USGS
science for a changing world

LANDFIRE Technical Documentation

Open-File Report 2023–1045

U.S. Department of the Interior
U.S. Geological Survey

LANDFIRE Technical Documentation

Edited by Inga P. La Puma

Open-File Report 2023–1045

U.S. Department of the Interior
U.S. Geological Survey

U.S. Geological Survey, Reston, Virginia: 2023

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit https://www.usgs.gov or call 1–888–392–8545.

For an overview of USGS information products, including maps, imagery, and publications, visit https://store.usgs.gov/ or contact the store at 1–888–275–8747.

Suggested citation:
La Puma, I.P., ed., 2023, LANDFIRE technical documentation: U.S. Geological Survey Open-File Report 2023–1045, 103 p., https://doi.org/10.3133/ofr20231045.

Associated data for this publication:
U.S. Geological Survey, 2016, GAP/LANDFIRE National Terrestrial Ecosystems 2011: U.S. Geological Survey data release, https://doi.org/10.5066/F7ZS2TM0.

U.S. Geological Survey, 2018, Protected Areas Database of the United States (PAD-US): U.S. Geological Survey data release, https://doi.org/10.5066/P955KPLE.

ISSN 2331-1258 (online)

Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile, nautical (nmi)	1.852	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
	Density	
ton per acre	2,241.7	kilogram per hectare (kg/ha)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
hectare (ha)	0.003861	square mile (mi^2)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

>	greater than
≥	greater than or equal to
<	less than
3DEP	3D Elevation Program
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BAECV	Burned Area essential climate variable
BARC	Burned Area Reflectance Classification
BP	burn probability
BpS	biophysical setting
CBD	canopy bulk density
CBH	canopy base height
CC	canopy cover
C-CAP	Coastal Change Analysis Program
CDL	Cropland Data Layer
CFFDRS	Canadian Forest Fire Danger Rating System
CG	canopy guide
CH	canopy height
CV	change vector
DEM	digital elevation model
dNBR	differenced normalized burn ratio
dNDMI	differenced Normalized Difference Moisture Index
dNDVI	differenced Normalized Difference Vegetation Index
DSWE	Dynamic Surface Water Extent
EPSG	European Petroleum Survey Group
ES	ecological system
EVC	existing vegetation cover
EVH	existing vegetation height
EVT	existing vegetation type
FBFM13	Anderson Fire Behavior Fuel Models
FBFM40	Scott and Burgan Fire Behavior Fuel Models
FCCS	Fuel Characteristic Classification System
FDist	fuel disturbance
FFE	Fire and Fuels Extension
FIA	Forest Inventory Analysis

FS	Forest Service
FVC	fuel vegetation cover
FVH	fuel vegetation height
FVS	Forest Vegetation Simulator
FVT	fuel vegetation type
GAP	Gap Analysis Program
GDEM	Global Digital Elevation Model
GeoArea	geographic area
HDist	historical disturbance
IFSAR	interferometric synthetic aperture radar
LCP	landscape file
LF	LANDFIRE
LFRDB	LANDFIRE reference database
LFTFC	LANDFIRE's Total Fuels Change
lidar	light detection and ranging
MIICA	Multi-Index Integrated Change Analysis
MoD–FIS	Modeling Fuels with an Index System
MTBS	Monitoring Trends in Burn Severity
NALCMS	North American Land Change Monitoring System
NDVI	Normalized Difference Vegetation Index
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
NVC	U.S. National Vegetation Classification
PAD	Protected Areas Database
RAVG	Rapid Assessment of Vegetation Condition after Wildfire
RCVMAX	relative change vector
RSLC	remote sensing of landscape change
SClass	succession class
STD	standard deviation
TNC	The Nature Conservancy
TSD	time since disturbance
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator

VPU	vegetation production unit
WFDSS	Wildland Fire Decision Support System
WPI	Wetland Potential Index
WRC	Wildfire Risk to Communities
WUI	wildland urban interface

LANDFIRE Technical Documentation

Edited by Inga P. La Puma[1]

Executive Summary

LANDFIRE (LF) completed the LF 2016 Remap effort in 2021, the biggest revision of its product suite since its inception. This document serves to describe the processes that went into this effort and elucidate the methods for creating each LF product. Although the document focuses on the LF 2016 Remap effort, it also details the two updates that have been completed since that effort, LF 2019 Limited (released June 2021) and LF 2020 (underway at the writing of this document).

The LF program is complex, requiring a team of interdisciplinary professionals to manage, produce, and maintain it (see section A.1.1). LF data production falls under six primary categories: reference, disturbance, vegetation, fuels, fire regime, and topography. Several data production units have the dual goals of producing a valuable stand-alone dataset and serving subsequent LF production needs. This document delves into the technical details of the six primary categories individually while also describing the connections to other LF products. Importantly, this LF technical documentation provides a transparent view of actual LF data layer production processes and can become a general information source for future production, production improvements, user questions, and leadership reference.

[1]KBR, Inc., under contract to the U.S. Geological Survey.

Chapter A. Introduction

By Julia Deis,[1] Eva Soluk,[1] Inga P. La Puma,[1] and Timothy D. Hatten[2]

A.1. LANDFIRE Overview

A.1.1. Background

LANDFIRE (LF), the Landscape Fire and Resource Management Planning Tools program, is an interagency program that provides comprehensive biological, ecological, and geospatial data and databases for the contiguous United States, Alaska, Hawaii, and insular areas. LF is a vegetation, fire, and fuels characteristic mapping program managed by the U.S. Department of Agriculture Forest Service and the U.S. Department of the Interior with cooperative involvement from The Nature Conservancy and production management via the U.S. Geological Survey at the Earth Resources Observation and Science Center.

LF represents a complete, nationally consistent collection of more than 25 geospatial layers of biological and ecological data (for example, vegetation, fuel, disturbance, and so on), databases, and models that can be used across all land cover types and for multiple disciplines at a 30-meter pixel scale. LF data are developed from field-collected plot data, remote sensing data, and ecological modeling using standardized methods. These data include a suite of fuels layers used for hazard planning and fire behavior modeling designed to be used at the landscape scale, facilitating cross-boundary national- and regional-level strategic planning and reporting of wildland fire management activities. The products also depict the Nation's ecosystems and vegetation types with a high level of detail not detected with any other national land cover product to date. These products aid in assessing environmental benefits of different management options and plans, and provide efficiencies in analyses, costs, and reviews. LF is primarily a spatial data program to support wildfire incidents and fire management planning; however, it also is a wide-reaching disturbance, vegetation, and land cover mapping program generating products useful for a variety of accounting and modeling efforts, including carbon, climate, wildlife, habitat, and numerous other management objectives.

A.1.2. History and Developments

The original LF mapping effort, LF National, began in 2004 and was based on Landsat data with products that represented the year 2001. LF National products were updated regularly to represent recent conditions and account for landscape disturbances and succession (LF 2008, 2010, 2012, and 2014). Subtle vegetation and landscape changes may not have been reflected in updated LF versions.

For the LF 2016 Remap effort, new remotely sensed data were used from Landsat 8 for most of the contiguous United States. Harmonized Landsat Sentinel-2 was used for Alaska disturbance mapping. Synthetic imagery was used from the U.S. Geological Survey Land Change Monitoring, Assessment, and Projection program for mapping vegetation in the Southeast and Northeast. In addition, better modeling capabilities were made possible by updated U.S. Department of Agriculture Forest Service Forest Inventory and Analysis (Forest Service, 2021) plot data; access to Assessment, Inventory, and Monitoring field plots from the Bureau of Land Management (Bureau of Land Management, 2022); Natural Resources Conservation Service National Resources Inventory plots (Natural Resources Conservation Service, 2021), located primarily in nonforested areas; and new data from other contributors and partners.

With the final release of LF 2016 Remap in the summer of 2021, the multiyear LF 2016 Remap product suite included improvements such as capable fuels, a 90-kilometer buffer into Canada along the Alaskan border, more than 1 million plots in the LF reference database, and the addition of new products: historical disturbance, national vegetation classification, and fuel vegetation type, cover, and height. Advances in image compositing to reduce cloud and shadow anomalies and satellite image tiling algorithms for disturbance mapping, plus faster computing hardware, ensured LF vegetation and fuels products remained relevant.

Also in the summer of 2021, to increase the frequency of product releases and reduce the latency of the LF products, LF released the LF 2019 Limited update for the contiguous U.S. products. Producing annual version releases reflecting conditions for the most recent calendar year is a goal for the LF program. LF 2019 Limited was the first step toward reaching this goal and transitioning to an annual update, then LF 2020 was released in 2022. The LF team continues to improve and update the products as work is underway for LF 2022, scheduled to be released in 2023.

[1]KBR, Inc., under contract to the U.S. Geological Survey.

[2]U.S. Geological Survey.

A.2. Document Organization

The LF technical documentation chapters included herein follow the flow of production. Each chapter focuses specifically on the methods and datasets used to create the LF data products; however, each chapter also describes how the datasets are related to the creation of subsequent LF data products. The chapters of this document are as follows:

- Chapter A provides an overview of the LF program,
- Chapter B provides details for the LF field plot reference database along with the disturbance Events Geodatabase,
- Chapter C provides details about how the Events Geodatabase feeds into the production of annual disturbance layers along with numerous other datasets,
- Chapter D describes vegetation mapping and shows how the reference data and disturbance layers are used for vegetation modeling and mapping,
- Chapter E describes fuels mapping and shows how vegetation and disturbance inputs affect fuel rules and maps,
- Chapter F describes fire regime data creation,
- Chapter G describes LF's general topography layers that are used for vegetation and fuels mapping,
- Appendix 1 includes supplementary tables of vegetation mapping, and
- Appendix 2 includes a supplementary table of Fire Protection Units.

The document organization generally follows the flow of production. Reference production is the first step in the LF process and is described in chapter B. Disturbance production (chap. C) requires reference products to proceed. Vegetation mapping production (chap. D) is dependent on reference and disturbance products. Fuels mapping production (chap. E) and fire regime mapping production (chap. F) are dependent on disturbance and vegetation products. Topography (chap. G) has only been produced twice in LF history and is described towards the end of this document; however, it is used in vegetation and fuels production. The interdependencies of LF production units, along with communication between units, help the suite of layers align. The purpose of this technical documentation is to help stakeholders understand those relations, and how final products are created.

A.3. References Cited

Bureau of Land Management, 2022, Assessment, inventory, and monitoring strategy: Bureau of Land Management web page, accessed June 28, 2022, at https://www.blm.gov/aim/strategy.

Forest Service, 2021, Forest Inventory and Analysis: Forest Service web page, accessed October 22, 2021, at https://www.fia.fs.usda.gov/.

Natural Resources Conservation Service, 2021, National Resources Inventory: Natural Resources Conservation Service web page, accessed October 21, 2021, at https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/.

Chapter B. LANDFIRE Reference Data

By Brenda Lundberg[1] and Inga P. La Puma[1]

B.1. Introduction to LANDFIRE Reference Data

B.1.1. The Need for LANDFIRE Reference Data

Mapping vegetation and fuels across the entire United States and insular areas requires a vast array of differently formatted input data. The LANDFIRE (LF) reference team maintains two substantial datasets: the LF reference database (LFRDB) and the Events Geodatabase. These databases are required for the disturbance, vegetation, and fuel maps that LF produces.

Modeling and mapping vegetation classes typically requires training or plot data to tell the model what is on the ground where satellite imagery and other spatial data overlay plot localities. Once the model is trained to how imagery bands, vegetation indices, or other data such as topography and climate variables relate to the plot location, the model can then take the relation between the spatial data inputs and use it to assign or impute the plot information to other locations with similar spatial data. LF uses the LFRDB plot data to train classification and regression tree models to map vegetation type, cover, and height and to validate model outputs using plot data withheld during the modeling process. Other projects, including one that mapped an annual invasive grass in the Southwest (Hak and Comer, 2017) and one that estimated chaparral biomass in California (Schrader-Patton and Underwood, 2021), also have used the LFRDB. Users of the LF 2016 Remap LFRDB data include researchers investigating the use of this training dataset for artificial intelligence applications for assessing rangeland conditions (Rigge, 2022).

The other data compilation effort supporting LF mapping is the Events Geodatabase. This geodatabase is made up of perimeters delineating disturbances on the landscape. Typically, LF sends out a data call letter in September to Federal, State, local, and nonprofit stakeholders requesting spatial data concerning fuel treatments, fires, and other changes to vegetation and fuels that they have recorded via a global positioning system or that are commonly stored as polygons in geographic information system shapefiles or geodatabases. LF also gathers numerous publicly available events datasets from the web. The Events Geodatabase is the main dataset used within the LF production flow for attributing disturbance type to annual disturbance, historical disturbance (section C.1.3), and fuel disturbance (section E.4.1) layers. The public Events Geodatabase also is a useful information source for research, including tracking forest harvest trends (Woodward and others, 2017) and filtering known disturbance causalities from unknown disturbance causalities (Palaiologou and others, 2020).

B.1.2. LANDFIRE Reference Data Background

LFRDB plot data were collected beginning in 2002 (with plot data dating back to 1905) and were used for vegetation mapping and modeling for LF National, which was released in 2005. For the LF 2016 Remap release, only the most recent plot from any remeasured plot was retained in the LFRDB for vegetation mapping. Plot dates range from 1905 to 2016 and were used for modeling vegetation type, cover, and height for the entire United States and insular areas (although most plots in the LFRDB that were used as model training data were gathered in the decade leading up to LF 2016 Remap).

The LF Events Geodatabase was first created after LF National as updating processes were being developed to incorporate disturbances into LF products; subsequently, additional events data have been collected annually via the data call letter and online data gathering. The events data are used on a regular basis to update LF maps to reflect conditions resulting from these disturbances. Years represented in the Events Geodatabase range from 1999 to 2020 in the LF 2020 release.

B.2. LANDFIRE 2016 Remap LANDFIRE Reference Database

The LFRDB is housed in a PostgreSQL 10 (The PostgreSQL Global Development Group, 2017) relational database and contains georeferenced field plot data that describe vegetation and fuel attributes for a given area. The LFRDB is one of the most important elements in the LF production process because it provides ground-truth data for mapping and modeling vegetation and contains more than 1 million plots. Data are collected from many sources and processed into a consistent format for the LFRDB.

[1]KBR, Inc., under contract to the U.S. Geological Survey.

B.2.1. Data Submissions

LF collects reference data through (1) data contributions submitted as part of LF's yearly data call and (2) active searches of web-based data clearinghouses and agency/corporate database systems. For LF 2016 Remap, the need for additional plot data was highlighted in the yearly data call. Submitted plot data helped improve map layers, and many contributors had an interest in sharing their plot data. LF's yearly data call is available under LF data needs in the reference section of the program website (https://landfire.gov/lfrdb.php).

A total of 1,450,051 plots from 959 sources are in the LF 2016 Remap LFRDB. LF added more than 770,000 plots to the LFRDB for LF 2016 Remap. These plots were used in conjunction with the plot data from LF National for modeling vegetation. Some of the primary contributors for LF 2016 Remap include the following:

- U.S. Department of Agriculture Forest Service Forest Inventory and Analysis (FIA);
- National Park Service Inventory and Monitoring and Feat/FireMon Integrated;
- Natural Resources Conservation Service (NRCS) National Resources Inventory;
- Bureau of Land Management Assessment, Inventory, and Monitoring; and
- Individual State natural heritage program data.

The contributions of LFRDB data by different agencies are shown in figure B1. The multipartner category includes data in which more than one agency or group is responsible for the collection and (or) funding of the data. The "other" category includes data contributions from the U.S. Fish and Wildlife Service, nongovernmental organizations, the Department of Defense, the Department of Energy, the Environmental Protection Agency, and municipal sources.

Plots in the LF 2016 Remap LFRDB are located throughout the contiguous United States, Alaska, Hawaii, and on the insular areas of Puerto Rico, U.S. Virgin Islands, America Samoa, Guam, Palau, Northern Mariana Islands, and the Federated States of Micronesia (not shown on figure). No known plots were available for the Marshall Islands.

B.2.2. Data Processing and Data Types

Data submissions vary widely in sampling design, format, and data quality and need extensive quality assurance and control checks for standardization and use within LF. Each data contribution was converted into the LFRDB format. The LFRDB relational PostgreSQL database consists of 22 data tables and 36 lookup tables. There are 457 attributes associated with the 22 data tables. Data tables contain information on plant communities, vegetation structure, species composition, tree and seedling data, surface and canopy fuels, exotic plants, disturbances, treatments, and predictor data derived from spatial overlays of imagery, spectral indices, and climate variables. Many data tables and attributes are available to accommodate the wide variety of data formats that LF compiles and to meet the mapping and modeling needs of LF. Through each step of the conversion process, data are summarized and reformatted as needed so the data can be brought into the LFRDB in a standardized format. Once all data are converted into a like format, the compiled information can be queried and summarized.

A variety of vegetation and fuels data are archived in the LFRDB, but the data can be broken out into five main data types: species composition data, community element occurrence data (see explanation later in this section), vegetation

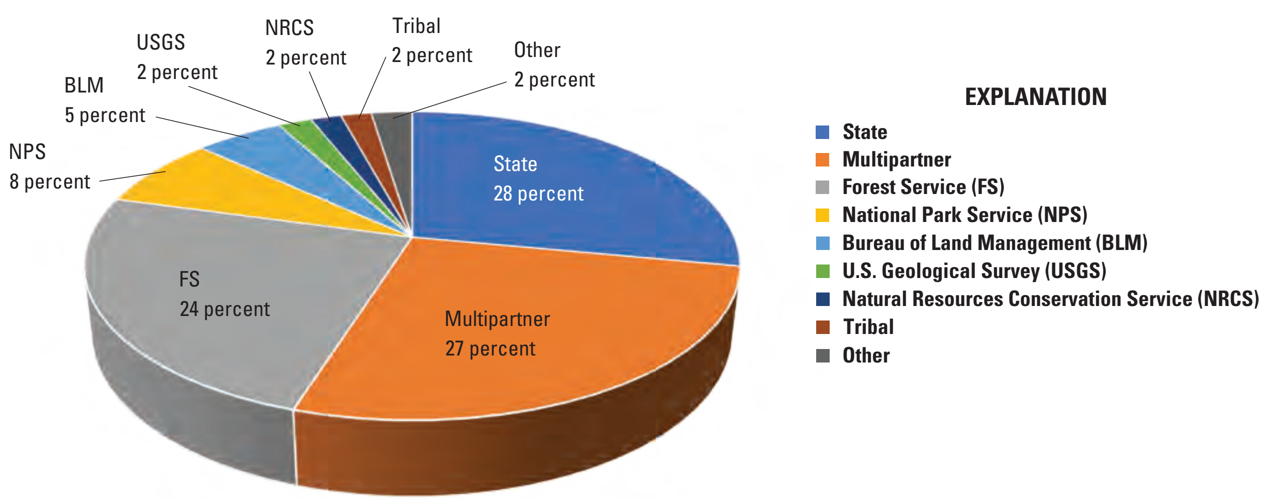


Figure B1. LANDFIRE reference database data contributions by agency. Percentages of all LANDFIRE reference database plots are accredited to different agencies.

structure data, fuels data, and exotic plant data. Overlap exists because a single sampling event could have several data types associated with it. The percentage of total plots in the LFRDB that have information about each data type is shown in figure B2.

