rate of Spread, Flame Length, and Fireline Intensity output.
CO-WRA	Colorado Wildfire Risk Assessment
Exposure	The placement of a highly valued resource or asset in a hazardous environment – such as building a home within a flammable landscape.
Fire Intensity	A quantitative measure of the potential level of intensity of a wildfire. Conventional fire behavior analysis outputs include two measures of fire intensity; flame length and fireline intensity. Both are used in the CO-WRA.
Fire Intensity Scale	A derived metric that summarizes the potential fire intensity in levels of magnitude, each output class having a ten-fold increase in values. Similar to

Term/Acronym	Definition
	the Richter scale for earthquakes, this method of quantifying fire intensity is easily understood by the public and non-scientific users.[1]
HVRA	Highly Valued Resources and Assets. This includes wildland urban interface (WUI), watershed protection, riparian areas, and forest assets in the CO-WRA.
Relative importance weightings	A method of assigning a measure of importance for different HVRA layers. Once response functions are assigned, weightings reflect the relative importance of one layer compared to another, such as WUI Risk versus Riparian Area Risk.
Response functions	A method of assigning a rating of net change to a resource value or asset (HVRA) based on susceptibility to fire intensity. These impacts can be negative or positive. The CO-WRA focused on resource values or assets that would be negatively impacted by fire.
Simulation	The area or extent of fire spread if ignited at a particular location. A simulation represents the spread area commonly referred to as Time of Arrival – a raster representation of the fire spread, while Fire Perimeters is the vector format representation of the fire spread. Deriving simulations is a key technical task in the development of the Burn Probability output.
Susceptibility	A measure of how easily a HVRA is damaged by wildfire of different intensities. However, susceptibility can also refer to beneficial fire effects to certain resources, like some wildlife habitat, that can benefit from fire.
Values-at-risk	A general term synonymous with HVRA.
Vulnerability	A combination of Exposure and Susceptibility, vulnerability is the measure of potential (sometimes called conditional) impacts to HVRA from wildfires of different intensities
Wildfire hazard (Wildland Fire hazard)	A physical situation with potential for causing damage to resources or assets. Hazard is measured by two main factors – burn probability and fire intensity.
Wildfire risk (Wildland Fire risk)	Overall measure of the possibility for loss or harm caused by wildfire. Risk is the combination of wildfire hazard and HVRA vulnerability. Risk is also referred to as expected impact.

1.6 Contact Information

For more information about the CO-WRA or the CFA web application please use the contact page at https://coloradoforestatlas.org/contact

[1] The FIS is based on a technical paper developed by Joe H. Scott and can be found at http://pyrologix.com/wp-content/uploads/2014/04/Scott_2006.pdf.

1.7 Supplemental Documents

Additional documents have been developed to support this report. These include:

- **CSFS 2022 Fuels Mapping Final Report (June 2023)** - a description of the technical methods used to derive the updated 2022 surface fuels dataset for Colorado. This report is available from the CSFS.

- **Wildfire Risk Reduction Planner & Wildfire Risk Viewer User Manuals (July 2023)** - documentation that describes how to use the CFA web applications that encapsulates the 2022 CO-WRA outputs. See https://coloradoforestatlas.org/support for access to related support information.

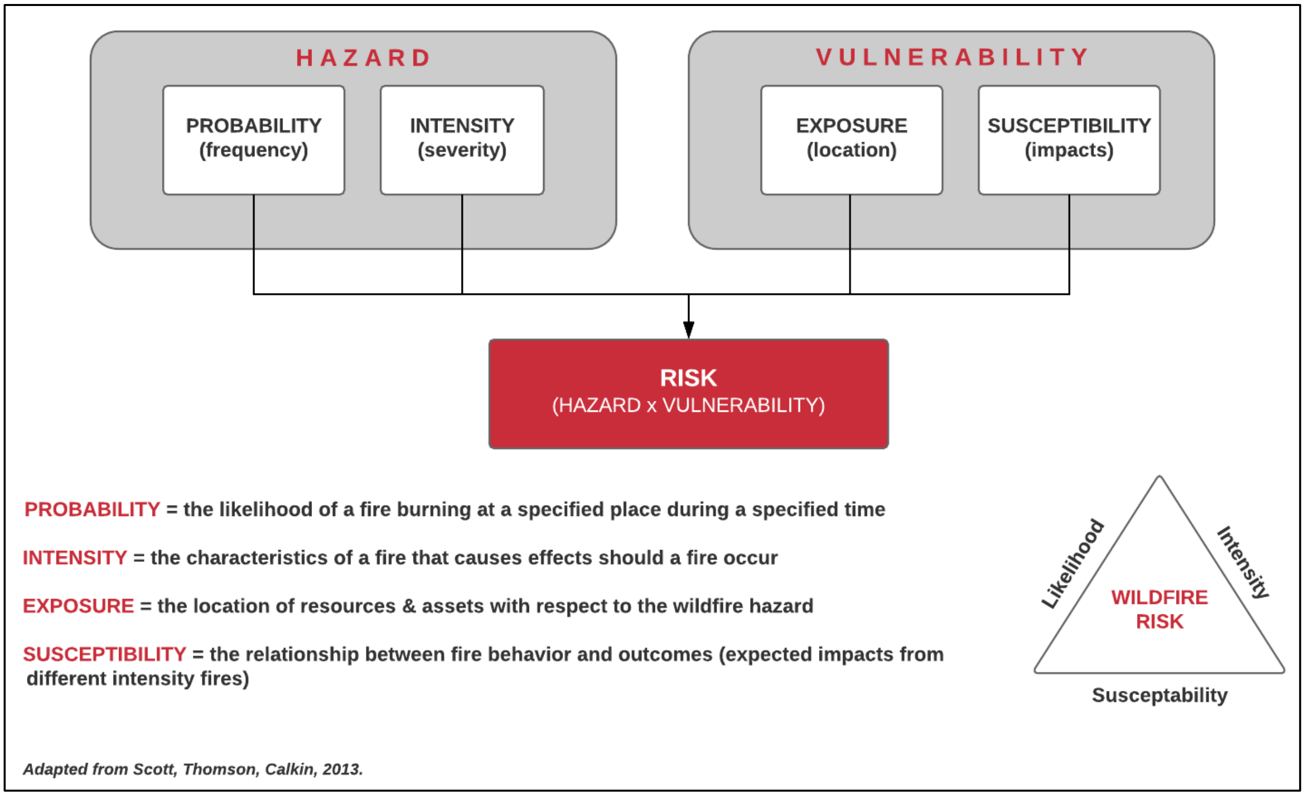
2. RISK ASSESSMENT FRAMEWORK OVERVIEW

This section provides a description of the methods that were used to conduct the 2022 CO-WRA.

2.1 Quantitative Risk Framework

The basis for a quantitative framework for assessing Wildland Fire risk to highly valued resources and assets (HVRAs) has been established for many years (Finney 2005, Scott 2006). The framework has been implemented across a variety of scales, from the continental United States (Calkin et al 2010), to individual states (Buckley et al 2011), to a portion of a National Forest (Thompson et al 2013), to an individual county (San Diego Wildfire Risk Assessment 2012). In this framework, Wildland Fire risk is a function of two main factors—1) Wildland Fire hazard and 2) HVRA vulnerability.

Figure 1. The components of the quantitative Wildland Fire Risk assessment framework.



Wildland Fire hazard is a physical situation with potential for causing damage to vulnerable resources or assets. Quantitatively, Wildland Fire hazard is measured by two main factors—1) burn probability (or likelihood or burning), and 2) fire intensity (measured as flame length, fireline intensity, or other similar measure). These factors are simulated using fire behavior modeling software systems, such as Technosylva's Wildfire Analyst™, which was used for this project. The Technosylva Wildfire Analyst™ software provides advanced fire behavior analysis and simulation capabilities and was used to calculate the CO-WRA outputs.[2]

HVRA vulnerability is also composed of two factors—1) exposure and 2) susceptibility. Exposure is the placement (or coincidental location) of an HVRA in a hazardous environment—for example, building a home within a flammable landscape. Some HVRAs, such as critical wildlife habitat or endangered plants, are not movable; they are not "placed" in hazardous locations. Still, their exposure to Wildland Fire is the Wildland Fire hazard where the habitat exists. Finally, the susceptibility of an HVRA to Wildland Fire is how easily it is damaged by Wildland Fire of different types and intensities. Some assets are *fire-hardened* and can withstand very intense fires without damage, whereas others are easily damaged by even low-intensity fire.

The framework characterizes Wildland Fire risk across a landscape, without regard for a specific ignition location. This framework has been used in the past with historical fire occurrence data to assess Wildland Fire risk across landscapes, such as counties, operating areas, National Forests, and states.

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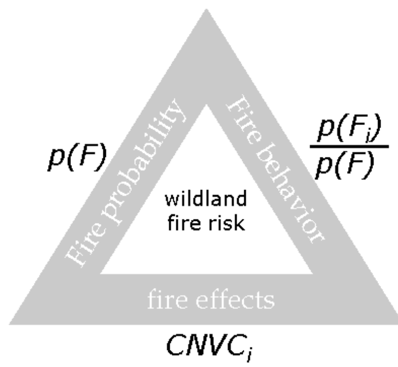
[2] For more information about Technosylva and their Wildfire Analyst product line please visit https://technosylva.com/.

The Wildland Fire risk triangle is an alternative formulation of this quantitative Wildland Fire risk assessment framework. *Fire effects* reflect the susceptibility of an HVRA to Wildland Fire, and fire probability and fire behavior together reflect hazard. Fire effects are measured as the conditional net value change (cNVC), which is calculated from fire behavior and response functions. Fire behavior refers to the intensity of a fire if one should occur.



The equation $P(F_i)/P(F)$ is the probability of fire of intensity class *i* divided by the overall probability of fire in any intensity class, which produces the conditional probability of that intensity class. Exposure is assessed by a geospatial assessment of these factors to identify where on the landscape they overlap. CNVC is the Conditional Net Value Change that represents the fire effects.

The Wildland Fire hazard component of the risk assessment is based on summaries of historical weather and fire occurrence patterns for the State of Colorado, and on a fire modeling landscape that characterizes fuel and topography across the state.

Primary outputs of the Wildland Fire hazard component include a spatial assessment of relative burn probability and potential Wildland Fire intensity. This assessment integrated the full range of weather scenarios encountered based on an analysis of weather data.

The assessment of HVRA vulnerability included compiling a spatial inventory of highly-valued resources and assets found across the State, consistent with those considered in the 2017 CO-WRA.

Once analyzed, the hazard and vulnerability components were then combined in an effects analysis—an assessment of Wildland Fire hazard (probability and intensity) in the context of HVRA susceptibility and importance, where each HVRA occurs.

2.2 Wildfire Hazard

To satisfy the Wildland Fire hazard component it was necessary to derive outputs that describe fire occurrence and burn probability within Colorado. Historical fire ignition data, as described in Section 4.3, was used to create a dataset of fire occurrence (ignition density). Fire occurrence was then combined with advanced fire simulation modeling to derive burn probability, as described in Section 4.5.

2.3 Wildfire Vulnerability

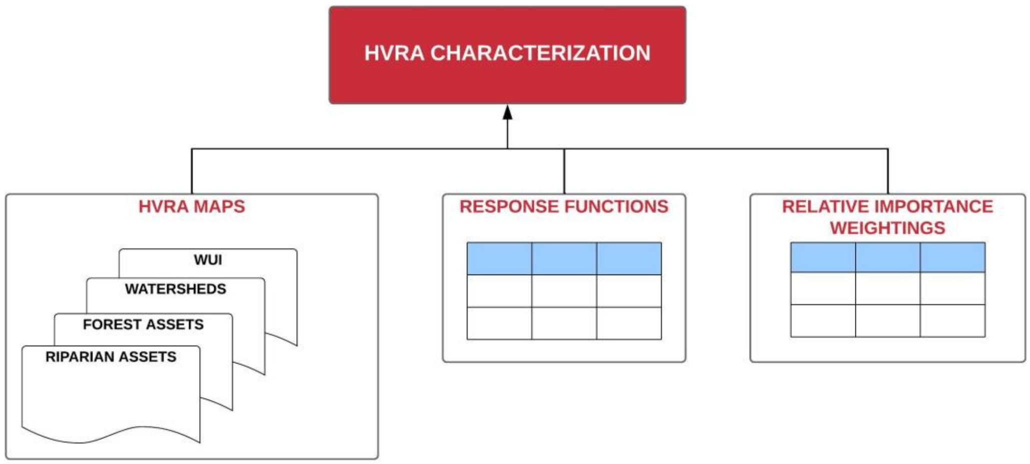
Calculating Wildland Fire vulnerability involves three key components:

1. Definition of HVRA layers (data)
2. Definition of response functions for HVRAs

3. Definition of relative importance weightings for HVRAs

The following figure shows the relationship of these components required to characterize the risk associated with HVRAs. For the CO-WRA these are shown as HVRA maps in the diagram (i.e. WUI = Wildland Urban Interface, Watersheds, Forest Assets, and Riparian Assets).

Figure 2. Components for characterizing risk for Highly Valued Resources and Assets.



Assignment of Response Functions

The primary underpinning of the Wildland Fire Vulnerability component of the risk framework is based on the use of "response functions". Response Functions are a method of assigning a rating of net change to a resource value or asset based on susceptibility to fire intensity. These impacts can be negative or positive.

Calculating risk at a given location requires spatially defined estimates of the likelihood and intensity of fire integrated with the identified resource/asset value. This interaction is quantified through the use of response functions that estimate expected benefits and losses to values/assets at the specified fire intensities. The measure of fire intensity used in the model is Flame Length. Specific classes of Flame Length have been defined that reflect key thresholds for damage from Wildland Fire to the resource values. Section 5 provides a detailed description of the response functions employed for the CO-WRA.

For the CO-WRA, response functions are defined for each category of the resource value inputs, for each given flame length category. The Flame Length output data were derived using Technosylva's Wildfire Analyst™ software. Positive response functions indicate a benefit or increase in value to the resource; negative response function values indicate a loss in resource value.

Using the response function matrices, GIS data of flame length and the HVRAs are combined to derive an output that reflects those areas where the least or most impact/susceptibility exists. Response functions represent mathematical relationships between fire characteristics (intensity) and fire outcome. Although fire outcomes could be related to any fire characteristic, response is typically related to some measure of fire intensity, e.g., flame length (Ager and others 2007; Finney 2005).

Assignment of Relative Importance Weightings

Balancing competing or conflicting land and resource management objectives is a significant challenge to land and resource management planners. Likewise, it is also difficult to articulate quantitative weights establishing the relative importance of HVRAs. This step is not necessary when assessing Wildland Fire risk to a single HVRA, such as WUI. It is only when comparing risk among several HVRAs that the issue of weighting arises.

Using relative importance scores helps to address all of these questions and allows for summarization and visualization of risks in a single metric. If assessment results are to ultimately be used for planning mitigation treatments and strategies, then prioritization decisions that integrate all HVRAs will still ultimately need to be made. Articulating relative importance scores and how objectives are balanced makes this decision explicit rather than implicit and increases the overall transparency of decision processes.

2.4 Incorporating Building Level Risk Metrics

The quantitative risk framework provides a technical foundation for calculating risk metrics at county and local scales. However, these methods do not easily accommodate more detailed analysis of using building data and high-resolution fuels and fire behavior data. For the 2022 CO-WRA, enhanced methods for assessing defensible space and building damage potential were incorporated using unique data and machine learning models that have been successfully employed and validated in California over the past three years. Using Technosylva's proprietary building loss factor dataset combined with high resolution fuels data incorporating LiDAR data sources, enhanced risk metrics are produced to support small communities and homeowners with understanding risk relative to their specific location and neighborhood.[3] Building or property level metrics are not provided, as it is believed that data is not yet refined enough to support this level of analysis. However, using buildings as anchors, high resolution risk metrics can be accurately produced that are significantly more detailed than previous risk assessments. These metrics will aid local homeowner associations and communities with better understanding their risk landscape. These new metrics are introduced in Section 5.3 and 5.4.

2.5 Incorporating Egress and Social Vulnerability

Risk as defined as the possibility of loss or harm with respect to wildfire incorporates more than simply fuels and fire behavior. It is well understood that transportation access, commonly referred to as ingress/egress, is an important component to the risk recipe for wildfire. The ability to escape or flee an active wildfire is key for WUI, wildland or rural landscape environments. Accessibility to transportation routes that can accommodate the flow of surrounding population can significantly impact the public's risk.

In addition, the socio-economic characteristics of population in high-risk areas can also substantially impact an individual's ability to flee an encroaching wildfire. Again, this is especially relevant to WUI,

[3] Technosylva's BLF data is a proprietary commercial dataset used for the development of risk metrics for the CO-WRA, however the data itself is not licensed or included in the CO-WRA or CFA deliverables. It is available directly from Technosylva via subscription.

wildland or urban areas. Characteristics such as economics, age and health may impede the resources available to an individual, or their physical ability to leave their home during a wildfire.

For the 2022 CO-WRA, new metrics were added that incorporate both egress and social vulnerability. Egress was calculated as a simple road availability model that includes road density by type relative to population using an assumption that all population is trying to leave at the same time. This basic metric is enhanced by considering three socio-economic variables, 1) ratio of population over 65 years of age, 2) ratio of population in poverty, and 3) ratio of population with a disability. These metrics will aid local homeowner associations and communities with a better understanding of characteristics that may increase their wildfire risk. The new egress and social vulnerability metrics are introduced in Section 5.5.

3. RISK MODEL DATABASE DEVELOPMENT

This section describes the datasets and methods used to develop the database used for the CO-WRA. The following table provides a list of the key datasets used in the CO-WRA. These datasets are available on the CFA web applications.[4] Note that datasets identified with * are new for the 2022 CO-WRA and were not in previous assessments. They reflect enhancements in fire modeling methods that have occurred since 2017 and provide a significant improvement to the level of information to support mitigation planning efforts. This is in addition to the improvements that have occurred with fire behavior modeling.

Table 2. Description of CO-WRA primary datasets.

CO-WRA Dataset	Description
PRIMARY OUTPUTS	
Wildfire Risk to Assets	Possibility of loss or harm occurring from a wildfire. The composite risk metric is obtained by combining Values at Risk and Burn Probability, although individual risk metrics also provide significant value for specific analysis purposes.
Burn Probability	Probability of any area burning.
Fire Intensity Scale	Quantifies the potential fire intensity for an area by orders of magnitude
INTERMEDIATE OUTPUTS	
Values at Risk Rating	Represents an overall composite rating of the potential impact of a wildfire for all values and assets created by combining the individual risk outputs.
Terrain Difficulty Index*	Represents those areas where terrain and vegetation characteristics impede ground-based suppression efforts
DERIVED OUTPUTS	
Building Damage Potential*	Represents the average loss potential for all buildings within a local area based on landscape characteristics conducive to historical building loss (does not incorporate building material).
Defensible Space Composite *	Represents the average building hazard within a local area based on defensible space characteristics of canopy cover, slope and adjacent fuel types. Multiple metrics are provided including each component.
Egress with Social Vulnerability*	Represents the ability to evacuate a fire in a local area when considering the road availability for the surrounding population. This includes egress with or without consideration of social vulnerability characteristics.
WUI Risk Index	Represents a rating of the potential impact of a wildfire on people and their homes in the WUI
Watershed Protection Risk	Measure of wildfire risk to watersheds requiring protection as a source for forest health and drinking or irrigation water.

[4] Please refer to https://coloradoforestatlas.org/

CO-WRA Dataset	Description
Forest Assets Risk Index	Measure of wildfire risk to forested lands characterized by height, cover and susceptibility/response to fire
Riparian Assets Risk Index	Measure of wildfire risk to forested riparian areas
Fire Occurrence	Ignition density derived from historical ignition locations
FIRE BEHAVIOR OUTPUTS	
Characteristic Flame Length	Represents the distance between the tip and base of the flame. This is a composite output created by combining flame length for individual weather percentile outputs.
Characteristic Rate of Spread	Represents the speed with which a fire moves in a horizontal direction across the landscape. This is a composite output created by combining flame length for individual weather percentile outputs.
Fire Type (extreme weather)	Potential for canopy fire type for extreme weather conditions (canopy fire potential)
Spotting & Spotting 50 mph Winds*	Potential for spotting in miles under specific weather conditions.
KEY INPUTS	
Fire Ignitions	Federal and non-federal wildfire ignitions point data for Colorado were compiled for the period 1992-2020
Watershed Protection Areas	Represents priority areas where opportunities exist to improve and maintain water quality and quantity, that may be subject to impacts from fire
Forest Assets	Forested lands characterized by height, cover and susceptibility / response to fire based on LANDFIRE 2020 data
Riparian Assets	Riparian areas characterized by functions of water quantity, quality and ecology
Surface and Canopy Fuels	Description of surface and canopy vegetation described by fuel conditions that reflect fire behavior characteristics
Vegetation	General vegetation and land cover types based on LANDFIRE 2020 data
Wildland Urban Interface (WUI)	Depicts where humans and their structures meet or intermix with wildland fuels. Presented as housing density (houses per acre).

3.1 Fuels and Landscape Data

A key element of the 2022 CO-WRA was the development of a new and accurate surface and canopy fuel models dataset. This is commonly referred to as fuels mapping and the data is defined as “fuel models”.

Fuel models constitute vegetation groups with similar physical characteristics that contribute to the spread, intensity, and severity of wildland fires. These characteristics reflect loading, size, and bulk density of vegetation. Given the complexity of nature, fuel families such as Scott & Burgan 2005 Fuel Model Set summarize typical groups of vegetation with similar characteristics that would produce an equivalent fire behavior under defined weather/topography conditions.[5]

The accurate mapping of fuel models is critical for fire behavior modeling and deriving the associated outputs, such as wildfire risk. Fire behavior models estimate fire behavior based on fuel models that provide numerical descriptions of the physical parameters of the vegetation.

The Scott & Burgan fuel model family was selected for the 2022 CO-WRA. It contains 40 default fuel models distributed in 7 fuel model groups.[6]

- Non-burnable Fuel Type Models (NB– 90)
- Grass Fuel Type Models (GR or 100)
- Grass-Shrub Fuel Type Models (GS or 120)
- Shrub Fuel Type Models (SH or 140)
- Timber Understory Fuel Type Models (TU or 160)
- Timber Litter Fuel Type Models (TL or 180)
- Slash-Blowdown Fuel Type Models (SB or 200).

The surface fuel model for the 2022 CO-WRA project was created using an OBIA (Object Based Image Analysis) technical approach. This is a remote sensing based image processing task that involves the conversion of pixels with homogeneous spectral characteristics into larger segments (polygons). Each segment received a fuel model classification based on these spectral characteristics.

Previous 2012 and 2017 CO-WRA assessments used the most recent version of the LANDFIRE dataset and applied corrections and enhancements to update the data.[7] For the 2022 CO-WRA, a better technical approach was used that included the integration of LiDAR and other detailed high resolution datasets with a more robust technical and scientific method for delineating fuel models. The OBIA approach results in a definition of fuels by homogeneous polygons. This polygon data is then rasterized to support the conventional fire behavior modeling methods. For 2022 CO-WRA, a 20-m resolution was selected representing a spatial accuracy consistent with other input datasets yet providing a significantly enhanced resolution compared to previous 30m resolution input data and assessments.

The development of a new fuel models dataset, rather than using LANDFIRE data as a source, afforded the ability for the development of additional fuel models that better characterize the landscape. Twenty-two (22) new fuel models were added for the 2022 Colorado fuel models. This not only better delineated the landscape with respect to vegetation fire behavior characteristics, but it also allowed for a better application of fire modeling methods for urban encroachment, spotting, and other modeling requirements important for risk characterization.

The CSFS 2022 Fuels Mapping Final Report provides a detailed explanation of the fuel models and the technical methods used. The following figure presents an example of the 2022 fuels models showing the new models that better characterize the WUI and urban fringe area subject to fire encroachment.

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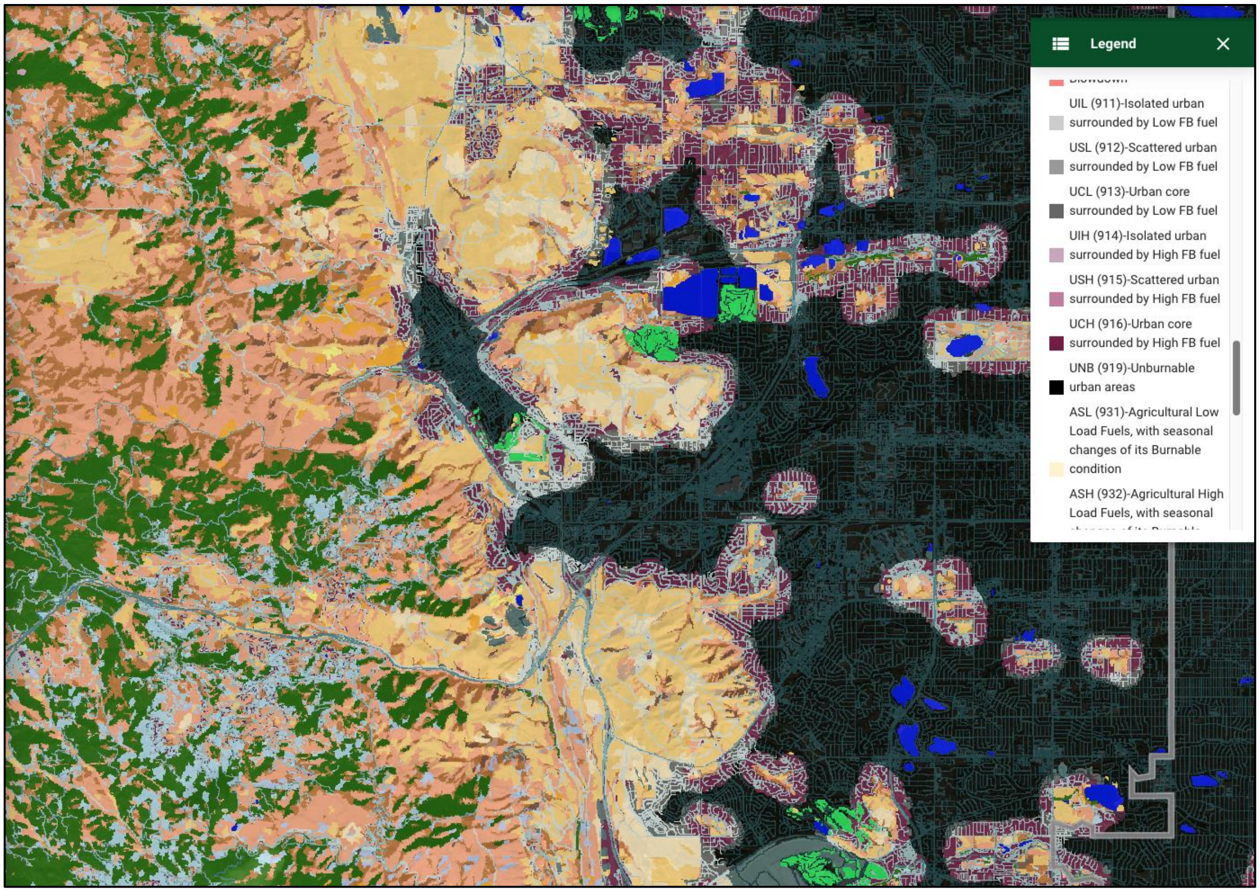
[5] Please see https://www.fs.usda.gov/rm/pubs_series/rmrs/gtr/rmrs_gtr153.pdf

[6] Each fuel model is represented by two letters (referred to the fuel model group) and a number, referred to a specific fuel model within that group. Group can also be represented as a number, i.e. GR is 100 and GR1 is 101.

[7] Please see https://landfire.gov/.

Figure 3. Example showing the enhanced fuel models for the 2022 CO WRA.



3.2 Highly Valued Resources and Assets

The following Highly Values Resources and Assets were considered during the 2022 CO-WRA update.

- Buildings
- Population
- Wildland Urban Interface (WUI)
- Watershed Protection Areas
- Forest Assets
- Riparian Assets

Buildings depicts building footprints from the latest Microsoft Buildings Dataset.[8]

Population is depicted by the LandScan 2021 dataset.[9]

Wildland Urban Interface depicts where humans and their structures meet or intermix with wildland fuels. Presented as housing density (houses per acre). WUI is a subset of a dataset called Where People Live (WPL) that depicts housing density for Colorado.

[8] Please see https://github.com/microsoft/USBuildingFootprints.

[9] Please see https://landscan.ornl.gov/.

Watershed Protection represents priority areas where opportunities exist to improve and maintain water quality and quantity, that may be subject to impacts from fire

Forest Assets depict forested lands characterized by height, cover and susceptibility / response to fire.

Riparian Assets depicts forested riparian areas characterized by functions of water quantity, quality and ecology.

A description of the data compilation and development methods employed for these HVRAs is provided.

