Colorado Wildfire Risk Assessment

Fuels Calibration

Final Report

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Prepared by:
Technosylva Inc. in collaboration with Colorado State Forest Service

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1. PROJECT OVERVIEW

1.1 Background

The initial Colorado Wildfire Risk Assessment (CWRA) was published in February 2013. The project was based on leveraging the data and achievements of the West Wide Wildfire Risk Assessment (WWA) project, and tailoring these to reflect Colorado conditions, requirements and priorities.

Once the Colorado Wildfire Risk Assessment (CWRA) project was completed, the data was released to Colorado State Forest Service (CSFS) staff, CSFS partners and collaborators, and the public. The data was also made available through an interactive web mapping application called the Colorado Wildfire Risk Assessment Portal (CO-WRAP). Since its publication, CO-WRAP data layers have been updated as new data has become available.

1.2 Purpose of the Report

This report describes the technical approach, development methods and findings of a recent project undertaken to update and calibrate the surface fuels data in the CWRA (and CO-WRAP). The fuels data is a core dataset that was used to derive fire behavior and wildfire risk outputs by applying the quantitative risk assessment framework methods (Scott 2013).1

The report includes detailed technical descriptions of the data processing methods undertaken to update fuels data to reflect issues identified by the project team.

Updating the surface fuels data is the baseline for updating the CWRA, to bring the assessment up to date and reflect risk conditions more accurately for 2017. This is important when considering the vintage and accuracy of the original LANDFIRE 2010 fuels data used in the WWA and CWRA projects.

Please refer to the CWRA Final Report and West Wide Wildfire Risk Assessment Final Report for more information about the risk assessment methods employed.

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1.3 Project Approach

To complete this project CSFS and Technosylva employed a core team of subject matter experts in fuels mapping, fuels modeling and fire behavior analysis. The team consisted of:

- Richard Homann, CSFS, CO-WRAP Project Manager
- Boyd Lebeda, CSFS, FBAN
- Rod Moraga, Anchor Point Group, FBAN
- Dr. Joaquin Ramirez, Technosylva, Fuels Modeling & Fire Behavior Scientist
- David Buckley, Technosylva, Senior Consultant

The team is a complement of skills and knowledge, incorporating local Colorado landscape fuels field experience along with leading edge technical fuels mapping and modeling expertise. This complement of skills provided the basis for identifying fuels data issues and investigating methods to address these. The focus of the fuels team was to conduct the following tasks:

1. Identify fuels data issues that need investigation;
2. Research issues and identify options for correcting the issues;
3. Investigate technical options;
4. Review technical findings;
5. Conduct fuels data updates; and

In addition to the core fuels team, Technosylva employed a team of technical analysts and image processing specialists to conduct the actual data extraction, processing and development of final results. The technical team consisted of:

- Javier Blanco, Technical Team Manager, Technosylva
- Leyre Pámpanas Yustres, Lead Fuels Analyst, Technosylva
- Francisco José Diez Vizcaíno, Lead Image Processing Analyst, Technosylva
- Adrián Cardil Forradellas, Lead Fire Behavior Analyst, Technosylva

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2 For more information about the project please contact Colorado State Forest Service at https://csfs.colostate.edu/.


1.4 Project Objectives and Scope

The purpose of this project is the review, identification, and adjustment to the core LANDFIRE fuels 2014 (LF 14) datasets to better represent expected and observed fire behavior in Colorado. The methods used in this report were developed by Technosylva Inc. under direction of the project fuels team. This collaboration provides an excellent combination of field knowledge and experience coupled with advanced technical data processing methods.

The outcome of this project is a more accurate fuels dataset that meets the Fire Behavior (FB) modeling requirements of the CWRA, that is, to support the mitigation and prevention planning purposes of the assessment and the CO-WRAP web site. However, to ensure that the FB outputs are correct, testing was conducted using operational wildfire examples. This provided a good benchmark to confirm the accuracy of the fuels data for FB modeling purposes. The fuels were calibrated using fire behavior modeling outputs.

Scope of Project Tasks

The following scope was identified to bound the project within the timelines and budget available:

- LANDFIRE 2014 will be the source surface fuels, vegetation and canopy data
- The default 30m spatial resolution of LANDFIRE shall be used
- While other more accurate local datasets may be available across the State, we will not integrate these with the final output fuels dataset. We will retain a consistent source for the project and focus on updating the LF 14 data to correct issues.
- Weather percentile data used in the original CWRA will be used to support the FB modeling during the calibration process.
- Some minor updating to canopy data will be undertaken after the surface fuels updates are finalized to ensure there is not a mismatch between surface and canopy datasets.
- While the primary purpose is to use the updated fuels to conduct a future update of the CWRA, we will make the fuels data available to other agencies and partners for use.
- A descriptive narrative will be compiled to aid users with using the updated fuels data. This narrative will describe caveats for use with certain fuel models that may exhibit different fire behavior in specific situations or weather conditions.
- Wherever possible the fuels team will confer with other agency fuels experts, such as USFS, BLM, etc., to get their insights and feedback on the issues identified.
will ensure we utilize the best possible local knowledge to conduct the calibration tasks.

**Identified Issues with LANDFIRE Fuels Data**

The primary objective of the project was to correct issues identified in the LANDFIRE 2014 data to derive an updated and more accurate fuels dataset for Colorado. A key element of this was to identify well known and understood issues and determine methods to enhance the fuels definitions. The following data issues were identified with the baseline LANDFIRE 2014 data.

1. Mapping zone seamlines  
   a. A well-known problem with LANDFIRE data is the edge effects of different fuel model calls along the mapping zone boundaries.
2. Recent large disturbances are not included, given the year of the LF data source (2014) and underlying satellite imagery (2012), such as:  
   a. Insect and disease  
   b. Large wildfires  
   c. Treatments and harvesting  
3. Fuels models SH07 and SH05 are over represented in Colorado and reduced significantly through various methods.  
4. Pinyon Juniper areas are not well represented  
5. Oak Shrubland areas are not well represented  
6. High altitude elevation effects on fire ignition and spread are not accommodated for.

Each issue was assigned investigation by a member of the fuels team. Technosylva provided technical support to prepare and extract data to meet the team member’s investigation requirements. The issues identified were organized into “Groups” reflecting cumulative processing of the data. Final deliverables are referenced by these groups in order to track incremental changes to the fuels data.

