



# 2017 Colorado Wildfire Risk Assessment Update

## Final Report

December 2018



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### COLORADO WILDFIRE RISK ASSESSMENT PORTAL

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PREPARED BY:

Technosylva Inc., La Jolla, CA

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# 1. PROJECT OVERVIEW

## 1.1 Introduction

This report is the final deliverable in the 2017 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 applied, results, and findings for the assessment. Wildfire risk assessments are a snapshot influenced by data, technology, the natural environment, and the social and cultural environment; all of which change and evolve over time.

## 1.2 Background

The initial 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. 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). Since its publication, some CO-WRAP data layers have been updated as new data has become 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 outputs that better reflected current risk conditions. The project had three key tasks:

1. Update and calibrate surface fuels data
2. Update the risk assessment by using the calibrated fuels data
3. Update the CO-WRAP to include the new risk assessment outputs.

## 1.3 Purpose of the Report

This report describes the datasets, methods and results of the updated risk assessment task (Task 2). It does not include a description of the fuels updating task or the CO-WRAP updating task. Task 2 (fuels update) is documented in a separate report (see [Section 1.7 – Supplemental Documents](#)). Task 3 (CO-WRAP update) was conducted under contract to CSFS and does not include a final report.

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 CO-WRAP 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 CO-WRAP 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, CSFS, Manager of Science Information and CO-WRAP Project Manager for CSFS
- Kristin Garrison, CSFS Fire, Fuels, and Watershed Manager and CO-WRA/CO-WRAP Technical Advisor
- Rich Homann, CSFS, Project Manager Support (Retired from CSFS in 2018)
- Boyd Lebeda, CSFS, Supervisory Science and Data Forester and CO-WRA Fuels and Fire Behavior Technical Lead
- Peter Barry, CSFS, GIS Specialist and CO-WRA/CO-WRAP Technical Advisor
- David Buckley, Technosylva, Senior Consultant & CO-WRAP Project Manager
- Dr. Joaquin Ramirez, Technosylva, Fuels Modeling & Fire Behavior Scientist
- Kate Sabourin, Technosylva, Senior Software Analyst & Technical Lead

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.

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

- Dr. Santiago Monedero, Chief Scientist, Technosylva
- Dr. Adrián Cardil Forradellas, Lead Fire Behavior Analyst, Technosylva
- Francisco José Díez Vizcaíno, Lead Image Processing Analyst, Technosylva
- Leyre Pámpanas Yustres, Lead Fuels Analyst, Technosylva
- Ignacio Moratiel, Web Development
- Natalia Alcoba, Web Development
- Humberto Diaz Fidalgo, Web Development
- Javier Blanco, Technical Team Manager, Technosylva

## 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**

<b>Term/Acronym</b>	<b>Definition</b>
<b>Burn probability</b>	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.
<b>Calibration</b>	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.
<b>Characteristic Output</b>	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.
<b>Exposure</b>	The placement of a highly valued resource or asset in a hazardous environment – such as building a home within a flammable landscape.
<b>Fire Intensity</b>	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.
<b>Fire Intensity Scale</b>	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 the Richter scale for earthquakes, this method of quantifying fire intensity is easily understood by the public and non-scientific users.
<b>HVRA</b>	Highly Valued Resources and Assets. This includes WUI, drinking water importance areas, riparian areas, and forest assets in the CO-WRA.
<b>Relative importance weightings</b>	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.
<b>Response functions</b>	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.
<b>Simulation</b>	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.
<b>Susceptibility</b>	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.
<b>Values-at-risk</b>	A general term synonymous with HVRA.

Term/Acronym	Definition
<b>Vulnerability</b>	A combination of Exposure and Susceptibility, vulnerability is the measure of potential (sometimes called conditional) impacts to HVRA from wildfires of different intensities
<b>Wildfire hazard (Wildland Fire hazard)</b>	A physical situation with potential for causing damage to resources or assets. Hazard is measured by two main factors – burn probability and fire intensity.
<b>Wildfire risk (Wildland Fire risk)</b>	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 CO-WRAP web application please contact [support@coloradowildfirerisk.com](mailto:support@coloradowildfirerisk.com).

## 1.7 Supplemental Documents

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

- **CSFS Fuels Calibration Final Report (June 2018)** - a description of the technical methods used to derive the updated 2017 surface fuels dataset for Colorado. This report is available from the CSFS.
- **Colorado Wildfire Risk Assessment: Summary Statistics Report** - a series of tables and charts that summarize the total acres, percent acres and total population for the primary risk outputs.
- **CO-WRAP User Manual (November 2018)** - documentation that describes how to use the Colorado Wildfire Risk Assessment Portal (CO-WRAP) web application that encapsulates the 2017 CO-WRA outputs. See [www.ColoradoWildfireRisk.com](http://www.ColoradoWildfireRisk.com) for access to this document and other related resource information.
- **A Wildfire Risk Assessment Framework for Land and Resource Management.** Scott, J.; Thompson, M.; Calkin, D. USDA Forest Service, Rocky Mountain Research Station, RMRS-GTR-315. October 2013. – a description of the quantitative risk framework methodology that was used to create the CO-WRA.

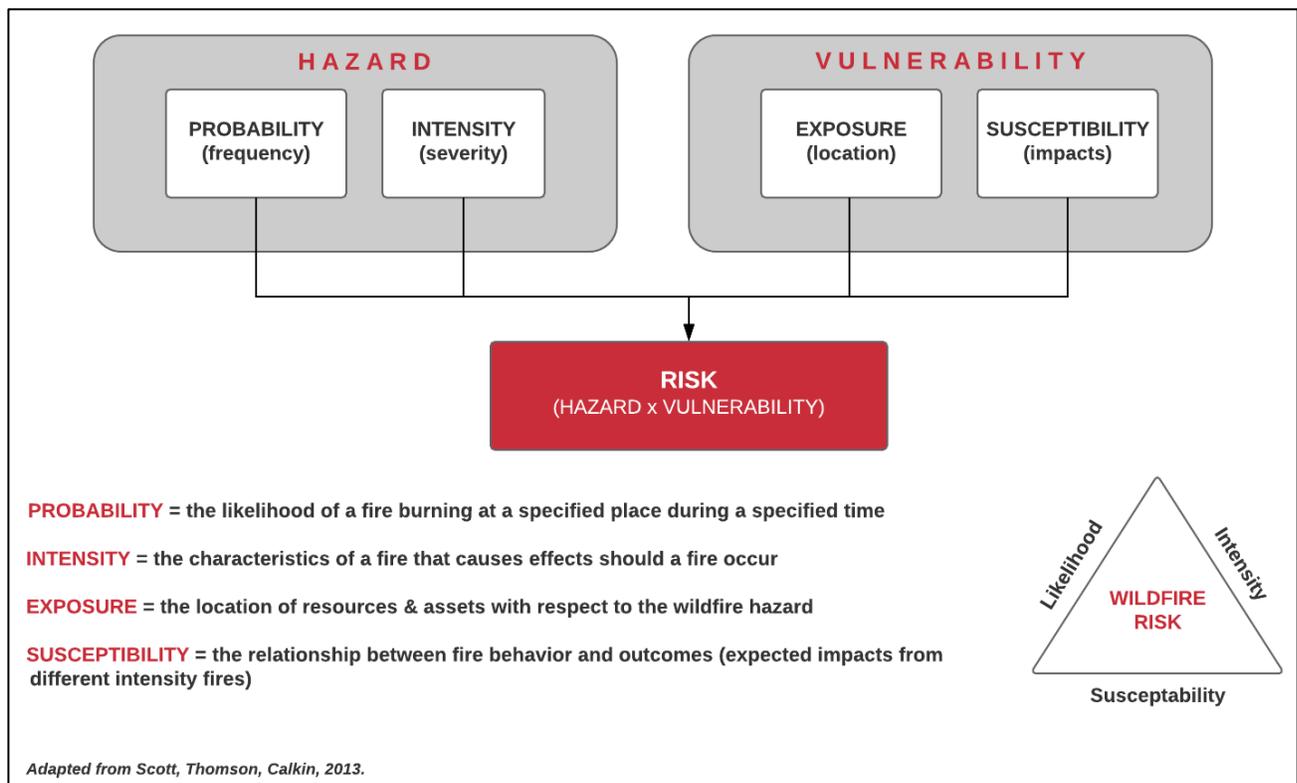
## 2. ASSESSMENT METHODS

This section provides a description of the methods that were used to conduct the 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.**



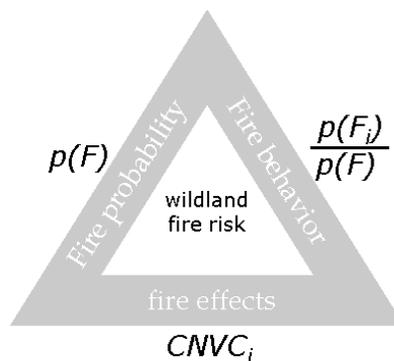
**Wildland Fire hazard** is a physical situation with potential for causing damage to vulnerable resources or assets. Quantitatively, Wildland Fire hazard is measured by two main factors—1) burn probability (or likelihood or burning), and 2) fire intensity (measured as flame length, fireline intensity, 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 used to calculate the CO-WRA outputs.

**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.

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. Please refer to [Section 3.2](#) for a detailed description of the weather data used in the CO-WRA.

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 2012 CO-WRA. A description of the values-at-risk included in the assessment is provided in [Section 3.4](#).

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 3.3](#), 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 4.3](#).

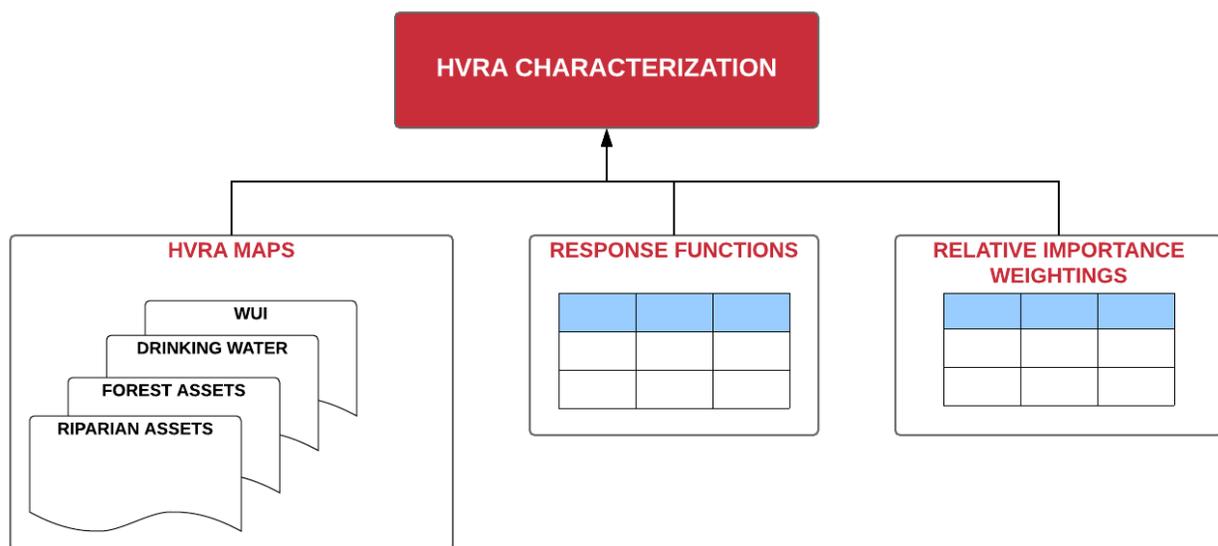
## 2.3 Wildfire Vulnerability

Calculating Wildland Fire vulnerability involves three key components:

1. Definition of HVRA layers (data)
2. Definition of response functions for HVRA
3. Definition of relative importance weightings for HVRA

The following figure shows the relationship of these components required to characterize the risk associated with HVRA. For the CO-WRA these are shown as HVRA maps in the diagram (i.e. WUI = Wildland Urban Interface Drinking Water, 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 estimates 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. There are some strong tradeoffs to consider before avoiding the step of articulating relative importance. Without relative importance, how does one 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 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.

### 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 CO-WRAP web applications.<sup>1</sup>

**Table 2. Description of CO-WRA primary datasets.**

CO-WRA Dataset	Description
<b>PRIMARY OUTPUTS</b>	
<b>Wildfire Risk</b>	Possibility of loss or harm occurring from a wildfire, obtained by combining Values at Risk and Burn Probability.
<b>Burn Probability</b>	Probability of any area burning.
<b>Fire Intensity Scale</b>	Quantifies the potential fire intensity for an area by orders of magnitude
<b>INTERMEDIATE OUTPUTS</b>	
<b>Values At Risk Rating</b>	Represents an overall composite rating of the potential impact of a wildfire for all values and assets created by combining the individual risk outputs.
<b>Suppression Difficulty Rating</b>	Represents those areas where terrain and vegetation characteristics impede dozer operability based on fireline production rates
<b>DERIVED OUTPUTS</b>	
<b>WUI Risk Index</b>	Represents a rating of the potential impact of a wildfire on people and their homes in the WUI
<b>Drinking Water Risk Index</b>	Measure of wildfire risk to drinking water importance areas
<b>Fire Occurrence</b>	Ignition density derived from on historical ignition locations
<b>Forest Assets Risk Index</b>	Measure of wildfire risk to forested lands characterized by height, cover and susceptibility/response to fire
<b>Riparian Assets Risk Index</b>	Measure of wildfire risk to forested riparian areas
<b>FIRE BEHAVIOR OUTPUTS</b>	
<b>Characteristic Flame Length</b>	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.
<b>Characteristic Rate of Spread</b>	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.
<b>Fire Type (extreme weather)</b>	Potential for canopy fire type for extreme weather conditions (canopy fire potential)
<b>KEY INPUTS</b>	
<b>Drinking Water Importance Areas</b>	Measure of quality and quantity of public surface drinking water categorized by watershed

<sup>1</sup> Please refer to <http://www.ColoradoWildfireRisk.com>

CO-WRA Dataset	Description
<b>Federal Fire Ignitions</b>	Point locations for federally reported wildfires from 1992 to 2017.
<b>Non-Federal Fire Ignitions</b>	Point locations for Colorado Non-Federal reported wildfires from 2009 to 2017.
<b>Forest Assets</b>	Forested lands characterized by height, cover and susceptibility / response to fire
<b>Riparian Assets</b>	Forested riparian areas characterized by functions of water quantity, quality and ecology
<b>Surface Fuels</b>	Description of surface vegetation conditions described by fuel conditions that reflect fire behavior characteristics
<b>Vegetation</b>	General vegetation and land cover types
<b>Wildland Urban Interface (WUI)</b>	Depicts where humans and their structures meet or intermix with wildland fuels. Presented as housing density (houses per acre).

A description of the data and development tasks for key improvements for the 2017 CO-WRA is provided.

### 3.1 Fuels and Landscape Data

The latest Colorado 2017 surface fuel dataset, based on Scott and Burgan (2005) fuel models, was used. This was the final datasets available from the recent Colorado Fuels Calibration project completed in 2018. This fuels calibration project utilized the latest LANDFIRE 2014 source datasets and provided updates to correct LANDFIRE mapping zone seamlines, i.e. natural disturbances (fires, insect & disease, and harvesting/fuel treatments) that occurred in Colorado from 2013 to 2017 (since LANDFIRE 2014), and other adjustments to better depict Colorado landscape conditions. More information about this Colorado Fuels Calibration project and the methods used can be found in the Colorado Fuels Calibration Final Report.<sup>2</sup>

Fuel loading data were also updated for each fuel model. Additionally, we also considered canopy fuel layers to simulate crown fire behavior from LANDFIRE 2014 data sources. This included:

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

Raster resolution for all datasets is 30 m across the entire state.

In order to avoid border effects in the dynamic fire simulations to compute Burn Probability (BP) and other related outputs (flame length probabilities and conditional flame length), we created a buffer by using the LANFIRE 2014 fuel models. This accommodated for the spread of simulation that may start outside the state, however may burn into Colorado. The following figure shows the final fuels dataset for Colorado.

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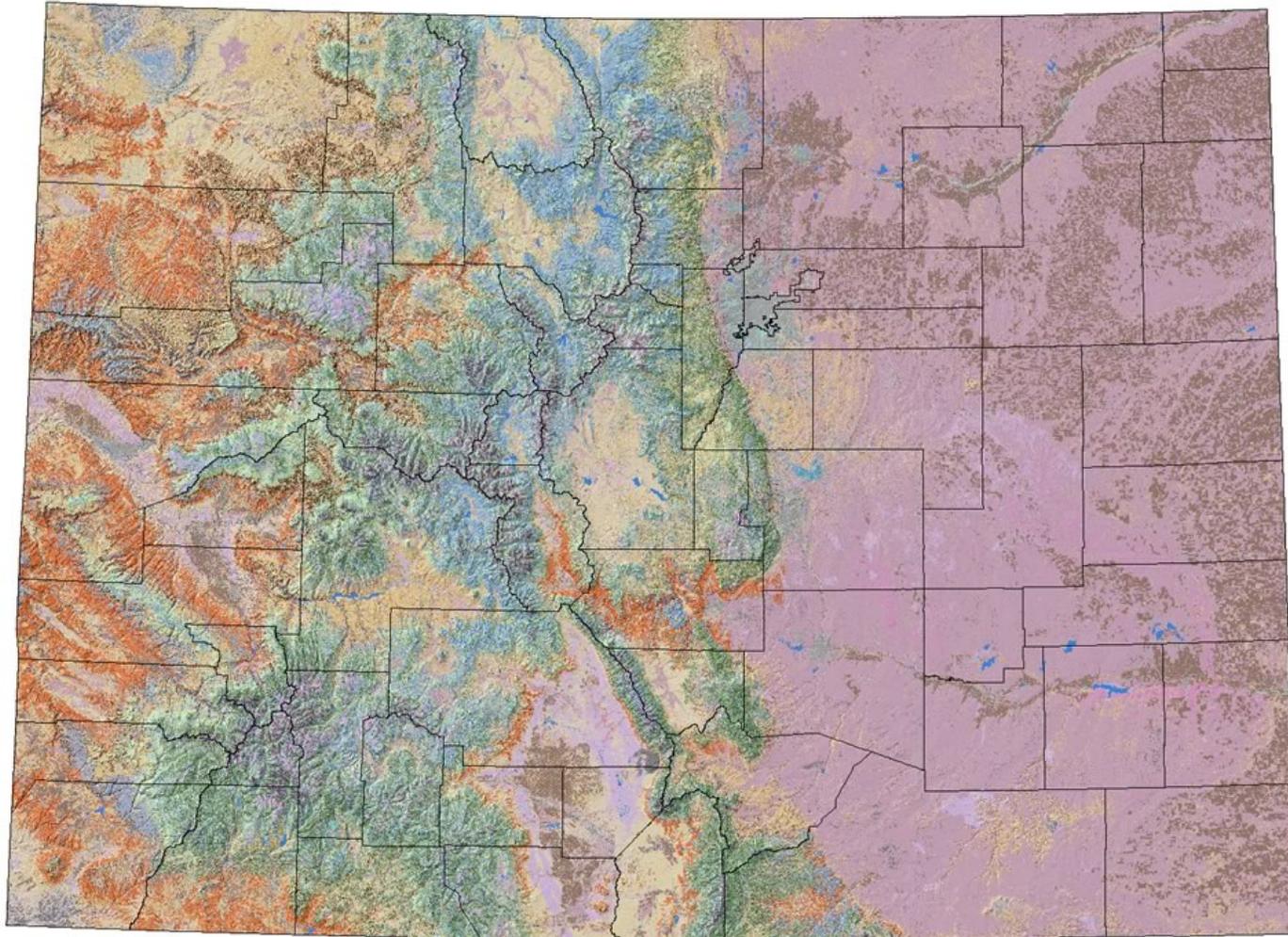
<sup>2</sup> Colorado Fuels Calibration Final Report. Technosylva June 2017

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

Figure 3. Colorado Surface Fuels 2017.



Colorado Wildfire Risk Assessment 2017  
SURFACE FUELS



- NB01 - 91 - Urban/Developed
- NB02 - 92 - Snow/Ice
- NB03 - 93 - Agriculture
- NB08 - 98 - Water
- NB09 - 99 - Barren
- GR01 - 101 - Short, sparse, dry climate grass
- GR02 - 102 - Low load, dry climate grass
- GR03 - 103 - Low load, very coarse, humid climate grass
- GR04 - 104 - Moderate load, dry climate grass
- GR01 - 111 - GT 10,000 ft elevation
- GR02 - 112 - GT 10,000 ft elevation
- GS01 - 121 - Low load, dry climate grass-shrub
- GS02 - 122 - Moderate load, dry climate grass-shrub
- GS01 - 131 - GT 10,000 ft elevation
- SH01 - 141 - Low load, dry climate shrub
- SH02 - 142 - Moderate load, dry climate shrub
- SH03 - 143 - Moderate load, humid climate shrub
- SH05 - 145 - High load, humid climate grass-shrub
- SH07 - 147 - Very high load, dry climate shrub
- SH07 - 157 - Oak Shrubland without changes
- TU01 - 161 - Light load, dry climate timber-grass-shrub
- TU02 - 162 - Moderate load, humid climate timber-shrub
- TU05 - 165 - Very high load, dry climate timber-shrub
- TL01 - 181 - Low load, compact conifer litter
- TL02 - 182 - Low load, broadleaf litter
- TL03 - 183 - Moderate load, conifer litter
- TL04 - 184 - Small downed logs
- TL05 - 185 - High load, conifer litter
- TL06 - 186 - Moderate load, broadleaf litter
- TL07 - 187 - Large downed logs
- TL08 - 188 - Long-needle litter
- TL09 - 189 - Very high load, broadleaf litter

## 3.2 Weather Data

For the 2012 CO-WRA, weather data were compiled for 11 Weather Influence Zones across the state.<sup>3</sup> These Zones were developed as part of the West Wide Risk Assessment project. The Weather Influence Zones (WIZ) reflected areas of homogeneous weather conditions, i.e. all 30-meter pixels within a specific WIZ contained the same weather data values. This approach resulted in data artifacts reflecting hard seamlines in the weather and fire behavior outputs. These seamline artifacts rippled through the risk outputs and were an issue raised by CO-WRA users.

In an effort to correct this defect, a more comprehensive technical approach was used that resulted in a continuous weather dataset across the state. This included a larger sampling of weather observations data. Weather data (1988-2017) from NCEP (National Center for Environmental Prediction)<sup>2</sup> was used to analyze potential weather scenarios when assessing fire behavior and spread. Particularly, we used the North American Regional Reanalysis (NARR) product from NCEP because of it provides high resolution weather data across the US. It covers data from 1979 to near present and is provided 8-times daily, daily and monthly on a Northern Hemisphere Lambert Conformal Conic grid for all variables. The grid resolution is 349x277 which is approximately 0.3 degrees (32km) resolution at the lowest latitude. The following figure presents an example of data from the NCEP North American Reanalysis.

The following variables from NARR were used:

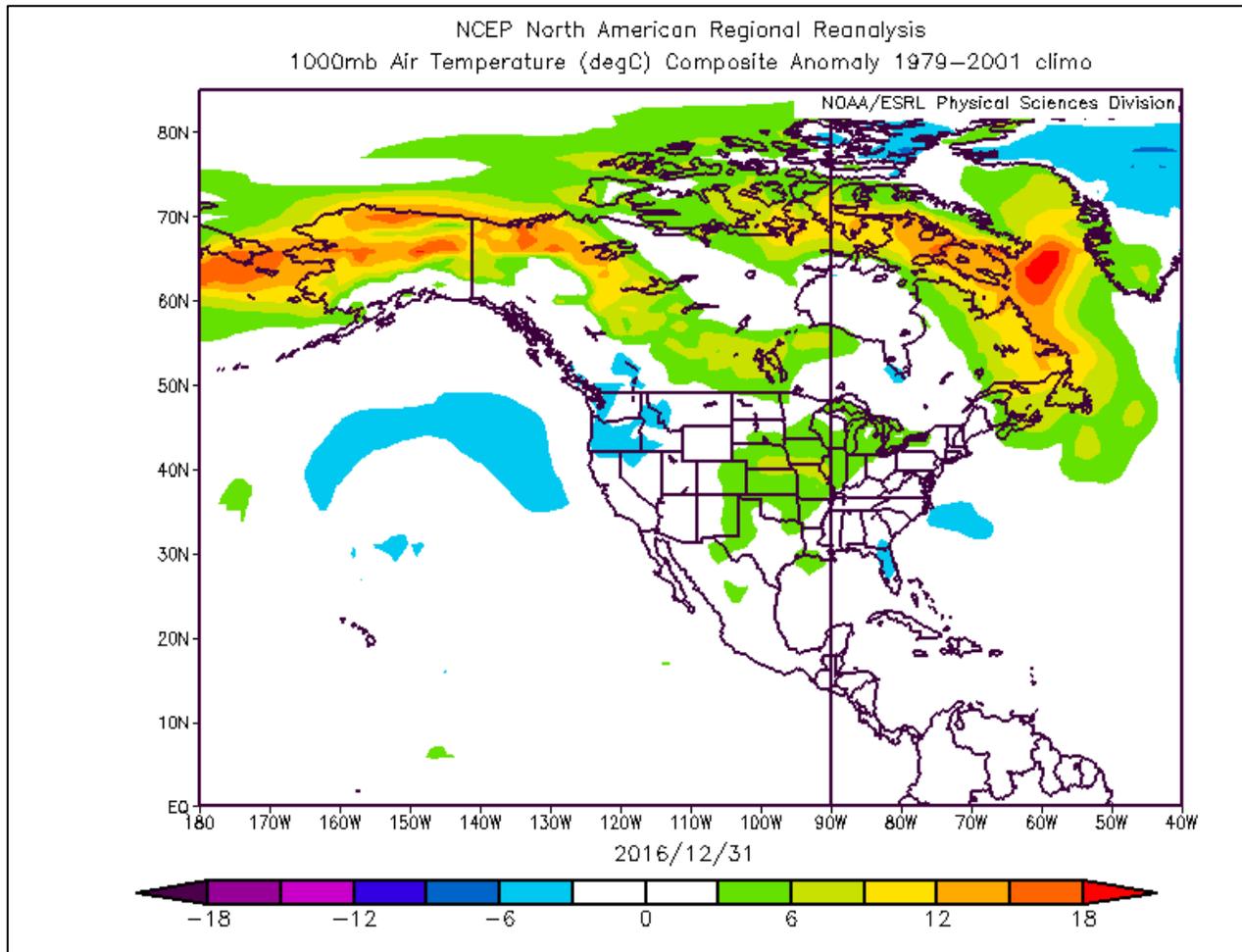
- temperature at 2m,
- relative humidity at 2m and
- wind speed and direction at 10 m.

Data were only selected at 2 pm local time (21 UTC) because it is usually the most adverse scenario for a fire start. Several percentiles (97<sup>th</sup>, 90<sup>th</sup>, 50<sup>th</sup> and 25<sup>th</sup>) for each variable were analysed in each 30km NARR point to create four weather scenarios to run the CO-WRA fire behavior analysis - “Extreme”, “High”, “Moderate” and “Low”. After computing the weather percentiles of the NARR variables, data were interpolated using IDW algorithms (Inverse Distance Weighting) at 30-meter pixel resolution (see examples for temperature and air relative humidity for the different scenarios in Figures 5 and 6).

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<sup>3</sup> Please refer to the West Wide Risk Assessment Final Report (March 2013) for a description of Weather Influence Zones used for both the WWA and 2012 CO-WRA ([https://www.thewflc.org/sites/default/files/WWA\\_FinalReport\\_3-6-2016-1.pdf](https://www.thewflc.org/sites/default/files/WWA_FinalReport_3-6-2016-1.pdf)).