Species composition data contain a full or partial list of plant species on a plot along with an estimate of percentage of cover for each species. All species names in the LFRDB were converted to NRCS symbol and NRCS scientific name around December 2013 (Natural Resources Conservation Service, 2021). The percentage of cover estimate for each species was either retained from the source dataset or calculated when data were available to do so. Cover estimates were sometimes averaged across subplots or calculated from transect data. Percentage of cover also was calculated from individual tree measurements where applicable. Only plots with species composition data and corresponding percentage of cover measurements can be run through the LF Auto-Key labeling system. The Auto-Key attributes each plot with a dominant lifeform and an existing vegetation type (EVT) using the ecological system (ES) classification and the U.S. National Vegetation Classification (NVC) system at the group level (section B.2.3) when enough information in the plot is available to do so.

Community element occurrence data (NatureServe, 2021) are plots that have only cover type or EVT labels. These plots do not have species composition data. LF enlisted the help of NatureServe experts to assign these plots to the ES and NVC group so they could be used for existing vegetation mapping when the source dataset had enough detail.

Vegetation structure data pertain to any plot that has information on plant height. LF calculated lifeform heights (using a cover weighted average) from species composition data or retained plot-level lifeform height data from source datasets when the information was available. Tree height specifically for FIA plots was modeled using the stem-map program and included trees greater than or equal to 5 inches in diameter at breast height in each FIA subplot and only dominant or codominant species (Toney and others, 2009). Lifeform height can be used to inform existing vegetation height modeling and mapping.

Fuels data contain information on surface and canopy fuels that are relevant to fire behavior and fire effects modeling. LF archives data relevant to fire behavior modeling such as live and dead herbaceous and woody vegetation cover and height, stand height, canopy base height, and fire-behavior fuel models. Some examples of fire effects modeling data that LF archives include fine and coarse downed woody biomass, duff and litter depth and biomass, and live and dead herbaceous and woody biomass. Data were brought through from the source dataset when available or calculated from transect data using the FireMon Analysis tool (Lutes and others, 2006).

Exotic plant data contain cover estimates or presence data for exotic plants. These plots contain information only on exotic plant species; nonexotic species were not inventoried. All exotic plant species were converted to NRCS symbol and NRCS scientific name around December 2013. Neither the fuels nor exotic plant plots were used in LF 2016 Remap modeling and mapping of vegetation or fuels; however, the data are still available in the LFRDB. The fuels data have

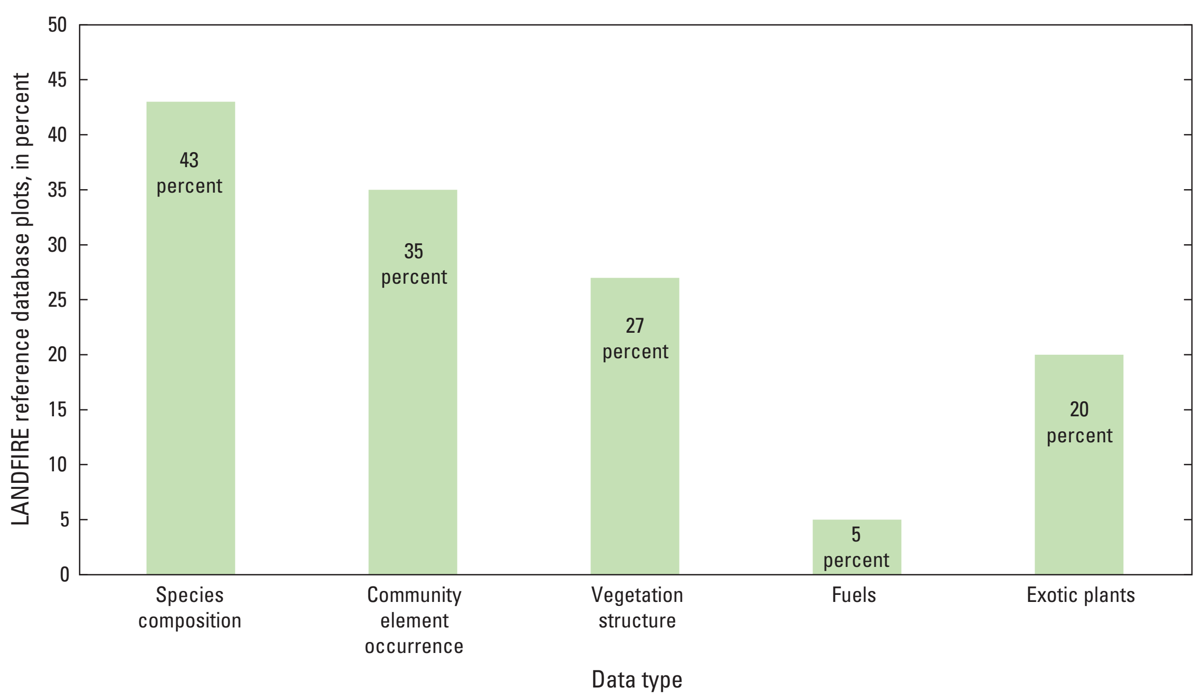


Figure B2. LANDFIRE reference database data types. Bar graph showing percentage of total plots that have information about each data type.

been used in the past for estimating canopy bulk density from canopy height and canopy cover via general linear models. Fuels and exotics plot data are of interest to fire managers for future LF modeling or assessment purposes and are available to the public.

B.2.3. Plot Labeling Using Auto-Keys

LF attributed plots in the LFRDB with ES labels and NVC group labels so they can be used to inform EVT mapping and modeling. The Auto-Key program (Reid and others, 2015) is a Python-based program developed by NatureServe that compares species and lifeform cover information on a plot to the sequence table criteria to determine what ES or NVC group should be assigned to each plot. Each plot is put through a sequential set of floristic and structural rules for each vegetation type (that is, a key) beginning with plot-level rules and advancing to species-level rules. If the conditions are met, the plot is assigned that vegetation type label; if conditions are not met, the plot goes to the next set of floristic rules in the list. The Auto-Key provides a consistent, repeatable method for attributing plots with vegetation types based on floristic composition (Reid and others, 2015). The steps in the Auto-Key that assign lifeform and vegetation types to plots in the LFRDB are as follows:

- First, each plant taxon was assigned a dominant lifeform. This is a necessary step in that simple structural characteristics (percentage of cover) for each plot are calculated by lifeform. Some species can be single stem (tree) or multistem (shrub), but for this purpose, the lifeform with the most cover was assigned to the plot because each species could have only one lifeform assignment.

- Second, species attributes for structure and composition were calculated for each plot, including relative lifeform cover for each species, calculated as percentage of absolute cover of the species divided by total cover of the lifeform to which it was assigned multiplied by 100 to achieve percentage of relative cover.

There were separate Auto-Keys for ES and NVC for all areas. The NVC Auto-Keys, completed in 2015, used the working version of the NVC groups classification available at the time, which was before the release of version 2.0 of the NVC standard in 2016. Because one source of error in the first generation Auto-Keys for LF 2001 was confusion between natural and ruderal types (areas with evidence of human disturbance), a third set of Auto-Keys was designed for the ruderal-to-cultural spectrum of vegetation (Reid and others, 2015).

The Auto-Keys were used in a stepwise fashion:

- First, the contiguous United States plots were put through the ruderal key, and either a ruderal or cultural type form were used as both the ES and NVC label. Most plots fell through the ruderal Auto-Key (because they had restrictive requirements) and resulted in an unclassified assignment.

- Second, plots not classified as ruderal types in the first step were then run through the ES and NVC Auto-Key to get their final assignments.

The ES and NVC Auto-Keys retained several types used previously in LF 2001 to classify introduced, ruderal, or managed vegetation. These types were retired for LF 2016 Remap, and plots were manually translated to the standardized ruderal and cultural classes in the LF 2016 Remap legend.

Not all plots that were run through the Auto-Keys received a final assignment of an ES or NVC group. Some plots did not meet the specific criteria in the sequence table and were either not labeled or were labeled with an unclassified system like unclassified forest and woodland or unclassified shrubland. The assignment of plots run through the ES and NVC group Auto-Key is shown in figure B3.

Each ES is associated with one or several dominant lifeforms. The program considers the ES label that is assigned to a plot and its associated dominant lifeform(s), then looks for the species with the greatest cover that has a matching lifeform(s). That species is labeled as the dominant species. The codominant species is the species with a matching lifeform to the dominant lifeform that has the second greatest cover. This information is archived in the LFRDB.

B.2.4. Plot Labeling Based on Expert Opinion

Although 630,250 vegetation samples were labeled through Auto-Keys, hundreds of thousands of samples could not be labeled through Auto-Key because of insufficient information associated with the plot. These samples were manually labeled via expert opinion by NatureServe using a cover type label provided in the source dataset, which included using existing classifications from LF National plots and local natural resource inventories to label documented locations without species composition and structure. In contrast, plots that were run through the Auto-Key but failed to receive a classification were not assigned a label by expert opinion because of time constraints of the LF program and cooperators.

The cover type labels provided by the source dataset needed to have enough detail to be assigned to an ES and NVC group. Cover type labels that were too broad, such as grass or shrub, did not contain enough detail to assign an ES or NVC group. Not all plots received a label, and some were classified as “none” or an unclassified system such as “unclassified grassland” via expert opinion. The assignment of plots evaluated in the expert assignment process is shown in figure B4.

More than 872,000 samples were assigned an ES label (532,241 from the Auto-Key and 340,372 from expert labeling), and about 790,000 plots were assigned an NVC group

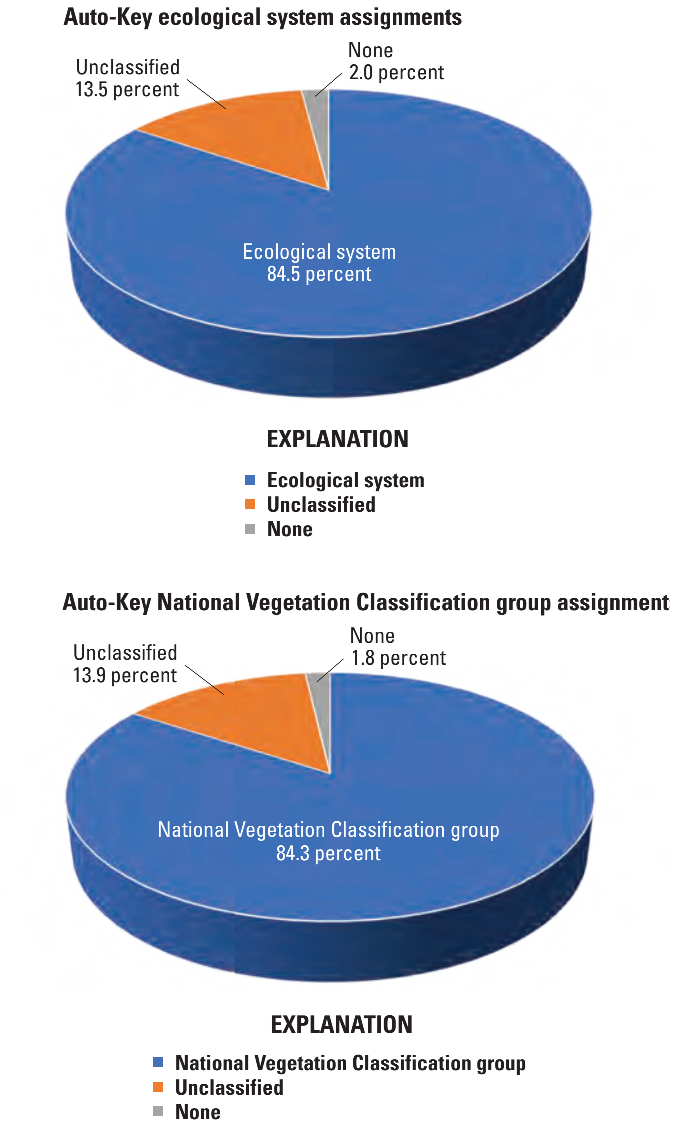


Figure B3. Percentage of Auto-Key plots that keyed to ecological system and U.S. National Vegetation Classification system group.

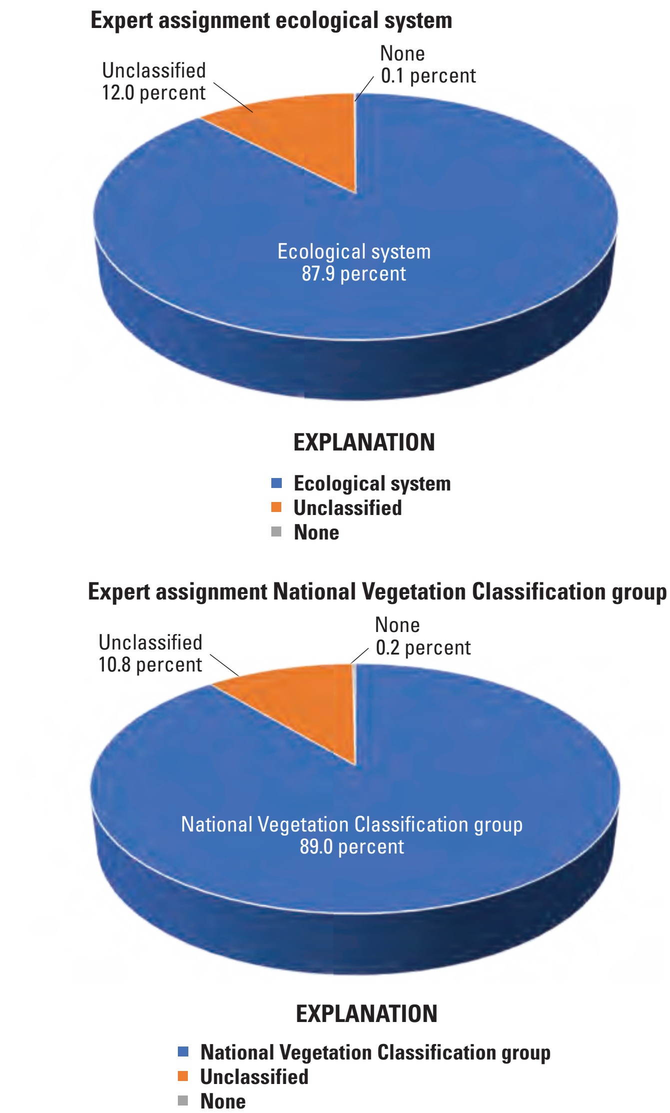


Figure B4. Percentage of expertly assigned plots that received an ecological system or U.S. National Vegetation Classification system group label.

label (530,987 from the Auto-Key and 259,641 from expert labeling). Plot labeling efforts resulted in 85 percent of all eligible plots receiving both an ES and NVC group label.

B.2.5. Extracted Data

Predictor data for all plots in the LFRDB were extracted by the LF U.S. Department of Agriculture Forest Service FIA liaison from spatial data layers and used for plot labeling as part of the Auto-Key and vegetation modeling input variables. The LF liaison for the U.S. Department of Agriculture Forest Service FIA program is the party responsible for extracting data associated with LFRDB plots because of data security restrictions associated with FIA plot locations which are considered controlled unclassified information. Because of the extraction process, latitude or longitude coordinates for FIA plots are neither stored in the LFRDB nor used in the LF mapping process. Other large Federal plot datasets such as the National Resources Inventory have similar data use restrictions.

Different sets of predictor data were used for different regions, so not all plots in the LFRDB have all predictor attributes. Elevation, aspect, and slope derived from U.S. Geological Survey 3D Elevation Program light detection and ranging data (U.S. Geological Survey, 2016); Ecological Classification and Mapping subsection (Cleland and others, 2007); U.S. Environmental Protection Agency ecoregion (Omernik and Griffith, 2014); mapzone (Wickham and others, 2014); and The Nature Conservancy ecoregion (The Nature Conservancy, 2008), landform, and bioclimate values (Sayre and others, 2009) were used as inputs to the Auto-Key program and as reference for expert labeling. Extracted predictor variables were stored in the LFRDB for the first time with the release of LF 2016 Remap. Previous versions of the public LFRDB did not include extracted predictor variables.

Some of the extracted data used in vegetation modeling and mapping included LF elevation, aspect, slope, National Land Cover Database land cover (U.S. Geological Survey, 2018), and topographic position. Scaled integer data also were extracted from the LF biophysical gradient layers (temperature and precipitation; Rollins, 2009), and soils data from various soil layers such as the Soil Survey Geographic database (Soil Survey Staff, 2014) and POLARIS (Chaney and others, 2016). Data also were extracted at plot locations for spectral reflectance and vegetation indices to use in EVT model development (section D.2.3). Disturbance extractions were used to complete quality assurance and quality control checks on the plots used in vegetation modeling. More information about the extracted predictor data is available in the LFRDB data dictionary (LANDFIRE, 2022).

B.2.6. Public LANDFIRE 2016 Remap LANDFIRE Reference Database

The public LFRDB includes a subset of the full suite of field-referenced data that were used in the production of the LF program deliverables. According to agreements between LF and its data contributors, certain proprietary or otherwise sensitive data have been removed to create this publicly available version of the database. Some examples of data that were removed from the public version include FIA, National Resources Inventory, and the Bureau of Indian Affairs continuous forest inventory data. A total of 539,373 plots from 487 different sources were included in the public version of the LFRDB. More than one-half of the plots in the public version of the LFRDB were acquired during the LF 2016 Remap effort.

Certain tables and fields also were removed from the public version of the LFRDB. Most of the tables and fields that were removed were specific to internal LF production, and utility to outside entities would be negligible; for example, the LFProductionQA table was not included in the public version because it houses data on internal quality assurance and quality control checks.

The public version of the LFRDB is available as a Microsoft Access database, a format easy for users to download and use. The public LFRDB contains a large amount of data, and therefore, it was necessary to split the data into LF contiguous U.S. geographic areas to avoid exceeding the Microsoft Access database size limits. Those geographic areas in the contiguous United States are Northwest, Southwest, North Central, South Central, Northeast, and Southeast, along with Alaska, Hawaii, and the insular area extents.

For a complete list of data tables and attributes in the public LFRDB please see the LF 2016 LFRDB data dictionary (LANDFIRE, 2022). The public LFRDB is available for download under the reference section of the LF website (https://landfire.gov/lfrdb.php).