Where People Live (housing density)

An understanding of the WPL dataset is required to properly understand how the WUI was derived from the WPL data. Both datasets depict housing density although WUI only represents those areas where people and their structures intermix with wildland fuels.

Using LandScan 2021 Data

Census block data has traditionally been used to define Wildland Urban Interface (WUI) areas. As such, the USFS SILVIS dataset has often been used for wildland fire planning in the past.[10] SILVIS defines WUI areas based on a combination of housing density and forest cover percent.

For the 2022 CO-WRA, updated LandScan data for 2021 was obtained and used to create the Where People Live (WPL) and Wildland Urban Interface (WUI) datasets.[11]

LandScan depicts an estimate of population count on a 90-meter cell basis. The model used to create LandScan data uses spatial data and imagery analysis technologies and a multi-variable dasymetric modeling approach to disaggregate census counts within an administrative boundary. Since no single population distribution model can account for the differences in spatial data availability, quality, scale, and accuracy as well as the differences in cultural settlement practices, LandScan population distribution models are tailored to match the data conditions and geographical nature of each individual country and region. A key component of the LandScan model is the integration of night time imagery to determine where people are living. LandScan is the preferred choice for population data and given its spatial resolution is ideal for defining *where people live*.

In particular, the resolution and accuracy of the LandScan data provides a better definition of the location of rural and wildland communities and residential population compared to traditional WUI datasets (i.e. USFS SILVIS) that were developed using Census Block data that has a coarser spatial resolution. The LandScan data has become the standard across the US in wildfire risk assessments for identifying population locations, specifically for wildland and rural areas. It was previously used in the 2012 and 2017 CO-WRA projects and undergoes continual refinement with new releases.

Figure 4 shows an example map of the LandScan 2021 data.

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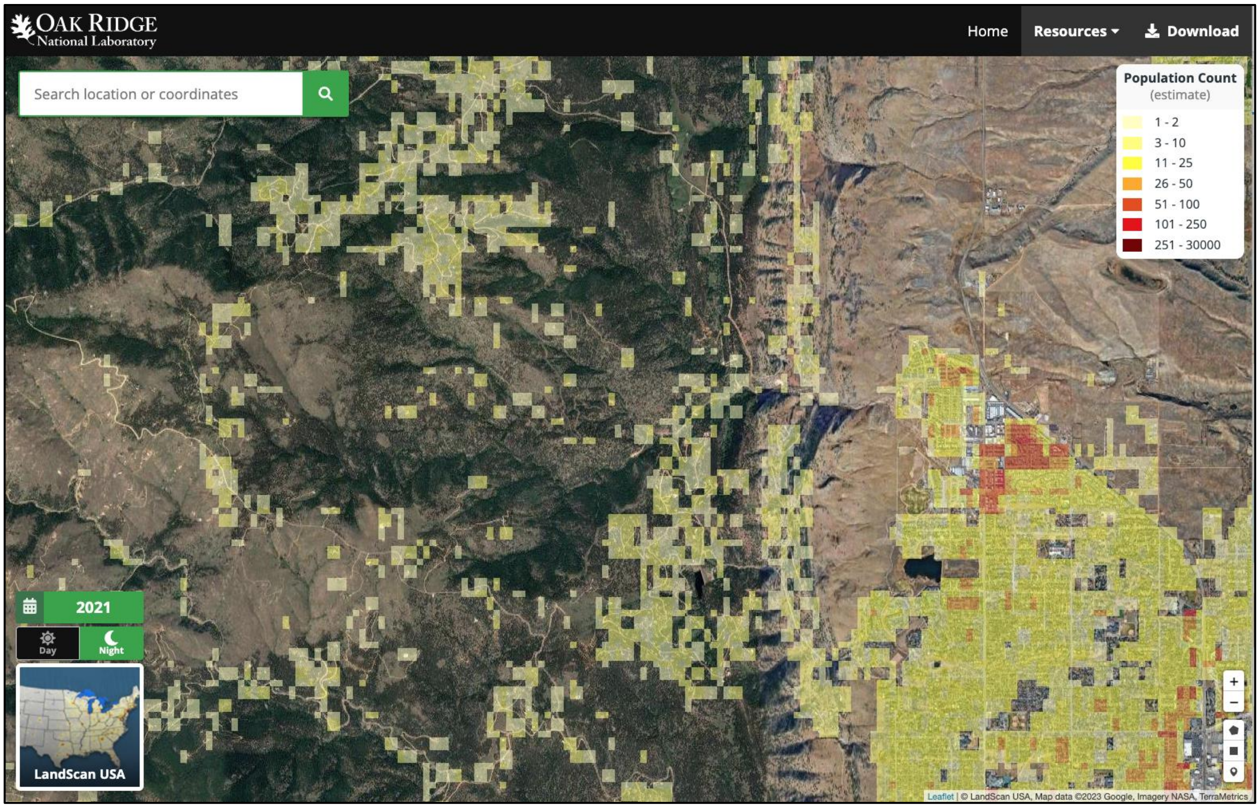
[10] Please see http://SILVIS.forest.wisc.edu/maps/WUI for more information about the SILVIS WUI data.

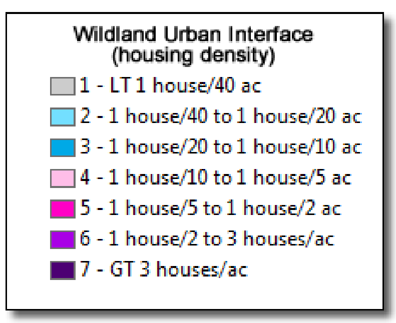
[11] Please visit https://landscan.ornl.gov/ for more information about this data source.

Figure 4. LandScan 2021 map showing population count (from the on-line ORNL LandScan Viewer).



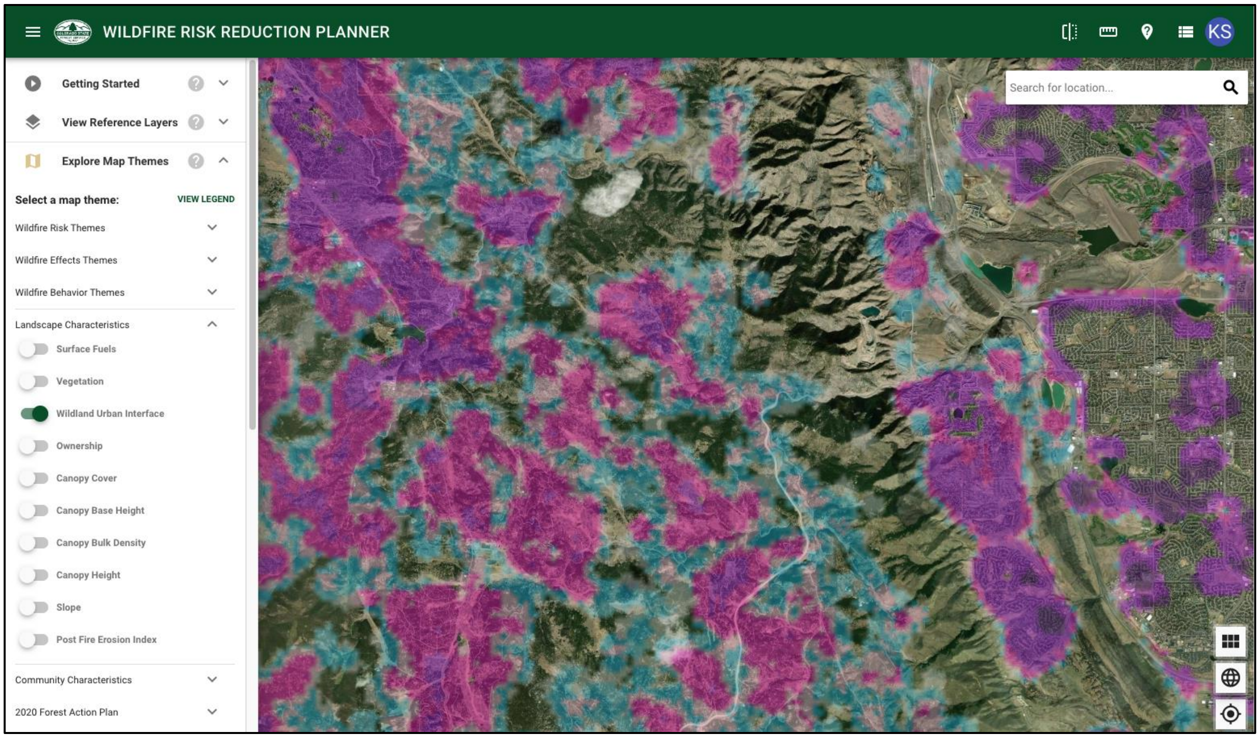
Technosylva developed a model that combined the LandScan data with other relevant datasets, i.e. Census County Housing Summaries, Colorado county parcel data, new 2022 fuel models for urban and agriculture areas, building footprints, and postal address locations, to derive a 20-meter resolution housing density dataset. The WPL dataset is calculated to represent the number of houses per acre, consistent with units defined by the Federal Register and USFS SILVIS. This was done to adhere to common use and understanding of WUI by planners and fire professionals. The following figure depicts the standard WPL/WUI legends classes used in the CO-WRA.

Figure 5. WPL and WUI housing density classes.



The following figure shows the 2022 WUI map for an example area.

Figure 6. Example WUI for an area in Colorado Front Range.



In the CO-WRA and in the CFA applications, both datasets are depicted as housing density classes in houses per acre. The WPL and WUI "houses per acre" class breaks also adhere to the standard Federal Register and USFS SILVIS classes. However, to provide a smoother gradient in housing density a few additional classes have been added. This was undertaken based on feedback from CSFS where often local planning standards may vary and accordingly, greater delineation of density classes was preferred. WPL/WUI classes 3, 4, and 6 represent new classes that have been inserted into the standard Federal Register classes.

Wildland Urban Interface

The WPL data incorporates both urban and wildland/rural areas as a measure of housing density. By applying an advanced model of urban encroachment using both Flame Length and Fuel Models, a WUI dataset can be derived by extracting the *urban core* areas from the WPL. These methods are described in this section of the report.

Urban Encroachment

Although non-burnable areas, such as urban, do not directly have a Flame Length assigned due to the lack of underlying surface fuels, it is understood that small urban areas in the wildlands and urban *fringe* areas are both highly susceptible to wildfire from adjacent fuels. The term *urban fringe* is used to refer to those areas on the periphery of highly urban areas that are also in close proximity to wildland areas.

Accordingly, so that the Response Function modeling will incorporate these urban areas into the risk outputs, the model must accommodate encroachment into urban, non-burnable areas. The agreed upon approach used in the CO-WRA was to *extend* the Flame Length data into urban areas using GIS neighborhood smoothing techniques.

A maximum penetration distance is defined (i.e. 0.25 mile), and GIS modeling techniques are applied to extend the Flame Length into urban areas. The best outputs were obtained by using an incremental neighborhood smoothing technique where the fire behavior value from the *wildland edge* was smoothed with incremental rings. This *incremental* approach ensured that the fire behavior values decayed as they penetrated the urban areas, understandably since the distance from the wildland edge increased, similar to a decay type function.

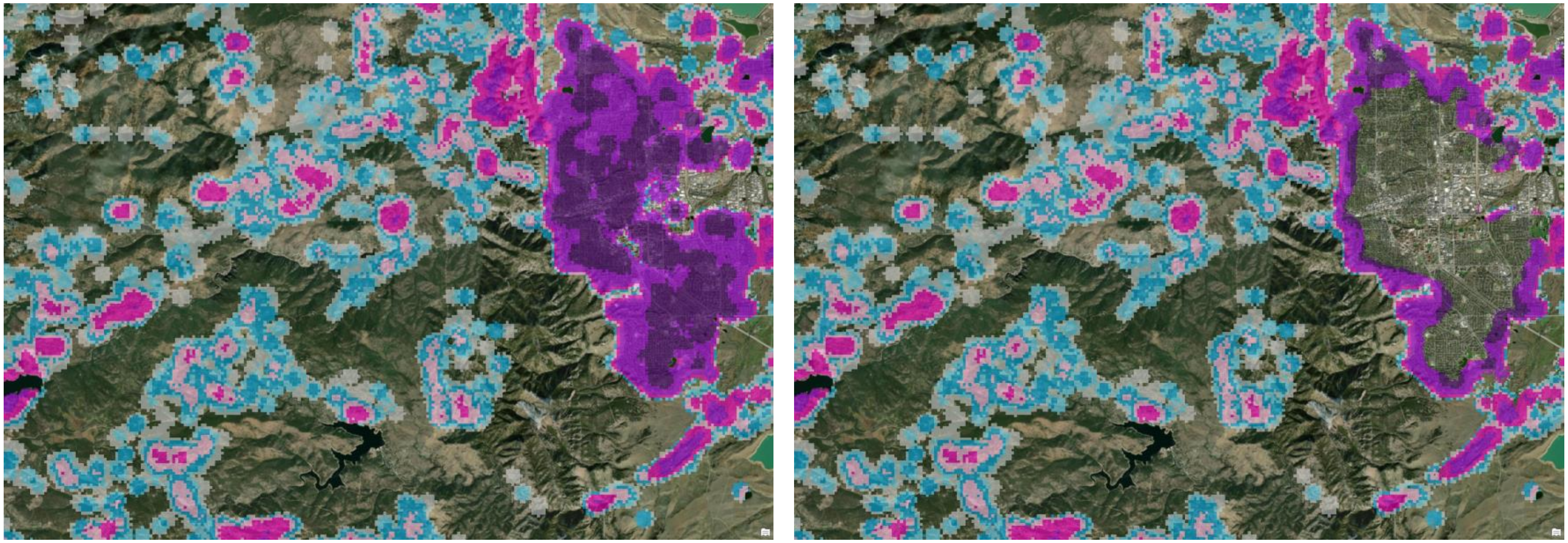
The fire modeling urban encroachment algorithm was enhanced for the 2022 CO-WRA to incorporate consideration of not only the flame length values of the fuels adjacent to urban areas, but also the type of fuel models, and the density of buildings. This incorporated changes to the 2022 fuel models to incorporate new WUI based definitions, in addition to enhanced modeling algorithms that make use of the new WUI fuel models. Independent of the flame length it is understood that certain grass and grass-shrub fuel types will have minimal, if any, encroachment into urban areas. This enhancement resulted in encroachment results that better represented CSFS' understanding of WUI areas on the fringe of urban areas, as well as accommodating wildland urban areas (small communities) accurately.

The urban encroachment approach was used to enhance the delineation of Wildland Urban Interface from the WPL dataset. Accordingly, this ensured that urban fringe areas and wildland urban areas were assigned a Response Function value and are reflected in the WUI Risk Index output. Additionally, this ripples into other outputs that utilize the WUI Risk Index, such as Values at Risk and Wildfire Risk.

The following figure shows an example of the WUI enhancements achieved with using urban encroachment. The map on the left shows the Where People Live housing density data. This dataset is the source for the WUI as it depicts *where people live*.

The map on the right shows the WUI with urban encroachment included. Areas on the fringe of the urban area are included in the WUI as they are potentially impacted should a wildfire occur, due to their close proximity to wildland fuels areas.

Figure 7. Examples show WPL and WUI with urban encroachment for the Boulder area.



Where People Live (housing density) | Wildland Urban Interface (WUI)

Forest Assets

This layer identifies forest land categorized by its height, cover and susceptibility or response to fire. Using these characteristics allows for the prioritization of landscapes reflecting forest assets that would be most adversely affected by fire. The rating of importance or value of the forest assets is relative to each state's interpretation of those characteristics considered most important for their landscapes. The following table summarizes height, cover, and the concept of susceptibility or response to fire (LANDFIRE 2020 Existing Vegetation Height (EVH) data set).

Table 3. Forest Asset layer characteristics

Height Class	Canopy Cover Class	Fire Response Class
0 to 10 meters 10.1 to 25 meters 25.1+ meters	Open or Sparse Closed	Sensitive Resilient Adaptive

LANDFIRE 2020's Existing Vegetation data (EVT) is the primary source for the forest assets data set. The Forest Assets combine specific values of forest height and canopy cover class to determine a fire response class. This crosswalk of values is broken down into three groups defined as sensitive to fire, resilient to fire, and adaptive to fire.

Table 4. General description of the Forest Assets fire response classes.

Value Impacted	General Description
Sensitive (Code = 1)	Fire sensitive. Intolerant trees sensitive to damage from fire with low intensities.
Resilient (Code = 2)	Fire resisters. Tolerant tree species whose adult stages can survive low severity fires.
Adaptive (Code = 3)	Fire endurers. Tree species adapted with the ability to regenerate following fire by sprouting or serotinous cones.

The following table presents a description of the canopy cover classes. The source is the National Vegetation Classification Standard (NVCS) class attribute (NVCSCLASS) in the LANDFIRE 2020 EVT data set.

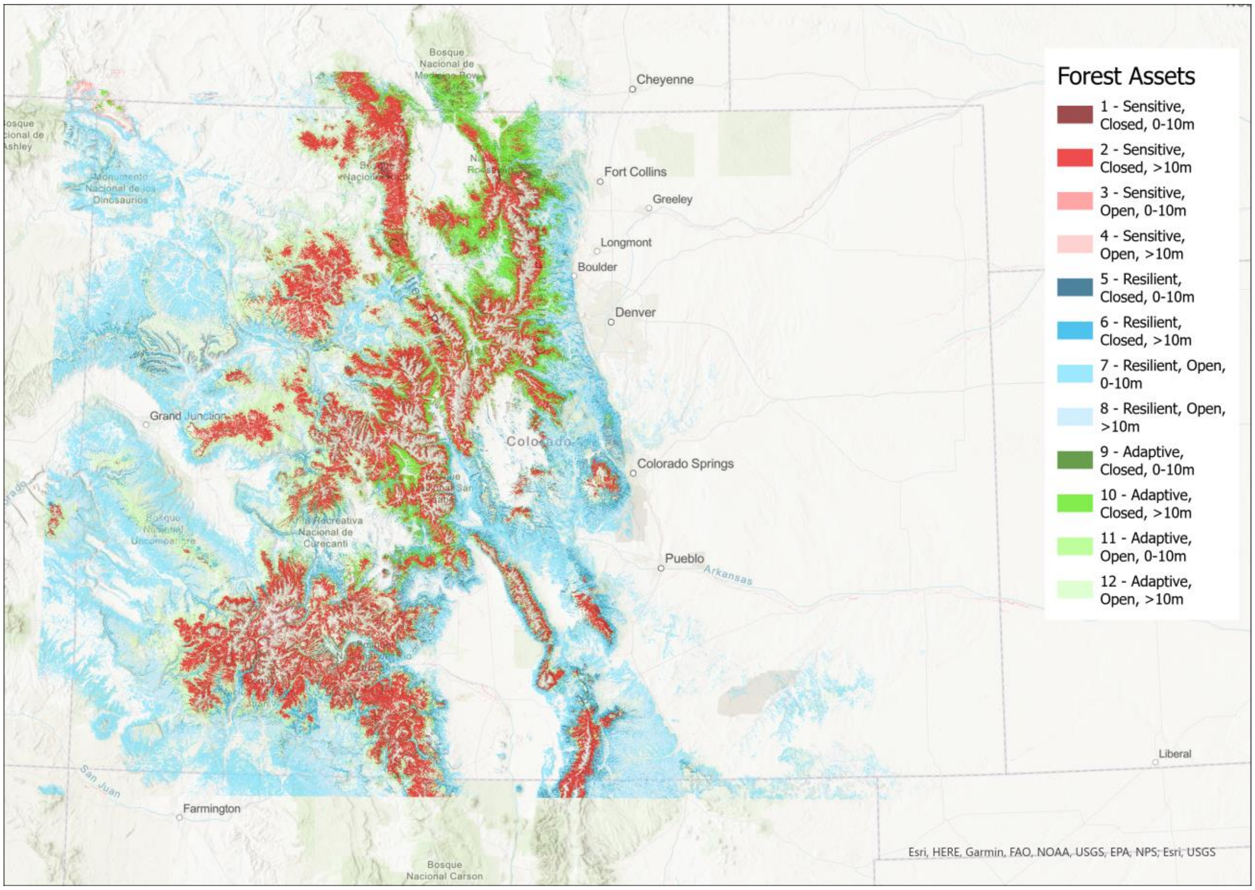
Table 5. Description of canopy cover classes for Forest Assets.

Value Impacted	General Description
Sparse	Canopy cover may be less than 25% in cases when the cover of each of the other life forms present (i.e. shrub, dwarf-shrub, herb, nonvascular) is less than 25% and tree cover exceeds the cover of the other life forms. Hence, the cover is 10-25%.
Open	Open stands of trees with crowns not usually touching (generally forming 25-60% cover).

Value Impacted	General Description
Closed	Trees with their crowns overlapping (generally forming 60-100% cover).

The following figure presents the Forest Assets dataset for Colorado.

Figure 8. Colorado Forest Assets.



Riparian Areas

This layer identifies riparian areas that are important as a suite of ecosystem services, including both terrestrial and aquatic habitat, water quality, water quantity, and other ecological functions. Riparian areas are considered an especially important element of the landscape in Colorado. Accordingly, a separate data set has been compiled to provide CSFS the opportunity to consider the impact from fire in riparian areas.

The process for defining these riparian areas was complex. It involved identifying the riparian footprint and then assigning a rating based upon two important riparian functions. These functions are water quantity and quality together as well as ecological significance. A technical team from the West Wide Risk Assessment project developed the riparian area data layer model with in-kind support from state representatives. Input data sets used in the model included the National Hydrography Data Set and the National Wetlands Inventory.

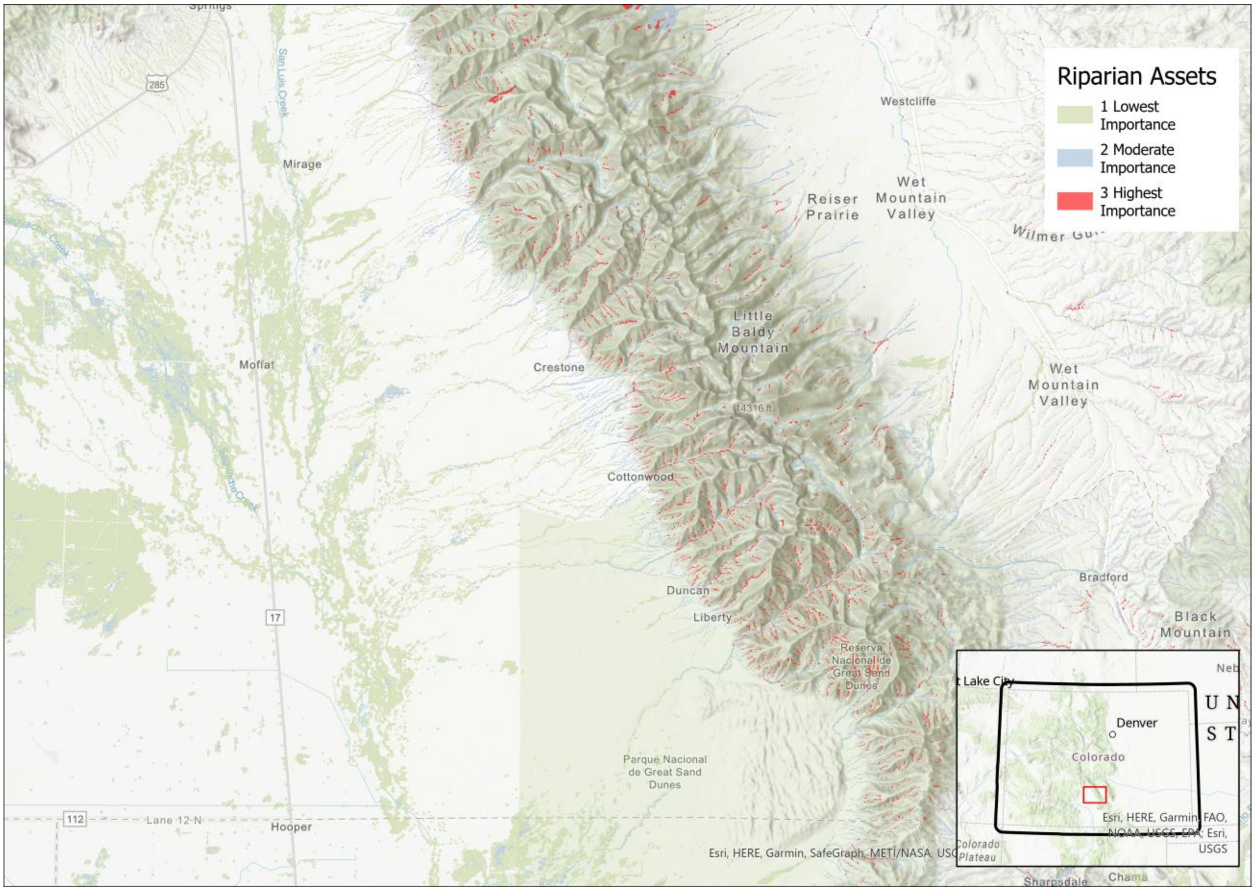
The National Hydrography Data Set (NHD) was used to represent hydrology. A subset of streams and water bodies, which represents perennial, intermittent, and wetlands, was created. The NHD water bodies' data set was used to determine the location of lakes, ponds, swamps, and marshes (wetlands).

At http://www.fws.gov/wetlands/index.html, the US Fish and Wildlife Service have posted the National Wetlands Inventory (NWI). This is a comprehensive data set covering the entire United States that explicitly maps wetland areas. This data set was used in two ways. The first way was to establish a wetland riparian footprint. The second way was to provide value information about the condition of the wetland riparian area. The NWI contains five categories: marine, estuarine, riverine, lacustrine, and palustrine. To avoid overlap with the wetland areas already identified, the only system used from the NWI is palustrine.

After selecting the correct features from the NHD and NWI, a buffer was used to create the riparian footprint. Buffering these spatial features at approximately 150 feet created footprints for perennial streams and wetlands. Seasonal watercourse extent was created based on 75-foot buffers. Development of a rating of impact for riparian areas was then done by initially considering water quality and quantity as measured by erosion potential, annual average precipitation and slope. In addition, ecological significance was included as measured by LANDFIRE vegetation classification to depict habitat quality and susceptibility to fire.

The model creates values impacted categories that range from 1 to 3 representing increasing importance of the riparian area as well as sensitivity to fire-related impacts on the suite of ecosystem services. A Value Impacted Category 3 generally represents riparian areas with conifer, hardwood, or riparian vegetation on steeper slopes, erodible soils and areas of higher annual rainfall. A Value Impacted Category 1 generally represents riparian areas with exotic or grass vegetation types, on flatter slopes, in areas of low annual rainfall. The following map presents an example of the riparian areas data layer.

Figure 9. Example of Riparian Assets.



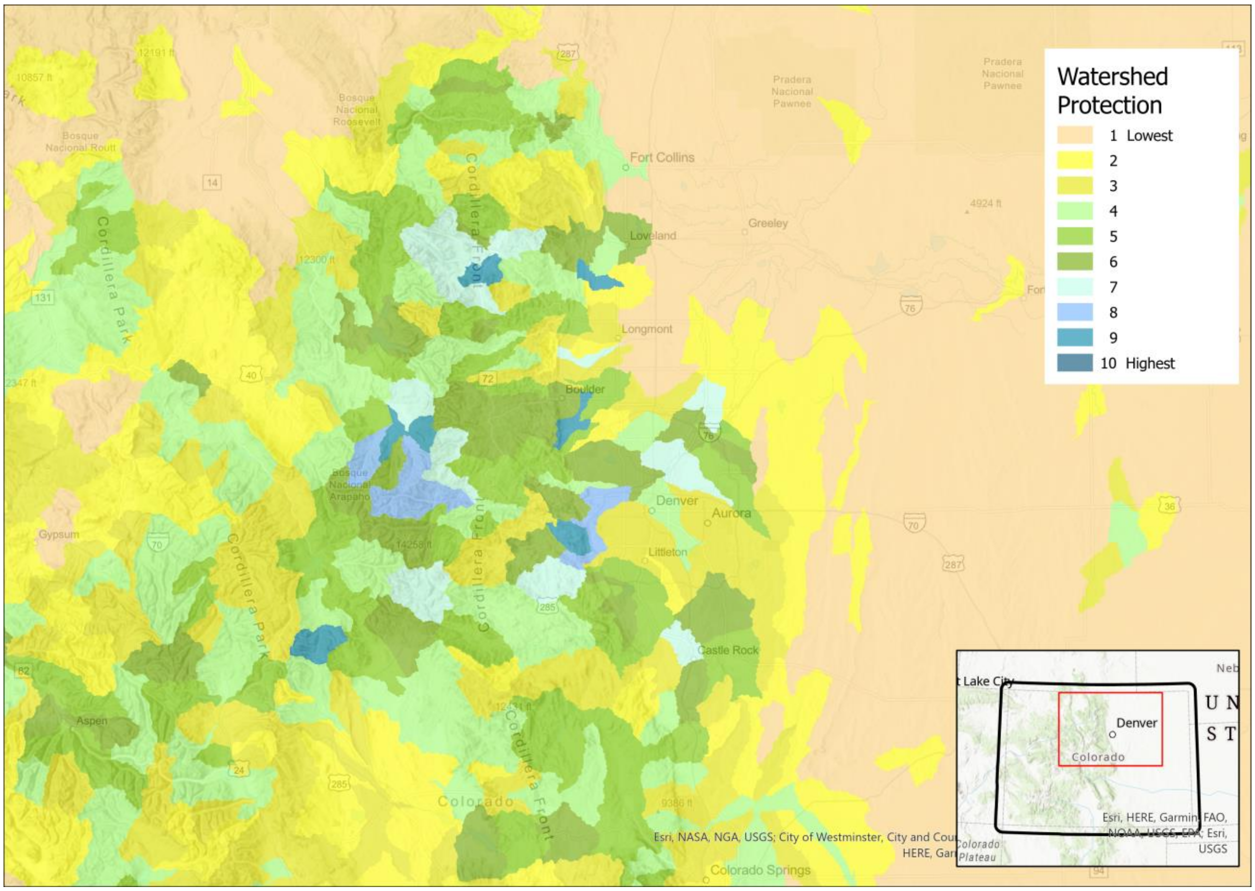
Watershed Protection Areas

Colorado's forested watersheds deliver clean water to residents, 18 other states and Mexico, and provide the biological diversity needed for a future that is balanced both socially and ecologically. Current and expected future conditions, including persistent droughts and uncharacteristic wildfires, have and will continue to negatively impact forest health and the source water and habitat these forests provide. Water is an increasingly limited resource in Western states. Therefore, practicing forest management to improve forest health is critical to protecting and enhancing this precious resource. Wildfire remains a substantial risk to the health of our watersheds.