**Figure 4. NCEP NARR data example.**



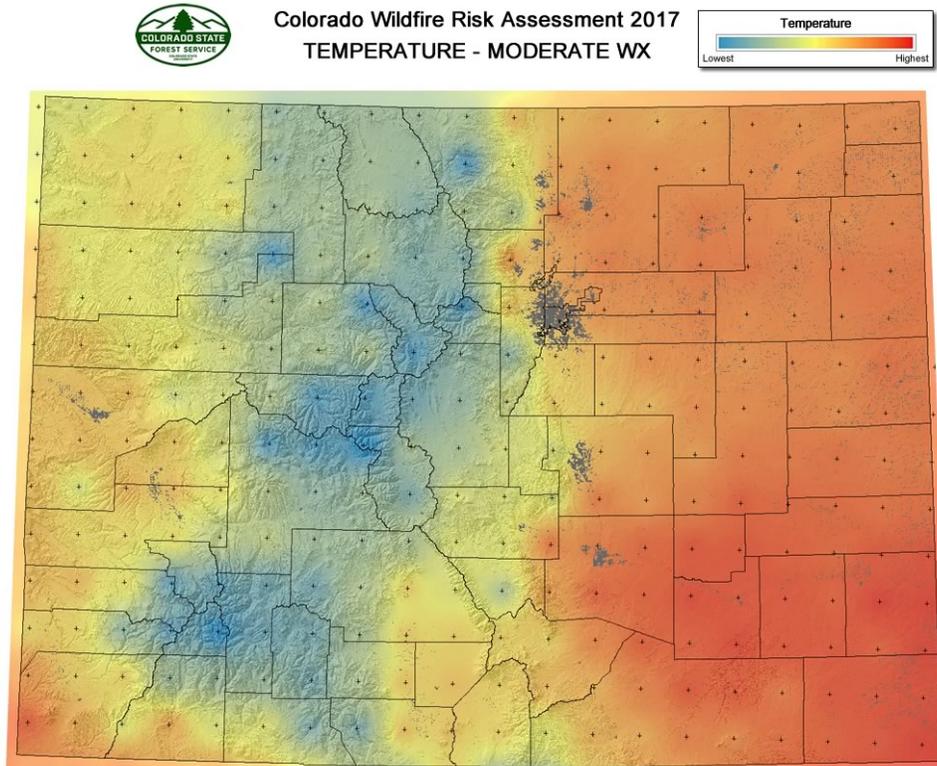
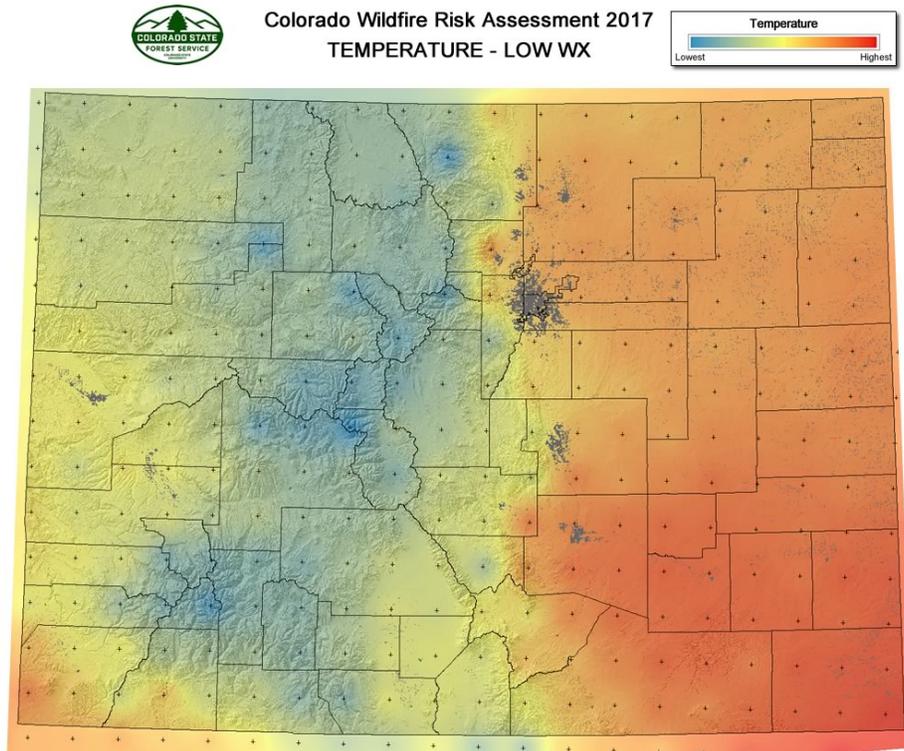
1h-dead fuel moisture was estimated by using the model of Rothermel and Rinehart (1983). Both temperature and air relative humidity at 2m from NARR fed the fuel moisture model although elevation and aspect was considered for each cell in order to take into account the accumulated solar radiation at 14h (local time). We added 2% and 4% to the 1h dead fuel moisture content to estimate 10h and 100h dead fuel moisture content, respectively. Herbaceous, woody and foliar moisture content in the canopies were considered as constant variables across the entire state although the values were estimated according to the studied weather scenarios (see Table 1) and were similar to the previous project in which fire behavior was estimated for Colorado.

**Table 3. Herbaceous, woody and foliar moisture content for Colorado in each weather scenario**

Fuel moisture content (%)	Extreme	High	Moderate	Low
Herbaceous	30	39	66	102
Woody	70	76	86	102
Foliar moisture	90	90	100	110

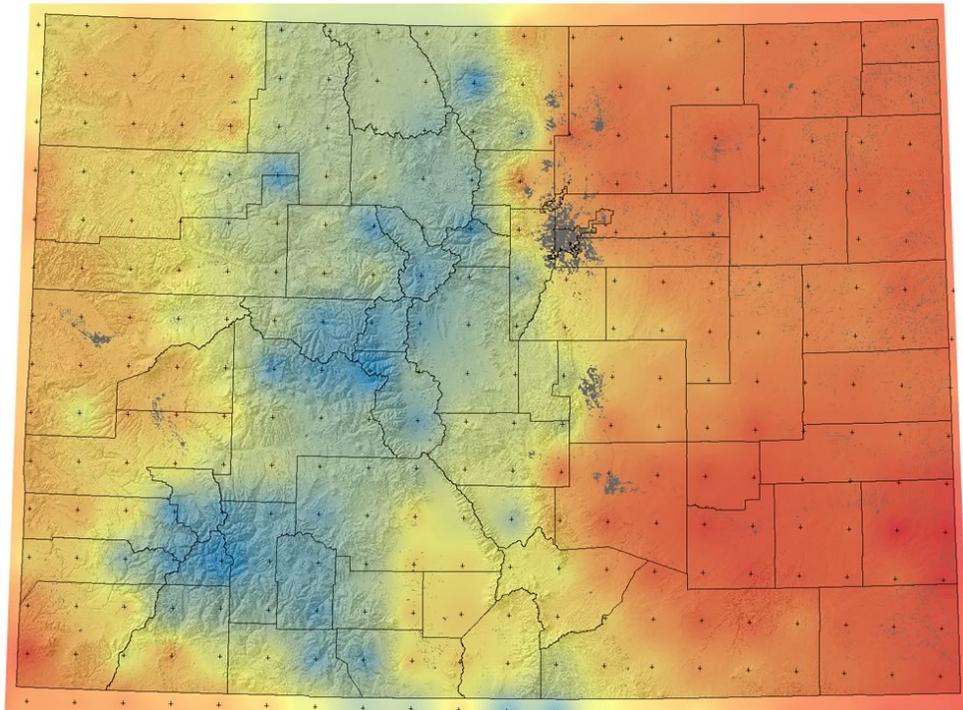
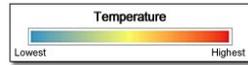
The following figure presents example of the interpolated temperature data for Colorado.

Figure 5. Interpolated 2m-temperature at 30 m pixel resolution (°C) from NARR points (marks) for the each weather percentile in a 30-year period (1988-2017).

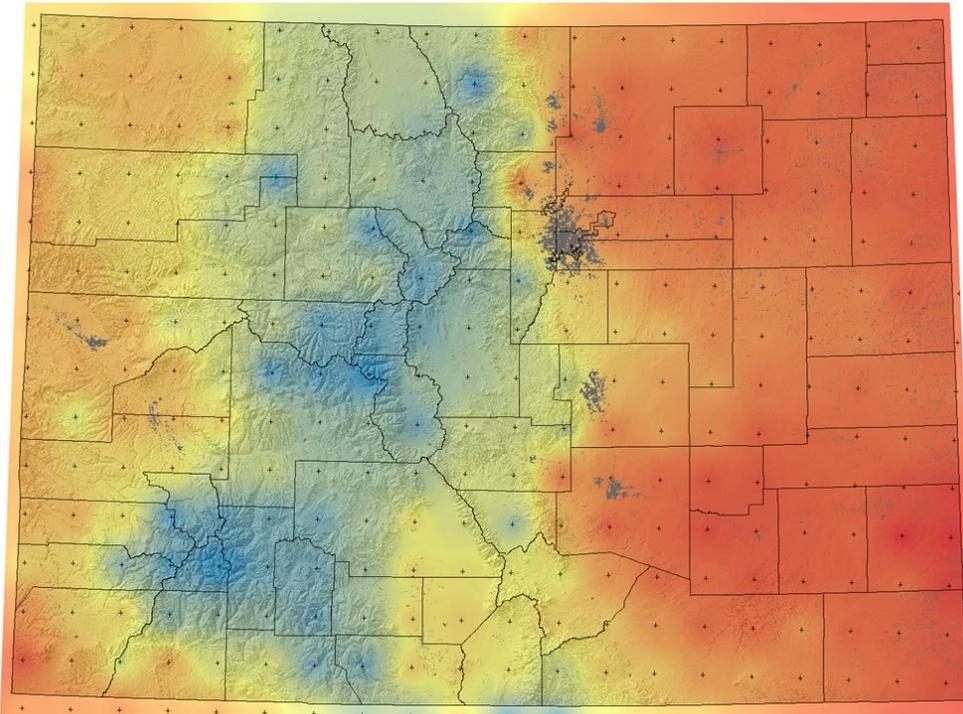
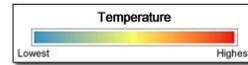




Colorado Wildfire Risk Assessment 2017  
TEMPERATURE - HIGH WX

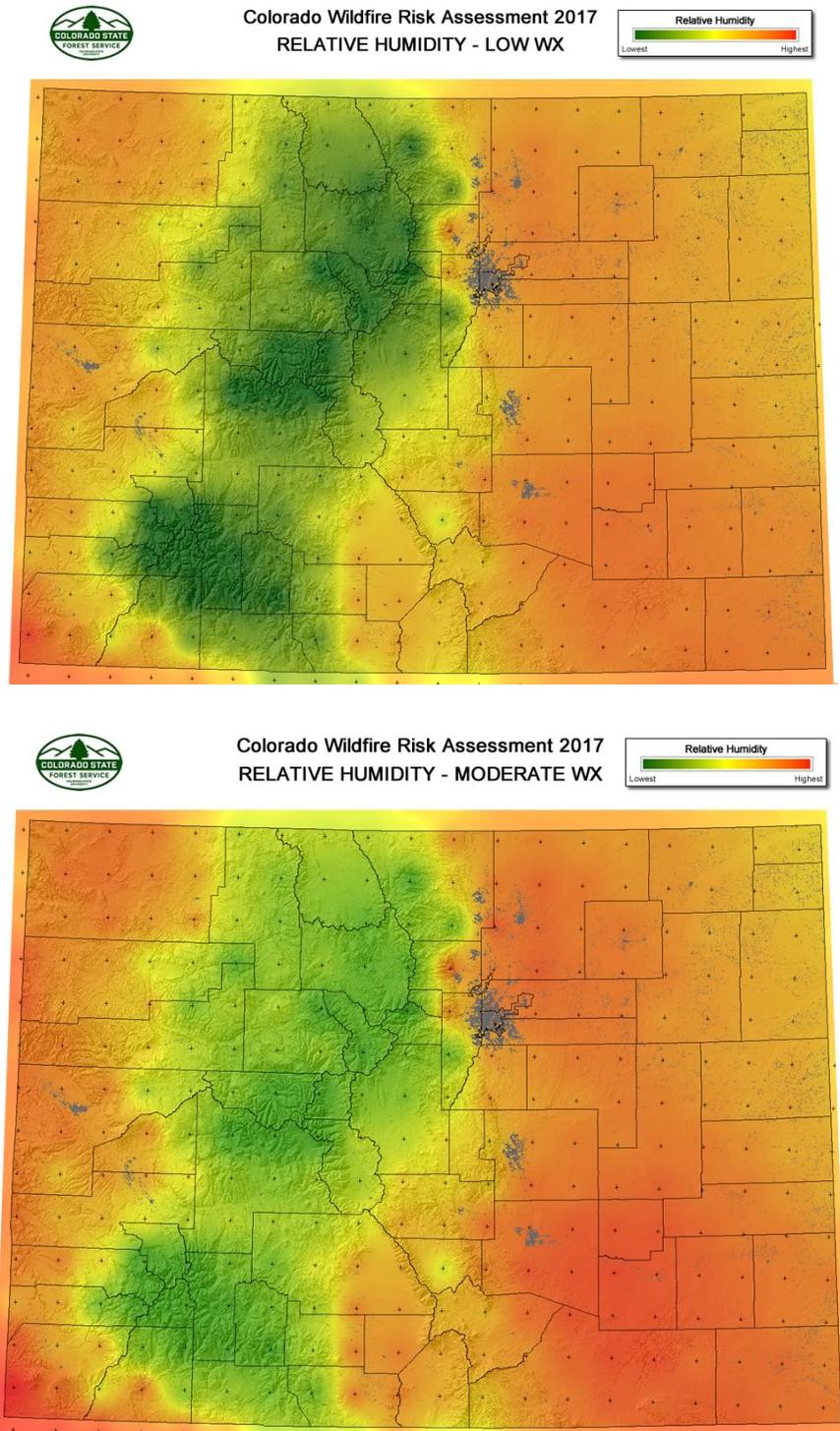


Colorado Wildfire Risk Assessment 2017  
TEMPERATURE - EXTREME WX



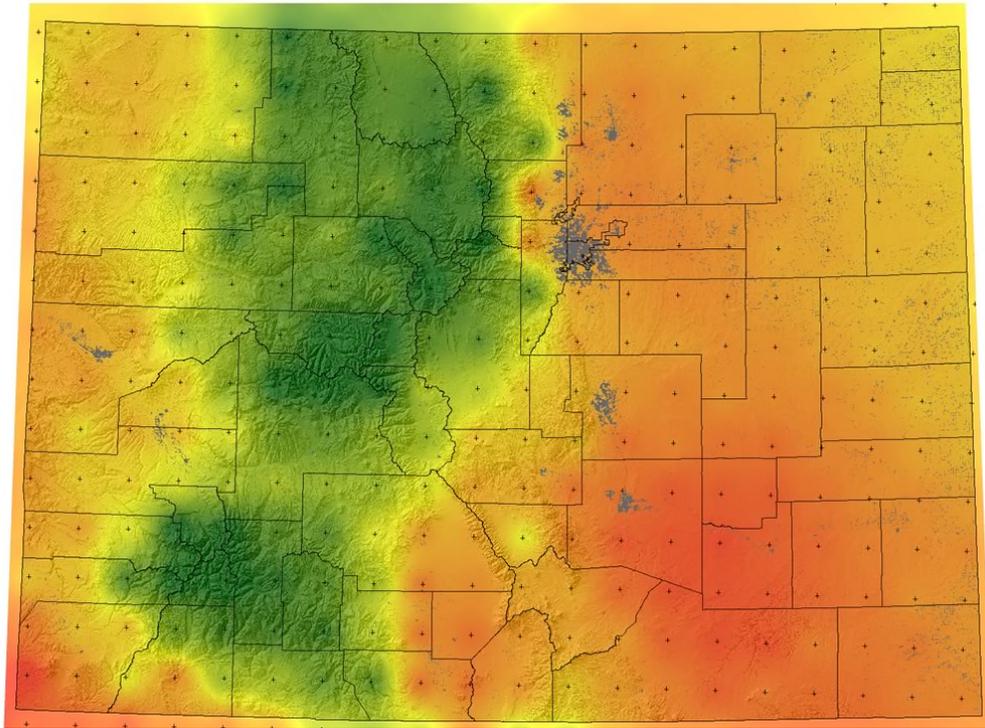
The following figure presents an example of the interpolated relative humidity data for Colorado.

**Figure 6. Interpolated 2m-air relative humidity at 30 m pixel resolution (%) from NARR points (marks) for each weather percentile in a 30-year period (1988-2017).**

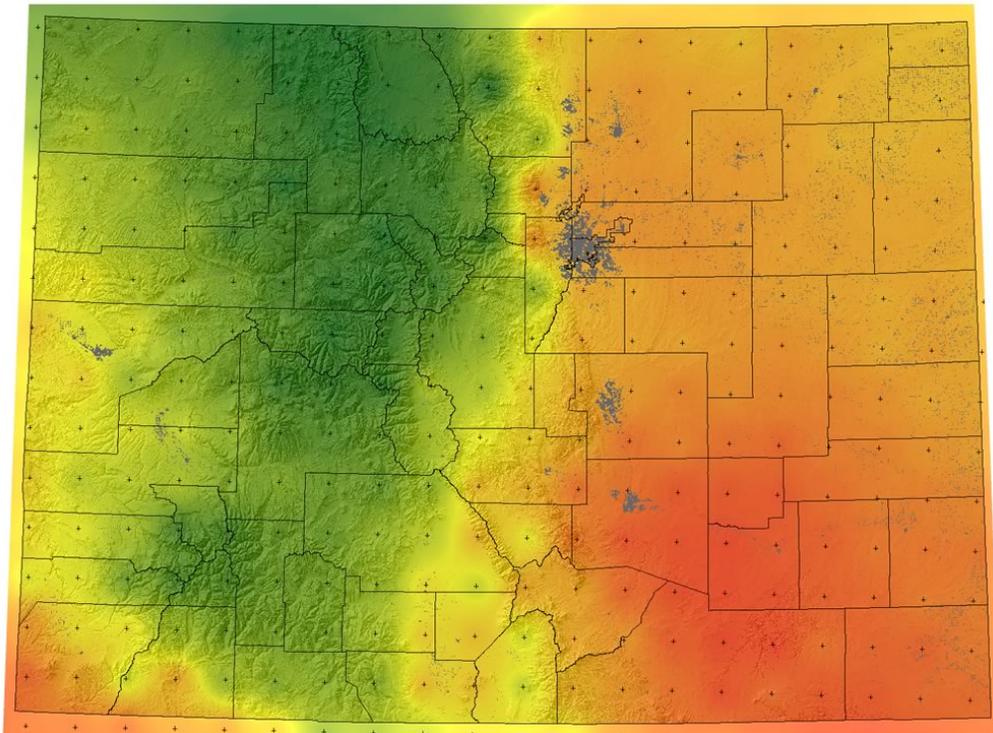




Colorado Wildfire Risk Assessment 2017  
RELATIVE HUMIDITY - HIGH WX



Colorado Wildfire Risk Assessment 2017  
RELATIVE HUMIDITY - EXTREME WX



Wind speed at 10 m (Figure 8) 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 30-meter pixel resolution. Wind direction for Colorado was analyzed for a 30-year period (1988-2017) considering the calculated wind speed percentiles from NARR data. Predominant wind direction is from SW to NE, especially when wind speed is high or very high (extreme scenario; Figure 7). For this reason, for each simulated fire, a random wind direction was used considering a Gaussian distribution of the NARR wind directions to keep the model as realistic as possible.

**Figure 7. Histogram for wind direction in Colorado by wind speed percentiles**

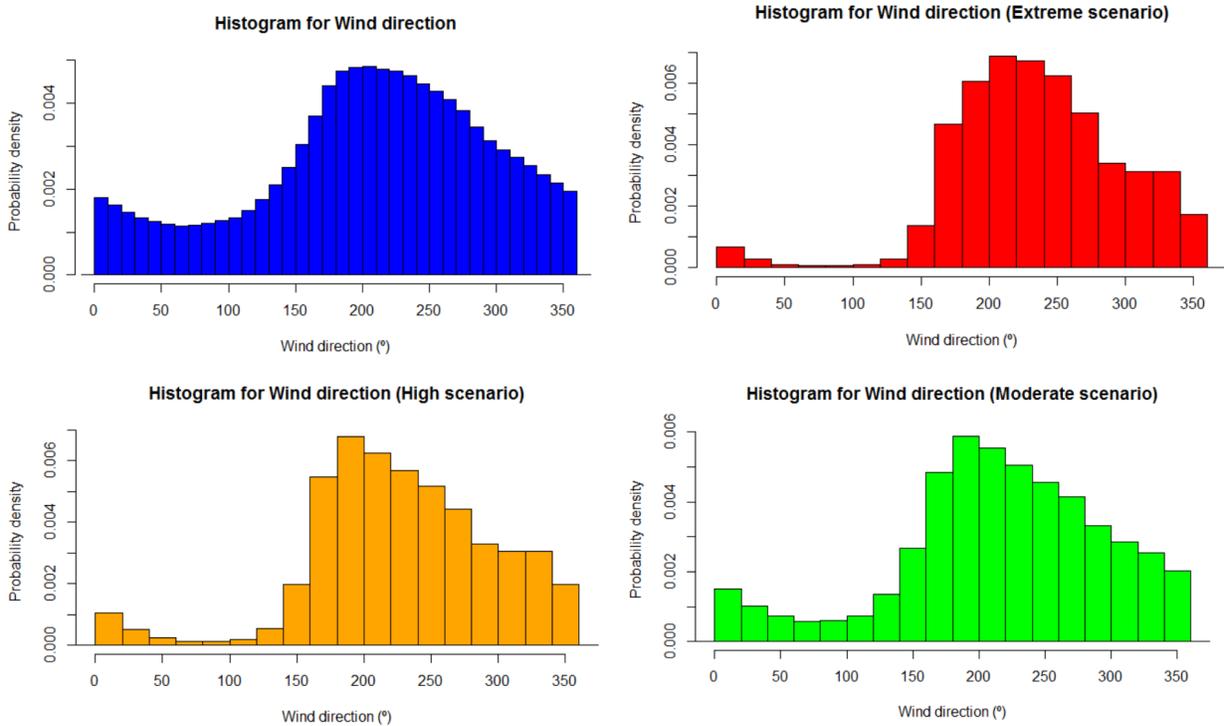
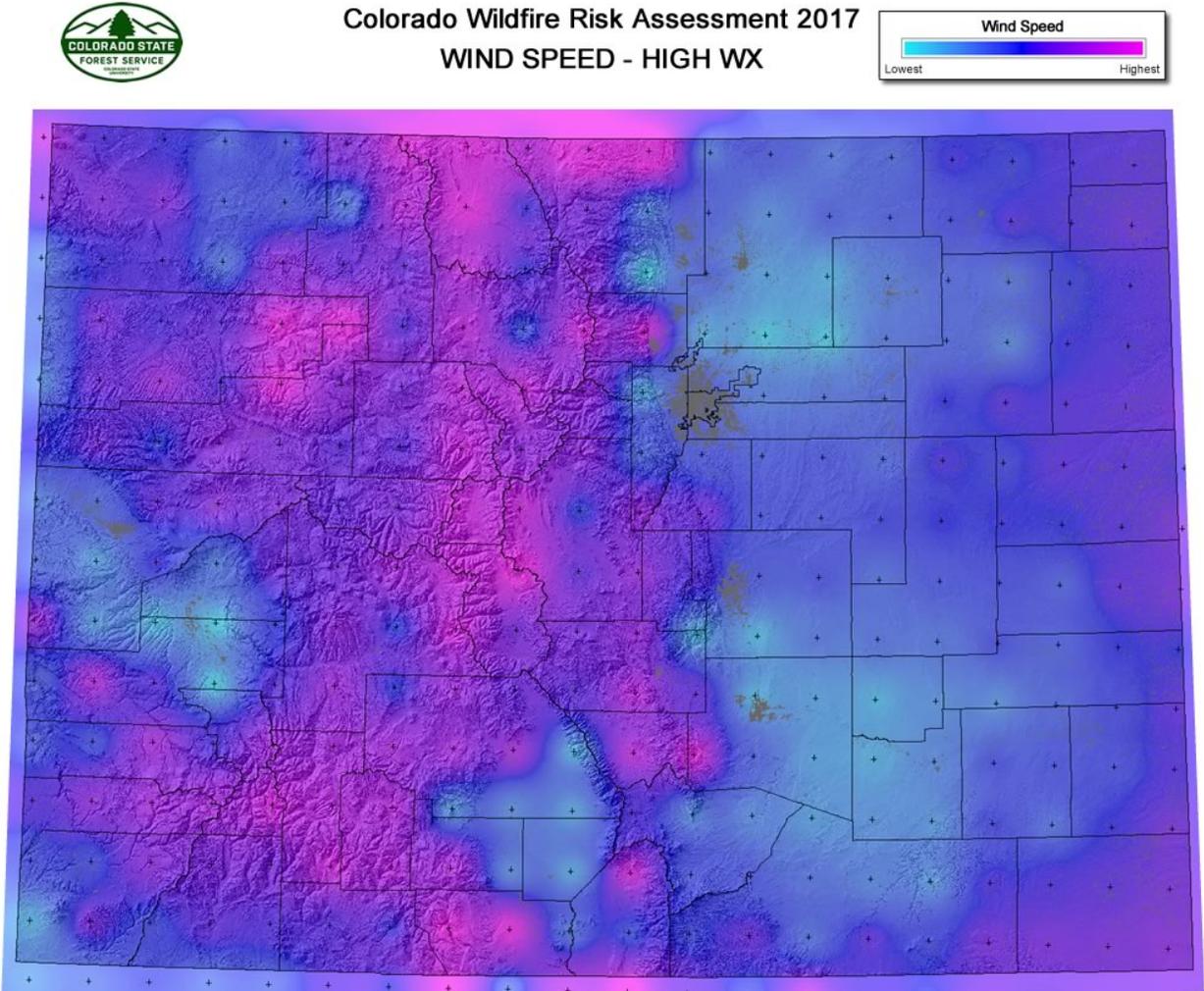


Figure 8. Interpolated 10m wind speed (mi/h) at 30 m pixel resolution from NARR points for the high weather scenario (90th percentile) over a 30-year period (1988-2017).



Finally, to better interpret and quality assure the final weather data, a comparison with the 2012 WIZs was conducted. This helped the technical team analyze the fire behavior outputs, compare them to 2012, and ensure that the calculations and results were correct. Since a comparison of 2012 versus 2017 risk outputs is necessary, it is important that key input datasets, such as fuels and weather data, be analyzed to support the description of differences in the risk outputs.

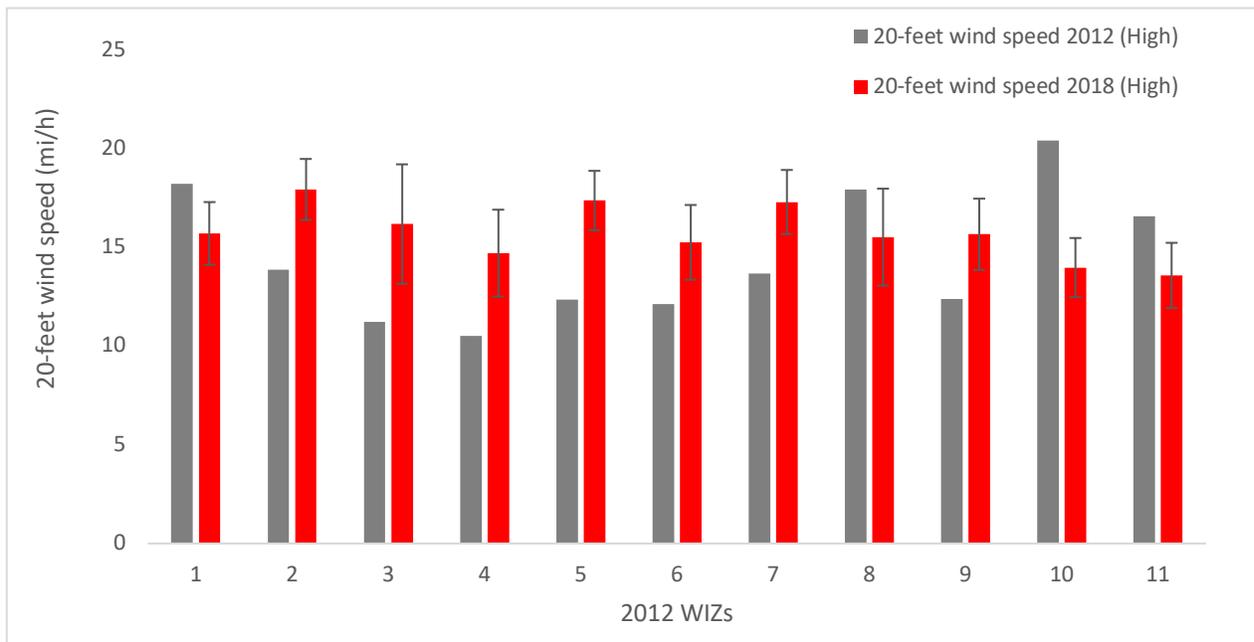
To facilitate a comparison of the weather data, the 2017 weather dataset was compiled into 2012 WIZ areas. A comparison of two key elements for the fire behavior modeling – wind speed and fuel moistures – was conducted. The following sections describe the comparison.

### ***Wind Speed Comparison Between 2017 and 2012 Risk Assessment***

Wind speed usually increases fire behavior in terms of flame length and rate of spread. This variable was considered constant within the 11 weather influence zones (WIZs) used in the 2012 risk assessment project (as comparison). Therefore, it is now difficult to compare a mean wind speed for a whole WIZ (mean area of a WIZ = 24,530 km<sup>2</sup>) with 2017 continuous wind fields throughout the study area at higher resolution. Wind spatial variability is usually high as Figure 7 shows for CO and needs to be considered in this type of analysis.

Figure 9 shows mean wind speed by WIZ for both 2012 and 2017 and no significant differences were found. In those WIZs with a higher wind speed, it is expected to have a higher fire behavior although spatial variability needs to be considered when comparing results at local scales.

**Figure 9. Wind speed for 2017 and 2012 risk assessment projects. Mean values by WIZ and standard deviation for the 2017 wind speed are shown for the High scenario (90th Percentile).**



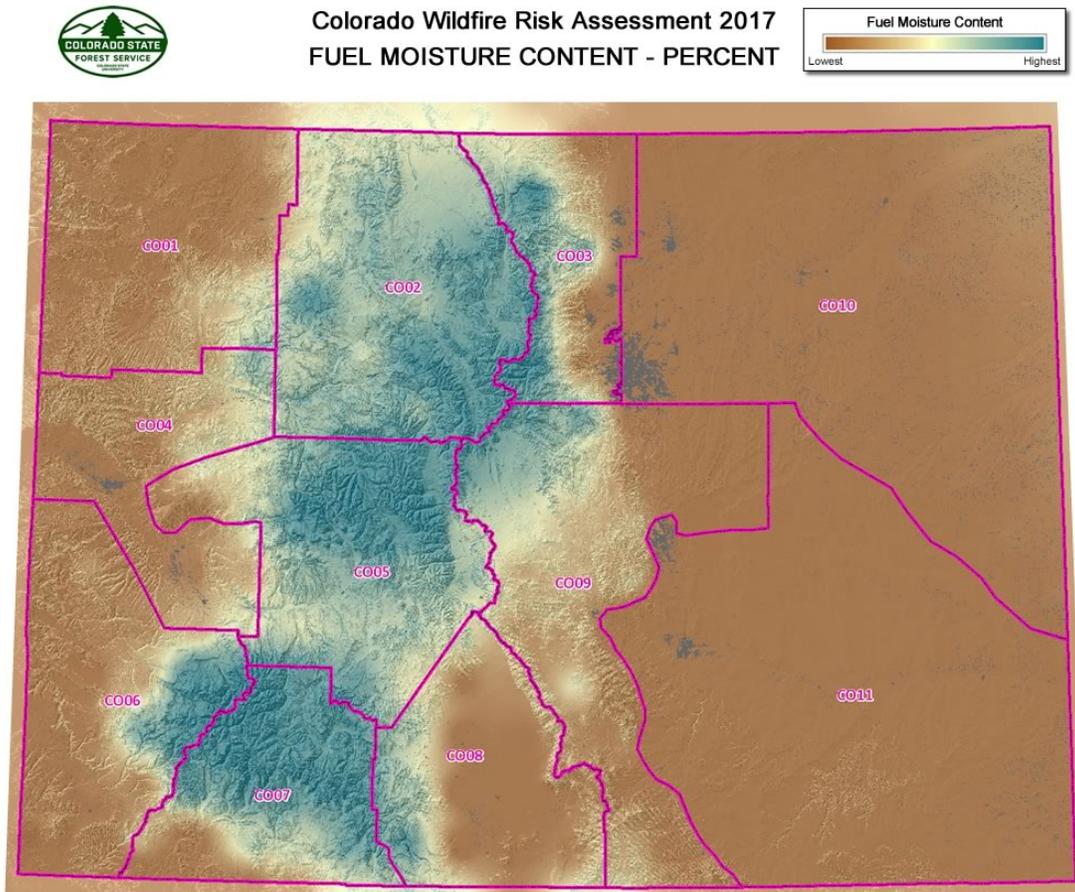
### ***Fuel Moisture Comparison Between 2017 and 2012 Risk Assessment***

Fine dead fuel moisture constant is one of the most influential variables for fire spread. In the 2012 risk assessment project, fuel moisture was considered as a constant variable in the 11 weather influence zones. In order to improve the accuracy of fire behavior outputs, we estimated 1h-FMC at 30-meter pixel resolution in the 2017 project by using the model of Rothermel and Rinehart (1983) and detailed weather scenarios. In this sense, we considered local conditions and better simulates the fire behavior at local scales considering FMC spatial variability. Figure 11 shows the mean 1h dead fuel moisture content (%) for 2017 and 2012 risk assessment projects in the high weather scenario (90<sup>th</sup> Percentile).