B.3. LANDFIRE Events Geodatabase

The LF Events Geodatabase contains a collection of perimeter data depicting disturbances and treatments that have been detected across the landscape. LF uses recent disturbance and treatment data to help attribute a cause to image-based change detections and update map layers in areas where vegetation and fuel have changed. LF collects data on the following disturbances: wildfires, development, insect and disease, weather damage, and management actions including harvest/thinning, mechanical, prescribed fires, seeding/planting, and chemical treatments (table B1).

B.3.1. Data Submissions

The collection of LF events data is based on two distinct methods. The first collection method is through an annual request from LF to submit disturbance and treatment event perimeters and associated data by November 30. This collection method is commonly used by State, municipal, private, and nonprofit entities. Some national sources, including the Bureau of Indian Affairs, National Parks Service, Bureau of Land Management, and U.S. Fish and Wildlife Service, also use this method. The second method of collection is from web-based data clearinghouses and agency/corporate database systems. Many national sources such as the National Fire Plan Operations and Reporting System, National Incident Feature Service, and Forest Service Activity Tracking System are collected in this manner. More information on LF's yearly data call is available under the contribute data/reference data tab on the LF website (https://landfire.gov/participate_refdata.php).

Although the Events Geodatabase contains events beginning in 1999, the events collection effort for LF 2016 Remap focused on collecting and processing events data from 2015 and 2016. A total of 233,962 event perimeters were collected and compiled for LF 2016 Remap. Data sources for the Events Geodatabase years of 2015 and 2016 are shown in figure B5.

The "other" category includes data contributed from The Nature Conservancy, Department of Defense, and private and municipal entities. Events in the LF Events Geodatabase are derived from the same areas as the LFRDB: contiguous

Table B1. LANDFIRE event type definitions and hierarchy.

LANDFIRE event type	Definition
Development	Conversion of natural lands into housing, commercial, or industrial building sites. Involves permanent land clearing.
Clearcut	The cutting of essentially all trees, producing a fully exposed microclimate for the development of a new age class.
Harvest	A general term for the cutting, felling, and gathering of forest timber. The term “harvest” was assigned to events where there was not enough information available to call them one of the two distinct types: clearcut or thinning.
Thinning	A tree removal practice that reduces tree density and competition between trees in a stand. Thinning concentrates growth on fewer, high-quality trees, provides periodic income, and generally enhances tree vigor.
Mastication	Means by which vegetation is mechanically “mowed” or “chipped” into small pieces and changed from a vertical to horizontal arrangement.
Other mechanical	Catchall term for a variety of forest and rangeland mechanical activities related to fuels reduction and site preparation including piling of fuels, chaining, lop and scatter, thinning of fuels, Dixie harrow, and so on.
Wildfire	An unplanned, unwanted wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to suppress or put out the fire.
Wildland fire use	The application of the appropriate management response to wildland fires ignited naturally to achieve specific resource management objectives in predefined designated areas outlined in fire management plans.
Prescribed fire	Any fire ignited by management actions to meet specific objectives. A written, approved prescribed fire plan must exist and National Environmental Protection Act requirements (where applicable) must be met before ignition.
Wildland fire	A catchall term used to describe any nonstructure fire that happens in the wildland. Three distinct types of wildland fire have been defined: wildfire, wildland fire use, and prescribed fire. The term “wildland fire” was assigned to events where there was not enough information available to call them one of the three distinct types.
Weather	A weather-related event that results in loss of vegetation such as blowdown, hurricane, or tornado.
Insecticide	Application of a chemical substance used to kill insects.
Chemical	Application of a chemical substance. The term “chemical” was assigned to events where there was not enough information available to call them one of the two distinct types, herbicide or insecticide.
Insects	Infestations of unwanted insects such as bark beetles that can affect vegetative health.
Disease	Infestations of disease such as root rot that can affect vegetative health.
Insects/disease	Infestations of insects and (or) disease that can affect vegetative health. This term was assigned to events where there was not enough information available to call them one of the specific types.
Herbicide	Application of a chemical substance used to kill or inhibit the growth of plants.
Biological	The use of living organisms, such as predators, parasites, and pathogens, to control weeds, pest insects, or diseases.
Planting	Reestablishing a vegetative community by planting.
Reforestation	Reestablishing a vegetative community by planting or seeding where there was not enough information available to specify the mode of reforestation.
Seeding	Reestablishing a vegetative community by seeding.

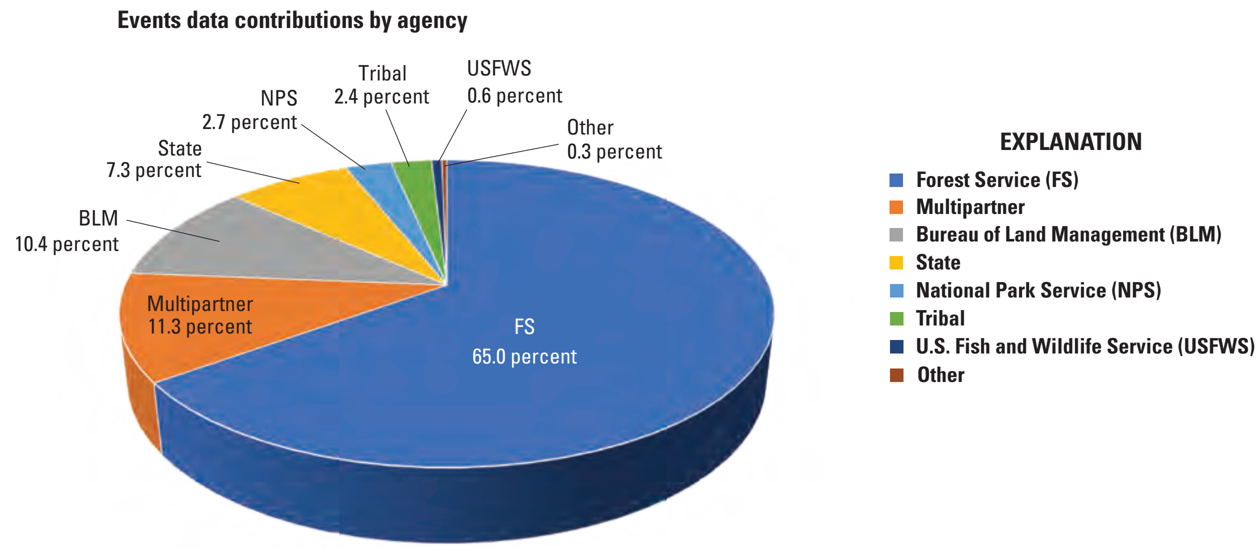


Figure B5. Events data contributions by agency. Percentages of all LANDFIRE 2016 Remap events are accredited to different agencies.

United States, Alaska, Hawaii and the insular areas, including the U.S. Virgin Islands, Puerto Rico, Guam, Palau, Northern Mariana Islands, and the Federated States of Micronesia.

B.3.2. Data Processing and Types

The quality of data submitted varies, and extensive quality assurance and quality control checks are needed for standardization and use for LF. All data submitted to LF for 2015 and 2016 were evaluated for inclusion into the LF Events Geodatabase. Acceptable events data had to meet the following minimum requirements: (1) the event must be represented by a polygon on the landscape and have a defined spatial coordinate system, (2) the event must have an acceptable event type, and (3) the event must be attributed with the year of occurrence. All acceptable events data were converted into a LF events format. During the conversion process, disturbances and vegetation/fuel treatments were assigned to a LF event type (table B1). Other information pulled from the source data included the designated name of the event, the year, start date, end date, unique identifiers, severity, and any relevant comments. To summarize the data in the LF Events Geodatabase, the LF event types can be grouped into eight main data types (fig. B6):

1. Fire—wildland fire, wildland fire use, wildfire, prescribed fire;
2. Harvest—harvest, thinning, clearcut;
3. Mechanical—mastication, other mechanical;
4. Chemical/biological—chemical, insecticide, herbicide, biological;
5. Insects/disease—insects, disease;
6. Reforestation—reforestation, planting, seeding;
7. Weather—weather; and
8. Development—development.

B.3.3. Raw Versus Model-Ready Events

The Events Geodatabase contains two feature classes that have disturbance and treatment perimeters: raw events and model ready events. The data in the raw events feature class have been analyzed to eliminate geospatial or information content errors but otherwise represent the full account of acceptable data processed for LF 2016 Remap. These data may include multiple perimeters for the same event and a high degree of overlap between events within a single year. Examples of the former include the same management activity or disturbance event reported by multiple agencies or individuals. Examples of the latter include locations in which multiple management activities and (or) natural disturbances were documented within the same year. A total of 233,962 events were compiled into the LF raw events feature class for 2016 Remap for 2015 and 2016.

The model ready events feature class contains only one unique event per year per location. To produce the model ready layer, a series of topologies (relations between spatial items) were created on the raw events data to identify areas of overlap between polygons within the same year. The standard hierarchy of LF event types, depicted in table B1, indicates the highest ranked events have the greatest effect on vegetation and (or) fuels composition and structure. The event type hierarchy was used to correct topology errors by merging lower ranked events into higher ranked events where polygons overlap. When there were multiple perimeters for the same event, one perimeter was chosen based on the following hierarchy

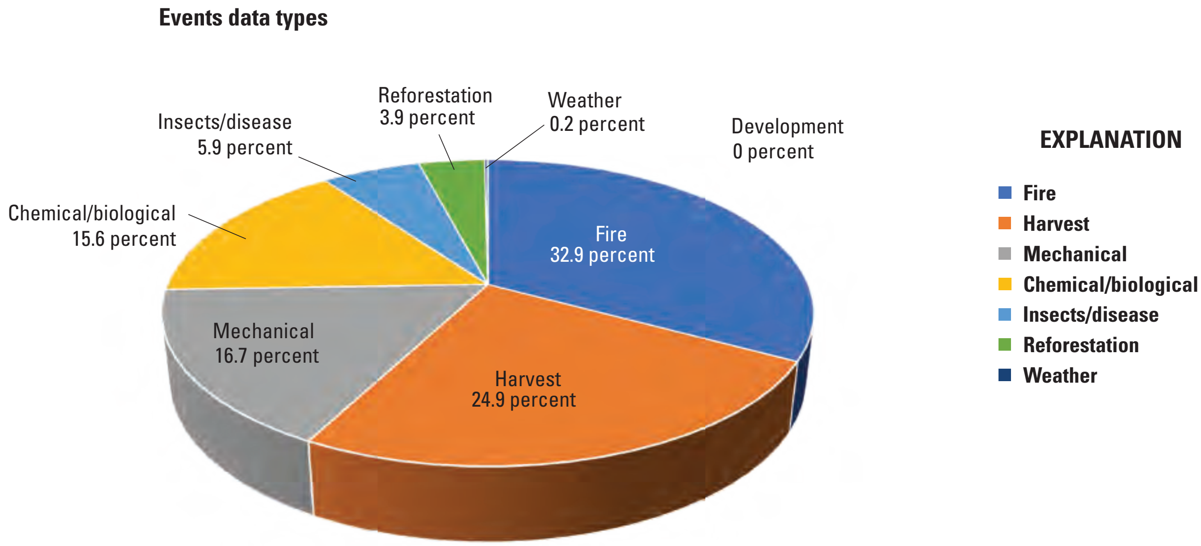


Figure B6. Percentage of events of each data type from the LANDFIRE Events Geodatabase from 2015 and 2016.

for attributes associated with the perimeter: (1) most severe, (2) most recent end date, (3) most recent start date, (4) local before nonlocal sources, and (5) the largest perimeter by acres. The result is a layer that contains only one event per year for a location. Reforestation (seeding and planting) events were analyzed further to remove all but the most recent event at each location. Point derived polygons and polygons that were less than 0.02 acre also were removed from the model ready events. After processing the 2015 and 2016 events for the LF 2016 Remap version of model ready events, a total of 120,209 events were in the geodatabase (about 51 percent of LF 2016 Remap raw events).

The model ready events are used for attributing the disturbance cause (disturbance type) in annual disturbance mapping (see chap. C). Disturbance type information is crucial to understanding and mapping changes in fuels and is used in deciding how different disturbance types affect fuels via the fuel disturbance layer (see chap. E).

B.3.4. Public Events Geodatabase

Public data collected and processed for LF 2016 Remap for 2015 and 2016 were added to the existing public Events Geodatabase, and an updated version is available on the LF website (https://landfire.gov/publicevents.php). The raw and model ready events layers are included in the public version. The public Events Geodatabase includes a subset of the full suite of data that were used in the production of LF 2008 Refresh, LF 2010, LF 2012, LF 2014, LF 2016 Remap, LF 2019 Limited, and LF 2020 versions. According to agreements between LF and its data contributors, certain proprietary or otherwise sensitive data have been removed to create this publicly available version of the geodatabase.

The public Events Geodatabase from the LF 2016 Remap release contains data from 1999 through 2016; a total of 1,239,644 events are in the public raw events layer, and a total of 751,242 events are in the public model ready events layer. The LF public Events Geodatabase includes a feature dataset for the contiguous United States, Alaska, Hawaii, and the insular areas of the Federated States of Micronesia, Guam/Northern Mariana Islands, and Palau. More information on the public Events Geodatabase is available under the reference section of the LF website (https://landfire.gov/lfrdb.php).

B.4. LANDFIRE 2019 Limited and LANDFIRE 2020 Reference Updates

The LFRDB format has only changed slightly since the LF 2016 Remap release. The adjusted EVT attribute was added and represents the final EVT–ES used in model training for LF 2016 Remap after adjusting for Auto-Key and expert opinion mislabeled plots; for example, if a plot was located in an alpine system but did not have an alpine EVT label after going through the Auto-Key, it would have to be reassigned to a more appropriate label.

The Events Geodatabase is updated regularly with LF releases; however, when LF 2019 Limited was released in June 2021, events covering the years 2017–19 were not released. LF 2020 contains 2020 events as well. As LF moves toward an annual release covering the previous year's disturbances, timely submission of agency-recorded events will increase in importance for LF products to use this information.

B.5. Conclusion

All large land cover mapping efforts, including LF, require data collection efforts to validate maps and to train models to classify correctly. The detail in LF maps would not be possible without the LFRDB. Taking disparate data sources and bringing them into a database with one format for more than 1 million records is a monumental task. Although data from different sources can come with the error associated with data gathering, they also come with the certainty of a professional personnel visit to the actual plot on the ground. Taking those data and assigning each plot to a vegetation type (both ES and NVC) in an automated manner when possible (and using expert opinion when not) gives LF the ability to map more than 700 ES vegetation classes. Capturing and formatting these data are crucial in LF's modeling and mapping efforts that derive from these data.

The events that the LF reference team gathers are another rich data source that takes time and effort to standardize into one cohesive geodatabase. Standards and technological abilities within all agencies at all levels change through time, which requires an extensive effort of quality control and the ability to reconcile reporting and formatting of attributes from different sources. LF's Events Geodatabase is the first step in the disturbance mapping process. Again, the personnel gathering these data from different agencies may have different levels of effort or standards for recording a polygon around a prescribed fire; however, the professional personnel gathering and recording the perimeter data are typically familiar with the area and have possibly even walked the perimeter with a global positioning system. These ground-truth data are not only crucial for assigning attributes such as disturbance cause but also are an important aspect of understanding how well LF's remote-sensing based disturbance detections are performing. Without the Events Geodatabase, there would be no way to account for changes that cannot be detected with multispectral remote sensing in our maps of vegetation and fuels. Together, the LFRDB and Events Geodatabase are foundational reference datasets for the LF vegetation and fuel layer mapping process. For further information, please reference the LF website (https://www.landfire.gov).

B.6. References Cited

Chaney, N.W., Wood, E.F., McBratney, A.B., Hempel, J.W., Nauman, T.W., Brungard, C.W., and Odgers, N.P., 2016, POLARIS—A 30-meter probabilistic soil series map of the contiguous United States: Geoderma, v. 274, p. 54–67. [Also available at https://doi.org/10.1016/j.geoderma.2016.03.025.]

Cleland, D.T., Freeouf, J.A., Keys, J.E., Nowacki, G.J., Carpenter, C.A., and McNab, W.H., 2007, Ecological subregions—Sections and subsections for the conterminous United States: U.S. Department of Agriculture General Technical Report WO–76D, 1 p., 1:3,500,000-scale, accessed October 5, 2021, at https://www.srs.fs.usda.gov/pubs/48672.

Hak, J.C., and Comer, P.J., 2017, Modeling landscape condition for biodiversity assessment—Application in temperate North America: Ecological Indicators, v. 82, p. 206–216. [Also available at https://doi.org/10.1016/j.ecolind.2017.06.049.]

LANDFIRE, 2022, LANDFIRE reference database—LF 2016 Remap (LF 2.0.0) public data dictionary: LANDFIRE technical document LF–PRD–014, 15 p., accessed October 3, 2021, at https://landfire.gov/DataDictionary/LF2016_LFRDB_DataDictionary.pdf.

Lutes, D.C., Keane, R.E., Caratti, J.F., Key, C.H., Benson, N.C., Sutherland, S., and Gangi, L.J., 2006, FIREMON—Fire effects monitoring and inventory system: Fort Collins, Colo., Forest Service, Rocky Mountain Research Station General Technical Report RMRS–GTR–164, 1 CD.

Natural Resources Conservation Service, 2021, PLANTS database: U.S. Department of Agriculture database, accessed October 3, 2021, at https://plants.usda.gov/home.

NatureServe, 2021, Element occurrence data standard: NatureServe web page, accessed October 3, 2021, at https://www.natureserve.org/products/element-occurrence-data-standard.

Omernik, J.M., and Griffith, G.E., 2014, Ecoregions of the conterminous United States—Evolution of a hierarchical spatial framework: Environmental Management, v. 54, no. 6, p. 1249–1266. [Also available at https://doi.org/10.1007/s00267-014-0364-1.]

Palaiologou, P., Essen, M., Hogland, J., and Kalabokidis, K., 2020, Locating forest management units using remote sensing and geostatistical tools in north-central Washington, USA: Sensors, v. 20, no. 9, art. 2454, 23 p., accessed October 3, 2021, at https://doi.org/10.3390/s20092454.

The PostgreSQL Global Development Group, 2017, PostgreSQL version 10.0 documentation: The PostgreSQL Global Development Group web page, accessed August 31, 2022, at https://www.postgresql.org/docs/10/release-10-1.html.

Reid, M., Comer, P., Lundberg, B., Smith, J., Drake, J., Faber-Langendoen, D., Harkness, M., Kittel, G., Menard, S., Nordman, C., Pyne, M., Schulz, K., Sneddon, L., and Teague, J., 2015, Developing Auto-Keys for LANDFIRE vegetation mapping—2014–2015 CONUS project report: Arlington, Va., prepared by NatureServe, 69 p. plus appendixes, accessed August 27, 2021, at https://landfire.gov/lf_improvements.php.