Numerous web meetings were held over a three-month period to review and discuss findings of the technical investigations. On-going data processing and analysis was undertaken until results were acceptable for areas of concern. Each technical processing method was documented. This report provides detailed description of the individual data processing tasks that were undertaken.
Processing Methods Used

A number of different processing methods were used to modify the LANDFIRE fuels data. These range from simply substituting fuel model classes to using advanced imagery processing. The following methods were used:

- Simple reclassification of one fuel model to another fuel model based on expert opinion
- Combination of vegetation classes, elevation classes and fuel models to define where to substitute fuel models (i.e. unique combinations of landscape characteristics that dictate a change in fuel model)
- Spatial overlay to define specific areas where fuels model substitutions will occur
- Satellite imagery processing to define areas of change and rules for substituting fuel models to reflect those disturbances

Data Sources Used

A range of different data was used to support the calibration and update process. This included:

- LANDFIRE 2014 surface fuels, vegetation, canopy and terrain datasets (primary source data)
- LandSat 8 imagery from 2014 to 2016
- Ancillary datasets to support identification of issues and disturbances, such as:
  - LANDFIRE mapping zone boundaries
  - Fire perimeter data (local and federal data sources)
  - Federal disturbance datasets, such as treatments, harvesting, etc., supplemented with the SMART treatment data collected by CSFS.
  - Federal insect and disease data sets, such as FHTET.

Description of the different data methods is provided later in this report.

Outputs and Deliverables

The data compiled and derived for the project is provided in an ArcGIS GDB format along with an ArcMap MXD document. The ArcGIS GDB is referred to as the “Delivery GDB” in this report. All the important interim datasets are provided (as referenced in the following sections), as well as the final surface fuels raster dataset. This deliverable is provided as a single .zip file that contains the following key files.

- .GDB with all interim and final datasets
- .MXD in ArcGIS 10.0 & 10.4 format.
- .LYR files for key fuels outputs.
• .PPT with description of methods
• .DOC/.PDF – draft fuels report (replaced with this report)

Figure 1. Colorado Fuels Update Deliverable Files.

Data is organized into “Groups” reflecting the updating process and issues identified by the fuels team. The following figure presents the Table of Contents of the ArcMap MXD document. Final fuels data is provided in Group 13.

Figure 2. Colorado Fuels ArcMap MXD Table of Contents

The following figure shows the final fuels data as delivered in the ArcMap application.
In addition to the primary GIS data deliverables, a web mapping tool was also developed to facilitate a quick review of the original LF 14 data and the final updated Colorado surface fuels dataset. This is described in Section 5.2.

Additionally, this report is supplemented with a detailed PowerPoint files (PPT) file that provides a detailed graphic description of the methods and results.

The following sections of this report describe the methods used and the results of the data processing.
2. RESOLVING LANDFIRE 2014 DATA ISSUES

The fuels updating process focused on addressing identified issues first, before embarking on integrating recent disturbance data into the fuels update. To complete this task the following source data was used (Delivery GDB dataset names in ““ quotes):

- Datasets from the `LANDFIRE fire behavior fuel Model 40` from 2014, representing Scott & Burgan models, were used (“G8_Fuels_LF_140fbfm40_general”).
- Datasets from the `LANDFIRE vegetation data` from 2014 were used to identify the issues with the data and detect areas for landscape change (“G8_Vegetation_LF_140evt_general”).
- Other base layers that were used for some processes include Colorado state boundary, Elevation (DEM). These layers include “Colorado_boundary”, “DEM_feet_general_reclassify”, “G0_DEM_feet_general” or “G0_DEM_feet_general_reclassify”.

In addition, other LANDFIRE canopy related datasets were used, such as canopy bulk density (CBD), canopy base height (CBH), canopy cover (CC) and canopy height (CH).

- G5_Canopy_layer_LF_140_CBD
- G5_Canopy_layer_LF_140_CBH
- G5_Canopy_layer_LF_140_CC
- G5_Canopy_layer_LF_140_CH

These layers are in Group 5 (G5) in the Delivery GDB and MXD.

2.1 Issues Detected in LANDFIRE 2014

The fuels team identified four specific scenarios where there are concerns with the existing LF 14 data in Colorado. These are:

1. Mapping zone boundary effects
2. Pinyon Juniper areas
3. Pine with Oak Shrubland areas
4. High elevation alpine areas
Each scenario was dealt with individually and included integration of the source data above to define different reclassification rules to correct the issues. This primarily involved reclassifying the fuel models based on unique conditions. In some cases the boundary effects were resolved by addressing the Pinyon-Juniper and Oak Shrubland issues. This involved several iterations of corrections to finalize the desired fuel model classifications.

**Group 1 (G1): Issues detected with LANDFIRE Mapping Zone Boundaries**

A common problem found with LANDFIRE fuels data is inconsistent fuel model classes detected at mapping zone boundaries. This can be caused by different LANDFIRE technical staff applying different rules for their zone of responsibility during the mapping process within the LANDFIRE program, and/or different underlying vegetation datasets for those zones.5

The following figure shows examples of different fuel model classifications that occur at mapping zone boundary. The LANDFIRE mapping zone is shown as a red line. Fuel models are represented by different colors. Note the sharp unnatural change in fuel model classes at the boundary in each example.

**Figure 4. Mapping zone edge effects examples.**

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5 Often different LANDFIRE technical analysts are assigned the responsibility to create the output data for different mapping zones. Combined with some differences in underlying vegetation or ancillary data, this can lead to a sharp change in fuel model classes at mapping zone boundaries that may not reflect actual conditions on the ground.
The fuels team and technical team identified a number of potential boundary edge effect areas within Colorado. These were investigated and resolved. The following map shows the LANDFIRE mapping zone boundaries in Colorado in blue. Red areas shown areas where edge effects occurred and needed to be resolved.

Figure 5. Areas where mapping zone boundary effects occur.

These areas of concern are identified by an “ObjectID” in the layer “issues_detected_LF2014_boundary_effect”. To solve these issues, the fuels team and technical team worked together to propose a series of rules for each areas of concern. This involved reviewing the fuels data along with underlying vegetation and terrain characteristics data. In some cases it involved changes to Pinyon-Juniper and Oak Shrubland fuel models.