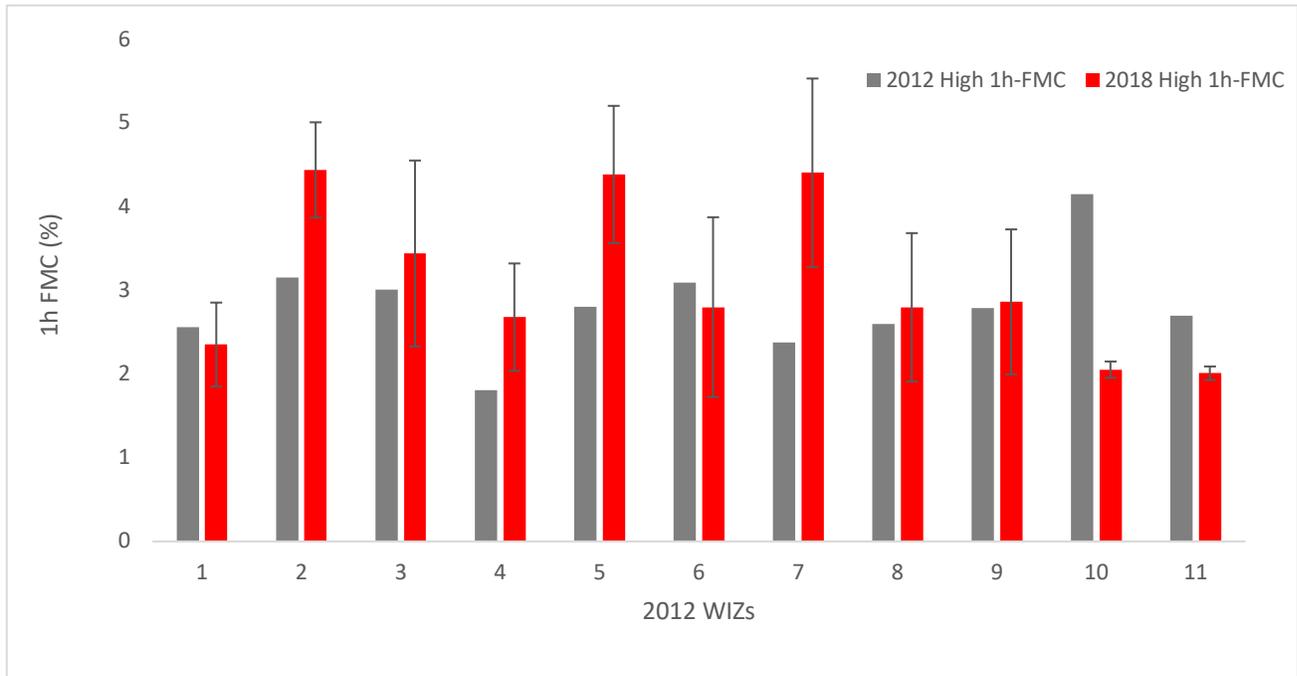
No relevant differences were found in most of WIZs in terms of mean 1h-FMC by WIZ between 2012 and 2017 projects for Colorado. Particularly, in the 2017 project, mean 1h-FMC values were very similar in

Eastern CO, a bit higher in Central CO (CO2, CO5 and CO7) and lower in western CO (CO10 and CO11), an area dominated by grasslands.

Figure 10. 1h dead fuel moisture content (%) for 2017 risk assessment with 2012 WIZ boundary overlay.



**Figure 11. 1h dead fuel moisture content (%) for 2017 and 2012 risk assessment projects. Mean values by 2012 WIZ and standard deviation for the 2017 1h FMC are shown for the High scenario (90th Percentile).**



### 3.3 Historical Fire Occurrence

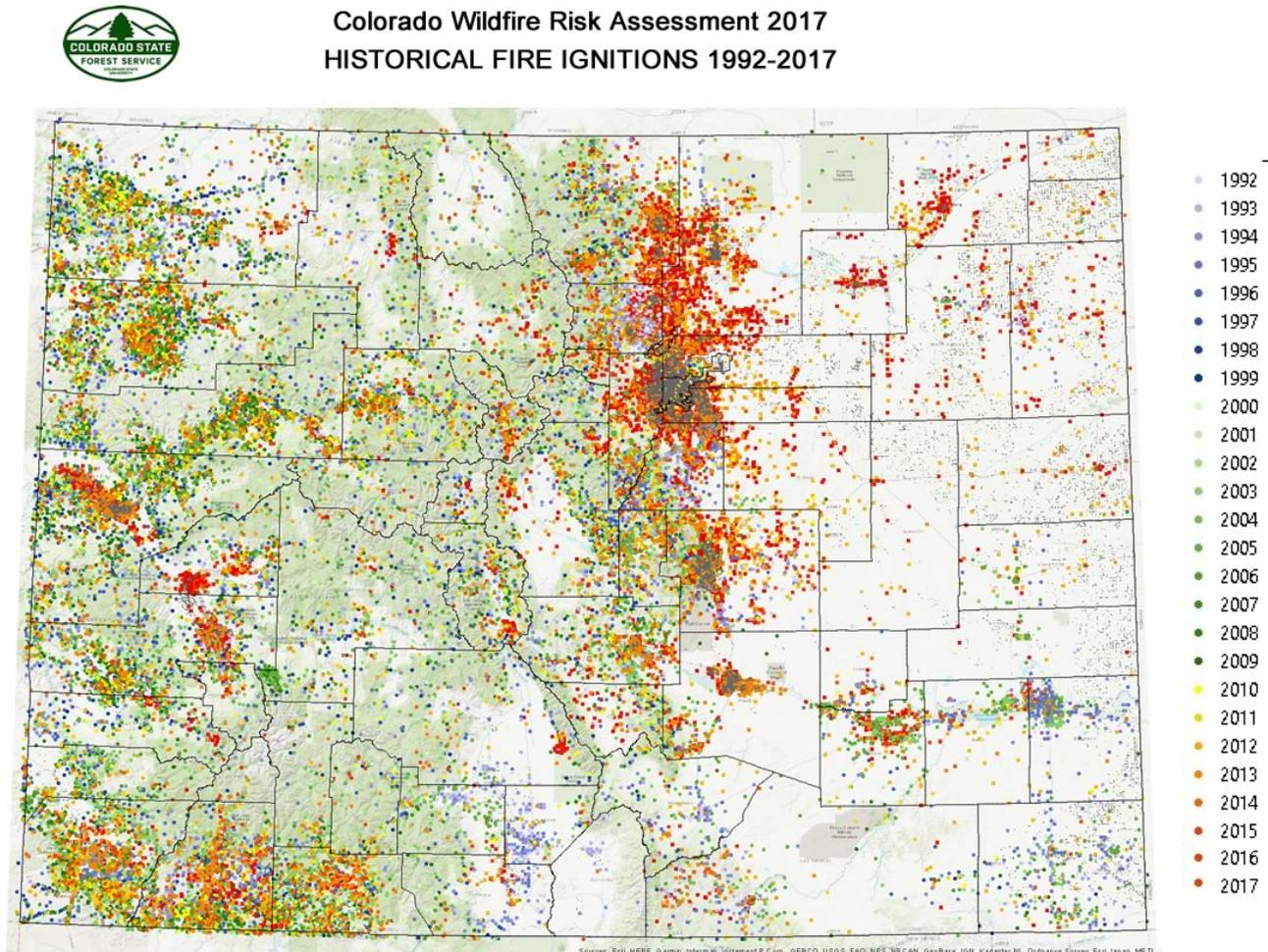
Historical fire occurrence was used as an input variable to produce the Burn Probability output as well as analysing FB outputs. Fire Occurrence is an ignition density that represents the likelihood of a wildfire starting based on historical ignition patterns. Occurrence is derived by modeling historic 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 wildfire ignitions data for Colorado were compiled for the period 1992-2017. The primary source for these data was the dataset compiled by the USFS Fire Sciences Laboratory (Karen Short). Federal wildfire ignitions are spatially referenced by latitude and longitude coordinates. All ignitions references were updated to remove duplicate records and correct inaccurate locations.

Non-federally reported fire ignition locations for Colorado were compiled for 2009 to 2017. All ignitions data sources were updated to remove duplicate records and correct inaccurate locations. The original source of the data is reported by local fire departments through the National Fire Incident Reporting System (NFIRS). It is the system used by structural (regular) fire departments for collecting all kinds of fires. Wildland fires are just a portion of them. It is administered nationally by FEMA. Reference info <https://www.nfirs.fema.gov/>. Annually, the Colorado Division of Fire Control & Prevention sends data to CSFS of the wildland fires that are reported within NFIRS. CSFS then formats and submits that data through the National Association of State Foresters to the USDA-Forest Service Data Warehouse, Fire and Aviation Management Web Applications (FAMWEB) site where it is hosted for all the federal, state, and local wildland fire management agencies. Reference site is <https://fam.nwcg.gov/fam-web/>.

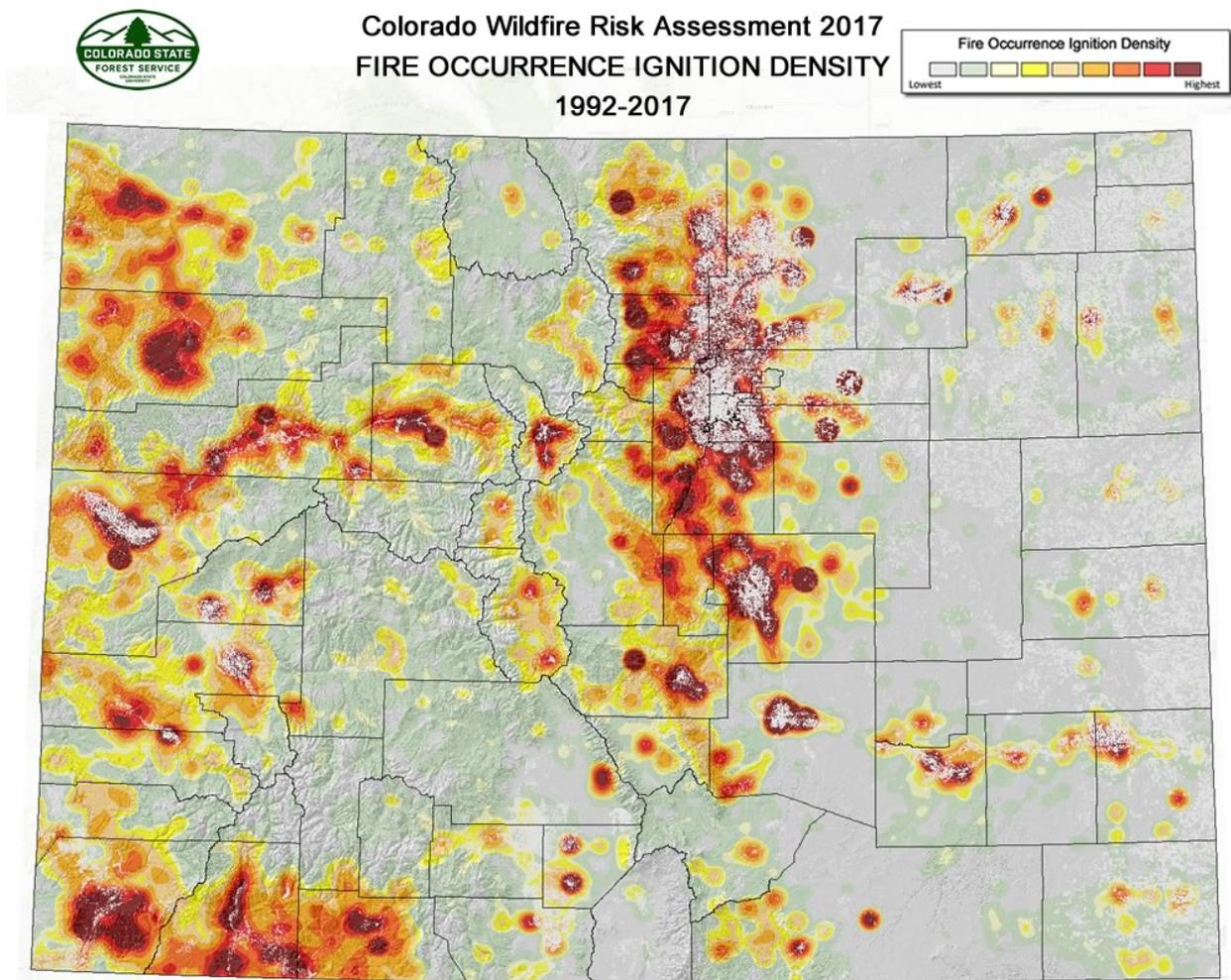
A 30-meter ignition density grid was derived using a Kernel function from the combined federal and non-federal point ignition data. Figure 12 shows the spatial distribution of the total number of fires for Colorado.

Figure 12. Historical ignitions for 1992 - 2017.



The following figure shows the ignition density (fire occurrence) based on the 1992-2017 fire ignition points.

Figure 13. Fire occurrence ignition density for 1992-2017.



### 3.4 Highly Valued Resources and Assets

The 2017 CO-WRA utilizes the same HVRA datasets as the 2012 assessment:

- Wildland Urban Interface (WUI)
- Drinking Water Importance
- Forest Assets
- Riparian Assets

**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.

**Drinking Water Importance** depicts a measure of quality and quantity of public surface drinking water categorized by watershed.

**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 HVRA 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 2016 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.<sup>4</sup> SILVIS defines WUI areas based on a combination of housing density and forest cover percent. Recent improvements on defining the WUI have been achieved by leveraging LandScan data for both the West Wide Risk Assessment (17 Western states), and the Southern Wildfire Risk Assessment (13 Southern states). Technosylva staff were the technical leads in defining these new methods.

In the 2012 CO-WRA project considerable investigation was undertaken to evaluate existing WUI data and methods. Based on this investigation, a new housing density dataset was developed (called Where People Live), based on methods developed for the West Wide Risk Assessment (2013) and the Southern Wildfire Risk Assessment (2014). Technosylva staff developed these datasets for 30 states based upon methods initially developed in the USFS First Approximation to Wildfire Risk project that utilized LandScan

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<sup>4</sup> Please see <http://SILVIS.forest.wisc.edu/maps/WUI> for more information about the SILVIS WUI data.

population count data to model housing density.<sup>5</sup> Accordingly, for the 2012 CO-WRA the Where People Live (WPL) dataset was derived by modeling the Oak Ridge National Laboratory LandScan 2012 data.<sup>6</sup>

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 or Theobald) that were developed using Census Block data that has a coarser spatial resolution. For the West Wide Risk Assessment project LandScan data for 2009 was used to create the WPL dataset. Urban areas were then extracted from the WPL data to create the WWA version of WUI, called Wildland Development Areas (WDA). The WWA project chose not to use the term WUI for this dataset to reflect preferences of the project steering committee.

For the 2012 CO-WRA, LandScan data for 2012 were obtained and modeled to create Colorado WPL and WUI 2012 datasets. These datasets were then used to model WUI Risk for Colorado.

For the 2017 CO-WRA, LandScan data for 2016 were obtained from the Department of Homeland Security, HSIP Dataset. This reflected the latest LandScan data available. The following figure shows the LandScan 2016 data for Colorado. It is important to note that while an example classified map of LandScan data is shown, DHS HSIP policies restrict the sharing or publishing of this original dataset. Accordingly, while LandScan remains a key component of delineating WPL and WUI for Colorado, the original source LandScan data cannot be shared by the CSFS, and cannot be shown in the CO-WRAP web site applications. Users must acquire this data directly from DHS.

Figure 14 presents a map of the LandScan 2016 population count data for Colorado.

Figure 15 shows a map of the LandScan 2016 data for the Fort Collins area.

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<sup>5</sup> Calkin, David E.; Ager, Alan A.; Gilbertson-Day, Julie, eds. 2010. Wildfire Risk And Hazard: Procedures For The First Approximation. Gen. Tech. Rep. RMRS-GTR-235. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.

<sup>6</sup> Please refer to the ORNL Landscan web site at <http://www.ornl.gov/sci/landscan/> for more information about LandScan.

Figure 14. LandScan 2016 statewide map of population count.

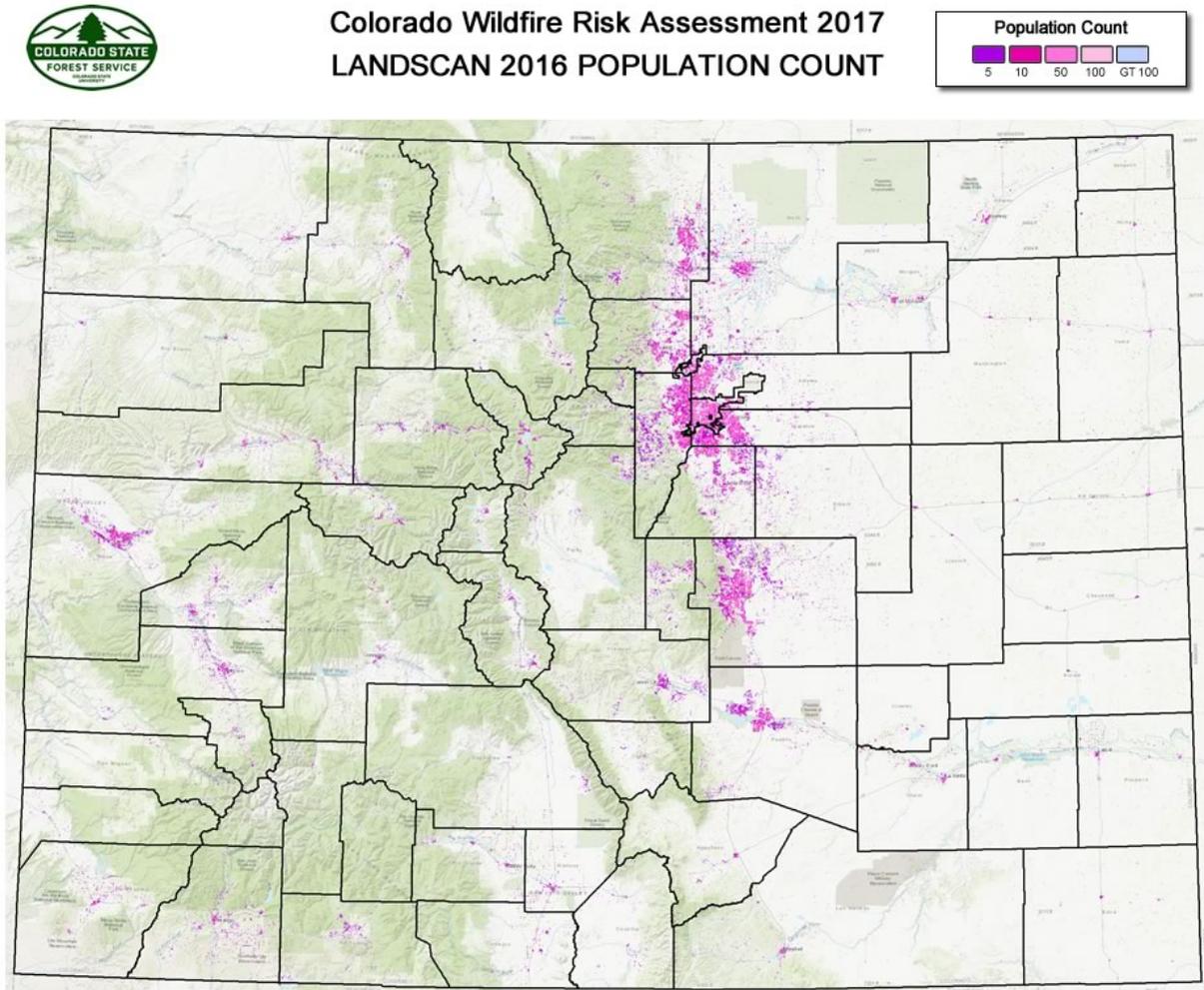
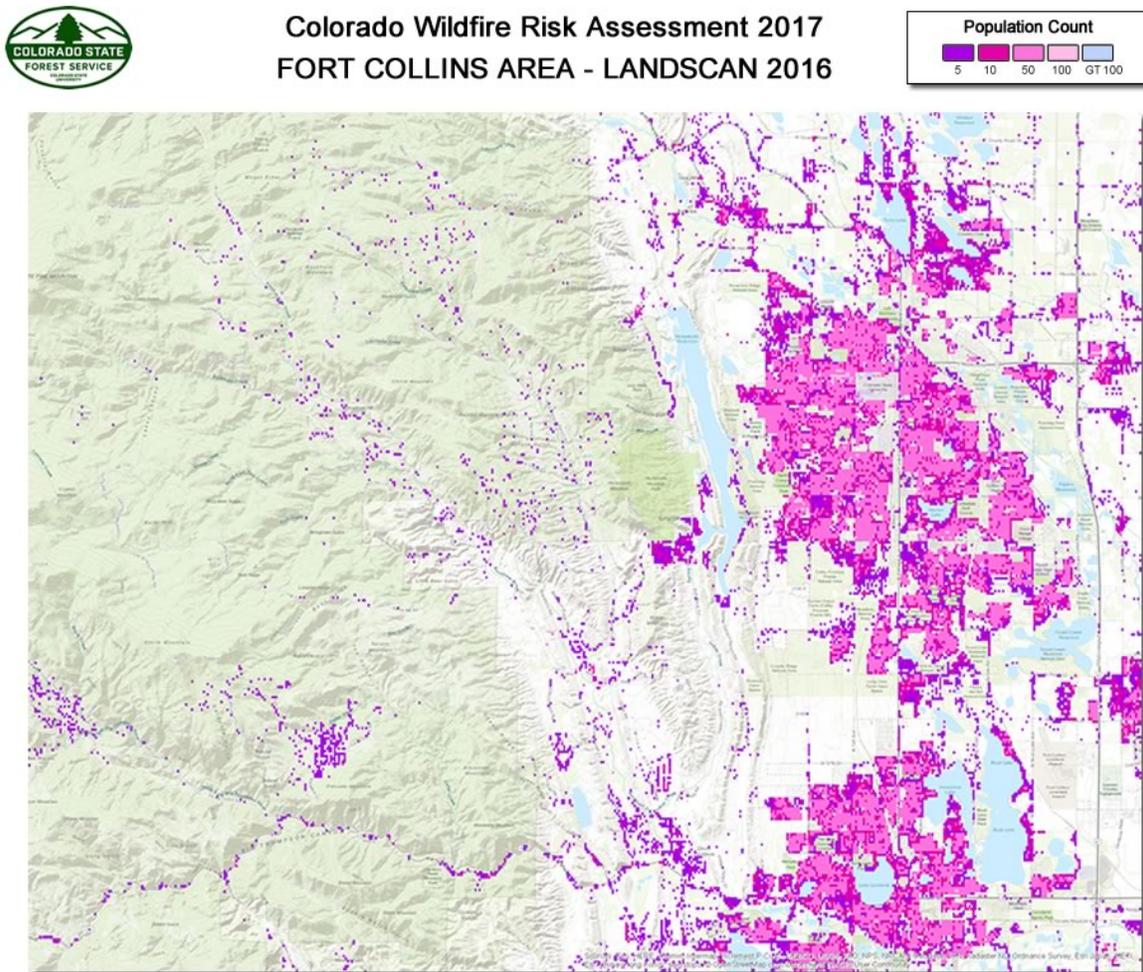
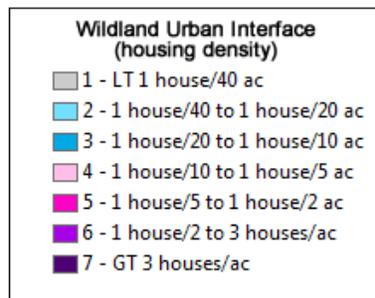


Figure 15. LandScan 2016 Boulder map of population count.



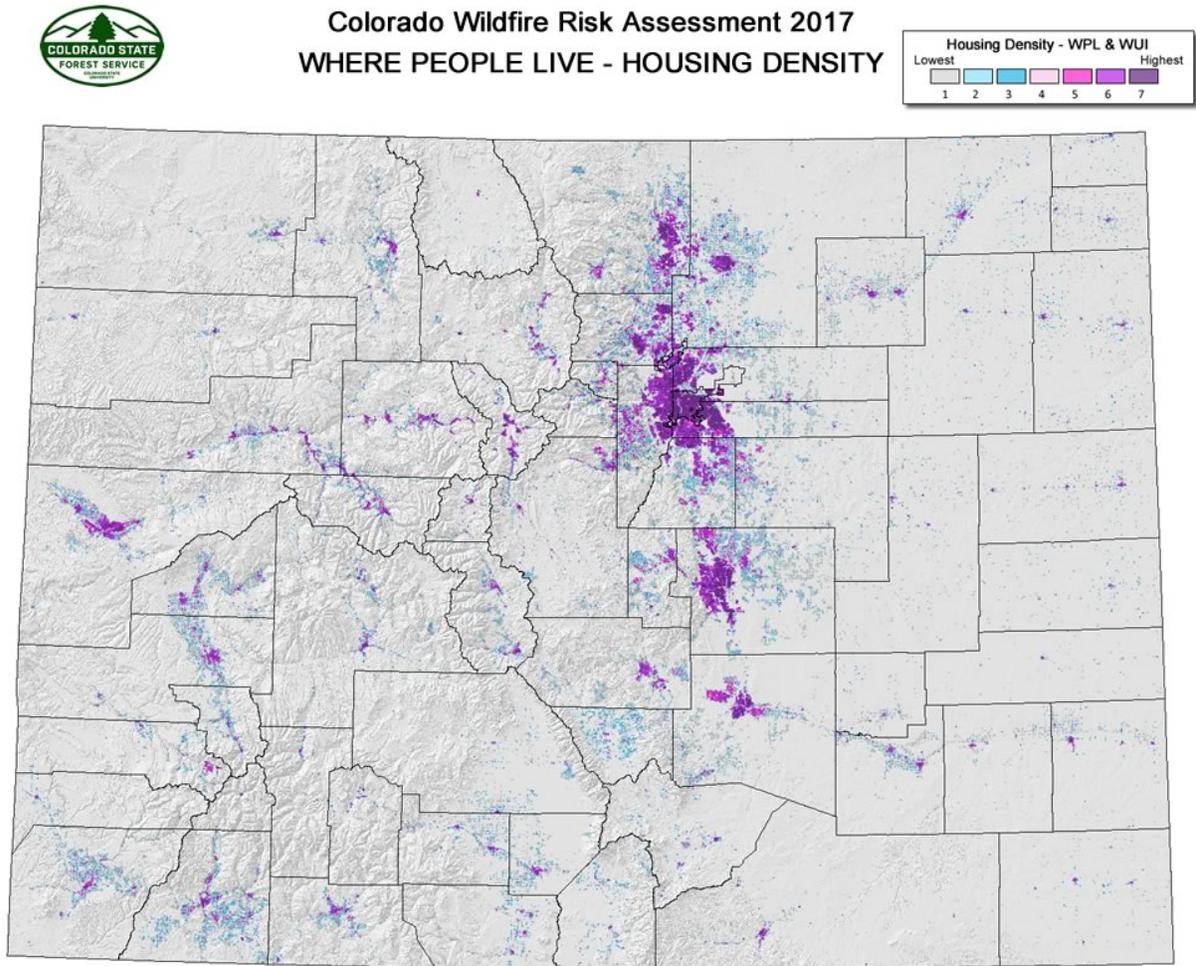
Technosylva developed a model that combined the LandScan 2016 data with other relevant datasets, i.e. Census 2010 County Housing Summaries, Colorado county parcel data, 2017 fuels urban and agriculture fuel models, building footprints, and 2014 postal address locations, to derive a 30-meter resolution 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 16. WPL and WUI housing density classes.



The following figures depict the 2016 WPL for Colorado.

**Figure 17. WPL housing density for Colorado.**



In the CO-WRA and in the CO-WRAP 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. Custom techniques were developed to implement this since the standard ESRI ArcGIS neighborhood decay function resulted in interior artifacts of high fire behavior values due to the existence of isolated edge cells. This occasionally produced artificially high values in the urban core that would not be realistic to represent the impact of wildland edges.

The urban encroachment algorithm was enhanced for the 2017 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. 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 show 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.