Rigge, M.B., 2022, Rangeland Condition Monitoring Assessment and Projection (RCMAP): U.S. Geological Survey Fact Sheet 2022–3036, 2 p., accessed August 31, 2022, at https://doi.org/10.3133/fs20223036.

Rollins, M.G., 2009, LANDFIRE—A nationally consistent vegetation, wildland fire, and fuel assessment: International Journal of Wildland Fire, v. 18, no. 3, p. 235–249. [Also available at https://doi.org/10.1071/WF08088.]

Sayre, R.G., Comer, P., Warner, H., and Cress, J., 2009, A new map of standardized terrestrial ecosystems of the conterminous United States: U.S. Geological Survey Professional Paper 1768, 17 p., accessed October 21, 2021, at https://doi.org/10.3133/pp1768.

Schrader-Patton, C.C., and Underwood, E.C., 2021, New biomass estimates for chaparral-dominated southern California landscapes: Remote Sensing, v. 13, no. 8, art. 1581, 24 p., accessed October 3, 2021, at https://doi.org/10.3390/rs13081581.

Soil Survey Staff, 2014, Gridded Soil Survey Geographic (gSSURGO) database for the conterminous United States: Natural Resources Conservation Service digital data, accessed May 2014 at https://gdg.sc.egov.usda.gov/.

The Nature Conservancy, 2008, Terrestrial ecoregions (TNC): The Nature Conservancy web page, accessed October 5, 2021, at http://www.landscope.org/map_descriptions/ecosystems/tnc_ecoregional_boundaries/15602/.

Toney, C., Shaw, J.D., and Nelson, M.D., 2009, A stem-map model for predicting tree canopy cover of Forest Inventory and Analysis (FIA) plots, in McWilliams, W., Moisen, G., and Czaplewski R., comps., Proceedings of the Forest Inventory and Analysis (FIA) Symposium 2008, Park City, Utah, October 21–23, 2008: Fort Collins, Colo., Forest Service, Rocky Mountain Research Station, 19 p.

U.S. Geological Survey, 2016, 3D Elevation Program 1-meter resolution digital elevation model: U.S. Geological Survey web page, accessed April 27, 2023, at https://www.usgs.gov/3d-elevation-program/tools.

U.S. Geological Survey, 2018, NLCD 2016 land cover (CONUS) all years: Multi-Resolution Land Characteristics Consortium web page, accessed October 5, 2021, at https://www.mrlc.gov/data/nlcd-land-cover-conus-all-years.

Wickham, J., Homer, C., Vogelmann, J., McKerrow, A., Mueller, R., Herold, N., and Coulston, J., 2014, The Multi-Resolution Land Characteristics (MRLC) Consortium—20 years of development and integration of USA national land cover data: Remote Sensing, v. 6, no. 8, p. 7424–7441. [Also available at https://doi.org/10.3390/rs6087424.]

Woodward, B., Engelstad, P., Vorster, A., Beddow, C., Krail, S., Vashisht, A., and Evangelista, P., 2017, Forest harvest dataset for northern Colorado Rocky Mountains (1984–2015) generated from a Landsat time series and existing forest harvest records: Data in Brief, v. 15, p. 724–727. [Also available at https://doi.org/10.1016/j.dib.2017.10.030.]

Chapter C. Disturbance Mapping

By Inga P. La Puma,[1] Brian L. Tolk,[1] Joshua J. Picotte,[2] and Sanath Sathyachandran[2]

C.1. Introduction to LANDFIRE Disturbance Mapping

C.1.1. The Need for LANDFIRE Annual Disturbance

Annual disturbance maps for the entire United States and insular areas are an important aspect of the LANDFIRE (LF) program given that disturbances affect the amount, arrangement, and types of vegetation and fuels detected on the landscape. The creation of comprehensive annual disturbance layers processed in a consistent manner for all nondeveloped lands is the first step in the LF vegetation and fuels mapping processes. LF uses disturbance information from the previous 10 years to apply changes to vegetation and fuels based on the disturbance type, its severity, and the time since disturbance (TSD). If a previous fire or fuel reduction treatment was completed in the path of an advancing wildfire, for example, the fire most likely behaves differently when it reaches that disturbed area. A fire behavior model with an adjusted surface fuels map accounting for disturbance more accurately reflects potential fire behavior on an incident (see chap. E). The annual disturbance layers also offer numerous applications as stand-alone layers and can provide the national, regional, and local information needed for land managers to understand how disturbance regimes are changing in scale or in timing. The interplay between natural and managed disturbances on the landscape also can be elucidated with annual disturbance products; for example, there are numerous reasons a regional land manager evaluates their landscape. They may be interested in the distribution and timing of disturbance as it relates to the size and spacing of a particular successional state required by a focal species of concern. Managers more focused on fire may be looking at the types, size, and frequency of disturbances in their region to identify areas of increased hazard. Using LF disturbance information, managers can understand how resources could be distributed or focus on mechanically treating areas that have not experienced disturbance as frequently where fuel reduction may be necessary to protect life and property.

[1]KBR, Inc., under contract to the U.S. Geological Survey.

[2]AFDS, Inc., under contract to the U.S. Geological Survey.

C.1.2. LANDFIRE Annual Disturbance Background

LF annual disturbance maps are 30-meter (m) resolution raster layers recording all known disturbances across the contiguous United States and Alaska on an annual basis covering the years 1999–2016. Disturbance mapping of Hawaii began with LF 2012, and disturbance mapping of the insular areas began with LF 2016 Remap. Disturbances are mapped via a combination of data sources (fig. C1), including remote sensing change detection and severity products produced by the LF disturbance team; external fire program change detection and severity mapping products; and the LF Events Geodatabase from the reference team, which contains submitted disturbance perimeters from local, State, Federal, and nonprofit sources (see chap. B). Disturbance types include different categories of fire and harvest along with insect defoliation and chemical applications. All these sources of data have associated levels of disturbance type confidence. They are combined in a hierarchical manner where the sources assigned to the lower value disturbance codes generally take priority in the annual layer before the sources with higher disturbance codes, with the exception of modeled and focal filled Monitoring Trends in Burn Severity (MTBS) data (table C1).

As mentioned previously, disturbance mapping in LF is the first step in understanding where vegetation and fuels have been affected or changed. These disturbance layers not only inform how vegetation was initially affected but also, when used in conjunction with vegetation and fuels transition rulesets, inform how vegetation has recovered through time. For the LF 2016 Remap effort, 10 years of annual disturbance layers were used for mapping circa 2016 vegetation and fuels. Disturbances can be of many types, but for the LF program, they generally fall into categories derived from the Events Geodatabase (see chap. B, table B1). Event types not included in the annual disturbance layers include planting, reforestation, and seeding. An additional category of fire is added in the disturbance legend that refers to fire-program-derived disturbance types (MTBS, Burned Area Reflectance Classification [BARC], and Rapid Assessment of Vegetation Condition after Wildfire [RAVG]) that were not included in the Events Geodatabase. Each disturbance type also is assigned a severity, split between low, medium, and high categories. Severity information is almost entirely based on the change signal from remote sensing data before and after a disturbance (see section C.2.1).

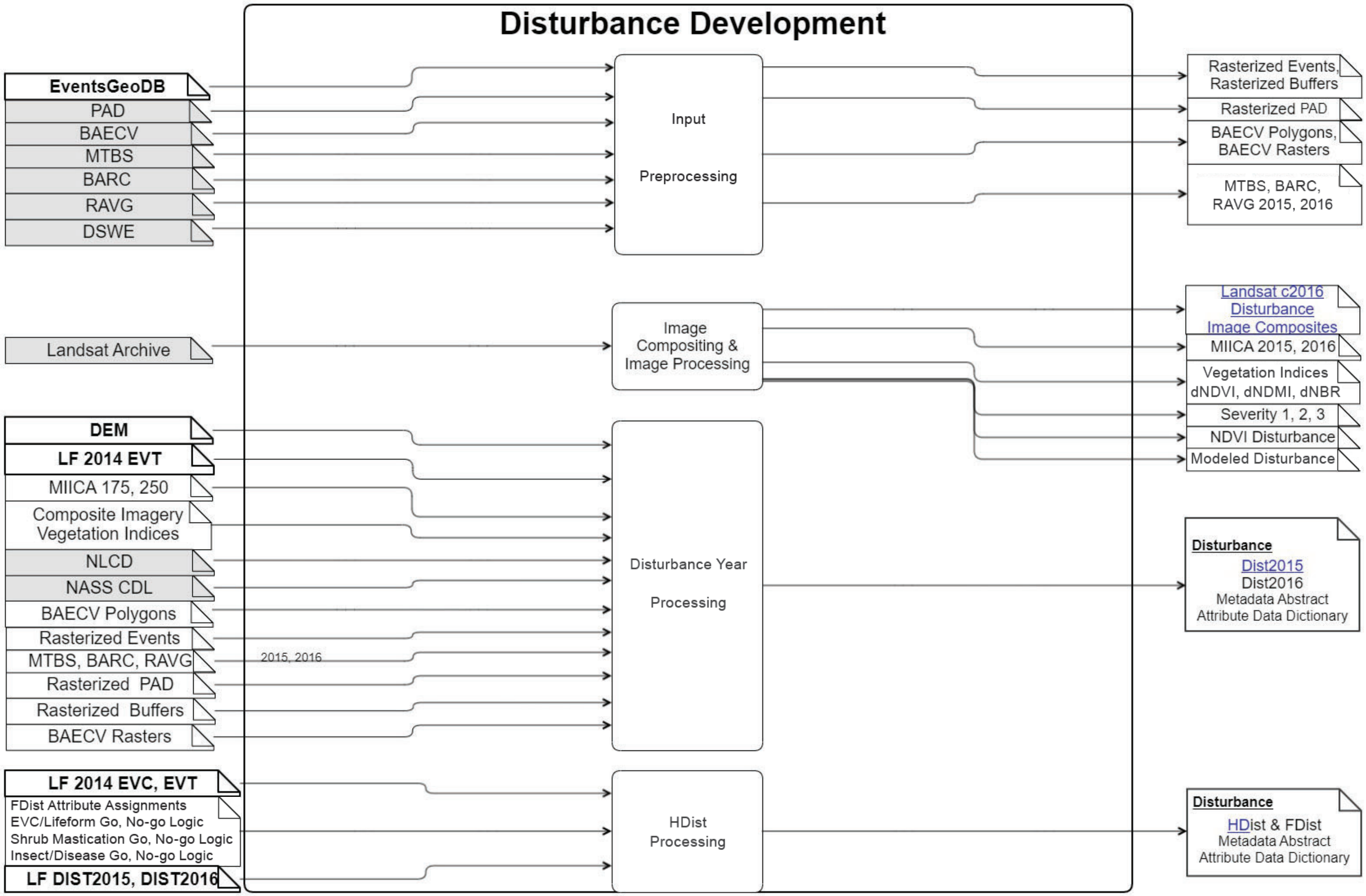


Figure C1. Disturbance development flow showing external inputs (top), Landsat inputs (middle), and processing of the inputs to external outputs (bottom, disturbance outputs) for LANDFIRE 2016 Remap. [EventsGeoDB, Events Geodatabase; PAD, Protected Areas Database; BAECV, Burned Area essential climate variable; MTBS, Monitoring Trends in Burn Severity; BARC, Burned Area Reflectance Classification; RAVG, Rapid Assessment of Vegetation Condition after Wildfire; DSWE, Dynamic Surface Water Extent; MIICA, Multi-Index Integrated Change Analysis; dNDVI, differenced Normalized Difference Vegetation Index; dNDMI, differenced Normalized Difference Moisture Index; dNBR, differenced normalized burn ratio; NDVI, Normalized Difference Vegetation Index; DEM, digital elevation model; LF, LANDFIRE; EVT, existing vegetation type; NLCD, National Land Cover Database; NASS, National Agricultural Statistics Service; CDL, Cropland Data Layer; DIST, disturbance; EVC, existing vegetation cover; FDist, fuel disturbance; HDist, historical disturbance]

Table C1. Hierarchy of annual disturbance datasets. Fire program data at the top of the table consist of Monitoring Trends in Burn Severity, Burned Area Reflectance Classification, and Rapid Assessment of Vegetation Condition after Wildfire.

[MTBS, Monitoring Trends in Burn Severity; BARC, Burned Area Reflectance Classification; RAVG; Rapid Assessment of Vegetation Condition after Wildfire; anthro, anthropogenic causality; PAD, Protected Areas Database; BA, Burned Area; <, less than; %, percent; m, meter; >, greater than]

Priority of disturbances mapped annually	Disturbance codes
MTBS	11–15
MTBS—gap filled See5	111–115
MTBS—gap filled focal majority	211–215
BARC	21–24
RAVG	31–34
RAVG—gap filled focal majority	231–234
Image-based change and event—all fire, mechanical, and development	411–503
Image-based change and event—chemical, biological, and weather	511–583
Image-based change but no event, anthro not expected, PAD 1 or 2, BA <95%	601–603
Image-based change but no event, anthro expected, PAD 3 or 4, BA <95%	701–703
Image-based change <500 m from events type—all fire, mechanical, and development	711–803
Image-based change <500 m from events type—chemical, biological, and weather	811–883
Event but no image-based change—all fire, mechanical, and development	910–1009
Event but no image-based change—chemical, biological, and weather	1010–1089
Image-based change but no event and no PAD protection	1101–1103
Image-based change but no event and no PAD protection, BA >95%	1111–1113
Image-based change but no event, PAD 1 or 2, BA >95%	1121–1123
Image-based change but no event, PAD 3 or 4, BA >95%	1131–1133

C.1.3. Historical Disturbance

A historical disturbance (HDist) layer also was compiled for LF 2016 Remap (see section C.6 for details). This layer aggregates 10 years of annual disturbance information. It primarily maintains attribute information for the most recent disturbance for each pixel. Disturbance data for 10 years are merged and used in mapping vegetation and fuels; an additional field describing the TSD informs changes to vegetation and fuels, including regrowth. Several steps are used to create a disturbance layer that fully represents all known disturbances and severities on the landscape annually. These steps are broken out in the sources of disturbance information in section C.2.

C.1.4. LANDFIRE Annual Disturbance Versions

Historical methods of deriving annual disturbance layers have been described in Vogelmann and others (2010); therefore, this document focuses on methods used for LF 2016 Remap (fig. C2). The LF 2019 Limited update and the methods used for the LF 2020 update also are included.

C.1.4.1. LANDFIRE 2016 Remap

The annual disturbance layers were used in several ways for the LF 2016 Remap. The LF 2016 Remap included new disturbances detected for 2015 and 2016 and incorporated advances in image processing and change detection methodologies. When 2015 and 2016 disturbances were combined with the previous 8 years of annual disturbance into the HDist product, the most recent year of disturbance was retained for each pixel. HDist informed vegetation mapping by determining where pixels would be labeled as recently disturbed (see section D.2.6.4) and applying a reduction in cover and height for 2015 and 2016. Annual disturbances also were used to create fuel disturbance (FDist), the year-capable version of HDist used for calculating fuels characteristics (see chap. E).

C.1.4.2. LANDFIRE 2019 Limited Disturbance Update

Limited annual disturbance layers were created in the contiguous United States for the LF 2019 Limited update that was released in June 2021. Limited annual disturbance layers included the years 2017–19 and consisted of LF events and fire program data for the contiguous United States. The distinction for the LF 2019 Limited update is that the remote sensing of landscape change (RSLC) process described later

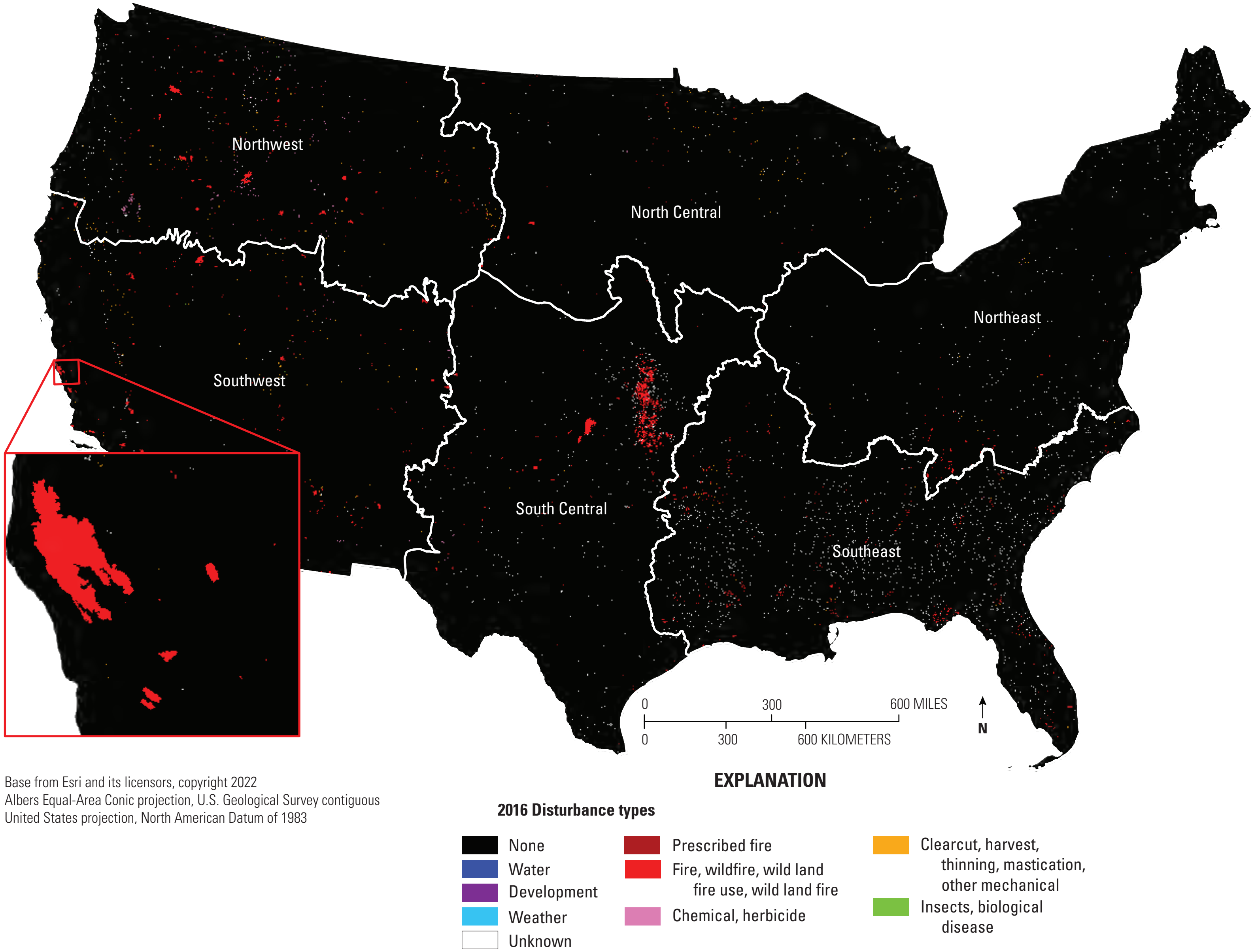


Figure C2. Annual disturbances from 2016 with LANDFIRE geographic areas and inset of large fires in California.

in this chapter was not used; therefore, the disturbance layers were limited. These layers were not released as stand-alone annual disturbance layers but were exclusively used to create the FDist layer used in the application of vegetation transition rules using ST-Sim (a package of SyncroSim, described in detail in chap. D) and fuel changes using LF's Total Fuels Change Tool, which applies transition rules for a given disturbance along with its severity and TSD to predisturbance fuels to derive the most recent fuels information (see chap. E).