This layer identifies priority areas where opportunities exist to improve, maintain and protect the watersheds to maintain water quality and quantity. Understanding the risk associated with each watershed is key to supporting forest management planning and activity initiatives.

Water in Colorado predominately comes from high-elevation forested watersheds that are facing an ever increasing threat from wildfire and anthropogenic pressure. When wildfires occur, there is a high likelihood of impaired water quality (excess Nitrogen, Carbon and Phosphorous), high sediment loads, increased stream temperatures, and suspended ash particles to transport to either the water intakes or a water storage reservoir. This can have a detrimental effect on aquatic habitat and fisheries. Determining which upland watersheds have the highest likelihood from a sediment export and water quality perspective, can give water providers and land managers an opportunity to understand the benefit of fuel treatments verses expected increases in sediment and water quality degradation. The following figure shows the Colorado watershed protection areas used on the 2022 CO-WRA; this watershed model was developed at the HUC-12 scale and incorporated raw data from the Colorado Department of Public Health and Environment's Source Water Protection Program. This replaces and enhances the previous USFS Forest to Faucets data used on the 2012 and 2017 CO-WRA projects, consistent with the most recent Colorado Forest Action Plan.[12]

Figure 10. Example of Colorado Watershed Protection Areas.



[12] Please visit the Colorado Forest Action Plan application on the CFA site at https://fap2020.coloradoforestatlas.org/#/.

4. FIRE BEHAVIOR MODELING

This section describes the fire behavior modeling methods and results from the 2022 CO-WRA.

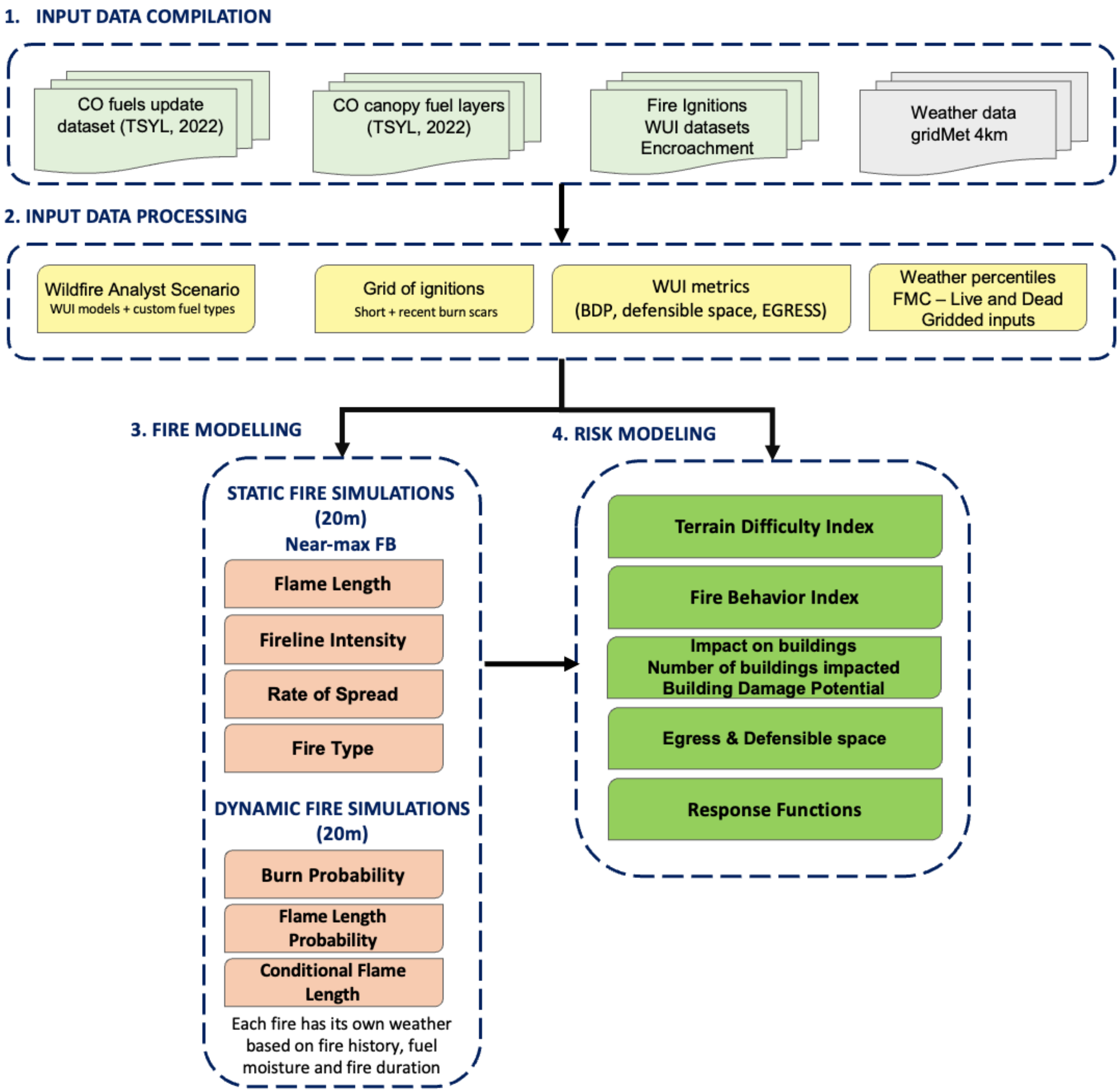
4.1 Overview of Processing Methods

Fire behavior modeling is a critical task that derives the primary fire behavior outputs used for calculation of risk outputs. The modeling leverages the investment made by the CSFS in the calibration of accurate surface fuels, canopy data and selection of values-at-risk. The main purpose of this task is to assess the potential fire behavior in Colorado using both static and dynamic fire simulation approaches.

The fire modeling tasks were completed using Technosylva's Wildfire Analyst™ (WFA) software (WFA, Ramirez et al, 2011).[13] WFA is a software that provides real-time analysis of wildfire behavior and simulates the spread of wildfires. WFA embodies Rothermel (1972) equations with enhanced processing methods to simulate fire behavior. The software also utilizes (Rothermel, 1991; Van Wagner, 1977) methods to propagate crown fire modeling. Rothermel (1983) equations are also used to estimate the dead fuel moisture. The fire behavior processing steps are shown in Figure 11, including input data collation and processing and the estimation of fire behavior outputs used to derive the fire risk.

[13] Please visit www.WildfireAnalyst.com for more information.

Figure 11. Fire behavior processing steps.



4.2 Input Data

Fuels and Landscape Data

An up-to-date surface fuel dataset at 20-meter (m) resolution was developed for this project, based on Scott and Burgan (2005) fuel models, enhanced with custom fuels created by Technosylva. The custom fuels distinguish this assessment from previous ones performed in Colorado as they allow a better characterization of fire behavior across the landscape. Additionally, the urban and road custom fuel models included in the assessment are key for better characterizing the exposure, vulnerability and risk of both buildings and population in the Wildland Urban Interface (WUI). This also allows for better modeling of fire encroachment in urban areas considering the building density, community structure and fuels surrounding the buildings and urban areas.

The following custom fuels were included in order to improve the fire modeling in timber, WUI and agricultural areas:

- Timber: 2 new categories (171 and 191)
- Urban: 7 new categories (911,912,913,914,915,916 and 919)
- Roads: 5 new categories (941,942,943,944 and 949)
- Agriculture: 4 new categories (931,932,938 and 939)
- Water: 3 new categories (981,982 and 989)

Additionally, we also considered canopy fuel data to better simulate crown fire behavior. This includes:

- canopy bulk density (CBD),
- canopy base height (CBH),
- canopy cover (CC) and
- canopy height (CH).

The updated fuel dataset also considered the effects of natural disturbances on vegetation (fires, insect and disease, and harvesting/fuel treatments) that occurred in Colorado from 2013 to 2022. More information about the methods used can be found in the CSFS 2022 Fuels Mapping Final Report.[14]

Weather Data

Weather data (1979-2022) from gridMET was used to analyze potential weather scenarios in which assessing fire behavior and spread. gridMET is a dataset of daily high-spatial resolution (~4-km, 1/24th degree) surface meteorological data covering the contiguous US. Air temperature data at 2m, relative humidity at 2m, and wind speed and direction at 10 m were all downloaded and used.[15]

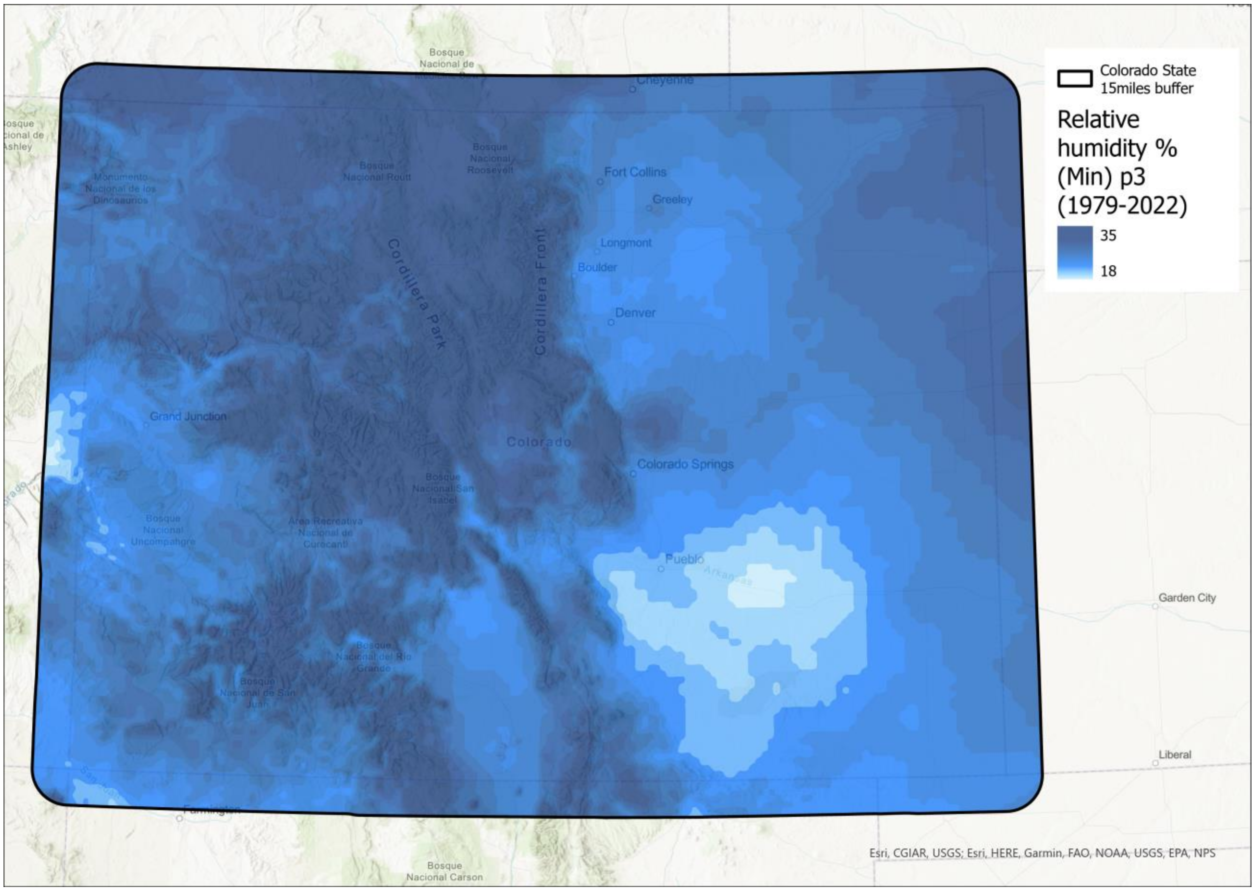
After computing the weather percentiles of the gridMET variables, data was interpolated using IDW algorithms (Inverse Distance Weighting) at 20-meter pixel resolution (see examples for temperature and air relative humidity).

Figure 12. Interpolated 2m-air relative humidity at 20 m pixel resolution (%) from gridMET weather data for the extreme weather scenario (3rd percentile) in a 40-year period (1979-2022).

[14] Colorado Fuels Mapping Final Report. Technosylva, June 2022. Available from the Colorado State Forest Service.

[2] NCEP Reanalysis data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their web site at https://www.esrl.noaa.gov/psd/

[15] https://www.climatologylab.org/gridmet.html

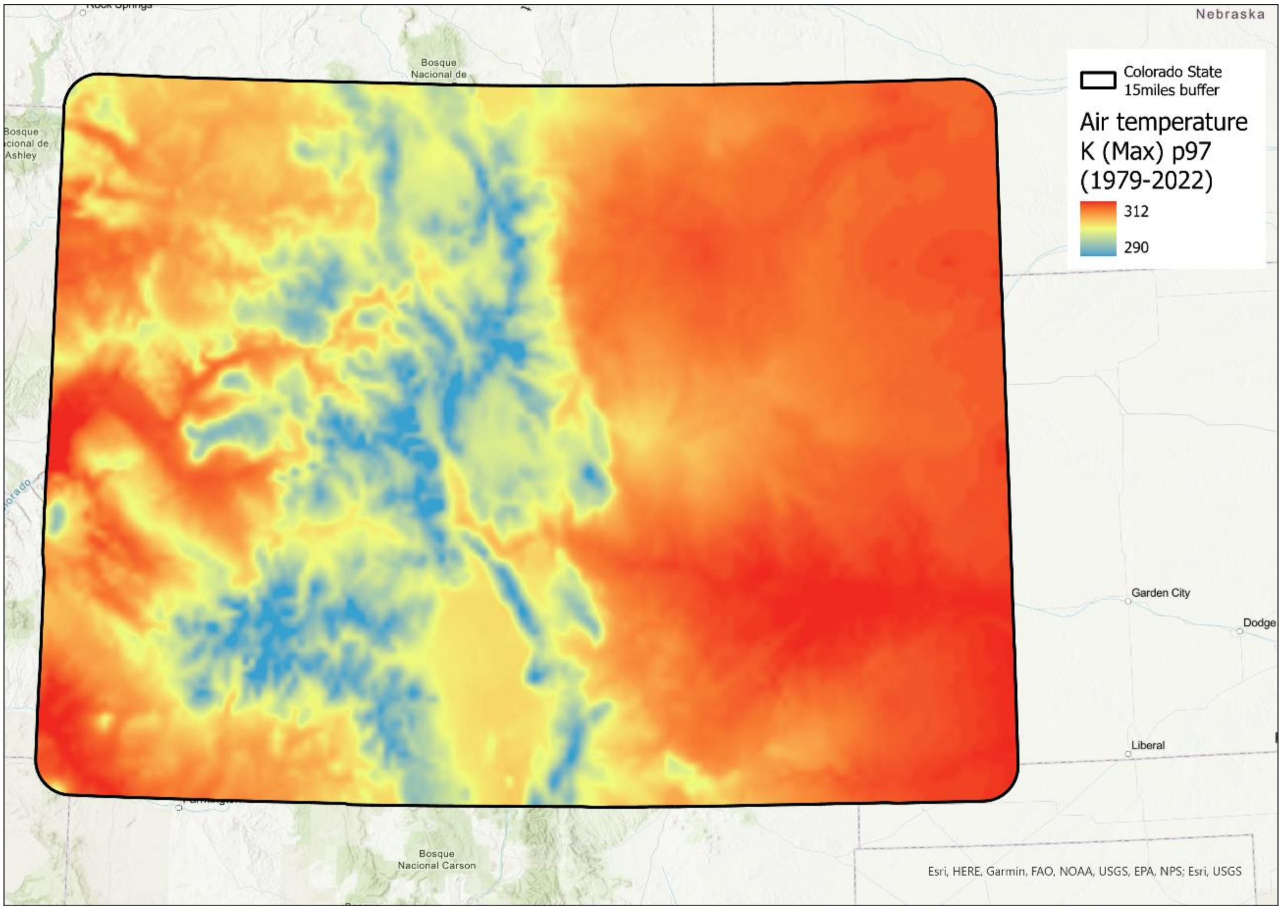


Dead fuel moisture content was estimated using the model of Rothermel and Rinehart (1983). Both temperature and air relative humidity at 2m from gridMET was used to define the fuel moisture model. The model also considered elevation and aspect to take into account the accumulated solar radiation at 14h (local time). 1% and 2% were added to the 1h-dead fuel moisture content to estimate 10h and 100h dead fuel moisture content, respectively.

For the first time in CO-WRA risk assessments, both herbaceous and woody live fuel moisture content was modelled using Technosylva's proprietary models based on optical imagery, drought indices and phenology. The models were trained with the WFAS National live fuel moisture content. Foliar moisture content in the canopies was considered as a constant value (80%) across the entire state.[16]

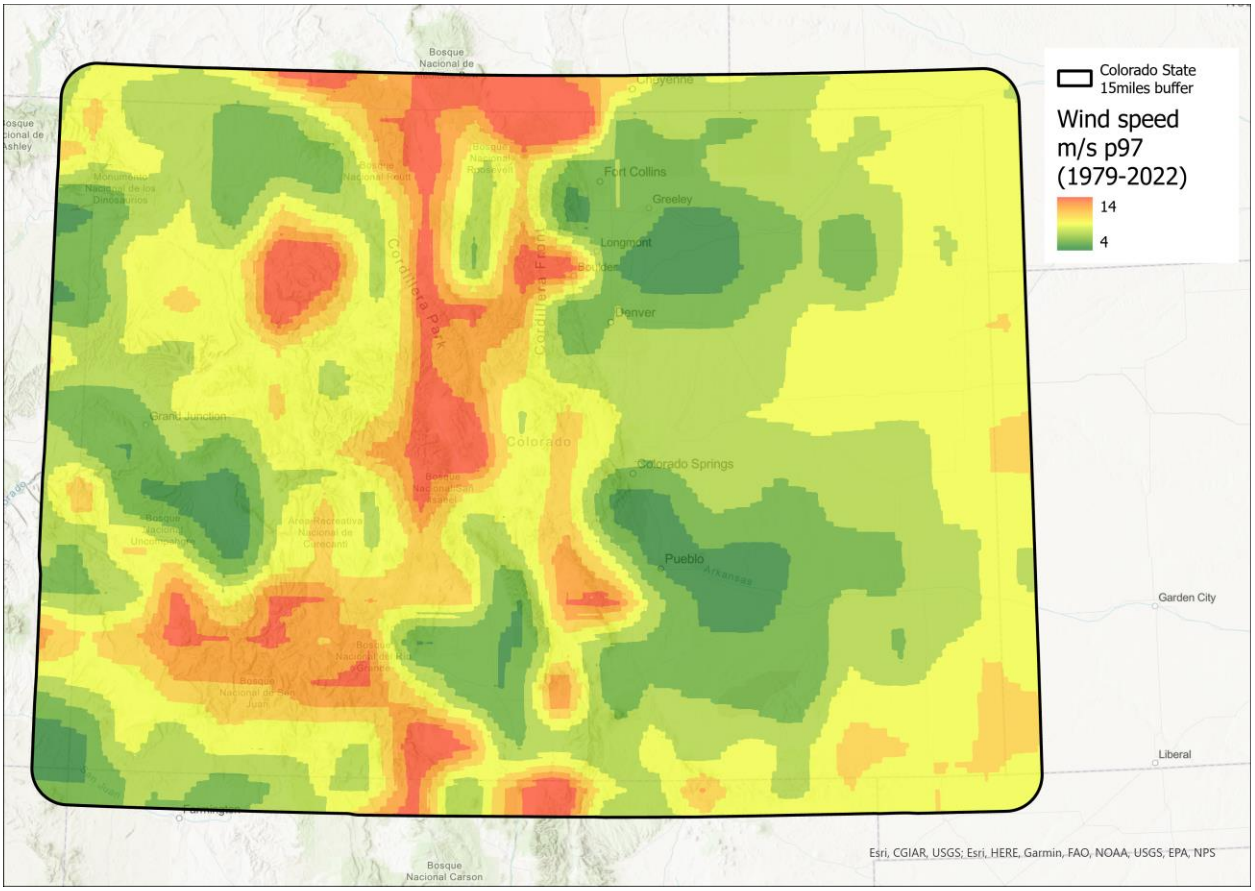
Figure 13. Interpolated 2m-temperature at 30 m pixel resolution (ºC) from gridMET weather data for the extreme weather scenario (97th percentile) in a 40-year period (1979-2022).

[16] Technosylva's proprietary LFM and DFM models are offered as data subscription services to agency and electric utility customers. The models have been calibrated across the Western US over the past four years and validated in daily fire behavior and risk forecasting production.



Wind speed at 10 m (Figure 14) was estimated at 20 ft applying a wind adjustment factor to use 20-ft wind speed in the fire spread and behavior equations. Afterward, wind speed percentiles were computed to use these data in the FB analysis at 20-meter pixel resolution. Wind direction for Colorado was analyzed for a 40-year period (1979-2022) considering the calculated wind speed percentiles from gridMET data. The predominant wind direction is from SW to NE, especially when wind speed is high or very high.

Figure 14. Interpolated 10m wind speed (mi/h) at 20 m pixel resolution (%) from gridMET weather data for the extreme weather scenario (97th percentile) in a 40-year period (1979-2022).



4.3 Historical Fire Occurrence

Historical fire occurrence was used as an input variable to produce the Burn Probability output as well as analysing FB outputs. Fire Occurrence is an ignition density that represents the likelihood of a wildfire starting based on historical ignition patterns. Occurrence is derived by modeling historic wildfire ignition locations to create an ignition density map. Historic fire report data were used to create the ignition points for all Colorado fires. These included both federal and non-federal fire ignition locations.

Federal and non-federal wildfire ignitions data for Colorado were compiled for the period 1992-2020. The primary source for these data was the dataset compiled by the USFS Fire Sciences Laboratory (Karen Short). Wildfire ignitions are spatially referenced by latitude and longitude coordinates. Note that fire ignition data is underreported in many rural areas of the state, where the responsibility lies with local jurisdictions. Reference info can be found at https://www.fs.usda.gov/rds/archive/catalog/RDS-2013-0009.6.

A 20-meter ignition density grid was derived using a Kernel function from the combined federal and non-federal point ignition data. Figure 15 shows the spatial distribution of the total number of fires for Colorado. Figure 16 shows the occurrence density map derived from the point ignition data.

Figure 15. Historical ignitions for 1992 - 2020.

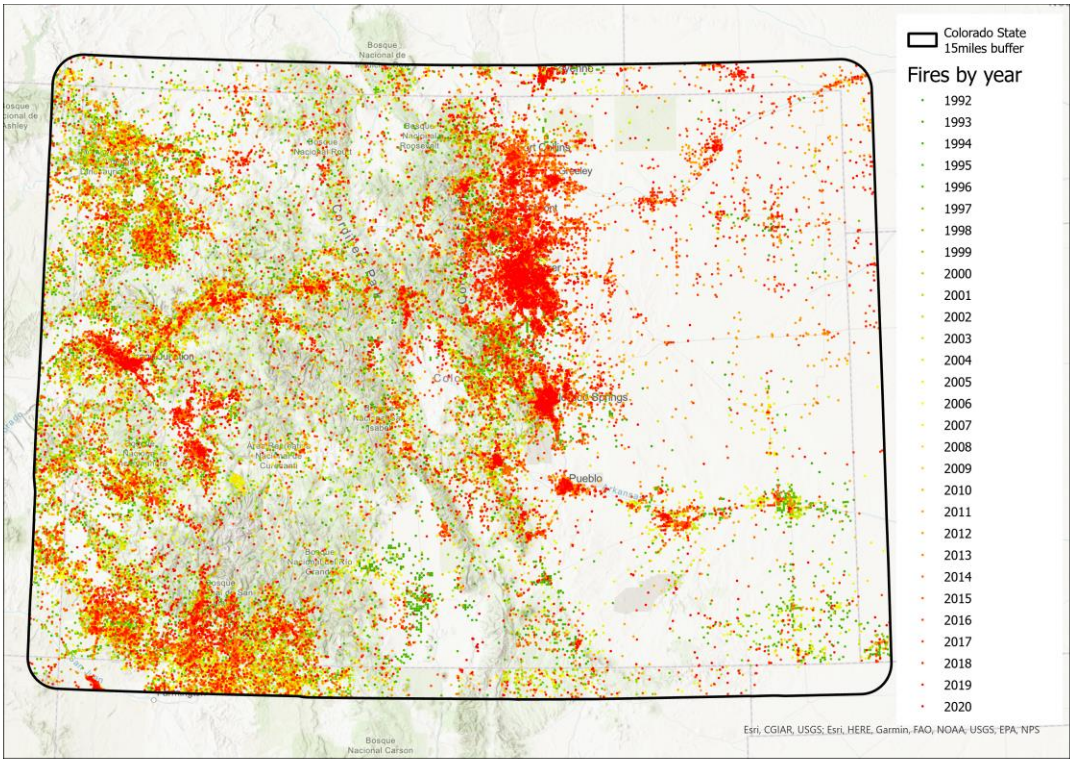
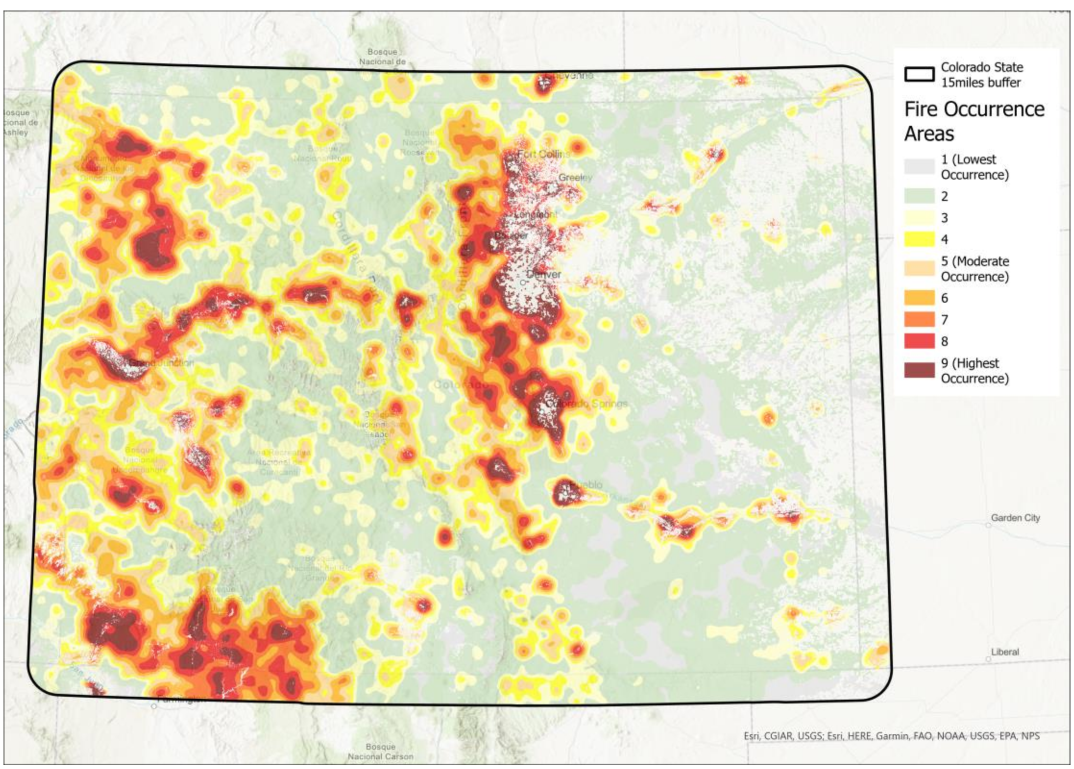


Figure 16. Fire occurrence density for 1992 - 2020.