The following rules (named ObjectID’s rules) and the changes made in the raster (original LF2014) are presented below:

1. ObjectID 65: 122 changes to 102 and 147 changes to 102
2. ObjectID 68: 103 changes to 122
3. ObjectID 70: 147 changes to 102 and 161 changes to 122
4. ObjectID 71: 141 changes to 102 and 101 changes to 122
5. ObjectID 72: 122 changes to 161 and 183 changes to 161
6. ObjectID 73: 147 changes to 141
7. ObjectID 74: 147 changes to 141
8. ObjectID 75: 141 changes to 102 and 121 changes to 122

Please refer to Section 5.1 for a description of the Colorado Fuels Review Web Tool that provides an easy way to review the individual areas of concern and the corrected fuels. Examples of corrected fuels data (before and after) are shown in the following figures.

Figure 6. Examples of edge effects corrections.
The raster layer with all fuel changes incorporated from ObjectID’s rule is: “G1_Fuels_LF_140fbfm40_corrected_boundary_effect”.

Changes from different ObjectID are treated separately in independent raster layers in G1 (“G1_Fuels_LF_140fbfm40_ObjectID70”, ...ObjectID72, etc). This allows you to compare each fuel change separately with the original raster layer of Landfire 2014 (G8_Fuels_LF_140fbfm40_general). The following figure shows this in the GDB and MXD table of contents.
Group 2 (G2): Issues in Pinyon-Juniper

The fuels team identified that areas with Pinyon-Juniper in Colorado are typically not well represented in fuel model definition. Often the fire behavior for assigned fuel models in these vegetation types is under represented, and often, more extreme fire behavior is possible under common conditions.

To help quantify the issue, a mask of Pinyon-Juniper vegetation areas was created from the LANDFIRE 2014 Vegetation datasets. From layer G8_Vegetation_LF_140evt_general the following vegetation types were selected:

- 3016 - "Colorado Plateau Pinyon-Juniper Woodland"
- 3019 - "Great Basin Pinyon-Juniper Woodland"
- 3059 - "Southern Rocky Mountain Pinyon-Juniper Woodland"

The following figure shows these areas of concern in Colorado.

This mask (named “Pinyon_Juniper_Woodland_mask”) was used to create a fuels dataset and to calculate the fuel model classes in acres in for each vegetation type. The fuels raster obtained from Pinyon_Juniper_Woodland_mask is named “G2_Fuels_LF_140fbm40_PJ”.

Group 2 (G2): Issues in Pinyon-Juniper

The fuels team identified that areas with Pinyon-Juniper in Colorado are typically not well represented in fuel model definition. Often the fire behavior for assigned fuel models in these vegetation types is under represented, and often, more extreme fire behavior is possible under common conditions.

To help quantify the issue, a mask of Pinyon-Juniper vegetation areas was created from the LANDFIRE 2014 Vegetation datasets. From layer G8_Vegetation_LF_140evt_general the following vegetation types were selected:

- 3016 - "Colorado Plateau Pinyon-Juniper Woodland"
- 3019 - "Great Basin Pinyon-Juniper Woodland"
- 3059 - "Southern Rocky Mountain Pinyon-Juniper Woodland"

The following figure shows these areas of concern in Colorado.

This mask (named “Pinyon_Juniper_Woodland_mask”) was used to create a fuels dataset and to calculate the fuel model classes in acres in for each vegetation type. The fuels raster obtained from Pinyon_Juniper_Woodland_mask is named “G2_Fuels_LF_140fbm40_PJ”.

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To help quantify the issue, a mask of Pinyon-Juniper vegetation areas was created from the LANDFIRE 2014 Vegetation datasets. From layer G8_Vegetation_LF_140evt_general the following vegetation types were selected:

- 3016 - "Colorado Plateau Pinyon-Juniper Woodland"
- 3019 - "Great Basin Pinyon-Juniper Woodland"
- 3059 - "Southern Rocky Mountain Pinyon-Juniper Woodland"

The following figure shows these areas of concern in Colorado.

This mask (named “Pinyon_Juniper_Woodland_mask”) was used to create a fuels dataset and to calculate the fuel model classes in acres in for each vegetation type. The fuels raster obtained from Pinyon_Juniper_Woodland_mask is named “G2_Fuels_LF_140fbm40_PJ”.

Group 2 (G2): Issues in Pinyon-Juniper

The fuels team identified that areas with Pinyon-Juniper in Colorado are typically not well represented in fuel model definition. Often the fire behavior for assigned fuel models in these vegetation types is under represented, and often, more extreme fire behavior is possible under common conditions.

To help quantify the issue, a mask of Pinyon-Juniper vegetation areas was created from the LANDFIRE 2014 Vegetation datasets. From layer G8_Vegetation_LF_140evt_general the following vegetation types were selected:

- 3016 - "Colorado Plateau Pinyon-Juniper Woodland"
- 3019 - "Great Basin Pinyon-Juniper Woodland"
- 3059 - "Southern Rocky Mountain Pinyon-Juniper Woodland"

The following figure shows these areas of concern in Colorado.

This mask (named “Pinyon_Juniper_Woodland_mask”) was used to create a fuels dataset and to calculate the fuel model classes in acres in for each vegetation type. The fuels raster obtained from Pinyon_Juniper_Woodland_mask is named “G2_Fuels_LF_140fbm40_PJ”.
To solve the issue, the fuels team reviewed the underlying datasets and identified the following corrections (applied in the raster “G1_Fuels_LF_140fbm40_corrected_boundary_effect”).

1. Non forested and PJ : use fuel model 122
2. PJ and 10% <= CC < 20% : use fuel model 122
3. PJ and 20% <= CC < 30% : use fuel model 145
4. PJ and 30% <= CC < 40% : use fuel model 145
5. PJ and 40% <= CC < 50% : use fuel model 183
6. PJ and 50% <= CC < 60% : use fuel model 183
7. PJ and 60% <= CC < 70% : use fuel model 183
8. PJ and CC >70% : use fuel model 183
Three masks were created to apply the PJ rules:

1) PJ_CC_Nofor_10CC20_mask (in dataset “G2_PJ_mask_LF_2014”):
   a) Mask of PJ and areas CC Non forested and 10% <= CC < 20% (from raster G5_Canopy_layer_LF_140_CC).
   b) Was designated fuel model 122.