C.1.4.3. LANDFIRE 2020 Disturbance Update

Annual disturbance layers produced for the LF 2020 update for 2017–20 were consistent with LF 2016 Remap procedures with some technical improvements, including the use of percentile image compositing and use of additional contextual and machine learning methods. These improvements are detailed in section C.8.2.

C.2. Disturbance Sources

The first step to mapping annual disturbance is to gather and assemble all disturbance data inputs. LF has approached disturbance mapping as an iterative process throughout its many years of development; accordingly, numerous datasets and image interpretation procedures contribute to the final disturbance product. The general flow of input development for LF disturbance production is shown in figure C3. The general hierarchy of the input data from top to bottom and the disturbance codes associated with those methods of disturbance mapping are listed in table C1. Inputs detailed later in this chapter follow the hierarchy of how pixels get assigned a source; for example, MTBS has the highest priority and would be the source assigned along with its severity values if an MTBS disturbance were to overlay an image-based change detection using the RSLC process.

C.2.1. Fire Program Inputs

The fire program inputs to annual disturbance layers have historically been lumped in as events within the LF internal program vernacular; however, they are derived from remotely sensed datasets and LF uses them as such in the disturbance mapping process. They do not represent submitted event perimeters (table B1), as detailed in the Events Geodatabase part of chapter B. The products represent detected change and measures of severity via the differenced normalized burn ratio (dNBR; Key and others, 2002) and the relativized dNBR (Picotte and others, 2016). These ratios take advantage of the difference in spectral reflectance of green vegetation versus burned vegetation after a fire in different parts of the electromagnetic spectrum, specifically the near-infrared and shortwave infrared bands (see fig. C4). Some of the highest priority datasets come from national fire detection programs. These programs include MTBS (Eidenshink and others, 2007), BARC, and RAVG. These products are produced by the U.S. Geological Survey (USGS) for Department of the Interior lands and by the Geospatial Technology and Applications Center for U.S. Department of Agriculture (USDA) Forest Service (FS) lands.

C.2.1.1. Monitoring Trends in Burn Severity

The MTBS program is an interagency program run by the USGS and the USDA FS. It is national in scope and is released annually, with a 1-year delay after the summer fire season. The MTBS program only maps fires greater than 1,000 acres in the western United States and greater than 500 acres in the eastern United States. MTBS uses the dNBR to discern where fires are detected and includes a measure of the fire's severity along with other attributes for each fire. The type of ecosystem in which the fire is detected can determine whether MTBS creates initial assessments or extended assessments; for example, initial assessments are completed in grasslands and low-biomass shrublands where the burn signal is typically fleeting. These initial assessments compare prefire imagery to immediate postfire imagery to assign initial severity. MTBS also releases extended assessments with postfire imagery gathered during the growing season after the fire to understand long-term fire effects in forested areas and high-biomass shrublands. LF used all MTBS data for each mapped year once extended assessments were available for LF 2016 Remap. It is important to note that, to date, all MTBS fires before 2015 are recorded as wildfire and fires during or after 2015 are recorded as fire in the LF annual disturbance layers because MTBS perimeter data are not part of the Events Geodatabase.

C.2.1.2. Burned Area Reflectance Classification

The BARC products are created by the USDA FS and USGS and were designed to address immediate postfire effects, typically related to hydrological effects and soil burn severity (Clark, 2013). Methods of burned area detections are like MTBS, using dNBR to delineate the burned areas and gain a measure of burn severity; however, ground validation is typically completed soon after and adjustments to data are made accordingly. The BARC product is typically restricted to the Department of the Interior and USDA FS requests and on lands managed by these agencies but also includes State, local, private, and Department of Defense lands. There are few requests for BARC mapped fires in the eastern United States, so spatial coverage is limited.

C.2.1.3. Rapid Assessment of Vegetation Conditions After Wildfire

The RAVG product also is produced by the USDA FS and USGS and is designed for understanding the condition of the vegetation after a wildfire (RAVG, 2021). The USDA

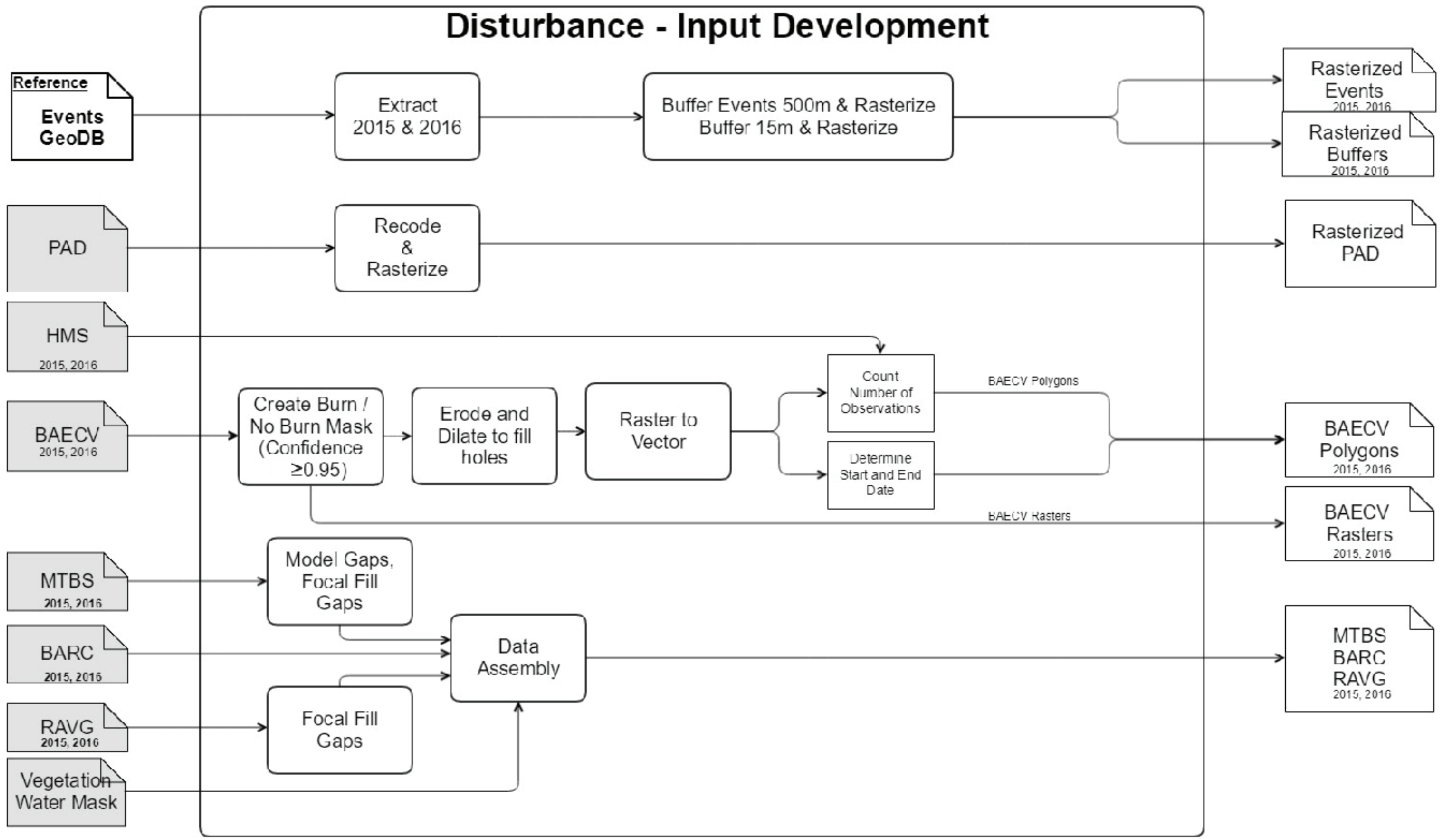


Figure C3. Workflow for disturbance inputs. [EventsGeoDB, Events Geodatabase; m, meter; PAD, Protected Areas Database; HMS, Hazard Mapping System; BAECV, Burned Area essential climate variable; ≥, greater than or equal to; MTBS, Monitoring Trends in Burn Severity; BARC, Burned Area Reflectance Classification; RAVG, Rapid Assessment of Vegetation Condition after Wildfire]

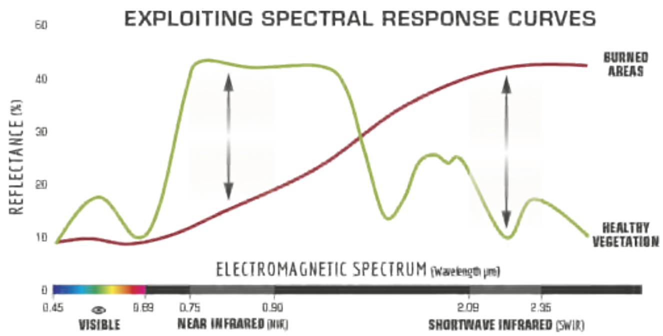


Figure C4. The normalized burn ratio uses the difference in reflectance for the near-infrared and shortwave infrared parts of the electromagnetic spectrum for healthy vegetation as compared to burned areas. Image courtesy of Wasser and Cattau (2022), licensed under the Creative Commons Attribution-Share Alike 4.0 International license. [%, percent; µm, micrometer]

FS and USGS create RAVG burn severity maps using the relativized dNBR and convert those outputs to loss of canopy cover, basal area, and other metrics designed for restoration efforts. Prefire RAVG vegetation information is aggregated from LF data. The RAVG program maps fires that are greater than 1,000 acres on USDA FS lands in the west and 500 acres in the east and uses Landsat and Sentinel imagery before and after a fire. Additional fires are mapped upon request.

C.2.1.4. Gap Filling and Focal Majority for Monitoring Trends in Burn Severity and Rapid Assessment of Vegetative Condition after Wildfire

MTBS commonly contained gaps in data when used during LF 2016 Remap because of the use of Landsat 7 data. Landsat 7 data scanlines are data gaps created because of the failure of the scanline corrector on the satellite. Clouds and water bodies are masked by MTBS analysts, which creates data gaps within MTBS perimeters in cloudy areas and along shorelines that do not align with the LF water mask. LF uses rule-based and predictive modeling with See5 classification trees to assign severity to no-data pixels that are within an MTBS perimeter to fill the data gaps. The models are trained by using pre- and postfire imagery or image composites and the severity data of the nongapped pixels in the fire. If modeling an MTBS fire was not practical (no adequate pre-/postimagery, for instance), a focal fill process was used instead. In such cases, the majority severity value in a 13 x 13 moving window of 30-m pixels was applied to the center pixel of the window. RAVG data gaps were filled using the focal majority method only and were not modeled. BARC data did not contain data gaps in 2016 or prior; therefore, neither focal filling nor modeling were required.

C.2.2. LANDFIRE Events Geodatabase

LF's Events Geodatabase is a stand-alone product delivered to the public and updated with each release (see chap. B); however, one of the main purposes for gathering event perimeters across the country each year in the LF program is to account for disturbance on the landscape, which directly feeds into disturbance mapping and affects how vegetation and fuels are mapped.

C.2.2.1. Events Geodatabase Preprocessing for Use in Annual Disturbance Mapping

To use the events in the Events Geodatabase to map annual disturbance, the model-ready events are first filtered to remove events covering less than 0.02 acre (less than one-tenth of a 30-m pixel). Disturbance processing of events includes selecting all event types excluding planting, seeding, and reforestation from the LF Events Geodatabase, buffering by 15 m to account for smaller linear events, and buffering by 500 m to help inform disturbances with unknown causality assignments. The events polygons are part of the prioritization process to assign causality and confirm disturbances detected by the RSLC process.

C.2.3. Remote Sensing for Landscape Change

Another important dataset with a high priority in the disturbance mapping methodology is the LF program's RSLC. The RSLC process consists of several steps and methods to detect different types of change on the landscape. It is important to remember that this process depends on the quality of image inputs along with the skill and consistency of LF image analysts. The process begins by defining the dates and location of the area being mapped. The mapping area is broken into a LF tile that typically represents a square of 10,000 x 10,000 pixels, with exceptions of larger and smaller tiles along the outside edges of the United States and insular area borders (fig. C5 for LF tiles in the contiguous United States; Nelson and Steinwand, 2015). If a Landsat scene intersects the location of the selected tile for the selected date range, it is downloaded, masked for clouds, assembled into a six-band image consisting of the three visible (one near-infrared and two shortwave infrared bands) processed to surface reflectance, and clipped to the tile boundary. The images are stacked and assembled into a composite image (see section C.2.3.1) to reduce the effects of data gaps from clouds and other artifacts commonly detected in single-scene images. The number of Landsat scenes processed for a tile varies based on tile size, location, and the number of years used in the composite.
In northern latitudes, the curvature of the Earth and path of the Landsat satellite results in more side overlap of scenes; therefore, more imagery must be downloaded in these areas.

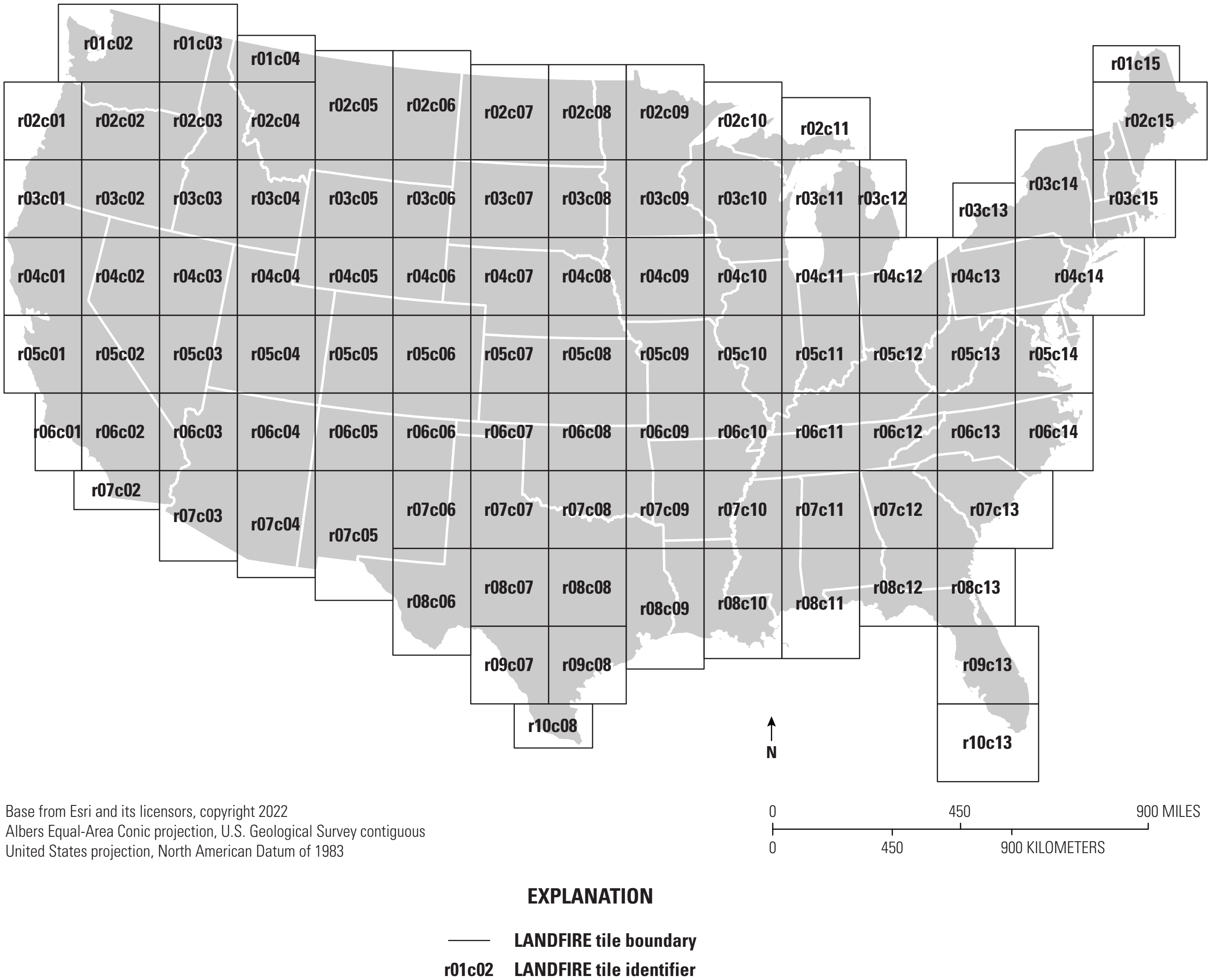


Figure C5. Tiling scheme for Landsat image processing within the LANDFIRE program. [r, row; c, column]

For a RSLC-based processing campaign, more than 90 percent of the tiles require the processing of 600–800 individual Landsat scenes.

Once the image composites are complete, they serve as inputs in creating common vegetation-based indices and other datasets that exploit the parts of the electromagnetic spectrum used to gauge the presence/absence of vegetation or its overall health (Rouse and others, 1974; Tucker, 1979). Some of the datasets commonly used from seasonal composites in LF include the differenced Normalized Difference Vegetation Index (dNDVI), Multi-Index Integrated Change Analysis (MIICA) algorithm, and dNBR. These datasets are differenced (year to year and by season) to produce change products used by the image analysts to locate disturbance.