4.4 Fire Behavior Modelling

A static fire simulation approach was used to model potential maximum fire behavior (FB) in terms of rate of spread (ROS), flame length (FL), fireline intensity (FLI) and Fire Type (surface, passive, torching or active) at 20m pixel resolution for the entire state under an extreme weather scenario (percentile 97th). Areas of non-burnable fuels were excluded from the analysis.

Static fire behavior outputs were calculated using Technosylva's Wildfire Analyst™ software using the following input datasets:

1. Elevation
2. Slope
3. Aspect
4. Temperature and Relative humidity to derive 1h dead fuel moisture content
5. Live and fuel moisture content (1h, 10h, 100h, herbaceous, woody, foliar moisture in the canopies)
6. Wind speed and direction
7. Fuels (surface and canopy characteristics).

Fire behavior outputs were calculated with true floating-point values for the 20-meter cell resolution dataset. However, standard classes are used to depict the data for viewing and response function modeling in CO-WRA. Please refer to Appendix B for a description of all data layers including the classification used for display of data.

The following three figures present examples of the Flame Length, Fire Type (Canopy Fire Potential), and Rate of Spread for Colorado.

Figure 17. Statewide map of Flame Length.

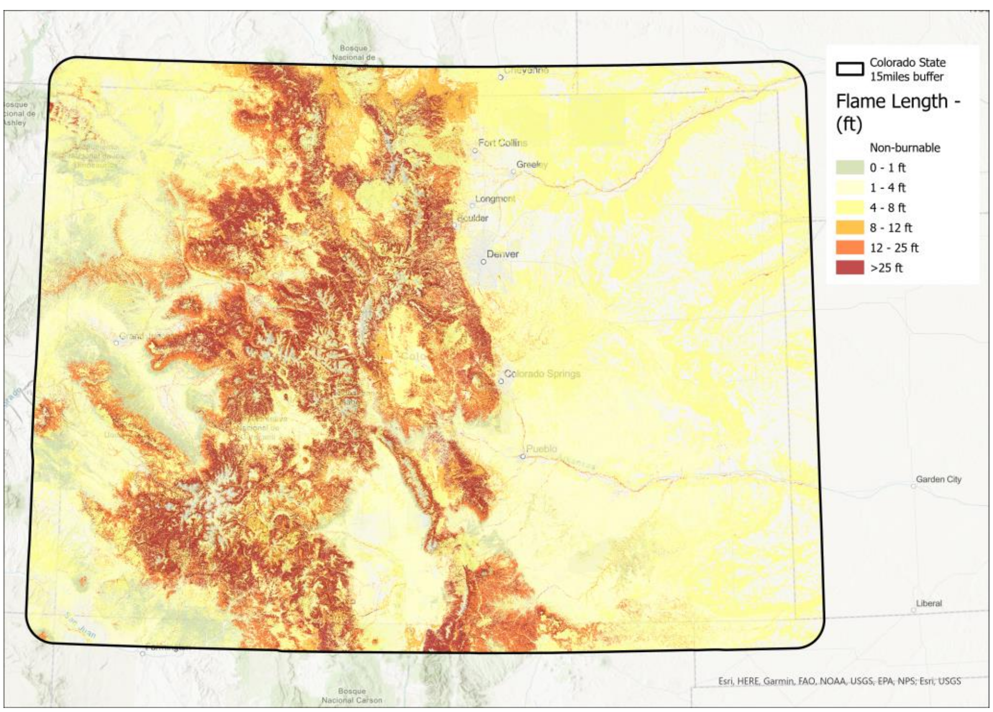


Figure 18. Statewide map of Fire Type.

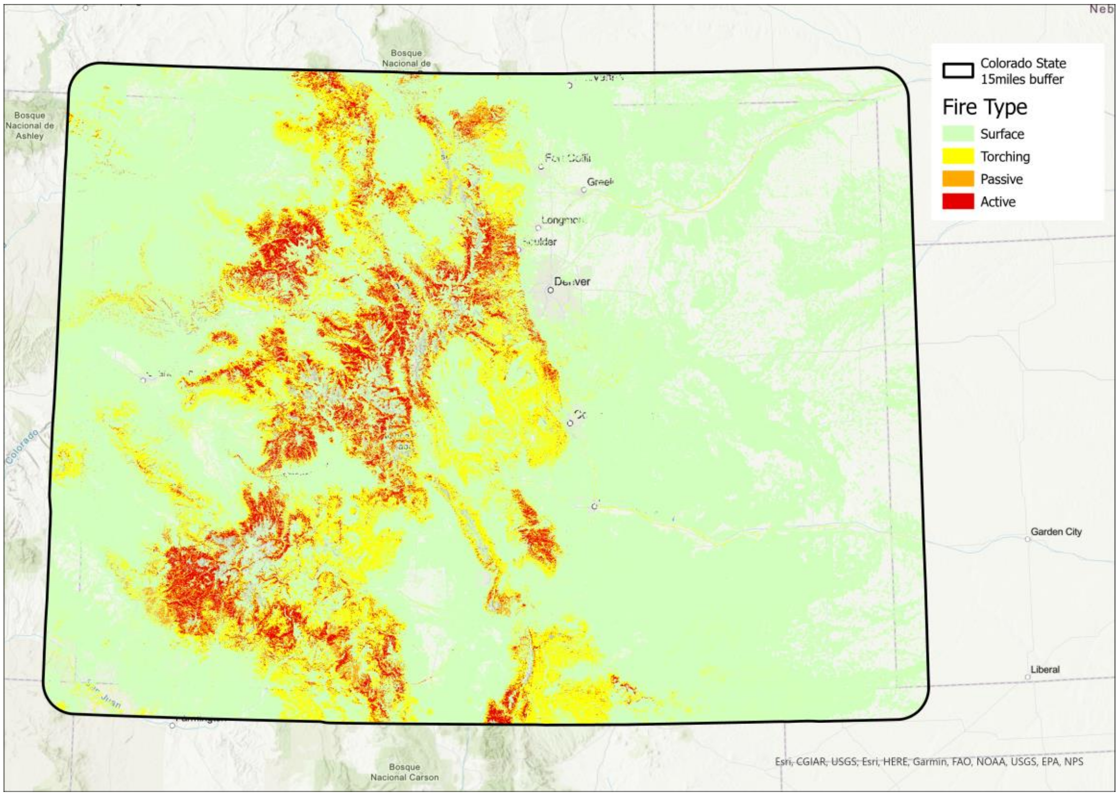


Figure 19. Statewide map of Rate of Spread (ROS).

4.5 Burn Probability

A dynamic fire simulation approach was used to estimate annual burn probability (BP), and conditional flame length (CFL) for the State at 20m pixel resolution. The BP output represents the probability that a fire will burn a given 20m cell in a year. However, it does not represent the fire recurrence due to fires as fires are not independent and they also modify fuels across the landscape. Wildfire analyst considered six standard fire intensity levels (FILs) in terms of flame length to calculate flame length probabilities and conditional flame length:

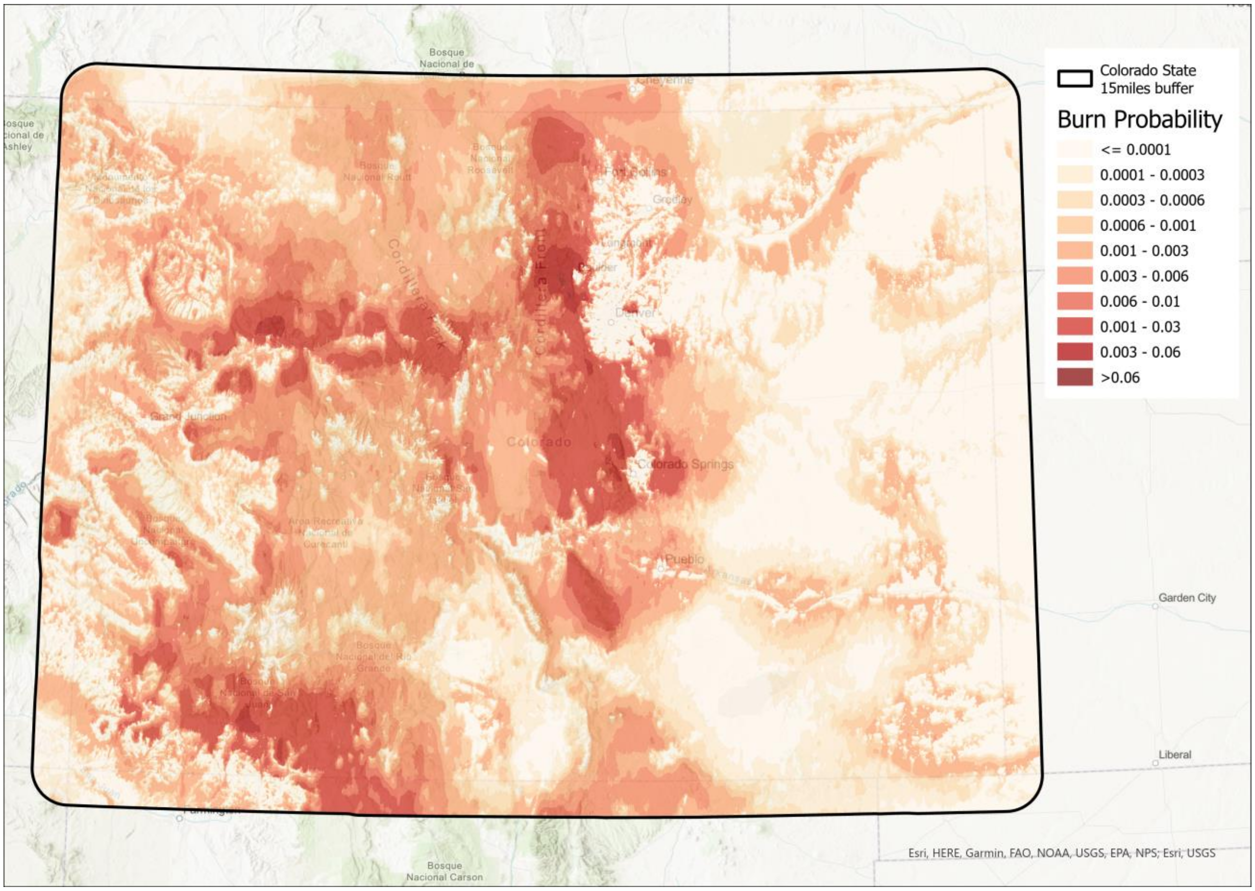
- FLP0 (0-2ft)
- FLP1 (2-4ft)
- FLP2 (4-6ft)
- FLP3 (6-8ft)
- FLP4 (8-12ft)
- FLP5 (>12 ft).

The FLP layers represent the probability distribution among the FILs given that several (n) fires burned that pixel. The FLP values at a pixel sum to 1. Conditional wildfire intensity is the average intensity of the n simulated wildfires that burned the pixel; it considers the input data variability (especially, weather data) on fire behavior and incorporates the effects of relative spread direction (heading, flanking, backing, etc.). As expected, the number of times that the fires burned each cell was different and the variable provides an average wildfire intensity for the n fires that reached each cell. Particularly, we assessed conditional flame length (CFL) as an estimator of the mean flame length (FL) of the n iterations that burned the pixel based on the equation of Scott et al (2013) as the sum-product of FLPs and flame length across all of the FILs.

The annual BP was calculated as the number of times that a cell resulted burned and the number of iterations used to run the models. The annual BP was estimated for the entire State by using a stochastic (Monte Carlo) wildfire simulation approach, which simulated more than 3 million fires with a mean ignition density of 10 fires/km2. The ignition points were spatially distributed by considering the historical fire occurrence for Colorado (1992-2020) through a density map created by a Kernel function. Note that after simulating all the fires, some cells were not burned by any simulated fire, resulting in a BP value of zero. Some cells were non-burnable due to the associated fuel type (water, roads, urban, agricultural areas, etc.). However, we assigned the lower BP value in those “burnable” cells that the simulated fires did not reach.

Note that the ignition pattern we used considered the historical fire occurrence. Again, ignitions in rural areas are underreported, and this does impact the conditional burn probability model. Enhancements were also undertaken in our fuel family to ensure the encroachment and spread of fire simulations across natural firebreaks, such as roads. The following figure presents the Burn Probability map for Colorado.

Figure 20. Burn Probability for Colorado.



Analysis of the Burn Probability in Pinyon Juniper Areas

Special consideration was provided to areas of Pinyon Juniper across the State leveraging the local knowledge and expertise of CSFS staff. The expected ROS in Pinyon Juniper (PJ) areas is generally low and, subsequently, the BP is expected to have low values. This is reflected in our outputs since the fire spread on these areas is usually difficult. This fact does not mean that a large wildfire could not occur. However, extreme weather conditions (dry fuels and very high wind speeds) are needed to boost fire behavior and spread.

An analysis of the fire history in this ecosystem was also conducted. The results showed numerous ignitions in PJ areas in the 1992-2020 period as shown in the following figures but most of the fires were very small (less than 1 acre). This represents the difficulty of fires to spread in PJ areas as all FB outputs showed for the whole Colorado.

Figure 21. Fuel models (purple is TL3, PJ areas), burn probability and fire activity from 1992 to 2020 in a region of Colorado.

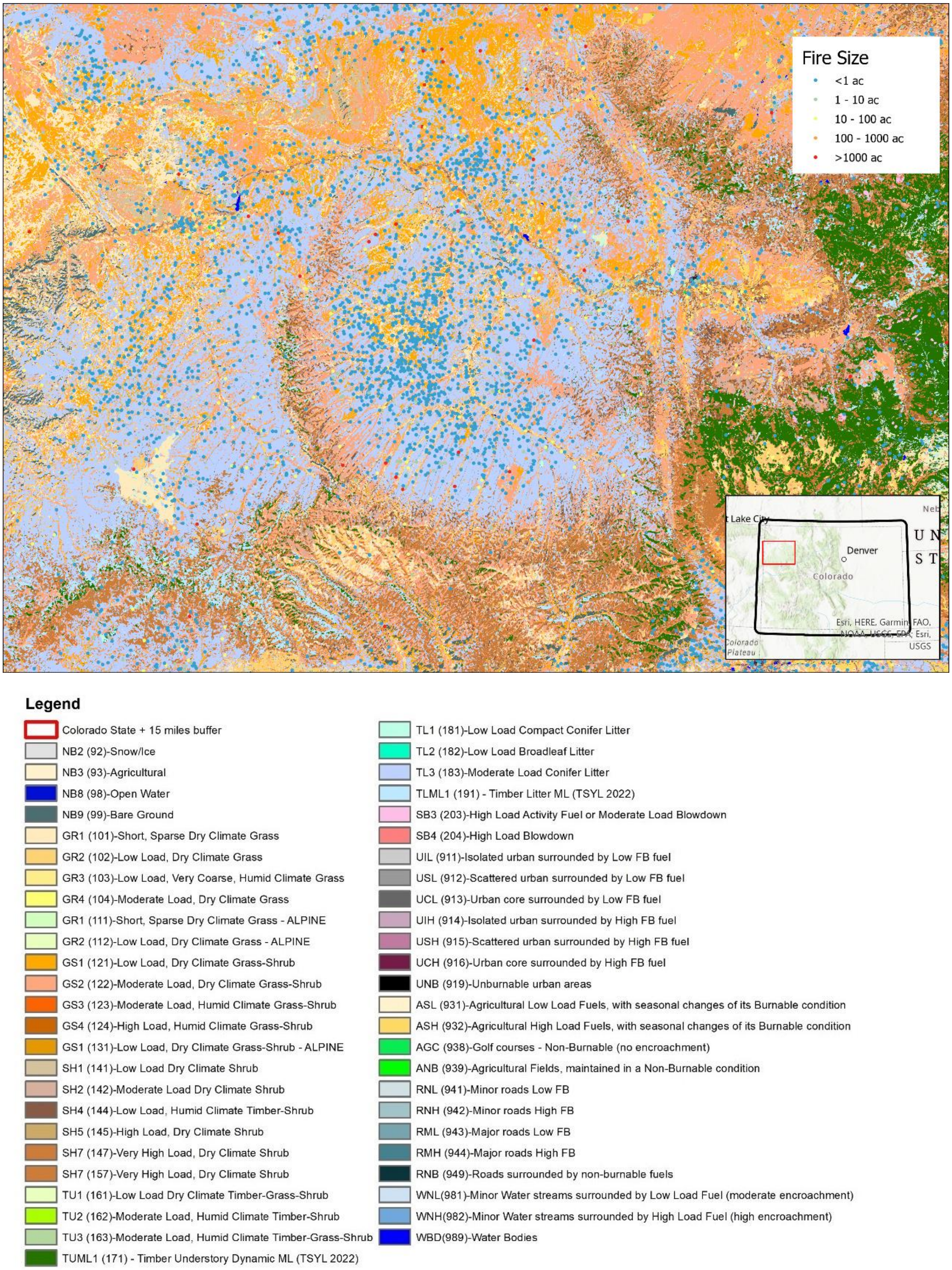
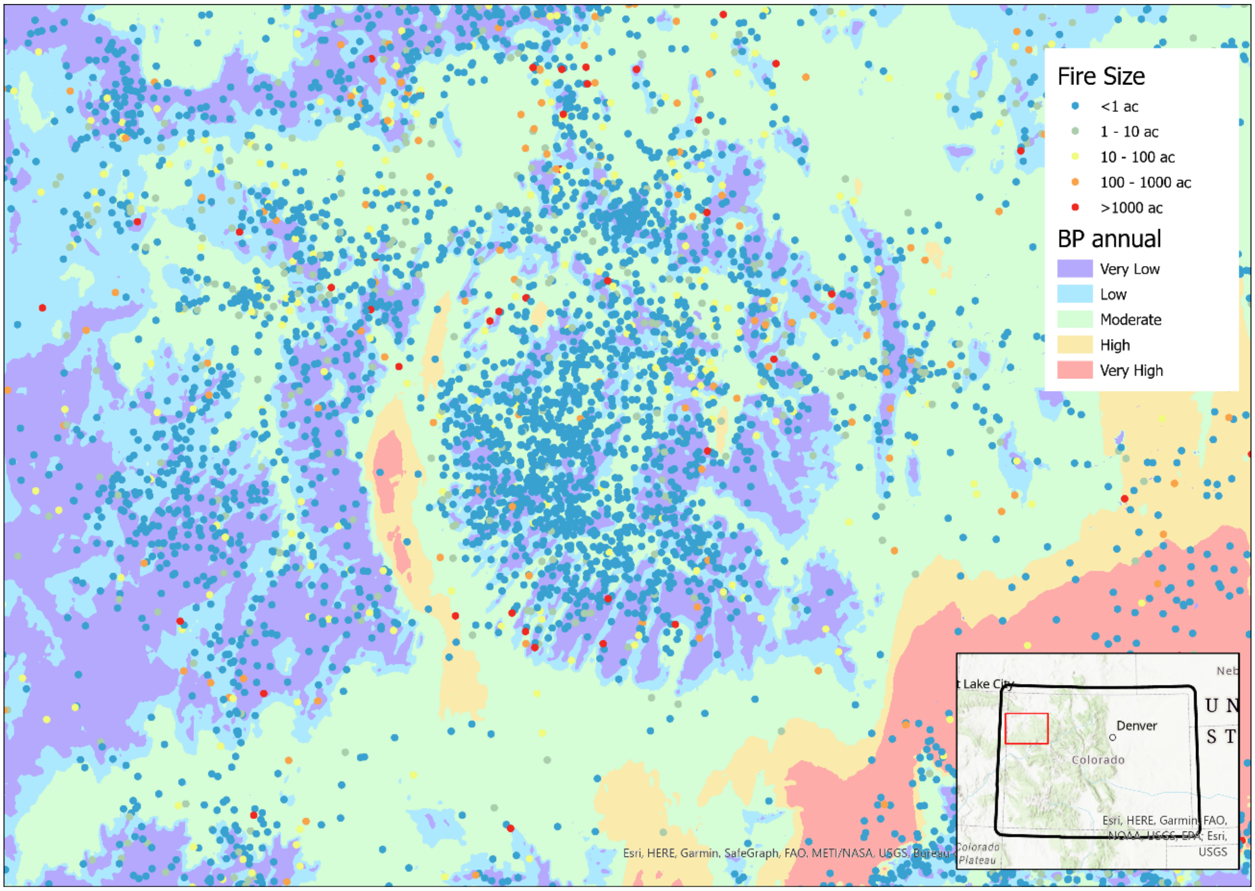


Figure 22. Burn Probability and fire activity from 1992 to 2020 overlaid for a small area in Colorado demonstrates the alignment of fire size with BP.



Quality Assurance of Fire Behavior Outputs

A considerable effort was undertaken by project team staff in reviewing and quality assuring the accuracy of the fire behavior outputs. The 2022 CO-WRA involved a change in surface fuels data in addition to weather data, resulting in enhancements to the accuracy and quality of the key input datasets. This resulted in differences compared to the 2017 CO-WRA fire behavior outputs. CSFS staff were instrumental in reviewing the fuels and resulting fire behavior outputs, including reviewing and validating data with local area staff across the State to obtain local knowledge and expertise. In addition, federal agency staff were involved in the review of the data.

To ensure these results were accurate and realistic, a number of testing protocols were implemented. These included visual inspection using imagery data, use of fire behavior calculators, field inspection, subject matter expert review, and comparison analysis with 2017 outputs.

5. RISK OUTPUT CALCULATIONS AND DEVELOPMENT

This section provides a description of the technical approach used to calculate the risk outputs.

5.1 Description of the Response Function Methods

Overview of Response Functions

The primary underpinning of the CO-WRA is based on the use of “response functions”. Response Functions are a method of assigning a rating of net change to a resource value or asset based on susceptibility to fire intensity. These impacts can be negative or positive. For the CO-WRA only adverse effects are being considered at this time, although the response methods approach has been designed to accommodate positive effects in the future if desired.

Calculating risk at a given location requires spatially defined estimates of the likelihood and intensity of fire integrated with the identified *resource/asset value*. This interaction is quantified through the use of *response functions* that estimate expected benefits and losses to values/assets at the specified fire intensities. The measure of fire intensity used in the CO-WRA is Flame Length. Specific classes of Flame Length have been defined that reflect key thresholds for damage from wildfire to the resource values.

For the CO-WRA, response functions are defined for each category of the resource value inputs, for each given flame length category. Flame length categories were defined by the fire experts on the CO-WRA team and reflect key thresholds for rating impacts. Positive response functions indicate a benefit or increase in value to the resource; negative response function values indicate a loss in resource value.

The CO-WRA response functions use a value range of +9 to -9. This 1 to 9 range is typical for suitability modeling and provides consistency with other natural resource modeling methods. With this scale, a value of 0 represents no measurable impact; -1 the least negative impact, ramping to a -9 where the worst possible impact or loss occurs. An example *response function value matrix* for the WUI resource value is presented in the following table. The response function outputs were combined into five qualitative classes.

This WUI example assumes that the higher the flame length the worse the impact on people and their homes. This could also be interpreted as the higher the value the more susceptible to wildfire. Areas with high population/structure density would result in more people/homes impacted while areas with low density would result in less people/homes impacted. The user defined response function value (-1 to -9) would only be applied to areas where the WUI and Flame Length overlap and both occur in the same area. Areas that do not have a Flame Length or WUI value are not assigned a RF value. Note that standard flame length classes are used based on commonly understood ranges where impacts may differ.

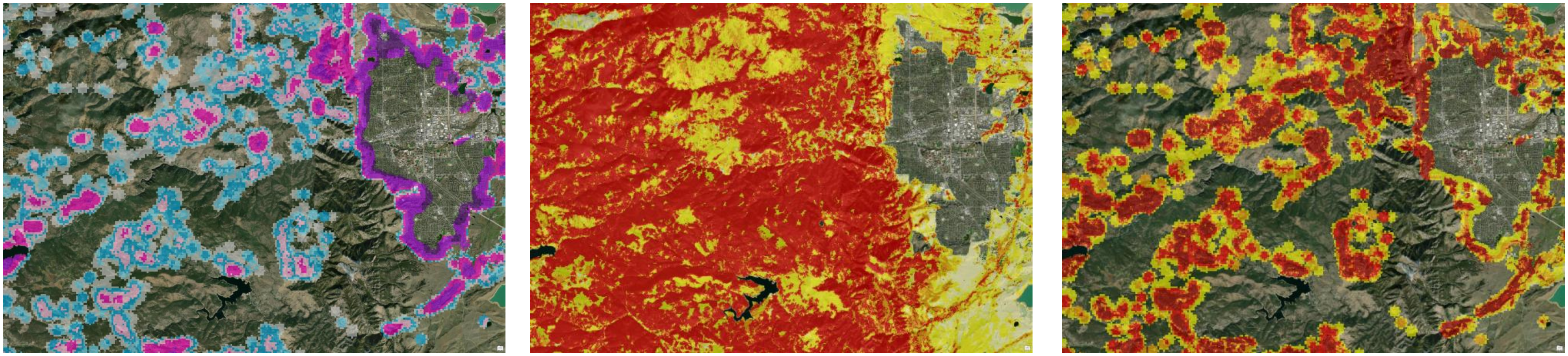
Table 6. Example RF Value Assignments for WUI

Flame Length	LT 1 house /40 ac	1 house/ 40 - 20 ac	1 house/ 20 - 10 ac	1 house/ 10 - 5 ac	1 house/ 5 - 2 ac	1 - 3 houses/ac	GT 3 houses/ac
	Wildland Urban Interface (housing density)						
0-2 ft	-0.5	-0.8	-1.0	-1.4	-1.7	-2.0	-2.0
2-4 ft	-1.0	-1.6	-2.0	-2.8	-3.4	-4.0	-4.0
4-6 ft	-1.25	-2.0	-2.5	-3.5	-4.25	-5.0	-5.0
6-8 ft	-1.75	-2.8	-3.5	-4.9	-5.95	-7.0	-7.0
8-12 ft	-2.0	-3.2	-4.0	-5.6	-6.8	-8.0	-9.0
12+ ft	-2.25	-3.6	-4.5	-6.3	-7.65	-9.0	-9.0

Using the response function matrices, GIS data of flame length and the resource value (WUI in the example above) can be combined to derive an output that reflects those areas where the least or most impact/susceptibility exists. The following figure presents an example response function value (RFV) output using the matrix shown in the table example for WUI.

The map on the left shows the WUI areas presented as housing density. The map in the center is the Flame Length. The map on the right is the RF output that represents an overlay of the two inputs with the RF values in the table above applied to each cell. This is referred to as WUI Risk. Note that these examples are presented with an urban encroachment algorithm that incorporates non-burnable WUI areas for urban fringe areas.

Figure 23. Response Function example showing Wildland Urban Interface, Flame Length and WUI Risk Index output.



WUI | Flame Length | WUI Risk

Fire Intensity Classes

Response functions represent mathematical relationships between fire characteristics (intensity) and fire outcome. Although fire outcomes could be related to any fire characteristic, response is typically related to some measure of fire intensity, e.g., flame length (Ager and others 2007; Finney 2005). Accordingly, the CO-WRA uses response functions that correspond to the following flame length classes:

- Low = 0 to 2 ft,
- Low to Moderate = greater than 2 to 4 ft,
- Moderate = greater than 4 to 6 ft,
- Moderate to High = greater than 6 to 8 ft,
- High = greater than 8 to 12 ft, and
- Very High = greater than 12 ft.

In detailed risk analyses conducted at smaller scales it is possible for outcomes to be expressed as absolute benefits and losses, such as people, structures or even dollars. However, such detail is not practical in this scale of statewide assessment. Rather than developing response functions that directly address absolute change in resource or asset value, the CO-WRA relies on generalized, relative response functions that can be applied to any number of resources values or assets.

Response Function Assignments

Response functions were assigned for each class in the four HVRA layers:

- Wildland Urban Interface
- Watershed Protection Areas
- Forest Assets
- Riparian Assets

The following table presents a summary of all HVRA response function assignments used in the CO-WRA project. The table includes:

- List of HVRAs
- HVRA data classes for which RF were assigned. Color coding is shown for the HVRA data classes.
- The RF assignments (values) for each fire intensity level (Flame Length 1 through 6). RF values are shaded using a green (0.00) to red (-9.00) scheme to aid in visualizing the transition for different HVRA classes.

Table 7. CO-WRA HVRA response functional assignments.