2) PJ_CC_20CC40_mask (in dataset “G2_PJ_mask_LF_2014”):
   a) Mask of PJ and CC areas 20% <= CC < 40% (from raster G5_Canopy_layer_LF_140_CC).
   b) Was designated fuel model 145.

3) PJ_CC_40CC100_mask (in dataset “G2_PJ_mask_LF_2014”):
   a) Mask of PJ and CC areas 40% <= CC < 100% (from raster G5_Canopy_layer_LF_140_CC).
   b) Was designated fuel model 183.

After applying PJ rules three ObjectID still showed a boundary effect (60, 71 and 72). It was identified in the analysis that many of the PJ issues were also simultaneous with mapping zone edge effects. Therefore, new ObjectID’s rules were reapplied (in ObjectID 60, 71 and 72).

1. ObjectID 60: 161 changes to 183
   (This change is in the raster named G1_Fuels_LF_140fbfm40_ObjectID60_PJ)

2. ObjectID 71: 122 changes to 145
   (This change is in the raster named G1_Fuels_LF_140fbfm40_ObjectID71_PJ)

3. ObjectID 72: 122 changes to 145
   (This change is in the raster named G1_Fuels_LF_140fbfm40_ObjectID72_PJ)

The raster layer with all fuels changes incorporated from ObjectID’s rules and PJ rules is: “G2_Fuels_LF_140fbfm40_corrected_PJ_OBJ”

The following figure presents an example of PJ fuel model correction.
Figure 8. Example of Pinyon-Juniper fuel model correction.

**Group 3 (G3): Issues in Oak Shrubland areas**

In Oak Shrubland vegetation areas, specifically those where Ponderosa pine may be present as an overstory, the fire behavior is subject to significant change in high/extreme weather conditions. Accordingly, the LANDFIRE fuel model often does not properly represent typical fire conditions.

This is complicated by the fact that fuel model SH7 is often defined in these areas, but the fuels team identified that SH7 is typically not valid in most of Colorado where it is defined (see Group 4). Accordingly, it was decided that in Oak Shrubland areas, SH7 was selected to be changed to another more appropriate fuel model.

To address this issue the following steps were undertaken. First, a mask of Shrubland areas was created from the LANDFIRE 2014 Vegetation datasets. In layer G8_Vegetation_LF_140evt_general the following vegetation types are selected:

- 3054 - "Southern Rocky Mountain Ponderosa Pine Woodland"
- 3117 - "Southern Rocky Mountain Ponderosa Pine Savanna"
- 3107 - "Rocky Mountain Gambel Oak-Mixed Montane Shrubland"
- 3217 - "Quercus gambelii Shrubland alliance"
- 3051 - "Southern Rocky Mountain Montane mixed conifer forest and woodland"
The following figure shows the Oak Shrubland areas within Colorado identified as different vegetation classes.

**Figure 9. Oak Shrubland areas in Colorado.**

The following steps were used to extract the SH7 fuel model for Oak Shrubland areas.

1. The vegetation mask (named “Oak_Shrubland_mask”) was used to extract fuels data for these specific areas. The fuels raster obtained from Oak_Shrubland_mask is named “G3_Fuels_LF_140fbfm40_OS”.

2. SH7 fuel model was then extracted from the fuels and named “G3_Fuels_LF_140fbfm40_OS_extractSH7”.

3. For this process, SH7 mask of Group 4 (G4) was used (“SH7_mask” or “G4_Fuels_LF_140fbfm40_SH7”).

To solve the Oak Shrubland issue, the fuels team reviewed the underlying datasets and identified the following corrections (applied in the raster “G2_Fuels_LF_140fbfm40_corrected_PJ_OBJ”.

1. Oak Shrubland areas with SH7 and CC >40%: use fuel model 165
2. In South Park and the Gunnison basin zones → Oak Shrubland areas with SH7 for elevations over 8500 feet: use fuel model 14
3. Oak Shrubland areas with SH7 where it has not changed was named SH7_oak and its fuel model code is 157.

The raster layer with all fuels changes incorporated from OS rules is: “G3_Fuels_LF_140fbfm40_corrected_PJ_OBJ_OS”.

*Group 4 (G4): SH7 Fuel Models*

The fuels team identified a concern that mapping of SH7 fuel models (and sometimes SH5) often over estimates the potential fire behavior for much of Colorado. To address this issue, it was decided to mask out the LF 14 SH7 (and SH5) fuels and quantify how much occurred within Colorado. Then, an assessment was made to determine if these areas overlapped with other issues identified. This resulted in the following layers:

- **SH7_mask** (in dataset “G4_SH7_mask_LF_2014”):
  - Mask out the SH7 fuels.
- **G4_Fuels_LF_140fbfm40_SH7**:
  - Fuels raster mask obtained from SH7_mask
- **G4_Vegetation_LF_140evt_SH7**:
  - Vegetation raster mask obtained from SH7_mask
- **G4_Fuels_LF_140fbfm40_SH5**:
  - Fuels raster mask obtained with a process similar to SH7
- **G4_Vegetation_LF_140evt_SH5**:
  - Vegetation raster mask obtained with a process similar to SH7

The following figure shows the areas of SH7 and SH5 in Colorado prior to any fuel model adjustments. **Blue** represents SH5 and **Brown** represents SH7.

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6 Note that data compiled to extract areas of SH7 in the Group 4 processing was actually used in the Group 3 adjustments for Oak Shrubland. Investigation by the fuels team identified that these issues were related and combined them into the Group 3 changes.
Figure 10. SH7 and SH5 fuels in Colorado in the original LF 14 fuel model dataset.

Upon investigation, it was determined that the issue of SH5 and SH7 overlapped with other issues, such as Group 1 (mapping zone edge effects) and Group 3 (Oak Shrubland). Accordingly, this issue was addressed within those groups and resolved. The following figure shows SH7 and SH5 in Colorado after the fuel model adjustments. Note this significantly reduced the acreage of both fuel models. For example, SH7 was reduced from approximately 1.2 million acres to 40,000 acres. Blue represents SH5 and Brown represents SH7.
Figure 11. SH7 and SH5 fuels in the updated fuel model dataset.