C.2.3.1. Image Compositing Methods

C.2.3.1.1. Best Pixel

Clouds and anomalies from a lack of available data in raw Landsat imagery can be minimized through image compositing, as noted previously. The algorithm(s) used to create composited products are not static and have evolved over time, in part, because of faster processing capability using multithreaded, high-performance computing systems, improved data access, and software innovation. At the onset of LF 2016 Remap, the best pixel process developed by Nelson and Steinwand (2015) was the algorithm of choice (fig. C6). Best pixel works by using two date ranges per year: early and late. Early season consists of Landsat scenes ranging from day

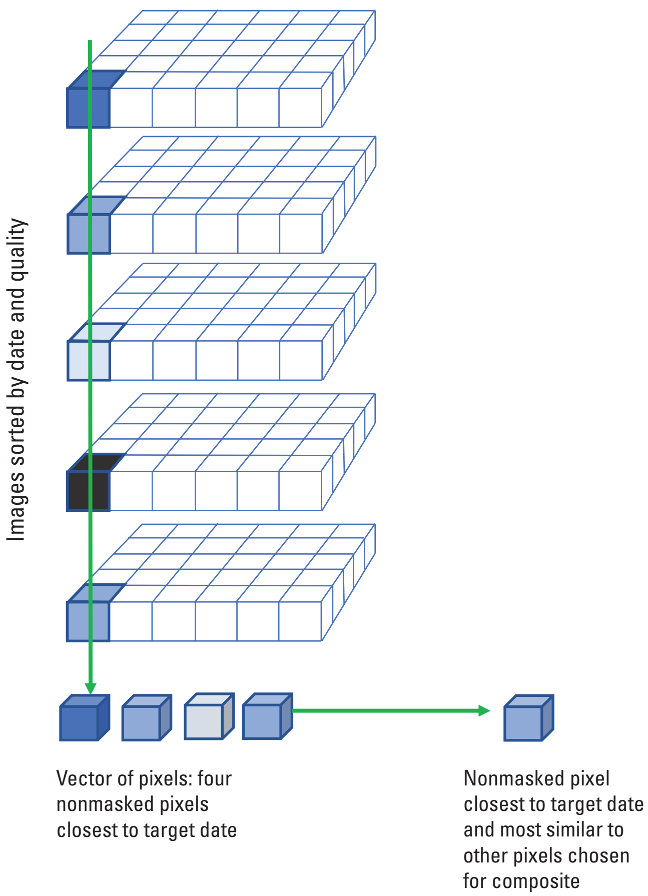


Figure C6. Best pixel similarity process. Black pixels are masked, and blue pixels are available for the best-pixel similarity process.

100 to day 199 with day 175 as the target date; late season ranges from day 200 to day 299 with a target day of 250. There are some adjustments to dates where seasonality is less pronounced, such as southern Florida and Texas. Details on the process of image ordering, converting to top of atmosphere reflectance, projecting, and tiling are available in Nelson and Steinwand (2015). In the best pixel algorithm, available nonmasked pixels are stacked by date. The five pixels closest to the target are then compared using a cosine similarity index. The final output pixel is chosen if it is considered most similar to the others. Three pixels are needed to complete the similarity test. If there are only one or two pixels, the one closest to the target date is selected. If there are no usable pixels in the stack, nothing is assigned, and a gap will be present.

C.2.3.1.2. Percentile Composite Remap

The best pixel compositing process is reliant on the availability of nonmasked pixels around the target date. In the contiguous United States, the process worked well in most areas; however, in certain locations, getting enough cloud-free pixels to yield a quality composite image can be difficult. Areas in the northern and Great Lakes States, the northeastern United States, Alaska, and the island regions, are perpetually troublesome; for example, in Alaska, the lack of cloud-free imagery combined with best pixel processing resulted in large areas of no data or poor-quality data that were considered unsuitable for large parts of the State. Consequently, a band-by-band percentile compositing approach was developed and implemented. This method takes a stack of Landsat images and selects the value closest to the 50th percentile of all cloud-free pixels in the entire stack rather than being tied to a specific target date. In other words, about 50 percent of the reflectance values are less than or greater than the output value (see fig. C7). The percentile composite method is completed pixel by pixel and band by band for every tile in the stack; therefore, the method is more computationally intensive than the best pixel process. The percentile composite approach was used on Harmonized Landsat Sentinel-2 (Claverie and others, 2018) data for Alaska, resulting in composites more spectrally consistent and with fewer data gaps than best pixel composites. The date range of the image stack in the percentile composite was adjusted for higher latitudes, but all cloud-free imagery within the range was used to rank the reflectance of the pixel.

C.2.3.2. Indices and Modeling for Disturbance Detection

Once imagery for early and late season dates for the 5 years are composited (that is, 10 total composites per tile), derivative datasets such as vegetation (dNDVI), moisture using the difference between images of the Normalized Difference Moisture Index (dNDMI), dNBR, severity, and other change detection products (such as MIICA) are created and used as inputs to machine learning models and as additional data layers used by image analysts to detect disturbances on each tile.

Effective at assigning severity to postburn fire scars, dNBR, as explained previously under MTBS, also is effective at identifying general changes in vegetation. For the RSLC process, LF produces composite-derived dNBR imagery year to year and by season (early and late growing season). This same process is used to produce the dNDVI and dNDMI. Both are similar in context to the dNBR but use alternative bands to tease out subtle differences in vegetation vigor and moisture. Severity products are used to find disturbance and assign a severity value of low, medium, or high for all disturbances. Severity is calculated from dNBR-based average and standard deviation (STD) breaks derived from the seasonal image composites. For early and late seasons, a dNBR raster using predisturbance and postdisturbance composite images, and a dNBR raster using composite images from the predisturbance year and two years postdisturbance are created. Ultimately, the maximum STD from the four dNBR datasets gets the assigned severity value as follows:

- STD greater than (>) 3 = high severity;

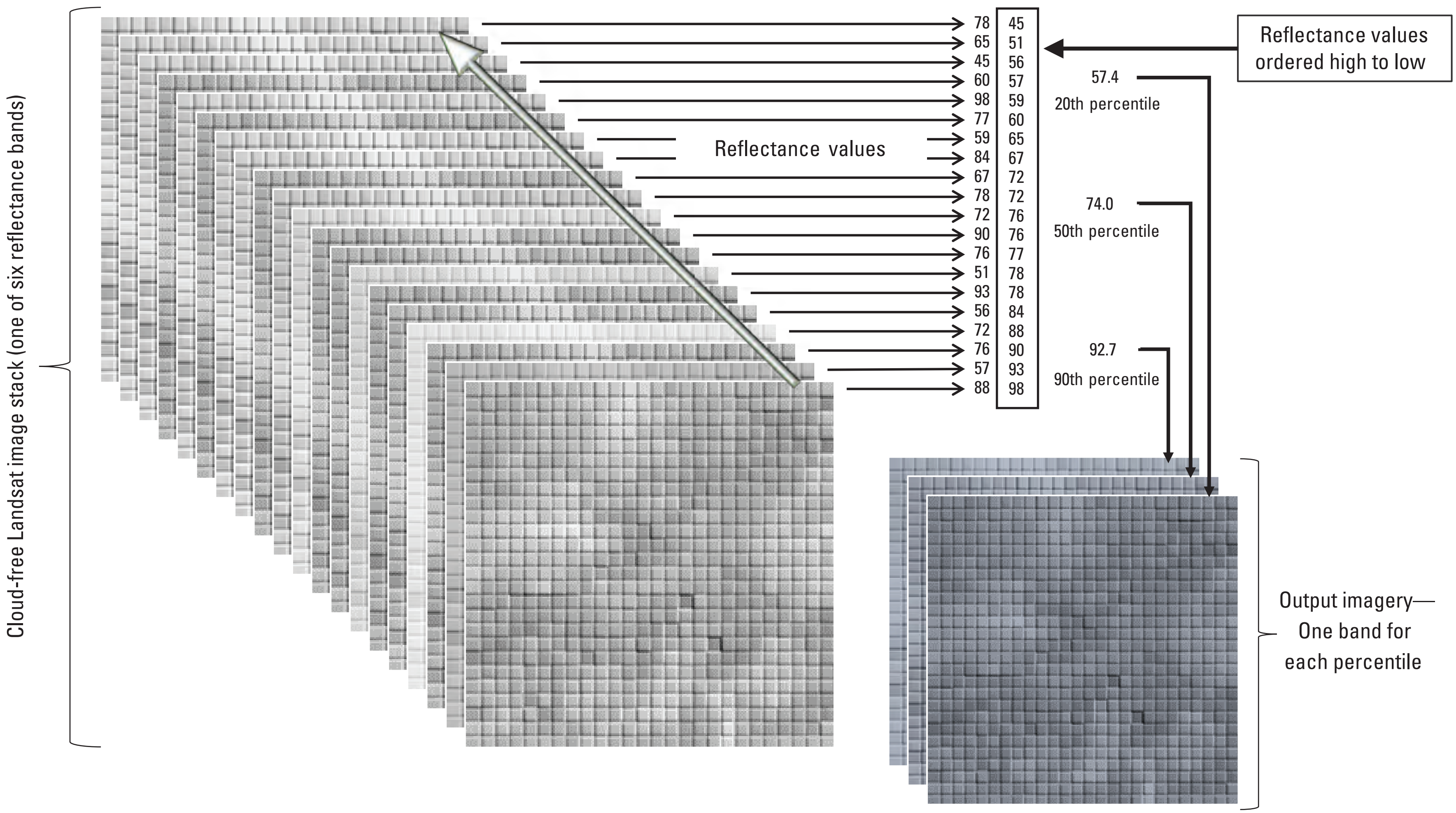


Figure C7. Cloud-free Landsat image stack.

- STD>2 and maximum STD less than (<) 3 = medium severity;
- STD>average and <2 = low severity; and
- STD<average = 0.

The 2-year postdisturbance dNBR is needed for cases where the actual disturbance is not detected in the composite imagery until the year after it occurred. This delay happens occasionally when event-based disturbances are mislabeled or a disturbance occurs during winter months (for example, November/December) when imagery is either unavailable or masked by snow.

C.2.3.2.1. Multi-Index Integrated Change Analysis

The MIICA index is the primary process that LF leverages to detect change between two dates (Jin and others, 2013). It integrates four indices to determine change: dNBR, dNDVI, change vector (CV), and relative change vector (RCVMAX). The CV captures the total spectral change of all bands from one date to the next, and the RCVMAX captures the relative change of all the bands across the area of interest. The CV and RCVMAX indices do not inform the direction of change, which can indicate either a loss or a gain in live biomass; therefore, dNBR and dNDVI also are used as part of integrating the four ranked indices into a change map. These indices contribute to the final change detection maps, which depict either biomass increase or biomass decrease (fig. C8); however, the LF image analyst uses only the biomass decrease information from the MIICA process.

An example of a combined MIICA layer is provided in table C2. It classifies the MIICA outputs for each imagery date so that the image analyst can see whether one or both dates demonstrate a decrease in vegetation.

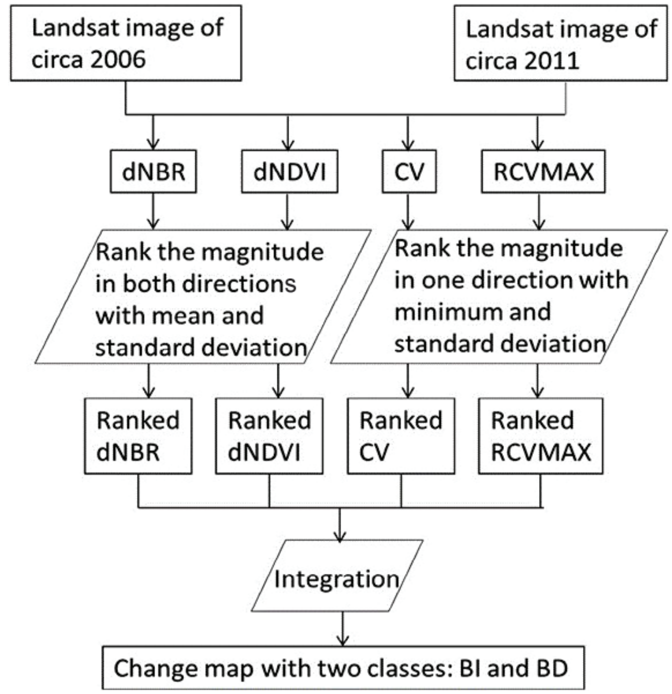


Figure C8. The four indices of the Multi-Index Integrated Change Analysis process combining for two change maps (from Jin and others [2013]). [dNBR, differenced normalized burn ratio; dNDVI, differenced Normalized Difference Vegetation Index; CV, change vector; RCVMAX, relative change vector; BI, biomass increase; BD, biomass decrease]

C.2.3.2.2. XGBoost—Machine Learning for Disturbance

In addition to the MIICA process, LF team members developed a machine learning process using XGBoost that uses disturbances identified in the MIICA product to help identify the disturbances within a tile. XGBoost is a

Table C2. Multi-Index Integrated Change Analysis combined legend for image analysis.

[MIICA, Multi-Index Integrated Change Analysis]

Output value	What it means
0	Neither = 2 (decreased green) or 10 (cloud)
1	Day 250 MIICA = 2 (decreased green)
2	Day 175 MIICA = 2 (decreased green)
3	Both day 175 and day 250 = 2 (decreased green)
4	Day 250 MIICA = 10 (cloud)
5	Not a possible combination
6	Day 250 MIICA = 10 (cloud) and day 175 MIICA = 2 (decreased green)
7	Not a possible combination
8	Day 175 MIICA = 10 (cloud)
9	Day 250 MIICA = 2 (decreased green) and day 175 MIICA = 10 (cloud)
10	Not a possible combination
11	Not a possible combination
12	Day 175 MIICA = 10 (cloud) and day 250 MIICA = 10 (cloud)

gradient-boosted decision tree algorithm that represents a way to decrease the amount of time it takes for the algorithm to "learn" by using weak relations. Pixel locations were randomly identified for training data locations in each LF MIICA tile wwithin disturbed areas (number of samples = 10,000) and outside of disturbed areas (number of samples = 40,000) for each disturbance year. Pixel values from each of the six image composite bands in the predisturbance year imagery and postdisturbance year imagery for day 175 and 250 LF image composites were extracted for each of the training data locations. Binary (disturbed/undisturbed) XGBoost models were then developed on a per tile basis using these pre- and postdisturbance LF composite data as a data source for identifying disturbance. These models were subsequently applied to the current and previous years' LF day 175 and 250 composite data (fig. C9).

C.2.3.3. Burned Area Essential Climate Variable

The Landsat Burned Area essential climate variable (BAECV), a USGS product, was used in conjunction with a value-added sensor data process for LF 2016 Remap. The BAECV algorithm uses the time series of Landsat data with an automated algorithm to identify burned areas using seven Landsat bands, Normalized Difference Vegetation Index, Normalized Difference Moisture Index, Normalized Differenced Water Index, tasseled-cap greenness and wetness, and normalized burn ratio as predictor variables in a gradient-boosted regression model (a sequential Classification And Regression Trees model process weighted with the residuals from previous Classification And Regression Trees models in the sequence) that was trained with confirmed MTBS fire perimeters (Hawbaker and others, 2017). The BAECV product outputs included a burn probability (BP) layer that LF used as a cutoff for assigning disturbance classes; for example, if the BP was >95 percent, then it could be assumed that a fire had occurred. This was informative for assigning disturbance type if the RSLC process detected an unknown disturbance with no overlying event perimeter.

The USGS BAECV product, although helpful for assigning fire as a probable cause to RSLC-detected disturbance, contained false positives that needed to be filtered out; hence, LF developed a value-added procedure that uses Hazard Mapping System (Ruminski and others, 2006) derived Moderate resolution Imaging Spectroradiometer, Visible and Infrared Imager Radiometer Suite, and Geostationary Operational Environmental Satellite active fire detections to corroborate the date and location of a disturbance. Specifically, BAECV pixels with a BP greater than or equal to 95 percent were polygonised then spatially intersected and temporally compared with the active fire detections. Each polygon was assigned the number of detections from the other three sensors within the previous 60 days; therefore, the higher the number of detections, the more likely the fire occurred. Image analysts used the value-added sensor-enhanced BAECV data along with the MIICA combined and XGBoost modeled disturbance to further classify the likelihood that a fire had occurred. For LF disturbance detection, the BAECV product with the added sensor data information adds confidence in identifying "unknown" disturbances as fire caused. This information is used when assigning fuels because these "unknown" disturbances with enhanced BAECV data get classified as fire in FDist and in the application of the fuel rules (see table C1).

C.2.3.4. Protected Areas Database

To label potential causality for as many disturbances on the landscape as possible, the LF team uses the USGS Protected Areas Database (PAD) in conjunction with BAECV data. The PAD dataset delineates all forms of protected land including Federal, State, municipal, and nonprofit lands on which some form of protection is assigned (U.S. Geological Survey, 2018). The form of protection can vary from 1 to 4 based on Gap Analysis Project status codes (table C3). PAD version 2.0 was used for LF 2016 Remap disturbance mapping.

The PAD Gap Analysis Project status code was separated into two categories based on consultation with PAD creators for LF 2016 Remap. One category consists of status codes 1 and 2. This category assumes that anthropogenic disturbances are not expected in these areas. Codes 3 and 4 were interpreted in the disturbance process as possibly having events that were human caused. These areas were separated out for subsequent use in aggregated FDist categories.

C.2.3.5. Image Analyst Review

Once all the indices, MIICA-based data, and modeled outputs are created, the disturbance mapping process moves to the image analyst. The analyst uses combinations of all the aforementioned data sources to either add or remove change pixels based on the preponderance of evidence. This work

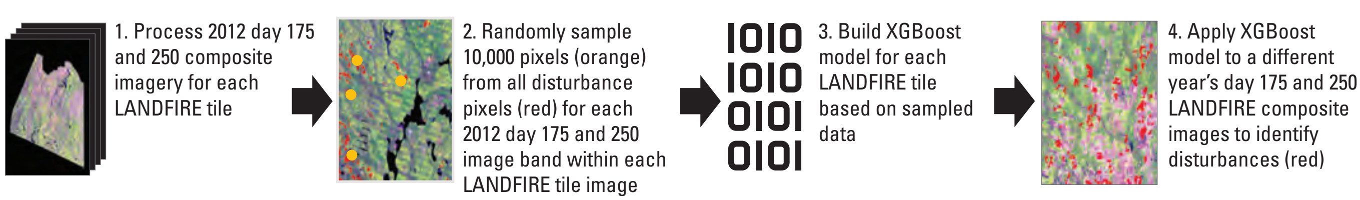


Figure C9. XGBoost application steps.

Table C3. Gap Analysis Project status codes used in LANDFIRE disturbance mapping.

Code	Description
1	Managed for biodiversity—disturbance events proceed or are mimicked.
2	Managed for biodiversity—disturbance events are suppressed.
3	Managed for multiple uses—subject to extractive (for example, mining or logging) or off highway vehicle use.
4	No known mandate for biodiversity protection.

is done while moving methodically across each tile using a grid overlay and requires familiarity with all data products processed or created by LF for disturbance mapping and attention to detail. If a disturbance is still under question, high-resolution Google Earth imagery is referenced to help determine whether a disturbance occurred in each scrutinized location. This process is applied to all tiles in the contiguous United States for each year of disturbance.