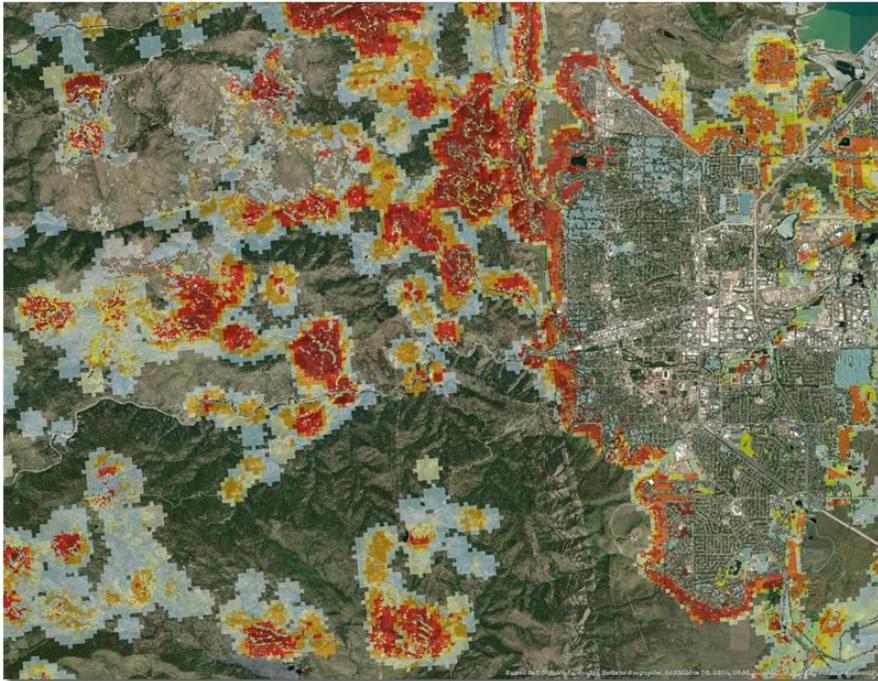
Figure 18. Example show WPL and WUI with urban encroachment for the Boulder area.



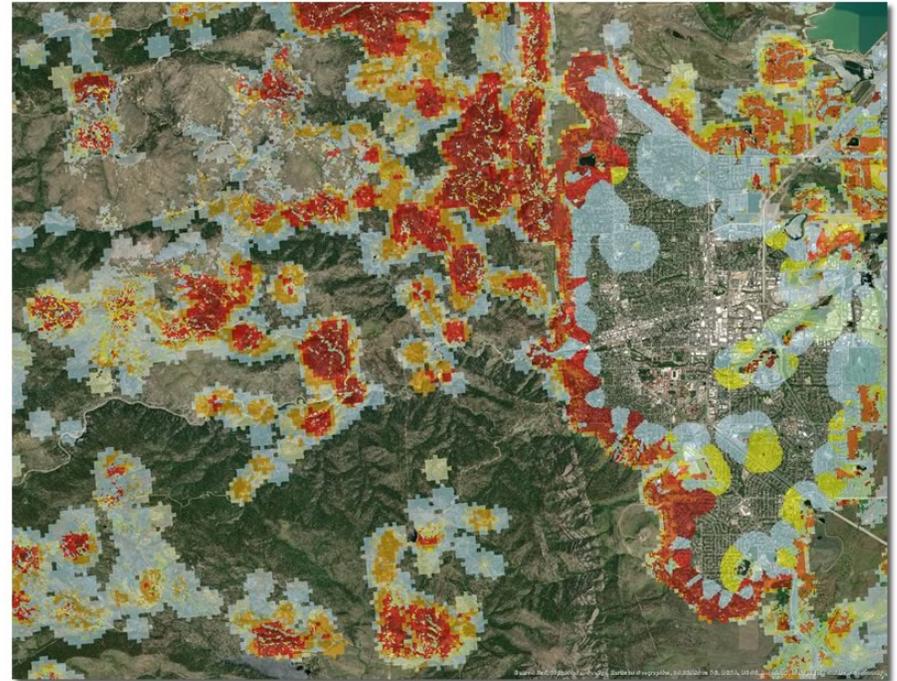
The urban encroachment enhancement is focused on the development of a WUI dataset that results in an enhanced WUI Risk Index output. The following figure presents an example of the WUI Risk Index output that is derived by combining the WPL with Flame Length using urban encroachment.

The map on the left shows the WUI Risk if no urban encroachment was applied. The map on the right shows the CO-WRA WUI Risk that uses urban encroachment.

Figure 19. Comparison of WUI Risk without and with urban encroachment for the Boulder area.



WUI Risk without urban encroachment



WUI Risk with urban encroachment

### 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 2014 Existing Vegetation Height (EVH) data set).

**Table 4. Forest Asset layer characteristics**

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

LANDFIRE 2014’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. 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.

**Table 5. General description of the Forest Assets fire response classes.**

Value Impacted	General Description
<b>Sensitive (Code = 1)</b>	Fire sensitive. Intolerant trees sensitive to damage from fire with low intensities.
<b>Resilient (Code = 2)</b>	Fire resisters. Tolerant tree species whose adult stages can survive low severity fires.
<b>Adaptive (Code = 3)</b>	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 2014 EVT data set.

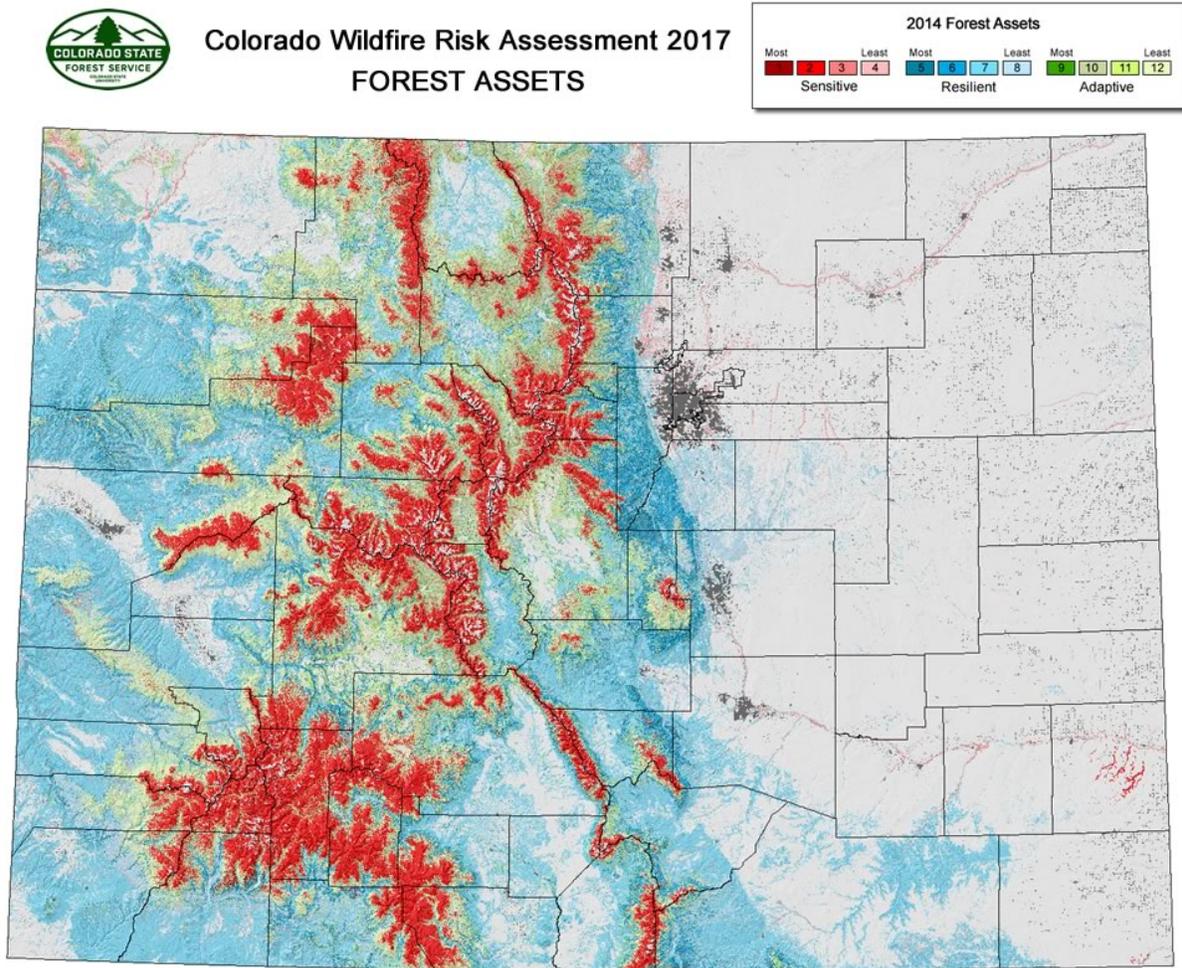
**Table 6. Description of canopy cover classes for Forest Assets.**

Value Impacted	General Description
<b>Sparse</b>	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%.

Value Impacted	General Description
<b>Open</b>	Open stands of trees with crowns not usually touching (generally forming 25-60% cover).
<b>Closed</b>	Trees with their crowns overlapping (generally forming 60-100% cover).

The following figure presents the Forest Assets dataset for Colorado.

Figure 20. 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.

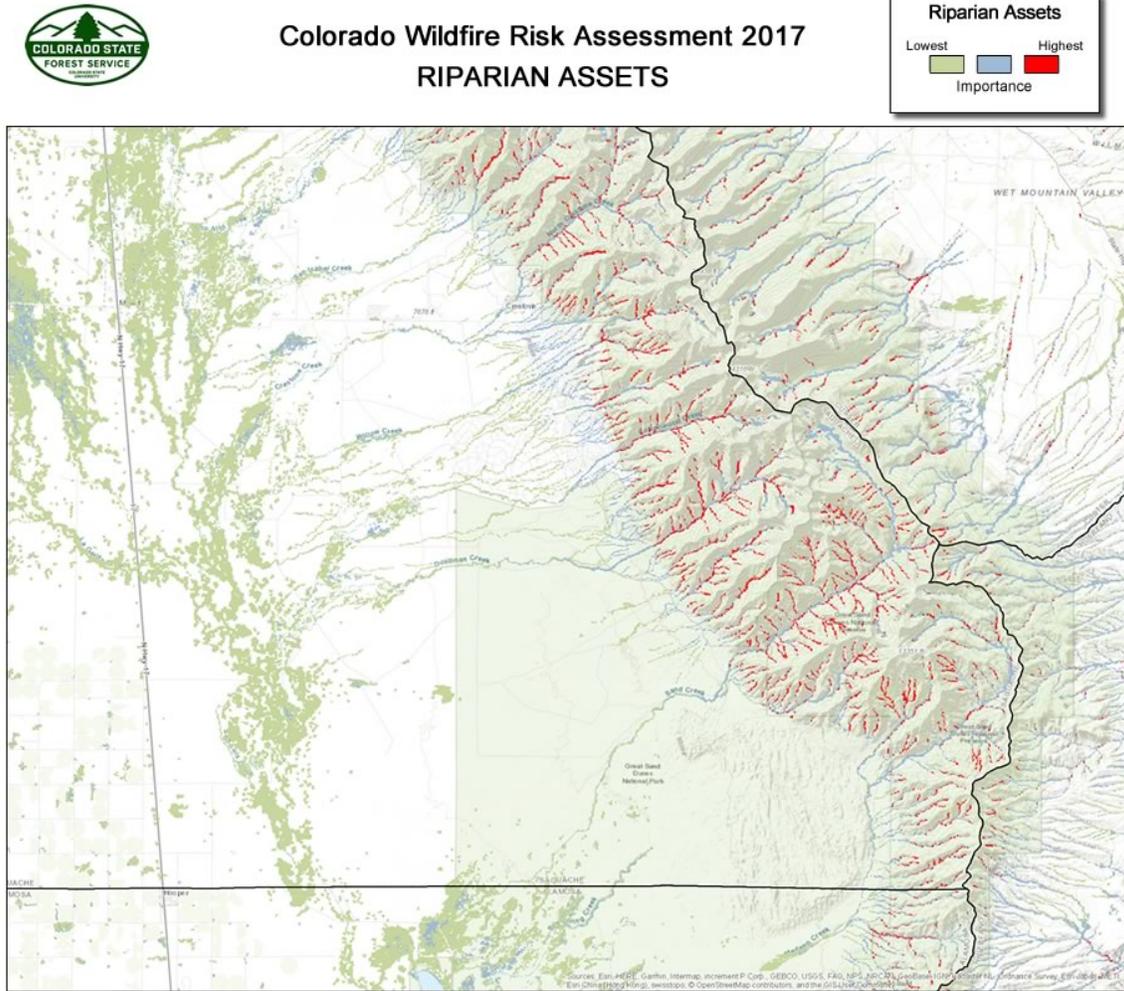
The National Hydrography Data Set (NHD) was used to represent hydrology. A subset of streams and water bodies, which represents perennial, intermittent, and wetlands, was created. The NHD water bodies' data set was used to determine the location of lakes, ponds, swamps, and marshes (wetlands).

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 2014 vegetation classification to depict habitat quality and susceptibility to fire.

The model creates value 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 21. Example of Riparian Assets.



### ***Drinking Water Importance***

This layer identifies an index of surface drinking water importance, reflecting a measure of water quality and quantity, characterized by Hydrologic Unit Code 12 (HUC 12) watersheds. The Hydrologic Unit system is a standardized watershed classification system developed by USGS.<sup>7</sup> Areas that are a source of drinking water are of critical importance and adverse effects from fire are a key concern.

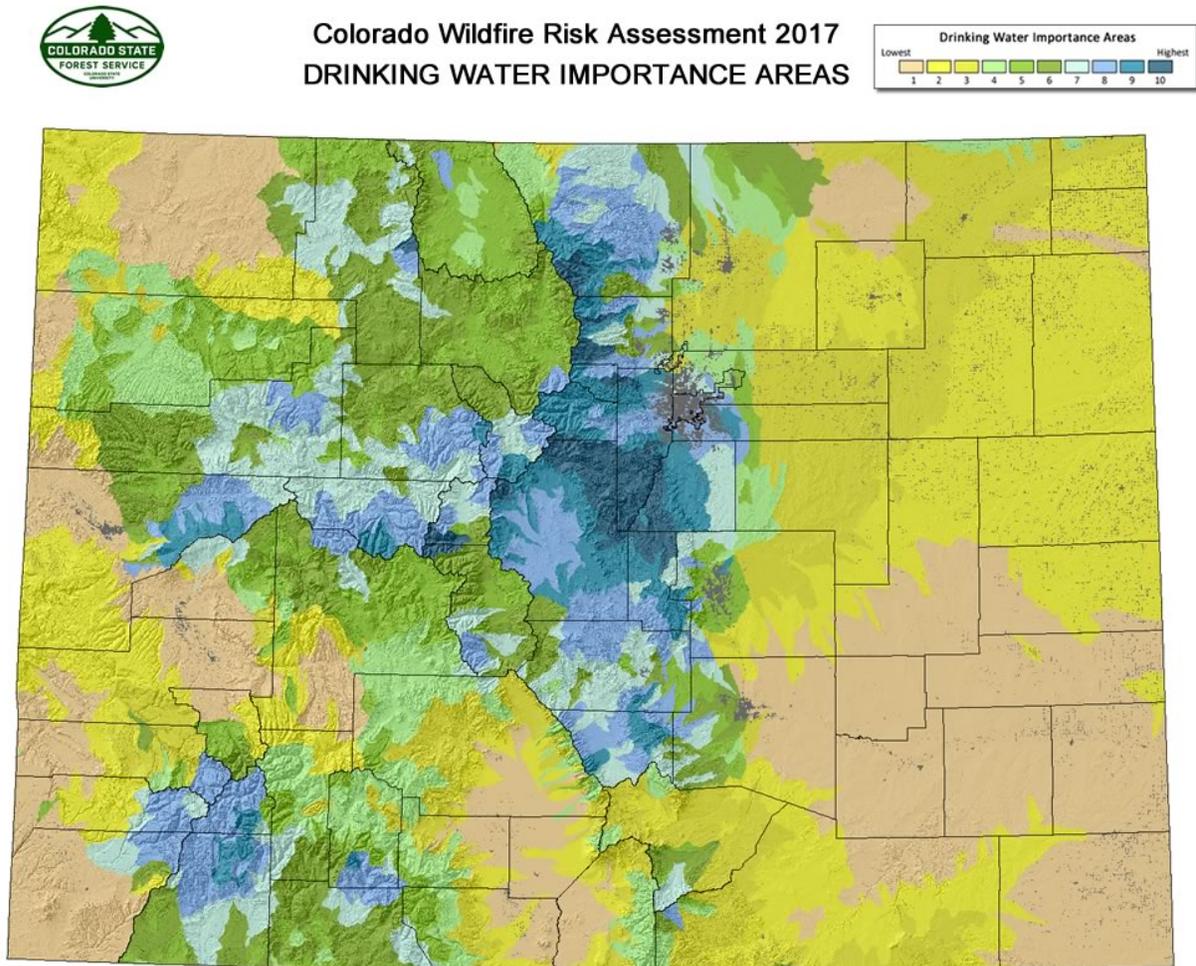
The U.S. Forest Service Forests to Faucets (F2F) project is the primary source of the drinking water dataset.<sup>8</sup> This project used GIS modeling to develop an index of importance for supplying drinking water using HUC 12 watersheds as the spatial resolution. Watersheds are ranked from 1 to 100 reflecting relative level of importance, with 100 being the most important and 1 the least important.

<sup>7</sup> Please refer to [http://nwis.waterdata.usgs.gov/tutorial/huc\\_def.html](http://nwis.waterdata.usgs.gov/tutorial/huc_def.html).

<sup>8</sup> Please refer to [http://www.fs.fed.us/ecosystemservices/FS\\_Efforts/forests2faucets.shtml](http://www.fs.fed.us/ecosystemservices/FS_Efforts/forests2faucets.shtml).

Several criteria were used in the F2F project to derive the importance rating including water supply, flow analysis, and downstream drinking water demand. The final model of surface drinking water importance used in the F2F project combines the drinking water protection model, capturing the flow of water and water demand, with a model of mean annual water supply. The values generated by the drinking water protection model are simply multiplied by the results of the model of mean annual water supply to create the final surface drinking water importance index (Weidner, E., Todd, A. 2011).

Figure 22. Colorado Drinking Water Importance Areas.



## 4. FIRE BEHAVIOR MODELING

This section describes the fire behavior modeling methods and results from the 2017 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 (and canopy data).

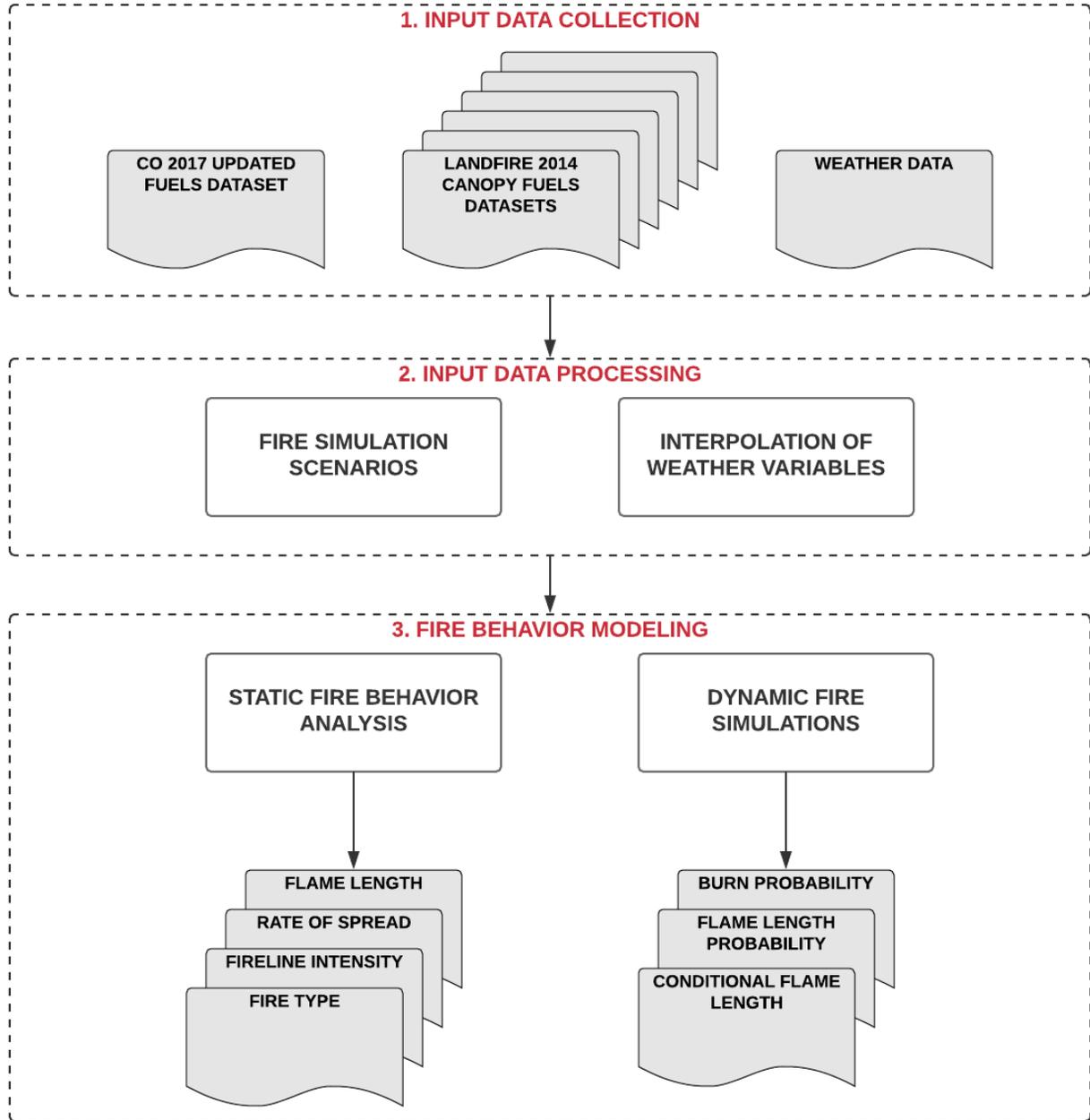
The main purpose of this task is to assess the potential fire behavior in Colorado using both static and dynamic fire simulation approaches.

The fire modeling tasks were completed using Technosylva's Wildfire Analyst™ (WFA) software (WFA, Ramirez et al, 2011).<sup>9</sup> 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 following diagram presents the general processing workflow that was employed.

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<sup>9</sup> Please visit [www.WildfireAnalyst.com](http://www.WildfireAnalyst.com) for more information about the software.

Figure 23. Fire behavior processing steps.



## 4.2 Fire Behavior Outputs

A static fire simulation approach was used to model potential maximum fire behavior (FB) for the state in terms of rate of spread, flame length, fireline intensity and type of fire in each pixel (unburnable, surface, torching or crowning). A 30-meter data resolution was employed matching the surface fuels input dataset. 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:<sup>10</sup>

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
1. Fuels (surface and crown).
  - a. Updated Colorado 2017 surface fuels
  - b. LANDFIRE 2014 crown fuels

Fire behavior outputs were calculated with true floating point values for the 30-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 the Colorado Front Range area (Boulder and Larimer County).

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<sup>10</sup> Please refer to [www.WildfireAnalyst.com](http://www.WildfireAnalyst.com) for more information.

Figure 24. Example Flame Length map of the Front Range.



Colorado Wildfire Risk Assessment 2017  
FLAME LENGTH

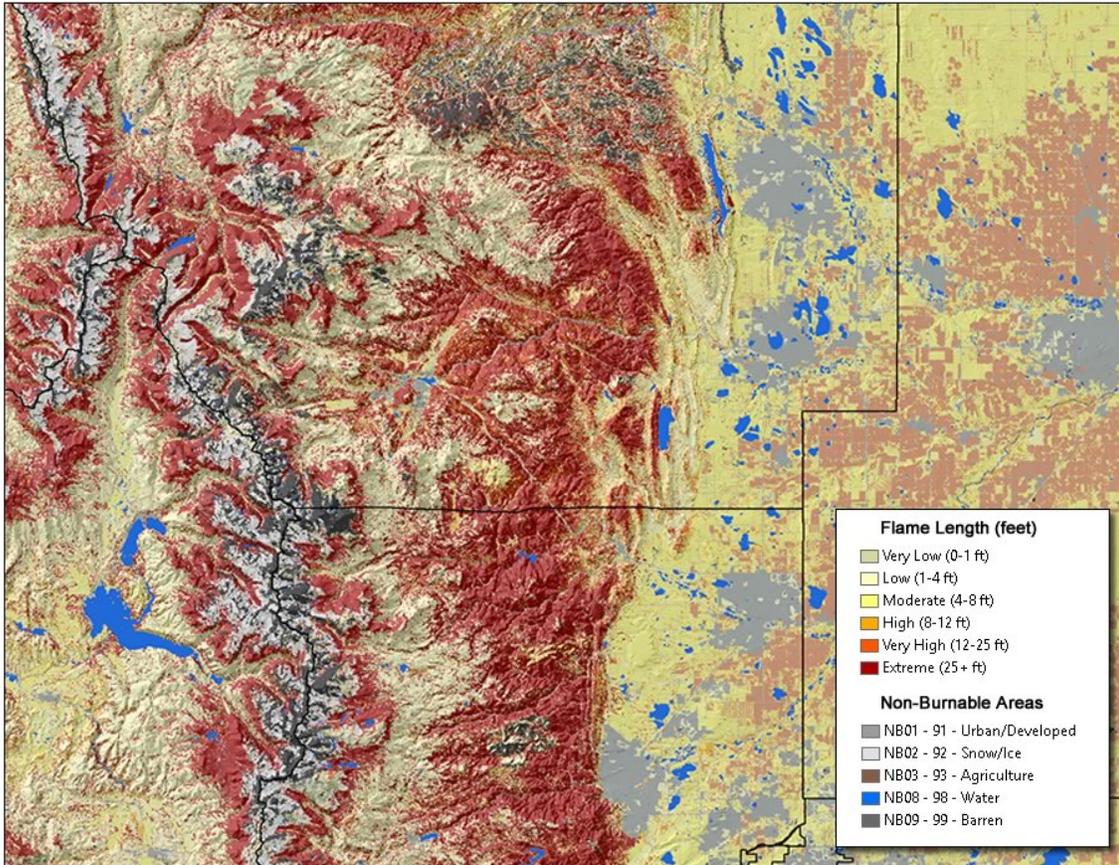


Figure 25. Example Fire Type map of the Front Range.



Colorado Wildfire Risk Assessment 2017  
FIRE TYPE

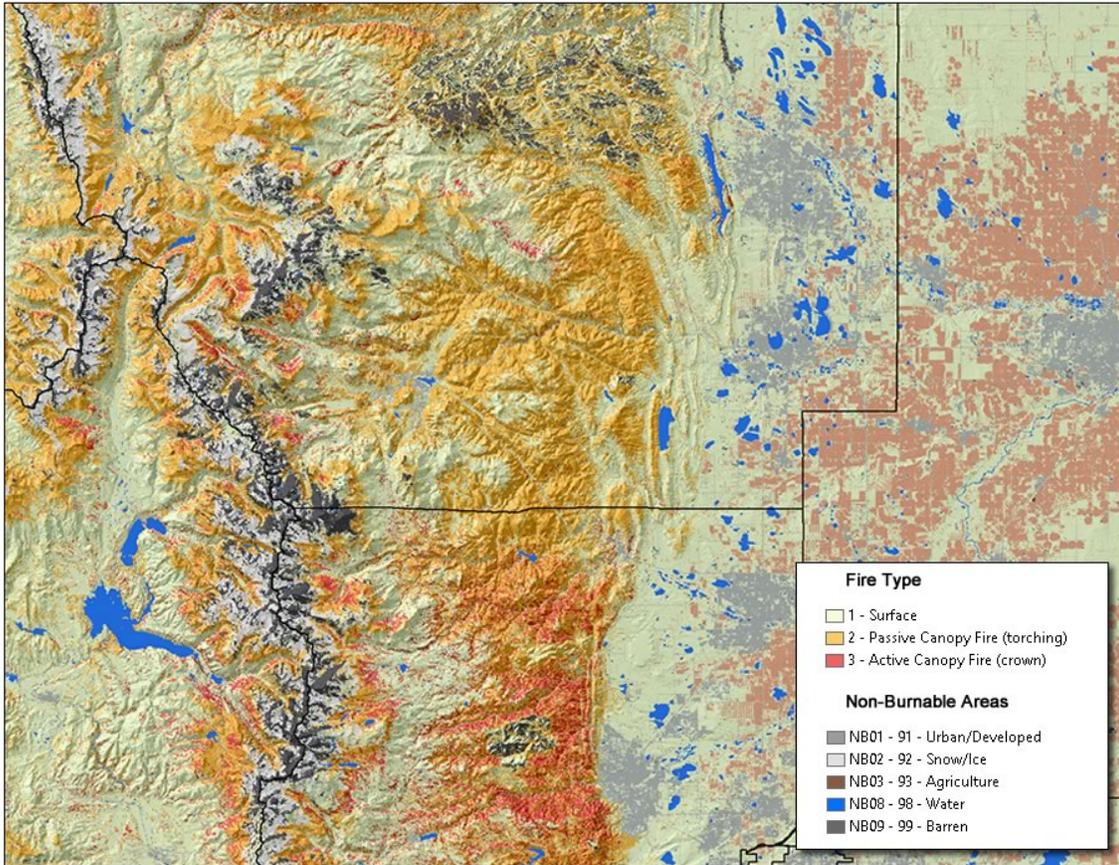
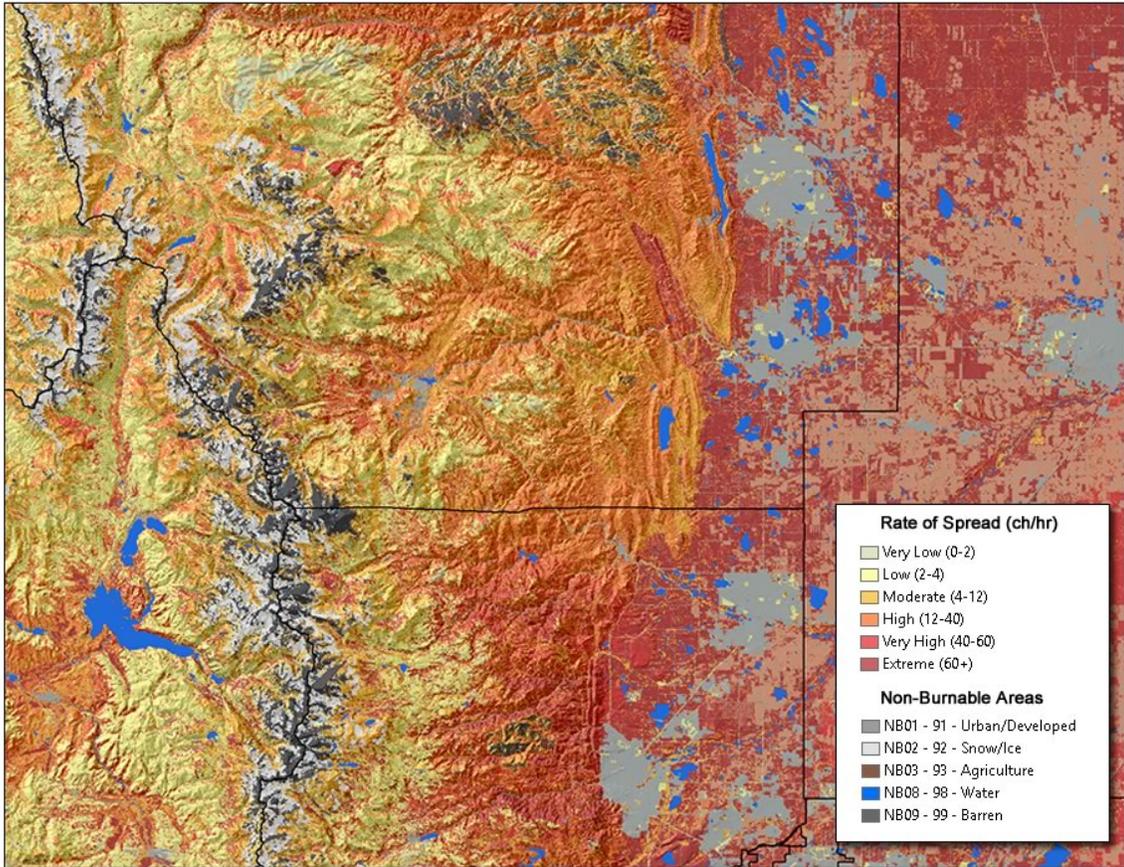


Figure 26. Example Rate of Spread map of the Front Range.