Group 6 (G6): Issues in Alpine Rangeland

The fuels team identified that often fuel models defined for high elevation areas reflect fire behavior conditions that are rare, due to weather and terrain conditions typical for high altitude alpine areas. Elevation greatly affects probability of ignition, due to low temperatures, snow cover, etc., and other conditions typical to alpine areas. Accordingly, the window of opportunity and requirements for fire ignition and growth are rarely met in these areas.

There was consensus among the fuels team that fuel models should be adjusted for these alpine areas to better match expected fire behavior, not vegetation characteristics. In this regard, the team wanted to tone down the fuels to reflect less volatile fire behavior.

It was agreed that the team would investigate some recent high altitude fires, such as West Fork Complex, to determine conditions that occurred as a baseline for defining rules for fuel changes at high altitude. A general approach would be to extract fuels and
vegetation data for elevations above 10,000 feet, and apply these rules (learned from empirical data) to these areas.

The following figure shows the areas of concern for high altitude areas.

Figure 12. Alpine areas in Colorado.

To address this issue the following steps were undertaken. First, a mask of Alpine Rangeland areas was created from the LANDFIRE 2014 Vegetation datasets. In layer G8_Vegetation_LF_140evt_general the following vegetation types were selected:

- 3070 - "Rocky Mountain Alpine Dwarf-Shrubland"
- 3143 - "Rocky Mountain Alpine Fell-Field"
- 3144 - "Rocky Mountain Alpine Turf"
- 3146 - "Southern Rocky Mountain Montane-Subalpine Grassland"

This mask (named “Alpine_rangeland_mask”) was used to create a fuels dataset. The fuels raster obtained from Alpine_rangeland_mask is named “G6_Fuels_LF_140fbfm40_AlpineRangeland”.

To solve the issues in alpine rangeland, the rules proposed by the Colorado fuels team were applied in the raster “G3_Fuels_LF_140fbfm40_corrected_PJ_OBJ_OS”.

The rules (named AR rules) are not fuel changes but a new fuel classification inside of alpine rangeland zones for elevations over 10,000 feet:

1. GR1_alpine → use fuel model 111 designation
2. GR2_alpine → use fuel model 112 designation
3. GS1_alpine → use fuel model 131 designation

In other words, an existing fuel model was applied for these high elevation areas but referred to under a separate fuel model number (i.e. 111, 112, 131).

The raster layer with new fuels classification incorporated from AR rules is: “G6_Fuels_LF_140fbfm40_corrected_PJ_OBJ_OS_AR”.

<table>
<thead>
<tr>
<th>Fuel Model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR1_alpine</td>
<td>Use fuel model 111 designation</td>
</tr>
<tr>
<td>GR2_alpine</td>
<td>Use fuel model 112 designation</td>
</tr>
<tr>
<td>GS1_alpine</td>
<td>Use fuel model 131 designation</td>
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</table>

Legend:
- N901: Urban/Developed
- N902: Snow/Ice
- N903: Agriculture
- N905: Water
- N909: Bare
- GR01: Short, sparse, dry climate grass
- GR02: Low load, dry climate grass
- GR03: Low load, very coarse, humid climate grass
- GR04: Moderate load, dry climate grass
- GR05: GT 10,000 ft elevation
- TS01: Light load, dry climate timber-grass-shrub
- TS02: Moderate load, dry climate timber-grass-shrub
- TS05: Very high load, dry climate timber-shrub
- TL01: Low load, compact conifer litter
- TL02: Low load, broadleaf litter
- TL03: Moderate load, conifer litter
- TL04: Small downed logs
- TL05: High load, conifer litter
- TL06: Moderate load, broadleaf litter
- TL07: Large downed logs
- TL08: Long needle litter
- TL09: Very high load, broadleaf litter
3. IMAGERY COLLECTION AND PROCESSING

To address the remaining issues, specifically disturbance updates, the collection and processing of satellite imagery was required. The LANDFIRE 2014 data was based on LandSat imagery up to 2014, supplemented with ancillary data provided by state and federal agencies.

Spectral information is very important because it allows definition of a spatial classification of terrain and vegetation behavior, specifically change detection for large disturbances. The technical team utilized LandSat 8 imagery for the period 2013 to 2016 to supplement the additional ancillary data, for the same phenological season (summer).

A description of the data collected and used is provided in this section.

3.1 Imagery

*LandSat 8*

LandSat 8 imagery from different years are used in this project (2013-2016). These products are available from the following web site [https://earthexplorer.usgs.gov](https://earthexplorer.usgs.gov). In this case, the spectral information of these images is organized in 11 bands, although only 4 of them were selected (Red, NIR and two bands with SWIR information). LandSat 8 offers a temporal resolution of 16 days and the spatial resolution is 30 meters. Different composites and vegetation indexes (NDVI, EVI, NBR or NDII) were created and were used in the disturbance analysis.

These images are used to compare different vegetation changes in the same location and to update land use changes or fuels changes from imagery 2014 (last date in LANDFIRE 2014) until the last scene taken (LandSat 2016). Hence, to get the best changes analysis, different 16 path-row for each year of LandSat 8 were downloaded and the different mosaics in each path-row were prepared.

The following figure presents an example of this data organization for 2013.
3.2 Ancillary Data

In addition to the Landsat 8 imagery used, other ancillary data was used to identify fuel models and disturbances. This included:

1. LANDFIRE Surface Fuels and Vegetation Datasets (2014)

   The LANDFIRE 2014 surface fuels, canopy and vegetation datasets, which describes the composition and characteristics of both surface fuel and canopy fuels, was used.

2. Federal Data Sources on Disturbance

   Data for historic fire perimeters, layers of disease disturbance (from FDM, Forest Disturbance Monitor, [https://foresthealth.fs.usda.gov/FDM](https://foresthealth.fs.usda.gov/FDM)) and layers which represent activities of hazardous fuel treatment reduction (polygons) were used (from NRM, Forest Service’s Natural Resource Manager, [https://data.fs.usda.gov](https://data.fs.usda.gov)). This is detailed in Section 4 of the report.
4. UPDATING FUELS FOR DISTURBANCES

The primary task for updating the Colorado LF 14 fuels data involved incorporating recent large disturbances. The LF 14 data is based on 2012 LandSat imagery, and even with regional workshops held by the LANDFIRE team, many of the recent large landscape disturbances that have occurred since 2012 are not reflected in the LF 14 data. Accordingly, the review, compilation, and integration of these disturbances was a key task in the fuels calibration process. This section of the report describes the methods and rules used to incorporate disturbance data from 2013 to 2016. Incorporating disturbance data helps to ensure the fuels data is up to date and reflecting the latest landscape conditions. This is especially important for large disturbance areas where fuels have been reduced and no long pose a significant potential for fire ignition or growth.