There are some differences outside of the contiguous United States as to which areas included certain steps in the disturbance mapping process. The RSLC process was used in Alaska for 2015 and 2016 but not for any other disturbance years. Other disturbance years used only fire program data and events in Alaska. Puerto Rico used RSLC in 2015 and 2016. Other Pacific Islands used only events when available.

C.3. Disturbance Type Confidence

Each disturbance type for LF annual disturbance is labeled with its associated confidence level as high, medium, or low. The confidence level of the disturbance type depends on the disturbance mapping methods; for example, for an MTBS wildfire, mappers are highly confident of that disturbance type label because of the vetting within the MTBS program, whereas a disturbance type derived from imagery-based RSLC change within 500 m of an event perimeter is labeled as medium confidence because the event does not directly overlay the image-based change.

C.4. Severity Sources and Confidence

Severity levels in LF annual disturbance layers are described as high, medium, low, unburned/low, and increased green; the latter two are derived from the fire program data. Each severity descriptor also has a confidence level associated with it depending on the disturbance mapping method that it was derived from; for example, MTBS, BARC, RAVG, and dNBR all have estimates of severity. Depending on the method of disturbance mapping, the confidence in the severity estimate could be high, medium, or low (table C4). MTBS, BARC, and RAVG are considered vetted sources, so they all receive a high rating under the severity confidence attribute.

C.5. Annual Disturbance

The 2015 and 2016 annual disturbance layers in LF 2016 Remap have 336 legend items accounting for all methods of disturbance detection and associated attributes detailed in this chapter. Each legend item includes the disturbance year, the disturbance type, the confidence in the disturbance type, the severity, the severity source, the confidence in the severity, as many as four disturbance sources, and a detailed description of how the disturbance for each 30-m pixel was derived from the given source, combination of sources, or processes (see https://landfire.gov/library_list.php?cat=1 for full annual disturbance legend [in comma-separated value file format]). When a user downloads LF 2016 Remap disturbance data for the contiguous United States, they receive a raster layer with a unique identifier for each pixel related to the 336 legend values. The detail provided in the legend gives users the ability to aggregate or show the data as they wish; for example, a disturbance layer with pixels filtered to show only severities where confidence in the source of the severity is high would largely consist of MTBS, BARC, and RAVG data. The prioritization process in which a disturbance mapping method takes precedence before another mapping method for a given pixel is represented by the order of the legend items, with lower legend values taking priority before higher ones if coexisting disturbances happen; for example, value 11 trumps value 711, so if both methods of detection were attributed to the same pixel, the final annual disturbance layer would list an 11 for that pixel.

C.6. Aggregate Disturbance Products

HDist aggregates the last 10 years of annual disturbances into one layer. This means that primarily the latest disturbance is shown for each pixel (but see disturbance type hierarchy details in FDist section E.4.1) along with its associated annual disturbance attributes. Several criteria such as illogical combinations of existing vegetation type and disturbance type are filtered from the annual disturbance layers during the creation of 10-year HDist. Examples include fire overlapping water or a wind event in herbaceous lifeforms. The year of disturbance is included for each pixel in HDist along with an FDist code listed in the HDist attribute table (table C5). The FDist code refers to the disturbance type, severity, and TSD (time since 2016 in the LF 2016 Remap HDist). These FDist codes

Table C4. Disturbance type and disturbance type confidence for different methods of disturbance mapping in LANDFIRE.

[BARC, Burned Area Reflectance Classification; MTBS, Monitoring Trends in Burn Severity; RAVG, Rapid Assessment of Vegetation Condition after Wildfire; m, meter; PAD, Protected Areas Database; GAP, Gap Analysis Project; BAECV, Burned Area essential climate variable; ≥, greater than or equal to; %, percent; <, less than; > greater than]

Disturbance type	Description
	High confidence
Wildfire	BARC mapped wildfire.
Wildfire	MTBS gap (value=6) filled with 13 x 13 focal majority matrix.
Wildfire	MTBS gap (value=6) filled with See5 classified output.
Wildfire	MTBS mapped water body or other nonmappable land cover type inside a fire polygon.
Wildfire	MTBS-mapped wildfire.
Wildfire	RAVG gap (value=9) filled with 13 x 13 focal majority matrix.
Wildfire	RAVG-mapped wildfire.
Clearcut	Landsat image-based change detection identified disturbance within clearcut LANDFIRE Events Geodatabase polygon.
Development	Landsat image-based change detection identified disturbance within development LANDFIRE Events Geodatabase polygon.
Harvest	Landsat image-based change detection identified disturbance within harvest LANDFIRE Events Geodatabase polygon.
Mastication	Landsat image-based change detection identified disturbance within mastication LANDFIRE Events Geodatabase polygon.
Mechanical	Landsat image-based change detection identified disturbance within other mechanical LANDFIRE Events Geodatabase polygon.
Prescribed fire	Landsat image-based change detection identified disturbance within prescribed fire LANDFIRE Events Geodatabase polygon.
Thinning	Landsat image-based change detection identified disturbance within thinning LANDFIRE Events Geodatabase polygon.
Wildfire	Landsat image-based change detection identified disturbance within wildfire LANDFIRE Events Geodatabase polygon.
Wildland fire	Landsat image-based change detection identified disturbance within wildland fire LANDFIRE Events Geodatabase polygon.
Wildland fire use	Landsat image-based change detection identified disturbance within wildland fire use LANDFIRE Events Geodatabase polygon.
Development	Within development LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
Mastication	Within mastication LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
Mechanical	Within other mechanical LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
Prescribed fire	Within prescribed fire LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
Wildfire	Within wildfire LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
Wildland fire	Within wildland fire LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
Wildland fire use	Within wildland fire use LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
	Medium confidence
Clearcut	Clearcut causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within clearcut LANDFIRE Events Geodatabase 500-m buffer).

Table C4. Disturbance type and disturbance type confidence for different methods of disturbance mapping in LANDFIRE.—Continued

[BARC, Burned Area Reflectance Classification; MTBS, Monitoring Trends in Burn Severity; RAVG, Rapid Assessment of Vegetation Condition after Wildfire; m, meter; PAD, Protected Areas Database; GAP, Gap Analysis Project; BAECV, Burned Area essential climate variable; ≥, greater than or equal to; %, percent; <, less than; > greater than]

Disturbance type	Description
	Medium confidence—Continued
Development	Development causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within development LANDFIRE Events Geodatabase 500-m buffer).
Harvest	Harvest causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within harvest LANDFIRE Events Geodatabase 500-m buffer).
Biological	Landsat image-based change detection identified disturbance within biological LANDFIRE Events Geodatabase polygon.
Chemical	Landsat image-based change detection identified disturbance within chemical LANDFIRE Events Geodatabase polygon.
Herbicide	Landsat image-based change detection identified disturbance within herbicide LANDFIRE Events Geodatabase polygon.
Insects	Landsat image-based change detection identified disturbance within insects LANDFIRE Events Geodatabase polygon.
Mastication	Mastication causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within mastication LANDFIRE Events Geodatabase 500-m buffer).
Mechanical	Other Mechanical causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within development LANDFIRE Events Geodatabase 500-m buffer).
Prescribed fire	Prescribed Fire causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within prescribed fire LANDFIRE Events Geodatabase 500-m buffer).
Thinning	Thinning causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within thinning LANDFIRE Events Geodatabase 500-m buffer).
Wildfire	Wildfire causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within wildfire LANDFIRE Events Geodatabase 500-m buffer).
Wildland fire	Wildland Fire causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within wildland fire LANDFIRE Events Geodatabase 500 -m buffer).
Wildland fire use	Wildland Fire Use causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within wildland fire use LANDFIRE Events Geodatabase 500-m buffer).
Biological	Within biological LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
Chemical	Within chemical LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
Disease	Within disease LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
Herbicide	Within herbicide LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
Insects	Within insects LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
Weather	Within weather LANDFIRE Events Geodatabase polygon, but no change identified by Landsat image-based change detection. Severity default of low.
	Low confidence
Biological	Biological causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within biological LANDFIRE Events Geodatabase 500-m buffer).
Chemical	Chemical causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within chemical LANDFIRE Events Geodatabase 500-m buffer).
Herbicide	Herbicide causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within herbicide LANDFIRE Events Geodatabase 500-m buffer).

Table C4. Disturbance type and disturbance type confidence for different methods of disturbance mapping in LANDFIRE.—Continued

[BARC, Burned Area Reflectance Classification; MTBS, Monitoring Trends in Burn Severity; RAVG, Rapid Assessment of Vegetation Condition after Wildfire; m, meter; PAD, Protected Areas Database; GAP, Gap Analysis Project; BAECV, Burned Area essential climate variable; ≥, greater than or equal to; %, percent; <, less than; > greater than]

Disturbance type	Description
	Low confidence—Continued
Insects	Insect causality likely but could be other causality type than assigned (Landsat image-based change detection pixels within insects LANDFIRE Events Geodatabase 500-m buffer).
	No disturbance type assigned/unknown
Unknown (probable fire)	Landsat image-based change detection identified change (outside LANDFIRE Events Geodatabase 500-m buffer, PAD GAP status=0). BAECV greater than burn/no burn threshold (≥95%).
Unknown	Landsat image-based change detection identified change (outside LANDFIRE Events Geodatabase 500-m buffer, PAD GAP status=0). BAECV less than burn/no burn threshold (<95%).
Unknown	Landsat image-based change detection identified change (outside LANDFIRE Events Geodatabase 500-m buffer, PAD GAP status=1 or 2). BAECV greater than burn/no burn threshold (≥95%).
Unknown (probable fire)	Landsat image-based change detection identified change (outside LANDFIRE Events Geodatabase 500-m buffer, PAD GAP status=3 or 4). BAECV greater than burn/no burn threshold (≥95%).
Unknown	Landsat image-based change detection identified disturbance. Anthropogenic causality likely but unknown (outside LANDFIRE Events Geodatabase 500-m buffer, PAD GAP status equals 3 or 4). BAECV less than burn/no burn threshold (>95%).
Unknown	Landsat image-based change detection identified disturbance. Anthropogenic causality not expected (outside LANDFIRE Events Geodatabase 500-m buffer, PAD GAP status equals 1 or 2). BAECV less than burn/no burn threshold (>95%).

Table C5. Example of wildfire recoding from historical disturbance attribute table.

[FDist code, refers to the disturbance type, severity, and time since disturbance (2016)]

Historical disturbance identifier	Disturbance code value	Disturbance type	Historical disturbance year	FDist code
20160011	11	Wildfire	2016	111
20160012	12	Wildfire	2016	111
20160013	13	Wildfire	2016	121
20160014	14	Wildfire	2016	131
20160015	15	Wildfire	2016	111
20160021	21	Wildfire	2016	111
20160022	22	Wildfire	2016	111
20160023	23	Wildfire	2016	121
20160024	24	Wildfire	2016	131
20160031	31	Wildfire	2016	111
20160032	32	Wildfire	2016	111

are subsequently adjusted for time since 2019 or 2020 in the stand-alone capable year LF 2016 Remap FDist rasters (see chap. E for more information on capable FDist layers).

C.7. LANDFIRE 2019 Limited Annual Disturbance Approach

The LF 2019 Limited versions of annual disturbance layers for the contiguous United States were derived exclusively from submitted events polygons in the Events Geodatabase and the fire program data. No RSLC processes were applied; therefore, the LF 2019 Limited versions of 2017–19 annual disturbance layers represented a limited, less comprehensive version of disturbance than LF typically releases for annual disturbance. These limited annual disturbance layers were not released to the public in anticipation of more complete versions with LF 2020. They were used only within the LF production flow to create FDist and update vegetation and fuels layers using established rulesets. This limited disturbance information helped to provide an interim product for users, accounting for most of the disturbances between 2017 and 2019 with known causes only 1 year after the LF 2016 Remap release.

C.8. LANDFIRE 2020 Annual Disturbance Update Approach

C.8.1. Disturbance Sources

LF 2020 contains events, fire program data, and LF's RSLC change detection processes for 2017–20. Disturbance source information for LF 2020 used initial assessments from MTBS for large fires that were available at the time of 2020 annual disturbance production rather than extended assessments used for large fires in previous years. The LF 2020 annual disturbance layers for 2017–19 supersede the LF 2019 Limited versions for those same years because they include the additional RSLC and image analyst processes for disturbance review, which is a more comprehensive disturbance accounting than the limited versions. LF 2020 also contains an additional year of annual disturbance (2020) using the full range of LF disturbance mapping sources and detection methods.

C.8.2. Remote Sensing of Landscape Change Refinements

C.8.2.1. Percentile Composite

Differences for LF 2020 in the percentile composite process included the addition of 20th percentile and 90th percentile composites. These percentiles tend to highlight different types of disturbance, where changes in persistently low values of reflectance are more obvious within dNBR composites and changes with persistently high reflectance values are more indicative of vegetation changes within dNDVI composites. This can help image analysts identify disturbances when median reflectance values are not clear. Additionally, percentile MIICA composites were created (see MIICA details in section C.2.3.2.1), which also helps to identify disturbances.

C.8.2.2. Supervised Reclassification

Use of aggregated seasonal MIICA disturbance products results in lower omission errors but yields higher commission errors as well. To reduce these commission errors, additional kinds and sources of information that were not leveraged in previous LF disturbance mapping processes (such as spatial change probabilities [Kumar and others, 2020]) have been computed. Parameterized as Z scores, these represent the statistical deviation between observations of a disturbed pixel and its local undisturbed neighboring pixels. Three such Z scores were computed using dNBR, dNDVI, and dNDMI observations that are known to be sensitive to vegetation disturbances.

In addition to these spatial change probabilities, a suite of multitemporal (seasonal and annual) pre-/postdisturbance observations with their corresponding spectral bands and indices also were included as predictor variables in a random forest model. The random forest model was trained in a tile-wise fashion using the final analyst's reviewed LF disturbances maps from the previous year. The random forests model is then applied to the current year (or year of interest) to classify the tile-wise aggregated seasonal MIICA detections as disturbance or errors of commission. Efforts to include other sources of disturbances, including thresholding different indices using analysts' prior experiences and supplementing MIICA detection(s) with different percentile composites of seasonal observations, are being developed. The supervised reclassification of MIICA detections using the previously described methods has been shown to reduce commission errors by more than 90 percent in some regions.

C.8.2.3. Modified Burned Area Product

For LF 2020, the BAECV product was improved using analysis ready data from Landsat, machine learning and image segmentation, and the name changed to the Burned Area layer (Hawbaker and others, 2020). The new Burned Area product was received as a polygon layer with BP thresholds as an attribute. The value-added sensor data process was applied to the Burned Area product for use by image analysts for the Burned Area years available at the time of production.

C.9. Conclusion

The annual disturbance data layer is a highly detailed dataset using multiple methods to detect and label disturbance occurrences along with severity, source, and confidence measures. It has evolved through time to use the best available data sources, image processing capabilities, and detection methods. Much of the annual disturbance process is focused on image interpretation of the RSLC products, and image interpreters are trained to calibrate their interpretations to each other by peer review of tiles. Automated disturbance detections typically work well in some ecosystems and worse in other ecosystems, which makes image interpretation an important and necessary component of the LF annual disturbance production process.

The detailed legend values for annual disturbance layers get aggregated at later stages within LF production when disturbance gets incorporated into vegetation and fuels mapping using HDist and FDist; however, the detail within the annual disturbance legend can be used for distinguishing data confidence levels, distinguishing severity confidence levels, or comparing data sources. The importance of recording this kind of detailed information within the disturbance layers is evident given stakeholders' interest and need for this type of data. For further information, please reference the LF website (https://www.landfire.gov).

C.10. References Cited

Clark, J., 2013, Remote sensing and geospatial support to burned area emergency response (BAER) teams in assessing wildfire effects to hillslopes, in Margottini, C., Canuti, P., and Sassa, K., eds., Landslide science and practice: Berlin, Heidelberg, Springer, p. 211–215, accessed October 26, 2021, at https://doi.org/10.1007/978-3-642-31337-0_27.

Claverie, M., Ju, J., Masek, J.G., Dungan, J.L., Vermote, E.F., Roger, J.-C., Skakun, S.V., and Justice, C., 2018, The Harmonized Landsat and Sentinel-2 surface reflectance dataset: Remote Sensing of Environment, v. 219, p. 145–161. [Also available at https://doi.org/10.1016/j.rse.2018.09.002.]

Eidenshink, J., Schwind, B., Brewer, K., Zhu, Z., Quayle, B., and Howard, S., 2007, A project for monitoring trends in burn severity: Fire Ecology, v. 3, no. 1, p. 3–21. [Also available at https://doi.org/10.4996/fireecology.0301003.]

Hawbaker, T.J., Vanderhoof, M.K., Beal, Y.-J., Takacs, J.D., Schmidt, G.L., Falgout, J.T., Williams, B., Fairaux, N., Caldwell, M., Picotte, J., Howard, S., Stitt, S., and Dwyer, J.L., 2017, Mapping burned areas using dense time-series of Landsat data: Remote Sensing of Environment, v. 198, p. 504–522. [Also available at https://doi.org/10.1016/j.rse.2017.06.027.]

Hawbaker, T.J., Vanderhoof, M.K., Schmidt, G.L., Beal, Y.J., Picotte, J.J., Takacs, J.D., Falgout, J., and Dwyer, J.L., 2020, The Landsat Burned Area algorithm and products for the conterminous United States: Remote Sensing of Environment, v. 244, art. 111801, accessed October 26, 2021, at https://doi.org/10.1016/j.rse.2020.111801.

Jin, S., Yang, L., Danielson, P., Homer, C., Fry, J., and Xian, G., 2013, A comprehensive change detection method for updating the National Land Cover Database to circa 2011: Remote Sensing of Environment, v. 132, p. 159–175. [Also available at https://doi.org/10.1016/j.rse.2013.01.012.]

Key, C.H., Benson, N.C., Coffelt, J.L., and Livingston, R.K., 2002, Post-fire burn assessment by remote sensing on National Park Service lands, appendix D of Coffelt, J.L., and Livingston, R.K., 2002, Second U.S. Geological Survey wildland fire workshop—Los Alamos, New Mexico, October 31–November 3, 2000: U.S. Geological Survey Open-File Report 2002–0011, p. 56. [Also available at https://doi.org/10.3133/ofr0211.]

Kumar, S., Picotte, J., Tolk, B., Dittmeier, R., La Puma, I.P., Peterson, B., and Hatten, T., 2020, A spatially adaptive filter for error reduction in satellite-based change detection algorithms: American Geophysical Union, Fall meeting 2020, abstract B034–0001.

Nelson, K.J., and Steinwand, D., 2015, A Landsat data tiling and compositing approach optimized for change detection in the conterminous United States: Photogrammetric Engineering and Remote Sensing, v. 81, no. 7, p. 573–586. [Also available at https://doi.org/10.14358/PERS.81.7.573.]