Colorado Wildfire Risk Assessment 2017  
RATE OF SPREAD



### 4.3 Burn Probability

A dynamic fire simulation approach was used to estimate the annual burn probability (BP), flame length probabilities (FLPs) and conditional flame length (CFL) for Colorado at 30-m resolution. The BP output represents the probability that a fire will burn a given cell in a year. However, it does not represent the fire recurrence due to that fires are not independent and fuels change across the landscape.

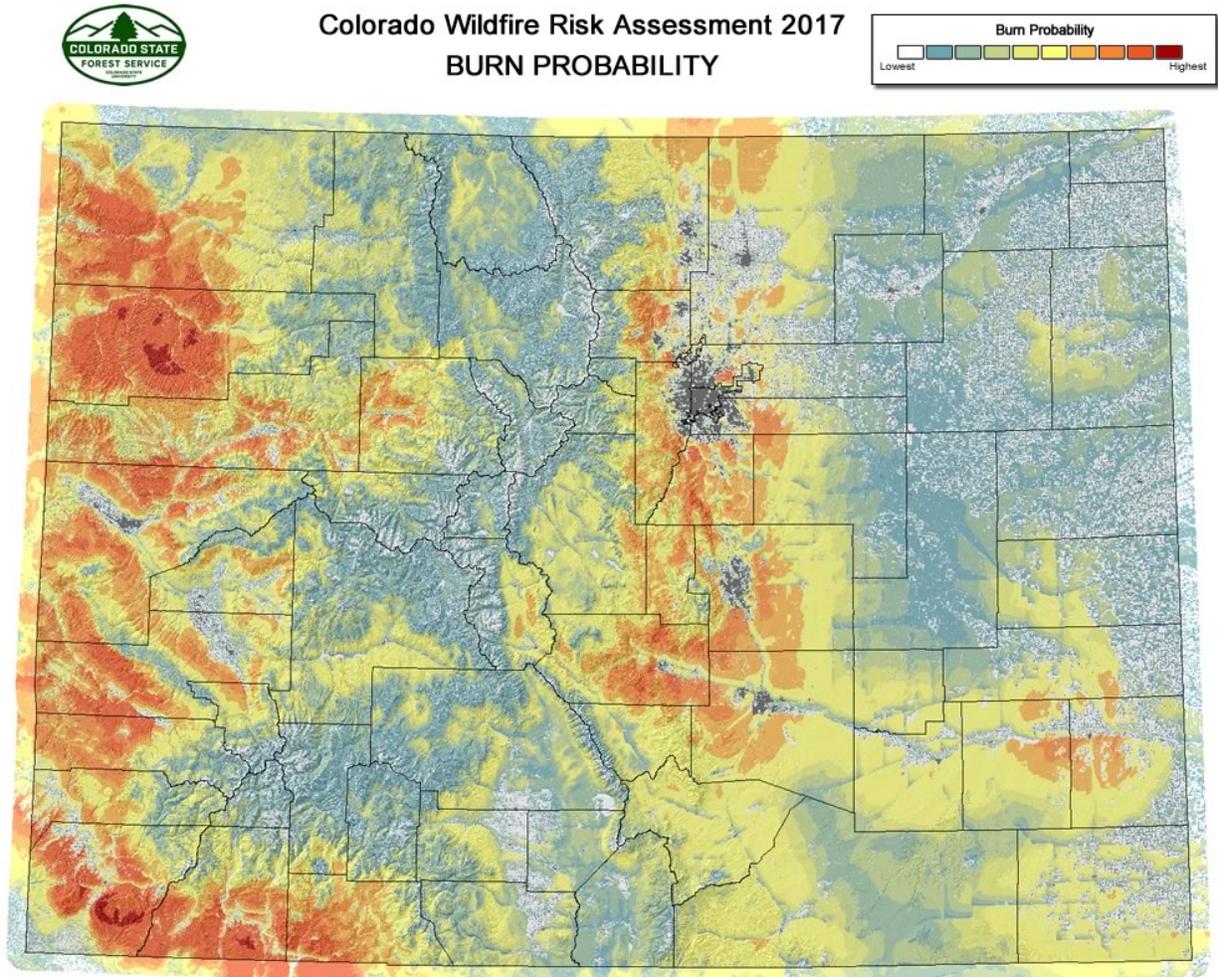
Six standard fire intensity levels (FILs) were considered in terms of flame length to calculate flame length probabilities and conditional flame length: FLP0 (0-2ft), FLP1 (2-4ft), FLP2 (4-6ft), FLP3 (6-8ft), FLP4 (8-12ft), and FLP5 (>12 ft). The FLP layers represent the probability distribution among 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 (e.g. heading, flanking, backing). 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. In particular, conditional flame length (CFL) was assessed 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 Colorado by using a stochastic (Monte Carlo) wildfire simulation approach, which simulated 2,342,334 fires (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/km<sup>2</sup>. The ignition points were spatially distributed every 500 meters. Only high and extreme weather conditions were considered to run the single fires since they usually burn most of the annual burned area. All fires simulations had a duration of 10 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). However, we assigned the lower BP value in those “burnable” cells that the simulated fires did not reach.

The fire simulator considered the number of times that the simulated fires burned each cell. After that, we weighted the results by considering the historical fire occurrence of those fires that burned in high and extreme weather conditions. 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.

Enhancements were also undertaken to ensure the spread of fire simulations across natural firebreaks, such as roads. This was undertaken in the area of the Colorado Front Range where spotting and embers are known to occur and fires commonly spread across these natural fire breaks. In Eastern Colorado roads were retained as fire breaks where they are known to stop grass related fires. CSFS staff provided subject matter expertise to define these areas for spread enhancements. The following figure presents the Burn Probability map for Colorado.

Figure 27. Burn Probability for Colorado.



## 4.4 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 2017 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 2012 CO-WRA fire behavior outputs. Although not fundamentally different from 2012 CO-WRA outputs, the fire behavior was overall “hotter” for the 2017 CO-WRA.

It is important to note that the 2012 FB outputs had several issues caused by limitations in the source data. This included:

- Seamlines in the source LANDFIRE 2008 data resulted in seamlines in the FB outputs. Seamlines were corrected for the 2017 fuels data as part of the CSFS Fuels Calibration project.
- Use of homogeneous Weather Influence Zones resulted in seamlines in the FB outputs (i.e. FB outputs sometimes appear tiered instead of continuous as an artifact of the WIZ polygon data).
- Continuous raster weather data were used for the 2017 CO-WRA eliminating seamlines and edges in the FB outputs.

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 2012 outputs.

FB is compared in different 2012 WIZs to validate and better understand the results. 2017 FB outputs were clipped to match the 2012 WIZ boundaries as a framework for comparison. The FB comparison exhibits the same spatial patterns and values are similar in assessments. However, it is necessary to consider all the inputs to compare FB in the two periods, especially the spatial weather variability added in the 2017 CO-WRA and changes in fuels since the 2008 imagery source of the 2012 fuels data. This is a ten year growth period.

### *Comparing Data for WIZ 3*

Overall, surface fire behavior is a bit higher in the 2017 in some areas (spatial weather variability needs to be considered to compare both projects at local scales), probably due to a higher wind speed in the study area (see [Section 3.2](#)) given that the mean 1h-FMC values are very similar in both projects (see [Section 3.2](#)). However, spatial FB patterns are similar in both projects and differences are relatively low. The following figure presents a snapshot of the 2017 and 2012 Flame Length and Rate of Spread outputs.

In areas with torching and crowning, the flame length is slightly higher and the rate of spread is generally similar in this project. The FL difference may be derived from the model to estimate crown fire behavior and canopy characteristics. The 2017 FL output was estimated by considering both the surface and crown flame length.

Figure 28. Comparison of 2017 and 2012 Flame Length outputs for WIZ 3.

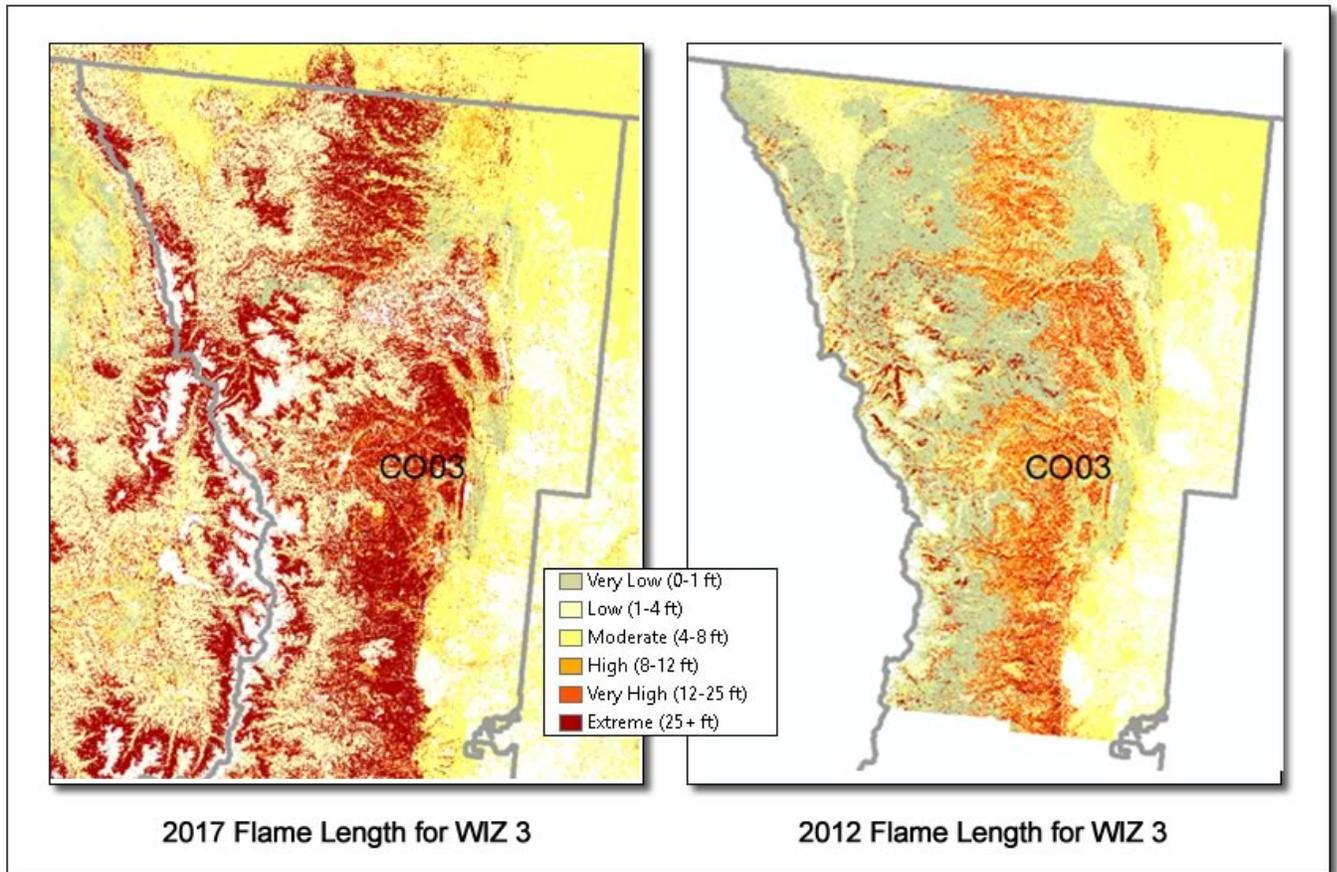
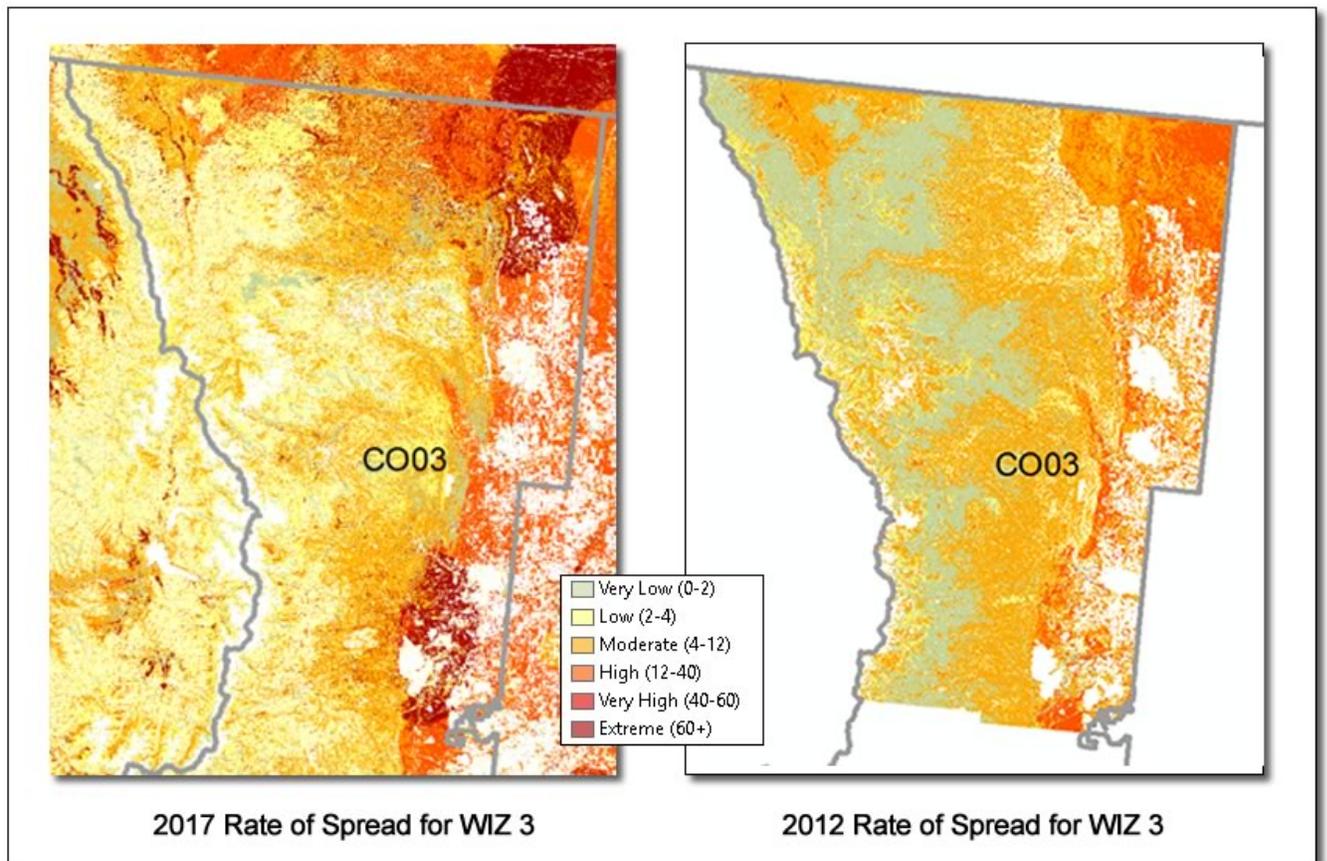


Figure 29. Comparison of 2017 and 2012 Rate of Spread outputs for WIZ 03.



#### Comparing Data for WIZ 9 and 11

The FB discontinuities across WIZ boundaries are very noticeable issues across CO in the 2012 project as shown in the edges between WIZ 09 and 11 (see Figure 31). This demonstrates the importance of considering the spatial weather variability for all of Colorado. In 2017 CO-WRA, the new FB outputs are continuous across the entire state, i.e. no seamlines.

Both the rate of spread and flame length have similar values and patterns in both WIZs. However, there are abrupt changes in terms of FB in some areas due to important changes in fuel types identified in the 2017 fuels calibration project. These changes for CO are related to issues detected with LANDFIRE Mapping Zone Boundaries (G1), in Pinyon-Juniper forests (G2), in Oak Shrubland areas (G3), in Alpine Rangeland (G6) and forest disturbances (i.e. insect and disease, fires, treatments).

Fuel types especially influence FB outputs and all the changes related to the last fuel calibrations modify FB and, therefore, they need to be considered when analyzing and comparing FB outputs.

Figure 30. Comparison of 2017 and 2012 Flame Length outputs for WIZ 9 and 11.

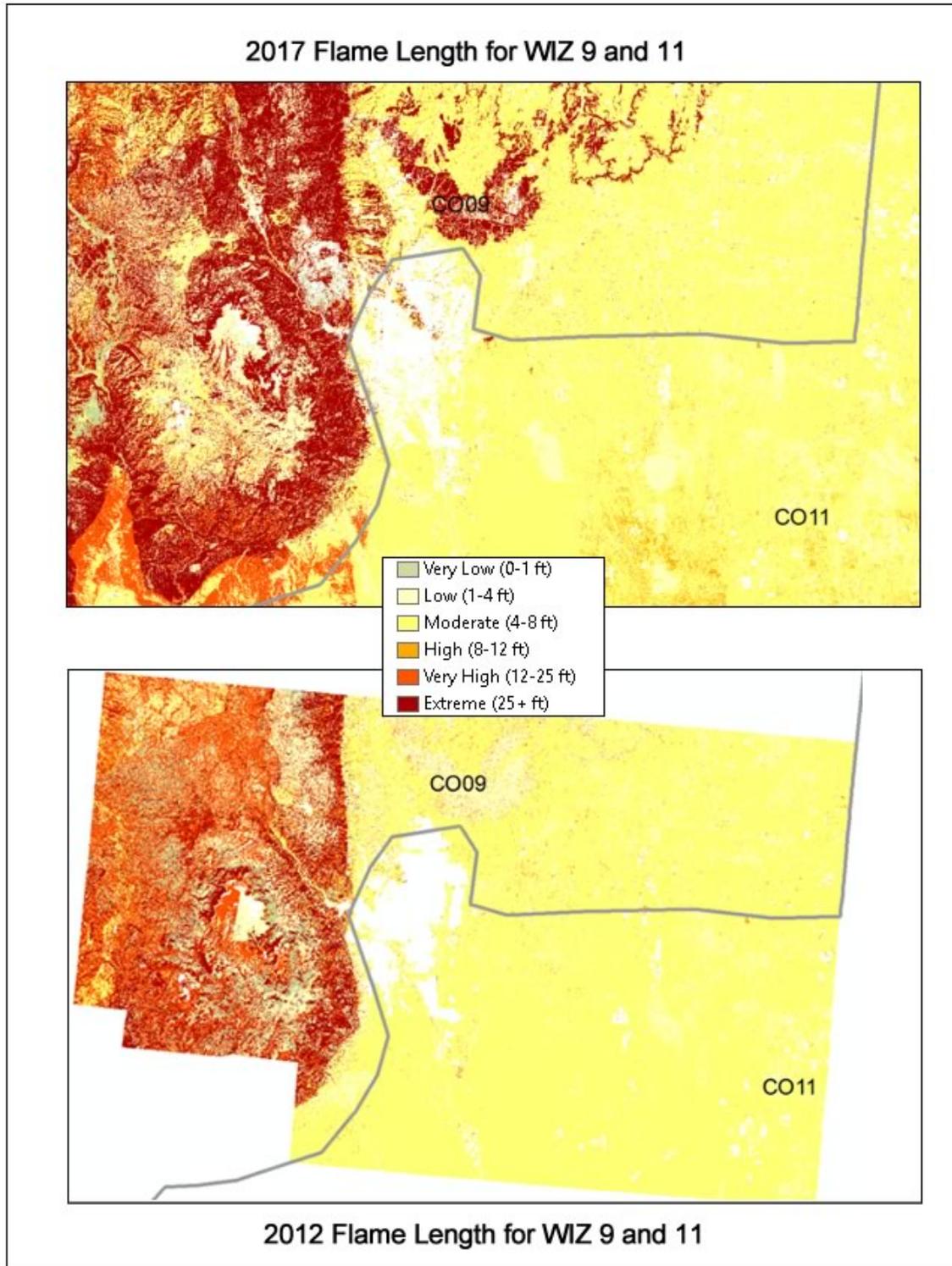
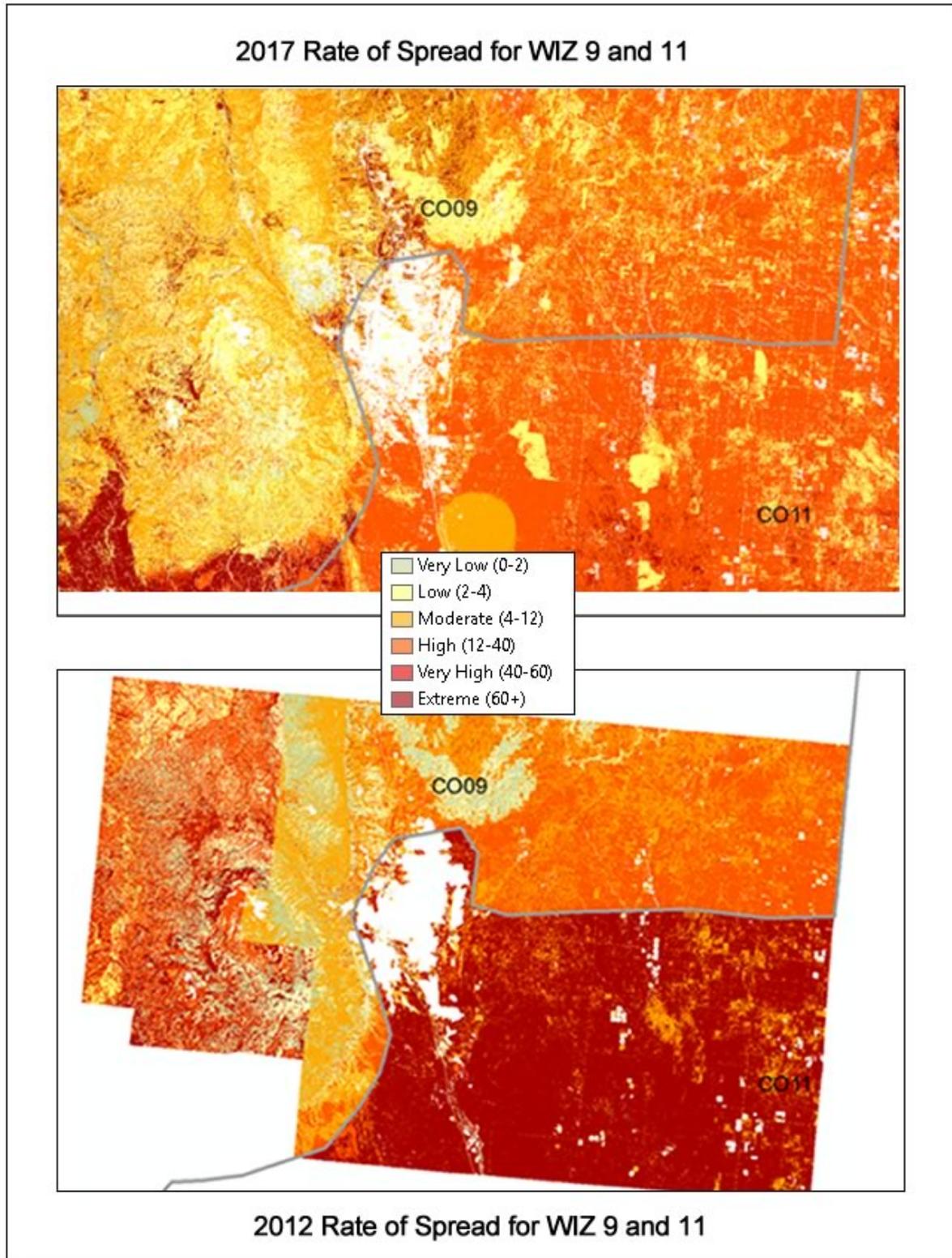


Figure 31. Comparison of 2017 and 2012 Rate of Spread for WIZ 9 and 11.



## 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 a 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.

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.

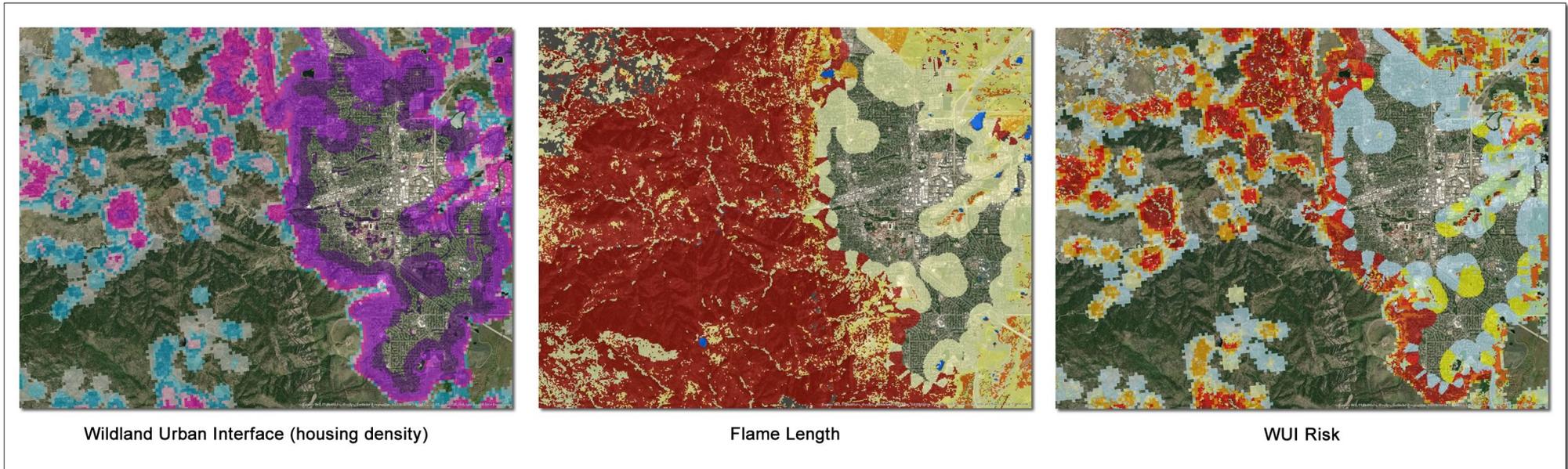
**Table 7. Example RF Value Assignments for WUI**

		<b>Wildland Urban Interface</b> (housing density)						
		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
Flame Length	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 and 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 32. Response Function example showing Wildland Urban Interface, Flame Length and WUI Risk Index output.



### ***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
- Drinking Water Importance 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 HVRA
- 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.
- Suppression Difficulty Rating is also included although it is not a HVRA layer. It is a standalone metric that was deemed important and included in the CO-WRA update. Response Functions were used to create this output.