2022 Colorado Wildfire Risk Assessment HVRA Response Function Assignments												
Flame Length Probability Class							Flame Length Probability Class					
							0	1	2	3	4	5
							0-2	2-4	4-6	6-8	8-12	12+
						Category						
Wildland Urban Interface (houses per acre)					1	Less than 1 house/40 ac	-0.40	-0.60	-1.00	-1.40	-1.80	-1.80
					2	1 house/40-20 ac	-0.80	-1.20	-2.00	-2.80	-3.60	-3.60
					3	1 house/20-10 ac	-1.20	-1.80	-3.00	-4.20	-5.40	-5.40
					4	1 house/10-5 ac	-1.50	-2.25	-3.75	-5.25	-7.10	-7.10
					5	1 house/5 - 2 ac	-1.90	-2.85	-4.75	-6.65	-7.90	-8.55
					6	1 - 3 houses/ac	-2.00	-3.00	-5.00	-7.10	-9.00	-9.00
					7	More than 3 houses/ac	-2.00	-5.00	-7.00	-8.00	-9.00	-9.00
FAP Watershed Protection Values				*From*	*To*							
Watershed Protection (level of importance)				*0*	*5*	1 - Lowest Importance	-0.05	-0.10	-0.25	-2.00	-2.00	-2.00
				6	*16*	2	-0.10	-0.20	-0.50	-2.50	-3.00	-3.00
				17	*27*	3	-0.20	-0.40	-1.00	-3.50	-4.00	-4.00
				28	*38*	4	-0.40	-0.80	-2.00	-4.50	-5.00	-5.00
				39	*49*	5	-0.80	-1.60	-3.00	-5.50	-6.00	-6.00
				50	*61*	6	-1.00	-2.00	-4.00	-6.50	-7.00	-7.00
				62	*72*	7	-2.00	-3.00	-5.00	-7.50	-8.00	-8.00
				73	*83*	8	-3.00	-4.00	-6.00	-8.00	-9.00	-9.00
				84	*94*	9	-4.00	-5.00	-7.00	-8.50	-9.00	-9.00
				96	*100*	10 - Highest Importance	-5.00	-6.00	-8.00	-9.00	-9.00	-9.00
Forest Assets	Sensitive	Closed	0-10 m	77		1	-2.00	-3.00	-4.00	-5.00	-9.00	-9.00
	Sensitive	Closed	10+m	77		2	-1.60	-2.40	-3.20	-4.00	-7.20	-7.20
	Sensitive	Open/Sp	0-10 m	34		3	-0.88	-1.32	-1.77	-2.21	-3.97	-3.97
	Sensitive	Open/Sp	10+m	34		4	-0.71	-1.06	-1.41	-1.77	-3.18	-3.18
	Resilient	Closed	0-10 m	78		5	0.00	0.00	-2.00	-3.00	-5.00	-5.00
	Resilient	Closed	10+m	78		6	0.00	0.00	-0.60	-0.90	-1.50	-1.50
	Resilient	Open/Sp	0-10 m	35		7	0.00	0.00	-0.90	-1.35	-2.24	-2.24
	Resilient	Open/Sp	10+m	35		8	0.00	0.00	-0.27	-0.40	-0.67	-0.67
	Adaptive	Closed	0-10 m	78		9	0.00	-1.00	-3.00	-4.00	-7.00	-7.00
	Adaptive	Closed	10+m	78		10	0.00	-0.50	-1.50	-2.00	-3.50	-3.50
	Adaptive	Open/Sp	0-10 m	36		11	0.00	-0.46	-1.38	-1.85	-3.23	-3.23
	Adaptive	Open/Sp	10+m	36		12	0.00	-0.23	-0.69	-0.92	-1.62	-1.62
Riparian Assets (importance & sensitivity to fire)						1 - Lowest importance	0.00	0.00	-0.50	-1.00	-1.75	-1.75
						2 - Moderate Importance	0.00	0.00	-1.00	-2.00	-3.50	-3.50
						3 - Highest Importance	0.00	0.00	-2.00	-4.00	-7.00	-7.00

Values At Risk Rating & Relative Importance Weightings

Once all four HVRA characteristic outputs were generated, they were combined using a weighted average to derive the overall composite Values at Risk Rating. Using relative importance weightings allows for the combination of multiple HVRAs into a single overall risk metric. Without relative importance, it is difficult to characterize risk in areas where multiple HVRAs overlap. How does one compare risks across different spatial areas that contain different HVRAs?

Using relative importance scores helps to address this question and allows for summarization and visualization of risks in a single metric. If assessment results are to ultimately be used for planning mitigation treatments and strategies, then prioritization decisions that integrate all HVRAs will still ultimately need to be made. Articulating relative importance scores and how objectives are balanced makes this decision explicit rather than implicit and increases the overall transparency of decision processes.

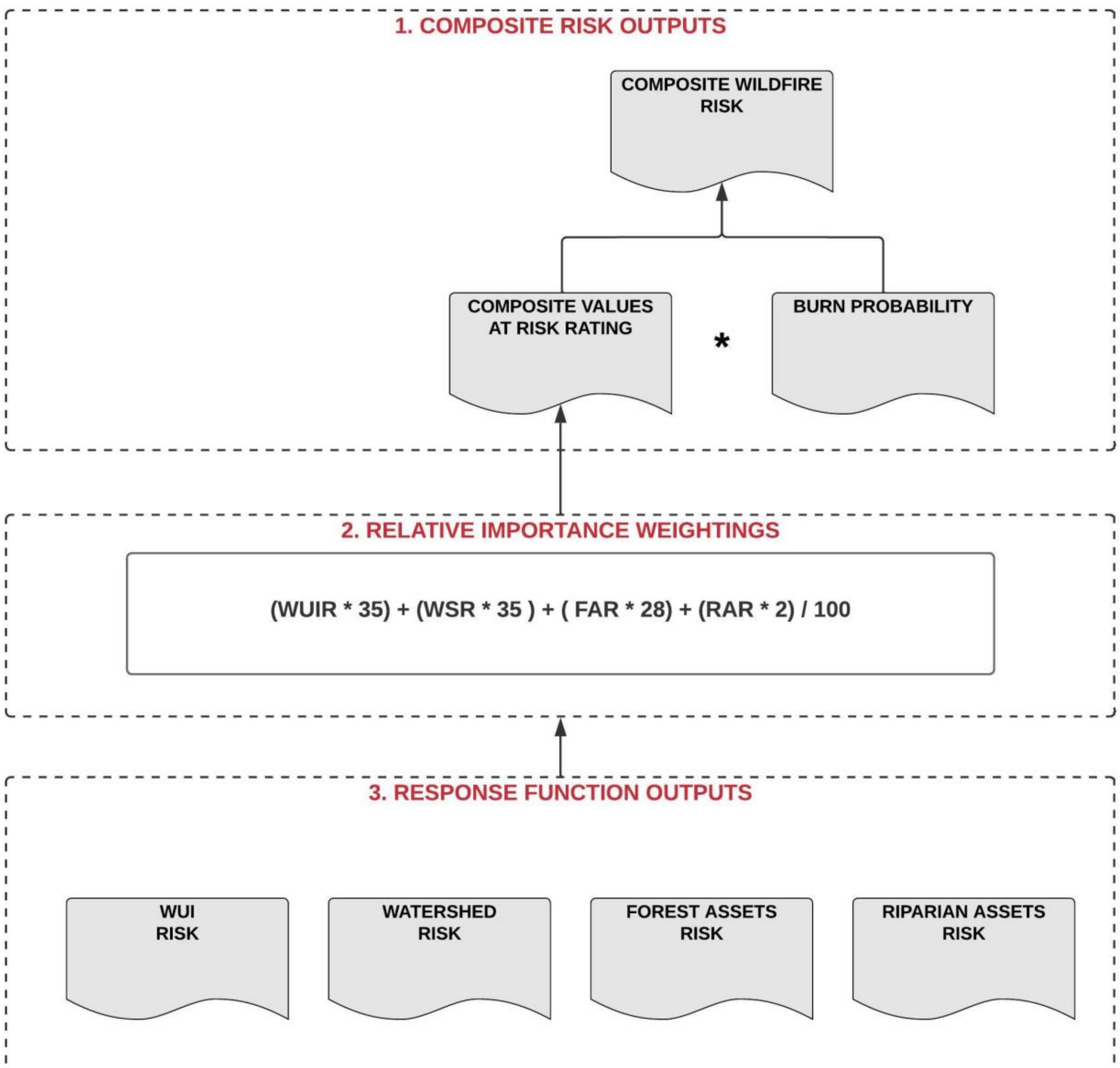
The following table presents the weights used for the Values at Risk Rating (VAR) output. These relative importance weightings were defined by a team of experts within CSFS reflecting the resource and asset priorities and conditions in Colorado.

Table 8. Colorado adjusted Values at Risk Rating weights for 2022 CO-WRA

VAR Input Layer	Relative Importance Weights
WUI	**35%**
Watershed	**35%**
Forest Assets	**28%**
Riparian Assets	**2%**

The following figure demonstrates this combination using the weightings discussed above, in addition to the combination of the Values at Risk Rating with the Burn Probability to derive the final composite Wildfire Risk to Assets output.

Figure 24. Combining risk layers with relative importance weightings to create risk outputs.

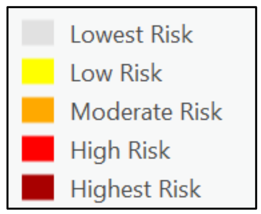


5.2 Classification of Map Outputs

Classification of Response Function Outputs

The RFV outputs are calculated as floating points values matching the actual RF assignment values. For the data to be easily interpreted it was decided that RFV outputs would be reclassified into standard integer classes using the standard RF values from -1 to -9. The response function outputs were combined into five qualitative classes. With this approach the output classes adhere to the RF value assignments defined by CSFS and provide for easy interpretation by the users of the CO-WRA. Accordingly, the following class breaks and symbology were used for all RFV outputs.

Figure 25. CO-WRA Response Function output legend.



These class breaks and color symbology is used for the following outputs:

- WUI Risk Index
- Watershed Risk Index
- Forest Assets Risk Index
- Riparian Assets Risk Index
- Values-At-Risk Rating

Class Breaks for Wildfire Risk to Assets Output

The Fire Occurrence output is a floating-point density raster dataset that was derived by modeling fire ignition point locations using GIS-based kernel functions. Similarly, the Wildfire Risk to Assets output is also a floating-point raster dataset that was derived by combining the Burn Probability and the Values at Risk Rating datasets. Given the large number of unique cell values, it is necessary to group these values into classes.

For the CO-WRA it was decided to utilize a standard approach that determines class breaks based on the cumulative percentile values of total area for each class. Nine categories were chosen. Data values for the entire state were used as inputs to determine the class breaks. This approach is commonly used in risk assessment and was also applied in the West Wide Risk Assessment and the Southern Wildfire Risk Assessment projects.

By design, the categories were developed to display the highest rated 10.6% of the cells in categories 6-9. The highest rated 16% of the cells are in categories 5-9. This places the highest rated cells (areas) into just about half of the categories (5-9) which allows the user to truly locate and distinguish the differences within these highly rated cells (areas). In this regard, Category 9 represents the top 1.1% of the area in Colorado. The following table presents the percent area break points that were used.

Table 9. Cumulative percentiles used for class breaks

Category	% Range	Cumulative % of Area	Categorical % of Area
1	0 – 41.0%	41.0%	**41%**
2	41.1 – 58.8%	58.8%	**17.8%**
3	58.9 – 68.7%	68.7%	**9.9%**
4	68.8 – 84%	84%	**15.3%**
5	84.1 – 89.4%	89.4%	**5.4%**
6	89.5 – 94.8%	94.8%	**5.4%**
7	94.9 – 97.6%	97.6%	**2.8%**
8	97.7 – 98.8%	98.8%	**1.3%**
9	98.9 - 100.0%	100.0%	**1.1%**

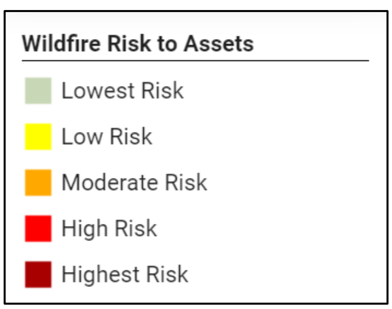
For Wildfire Risk to Assets, it was decided to combine classes to present the data in five classes. This was done to aid with interpretation of the overall composite risk map. The following groupings were used.

Table 10. Wildfire Risk to Assets class groupings.

Wildfire Risk to Assets Class Groupings	
Category	**Final Class**
1	1 – Lowest Risk
2-3	2 – Low Risk
4-5	3 – Moderate Risk
6-7	4 – High Risk
8-9	5 – Highest Risk

The following figure presents the final Wildfire Risk to Assets classes used on CFA.

Figure 26. Wildfire Risk to Assets classified legend (as shown in CFA).



5.3 Defensible Space Analysis

Overview

The defensible space in a Wildfire Urban Interface (WUI) analysis context refers to the space that surrounds a specific building and can be used to define the hazard, or the exposure, to a wildfire occurrence. In this area, natural and manmade fuels are treated, cleared, or reduced to slow the spread of wildfire near structures.

Establishing defensible space reduces the likelihood of a home igniting by direct contact with flame or by exposure to the radiant heat of the fire. It also helps limit local production of embers and reduces the chance a structure fire will spread to neighboring homes or surrounding vegetation.

Please refer to the CSFS web site for a detailed explanation of Defensible Space Zones and how you can start to protect your home by managing your defensible space.

https://csfs.colostate.edu/wildfire-mitigation/protect-your-home-property-from-wildfire/

To support landowners' efforts for defensible space planning, CSFS has incorporated some new risk metrics to better describe the defensible space characteristics across Colorado. The new defensible space risk scores created for the 2022 Colorado Wildfire Risk Assessment (CO-WRA) assessment were derived using a 300 ft radius buffer around each individual building. Since fires rarely ignite within defensible space zones, and typically burn into these areas around structures, it was decided that this analysis must incorporate the fuels and wildfire spread conditions beyond the standard 100 ft zones.

Individual building footprints were used to identify structure locations. Buildings were then grouped using Uber's hexagonal hierarchical spatial index[17]. Within each hexagon, the building values were averaged and applied to the hexagon to remove building specific metrics. This provides a detailed measure of defensible space characteristics for small areas consistent with the accuracy of the structure locations and wildfire fuels and risk analysis data.

Each hexagon in the defensible space risk has a relative value from 0 to 1 that represents the average building hazard in that hexagon. This defensible space value is based on three spatial components/variables: 1) canopy cover, 2) slope, and 3) fuel models present within the buffer around the buildings analyzed. A detailed description of the methods used is provided.

[17] Please see https://www.uber.com/blog/h3/ for a description of the Uber data framework used to summarize CO-WRA risk metrics. The hexagon structure is ideal for characterizing risk data that incorporates the movement of fire across the landscape. For this reason, it is preferred over traditional GIS raster data formats.

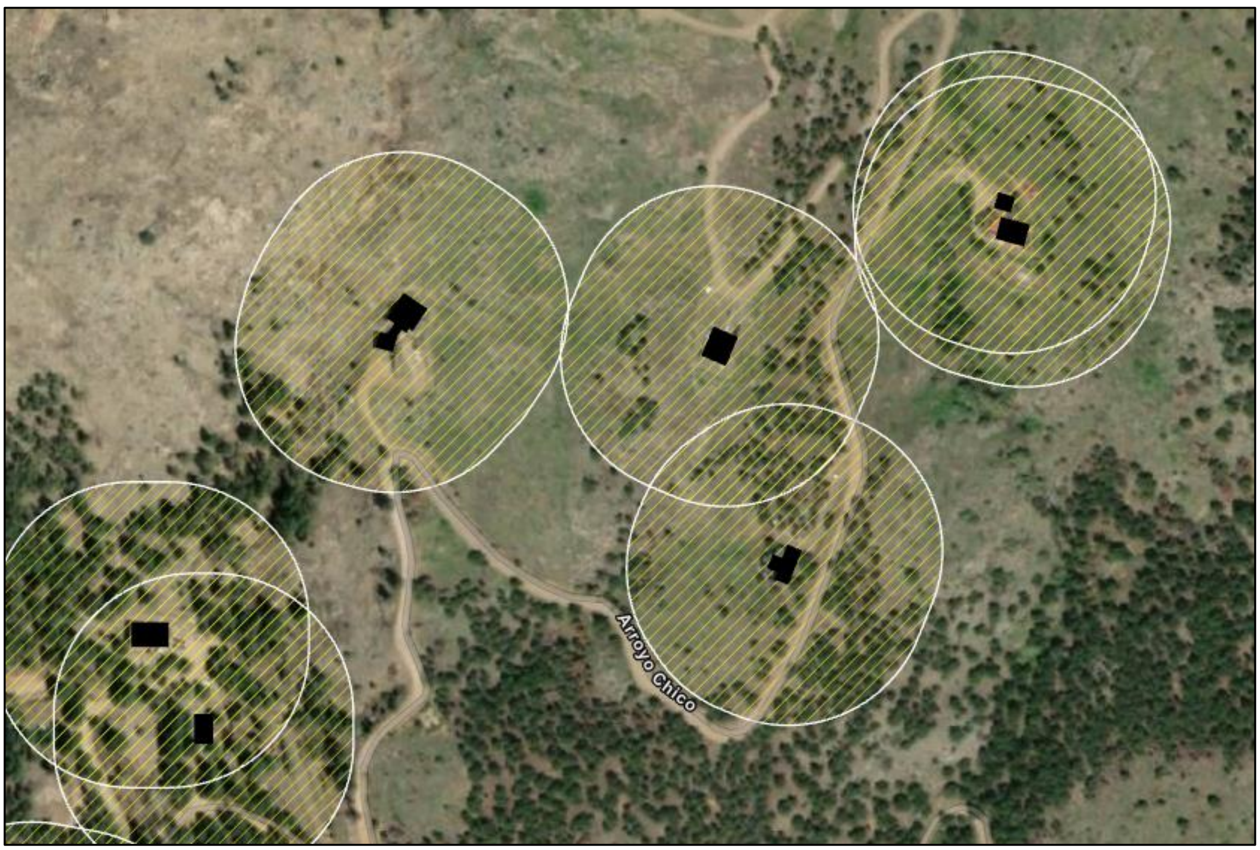
Methodology

Definition of the Area of Influence

The analysis for Defensible Space was based on the latest version of the Microsoft building footprints[18]. Based on the building locations, the areas of influence for defensible space were calculated, focusing on the land area not covered by any building.

Three different distance buffers around the buildings were analyzed: for consideration 100ft, 200ft and 300 ft. The 300 ft. buffer was selected to generate defensible space characteristics to allow for consideration of fuels and potential fire behavior around the structure. This larger distance also affords a better description of surrounding canopy cover and slope. The following figure shows an example of the 300 ft. buffer around houses allowing for better consideration of important terrain and vegetation characteristics.

Figure 27. Representation of the defensible space (300 ft.).



[18] https://github.com/microsoft/USBuildingFootprints

Data Component Selection

Using the 300 ft. buffer for the defensible space, the following metrics were extracted and assessed to consider the best description of the surrounding area:

- Canopy cover (mean value of the tree coverage)
- Slope (mean value of the slope)
- Fuel model (the fuel model that is the majority surrounding the building)
- Canopy height (height of surrounding trees)
- Canopy bulk density (describes the density of available canopy fuels)
- Canopy base height (height where the first branch of the tree is found).
- Aspect of the terrain (average slope direction)

Of these metrics, the canopy cover, slope, and fuel model were ultimately selected to be combined for defining a composite defensible space score. The selection of these data components was based on expert opinion and input from Colorado State Forest Service specialists in consultation with partners. This included the technical approach to weight each of the three components to create a composite score. Ultimately, all three data components were weighted equally.

Normalization and Aggregation for Each Component

Normalization of the three defensible space data components is necessary to properly combine them into a composite score. The three selected metrics (canopy cover, slope and fuel model) were extracted per each building defensible space (300 ft-radius) and normalized using the following tables and conversions functions. The following thee figures present the conversion functions used to normalize the three data variables.

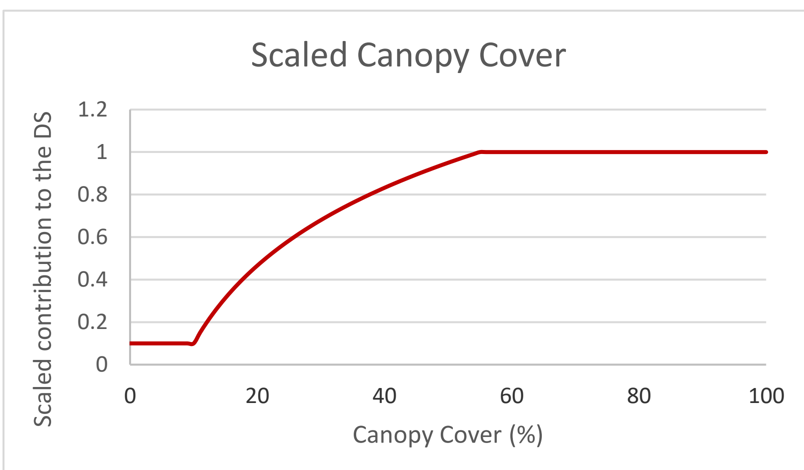


Figure 28. Canopy cover scaling function

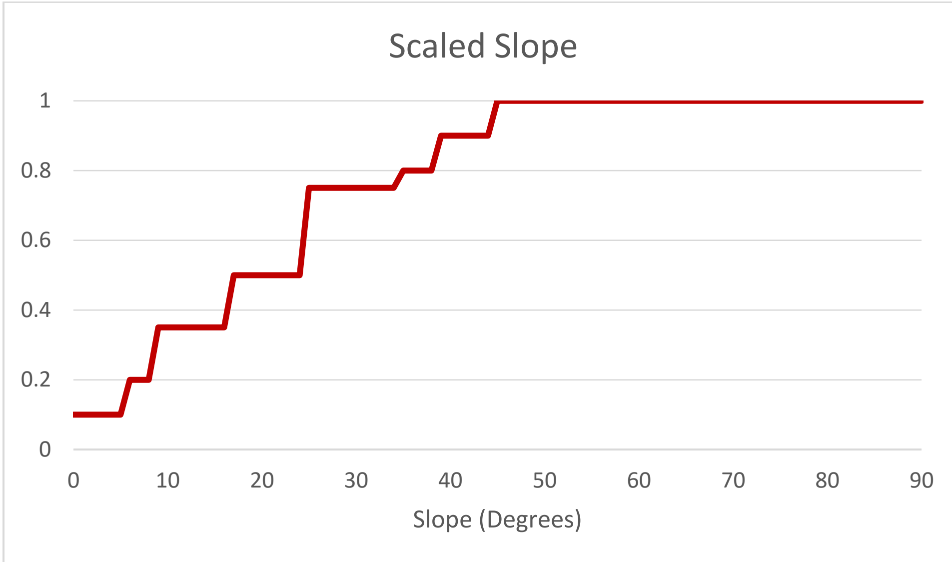


Figure 29. Slope scaling function

For inclusion of the fuel model majority data element a conversion table was necessary. The following tables present the factors used for the normalization. The tables are color coded to distinguish general fuel types, i.e. non-burnable, grass, grass-shrub, shrub, etc.

Table 11. Majority Fuel Model conversion table

Non Ignitable	Grass	Grass-Shrub	Shrub	Timber	Timber	Slash-Blowdown

Fuel Model	Scaled
90x	0.05
101	0.15
102	0.4
103	0.5
104	0.6
105	0.6
106	0.6
107	0.6
108	0.6
109	0.6
111	0.15
112	0.4
121	0.15
122	0.5
123	0.6

Fuel Model	Scaled
161	0.25
162	0.5
163	0.5
164	0.5
165	1
171	1
181	0.25
182	0.25
183	0.25
184	0.35
185	0.35
186	0.5
187	0.5
188	0.6
189	0.75

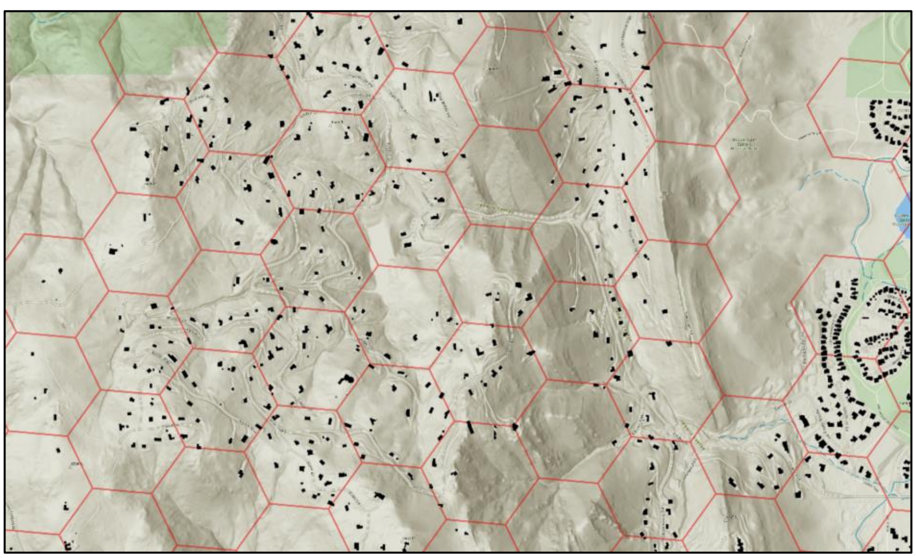
Fuel Model	Scaled
124	0.75
131	0.15
141	0.1
142	0.25
143	0.5
144	0.75
145	1
146	0.75
147	1
148	1
149	1
157	1

Fuel Model	Scaled
191	0.75
201	0.75
202	0.75
203	1
204	1

Once the defensible space outputs for each building were calculated, the three data components and composite score were aggregated and averaged using the Uber H3 level 9 hexagon framework.[19] The Uber H3 spatial index framework provides many benefits for aggregating spatial data across hierarchical scales and has been applied for use within the 2022 Colorado Wildfire Risk Assessment Update. This scale promotes a community approach to wildfire risk reduction versus a single homeowner approach.

The following figure shows the H3 Level 9 hexagons overlaid with building footprints. This provides an example of the scale of the final Level 9 defensible space outputs with the H3 shown in **red** and building footprints in **black**.

Figure 30. Uber H3 level 9 hexagons represented overlaying building footprints



[19] Please visit https://www.uber.com/blog/h3/ for a detailed description of the Uber H3 hexagon spatial framework. Additional references and details can be found at https://h3geo.org/.

Composite Defensible Space Layer

Each metric was calculated and transformed into a relative value (from 0 to 1) and was aggregated to Uber H3 Level 9 hexagons as described above. The arithmetic mean of the three metric scores in each hexagon was calculated, resulting in the composite defensible space score.

The results of the described methodology are contained in four H3 layers:

- Composite defensible space
- Canopy cover
- Slope
- Fuel model

Figure 31 shows an example of the three individual Defensible Space input layers and the final composite DF score. Figure 32 shows an example of the DF Composite Score for an area of the Front Range. Higher values represent a relative higher hazard, based on the characteristics of the defensible space of all buildings included in the H3 hexagon. Building footprints are shown in **black** as reference.

Figure 31. Example Defensible Space layers.