A general layer of disturbances was derived from LandSat spectral information and the ancillary vector data of different sources.

A comparison between the different years was made:

- 2013-2014
- 2014-2015
- 2015-2016

A description of the methods used to update for the following disturbance types is provided:

1. fire
2. treatments and harvesting
3. insect and disease

Only disturbances detected for 50 acres or larger were included. All data is referenced for the final fuels update as the ArcGIS “Delivery GDB” in Group 7.
The following figures show the disturbance data derived from 2013 – 2016 for the three disturbance types.
Figure 14. Fire disturbance in Colorado 2013-2016.
Figure 15. Treatment disturbances in Colorado 2013-2016.
4.1 Fire Disturbance

**Data Source**

Fire disturbances were extracted from the LandSat imagery, supported by the mapping of historic fire perimeters (available in [www.geomac.gov](http://www.geomac.gov)). Large fire perimeters were used to guide the updates. Note that the Colorado State Forest Service also requested fire perimeters from the Colorado Division of Fire Prevention & Control (DFPC) to obtain local perimeter data.

Data for 2016 was provided by DFPC from the COWIMS system. This data was compared to other disturbance and fire occurrence sources compiled for the project through Geomac, MTBS and satellite image processing sources. Ultimately, only a small amount of the DFPC 2016 data was used to augment the fire disturbances. It is anticipated with future fuels updates that the DFPC COWIMS data may provide additional benefit for incorporating local fire disturbance data.
In the Delivery GDB, the original layer is in the dataset “G7_Disturbances_update_LF_2014” and is called “A_Original_Data_CO_Fire_Perimeters_2000_2016”.

**Results**

Final fire disturbance data can be found in the dataset “G7_Disturbances_update_LF_2014”:

- CO_Fires_2016_2017. Layer with data from September 2016 to September 2017

These vector layers with different fires detected show the following fields: **Source, fire_name, fire_year, fire_severity and current_severity_state**.

A severity burn analysis, using imagery processing techniques with the LandSat 8 imagery, was conducted where possible to identify different categories (indicated in “fire_severity” field). The following classes of severity were used.

![Severity classes](image)

The severity of a fire is calculated using spectral information with the NBR vegetation index. This index requires two satellite images (a pre-fire image and a post-fire image) and two spectral regions (NIR and SWIR).

\[
NBR = \frac{(\rho_{\text{NIR}} - \rho_{\text{SWIR}})}{(\rho_{\text{NIR}} + \rho_{\text{SWIR}})}
\]

\[
\Delta NBR = NBR \text{ pre-fire} - NBR \text{ post-fire}
\]

Using this equation, a response of terrain (vegetation) after fire is extracted which offers important information about terrain (vegetation) state.
For each fire, a burn severity analysis was conducted using the LandSat 8 imagery prepared in this project. Different remote sensing years are combined in this way: 2013-2014, 2014-2015 and 2015-2016.

It is important to note that fire severity analysis was carried using images which occur in two different years. For this reason, severity data may be distorted, but the main objective was to know a near burn severity level induced by different fires over terrain.

To improve our results, eight large fires that occurred in Colorado during the analysis time were extracted and their severity was determined individually. This analysis offers a better vision of burn effects over the terrain. The scope and budget of the project did not allow for ground truthing.

Furthermore, to complete this information, a “current_severity_state” field is attached in the attribute table of each layer where it’s possible to obtain an idea of the terrain recovery up to the present (2016).

The following figures show two examples of burn severity analysis conducted for two large fires, Beaver Creek (2016) and Hayden Pass (2016).
Figure 17. Beaver Creek Fire severity analysis.
Section 4.5 provides a detailed description how the burn severity analysis and fire disturbance data was used to update fuel models.
4.2 Treatments & Harvesting

Data source

Treatments disturbances were extracted from the LandSat imagery, supported by the layers which represents activities of hazardous fuel treatment reduction and timber harvests (available in https://data.fs.usda.gov/geodata/edw/datasets.php). Treatments and harvest data was used from federal databases first, and state based data sources (from the Colorado State Forest Service SMART data was later applied).

In the Delivery GDB, the original federal data layers are in the dataset “G7_Disturbunces_update_LF_2014“ and are called:

- “B_Original_Data_CO_USFS_HazFuelTrt”,
- “C_Original_Data_CO_USFS_TimberHarvest”,
- “E_Original_Data_CSFS_SMART_Management_Plans_GT50_2014_2017”, and
- “F_Original_Data_CSFS_SMART_Stands_GT50_2014_2017”.

Using this information, different disturbance categories were identified:

- Harvest (from “C_Original_Data_CO_USFS_TimberHarvest”)
- Prescribed burn (from “B_Original_Data_CO_USFS_HazFuelTrt”,
- Mechanical (from “B_Original_Data_CO_USFS_HazFuelTrt”)
- Other (chemical-animal, from “B_Original_Data_CO_USFS_HazFuelTrt”)

Results

In dataset “G7_Disturbunces_update_LF_2014“:

- CO_Treatments_2016_2017. Layer with data from September 2016 to September 2017

These vector layers, with different treatments detected, show the following fields: Source, Treatments_Description, and Date. The follow classes are shown on the treatments data to show the different types:

- Harvest
- Mechanical
- Others
- Prescribed burn

The following figure shows an example of treatment data.
Figure 19. Example treatment data derived by combing image processing with vector data.

Section 4.5 provides a detailed description how the treatment type data was used to update fuel models.
4.3 Insect & Disease Disturbance

Data Source

Insect & Disease disturbances were extracted from the LandSat imagery, supported by Viewer IDS, Insect and Disease Survey (available in Forest Disturbance Monitor https://foresthealth.fs.usda.gov/FDM).

In the Delivery GDB, the original layer is in the dataset “G7_Disturbances_update_LF_2014” and is called “D_Original_Data_CO_Aerial_Survey_Data_1996_2016”.