**Table 8. CO-WRA HVRA response functional assignments.**

2017 Colorado Wildfire Risk Assessment Update											
HVRA Response Functional Assignments											
Flame Length (classes in feet)					Flame Length Class (1 to 6)						
					1	2	3	4	5	6	
					0-2	2-4	4-6	6-8	8-12	12+	
Wildland Urban Interface (houses per acre)					1 - LT 1hs/40 ac	-0.40	-0.60	-1.00	-1.40	-1.80	-1.80
					2 - 1 hs/40-20 ac	-0.80	-1.20	-2.00	-2.80	-3.60	-3.60
					3 - 1 hs/20-10 ac	-1.20	-1.80	-3.00	-4.20	-5.40	-5.40
					4 - 1 hs/10-5 ac	-1.50	-2.25	-3.75	-5.25	-7.10	-7.10
					5 - 1 hs/5-2 ac	-1.90	-2.85	-4.75	-6.65	-7.90	-8.55
					6 - 1-3 hs/ac	-2.00	-3.00	-5.00	-7.10	-9.00	-9.00
					7 - GT 3hs/ac	-2.00	-5.00	-7.00	-8.00	-9.00	-9.00
Drinking Water (level of importance)					1 - Lowest	-0.10	-0.20	-0.50	-0.60	-0.80	-0.90
					2	-0.10	-0.20	-0.50	-0.60	-0.80	-0.90
					3	-0.20	-0.40	-1.00	-1.20	-1.60	-1.80
					4	-0.30	-0.60	-1.50	-1.80	-2.40	-2.70
					5	-0.40	-0.80	-2.00	-2.40	-3.20	-3.60
					6	-0.50	-1.00	-2.50	-3.00	-4.00	-4.50
					7	-0.60	-1.20	-3.00	-3.60	-4.80	-5.40
					8	-0.70	-1.40	-3.50	-4.20	-5.60	-6.30
					9	-0.80	-1.60	-4.00	-4.80	-6.40	-7.20
					10 - Highest	-1.00	-2.00	-5.00	-6.00	-8.00	-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 Impt	0.00	0.00	-0.50	-1.00	-1.75	-1.75
					2 - Moderate Imp	0.00	0.00	-1.00	-2.00	-3.50	-3.50
					3 - Highest Imp	0.00	0.00	-2.00	-4.00	-7.00	-7.00
Suppression Difficulty	Fuel Type		Code		Slope Steepness						
					0-25	26-40	41-55	56-74	75+		
					1	2	3	4	5		
	Grass	1	-1.0	-3.7	-6.9	-8.7	-9.0				
	Brush/Slash	2	-3.0	-5.2	-7.9	-8.9	-9.0				
TL	3	-4.2	-5.9	-8.0	-8.9	-9.0					

### Percentile Weather Weights

Response function values are applied to each layer independently to create a RFV output for that layer (resource value). Calculations are first applied on a per weather percentile category (low, moderate, high and extreme) using the Flame Length probability for each weather category. These interim *weather bin* outputs are then combined to create the final *characteristic RFV* output. This output reflects the response of the resource/asset to wildfire assuming that a fire occurs and the Flame Length conditions are met.

A constant weighting that reflects the *percent acres burned in each weather category* is applied to derive a weighted RFV output across the four percentile weather classes for each resource/asset. Using constant weights provides flexibility for production and future modification if desired. These weightings were derived by conducting historical analysis of past fires. The following table shows the default constant weightings used for combining the RFV outputs to create an overall characteristic RFV outputs for the HVRAs.

**Table 9. Constant weightings used for combining weather percentile RFV outputs into a single characteristic output.**

Percentile Weather Category	Weighting
Low	.01
Moderate	.09
High	.20
Extreme	.70

### ***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 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.

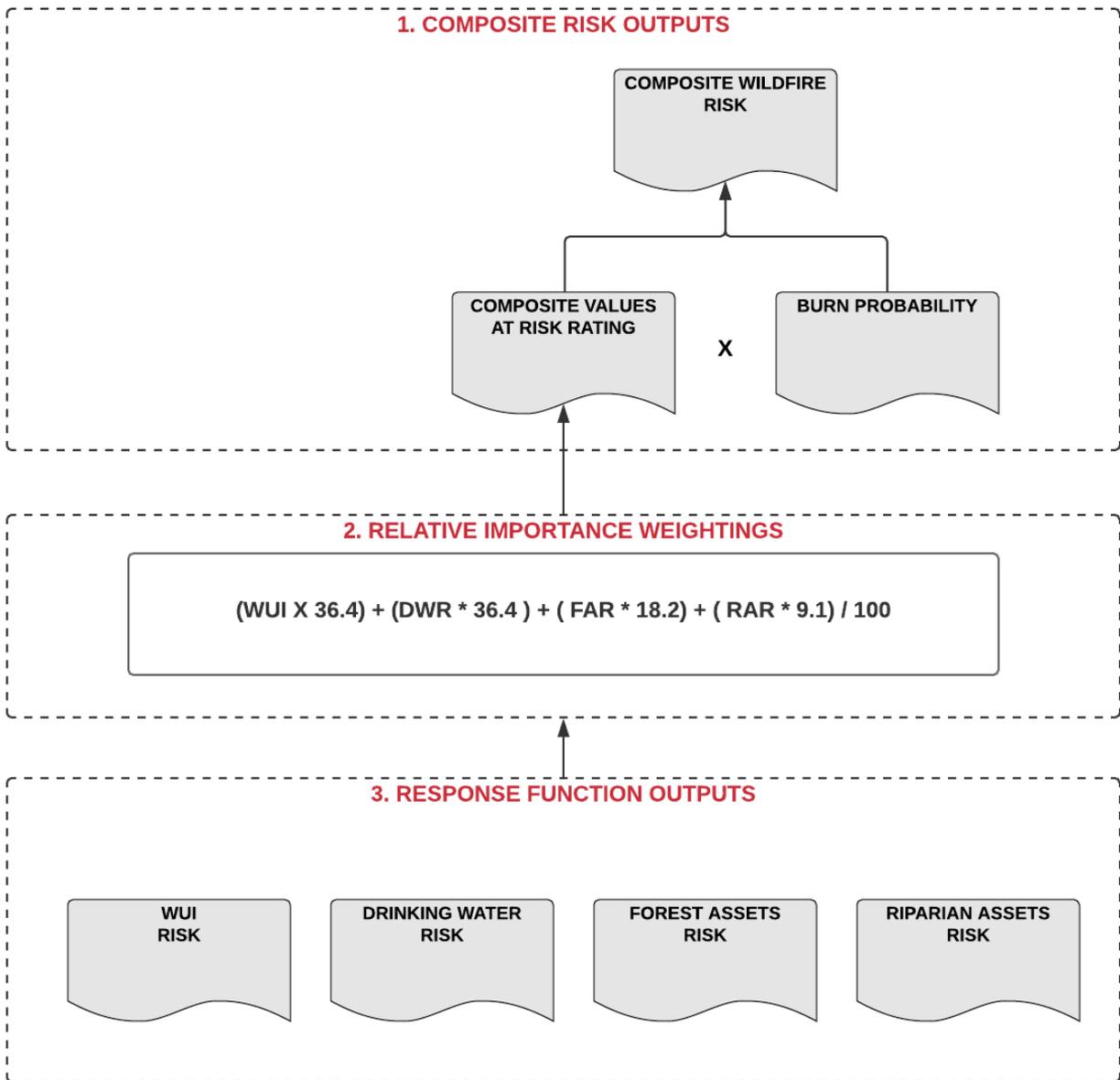
The following table presents the weights used for the Values At Risk Rating (VAR) output. These relative importance weightings were defined by a team of experts within CSFS reflecting the resource and asset priorities and conditions in Colorado.

**Table 10. Colorado adjusted Values At Risk Rating weights**

VAR Input Layer	Relative Importance Weights
WUI	36.4%
Drinking Water	36.4%
Forest Assets	18.1%
Riparian Assets	9.1%

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 output.

Figure 33. Combining risk layers with relative importance weightings to create risk outputs.

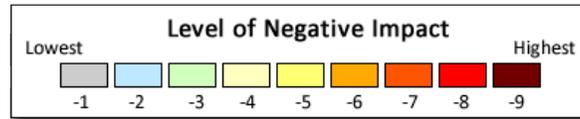


## 5.2 Classification of Map Outputs

### *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. 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 34. CO-WRA Response Function output legend.**



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

- WUI Risk Index
- Drinking Water Risk Index
- Forest Assets Risk Index
- Riparian Assets Risk Index
- Values-At-Risk Rating
- Suppression Difficulty Rating

***Class Breaks for Fire Occurrence & Wildfire Risk 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 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 example, the Wildfire Risk dataset has 258,005,612 unique cellular values.

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 14.5% of the cells in categories 6-9. The highest rated 22.5% 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 1.5% of area in Colorado. The following table presents the percent area break points that were used.

**Table 11. Cumulative percentiles used for class breaks**

Category	% Range	Cumulative % of Area	Categorical % of Area
1	0 – 32.9%	32.9%	<b>32.9%</b>
2	33.0 - 63.5%	63.5%	<b>30.5%</b>
3	63.5 -70.0%	70.0%	<b>6.5%</b>
4	70.0 - 77.5%	77.5%	<b>7.5%</b>
5	77.5 - 85.5%	85.5%	<b>8.0%</b>
6	85.5 - 92.5%	92.5%	<b>7.0%</b>
7	92.5 - 96.5%	96.5%	<b>4.0%</b>
8	96.5 - 98.5%	98.5%	<b>2.0%</b>
9	98.5 - 100.0%	100.0%	<b>1.5%</b>

Using this approach the following table presents the class breaks calculated for the Fire Occurrence output dataset.

**Table 12. Fire Occurrence class breaks**

Fire Occurrence Classes			
Category	Cumulative%	Min Value	Max Value
1	33.30%	0.000000	0.018000
2	63.58%	0.018001	0.089000
3	70.12%	0.089001	0.126000
4	77.55%	0.126001	0.194000
5	85.52%	0.194001	0.327000
6	92.52%	0.327001	0.551000
7	96.50%	0.551001	0.843000
8	98.50%	0.843001	1.214000
9	100.00%	1.214001	

The nine classes are presented as a qualitative legend in CO-WRAP as shown in the following figure.

**Figure 35. Fire Occurrence classified legend (as shown in CO-WRAP)**



The following table presents the class breaks calculated for the Wildfire Risk output dataset.

**Table 13. Wildfire Risk class breaks**

Wildfire Risk Classes			
Category	Cumulative%	Min Value	Max Value
1	32.9%	-0.010000	-3.620000
2	30.6%	-3.620001	-17.570000
3	6.5%	-17.570001	-24.520000
4	7.5%	-24.520001	-39.630000
5	8.0%	-39.630001	-70.500000
6	7.0%	-70.500001	-131.200000
7	4.0%	-131.200001	-228.850000
8	2.0%	-228.850001	-362.150000
9	1.5%	-362.150001	0.000000

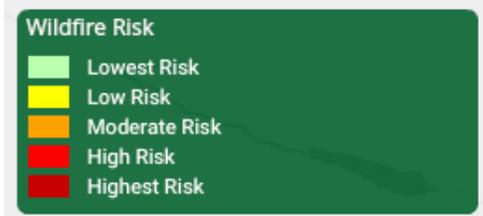
For Wildfire Risk it was decided to combine classes to present the data in five classes. This was done to aid with interpretation of the overall composite risk map. The following groupings were used.

**Table 14. Wildfire Risk class groupings.**

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

The following figure presents the final Wildfire Risk classes used on CO-WRAP.

**Figure 36. Wildfire Risk classified legend (as shown in CO-WRAP).**



### 5.3 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).<sup>11</sup> 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.

Technosylva staff worked with Joe Scott (Pyrologix, Missoula, MT) to develop the FIS model and implement it for use in state risk assessments.<sup>12</sup> 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 CO-WRAP Public Viewer web application to support the identification of risk for specific locations. A custom tool, called *What's Your Risk?* 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 CO-WRAP Public Viewer *What's Your Risk?* 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

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<sup>11</sup> 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

<sup>12</sup> Joe Scott is a leading wildland fire research scientist best known for his establishment of the 2005 FBPS Fuel Models (Scott & Burgan) and his research into fire behavior analysis for surface and canopy fuels, and related fuels modeling. Mr. Scott actively works with western forestry agencies to provide custom fuels analysis and fire behavior analysis to support values-at-risk assessments. See [www.Pyrologix.com](http://www.Pyrologix.com).

Risk Assessment) that provides much greater utility to the risk assessment outputs to support public awareness and education.

FIS consists of 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 6, represents extreme wildfire intensities. In Colorado, only classes 1 through 5 exist.

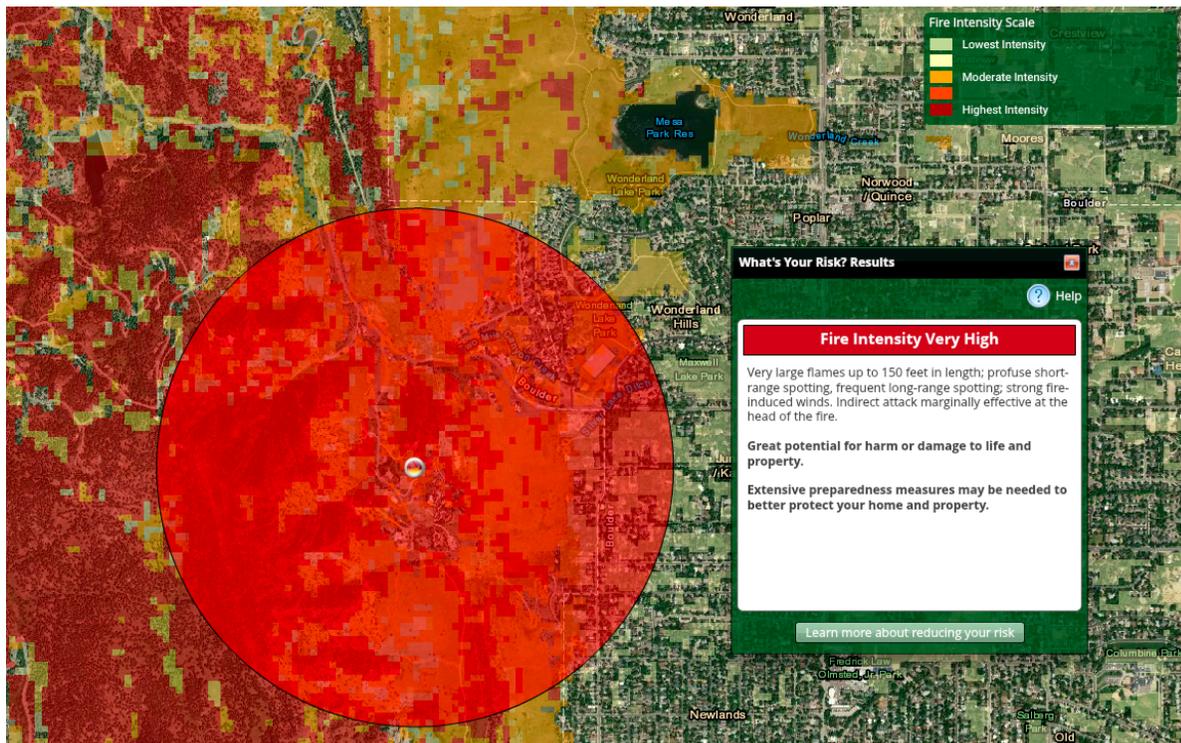
**Figure 37. Fire Intensity Scale legend**

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

FIS data is modeled at 30-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 Public Viewer *What's Your Risk?* 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.<sup>13</sup>

The following figure shows an example of FIS output, with the description of fire conditions and general preparedness recommendations, that are provided in the CO-WRAP Public Viewer application WYR tool.

**Figure 38. CO-WRAP Example of FIS Data (What's Your Risk? tool)**



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

<sup>13</sup> Please see <https://csfs.colostate.edu/wildfire-mitigation/>.

Table 15. 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.	<p><b>Basic preparedness measures will better protect your home and property.</b></p> <p>Be fire wise and take the necessary steps to protect your home and property today.</p>
II	$1 \leq FIS < 2$	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.	<p><b>Increasing potential to cause harm or damage to life and property.</b></p> <p>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.</p>
III	$2 \leq FIS < 3$	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.	<p><b>Increasing potential to cause harm or damage to life and property.</b></p> <p>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.</p>

Fire Intensity Class	Fire Intensity Scale	Description of fire behavior and potential effects	General Preparedness Recommendations
<b>IV</b>	$3 \leq FIS < 4$	<p>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.</p>	<p><b>Significant potential for harm or damage to life and property.</b></p> <p>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.</p>
<b>V</b>	$4 \leq FIS < 5$	<p>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.</p>	<p><b>Extensive preparedness measures may be needed to protect your home and property.</b></p> <p>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.</p>

## 6. ASSESSMENT RESULTS AND FINDINGS

This section provides a description of the assessment results and findings, including a list of enhancements for the 2017 CO-WRA.

### 6.1 Background

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. The 2012 CO-WRA leveraged the West Wide Risk Assessment (17 western states and the Pacific islands) to tailor the methods and outputs to better match Colorado conditions and priorities.

The Colorado Wildfire Risk Assessment Portal (CO-WRAP) is a suite of web mapping applications that was developed with the 2012 CO-WRA to provide access to the assessment results.<sup>14</sup> Through CO-WRAP, 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 2018, the CSFS updated CO-WRA and CO-WRAP to reflect updated data to 2017 and enhanced the methods in response to user feedback and scientific advancements. This update is the first time any state is able to compare risk assessment outputs from two different time periods based on the same standard technical methods.<sup>15</sup>

CO-WRA (assessment) and CO-WRAP (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) and other hazard mitigation plans;
5. complement forest stewardship and forest management plans; and
6. inform decision-making at local and state levels.

#### The Colorado Wildfire Risk Assessment:

- ✓ **Is based on the best available science**
- ✓ **Provides wall-to-wall coverage for all lands in Colorado**
- ✓ **Has a spatial resolution of 30 m, which is applicable for community-level analysis or greater**
- ✓ **Uses consistent methods and is comparable across Colorado**
- ✓ **Is repeatable and can be updated as new data become available**
- ✓ **Is displayed through the Colorado Wildfire Risk Assessment Portal (CO-WRAP)**

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<sup>14</sup> CO-WRAP is accessible at [www.ColoradoWildfireRisk.com](http://www.ColoradoWildfireRisk.com).

<sup>15</sup> Please refer to the Scott, Thompson, Calkin RMRS-GTR-315 publication referenced in the [Appendix A](#).

## 6.2 List of CO-WRA 2017 and CO-WRAP Enhancements

The 2017 CO-WRA includes numerous technical, scientific and data enhancements that greatly improve the results compared to the 2012 assessment. In addition, several enhancements were made to the CO-WRAP applications to portray this data. These enhancements include:

### **CO-WRA Data Enhancements**

- The **new CSFS statewide seamless Surface Fuels dataset** is an enhancement to 2014 LANDFIRE and better represents observed and expected fire behavior in Colorado through the incorporation of disturbance data (fire perimeters, CSFS forest treatments greater than 50 acres, Federal forest treatments, and insect and disease); Landsat imagery analysis through 2017; correction of LANDFIRE mapping zone seamlines, correction of LANDFIRE image tile seamlines, adjustments to specific Oak-Shrubland and Pinyon Juniper fuels; and expert knowledge decisions from CSFS fuels team comprised of specialists from CSFS, Technosylva Inc., Anchor Point Group LLC, USFS and BLM).
- The **weather data used to analyze fire behavior is greatly improved using continuous data instead of homogenous weather zones**. The data cover the years 1988-2017 and was acquired from the National Center for Environmental Prediction - North American Regional Reanalysis (NARR). Temperature, relative humidity, and wind speed and direction variables were incorporated in potential weather scenarios (Extreme, High, Moderate and Low). The variables were selected at 2 pm local time, considered the most adverse scenario for a fire start. A 1-h dead fuel moisture variable was estimated using the Rothermel and Rinehart (1983) model, and incorporated elevation and aspect to accumulate solar radiation at 14-h. Then, 2% and 4% were added to the 1-h dead fuel moisture content to estimate 10h and 100h content, respectively. Herbaceous, woody and foliar canopy moisture content were included as constants across the state; these values were estimated using the weather scenarios.
- A **new Wildland Urban Interface (WUI) layer was produced using the best available population data from LandScan 2016** (U.S. Department of Homeland Security), and also incorporated ownership parcels, building footprints, and postal service addresses for refinement. Overall, the WUI pattern across Colorado has not changed dramatically from 2012, which was expected. However, there was a very large reduction (2,720,209 acres) from 2012 to 2017 in WUI housing density classes 1-3 (less than 1 house/40 acres to 1 house/10 acres), therefore the entire footprint of the 2017 WUI is smaller (there were 6,606,348 WUI acres in 2012 and 3,886,139 WUI acres in 2017). This is primarily a result of improvements in population data distribution with the LandScan product, and also a result of the improved fuels dataset. In 2016, LandScan performed a quality assessment of the nighttime lights data, which resulted in many rural areas being removed (e.g. lights on barns do not qualify as less than 1 house/40 acres). Up to a 300-meter buffer into urban fringe is considered WUI because it is susceptible to encroachment of wildfire. This encroachment distance into urban areas varies across the state based on the underlying flame length output and the surface fuels type (i.e. grass vs non-grass). Core urban areas are excluded from the WUI.

- There is a **new statewide Burn Probability layer**, produced using Technosylva’s Wildfire Analyst™ software, an advanced GIS application for modeling wildfire behavior and spread.<sup>16</sup> Burn probability is based on millions of wildfire simulations and weighted by historical wildfire density, weather scenarios and ignition points. This layer replaces the old “Wildfire Threat layer” in 2012 CO-WRA.
- The **new non-federal fire ignition data is no longer by zip code** – they are discrete point data (lat/long), which also **improves the accuracy of the derived fire occurrence layer** (likelihood of a wildfire ignition based on historical ignition patterns).
- The new **Fire Occurrence (ignition density)** data for 2017 that was derived from the enhanced federal and non-federal fire ignition points data.

### **CO-WRAP Data Enhancements**

- **CSFS Forest Management Activity data (2008 - 2017) went through an extensive QA/QC process**; only completed activities are now available and there are two broad categories: silviculture and fire (fire only includes pile or broadcast). Note these data only include federally reported CSFS treatment data. Some of these data were used in the fuels calibration process.
- Updated **Ownership** data for 2016 obtained from CoMAP (<https://comap.cnhp.colostate.edu/>).
- Updated **Threats to Forest Health** layer that now includes insect and disease data from 1996 to 2016.
- Updated reference layers for **CWPP Community data and Firewise USA® Community (points and polygons) for 2018**.
- New reference layers for **Large Fire Perimeters that now include data from 2000 to 2018**.
- New reference layers for **Fires, Treatments, and Insect and Disease disturbance areas** that were used to update the surface fuels to 2017 vintage.
- Updated reference layer for **Fire Protection Districts for 2018** that was provided by Colorado Dept. of Fire Prevention and Control.

[Appendix B](#) provides a detailed description of the key CO-WRA datasets.

[Appendix D](#) provides a summary of the data sources and their vintage for both the 2017 and 2012 CO-WRA projects.

## **6.3 Project Deliverables**

The CO-WRA project involved the following key deliverables:

1. Statewide Colorado wildfire risk assessment GIS datasets
2. Final report that documents the data, methods and outputs for the assessment (this document)

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<sup>16</sup> Please visit [www.Technosylva.com](http://www.Technosylva.com) or [www.WildfireAnalyst.com](http://www.WildfireAnalyst.com) for more information.

3. Summary statistics report that documents the acres and population by different outputs.
4. Enhancements to the CO-WRAP web site to include the 2017 CO-WRA data along with updates to other datasets. This includes enhancements to the Public Viewer application to utilize modern web mapping components that now provide a better user experience and support for viewing on mobile devices. Similar updates to the Professional Viewer are planned for early 2019.

## 6.4 Final Risk Maps

Maps are presented for the following key CO-WRA outputs:

- **Wildfire Risk**
- **Burn Probability**
- **Fire Intensity Scale**
- **Values At Risk Rating**
- **WUI Risk Index**
- **Drinking Water Risk Index**

Urban areas are represented in dark grey areas on the maps. County boundaries are also shown.

The following legend is used for the Response Function outputs (Values at Risk Rating, WUI Risk, and Drinking Water Risk).



Figure 39. Composite Wildfire Risk for Colorado.

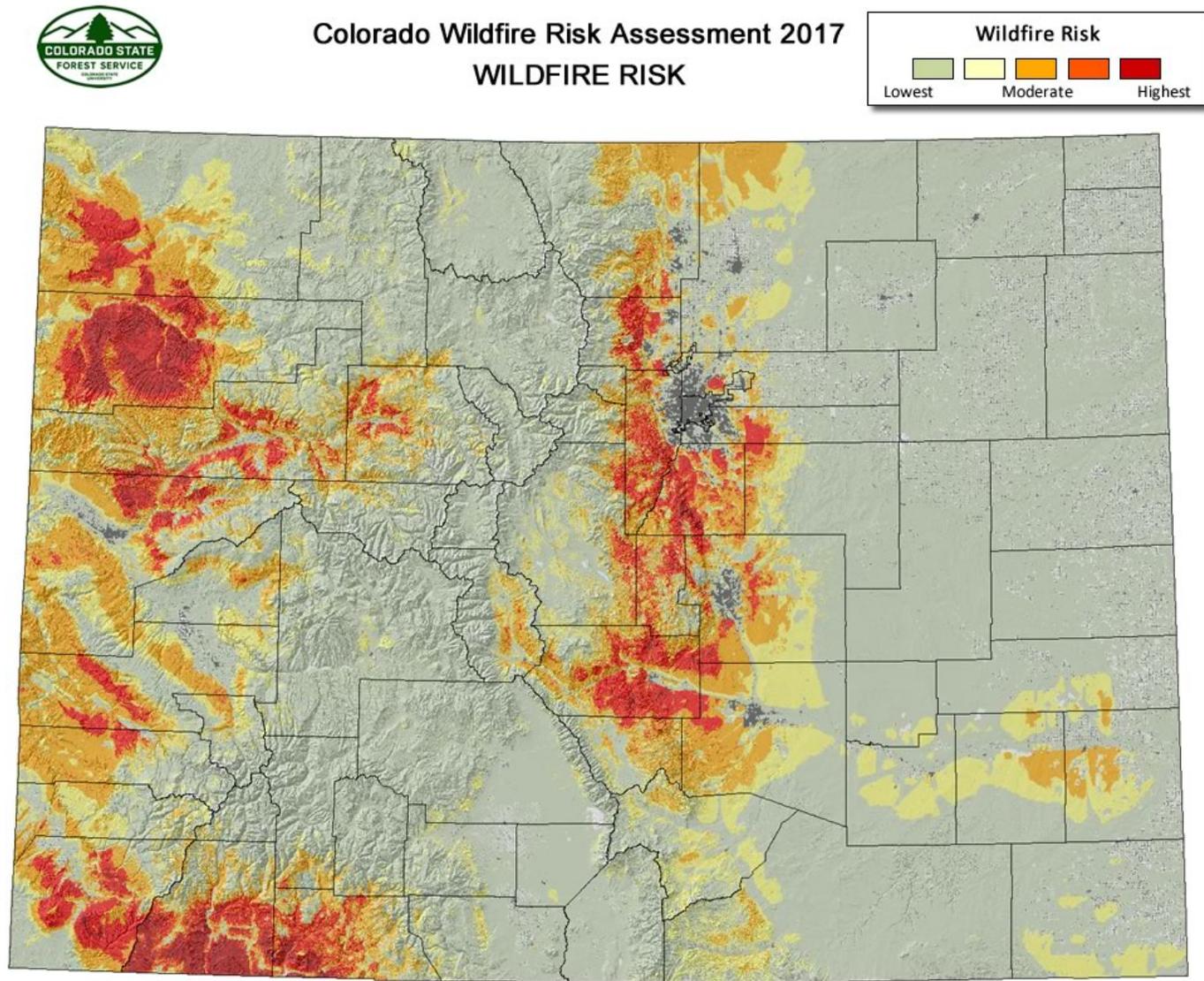


Figure 40. Burn Probability for Colorado.

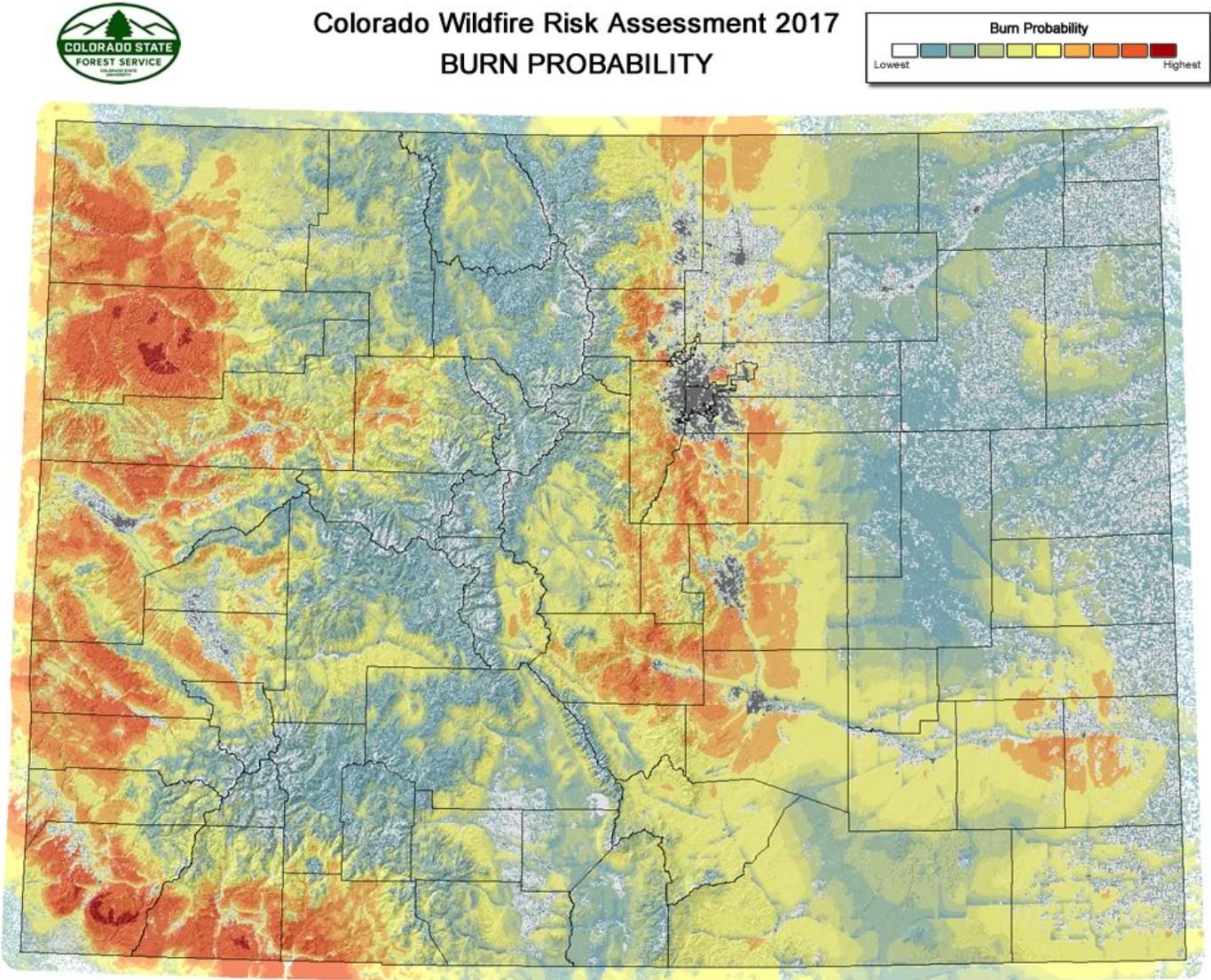


Figure 41. Fire Intensity Scale for Colorado.