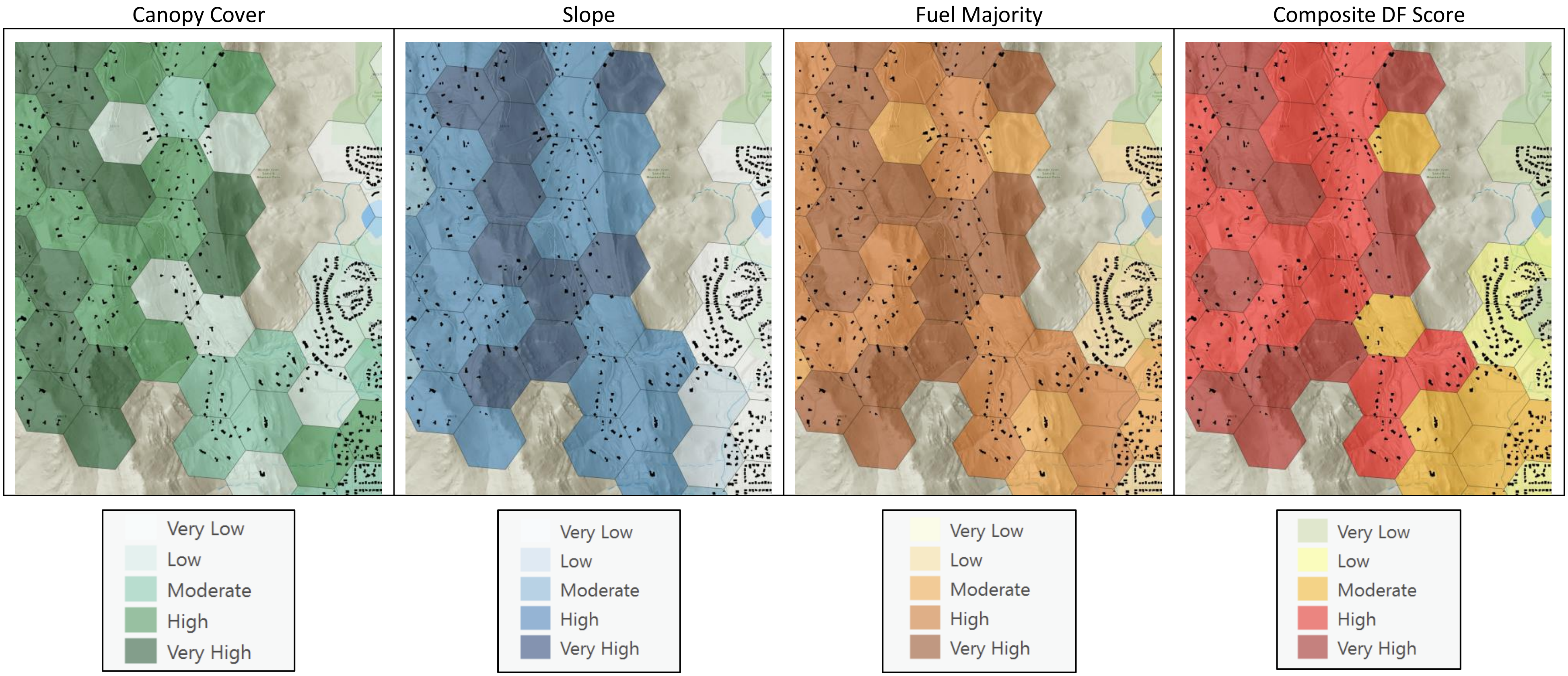
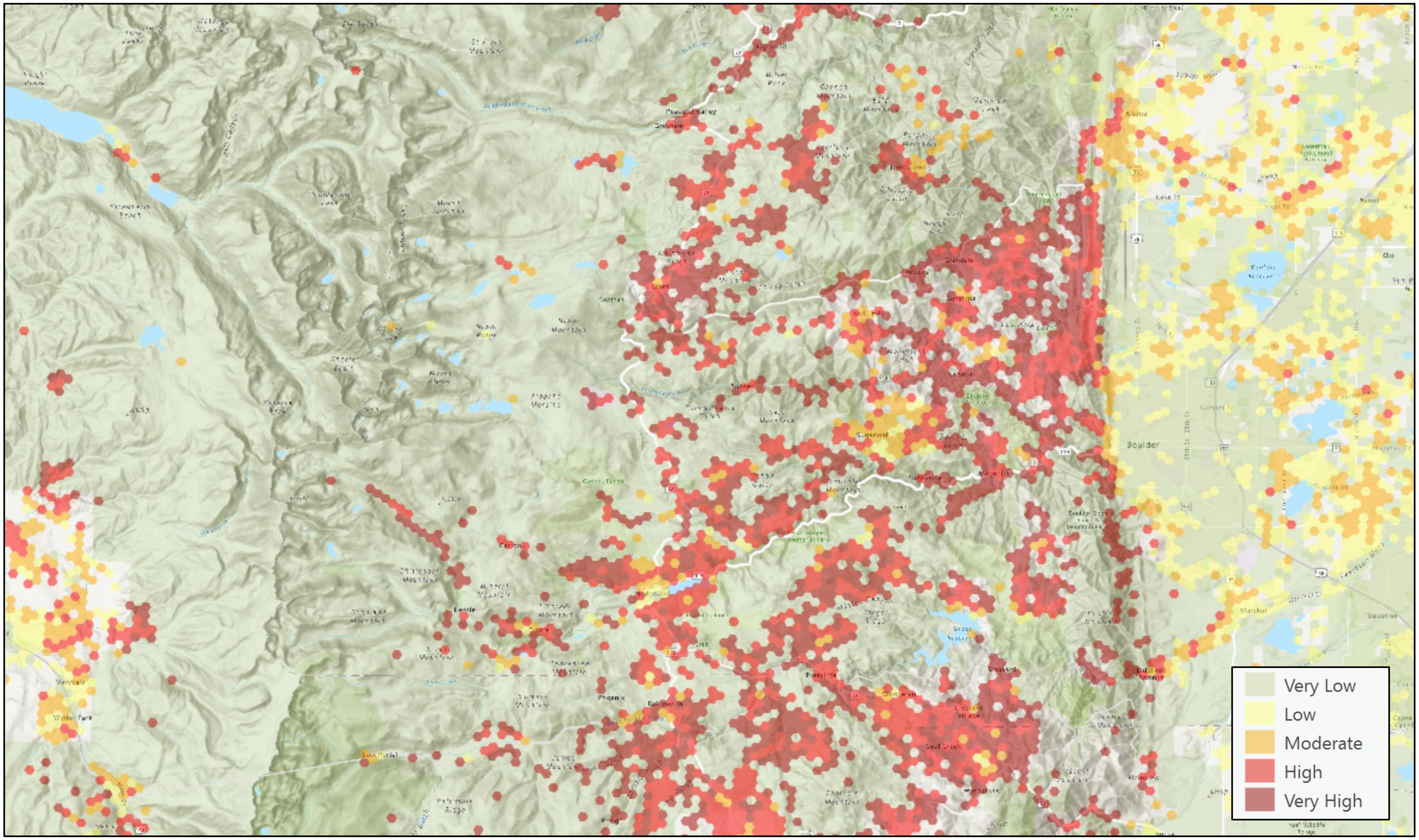


Figure 32. Example of the DF Composite Score for the Colorado Front Range.



5.4 Building Damage Potential Analysis

Overview

The 2022 CO-WRA includes a new metric that estimates the potential for building loss or damage. This metric was derived using proprietary data from Technosylva Inc. on building damages that was created by analyzing 13 years of building damage data from state agency inspections after large fires. The majority of the damage inspection data were obtained from the California Dept. of Forestry and Fire Protection (CAL FIRE). The analysis of the damage inspection data identified common landscape factors consistent with building loss during wildfires. A machine learning model was developed that correlated loss or damage with these factors across Colorado. The new metric is called Building Damage Potential (BDP).

BDP is a spatially variable metric that is calculated on a building-by-building basis and aggregated to Uber H3 hexagons, providing a measure of the number of potential buildings lost or damaged based on the number of buildings threatened by fires in the specific area. BDP was calibrated using machine learning algorithms that identified the key factors that influenced building loss or damage from historical damage inspection databases. The model has been calibrated using 13 years of damage inspection data and validated across multiple Western States with current wildfire data.

BDP is available as a static risk layer, although a key factor involved in the metric is conditional fire behavior. Conditional Flame Length derived in the fire behavior analysis conducted for the 2022 CO-WRA was used. However, the metric can also be used as a dynamic layer when modulated by the fire intensity of an active wildfire through conventional fire behavior analysis. Although applied as a static layer for the 2022 CO-WRA, the metric is used operationally in California by state agencies and private industry for risk forecasting.[20]

Methodology

The BDP metric uses different input variables that characterize the topography, vegetation, WUI type (building density) and fire behavior near each building. Key input variables include:

- Terrain
    - Slope
    - Aspect
- Landform
- Fuel Model (majority)
- Building density
- Conditional Flame Length

The BDP is calculated as follows:

[20] This is a core capability available within Technosylva's Wildfire Analyst™ product. See https://technosylva.com/products/wildfire-analyst/.

$$BDP_i = (\sum_{var=1}^{k} imp_k \ * \ BLF_{i,k}) * CFL_i$$

BDP_i *represents the loss or damage factor for each building*

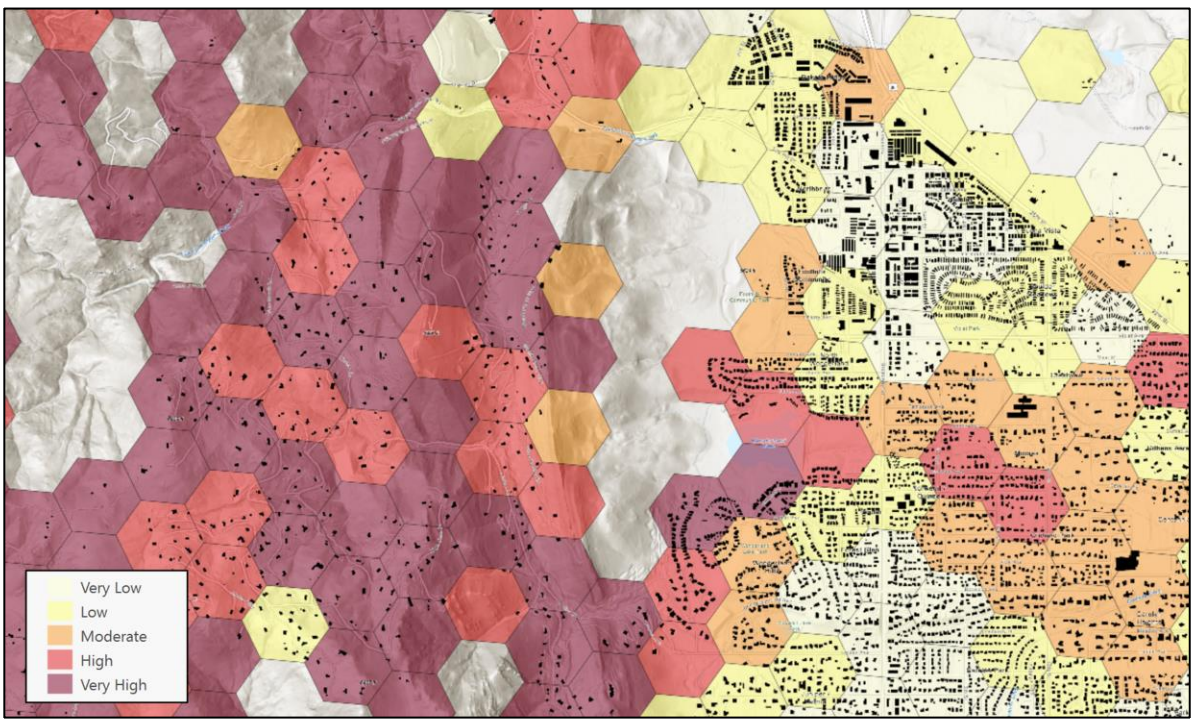
imp *is the importance of input variable k in the model*

$BLF_{i,k}$ *is the coefficient for each input variable in the ML model trained with the damage inspection data.*

CFL_i *is a relative factor between 0 and 1 based on the average Flame Length in a 300 ft. buffer around each building.*

Using the Uber H3 Level 9 framework, the individual building loss or damage factors were aggregated to represent an average loss or damage for the hexagon. This is represented as the BDP. The following figure presents the BDP output for a sample area of Colorado. This example shows urban, urban fringe, WUI and wildland areas. Building footprints are shown in **black** as reference. Advanced fire behavior modeling was used to incorporate encroachment into urban areas.

Figure 33. Example BDP data for Colorado.



5.5 Egress and Social Vulnerability Analysis

Overview

A separate analysis was also undertaken to enhance the suite of risk metrics by incorporating local area characteristics for egress and social vulnerability. In the context of the CO-WRA, egress was defined as road availability considering the evacuation potential of a surrounding population with major and minor roads nearby. In addition, the ability of the population to evacuate was not considered equal. Basic socio-demographic and economic characteristics of the population were considered, namely:

- Senior population ratio (percent of population over 65 years of age).
- Poverty ratio (percent of population below the poverty line)
- Disability ratio (percent of the population with limiting disabilities)

Methodology

Combining these datasets, risk metrics that accurately describe a local area's ability to evacuate a fire were calculated considering (1) social characteristics and (2) without considering social characteristics. While simplistic, these two metrics are easily understandable and can be used to assess risk and related preparedness planning efforts. The metrics were developed and validated in California for areas with similar terrain and WUI characteristics as Colorado. The basic equation for calculating egress is:

$$\text{Road\_Availability} = \frac{\textbf{Net\_Pop} = \text{Healthy\_Pop} + \beta 1 * \text{Disable\_Pop} + \beta 2 * \text{Senior\_Pop} + \beta 3 * \text{Poverty\_Pop}}{\textbf{Net\_Roads} = \text{Minor\_Roads} + \gamma * \text{Major\_Roads}}$$

Where

- γ reflects the evacuation potential of one major road is equivalent to how many minor roads
- β reflects the ease of evacuating for one healthy person is equivalent to how many disabled, senior or low-income persons

One metric was created where social vulnerability was not included. That is, the weighting factor between healthy persons and senior, low income, and disabled persons was 1. Another metric was created where a factor of 3 was used to identify the increased ability of a non-impacted person to evacuate.

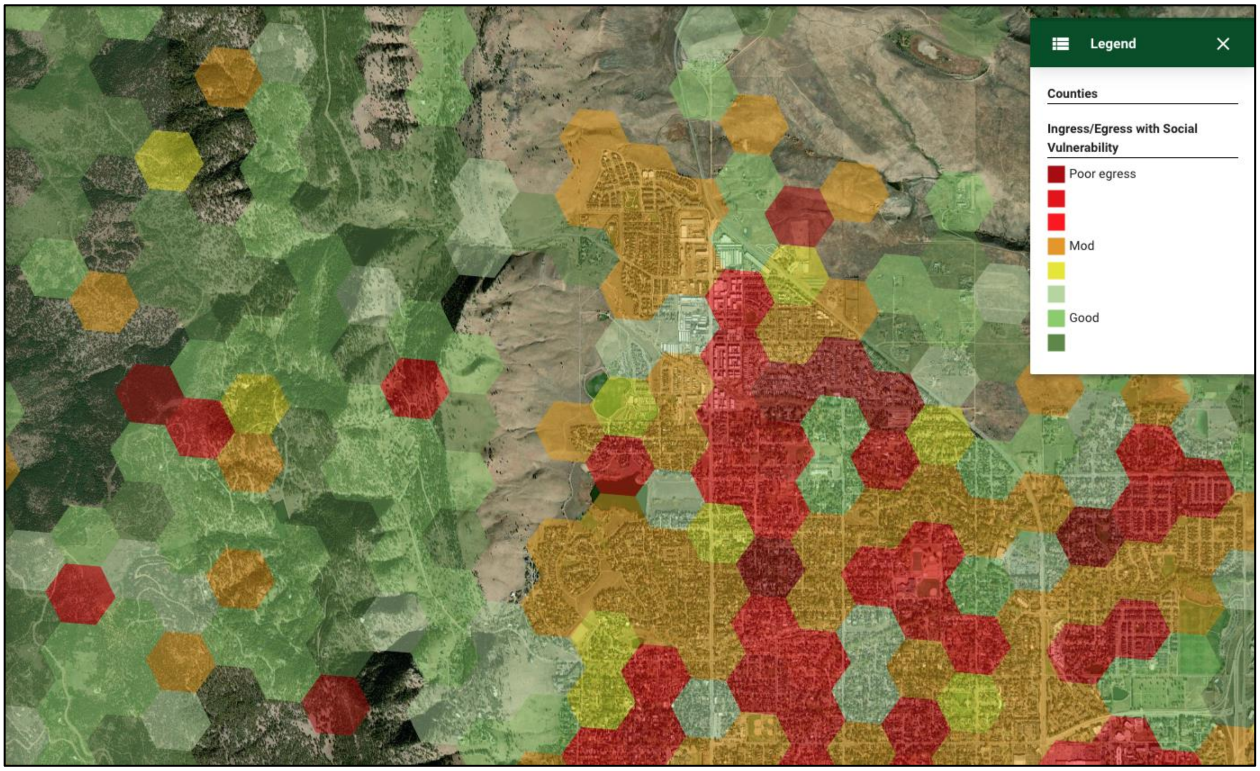
A general factor of 5 was used to parametrize the number of minor roads equal to one major road for ease of evacuation.

Consistent with the Defensible Space Composite and the Building Damage Potential metrics, the Uber H3 Level 9 hexagon framework was used to aggregate data. Source data was obtained from the Esri's ArcGIS Living Atlas and aggregated to the Level 9 framework.[21]

The following figure shows an example of the egress metric with social vulnerability weightings included.

[21] Please visit https://livingatlas.arcgis.com/en/home/ for more information about Esri's Living Atlas of the World data.

Figure 34. Example showing Egress with Social Vulnerability.



5.6 Fire Intensity Scale

An additional risk index was developed to support public awareness and education. Building upon achievements of previous statewide assessments, it was decided that the Fire Intensity Scale output would be developed in the CO-WRA.

The Fire Intensity Scale (FIS) quantifies potential fire intensity based on high to extreme weather conditions, fuels, and topography. It is similar to the Richter scale for earthquakes, providing a standard scale to measure potential wildfire intensity by magnitude.

As an alternative way to deal with Byram's wide-ranging fireline intensity values, Joe Scott (2006) suggested using the common logarithm of fireline intensity (kW/m) as a standard scale of wildfire intensity (called the Fire Intensity Scale, or FIS).[22] The common logarithm is also used in the Richter scale of earthquake magnitude; each unit increase on the Richter scale represents a ten-fold increase in the amplitude of ground shaking.

The same is true of the FIS. Each unit increase in FIS is a meaningful ten-fold increase in fireline intensity. FIS values range from just less than 1 (10 kW/m) to just over 5 (100,000 kW/m), suggesting a classification by orders of magnitude that lends itself to a multi-class dataset.

The FIS data is ideal for helping non-fire specialists easily understanding the potential risk around a specific location. Accordingly, FIS was developed for Colorado and encapsulated in the CFA Wildfire Risk Viewer

[22] Scott, Joe. November 2006. Off the Richter: Magnitude and Intensity Scales for Wildland Fire. A non-published white paper prepared for the AFE Fire Congress, November 2006, San Diego, CA

web application to support the identification of risk for specific locations. A custom tool, called *Identify Fire Intensity* was developed to help public users determine the risk for their homes (or businesses) based on FIS values.

To ensure that FIS provides a risk rating that not only considers the specific location defined by the user, but also incorporates risk for the surrounding area (0.25 mile), further modeling was undertaken to enhance the FIS output. A modified FIS output was generated that utilizes a *decay function* to calculate risk for any given location. A 0.25 mile buffer was used, with values closer to the user location weighted higher than those farther away. This results in a FIS value that considers the risk *around* any location, not just the value at the specific location.

The benefit of using FIS for the CFA Wildfire Risk Viewer *Identify Fire Intensity* tool is that it provides a description of the potential fire conditions that the user can understand, in units the user can understand. In addition, given the fire conditions associated with each FIS class, CSFS was able to accommodate a general description of prevention recommendations as guidance for the user. This provides the two basic bits of information the public needs: 1) a description of potential fire conditions, and 2) a description of mitigation recommendations. We consider this a significant achievement (not included in the West Wide Risk Assessment) that provides much greater utility to the risk assessment outputs to support public awareness and education.

FIS consists of 6 classes where the order of magnitude between classes is ten-fold. The minimum class, Class 1, represents very low wildfire intensities and the maximum class, Class 6, represents extreme wildfire intensities. In Colorado, only classes 1 through 5 exist.

Figure 35. Fire Intensity Scale legend

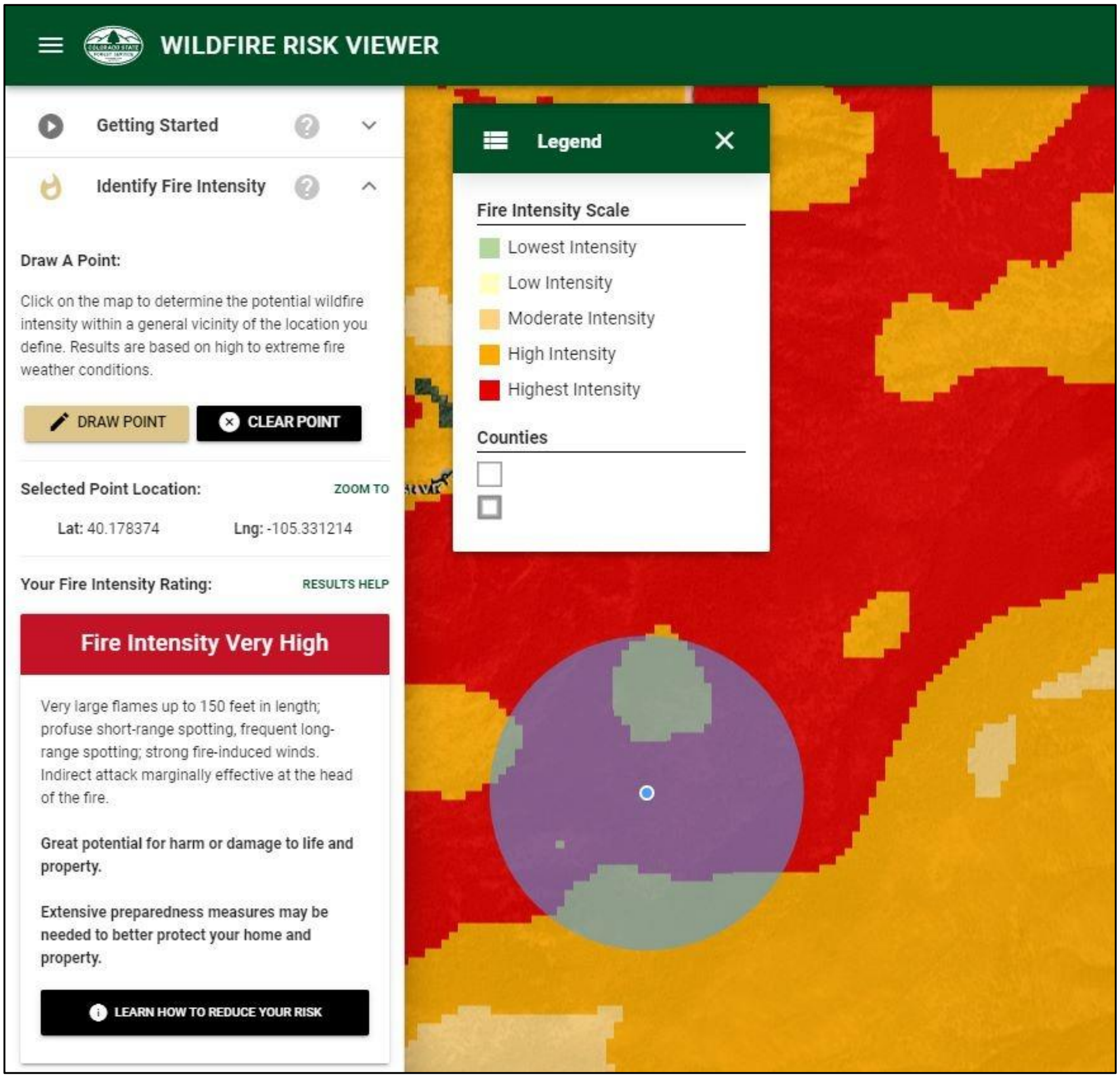
Class 1 Lowest Intensity	Class 2 (Low)	Class 3 (Moderate)	Class 4 (High)	Class 5 Highest Intensity

FIS data is modeled at 20-meter resolution, consistent with all other CO-WRA outputs. Accordingly, while this is accurate enough to provide general ratings, it is not appropriate for site specific recommendations. For site specific advice, the user would press on the link in the Wildfire Risk Viewer *Identify Fire Intensity* tool to be directed to the CSFS web site where they can obtain information for contacting a local mitigation planner for help as they can incorporate local conditions not available in the risk assessment scale of data.[23]

The following figure shows an example of FIS output, with the description of fire conditions and general preparedness recommendations, that are provided in the CFA Wildfire Risk Viewer application *Identify Fire Intensity* tool.

[23] Please see https://csfs.colostate.edu/wildfire-mitigation/.

Figure 36. CFA Example of FIS Data (Identify Fire Intensity tool)



A detailed description of the FIS classes is provided in the following table.

Table 12. Description of Fire Intensity Scale classes.

Fire Intensity Class	Fire Intensity Scale	Description of fire behavior and potential effects	General Preparedness Recommendations
I	*FIS* < 1	Very small, discontinuous flames, usually less than 1 foot in length; very slow spread rate; no spotting. Fires suppressible by lay-firefighters without specialized tools. Very little potential for harm or damage. Fires of this intensity occur on the flanks and rear of large fires, and near the beginning and end of burning periods. These fires are relatively rare due to their slow spread rate and easy control.	**Basic preparedness measures will better protect your home and property.** Be fire wise and take the necessary steps to protect your home and property today.
II	1 ≤ *FIS* < 2	Small flames, usually less than two feet long; small amount of very short range spotting possible. Fires easily suppressed by trained hand crews with protective equipment and firefighting tools. Little potential for harm or damage. This intensity class can occur at the head of a fire in a mild fire environment or on the flanks and rear of fires in more severe fire environments. This intensity class is very common, especially on fires not being actively suppressed.	**Increasing potential to cause harm or damage to life and property.** Increased preparedness measures may be needed to better protect your home and property. This is an important consideration in a scenario where sufficient firefighting resources are not available to protect your home or property. Be fire wise and take the necessary steps to protect your home and property today.
III	2 ≤ *FIS* < 3	Flames up to 8 feet in length; short-range spotting is possible. Hand crews will find these fires difficult to suppress without support from aircraft or engines, but dozers and plows are generally effective. Increasing potential to cause harm or damage. This intensity class occurs at the head and flanks of fires in moderate fire environments, or near the rear of fires in heavy fuel. This intensity class is common.	**Increasing potential to cause harm or damage to life and property.** Increased preparedness measures may be needed to better protect your home and property. This is an important consideration in a scenario where sufficient firefighting resources are not available to protect your home or property. Be fire wise and take the necessary steps to protect your home and property today.

Fire Intensity Class	Fire Intensity Scale	Description of fire behavior and potential effects	General Preparedness Recommendations
IV	3 ≤ *FIS* < 4	Large flames, up to 30 feet in length; short-range spotting common; medium-range spotting possible. Direct attack by hand crews and equipment is generally ineffective, indirect attack may be effective. Moderate potential for harm or damage. This intensity class is generally observed at the head of fires in moderate fire environments or near the head and flank of fires in moderate to severe fire environments. This intensity class is relatively common.	**Significant potential for harm or damage to life and property.** Increased to extensive preparedness measures may be needed to better protect your home and property. This is an important consideration in a scenario where sufficient firefighting resources are not available to protect your home or property. Be fire wise and take the necessary steps to protect your home and property today.
V	4 ≤ *FIS* < 5	Very large flames up to 150 feet in length; copious short-range spotting, frequent long-range spotting; strong fire-induced winds. Indirect attack marginally effective at the head. Great potential for harm or damage. This intensity class is usually observed near the head of fires in severe fire environments. Despite the high spread rate, this intensity class is relative infrequent due to the rarity of the fire environment and spread direction.	**Extensive preparedness measures may be needed to protect your home and property.** Increased to extensive preparedness measures may be needed to better protect your home and property. This is an important consideration in a scenario where sufficient firefighting resources are not available to protect your home or property. Be fire wise and take the necessary steps to protect your home and property today.

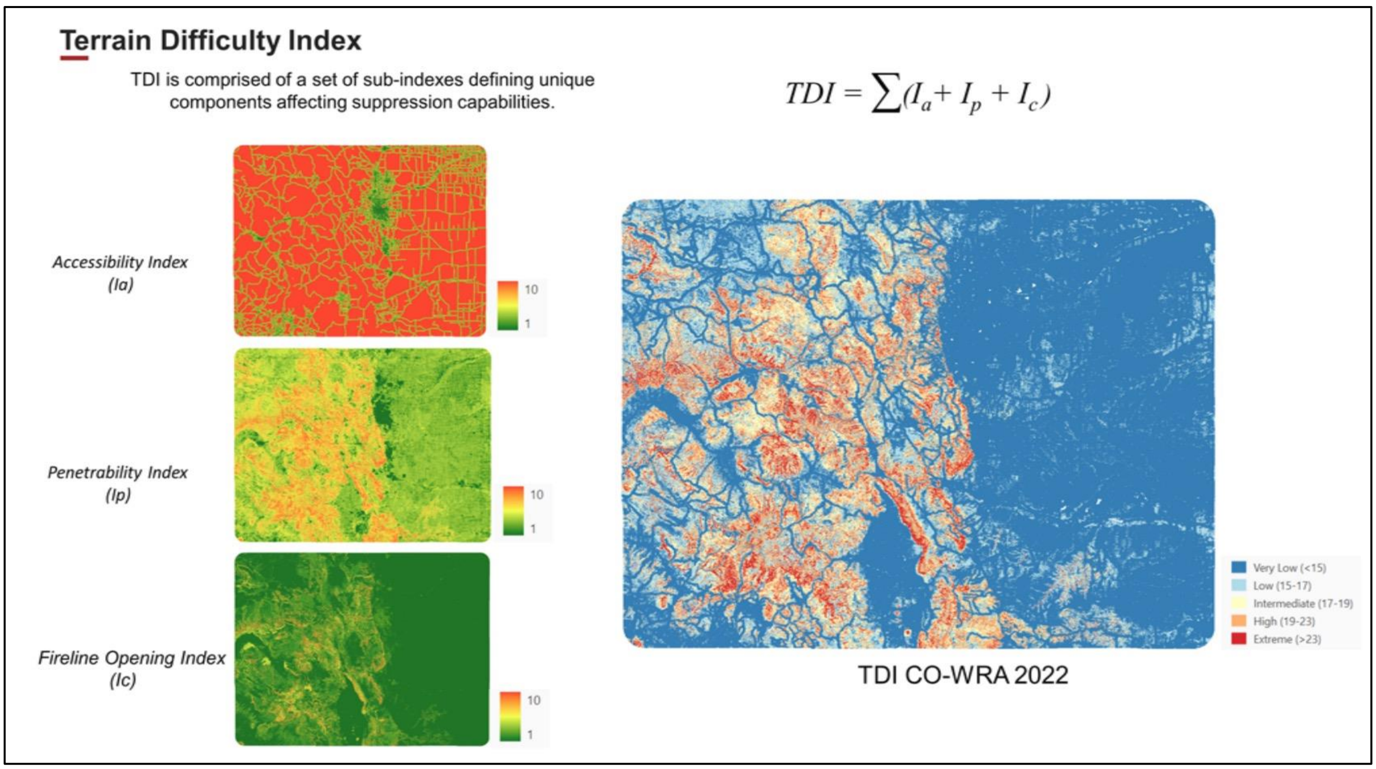
5.7 Terrain Difficulty Index

The 2012 and 2017 CO-WRA included a simple metric that described suppression difficulty based on fireline dozer rates. For 2022 CO-WRA, this standalone metric has been updated to reflect a more enhanced definition of areas where access to fires and suppression from ground resources is difficult. Although not a component of the standard risk assessment outputs, this metric is provided as it helps inform which areas may have limited suppression capabilities, especially for initial attack, across the State.