Results

In dataset “G7_Disturbances_update_LF_2014”:

- **CO_Insects_and_Diseases_2013_2014.** Layer with data from January 2014 to September 2014
- **CO_Insects_and_Diseases_2014_2015.** Layer with data from September 2014 to September 2015
- **CO_Insects_and_Diseases_2015_2016.** Layer with data from September 2015 to September 2016

These vector layers with different issues detected show the following fields: **Source, Disease_category, Disease_description, First_appearance** and **Date**.

In this case, disease disturbances (detected by Viewer IDS) can be identified using the “**Source**” field: **Source = CSFS Aerial Survey Data**.

Important: The source data of the disease-insect information between 2014-2015 and 2015-2016 are imprecise because date data (month and day) are not attached in each disturbance. The following classes are used to identify the insect and disease data for each layer.

- **1996-2005**
- **2007-2011**
- **2012-2016**

The following figure shows an example of insect and disease areas.
Figure 20. Example insect and disease areas.

Section 4.5 provides a detailed description how the insect and disease disturbance data was used to update fuel models.
4.4 Spectral Information and Processing Methods

**Data Source**

In order to get the best results, it was necessary to identify the spectral band of each image that offered the best vegetation information. This information is essential to identify the main changes which occurred in each vegetation zone.

Band5 (NIR spectral region) was selected and a comparison between the different years was made: 2013-2014; 2014-2015 and 2015-2016.

The methodology selected was based on a normalized equation where we carried on the following next relation:

\[
(\text{First year}-\text{last year}/\text{first year}+\text{last year})
\]

This equation offers a normalized result with data between -1 (positive changes) and 1 (negative changes). The following figure presents an example of these results.

**Figure 21. Example results of the normalized equation for 2013-14 comparison.**

The disturbance data was extracted with a standard deviation analysis and without extreme values because we observed that highest and lowest data offered wrong data (these thresholds identify problems with clouds).

Then, using a layer with known disturbances (for example, fires layer, treatments layer, disease layer or disturbances detected in LANDFIRE 2014), other categories were eliminated until the
best threshold was reached. The following figure shows an example of spectral categorization used to identify disturbance using known data.

Figure 22. Example of spectral categorization used to identify disturbances from known data.

Based on these thresholds, a specific range was selected as disease disturbances. This range was supported by the mapping of Insect & Disease Activity in Colorado 2015, 2014 and 2013 (available in Report on the Health of Colorado’s Forest 2015 [http://csfs.colostate.edu/media/sites/22/2016/02/ForestHealthReport-2015.pdf]). This process was carried on for each year’s relations (2013-2014, 2014-2015 and 2015-2016). The following figure provides an example of the interim output.
Finally, we needed to debug the polygon disturbance information. So:

- **Areas = 900 m²** (corresponding to a only one pixel) were eliminated (these zones did not offer a realistic vegetation change)
- **Agriculture zones** were eliminated. Using GR and NB3 information of Colorado, agricultural polygons were eliminated (not representative of vegetation changes based on diseases)

This produced a dataset that identified disturbances without small artifacts and agricultural change. The following figure shows an example.
Results

In dataset “G7_Disturbances_update_LF_2014”:

- CO_Insects_and_Diseases_2014_2015. Layer with data from September 2014 to September 2015

These vector layers with different issues detected show the following fields: Source, Disease_category, Disease_description, First_appearance and Date.

In this case, disease disturbances (detected by spectral information) can be identified using the “Source” field: Source = Spectral information.
4.5 Final Fuel Changes Using the Disturbance Layers

To incorporate the disturbance analysis results to update fuel models, a series of rules identified by the fuels team was applied to the raster from Group 6 processing “G6_Fuels_LF_140fbfm40_corrected_PJ_OBJ_OS_AR”.

A description of the updating rules employed is provided for Fire, Treatments and Insect/Disease.
Fire Disturbance Updating Rules

The following table shows the rules for updating the fuel models within fire disturbance areas. These are heavily based on the fire severity classes.

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<td>2022 - 2023</td>
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</table>

Note that the Severity 1-2 proposed fuel models are also used on the 'HazFuel_prescribed_burn' for Treatments updates. The Severity 4-7 covers a range of 'Low-severity' thru Moderate low and high to High severity. This is complicated as it presents a wide range of conditions and recovery. A basic assumption is that a particular fuel model will result in a particular severity. This is an attempt to assign generalized fuel models to fires that had occurred since the LF 2014 data was developed. Accordingly, the fuels team decided to utilize the High severity for making fuel adjustments. In addition, the further analysis of large fires led to some changes for those areas (seven fires) for the fuel adjustments to reflect the range of severity within the fire burn perimeter.
**Treatments Disturbance Updating Rules**

The following tables show the rules used for updating the fuel models for the different disturbance types.

**Prescribed Burn**

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<tr>
<td>Fuel models affected by 'HazFuel_prescribed_burn' that need to be updated</td>
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“Prescribed burn” proposed fuel models are also used for Severity 1-2 on Fires.
### Mechanical

<table>
<thead>
<tr>
<th>Fuel Models Affected by 'Haz/fuel_mechanical' that need to be updated</th>
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<tbody>
<tr>
<td><em>CO-WRA Fuels Calibration Project Final Report</em></td>
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<tr>
<td><strong>Mechanical</strong></td>
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### Harvesting

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Fuel models affected by `HazFuel_mechanical` that need to be updated.
**Disease Disturbance Updating Rules**

The following list shows the rules for updating the fuel models within insect and disease disturbance areas. These rules were defined by the fuels team. The time period for these updates is from the LANDFIRE 2014 source imagery until 2017.

1. **Abiotic damage**
   
   Small number of pixels detected. Not able to identify impacts to fuels in these areas. No changes made.

2. **Bark beetle**
   
   It is understood that bark beetles and pine beetles can have significant short term and long term affects on crown fire propagation, spotting potential, and surface fire behavior. Mainly these effects are through changes in; surface and aerial fuel loadings, fuel arrangement, wind infiltration, shading, ratios of live fuels to dead fuels and in the chemical composition of needles. However, aerial survey polygons that were collected and used in the project are too coarse (spatially and definition of intensity) and there are too many different stand situations to make conclusions / rules from this data. The effects of the bark beetles on fuels are real at the tree, tree group and stand levels but it is hard to identify where that disturbance (bark beetles) are responsible for large fire growth. CSFS experience is that recent fires with mountain pine beetle affected lodgepole pine areas appear to be significantly more influenced by wind and fuel dryness. Specifically in the recent High Park and Beaver Creek Fires - fire growth due to mountain pine beetle affected fuels seemed subtle compared to wind factors. Accordingly, it was decided that no changes would be made using this aerial sketch mapping data.