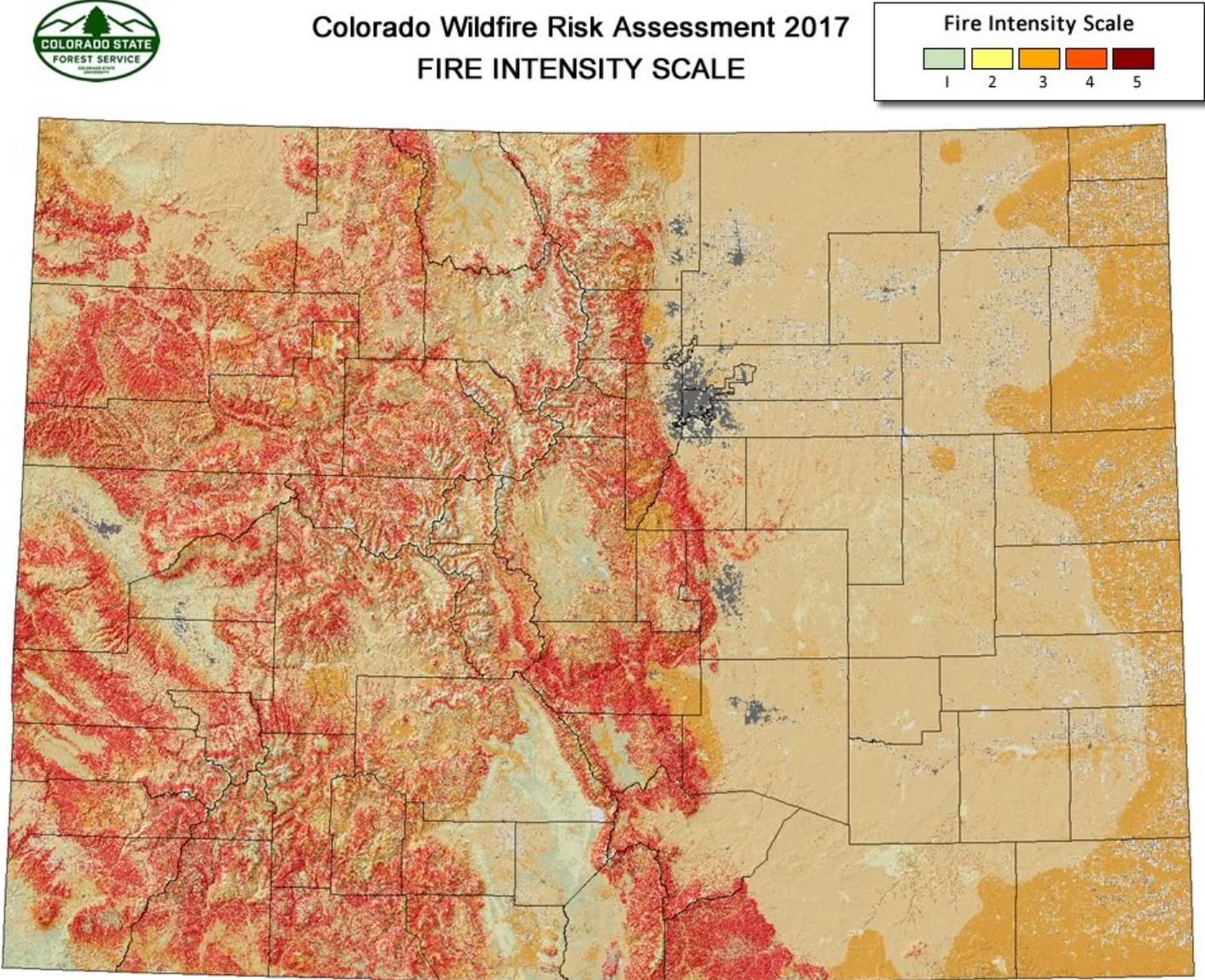


Figure 42. Values at Risk Rating for Colorado.

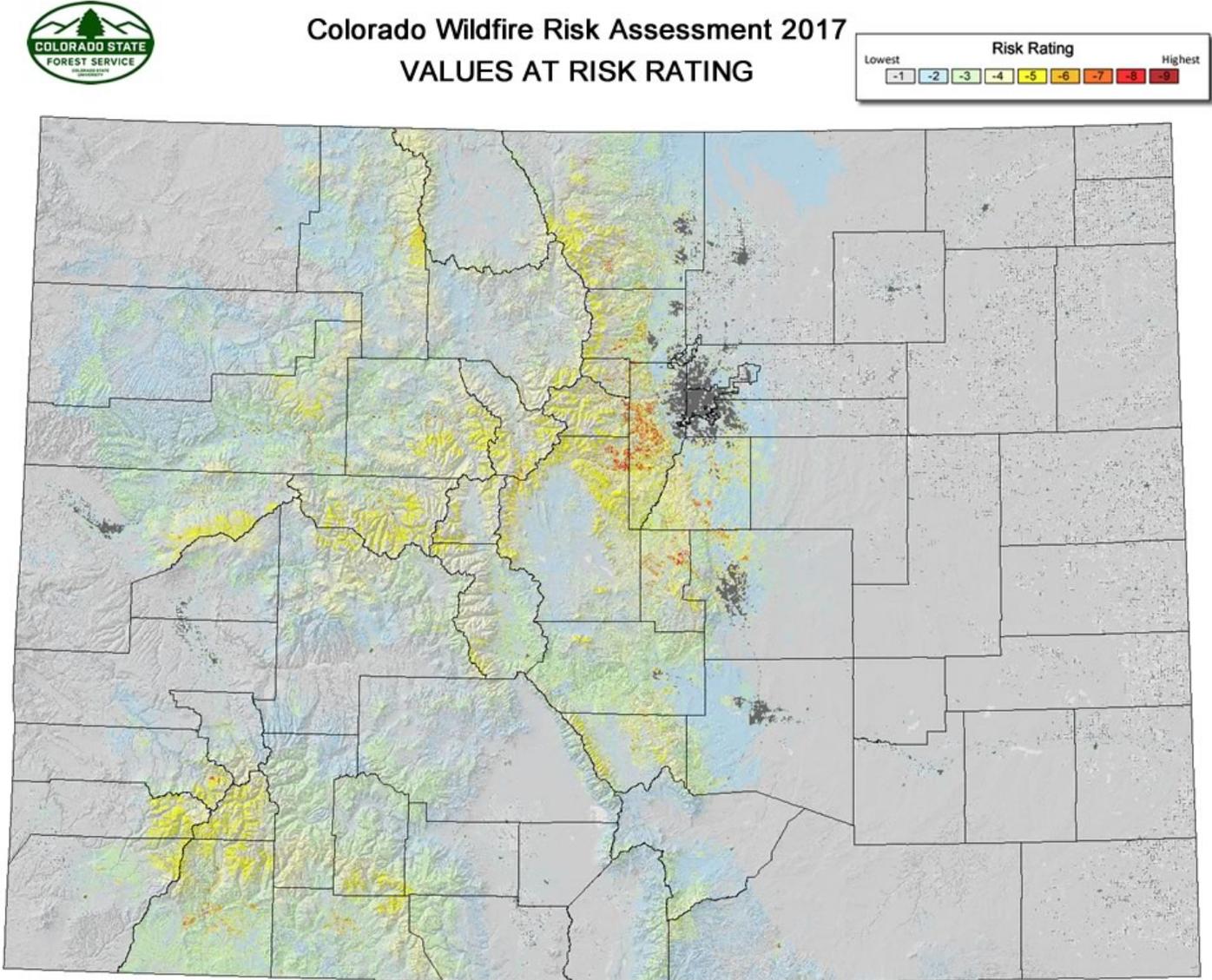


Figure 43. WUI Risk for Colorado.

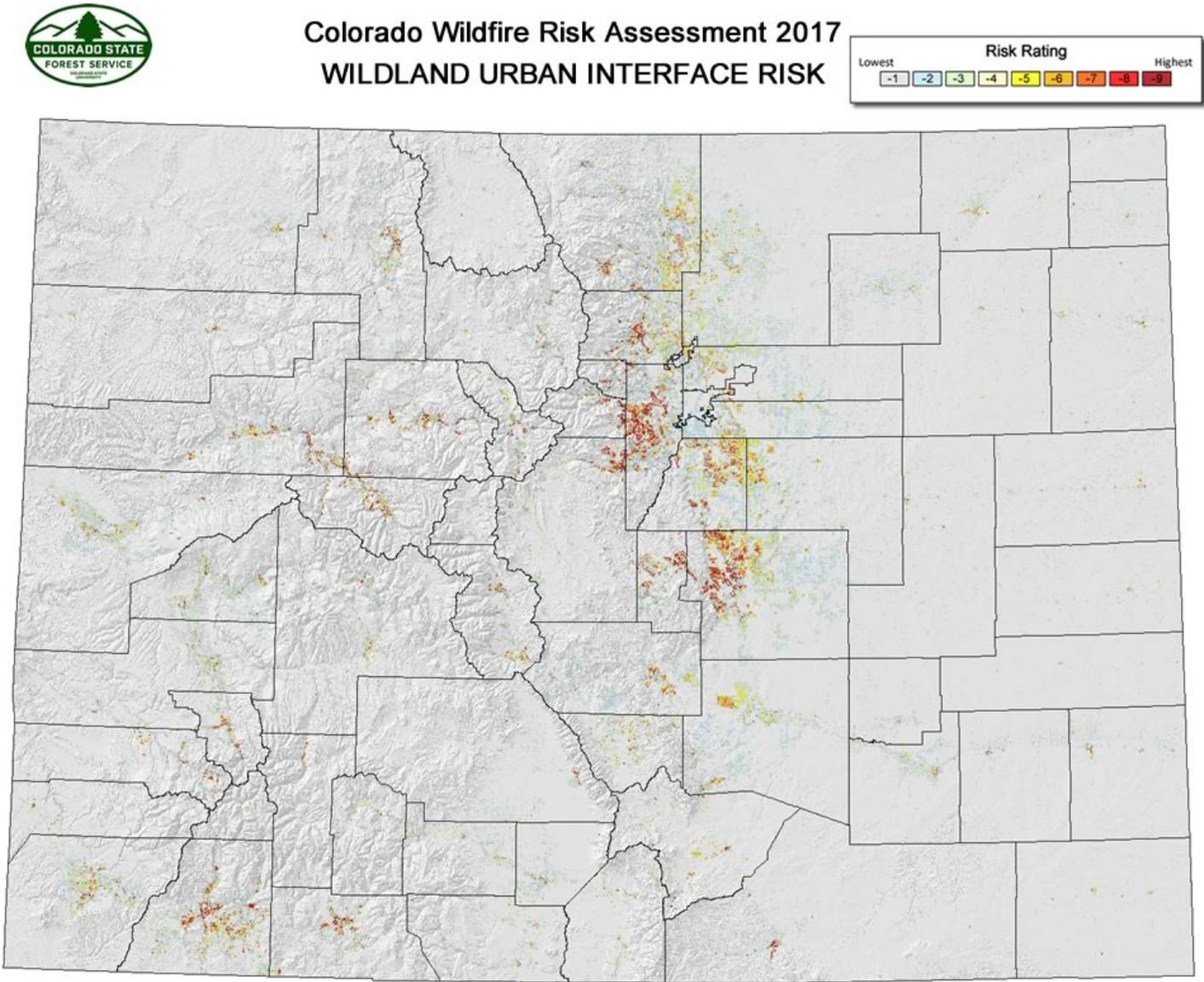
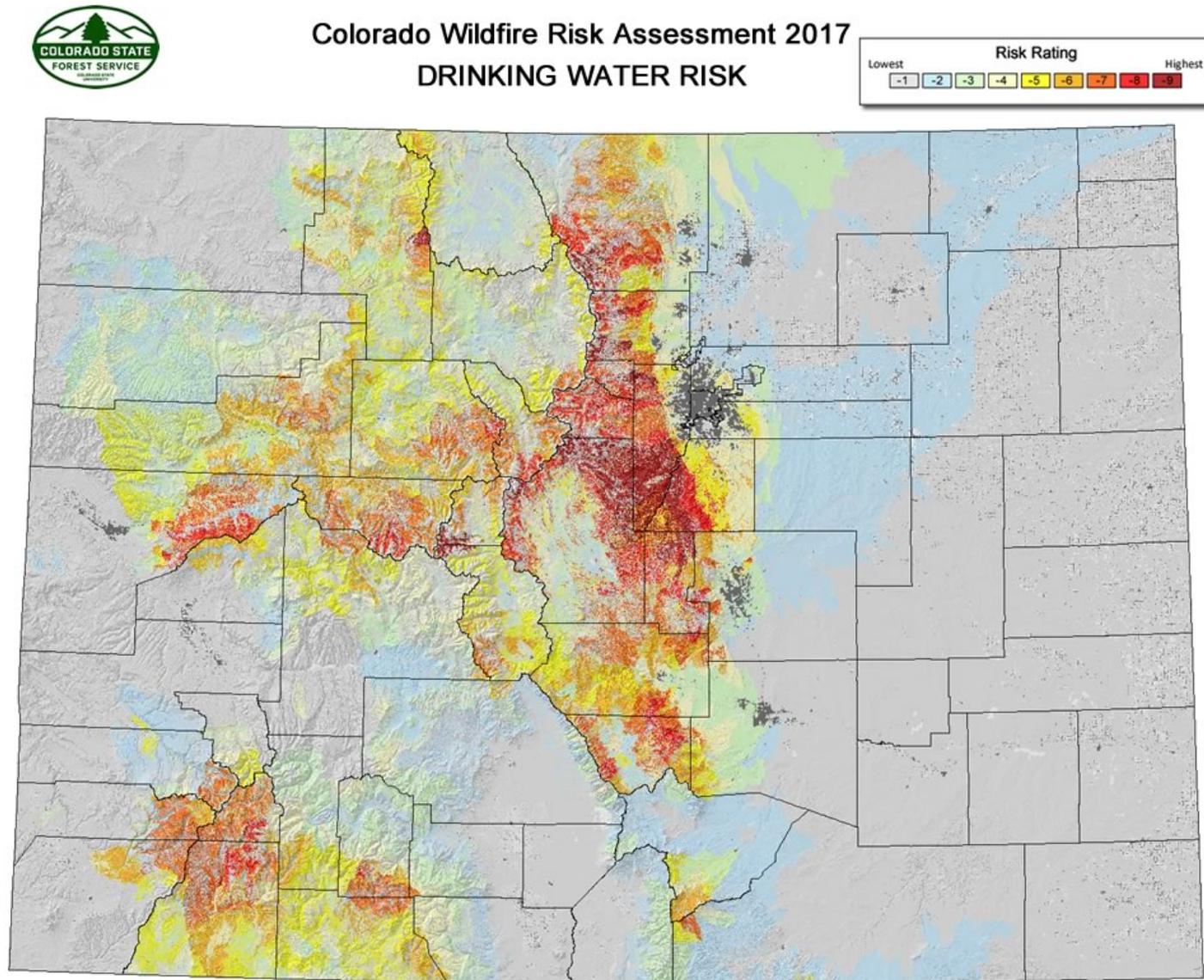


Figure 44. Drinking Water Risk for Colorado.



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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 CO-WRAP web applications that provide access to the CO-WRA results.

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

### Wildfire Risk Themes

#### Wildfire Risk

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



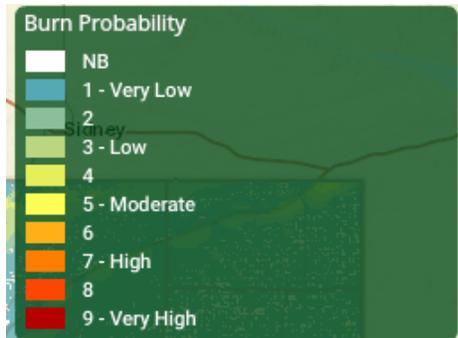
It identifies areas with the greatest potential impacts from a wildfire – i.e. those areas most at risk when considering the four values layers.

The Values at Risk Rating is a key component of Wildfire Risk. It is comprised of several individual risk layers including Wildland Urban Interface (housing density), Forest Assets, Riparian Assets and Drinking Water Importance Areas 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 found individual risk layers are weighted to derive the Values at Risk Rating layer.

The risk map is derived at a 30-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 stochastic (Monte Carlo) wildfire simulation approach with Technosylva’s Wildfire Analyst software ([www.WildfireAnalyst.com](http://www.WildfireAnalyst.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/km<sup>2</sup>. 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 due to they usually burn most of the annual burned area. All fires simulations had a duration of 10 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 of those fires that burned in high and extreme weather conditions. 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 30-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 consist 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.

Wildfire Threat and Fire Intensity Scale are designed to complement each other. Unlike Wildfire Threat, 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. 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 weather influence zone in Colorado. A weather influence zone is an area where, for analysis purposes, the weather on any given day is considered uniform. There are 11 weather influence zones in Colorado. The FIS represents the weighted average for all four weather percentiles.

The fire intensity scale map is derived at a 30-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 Drinking Water Importance 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).

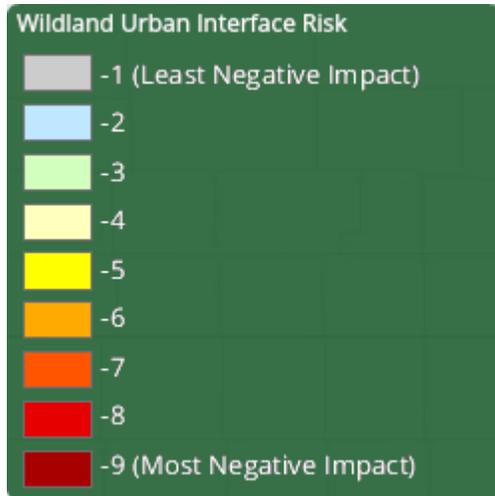
Calculating the VAR at a given location requires spatially defined estimates of the likelihood and intensity of fire integrated with the identified resource value. This interaction is quantified through the use of *response functions* that estimate expected impacts to resources or assets at the specified 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 30-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.

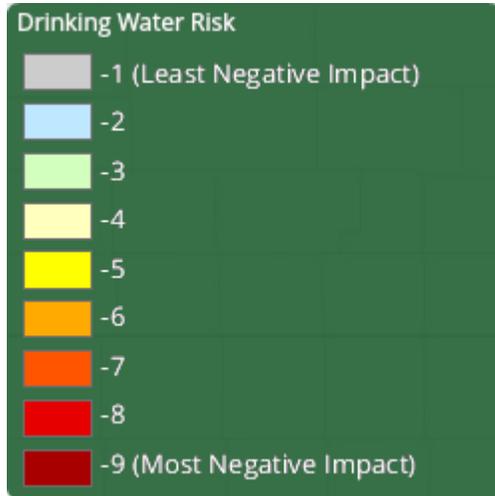
To calculate the WUI Risk Index, the WPL housing density data were combined with flame length data and response functions were defined to represent potential impacts. The response functions were defined by a team of experts led by Colorado State Forest Service mitigation planning staff. By combining flame length with the WPL 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 range of values is from -1 to -9, with -1 representing the least negative impact and -9 representing the most negative impact. For example, areas with high housing density and high flame lengths are rated -9, while areas with low housing density and low flame lengths are rated -1.

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 30-meter cell resolution, which is consistent with other CO-WRA layers.

## Drinking Water Risk Index

**A measure of the risk to Drinking Water Importance 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.

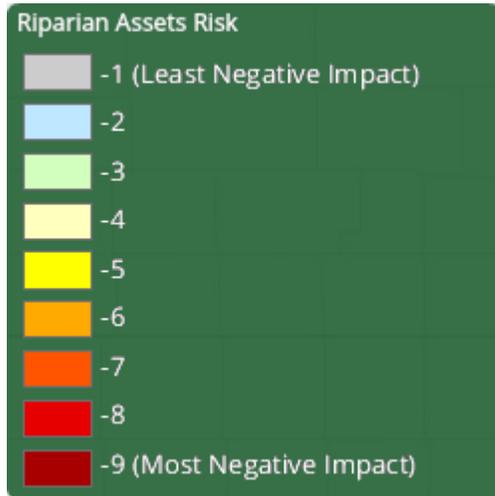
The loss of critical surface vegetation leaves forested slopes extremely vulnerable to large-scale soil erosion and flooding during subsequent storm events. In turn, these threats can impact the health, safety and integrity of communities and natural resources downstream. The likelihood that such a post-fire 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 range of values is from -1 to -9, with -1 representing the least negative impact and -9 representing the most negative impact.

### Riparian Forest Assets Risk Index

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



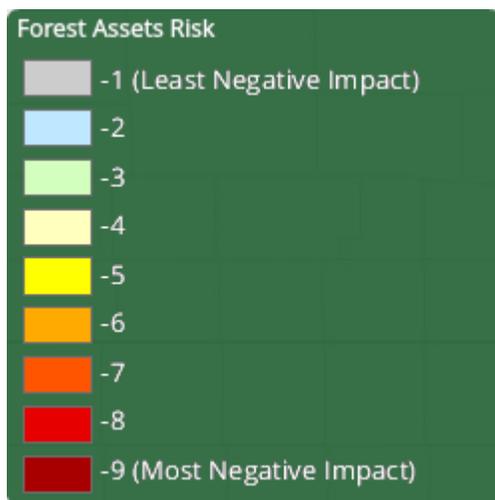
The range of values is from -1 to -9, with -1 representing the least negative impact and -9 representing the most negative impact.

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.

This risk output is intended to supplement the Drinking Water 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 range of values is from -1 to -9, with -1 representing the least negative impact and -9 representing the most negative impact.

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.

and high resilience or adaptability to fire.

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.

## Suppression Difficulty Index

Reflects the difficulty or relative cost to suppress a fire given the terrain and vegetation conditions that may impact machine operability



This layer is an overall index that combines the slope steepness and the fuel type characterization to identify areas where it would be difficult or costly to suppress a fire due to the underlying terrain and vegetation conditions that would impact machine operability (in particular Type II dozer).

The rating was calculated based on the fireline production rates for hand crews and engines with modifications for slope, as documented in the NWCG Fireline Handbook 3, PMS 401-1.

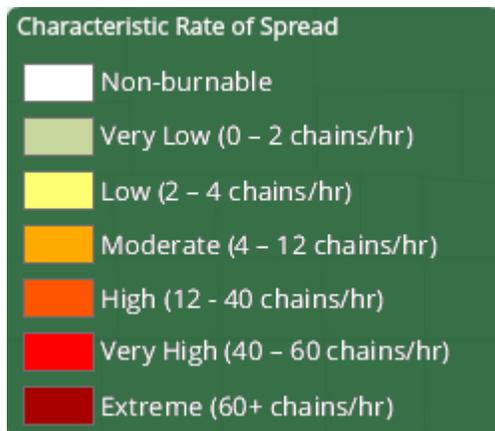
The burnable fuel models in the CO-WRA were grouped into three categories: slow (0-66 feet), medium (67-165 feet) and fast (greater than 165 feet).

Fireline production capability on five slope classes was used as the basic reference to obtain the suppression difficulty score. To remain constant with the Value At Risk Rating output values, a response function (-1 to -9) is assigned to each combination of fuel model group (slow, medium and fast) and slope category. Note that this layer is not used in the calculation of composite risk outputs. It is simply provided as a standalone output.

## Wildfire Behavior Outputs

### Characteristic 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 used in the calculation of Wildfire Threat in the CO-WRA.

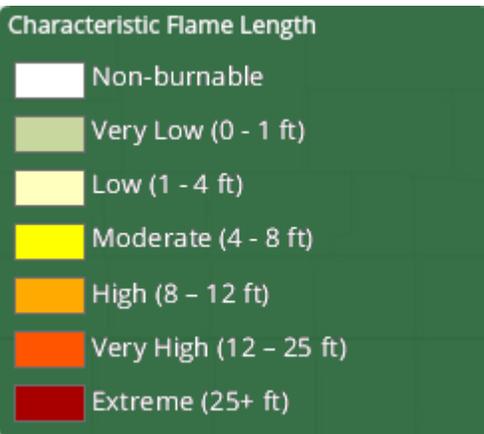
Rate of spread is a fire behavior output, which is influenced by three environmental factors - fuels, weather, and topography. Weather is by far the most dynamic variable as it changes frequently. To account for

this variability, four percentile weather categories were created from historical weather observations to represent low, moderate, high, and extreme weather days for a 30-meter grid cell in Colorado.

The Characteristic Rate of Spread represents the weighted average for all four weather percentiles. While not discussed in this report, the individual percentile weather ROS outputs are available in the CO-WRA data.

### Characteristic Flame Length

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



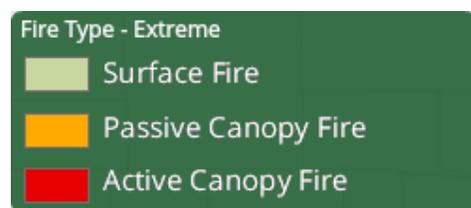
Flame Length is defined as the distance between the flame tip and the midpoint of the flame depth at the base of the flame, which is generally the ground surface. It is an indicator of fire intensity and is often used to estimate how much heat the fire is generating. Flame length is typically measured 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 30-meter grid cell in Colorado.

The Characteristic Flame Length represents the weighted average for all four weather percentiles. While not discussed in this report, the individual percentile weather Flame Length outputs are available in the CO-WRA data

### Fire Type - Extreme Weather

**Represents the potential fire type under the extreme percentile weather category**



The extreme percentile weather category represents the average weather based on the top three percent fire weather days in the analysis period. It is not intended to represent a worst case scenario weather event. Accordingly, the potential fire type is based on fuel conditions, extreme percentile weather, and topography.

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 – Extreme 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).
- 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 - extreme map is derived at a 30-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.

## Landscape Characteristics

### Surface Fuels

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

	NB01 - 91 - Urban/Developed
	NB02 - 92 - Snow/Ice
	NB03 - 93 - Agriculture
	NB08 - 98 - Water
	NB09 - 99 - Barren
	GR01 - 101 - Short, sparse, dry climate grass
	GR02 - 102 - Low load, dry climate grass
	GR03 - 103 - Low load, very coarse, humid climate grass
	GR04 - 104 - Moderate load, dry climate grass
	GR01 - 111 - GT 10,000 ft elevation
	GR02 - 112 - GT 10,000 ft elevation
	GS01 - 121 - Low load, dry climate grass-shrub
	GS02 - 122 - Moderate load, dry climate grass-shrub
	GS01 - 131 - GT 10,000 ft elevation
	SH01 - 141 - Low load, dry climate shrub
	SH02 - 142 - Moderate load, dry climate shrub
	SH03 - 143 - Moderate load, humid climate shrub
	SH05 - 145 - High load, humid climate grass-shrub
	SH07 - 147 - Very high load, dry climate shrub
	SH07 - 157 - Oak Shrubland without changes
	TU01 - 161 - Light load, dry climate timber-grass-shrub
	TU02 - 162 - Moderate load, humid climate timber-shrub
	TU05 - 165 - Very high load, dry climate timber-shrub
	TL01 - 181 - Low load, compact conifer litter
	TL02 - 182 - Low load, broadleaf litter
	TL03 - 183 - Moderate load, conifer litter
	TL04 - 184 - Small downed logs
	TL05 - 185 - High load, conifer litter
	TL06 - 186 - Moderate load, broadleaf litter
	TL07 - 187 - Large downed logs
	TL08 - 188 - Long-needle litter
	TL09 - 189 - Very high load, broadleaf litter

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.

Surface fuels are typically categorized into one of four primary fuel types based on the primary carrier of the surface fire: 1) grass, 2) shrub/brush, 3) timber litter and 4) slash. There are two standard fire behavior fuel model sets published for use. The Fire Behavior Prediction System 1982 Fuel Model Set (Anderson, 1982) contains 13 fuel models and the Fire Behavior Prediction System 2005 Fuel Model Set (Scott & Burgan, 2005) contains 40 fuel models. The CO-WRA uses fuel models from the 2005 Fuel Model Set.

The surface fuels for the 2017 Colorado Wildfire Risk Assessment Update uses a dataset based on 2014 LANDFIRE data supplemented with considerable enhancements and calibration to update the dataset to 2017. This included several calibration activities such as 1) removal of LANDFIRE mapping zone seamlines, 2) adjustments for disturbances that occurred from 2013-2017 including wildfires, treatments, and insect and disease, 3) fuel adjustments to consider high elevation fire behavior, oak shrublands, pinyon-juniper vegetation, and SH7 fuel model assignments. A team of local fuels experts led by the CSFS and supplemented by private industry and federal agency experts completed this effort. More detailed information including a description of methods used for the CO-WRAP fuels calibration can be found in the 2017 Colorado Fuels Calibration Final Report, July 2018, Colorado State Forest Service.