The Terrain Difficulty Index (TDI) is a metric that describes the characteristics of the landscape which evaluates the difficulty of extinction, especially in initial attack, although it can also be extrapolated to extended attacks. This static index quantifies the availability of access for the arrival of terrestrial means, the ability to penetrate the area where the fire originates, and the difficulty of extinguishing fuels.

Indicators such as the Accessibility Index, Penetrability Index and Fireline Opening Index (construction) have been used for the formulation of TDI. This index is based on other indices such as the Wildfire Suppression Difficulty Index (terrestrial) (SDIt) (Matthew P Thompson et al, 2018. Francisco Rodriguez and Silva et al, 2020.) which is a quantitative rating of the relative difficulty to perform fire control work. However, TDI is dynamic as it incorporates changes in surface fuels over time providing a less static perspective for a planning point of view. The following diagram shows the key components used to derive TDI.

Figure 37. TDI metric components.

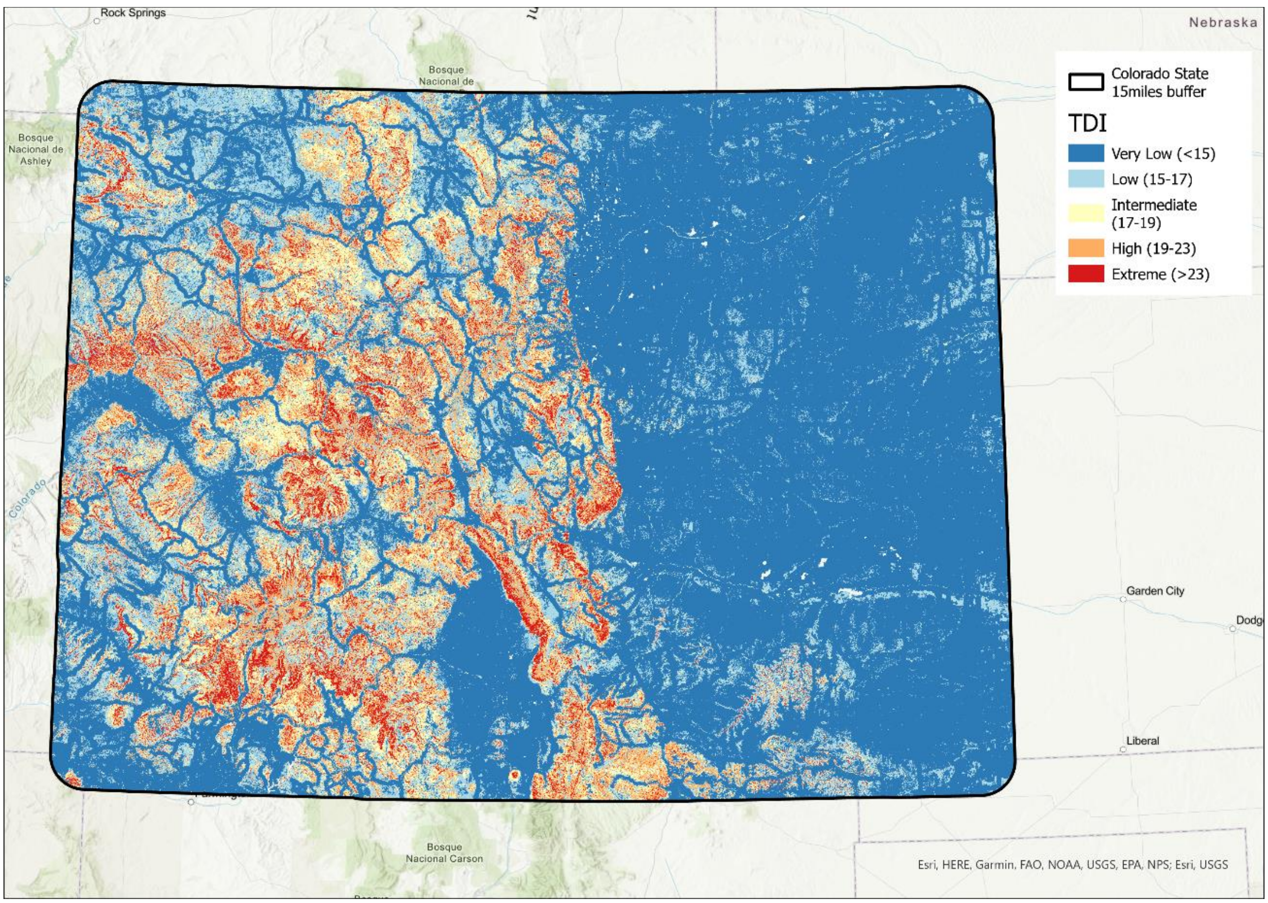


TDI index is represented using five qualitative categories:

1. **Class 1, Very low:** No accessibility limitations to the firefighting resources, allowing quick deployment of wildfire suppression ground resources.
2. **Class 2, Low:** High density of tracks and paths. Terrain conditions allow the deployment of wildfire suppression ground resources.
3. **Class 3, Intermediate:** Roads and tracks are slightly more difficult to access and terrain is mildly difficult with increasing slopes.
4. **Class 4, High:** Low density of roads/tracks in the area. Difficult terrain access with limitations to ground travel.
5. **Class 5, Extreme:** Very low density of tracks/roads to support strategies. Highly complex terrain conditions including high-slope areas limit the use of heavy equipment.

The following figure presents the TDI metric for the State of Colorado.

Figure 38. Terrain Difficulty Index for Colorado.



6. ASSESSMENT SUMMARY AND RESULTS

This section provides a description of the assessment results.

6.1 Summary

The CSFS developed the Colorado Wildfire Risk Assessment (CO-WRA) in 2012 to help decision-makers, landowners and communities assess wildfire risk across the state. CSFS was the first agency in the West to conduct their own wildfire risk assessment and encapsulate the results into interactive web mapping applications, formerly known as the Colorado Wildfire Risk Assessment Portal.[24] In 2018, the CFA was released with enhanced mapping applications containing the updated 2017 CO-WRA data.

The Colorado Forest Atlas is a web portal providing a suite of interactive mapping applications portraying information about Colorado's forests. These applications provide Colorado residents the best available information about forest conditions and CSFS activities. The Forest Atlas is designed to satisfy the mission of the CSFS by providing easy access to this information. Applications are organized to best meet public information demands.

Through CFA, wildfire mitigation/prevention planners and the public can generate maps and download data and reports highlighting areas that may benefit from focused wildfire mitigation efforts. In addition, the tools are specifically designed to support the grant process facilitated by CSFS. In 2018, the CSFS updated CO-WRA and CFA to reflect updated data to 2017 and enhanced the methods in response to user feedback and scientific advancements.

For 2022, CSFS continued the journey of making CO-WRA and CFA even better – by enhancing the resolution and accuracy of the risk assessment and adding new metrics that provide better information for planners and the public to support local planning efforts.

Together, CO-WRA (assessment) and CFA (mapping apps) provide a consistent set of scientific results to support wildfire mitigation and prevention planning in Colorado. The data and information can be used to:

1. create public awareness about wildfire risk;
2. provide state and local planners with information to support mitigation and prevention efforts;
3. identify areas that may require additional planning related to wildfire mitigation projects;
4. assist in the development of Community Wildfire Protection Plans (CWPPs), other hazard mitigation plans, and key information necessary to support grant applications;
5. complement forest stewardship and forest management plans; and
6. inform decision-making at local, county and state levels.

[24] CO-WRAP was superseded with the release of the Colorado Forest Atlas Information Portal in 2018 that extended the suite of interactive mapping application beyond just wildfire to better support CSFS' goal of providing the best information regarding our forest lands in Colorado.

The 2022 CO-WRA has the following benefits over other available wildfire risk information. CO-WRA:

- ✓ **Is based on the best available operational fire science, battle tested daily in other Western states**
- ✓ **Provides wall-to-wall coverage for all lands in Colorado**
- ✓ **Uses consistent methods and is comparable across Colorado**
- ✓ **Has a spatial resolution of 20 m, which is applicable for local and community-level analyses**
- ✓ **Uses enhanced, 20 m resolution surface and canopy fuels data, that incorporated detailed LiDAR data for much of the state, including the Front Range**
- ✓ **Applies enhanced fire behavior and risk models that have been validated in California and other Western States. The Technosylva Wildfire Analyst™ models are the only operationally validated models in the industry and are documented in a peer reviewed publication.[25]**
- ✓ **Incorporates enhanced building level risk metrics for damage potential and defensible space to enhance local mitigation planning**
- ✓ **Is displayed and available for download through the Colorado Forest Atlas Information Portal https://coloradoforestatlas.org/ , where users can also access additional information and resources concerning wildfire mitigation, and request support from the CSFS**

6.2 Assessment Deliverables

The 2022 CO-WRA includes the following key deliverables that are available to the public.

1. Statewide Colorado wildfire risk assessment GIS datasets, available through the CFA and CSFS.
2. Final report that documents the surface and canopy fuels mapping methods and results. This document is available from the CSFS. This report will be posted to the CSFS web site as the updated CFA is released.
3. Final report that documents the data, methods, and outputs for the risk assessment (this document)
4. Enhancements to the CFA web site to include the 2022 CO-WRA data along with updates to other datasets.

[25] The peer reviewed publication for the International Journal of Wildland Fire can be obtained from https://www.publish.csiro.au/WF/WF22128

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Appendix B: Description of Assessment Key Datasets

This appendix provides descriptions of the key datasets used in the CO-WRA. Outputs are organized into categories as reflected in the CFA web applications that provide access to the CO-WRA results.

- Wildfire Risk Themes
- Wildfire Effects Themes
- Wildfire Behavior Outputs
- Landscape Characteristics
- Community Risk Characteristics
- Historical Wildfire Ignitions

Wildfire Risk Themes

Wildfire Risk to Assets

Wildfire Risk to Assets is a composite risk map created by combining the Values at Risk Rating and the Burn Probability layers.

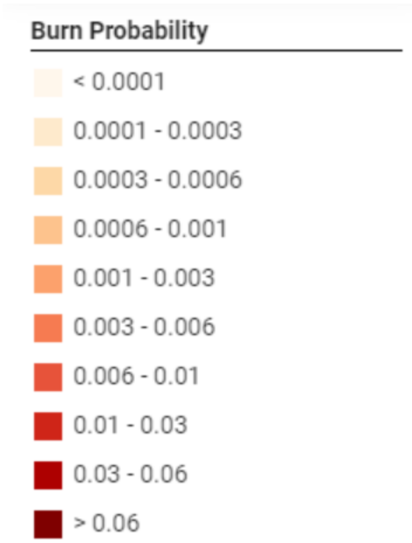
It identifies areas with the greatest potential impacts from a wildfire – i.e., those areas most at risk when considering the four values layers.

The Values at Risk Rating is a key component of Wildfire Risk to Assets. It is comprised of several individual risk layers including Wildland Urban Interface (housing density), Forest Assets, Riparian Assets, and Watershed Protection risk outputs. The WUI component is a key element of the composite risk since it represents where people live in the wildland and urban fringe areas that are susceptible to wildfires and damages. The four individual risk layers are weighted to derive the Values at Risk Rating layer. The Values at Risk layer is then combined with the Burn Probability layer to create Wildfire Risk to Assets.

The risk map is derived at a 20-meter resolution. This scale of data was chosen to be consistent with the accuracy of the primary surface fuels dataset used in the assessment. While not appropriate for site specific analysis, it is appropriate for regional, county, or local planning efforts.

Burn Probability

Burn Probability (BP) is the annual probability of any location burning due to a wildfire.



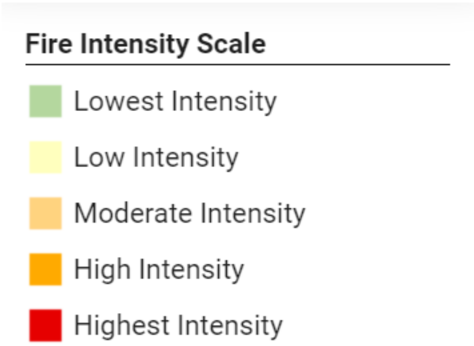
The annual BP was calculated as the number of times that a cell was burned and the number of iterations used to run the models. The annual BP was estimated for Colorado by using a wildfire simulation approach with Technosylva's Wildfire Analyst software (www.WildfireAnaylst.com). A total number of 2,342,334 fires were simulated (3,200,000 if we consider those fires outside the Colorado border which were used in a buffer area around the study area to compute BP) with a mean ignition density of 8.68 fires/km2. The ignition points were spatially distributed evenly every 500 meters across the state. Only high and extreme weather conditions were used to run the single fires because they usually burn most of the annual burned area. All fires simulations had a duration of 8 h. After simulating all the fires, some cells were not burned by any simulated fire, resulting in a BP value of zero. Some cells were non-burnable due to the associated fuel type (i.e., water, roads, urban, agricultural areas, barren areas). However, the lowest BP value found in "burnable" cells was assigned to cells where the simulated fires did not reach.

The Wildfire Analyst fire simulator considered the number of times that the simulated fires burned each cell. After that, results were weighted by considering the historical fire occurrence. The weighting was done by assessing the relation between the annual historical fire ignition density in Colorado and the total number of simulated fires with varying input data in high and moderate weather scenarios and the historical spatial distribution of the ignition points.

The probability map is derived at a 20-meter resolution. This scale of data was chosen to be consistent with the accuracy of the primary surface fuels dataset used in the assessment. While not appropriate for site specific analysis, it is appropriate for regional, county, or local protection mitigation or prevention planning.

Fire Intensity Scale

Quantifies the potential fire intensity by orders of magnitude



Fire Intensity Scale (FIS) specifically identifies areas where significant fuel hazards and associated dangerous fire behavior potential exist. Similar to the Richter scale for earthquakes, FIS provides a standard scale to measure potential wildfire intensity. FIS consists of five (5) classes where the order of magnitude between classes is ten-fold. The minimum class, Class 1, represents very low wildfire intensities and the maximum class, Class 5, represents very high wildfire intensities.

1. Class 1, Lowest Intensity:
   Very small, discontinuous flames, usually less than 1 foot in length; very low rate of spread; no spotting. Fires are typically easy to suppress by firefighters with basic training and non-specialized equipment.
2. Class 2, Low:
   Small flames, usually less than two feet long; small amount of very short range spotting possible. Fires are easy to suppress by trained firefighters with protective equipment and specialized tools.
3. Class 3, Moderate:
   Flames up to 8 feet in length; short-range spotting is possible. Trained firefighters will find these fires difficult to suppress without support from aircraft or engines, but dozer and plows are generally effective. Increasing potential for harm or damage to life and property.
4. Class 4, High:
   Large Flames, up to 30 feet in length; short-range spotting common; medium range spotting possible. Direct attack by trained firefighters, engines, and dozers is generally ineffective, indirect attack may be effective. Significant potential for harm or damage to life and property.
5. Class 5, Highest Intensity:
   Very large flames up to 150 feet in length; profuse short-range spotting, frequent long-range spotting; strong fire-induced winds. Indirect attack marginally effective at the head of the fire. Great potential for harm or damage to life and property.

Burn Probability and Fire Intensity Scale are designed to complement each other. The Fire Intensity Scale does not incorporate historical occurrence information. It only evaluates the potential fire behavior for an area, regardless if any fires have occurred there in the past. This additional information allows mitigation planners to quickly identify areas where dangerous fire behavior potential exists in relationship to nearby homes or other valued assets.

Since all areas in Colorado have fire intensity scale calculated consistently, it allows for comparison and ordination of areas across the entire state. For example, a high fire intensity area in Eastern Colorado is equivalent to a high fire intensity area in Western Colorado.

Fire intensity scale is a fire behavior output, which is influenced by three environmental factors - fuels, weather, and topography – and the spread itself (back, flank or head fire influences fire behavior for a given pixel for a specific fire simulation). Weather is by far the most dynamic variable as it changes frequently. Thus, each pixel may burn many times with different fire spread patterns based on the aforementioned factors. The fire intensity scale maps represent an average fire intensity map.

The fire intensity scale map is derived at a 20-meter resolution. This scale of data was chosen to be consistent with the accuracy of the primary surface fuels dataset used in the assessment. While not appropriate for site specific analysis, it is appropriate for regional, county, or local planning efforts.

Wildfire Effects Themes

Values At Risk Rating

The Values at Risk Rating (VAR) is an overall rating that combines the risk ratings for Wildland Urban Interface (WUI), Forest Assets, Riparian Assets, and Watershed Protection Areas into a single measure of values-at-risk.

The individual ratings for each value layer were derived using a Response Function approach.

Response functions are a method of assigning a net change in the value to a *resource* or *asset* based on susceptibility to fire of different intensity levels. A resource or asset is any of the Fire Effects input layers, such as WUI, or Forest Assets. These net changes can be adverse (negative) or beneficial (positive).

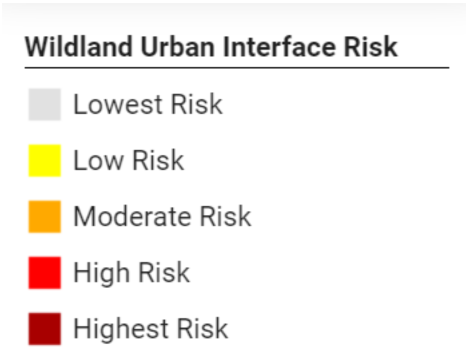
Calculating the VAR at a given location requires spatially defined estimates of the likelihood and intensity of fire integrated with the identified resource value. This interaction is quantified through the use of *response functions* that estimate expected impacts to resources or assets at the specified fire intensity levels. The measure of fire intensity level used in the Colorado assessment is flame length for a location. Response Function outputs were derived for each input data set and then combined to derive the Values at Risk Rating.

Different weightings are used for each of the input layers with the highest priority placed on protection of people and structures (i.e., WUI). The weightings represent the value associated with those assets. Weightings were developed by a team of experts during the assessment to reflect priorities for fire protection planning in Colorado. Refer to the CO-WRA Final Report for more information about the layer weightings.

Since all areas in Colorado have the VAR calculated consistently, it allows for comparison and ordination of areas across the entire state. The VAR data were derived at a 20-meter resolution.

Wildland Urban Interface Risk Index

The Wildland-Urban Interface (WUI) Risk Index layer is a rating of the potential impact of a wildfire on people and their homes.



The key input, WUI, reflects housing density (houses per acre) consistent with Federal Register National standards. The location of people living in the wildland-urban interface and rural areas is essential for defining potential wildfire impacts to people and homes.

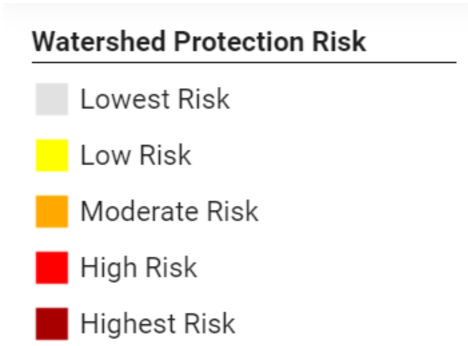
The WUI Risk Index is derived using a response function modeling approach. Response functions are a method of assigning a net change in the value to a resource or asset based on susceptibility to fire at different intensity levels, such as flame length.

To calculate the WUI Risk Index, the WUI housing density data were combined with flame length data and response functions were defined to represent potential impacts. The response functions were defined by a team of experts led by Colorado State Forest Service mitigation planning staff. By combining flame length with the WUI housing density data, it is possible to determine where the greatest potential impact to homes and people is likely to occur. Customized urban encroachment algorithms were used to ensure those fringe urban areas were included in the WUI Risk outputs. Encroachment distances into urban areas were based on the underlying fuel models and their fuel types and propensity for spotting and spreading.

The WUI Risk Index has been calculated consistently for all areas in Colorado, which allows for comparison and ordination of areas across the entire state. Data is modeled at a 20-meter cell resolution, which is consistent with other CO-WRA layers.

Watershed Protection Risk Index

A measure of the risk to Watershed Protection Areas based on the potential negative impacts from wildfire



In areas that experience low-severity burns, fire events can serve to eliminate competition, rejuvenate growth and improve watershed conditions. But in landscapes subjected to high, or even moderate-burn severity, the post-fire threats to public safety and natural resources can be extreme.

High-severity wildfires remove virtually all forest vegetation – from trees, shrubs and grasses down to discarded needles, decomposed roots and other elements of ground cover or duff that protect forest soils. A severe wildfire also can cause certain types of soil to become hydrophobic by forming a waxy, water-repellent layer that keeps water from penetrating the soil, dramatically amplifying the rate of runoff.

The loss of critical surface vegetation leaves forested slopes extremely vulnerable to large-scale soil erosion and flooding during subsequent storm events. In turn, these threats can impact the health, safety and integrity of communities and natural resources downstream. The likelihood that such a post-fire event will occur in Colorado is increased by the prevalence of highly erodible soils in several parts of the state, and weather patterns that frequently bring heavy rains on the heels of fire season.

In the aftermath of the 2002 fire season, the Colorado Department of Health estimated that 26 municipal water storage facilities were shut down due to fire and post-fire impacts. The potential for severe soil erosion is a consequence of wildfire because as a fire burns, it destroys plant material and the litter layer. Shrubs, forbs, grasses, trees and the litter layer disperse water during severe rainstorms. Plant roots stabilize the soil, and stems and leaves slow the water to give it time to percolate into the soil profile. Fire can destroy this soil protection.

The risk index has been calculated by combining the Watershed Protection data with a measure of fire intensity using a Response Function approach. Those areas with the highest negative impact (-9) represent areas with high potential fire intensity and high importance for ecosystem services. Those areas with the lowest negative impact (-1) represent those areas with low potential fire intensity and a low importance for ecosystem services. The response function outputs were combined into 5 qualitative classes.

Riparian Forest Assets Risk Index

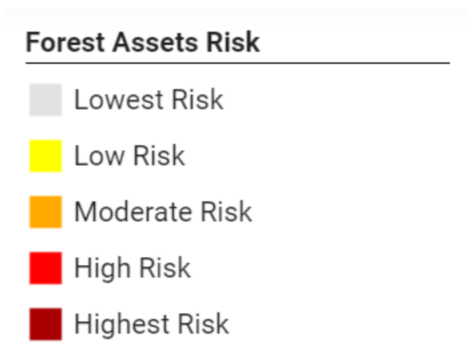
A measure of the risk to riparian areas based on the potential negative impacts from wildfire

The risk index has been calculated by combining the Riparian Assets data with a measure of fire intensity using a Response Function approach. Those areas with the highest negative impact (-9) represent areas with high potential fire intensity and high importance for ecosystem services. Those areas with the lowest negative impact (-1) represent those areas with low potential fire intensity and a low importance for ecosystem services. The response function outputs were combined into 5 qualitative classes.

This risk output is intended to supplement the Watershed Protection Risk Index by identifying wildfire risk within the more detailed riparian areas.

Forest Assets Risk Index

A measure of the risk to forested areas based on the potential negative impacts from wildfire



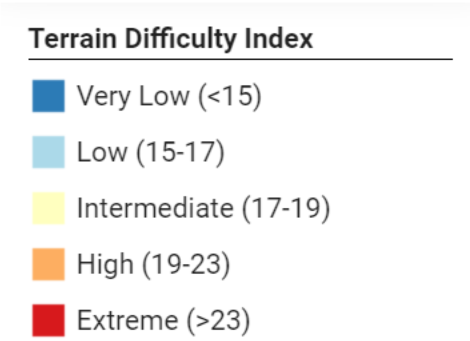
This layer identifies those forested areas with the greatest potential for adverse effects from wildfire.

The risk index has been calculated by combining the Forest Assets data with a measure of fire intensity using a Response Function approach. Those areas with the highest negative impact (-9) represent areas with high potential fire intensity and low resilience or adaptability to fire. Those areas with the lowest negative impact (-1) represent those areas with low potential fire intensity and high resilience or adaptability to fire. The response function outputs were combined into 5 qualitative classes.

This risk output is intended to provide an overall forest index for potential impact from wildfire. This can be applied to consider aesthetic values, ecosystem services, or economic values of forested lands.

Terrain Difficulty Index

Reflects the difficulty to suppress a fire given the terrain and vegetation conditions that may impact ground resource access and capabilities



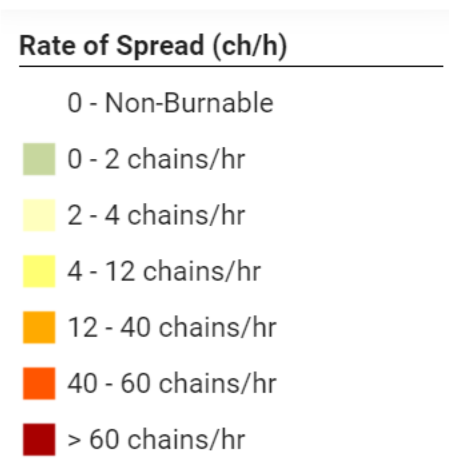
The Terrain Difficulty Index (TDI) is a metric that describes the characteristics of the landscape which evaluates the difficulty of extinction, especially in initial attack, although it can also be extrapolated to extended attacks. This static index quantifies the availability of access for the arrival of terrestrial means, the ability to penetrate the area where the fire originates, and the difficulty of extinguishing fuels.

Indicators such as the Accessibility Index, Penetrability Index and Fireline Opening Index (construction) have been used for the formulation of TDI. This index is based on other indices such as the Wildfire Suppression Difficulty Index (terrestrial) (SDIt) (Matthew P Thompson et al, 2018. Francisco Rodriguez and Silva et al, 2020.) which is a quantitative rating of the relative difficulty to perform fire control work. However, TDI is dynamic as it incorporates changes in surface fuels over time providing a less static perspective for a planning point of view.

Wildfire Behavior Outputs

Rate of Spread

The typical or representative rate of spread of a potential fire based on a weighted average of four percentile weather categories



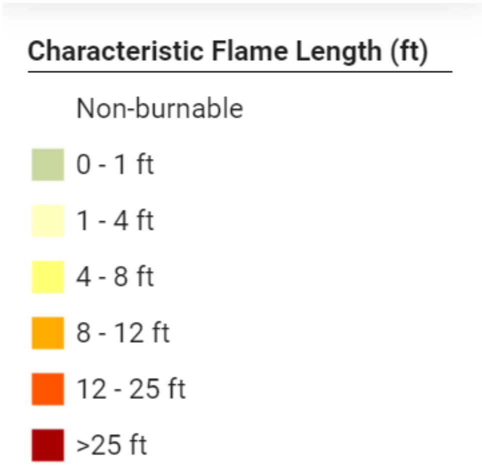
Rate of spread is the speed with which a fire moves in a horizontal direction across the landscape, usually expressed in chains per hour (ch/hr) or feet per minute (ft/min). For purposes of the CO-WRA, this measurement represents the maximum rate of spread of the fire front.

Rate of spread is a fire behavior output, which is influenced by three environmental factors - fuels, weather, and topography. Weather is by far the most dynamic variable as it changes frequently. To account for this variability, four percentile weather categories were created from historical weather observations to represent low, moderate, high, and extreme weather days for a 20-meter grid cell in Colorado.

The Characteristic Rate of Spread represents the weighted average for all four weather percentiles.