3. **Defoliators**
   
   Defoliators have limited and irregular impact on aerial fuels and crown fire behavior. They are not a significant contributor to surface fuels. No changes made.

4. **Disease_insect**
   
   These polygons are generally small, widely dispersed, and don't seem to represent a common theme. Difficult to make recommendations based on this. No changes made.

5. **Mountain Pine Beetle**
   
   The occurrence of mountain pine beetle within these polygons is generally a few trees per acre. While this might occur for a number of years - this three-year period of occurrence will not be a significant factor to make changes to these year’s fuel models.
The accumulated mountain pine beetle impact will be more affected by tree fall, redistribution of fuels and regrowth over a number of years. These changes are slower to occur and would be considered in previous iterations of LF.
5. DESCRIPTION OF FINAL LANDFIRE 2014 FUELS UPDATE

Once all the issues were addressed, the fuels data went through another iterative review with the fuels team. This is reflected in the Delivery GDB as Group 8 -G8-, Group9-G9-, Group 10-G10- and Group 13-G13. A description of these final changes is provided below.

5.1 Final Updates

*Group 8 (G8): First update results*

The LANDFIRE update is “G8_Fuels_LF_140fbfm40_corrected_FINAL_V2”. The layer “G8_Fuels_LF_140fbfm40_corrected_FINAL” which can also be found.

The differences of these two layers are found in the different changes applied to the larger fires (seven fires: Beaver Creek, Hayden Pass, Lost Solar, Long Draw, Blair, Junkins and Beulah Hill). “G8_Fuels_LF_140fbfm40_corrected_FINAL_V2” presents the changes proposed by the Colorado fuels team.

“G8_Fuels_LF_140fbfm40_corrected_FINAL” presents less critical changes in these seven fires (because there could be vegetation regeneration).

*Group 9 (G9): Expert Criteria Review*

This group incorporates the final layers with the latest revisions made by the Colorado fuels team.

From the issues detected, it was verified that it was a boundary effect problem (similar to group 1) and the changes applied in the zone (area delimited in the layer “issues_detected_points_review”) were:

1. 122 changes to 121
2. 142 changes to 141

The layers are:

- “G9_Fuels_LF_140fbfm40_corrected_FINAL”
- “G9_Fuels_LF_140fbfm40_corrected_FINAL_V2”.

The differences of these two layers are the same as in group 8.

These differences were reviewed and the most appropriate layer was chosen and it was incorporated into Group 10. Finally, some last improvements were incorporated with the use of new treatment data from CSFS (2013-2017) and it was added into Group 13.
Group 10 (G10): LANDFIRE Colorado updated 2016

- In the GDB deliverable, the original fuel layer of LANDFIRE 2014 is “G10_Fuels_LF_140fbfm40_original”, and
- the original vegetation layer is “G10_Vegetation_LF_140evt_original”.

The LANDFIRE update (with all fuels changes detailed in the previous sections) is

- “G10_Fuels_LF_140fbfm40_updated2016_CO”.

Group 13 (G13): Final and improved LANDFIRE Colorado updated 2016

This group incorporates the final SMART treatment data from CSFS with the latest changes made by the Colorado fuel team. This CSFS SMART data represents treatment data collected from 2013-2017 for areas greater than 50 ac in size.

Based on attribute data provided with the treatment polygons this information was classified into two types of treatment (disturbance): harvest and prescribed burning. The changes that were made were based in the rules used for updating the fuel models for the different disturbance types, detailed in the section 4.5.

Data source

In the Delivery GDB, the original layers are in the dataset “G13_ Review_Treatments_added” and are called:

- “CSFS_MA_treats_flat”, and
- “CSFS_stands_treats_flat”.

Using this information, different disturbance categories were identified:

- Harvest: “CSFS_MA_treats_flat_HARVEST” and “CSFS_stands_treats_flat_HARVEST”
- Prescribed burn: “CSFS_MA_treats_flat_PRESC_BURN” and “CSFS_stands_treats_flat_PRESC_BURN”.

Results

The LANDFIRE update and improvement (with all fuels changes detailed in the previous sections and the latest improvements) is

- “G13_Fuels_LF_140fbfm40_updated2016_CO”.
5.2 Colorado Fuels Data Review Tool

A web mapping tool was created to aid in the review of the fuel model changes. This tool allows the fuels team, and other fuels specialists, to:

- compare the original LF 14 surface fuels data with the final calibrated LF 14 data;
- zoom and review to specific areas of concern identified by the fuels team, such as LANDFIRE mapping seams and recent large fires;
- swipe between the original and final calibrated data; and
- record comments for specific areas of interest.

The web tool is publicly available at the following web link:

http://tecnosylva.maps.arcgis.com/apps/webappviewer/index.html?id=a2726d03198d4bb2bbe77c3fc1c2d3ff

We highly recommend that this tool should not be publicly advertised and should be used primarily by the Colorado fuels team and agency reviewers that we intend to share the methods with. Accordingly, it is intended for internal use only, not public distribution.

This tool was used to share the final updates to the fuels layers among the fuels team, and agency partner fuel specialists (i.e. USFS, BLM), to make it easier to quickly review the areas of concern and proposed changes. We found this much more efficient than sharing very large datasets in ESRI ArcGIS GDB format. Ultimately this web tool provides an ideal reference point for other fuels specialists to review the changes completed for the Colorado fuels data.

In addition, the final Colorado surface fuels data set was delivered as a raster data layer in an ArcGIS MXD document with bookmarks. The name of the final dataset in both the web tool and the MXD data is:

- CSFS_fuel_corrected_final improved (= G13_Fuels_LF_140fbfm40_updated2016_CO)

The following figures present the Colorado fuels data review web tool.
Figure 25. Colorado Fuels Web Tool - Legend identifies available layers for review.
Figure 26. Colorado Fuels Web Tool - Bookmarks identify the primary areas of concern and issues.
Figure 27. Colorado Fuels Web Tool - Swipe tool allows easy comparison of original vs final calibrated datasets.