Table 1 provides a description of the FBPS 2005 fuel model set (Scott & Burgan, 2005).

**Table 16. FBPS 2005 Fuel Model Set (modified for Colorado 2017 Fuels Calibration)**

Value	Fuel Model Name	Description
101	GR01	Short, sparse dry climate grass
102	GR02	Low load dry climate grass
103	GR03	Low load, very coarse, humid climate grass
104	GR04	Moderate load dry climate grass
105	GR05	Low load humid climate grass
106	GR06	Moderate load humid climate grass
107	GR07	High load dry climate grass
108	GR08	High load very coarse humid climate grass
109	GR09	Very high load humid climate grass
111	GR01	GT 10,000 elevation
112	GR02	GT 10,000 elevation
121	GS01	Low load dry climate grass-shrub
122	GS02	Moderate load dry climate grass-shrub
123	GS03	Moderate load humid climate grass-shrub
124	GS04	High load humid climate grass-shrub
131	GS01	GT 10,000 Elevation
141	SH01	Low load dry climate shrub
142	SH02	Moderate load dry climate shrub
143	SH03	Moderate load humid climate shrub
144	SH04	Low load humid climate timber-shrub
145	SH05	High load humid climate grass-shrub
146	SH06	Low load humid climate shrub
147	SH07	Very high load dry climate shrub
148	SH08	High load humid climate shrub
149	SH09	Very high load humid climate shrub
157	SH07	Oak shrubland without changes
161	TU01	Light load dry climate timber-grass-shrub
162	TU02	Moderate load humid climate timber-shrub
163	TU03	Moderate load humid climate timber-grass-shrub

164	TU04	Dwarf Conifer with Understory
165	TU05	Very High Load, Dry Climate Timber-Shrub
181	TL01	Low load compact conifer litter
182	TL02	Low load broadleaf litter
183	TL03	Moderate load conifer litter
184	TL04	Small downed logs
185	TL05	High load conifer litter
186	TL06	Moderate load broadleaf litter
187	TL07	Large downed logs
188	TL08	Long-needle litter
189	TL09	Very high load broadleaf litter
201	SB01	Low load activity fuel
202	SB02	Moderate load activity or low load blowdown
203	SB03	High load activity fuel or moderate load blowdown
204	SB04	High load blowdown
91	NB01	Urban
92	NB02	Snow and Ice
93	NB03	Agriculture
98	NB08	Water
99	NB09	Bare Ground

## Vegetation

### General vegetation and land cover types

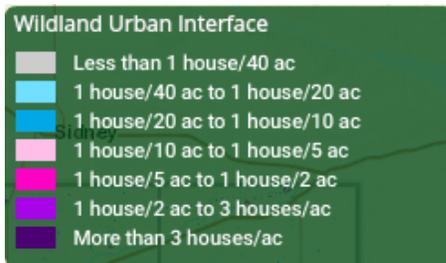


The Vegetation map describes the general vegetation and landcover types across the state of Colorado. In the CO-WRA, the Vegetation dataset is used to support the development of the Surface Fuels, Canopy Cover, Canopy Stand Height, Canopy Base Height, and Canopy Bulk Density datasets.

The 2014 LANDFIRE program data product (Existing Vegetation Type) was used to compile the Vegetation data for the West Wide Risk Assessment and the CO-WRA. This reflects data current to 2014. The LANDFIRE EVT data were classified to reflect general vegetation cover types for representation with CO-WRAP.

## Where People Live

Reflects housing density depicting where humans and their structures are located.



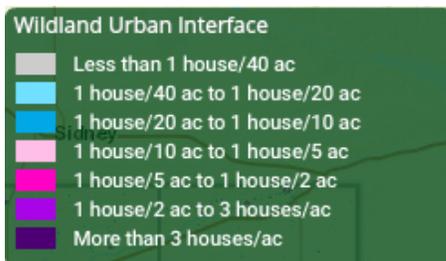
The Where People Live (WPL) layer reflects housing density depicting where humans and their structures are located in Colorado.

The new WPL data set is derived using advanced modeling techniques based on the 2016 LandScan USA population count data available from the Department of Homeland Security, HSIP data. WPL does not differentiate between wildland and urban areas.

Data is modeled at a 30-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.

## 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 2016 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 30-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.

### Drinking Water Importance Areas

#### A measure of quality and quantity of public surface drinking water categorized by watershed



This layer identifies an index of surface drinking water importance, reflecting a measure of water quality and quantity, characterized by Hydrologic Unit Code 12 (HUC 12) watersheds. The Hydrologic Unit system is a standardized watershed classification system developed by the USGS. Areas that are a source of drinking water are of critical importance and adverse effects from fire are a key concern.

The U.S. Forest Service Forests to Faucets (F2F) project is the primary source of the drinking water data set. This project used GIS modeling to develop an index of importance for supplying drinking water using HUC 12 watersheds as the spatial resolution. Watersheds are

ranked from 1 to 100 reflecting relative level of importance, with 100 being the most important and 1 the least important.

Several criteria were used in the F2F project to derive the importance rating including water supply, flow analysis, and downstream drinking water demand. The final model of surface drinking water importance used in the F2F project combines the drinking water protection model, capturing the flow

of water and water demand, with a model of mean annual water supply. The values generated by the drinking water protection model are simply multiplied by the results of the model of mean annual water supply to create the final surface drinking water importance index.

Water is critical to sustain life. Human water usage has further complicated nature’s already complex aquatic system. Plants, including trees, are essential to the proper functioning of water movement within the environment. Forests receive precipitation, utilize it for their sustenance and growth, and influence its storage and/or passage to other parts of the environment.

Four major river systems – the Platte, Colorado, Arkansas and Rio Grande – originate in the Colorado mountains and fully drain into one-third of the landmass of the lower 48 states. Mountain snows supply 75 percent of the water to these river systems.

Approximately 40 percent of the water comes from the highest 20 percent of the land, most of which lies in National Forests. National forests yield large portions of the total water in these river systems. The potential is great for forests to positively and negatively influence the transport of water over such immense distances.

## 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.

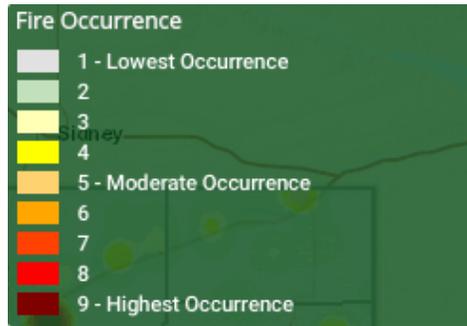
The process for defining these riparian areas involved identifying the riparian footprint and then assigning a rating based upon two important riparian functions – water quantity and quality, and ecological significance. A scientific model was developed by the West Wide Risk Assessment technical team 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.

## Historical Wildfire Ignitions

### Fire Occurrence



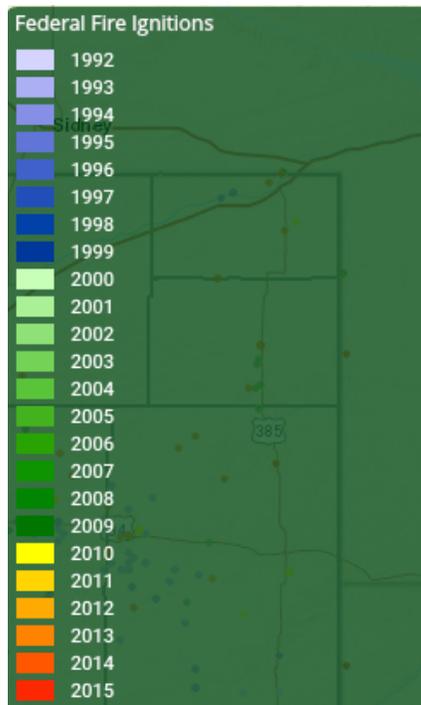
**Fire Occurrence is an ignition density that reflects historical ignition patterns.**

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). Refer to the CO-WRA Final Report for a more detailed description of the mapping classes and the methods used to derive these.

The Fire Occurrence map is derived at a 30-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.

### Federal Wildfire Ignitions



**Point locations for all federally reported wildfires from 1992 to 2017.**

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 and mitigation 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 1992-2017. 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 ignitions 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>

## Non-Federal Wildfire Ignitions

### Total non-federal fires reported from 2009 to 2017.



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 and mitigation 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.

Non-federally reported fire ignition locations for Colorado were compiled for 2009 to 2017. All ignitions data sources were updated to remove duplicate records and correct inaccurate locations. The original source of the data is reported by local fire departments through the National Fire Incident Reporting System (NFIRS). It is the system used by structural (regular) fire departments for collecting all kinds of fires. Wildland fires are just a portion of them. It is administered nationally by FEMA. Reference info <https://www.nfirs.fema.gov/>. Annually, the Colorado Division of Fire Control & Prevention sends data to CSFS of the wildland fires that are reported within NFIRS. CSFS then formats and submits that data through the National Association of State Foresters to the USDA-Forest Service Data Warehouse, Fire and Aviation Management Web Applications (FAMWEB) site where it is hosted for all the federal, state, and local wildland fire management agencies. Reference site is <https://fam.nwcg.gov/fam-web/>.

## 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. The Suppression Difficulty Rating is a standalone output that is not used in the calculation of the risk outputs.

2017 Colorado Wildfire Risk Assessment Update													
HVRA Response Functional Assignments													
Flame Length (classes in feet)					Flame Length Class (1 to 6)								
					1	2	3	4	5	6			
					0-2	2-4	4-6	6-8	8-12	12+			
Wildland Urban Interface (houses per acre)					1 - LT 1hs/40 ac	-0.40	-0.60	-1.00	-1.40	-1.80	-1.80		
					2 - 1 hs/40-20 ac	-0.80	-1.20	-2.00	-2.80	-3.60	-3.60		
					3 - 1 hs/20-10 ac	-1.20	-1.80	-3.00	-4.20	-5.40	-5.40		
					4 - 1 hs/10-5 ac	-1.50	-2.25	-3.75	-5.25	-7.10	-7.10		
					5 - 1 hs/5-2 ac	-1.90	-2.85	-4.75	-6.65	-7.90	-8.55		
					6 - 1-3 hs/ac	-2.00	-3.00	-5.00	-7.10	-9.00	-9.00		
					7 - GT 3hs/ac	-2.00	-5.00	-7.00	-8.00	-9.00	-9.00		
Drinking Water (level of importance)					1 - Lowest	-0.10	-0.20	-0.50	-0.60	-0.80	-0.90		
					2	-0.10	-0.20	-0.50	-0.60	-0.80	-0.90		
					3	-0.20	-0.40	-1.00	-1.20	-1.60	-1.80		
					4	-0.30	-0.60	-1.50	-1.80	-2.40	-2.70		
					5	-0.40	-0.80	-2.00	-2.40	-3.20	-3.60		
					6	-0.50	-1.00	-2.50	-3.00	-4.00	-4.50		
					7	-0.60	-1.20	-3.00	-3.60	-4.80	-5.40		
					8	-0.70	-1.40	-3.50	-4.20	-5.60	-6.30		
					9	-0.80	-1.60	-4.00	-4.80	-6.40	-7.20		
					10 - Highest	-1.00	-2.00	-5.00	-6.00	-8.00	-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 Impt	0.00	0.00	-0.50	-1.00	-1.75	-1.75		
					2 - Moderate Imp	0.00	0.00	-1.00	-2.00	-3.50	-3.50		
					3 - Highest Imp	0.00	0.00	-2.00	-4.00	-7.00	-7.00		
Suppression Difficulty					Fuel Type Code		Slope Steepness						
							0-25	26-40	41-55	56-74	75+		
							1	2	3	4	5		
					Grass	1	-1.0	-3.7	-6.9	-8.7	-9.0		
					Brush/Slash	2	-3.0	-5.2	-7.9	-8.9	-9.0		
TL	3	-4.2	-5.9	-8.0	-8.9	-9.0							
Values At Risk Relative Importance					Individual Risk Layers		Relative Imp.						
					WUI		36.4%						
					Drinking Water		36.4%						
					Forest Assets		18.2%						
					Riparian Assets		9.1%						

## **Appendix D: Data Vintage Summary**

This appendix provides a summary of the data sources and vintage (creation date) for the key CO-WRA datasets. It includes a summary of both the 2017 and 2012 assessment data so that users can fully understand the changes that occurred with assessment data, input, derived and output.

**CO-WRA 2017 & 2012 - Data Vintage Summary**

<i>Layer / Dataset</i>	<i>Description</i>	<i>Type</i>	<i>2012 Assessment</i>	<i>2017 Assessment Update</i>
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<b>Landscape Characteristics</b>				
<b>Surface Fuels</b>	Surface fuels data	Input	2008 LANDFIRE Refresh	2017 update to 2014 LANDFIRE
<b>Canopy Fuels (CBD, CBH, CCH, CC)</b>	LANDFIRE canopy fuels	Input	2008 LANDFIRE Refresh	2017 minor updates to 2014 LANDFIRE
<b>Vegetation</b>	LANDFIRE vegetation data	Standalone	2008 LANDFIRE Refresh EVT	2014 LANDFIRE EVT
<b>Where People Live (WPL)</b>	Housing density derived from DHS LandScan population count data, and 2010 Census county profiles data. Input for deriving WUI Risk output. <u>Note this dataset is used in CO-WRA production but is not currently shown in CO-WRAP.</u>	Derived & Input	2010 Census County 2012 HSIP LandScan	2010 Census County 2016 HSIP LandScan 2014 Post Office Addresses
<b>Wildland Urban Interface (WUI)</b>	This housing density dataset is the WPL dataset with core urban areas that are not susceptible to wildfires removed. Output from WUI Risk analysis process.	Output	2010 Census County 2012 HSIP LandScan	2010 Census County 2016 HSIP LandScan 2014 Post Office Addresses 2017 Flame Length (mask for encroachment)
<b>Forest Assets</b>	The Forest Assets 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 three classes are sensitive, resilient and adaptive:	Derived & Input	2008 LANDFIRE Refresh CC, CH & EVT	2014 LANDFIRE CC, CH & EVT

**CO-WRA 2017 & 2012 - Data Vintage Summary**

<i>Layer / Dataset</i>	<i>Description</i>	<i>Type</i>	<i>2012 Assessment</i>	<i>2017 Assessment Update</i>
	<p>Sensitive: These are tree species that are intolerant or sensitive to damage from fire with low intensity.</p> <p>Resilient: These are tree species that have characteristics that help the tree resist damage from fire and whose adult stages can survive low intensity fires.</p> <p>Adaptive: These are tree species adapted with the ability to regenerate following fire by sprouting or serotinous cones.</p>			
<b>Riparian Assets</b>	<p>The Riparian Assets 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.</p> <p>A model developed by CALFIRE uses riparian areas as a means of representing the most</p>	Modeled & Input	2008 LANDFIRE EVT 2012 NWI 2012 NHD	2008 LANDFIRE EVT 2012 NWI 2012 NHD (same source data as 2012 assessment)

**CO-WRA 2017 & 2012 - Data Vintage Summary**

<i>Layer / Dataset</i>	<i>Description</i>	<i>Type</i>	<i>2012 Assessment</i>	<i>2017 Assessment Update</i>
	essential ecosystem variables associated with watersheds. This model attempts to represents the spatial extent of riparian zones on perennial streams, intermittent streams, and wetland areas. Additionally, this model will allow the user to analyze a suite of variables in those riparian areas that may be most affected by fire. The National Hydrography Dataset (NHD), the National Wetlands Inventory (NWI) and LANDFIRE's Existing Vegetation Dataset (EVT) were the primary inputs to this dataset. Riparian Assets are ranked from 1 to 3 reflecting relative level of importance, with 3 being the most important and 1 the least important.			
<b>Drinking Water Importance Areas</b>	The Drinking Water Importance Areas layer identifies an index of surface drinking water importance, reflecting a measure of water quality and quantity, characterized by Hydrologic Unit Code 12 (HUC 12) watersheds. The Forest Service Forests to Faucets (F2F) project is the primary source of the drinking water data set. This project used GIS modeling to develop an index of importance for supplying drinking water using HUC 12 watersheds as the spatial resolution. Watersheds are ranked from 1 to 100 reflecting relative level of importance, with	Input	2011 USFS Forest 2 Faucets	2011 USFS Forest 2 Faucets (same source as 2012 assessment)

**CO-WRA 2017 & 2012 - Data Vintage Summary**

<i>Layer / Dataset</i>	<i>Description</i>	<i>Type</i>	<i>2012 Assessment</i>	<i>2017 Assessment Update</i>
	100 being the most important and 1 the least important.			
<b>Ownership</b>	Ownership data were acquired from the Colorado Ownership, Management, and Protection v9 Database as developed by the Colorado Natural Resource Ecology Lab (NREL), Fort Collins, Colorado. The NREL compiled data from federal, state, and local agencies including NGOs, city, county, and land trust sources. See <a href="https://comap.cnhp.colostate.edu/history/">https://comap.cnhp.colostate.edu/history/</a> .	Standalone	September 2011 CMap	September 2016 CMap
<b>Threat to Forest Health</b>	Threat to forest health are identified as insect and disease data compiled by CSFS and USFS Rocky Mountain Region.	Standalone	2009 CSFS Forest Resource Assessment	1996 - 2016 CSFS
<b>Reference Base Layers</b>				
<b>Cities</b>	Cities and municipalities polygons as available in source data.	Standalone	2010 ESRI v10 ArcGIS Data	Same as 2012 CO-WRA.
<b>County Boundaries</b>	County boundaries.	Standalone	2010 ESRI v10 ArcGIS Data	Same as 2012 CO-WRA.
<b>Fire Protection Districts</b>	FPD boundaries as compiled by CSFS. Infrequent updates occur based on FPD feedback.	Standalone	2012 FPD from CSFS.	2017 update from CO Dept. of Fire Prevention & Control
<b>Schools</b>	School points as available in source data.	Standalone	2010 ESRI v10 ArcGIS Data	Removed from 2017 assessment & CO-WRAP apps.
<b>Hospitals</b>	Hospital points as available in source data.	Standalone	2010 ESRI v10 ArcGIS Data	Removed from 2017 assessment & CO-WRAP apps.

**CO-WRA 2017 & 2012 - Data Vintage Summary**

<i>Layer / Dataset</i>	<i>Description</i>	<i>Type</i>	<i>2012 Assessment</i>	<i>2017 Assessment Update</i>
<b>Active Coal Fires</b>	Location of active coal fires tracked and reported by CSFS.	Standalone	2014 CSFS Compiled	Removed from 2017 assessment & CO-WRAP apps.
<b>2017-18 Large Fire Perimeters</b>	Large fire perimeters for the identified years as captured by the 209 system in the USFS Geomac data repository. Only includes 2018 data to October 2018.	Standalone	Not included.	Geomac USGS 2017-18
<b>2015-16 Large Fire Perimeters</b>	Large fire perimeters for the identified years as captured by the 209 system in the USFS Geomac data repository	Standalone	Not included.	Geomac USGS 2015-16
<b>2013-14 Large Fire Perimeters</b>	Large fire perimeters for the identified years as captured by the 209 system in the USFS Geomac data repository	Standalone	Geomac USGS 2013-14 (updated in 2014 to CO-WRAP)	Geomac USGS 2013-14
<b>2011-12 Large Fire Perimeters</b>	Large fire perimeters for the identified years as captured by the 209 system in the USFS Geomac data repository	Standalone	Geomac USGS 2011-12	Geomac USGS 2011-2012
<b>2000-10 Large Fire Perimeters</b>	Large fire perimeters for the identified years as captured by the 209 system in the USFS Geomac data repository	Standalone	Geomac USGS 2000-12	Geomac USGS 2000-012
<b>HUC 12 Watersheds</b>	HUC 12 (6 <sup>th</sup> order watershed) boundaries as published by USGS.	Standalone	2015 USGS HUC	2015 USGS HUC
<b>CWPP Community</b>	CWPP area boundaries for community based CWPPs compiled by CSFS. Minor updates undertaken to match FireWise community boundaries.	Standalone	2015 CSFS	2018 CSFS Update
<b>CWPP County</b>	CWPP area boundaries for county based CWPPs. Minor updates undertaken to match	Standalone	2015 CSFS	2015 CSFS

**CO-WRA 2017 & 2012 - Data Vintage Summary**

<i>Layer / Dataset</i>	<i>Description</i>	<i>Type</i>	<i>2012 Assessment</i>	<i>2017 Assessment Update</i>
	FireWise community boundaries where appropriate.			
<b>CWPP FPD</b>	CWPP area boundaries for FPD based CWPPs. Minor updates undertaken to match FireWise community boundaries where appropriate.	Standalone	2015 CSFS	2015 CSFS
<b>FireWise Communities (Sites)</b>	FireWise communities compiled by CSFS in collaboration with NFPA.	Standalone	2015 CSFS & NFPA	2018 CSFS Update
<b>Disturbance Fire</b>	Fire perimeter data compiled as an input data source for the 2017 fuels calibration. Included to show users where fire perimeter updates were done for the 2017 fuels update.	Standalone & Input	Not included.	2013-17 Large Fire Perimeters from MTBS & Geomac, used as input for 2017 fuels update.
<b>Disturbance Treatments</b>	Treatment polygon data compiled as an input data source for the 2017 fuels calibration. Included to show users where treatment area updates were done for the 2017 fuels update.	Standalone & Input	Not included.	2013-17 data from SMART, federal treatment databases, and CO state treatment data (districts), used as input for 2017 fuels update.
<b>Disturbance Insect &amp; Disease</b>	Insect and disease polygon data compiled as an input data source for the 2017 fuels calibration. Included to show users where I&D updates were done for the 2017 fuels update.	Standalone & Input	Not included.	2013-17 aerial sketch map polygons obtained from USFS FHTET Forest Disturbance Monitor database, used as input for 2017 fuels update.
<b>Wildfire Behavior Outputs</b>				
<b>Characteristic Flame Length</b>	Flame length (feet) derived from latest fuels mapping. This is a conditional output that combines FL for the four weather percentiles.	Derived	2008 LANDFIRE Refresh	2017 Update to 2014 LANDFIRE

**CO-WRA 2017 & 2012 - Data Vintage Summary**

<i>Layer / Dataset</i>	<i>Description</i>	<i>Type</i>	<i>2012 Assessment</i>	<i>2017 Assessment Update</i>
<b>Characteristic ROS</b>	Rate of Spread (chains/hr) derived from latest fuels mapping. This is a conditional output that combines FL for the four weather percentiles.	Derived	2008 LANDFIRE Refresh	2017 Update to 2014 LANDFIRE
<b>Fire Type - Extreme</b>	Crown fire potential for the Extreme weather percentile only. Derived from the latest fuels mapping.	Derived	2008 LANDFIRE Refresh	2017 Update to 2014 LANDFIRE
<b>Historical Wildfire Occurrence</b>				
<b>Federal Fire Ignitions</b>	Federal source ignition data collected from various agencies and sources including: <ul style="list-style-type: none"> <li>• US Forest Service</li> <li>• US Fish and Wildlife Service</li> <li>• Bureau of Land Management</li> <li>• Bureau of Indian Affairs</li> <li>• National Park Service</li> </ul>	Standalone & Fire Occurrence	1999-2008	1992-2017
<b>Fire Occurrence (Wildfire Ignition Density)</b>	Wildfire ignition density derived from federal and non-federal ignition points.	Standalone & used in BP weighting	1999-2008 federal & non-federal ignition points	<ul style="list-style-type: none"> <li>• 1992-2017 federal ignitions</li> <li>• 2009-2017 non-federal ignitions</li> </ul>
<b>Non Federal Fire Ignitions</b>	Wildfire ignition points compiled the NFIRS database with only CO non-federal fires extracted.	Standalone & Fire Occurrence	1999-2008 (zip code based)	2009-2017 point ignitions from NFIRS – non-federal data only.

**CO-WRA 2017 & 2012 - Data Vintage Summary**

<i>Layer / Dataset</i>	<i>Description</i>	<i>Type</i>	<i>2012 Assessment</i>	<i>2017 Assessment Update</i>
<b>Forest Management Activities</b>				
<b>Activities 2008</b>	Forest treatment polygons compiled by CSFS, conducted by CSFS with partner agencies for 2008.	Standalone	CSFS WebDet 2014	CSFS WebDet 2014. Expect to update this data in Q4 2018 to 2017.
<b>Activities 2009</b>	Same as above for 2009	Standalone	CSFS WebDet 2014	Same as above 2008
<b>Activities 2010</b>	Same as above for 2010	Standalone	CSFS WebDet 2014	Same as above 2008
<b>Activities 2011</b>	Same as above for 2011	Standalone	CSFS WebDet 2014	Same as above 2008
<b>Activities 2012</b>	Same as above for 2012	Standalone	CSFS WebDet 2014	Same as above 2008
<b>Wildfire Effects Themes</b>				
<b>Values at Risk Rating</b>	A composite risk rating by combining all response function derived risk ratings layers (WUI, Drinking Water, Forest Assets, Riparian)	Derived	2012 CO-WRA	2017 CO-WRA
<b>Suppression Difficulty Rating</b>	<p>Reflects the difficulty or relative cost to suppress a fire given the terrain and vegetation conditions that may impact machine operability.</p> <p>This layer is an overall index that combines the slope steepness and the fuel type characterization to identify areas where it would be difficult or costly to suppress a fire due to the underlying terrain and vegetation conditions that would impact machine operability (in particular Type II dozer).</p>	Derived	<ul style="list-style-type: none"> <li>• Rate of Spread calculated from 2008 LANDFIRE Refresh</li> <li>• Slope</li> <li>• NWCG Fireline Handbook 3, PMS 401-1</li> </ul>	<ul style="list-style-type: none"> <li>• Rate of Spread calculated from 2017 updated fuels.</li> <li>• Slope</li> <li>• NWCG Fireline Handbook 3, PMS 401-1</li> </ul>

**CO-WRA 2017 & 2012 - Data Vintage Summary**

<i>Layer / Dataset</i>	<i>Description</i>	<i>Type</i>	<i>2012 Assessment</i>	<i>2017 Assessment Update</i>
<b>WUI Risk</b>	A measure of the potential impact on people and their homes from wildfire within WUI areas, derived by combing flame length (fire intensity), Where People Live (housing density), and urban encroachment algorithms based on underlying fuel types and proximity.	Derived	<ul style="list-style-type: none"> <li>Flame Length calculated from 2008 LANDFIRE refresh</li> <li>2012 WPL derived from 2012 LandScan</li> </ul>	<ul style="list-style-type: none"> <li>2017 Fuels Updated</li> <li>2017 Flame Length</li> <li>2016 WPL derived from 2016 LandScan</li> <li>2017 fuel types used for calculating urban encroachment distances</li> </ul>
<b>Drinking Water Risk</b>	A measure of the risk to Drinking Water Importance Areas based on the potential negative impacts from wildfire.	Derived	<ul style="list-style-type: none"> <li>Flame Length calculated from 2008 LANDFIRE refresh</li> </ul>	<ul style="list-style-type: none"> <li>2017 Fuels Updated</li> <li>2017 Flame Length</li> </ul>
<b>Forest Assets Risk</b>	<p>A measure of the risk to forested areas based on the potential negative impacts from wildfire.</p> <p>This layer identifies those forested areas with the greatest potential for adverse effects from wildfire.</p>	Derived	<ul style="list-style-type: none"> <li>2008 LANDFIRE Refresh (CC, CH &amp; EVT)</li> <li>Flame Length calculated from 2008 LANDFIRE refresh</li> </ul>	<ul style="list-style-type: none"> <li>2017 Fuels Updated</li> <li>2017 Flame Length</li> <li>2014 LANDFIRE Refresh (CC, CH &amp; EVT)</li> </ul>
<b>Riparian Assets Risk</b>	<p>A measure of the risk to riparian areas based on the potential negative impacts from wildfire.</p> <p>This layer identifies those riparian areas with the greatest potential for adverse effects from wildfire</p>	Derived	<ul style="list-style-type: none"> <li>2008 LANDFIRE EVT</li> <li>2012 NWI</li> <li>2012 NHD</li> <li>Flame Length calculated from 2008 LANDFIRE refresh</li> </ul>	<ul style="list-style-type: none"> <li>2017 Fuels Updated</li> <li>2017 Flame Length</li> <li>2008 LANDFIRE EVT</li> <li>2012 NWI</li> <li>2012 NHD</li> </ul>
<b>Wildfire Risk Themes</b>				

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<b>Wildfire Risk</b>	An overall composite risk layer derived by combing Values at Risk Rating with Burn Probability (previously Wildfire Threat in 2012).	Derived	<ul style="list-style-type: none"> <li>• 2012 Values at Risk Rating</li> <li>• 2012 Suppression Difficulty Rating</li> <li>• 2012 Wildfire Threat</li> </ul>	<ul style="list-style-type: none"> <li>• 2017 Values at Risk Rating</li> <li>• 2017 Burn Probability</li> </ul>
<b>Wildfire Threat</b>	Wildland Fire Susceptibility Index (WFSI), a surrogate for burn probability, that is defined as the likelihood of an acre burning. This is a legacy layer that will be replaced in 2018 update with Burn Probability.	Modeled	<ul style="list-style-type: none"> <li>• 2009 Wildfire Ignition Density</li> <li>• Rate of Spread derived from 2008 LANDFIRE Refresh</li> </ul>	Not included, replaced by Burn Probability
<b>Burn Probability</b>	Probability of a wildfire occurring anywhere on the landscape based on conditions defined by the fuels data, terrain and weather scenarios used.	Modeled	Not Included	<ul style="list-style-type: none"> <li>• Regular grid of fire ignition points every 500 m across the entire state (i.e. 3.2 million points)</li> <li>• 2017 Fuels Update</li> <li>• 2017 Fire Occurrence</li> </ul>
<b>Fire Intensity Scale</b>	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 classes where the order of magnitude between classes is ten-fold. The minimum class, Class 1, represents very low wildfire	Derived	Fireline Intensity derived from 2008 LANDFIRE refresh	Fireline Intensity derived from 2017 fuels update

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	intensities and the maximum class, Class 5, represents very high wildfire intensities.			