Characteristic Flame Length

The typical or representative flame length of a potential fire based on a weighted average of four percentile weather categories

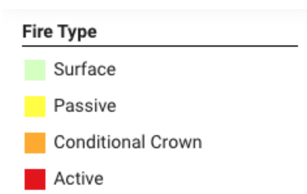


Flame Length is defined as the distance between the flame tip and the midpoint of the flame depth at the base of the flame, which is generally the ground surface. It is an indicator of fire intensity and is often used to estimate how much heat the fire is generating. Flame length is typically measured in feet. Flame length is the measure of fire intensity used to generate the Fire Effects outputs for the CO-WRA and it is influenced by three environmental factors - fuels, weather, and topography. Weather is by far the most dynamic variable as it changes frequently. To account for this variability, four percentile weather categories were created from historical weather observations to represent low, moderate, high, and extreme weather days for each 20-meter grid cell in Colorado.

The Characteristic Flame Length represents the weighted average for all four weather percentiles.

Fire Type - Extreme Weather

Represents the potential fire type under the extreme percentile weather category



Canopy fires are very dangerous, destructive, and difficult to control due to their increased fire intensity. From a planning perspective, it is important to identify where these conditions are likely to occur on the landscape so that special preparedness measure can be taken if necessary. The Fire Type layer shows the footprint of where these areas are most likely to occur. However, it is important to note that canopy fires are not restricted to these areas. Under the right conditions, it can occur in other canopied areas.

There are two primary fire types – surface fire and canopy fire. Canopy fire can be further subdivided into passive canopy fire and active canopy fire. A short description of each of these is provided below.

- Surface Fire - A fire that spreads through surface fuel without consuming any overlying canopy fuel. Surface fuels include grass, timber litter, shrub/brush, slash and other dead or live vegetation within about 6 feet of the ground.
- Passive Canopy Fire – A type of crown fire in which the crowns of individual trees or small groups of trees burn, but solid flaming in the canopy cannot be maintained except for short periods (Scott & Reinhardt, 2001).
- Conditional Crown Fire – A type of crown fire in which an active crown fire is possible, but one would not be predicted to initiate. Two outcomes are possible in that situation: surface fire if the fire starts in the stand as a surface fire, or active crown fire if fire enters the stand as an active crown fire.

- Active Canopy Fire - A crown fire in which the entire fuel complex (canopy) is involved in flame, but the crowning phase remains dependent on heat released from surface fuel for continued spread (Scott & Reinhardt, 2001).

The fire type map is derived at a 20-meter resolution and was estimated based on the extreme weather scenario (percentile 97th). This scale of data was chosen to be consistent with the accuracy of the primary surface fuels dataset used in the assessment. While not appropriate for site specific analysis, it is appropriate for regional, county, or local planning efforts.

Landscape Characteristics

Surface Fuels

Fire behavior fuel models that contain the parameters required to calculate fire behavior outputs

Surface fuels, or fire behavior fuel models as they are technically referred to, contain the parameters needed by the Rothermel (1972) surface fire spread model to compute surface fire behavior characteristics, e.g. rate of spread, flame length, fireline intensity, and other fire behavior metrics. As the name might suggest, surface fuels account only for surface fire potential. Canopy fire potential is computed through a separate but linked process. The CO-WRA accounts for both surface and canopy fire potential in the fire behavior outputs.

An up-to-date surface fuel dataset at 20-meter (m) resolution was developed for this project, based on Scott and Burgan (2005) fuel models, enhanced with custom fuels created by Technosylva. The custom fuels distinguish this assessment from previous ones performed in Colorado as they allow a better characterization of fire behavior across the landscape. Additionally, the urban and road custom fuel models included in the assessment are key for better characterizing the exposure, vulnerability and risk of both buildings and population in the Wildland Urban Interface (WUI). This also allows for better modeling of fire encroachment in urban areas considering the building density, community structure and fuels surrounding the buildings and urban areas.

The following custom fuels were included to improve the fire modeling in timber, WUI and agricultural areas

- Timber: 2 new categories (171 and 191)
- Urban: 7 new categories (911,912,913,914,915,916 and 919)
- Roads: 5 new categories (941,942,943,944 and 949)
- Agriculture: 4 new categories (931,932,938a and 939)
- Water: 3 new categories (981,982 and 989)

Additionally, we also considered canopy fuel data to better simulate crown fire behavior. This includes:

- canopy bulk density (CBD),
- canopy base height (CBH),
- canopy cover (CC) and
- canopy height (CH).

The updated fuel dataset also considered the effects of natural disturbances on vegetation (fires, insect and disease, and harvesting/fuel treatments) that occurred in Colorado from 2013 to 2022. More information about the methods used can be found in the Colorado 2022 Fuels Mapping Final Report.[26]

Table 13 provides a description of the 2022 CO-WRA fuels dataset classes.

Table 13. 2022 Colorado 2022 Fuel Model Dataset classes,

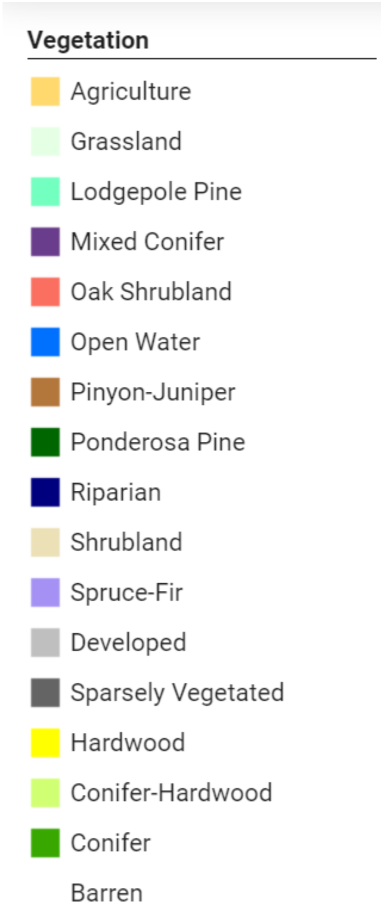
Legend

- Colorado State + 15 miles buffer
- NB2 (92)-Snow/Ice
- NB3 (93)-Agricultural
- NB8 (98)-Open Water
- NB9 (99)-Bare Ground
- GR1 (101)-Short, Sparse Dry Climate Grass
- GR2 (102)-Low Load, Dry Climate Grass
- GR3 (103)-Low Load, Very Coarse, Humid Climate Grass
- GR4 (104)-Moderate Load, Dry Climate Grass
- GR1 (111)-Short, Sparse Dry Climate Grass - ALPINE
- GR2 (112)-Low Load, Dry Climate Grass - ALPINE
- GS1 (121)-Low Load, Dry Climate Grass-Shrub
- GS2 (122)-Moderate Load, Dry Climate Grass-Shrub
- GS3 (123)-Moderate Load, Humid Climate Grass-Shrub
- GS4 (124)-High Load, Humid Climate Grass-Shrub
- GS1 (131)-Low Load, Dry Climate Grass-Shrub - ALPINE
- SH1 (141)-Low Load Dry Climate Shrub
- SH2 (142)-Moderate Load Dry Climate Shrub
- SH4 (144)-Low Load, Humid Climate Timber-Shrub
- SH5 (145)-High Load, Dry Climate Shrub
- SH7 (147)-Very High Load, Dry Climate Shrub
- SH7 (157)-Very High Load, Dry Climate Shrub
- TU1 (161)-Low Load Dry Climate Timber-Grass-Shrub
- TU2 (162)-Moderate Load, Humid Climate Timber-Shrub
- TU3 (163)-Moderate Load, Humid Climate Timber-Grass-Shrub
- TUML1 (171) - Timber Understory Dynamic ML (TSYL 2022)
- TL1 (181)-Low Load Compact Conifer Litter
- TL2 (182)-Low Load Broadleaf Litter
- TL3 (183)-Moderate Load Conifer Litter
- TLML1 (191) - Timber Litter ML (TSYL 2022)
- SB3 (203)-High Load Activity Fuel or Moderate Load Blowdown
- SB4 (204)-High Load Blowdown
- UIL (911)-Isolated urban surrounded by Low FB fuel
- USL (912)-Scattered urban surrounded by Low FB fuel
- UCL (913)-Urban core surrounded by Low FB fuel
- UIH (914)-Isolated urban surrounded by High FB fuel
- USH (915)-Scattered urban surrounded by High FB fuel
- UCH (916)-Urban core surrounded by High FB fuel
- UNB (919)-Unburnable urban areas
- ASL (931)-Agricultural Low Load Fuels, with seasonal changes of its Burnable condition
- ASH (932)-Agricultural High Load Fuels, with seasonal changes of its Burnable condition
- AGC (938)-Golf courses - Non-Burnable (no encroachment)
- ANB (939)-Agricultural Fields, maintained in a Non-Burnable condition
- RNL (941)-Minor roads Low FB
- RNH (942)-Minor roads High FB
- RML (943)-Major roads Low FB
- RMH (944)-Major roads High FB
- RNB (949)-Roads surrounded by non-burnable fuels
- WNL(981)-Minor Water streams surrounded by Low Load Fuel (moderate encroachment)
- WNH(982)-Minor Water streams surrounded by High Load Fuel (high encroachment)
- WBD(989)-Water Bodies

[26] CSFS 2022 Fuels Mapping Final Report. Technosylva, June 2022. Available from the Colorado State Forest Service.

[2] NCEP Reanalysis data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their web site at https://www.esrl.noaa.gov/psd/

Vegetation

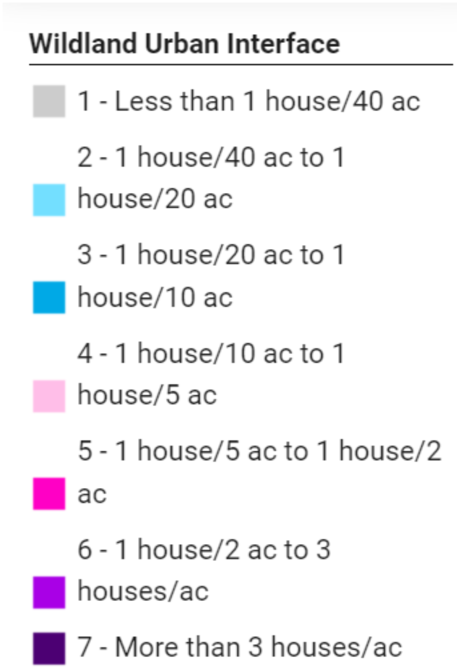


The Vegetation map describes the general vegetation and landcover types across the state of Colorado.

The 2020 LANDFIRE program data product (Existing Vegetation Type) was used to compile the Vegetation data for the CO-WRA. This reflects data current to 2020. The LANDFIRE EVT data were classified to reflect general vegetation cover types for representation with CFA.

Wildland Urban Interface

Reflects housing density depicting where humans and their structures meet or intermix with wildland fuels



Colorado is one of the fastest growing states in the Nation, with much of this growth occurring outside urban boundaries. This increase in population across the state will impact counties and communities that are located within the Wildland Urban Interface (WUI). The WUI is described as the area where structures and other human improvements meet and intermingle with undeveloped wildland or vegetative fuels. Population growth within the WUI substantially increases the risk from wildfire.

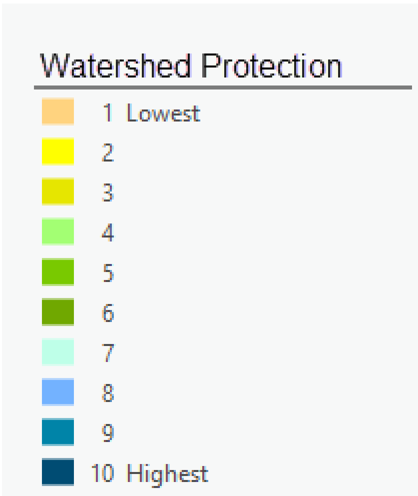
The Wildland Urban Interface (WUI) layer reflects housing density depicting where humans and their structures meet or intermix with wildland fuels. In the past, conventional wildland-urban interface data sets, such as USFS SILVIS, have been used to reflect these concerns. However, USFS SILVIS and other existing data sources did not provide the level of detail needed by the Colorado State Forest Service and local fire protection agencies, particularly reflecting encroachment into urban core areas.

The new WUI data set is derived using advanced modeling techniques based on the Where People Live (housing density) data set and 2021 LandScan USA population count data available from the Department of Homeland Security, HSIP data. WUI is simply a subset of the Where People Live data set. The primary difference is populated areas surrounded by sufficient non-burnable areas (i.e., interior urban areas) are removed from the Where People Live data set, as these areas are not expected to be directly impacted by a wildfire. Fringe urban areas, i.e., those on the edge of urban areas directly adjacent to burnable fuels are included in the WUI. Advanced encroachment algorithms were used to define these fringe areas.

Data is modeled at a 20-meter grid cell resolution, which is consistent with other CO-WRA layers. The WUI classes are based on the number of houses per acre. Class breaks are based on densities well understood and commonly used for fire protection planning.

Watershed Protection

Represents priority areas where opportunities exist to improve and maintain water quality and quantity, improve resiliency of critical water infrastructure, and sustain or restore fundamental ecological functions for watershed health.



Colorado's forested watersheds deliver clean water to residents, 18 other states and Mexico, and provide the biological diversity needed for a future that is balanced both socially and ecologically. Current and expected future conditions, including persistent droughts and uncharacteristic wildfires, have and will continue to negatively impact forest health and the source water and habitat these forests provide. Water is an increasingly limited resource in Western states. Therefore, practicing forest management to improve forest health is critical to protecting and enhancing this precious resource.

This layer was derived from the 2020 Colorado Forest Action Plan Watershed Protection Theme. For this theme, data were integrated from the Colorado Department of Public Health and the Environment's Source Water Assessment and Protection (SWAP) Program to improve consistency with other statewide prioritization efforts. These included municipal drinking water intakes served by area, surface water zones, groundwater under the influence of surface water zones, groundwater zones, conveyances — open channels, ditches, open-channel tunnels, surface water diversion intakes, surface water source intakes, groundwater under the influence of surface water intakes, and groundwater wells. Predicted post-fire erosion rates were also incorporated (Miller et al. 2011; 2023). For more detailed information, please refer to the 2020 Colorado Forest Action Plan.

Forest Assets

Forested areas categorized by height, cover, and susceptibility/response to fire

This layer identifies forested land categorized by height, cover and susceptibility or response to fire. Using these characteristics allows for the prioritization of landscapes reflecting forest assets that would be most adversely affected by fire. The rating of importance or value of the forest assets is relative to each state's interpretation of those characteristics considered most important for their landscapes.

Canopy cover from LANDFIRE was re-classified into two categories: open or sparse and closed. Areas classified as open or sparse have a canopy cover less than 60%. Areas classified as closed have a canopy cover greater than 60%.

Canopy height from LANDFIRE was re-classified into two categories, 0-10 meters and greater than 10 meters.

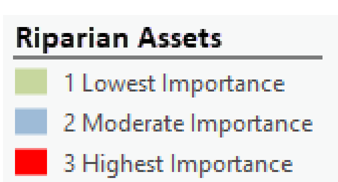
Response to fire was developed from the LANDFIRE existing vegetation type (EVT) dataset. There are over 1,000 existing vegetation types in the project area. The Forest Assets combine specific values of forest height and canopy cover class to determine a fire response class. This crosswalk of values is broken down into three groups defined as sensitive to fire, resilient to fire, and adaptive to fire. The model crosswalk was defined by a team of forest ecologists during the West Wide Risk Assessment project and adopted by the 17 Western state participants. This definition was used for the CO-WRA.

These three classes are sensitive, resilient, and adaptive.

- **Sensitive** = Tree species that are intolerant or sensitive to damage from fire with low intensity.
- **Resilient** = Tree species that have characteristics that help the tree resist damage from fire and whose adult stages can survive low intensity fires.
- **Adaptive** = Tree species adapted with the ability to regenerate following fire by sprouting or serotinous cones

Riparian Assets

Forested riparian areas characterized by functions of water quantity and quality, and ecology



This layer identifies riparian areas that are important as a suite of ecosystem services, including both terrestrial and aquatic habitat, water quality, water quantity, and other ecological functions. Riparian areas are considered an especially important element of the landscape in the west. Accordingly, riparian assets are distinguished from other forest assets so they can be evaluated separately.

The process for defining these riparian areas involved identifying the riparian footprint and then assigning a rating based upon two important riparian functions – water quantity and quality, and ecological significance. A scientific model was developed by the West Wide Risk Assessment technical team with in-kind support from CAL FIRE state representatives. Several input datasets were used in the model including the National Hydrography Dataset and the National Wetland Inventory.

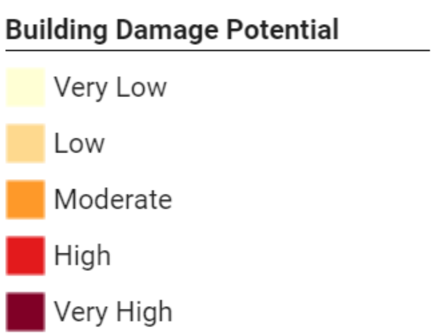
The National Hydrography Data Set (NHD) was used to represent hydrology. A subset of streams and water bodies, which represents perennial, intermittent, and wetlands, was created. The NHD water bodies' data set was used to determine the location of lakes, ponds, swamps, and marshes (wetlands).

To model water quality and quantity, erosion potential (K-factor) and annual average precipitation was used as key variables. The Riparian Assets data is an index of class values that range from 1 to 3 representing increasing importance of the riparian area as well as sensitivity to fire-related impacts on the suite of ecosystem services.

Community Risk Characteristics

Building Damage Potential

This metric estimates the potential for building loss and was derived using proprietary data from Technosylva Inc. on building damages that was created by analyzing 13 years of building damage data from state agency inspections after large fires.



BDP is a spatially variable metric that is calculated on a building-by-building basis and aggregated to Uber H3 hexagons, providing a measure of the number of potential buildings lost based on the number of buildings threatened by fires in the specific area. BDP was calibrated using Machine Learning algorithms that identified the key factors that influenced building loss from historical damage inspection databases. The model has been calibrated using 13 years of damage inspection data and validated across multiple Western States with current wildfire data.

BDP is available as a static risk layer, although a key factor involved in the metric is conditional fire behavior. Conditional Flame Length derived in the fire behavior analysis conducted for the 2022 CO-WRA was used. However, the metric can also be used as a dynamic layer when modulated by the fire intensity of an active wildfire through conventional fire behavior analysis. Although applied as a static layer for the 2022 CO-WRA, the metric is used operationally in California by state agencies and private industry for risk forecasting

Defensible Space Composite & Components

Defensible Space Composite

- Very Low
- Low
- Moderate
- High
- Very High

The defensible space in a Wildfire Urban Interface (WUI) analysis context refers to the space that surrounds a specific building and can be used to define the hazard, or the exposure, to a wildfire occurrence. In this area, natural and manmade fuels are treated, cleared, or reduced to slow the spread of wildfire near structures.

Individual building footprints were used to identify structure locations. Buildings were then grouped using Uber's hexagonal hierarchical spatial index[27]. Within each hexagon, the building values were averaged and applied to the hexagon to remove building specific metrics. This provides a detailed measure of defensible space characteristics for small areas consistent with the accuracy of the structure locations and wildfire fuels and risk analysis data.

Each hexagon in the defensible space risk has a relative value from 0 to 1 that represents the average building hazard in that hexagon. This defensible space value is based on three spatial components/variables: 1) canopy cover, 2) slope, and 3) fuel models present within the buffer around the buildings analyzed.

Defensible Space Fuels Component

- Very Low
- Low
- Moderate
- High
- Very High

Defensible Space Slope Component

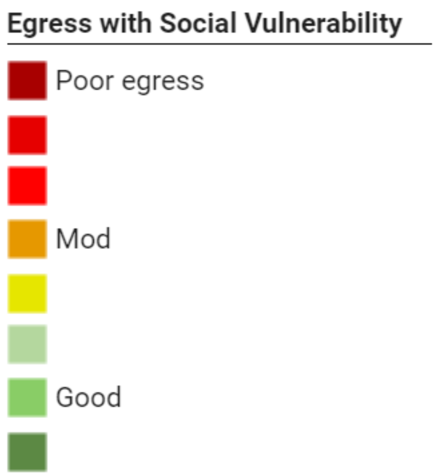
- Very Low
- Low
- Moderate
- High
- Very High

Defensible Space Canopy Component

- Very Low
- Low
- Moderate
- High
- Very High

[27] Please see https://www.uber.com/blog/h3/ for a description of the Uber data framework used to summarize CO-WRA risk metrics. The hexagon structure is ideal for characterizing risk data that incorporates the movement of fire across the landscape. For this reason, it is preferred over traditional GIS raster data formats.

Egress and Social Vulnerability



Analysis based on H3 layers (h3 level 9 hexagons with at least one building inside a hexagon) which offers information about the egress in the CO-WRA territory based on the following variables:

- Buildings
- Roads
- Population:

Egress was defined as road availability considering the evacuation potential of a surrounding population with major and minor roads nearby. In addition, the ability of the population to evacuate was not considered equal. Basic socio-demographic and economic characteristics of the population were considered, namely:

- Senior population ratio (percent of population over 65 years of age).
- Poverty ratio (percent of population below the poverty line)
- Disability ratio (percent of the population with limiting disabilities)

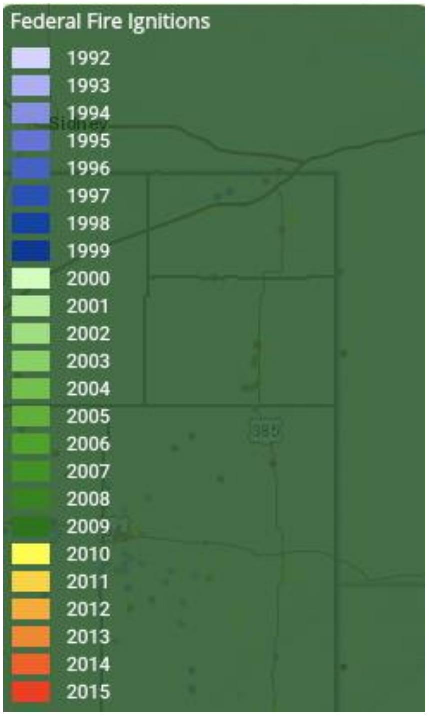
For CO-WRA project two different outputs are generated:[28]

- Egress with Social Vulnerability: the vulnerability population has more weight in the egress calculation
- Egress without Social Vulnerability: the vulnerability population doesn't have more weight in the egress calculation.

[28] Note the same legend and classes apply for both Egress with or without social vulnerability.

Historical Wildfire Data

Federal Wildfire Ignitions



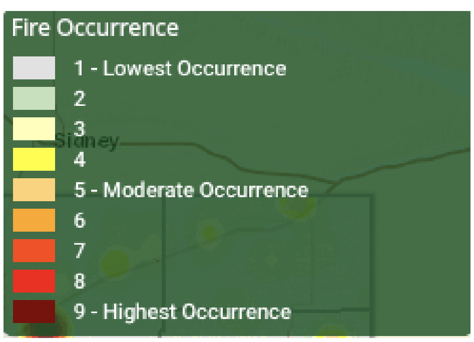
Point locations for all federally reported wildfires from 1992 to 2020.

Fire history statistics provide insight as to the number of fires, acres burned and cause of fires in Colorado. These statistics are useful for prevention planning. They can be used to quantify the level of fire business, determine the time of year most fires typically occur, and develop a fire prevention campaign aimed at reducing a specific fire cause.

Federal wildfire ignitions data for Colorado were compiled for the period 1992-2020. The primary source was the dataset compiled by the USFS Fire Sciences Laboratory (Karen Short). Federal wildfire ignitions are spatially referenced by latitude and longitude coordinates. All ignition references were updated to remove duplicate records and correct inaccurate locations.

Please reference the following publication for more information about the primary source: Short, Karen C., 2017. Spatial wildfire occurrence data for the United States, 1992-2015 [FPA_FOD_20170508]. 4th Edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2013-0009.4

Fire Occurrence



Fire Occurrence is an ignition density that reflects historical ignition patterns.

Occurrence is derived by modeling historic wildfire ignition locations to create an ignition density map. Historic fire report data were used to create the ignition points for all Colorado fires. This included both federal and non-federal fire ignition locations.

The class breaks are determined by analyzing the Fire Occurrence output values for the entire state and determining cumulative percent of acres (i.e., Class 9 has the top 1.5% of acres with the highest occurrence rate).

The Fire Occurrence map is derived at a 20-meter resolution. This scale of data was chosen to be consistent with the accuracy of the primary surface fuels dataset used in the assessment. While not sufficient for site specific analysis, it is appropriate for regional, county, or local protection mitigation or prevention planning.

Appendix C: Response Function and Relative Importance Weightings

This appendix presents the final RF value assignments used to derive risk outputs for the CO-WRA.

2022 Colorado Wildfire Risk Assessment

HVRA Response Function Assignments

				Flame Length Probability Class					
Flame Length Probability Class				0	1	2	3	4	5
				0-2	**2-4**	**4-6**	**6-8**	**8-12**	**12+**
			Category						
Wildland Urban Interface (houses per acre)		**1**	Less than 1 house/40 ac	-0.40	-0.60	-1.00	-1.40	-1.80	-1.80
		2	1 house/40-20 ac	-0.80	-1.20	-2.00	-2.80	-3.60	-3.60
		3	1 house/20-10 ac	-1.20	-1.80	-3.00	-4.20	-5.40	-5.40
		4	1 house/10-5 ac	-1.50	-2.25	-3.75	-5.25	-7.10	-7.10
		5	1 house/5 - 2 ac	-1.90	-2.85	-4.75	-6.65	-7.90	-8.55
		6	1 - 3 houses/ac	-2.00	-3.00	-5.00	-7.10	-9.00	-9.00
		7	More than 3 houses/ac	-2.00	-5.00	-7.00	-8.00	-9.00	-9.00
FAP Watershed Protection Values	*From*	*To*							
Watershed Protection (level of importance)	*0*	*5*	**1 - Lowest Importance**	-0.05	-0.10	-0.25	-2.00	-2.00	-2.00
	6	*16*	**2**	-0.10	-0.20	-0.50	-2.50	-3.00	-3.00
	17	*27*	**3**	-0.20	-0.40	-1.00	-3.50	-4.00	-4.00
	28	*38*	**4**	-0.40	-0.80	-2.00	-4.50	-5.00	-5.00
	39	*49*	**5**	-0.80	-1.60	-3.00	-5.50	-6.00	-6.00
	50	*61*	**6**	-1.00	-2.00	-4.00	-6.50	-7.00	-7.00
	62	*72*	**7**	-2.00	-3.00	-5.00	-7.50	-8.00	-8.00
	73	*83*	**8**	-3.00	-4.00	-6.00	-8.00	-9.00	-9.00
	84	*94*	**9**	-4.00	-5.00	-7.00	-8.50	-9.00	-9.00
	96	*100*	**10 - Highest Importance**	-5.00	-6.00	-8.00	-9.00	-9.00	-9.00
Forest Assets – **Sensitive** **Closed** 0-10 m	77		**1**	-2.00	-3.00	-4.00	-5.00	-9.00	-9.00
Sensitive **Closed** 10+m	77		**2**	-1.60	-2.40	-3.20	-4.00	-7.20	-7.20
Sensitive **Open/Sp** 0-10 m	34		**3**	-0.88	-1.32	-1.77	-2.21	-3.97	-3.97
Sensitive **Open/Sp** 10+m	34		**4**	-0.71	-1.06	-1.41	-1.77	-3.18	-3.18
Resilient **Closed** 0-10 m	78		**5**	0.00	0.00	-2.00	-3.00	-5.00	-5.00
Resilient **Closed** 10+m	78		**6**	0.00	0.00	-0.60	-0.90	-1.50	-1.50
Resilient **Open/Sp** 0-10 m	35		**7**	0.00	0.00	-0.90	-1.35	-2.24	-2.24
Resilient **Open/Sp** 10+m	35		**8**	0.00	0.00	-0.27	-0.40	-0.67	-0.67
Adaptive **Closed** 0-10 m	78		**9**	0.00	-1.00	-3.00	-4.00	-7.00	-7.00
Adaptive **Closed** 10+m	78		**10**	0.00	-0.50	-1.50	-2.00	-3.50	-3.50
Adaptive **Open/Sp** 0-10 m	36		**11**	0.00	-0.46	-1.38	-1.85	-3.23	-3.23
Adaptive **Open/Sp** 10+m	36		**12**	0.00	-0.23	-0.69	-0.92	-1.62	-1.62
Riparian Assets (importance & sensitivity to fire)			**1 - Lowest importance**	0.00	0.00	-0.50	-1.00	-1.75	-1.75
			2 - Moderate Importance	0.00	0.00	-1.00	-2.00	-3.50	-3.50
			3 - Highest Importance	0.00	0.00	-2.00	-4.00	-7.00	-7.00