Picotte, J.J., Peterson, B., Meier, G., and Howard, S.M., 2016, 1984–2010 trends in fire burn severity and area for the conterminous US: International Journal of Wildland Fire, v. 25, no. 4, p. 413–420. [Also available at https://doi.org/10.1071/WF15039.]

RAVG, 2021, Rapid Assessment of Vegetation Condition after Wildfire: National Wildfire Coordinating Group web page, accessed May 1, 2023, at https://burnseverity.cr.usgs.gov/ravg/.

Rouse, J.W., Jr., Haas, R.H., Deering, D.W., Schell, J.A., and Harlan, J.C., 1974, Monitoring the vernal advancement and retrogradation (green wave effect) of natural vegetation: College Station, Tex., Remote Sensing Center, 390 p.

Ruminski, M., Kondragunta, S., Draxler, R., and Zeng, J., 2006, Recent changes to the hazard mapping system: Proceedings of the 15th International Emission Inventory Conference, New Orleans, La., May 15–18, 2006, session 10 [presentation].

Tucker, C.J., 1979, Red and photographic infrared linear combinations for monitoring vegetation: Remote Sensing of Environment, v. 8, no. 2, p. 127–150. [Also available at https://doi.org/10.1016/0034-4257(79)90013-0.]

U.S. Geological Survey, 2018, Protected Areas Database of the United States (PAD-US): U.S. Geological Survey data release, accessed October 26, 2021, at https://doi.org/10.5066/P955KPLE.

Vogelmann, J.E., Kost, J.R., Tolk, B., Howard, S., Short, K., Chen, X., Huang, C., Pabst, K., and Rollins, M.G., 2010, Monitoring landscape change for LANDFIRE using multi-temporal satellite imagery and ancillary data: IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, v. 4, no. 2, p. 252–264. [Also available at https://doi.org/10.1109/JSTARS.2010.2044478.]

Wasser, L., and Cattau, M., 2022, Lesson 4—Work with the difference Normalized Burn Index—Using spectral remote sensing to understand the impacts of fire on the landscape: Earth Lab web page, accessed December 15, 2022, at https://www.earthdatascience.org/courses/earth-analytics/multispectral-remote-sensing-modis/normalized-burn-index-dNBR/.

Chapter D. Vegetation Mapping

By Daryn Dockter,[1] Inga P. La Puma,[1] Erica J. Degaga,[1] and James L. Smith[2]

D.1. Introduction/Background

D.1.1. The Need for LANDFIRE Vegetation Maps

The classification of vegetation type, cover, and height for every 30-meter (m) pixel on the landscape is critical for numerous user groups, including those involved in climate science, habitat assessment, and fire. Within the LANDFIRE (LF) production flow, vegetation layers, once created, are used as a base layer to assign surface fuel models and canopy characteristics to each undisturbed pixel and to inform disturbed fuels. Researchers regularly use LF's comprehensive, wall-to-wall vegetation layers for the United States. LF vegetation maps have been used to evaluate the effects of fire on ecosystems and have helped researchers understand how different an ecosystem is now versus pre-European arrival (Macfarlane and others, 2017). A few recent studies include an evaluation of management objectives based on existing vegetation type (EVT), pinpointing areas in need of restoration (Carter and others, 2021) and using vegetation groups to assign fuel-bed loads and biomass for different vegetation strata (Prichard and others, 2019).

D.1.2. LANDFIRE Vegetation Mapping Background

Vegetation mapping in the LF program began in 2001 with the first base map, LF National, released in 2009 (Rollins, 2009). Numerous updates have been completed since 2009 using a set of rules based on disturbance type, severity, and time since disturbance (TSD) to determine vegetation change and basic growth expectations. For forest types, the rules used Forest Vegetation Simulator regional outputs to transition vegetation type, cover, and height; for herbs and shrubs, general rules were designed to apply to many vegetation types (Dixon, 2002; LANDFIRE, 2008). These rules were used for LF updates until LF 2014. A key tenant of LF mapping has been to keep up with the latest scientific advancements of vegetation mapping; therefore, LF Remap 2016 used a much-improved set of base composite imagery, modeling methods, the addition of around 1 million samples derived from light detection and ranging (lidar), hundreds of thousands of new field sample plots, and improved disturbance detections to refine estimates of vegetation type, cover, and height for the U.S. landscape. Additional improvements to LF 2016 Remap resulted in an entirely new base map.

D.1.3. LANDFIRE Vegetation Versions

A description of LF's vegetation mapping process and products from LF 2016 Remap to LF 2020 is provided later in this chapter. Although the LF user may be interested in comparing LF versions, it should be noted that changes in legends make version comparisons on a pixel-by-pixel basis challenging. A document detailing differences among LF versions is available at https://landfire.gov, with emphasis on the primary vegetation classification changes through the years (LANDFIRE, 2021a).

D.1.3.1. LANDFIRE 2016 Remap

As noted previously, LF 2016 Remap included numerous improvements from the previous base map, which are described in this chapter. Overall, improved plot data, vegetation classifications, modeling methods, review, rectification processes, and improved disturbance data, helped create an updated set of layers.

D.1.3.2. LANDFIRE 2019 Limited Update

The LF 2019 Limited update used the same vegetation transition rules for vegetation layers that had been used for previous updates before LF 2016 Remap; however, the rules were updated to reflect the improved classification legend and codes that were implemented for LF 2016 Remap. Implementation using ST-Sim, a package of SyncroSim, is described in detail later in this chapter. The LF 2019 Limited update included limited disturbances from 2017 to 2019. No LF remote sensing of landscape change (RSLC) disturbances were included; only fire program data (see chap. C) and the Events Geodatabase (see chap. B) informed areas of change. Anything that was not disturbed between 2017 and 2019 remained unchanged, including the classes labeled as recently disturbed in LF 2016 Remap. One other difference with this update compared to previous updates was that the vegetation in disturbed areas used the type, severity, and TSD in the fuel disturbance (FDist) layer and represented the vegetation

[1]KBR, Inc., under contract to the U.S. Geological Survey.

[2]The Nature Conservancy.

at the beginning of the growing season when it was released (June 2021). This means that vegetation disturbed between 2017 and 2019 regrew after disturbance to 2021 levels in cover and height. Note that disturbances after 2019 were not included and would not be represented in the 2021 capable vegetation layers. See chapter E for more details on how capable FDist is created.

D.1.3.3. LANDFIRE 2020

Vegetation layers in LF 2020 undergo a similar process to LF 2019 Limited in terms of using the established transition rulesets to effect change using ST-Sim and SyncroSim (Apex Resource Management Solutions, 2019); however, LF 2020 includes an extra year of disturbance and has LF RSLC included in all disturbance years for 2017–20; therefore, LF 2020 replaces LF 2019 Limited vegetation layers with more comprehensive changes based on a more complete disturbance record along with an extra year of disturbance included. The LF 2020 disturbed vegetation was 2022 capable when it was released in June 2022. Refer to section D.2.11 for more details.

Other updates to LF 2020 include land cover classes such as roads, urban, and agriculture using the latest comprehensive spatial data available. The developed ruderal classes and the recently disturbed classes were replaced in LF 2020, which could affect comparisons between LF versions but also improves estimations of natural vegetation and fuels near development. Additionally, agriculture detected on most Federal lands was classed as burnable vegetation. Finally, a new operational roads layer was created to accompany the vegetation and fuels layers. Details of these important changes are provided in section D.2.12.

D.2. Vegetation Product Development

D.2.1. Existing Vegetation Type Classification and Legend Development

EVT product development began by adopting an existing vegetation classification and designing a map unit legend. Designing the initial legend classification is different from mapping and modifying those legend classes on the landscape, which happens after the initial legend classes are determined. Vegetation map classes developed for the legend were ideally identifiable, mappable, modellable, and scalable. For LF National, the vegetation classes for the legend originated conceptually from NatureServe's ecological system (ES) classification, which is a nationally consistent set of midscale ecological units (Comer and others, 2003; NatureServe, 2009). ES is defined as "groups of biological communities that are found in similar physical environments and are influence by similar dynamic ecological processes, such as fire or flooding" (Comer and others, 2003, p. iv). These systems were classified and described using characteristic vegetative composition and physiognomy along with a suite of environmental and geographical modifiers. Like past product versions, the LF 2016 Remap EVT legend was based on NatureServe's ES classification. Auto-Key sequence tables and class assignments were improved before EVT mapping for LF 2016 Remap (see chap. B).

A second EVT map legend was developed for LF 2016 Remap using the group-level concepts of the U.S. National Vegetation Classification (NVC) hierarchy to align with the Federal Geographic Data Committee's guidance for Federal agencies to use this classification (Federal Geographic Data Committee, 2008). Groups within the NVC hierarchy were defined as combinations of narrow sets of diagnostic plant species that include dominants and codominants with broadly similar composition and diagnostic growth forms. When the NVC legend was being revised by NatureServe, every effort was made to comprehensively link the existing individual ES to one or more groups (NatureServe, 2017, 2018) before mapping began. In some cases, the ES class is nearly equivalent in its core concept to an NVC group; in other cases, several systems were conceptually linked to the same group. Still others have a more complex relation (but these were the minority of system types).

The EVT legend using ES underwent several substantial changes for LF 2016 Remap in partnership with the U.S. Geological Survey (USGS) Gap Analysis Program (GAP) to provide useful information for users beyond the fire community. Before LF 2016 Remap, the LF and GAP programs merged efforts for producing and updating an ecologically meaningful map that would serve the needs of both programs, which helped guide the program toward adding new classes (U.S. Geological Survey, 2015). Some of the changes that were made before mapping EVT for LF 2016 Remap were as follows:

- ESs that were previously aggregated in past EVT product versions were separated. Wetland, riparian, and sparse vegetation types were aggregated into thematically broader units in past products because they shared similar fire behavior fuel models before LF 2016 Remap. Such types were important to the GAP program and useful for users beyond the fire community. Many of these were separated for LF 2016 Remap.

- ESs that were omitted in past EVT–ES product versions were included in LF 2016 Remap. Most of these systems were patchy in character, existing in local, fine-scale spatial patterns that were omitted in past products because they were of little interest for fire behavior fuel modeling. These included systems remnant prairies, seepage fens, and rock outcrops. Like the aggregates described previously, these types were important for GAP and useful for users beyond the fire community.

- NVC alliances included in past EVT–ES product versions as additional attributes were retired for LF 2016 Remap because of redundancy with the new NVC mapped vegetation product using the NVC group level of the NVC hierarchy.
- Ruderal and introduced vegetation types included in past EVT–ES product versions were replaced with a standardized set of ruderal and cultural map classes using only NVC group concepts because ES concepts were not applied to ruderal vegetation.

The base units in the ES and NVC group legend classes were modified for types that can be split into forest, shrubland, herbaceous, and sparse variants before mapping efforts began.

D.2.2. Reference—LANDFIRE Reference Database

Field plot samples compiled and labeled to an ES or NVC group come from the LF reference database (LFRDB). Assigning the plots to a class within each of these classification systems via the Auto-Key process (Reid and others, 2015) or expert assignment in the LFRDB (see chap. B) is the first step in using the plots and other input variables stored in the LFRDB (see section D.2.5) for modeling lifeform and LF's three existing vegetation products, including the following:

- Existing vegetation type (EVT–ES and EVT–NVC),
- Existing vegetation cover (EVC), and
- Existing vegetation height (EVH).

D.2.3. Imagery

Seasonal image composites were created using high-performance computing systems and a best pixel image compositing process (Nelson and Steinwand, 2015) to produce cloud-free image composites per LF tile (see chap. C). The resulting six-band rasters used 5 years of Landsat imagery for vegetation mapping (2013–17) with a target year of 2016 (see chap. C). The following date ranges and center days were used for the contiguous United States:

- Winter A: January 1–April 15 (March 31 center day),
- Spring: April 16–June 27 (June 13 center day),
- Summer: June 28–August 31 (August 1 center day),
- Fall: September 1–October 31 (October 1 center day), and
- Winter B: November 1–December 31 (November 12 center day).

The image composites per LF tile were then mosaicked to cover each vegetation production unit (VPU). VPU boundaries were created by grouping individual Omernik level III ecoregions (Omernik and Griffith, 2014) and were used to provide ecologically meaningful boundaries for building and applying vegetation models. They were mapped sequentially, as shown in figure D1, for the contiguous United States.

Alaska and insular area composite date ranges were adjusted to reflect latitudinal and seasonal wet and dry effects. Landsat 7 and 8 images were used for compositing, but preference was given to Landsat 8 in the best-pixel algorithm because of missing data for scan lines in Landsat 7. Mapping started with three seasons in the western contiguous United States, then winter was added in the south central VPU to help distinguish deciduous vegetation types. In the north woods VPU, LF began reviewing full VPU mosaics of the tiled image composites to identify seamlines at the boundaries of individual image composites (see fig. D1). This issue only became evident when mapping the north woods, southeast, Appalachia, and northeast VPUs with the dominance of deciduous trees, short leaf-on season, and persistent snow and cloud cover limiting the number of clear scenes available for the image composites. If seamlines were identified, the order and priority of the scene stack list was manually adjusted. This recompositing process typically reduced or eliminated seamline artifacts.

Some best pixel composites still had gaps in data for clouds and cloud shadows, contained artifacts from phenology changes, and showed "noisy" areas where adjacent pixel values were widely variable and did not reflect ground conditions; therefore, a cleaning process was used by adapting Python scripts from spectral similarity grouping methods developed by scientists from the National Land Cover Database (NLCD) program (Jin and others, 2013). A LF team of analysts cleaned the composites by manually drawing polygons around areas of poor imagery in the composites. The spectral similarity grouping algorithm locates similar pixel values in a buffer around the polygon using a clean reference image then locates the same pixel locations in the original composite, reads the values for those pixels, and assigns those values back to the original flagged pixels. Starting in the southern great plains (VPU 6), a growing season reference composite was created from an extended window from June 15 to November 30 (August 26 center day) to reduce "noise" and artifacts in the spectral similarity grouping cleaning process.

Manual reworks started in the south central VPU, where good scenes were manually selected as preferred for inclusion in the best-pixel compositing process. This selection involved the review of individual Landsat scenes. In the southeast VPU, LF began using Land Change Monitoring, Assessment, and Projection synthetic images (Zhu and others, 2015). The synthetic images were produced from the Land Change Monitoring, Assessment, and Projection continuous change detection process that predicts values per band for each day of the year with a best-fit sinusoidal curve. For southeast, Appalachia, and northeast VPUs, synthetic data were used

Figure D1. LANDFIRE vegetation production units created by grouping several Omernik level III ecoregions (Omernik and Griffith, 2014).

for all seasons in place of the best-pixel composites. The LF vegetation mapping team also moved the date for spring from day 150 to 165 in southeast, Appalachia, and northeast VPUs to account for seasonal phenological signals.

A tasseled-cap transformation (Kauth and Thomas, 1976) was calculated for the seasonal image composites to use differences in brightness, greenness, and wetness. Normalized Difference Vegetation Index (NDVI) 5-year temporal statistics (2013–17) were calculated to help delineate variation in photosynthetic vegetation and were compiled in a four-band raster as follows:

- Band 1: minimum NDVI (5th percentile for the contiguous United States, 20th percentile for insular areas and Alaska),
- Band 2: maximum NDVI (90th percentile),
- Band 3: median NDVI (50th percentile), and
- Band 4: difference between maximum (band 2) and median (band 3).

For the insular areas, the best-pixel compositing method was used with manual scene selection specifically in the South Pacific, where not many clear scenes were available. In these areas, two longer seasons were used to represent rainy and dry seasons, plus the growing season reference composite. The insular area date ranges were as follows:

- Rainy: July 1–November 30 (October 26 center day),
- Dry: December 1–June 30 (March 30 center day), and
- Growing season reference: January 1–December 31 (July 1 center day).

For Alaska, a new method was used involving percentiles for each season (see section C.2.3.1.2 in chap. C). The 50th percentile was used for each season for 2013–17 (target year 2016). The LF team explored incorporating Harmonized Landsat Sentinel-2 imagery, but there were alignment issues with previous LF data (because of Harmonized Landsat Sentinel-2 projection of the Universal Transverse Mercator), so it was not used.

Alaska vegetation imagery using 50th percentile composites drawing from 5 years of imagery consisted of the following images and date ranges:

- Early season leaf off: March 1–June 1,
- Spring: May 16–July 31,
- Summer: July 15–September 30,
- Fall: September 1–November 15, and
- Growing season reference: June 1–September 30.

Imagery is generated and processed by LF tile for Alaska in a similar manner to the contiguous United States and raster data is extracted for plot locations (see chap. B, section B.2.5). After all tiles for a given VPU were finalized, they were mosaicked and provided to the U.S. Department of Agriculture Forest Service Forest Inventory and Analysis (FIA) liaison to extract spectral information at plot locations, along with any other modeling predictor layers, such as topography and gradients. Attributes extracted for each plot included elevation, aspect, slope, ecoregion, landform, and bioclimate variables and were included in the LFRDB to be used for creating models so that model results could be imputed across the landscape.

D.2.4. Mask Development for Nonmodeled Classes

An important aspect of delineating where certain classes can exist is the development of masks, which stratify an area of interest based on certain criteria to be used in restricting where specific classes can or cannot be mapped. Several masks were developed to identify open water, barren land, sparse vegetation, development, agricultural lands, and snow or ice.

D.2.4.1. Agriculture Mask

Agricultural land was identified using the 2016 Cropland Data Layer (CDL; Boryan and others, 2011). The CDL was converted to a raster; the classes were separated into burnable and nonburnable categories and then grouped into LF classes with similar growth characteristics (for example, close-grown row crop) and fire behavior (see appendix 1). Pasture/hay was added from NLCD class 81 because CDL did not include this class. The next step was to complete a zonal majority using a Common Land Unit (U.S. Department of Agriculture, 2008) to smooth out noise in fields where there were mixed pixels of different crop types within the same field.

California State data from the California Natural Resources Agency were used to replace CDL after it was determined the data were more useful for LF purposes (California Department of Water Resources, 2017). The 2016 Statewide Crop Mapping geographic information system data layer was converted to raster and inserted into an agriculture mask within the State boundary based on a crosswalk to LF agricultural classes.

Alaska agriculture classes EVT 7755 and EVT 7754 were applied directly from NLCD 2016 land cover class 82 (cultivated crops) and class 81 (pasture and hay), respectively (Jin and others, 2013; Homer and others, 2020). In Hawaii, pasture/hay (EVT 7754) was taken from NLCD 2001 land cover (Homer and others, 2004). Most cultivated crops were taken from the Coastal Change Analysis Program (C-CAP) 2005 and C-CAP 2011 (National Oceanic and Atmospheric Administration, 2005, 2011). Other agriculture classes in Hawaii were crosswalked to LF classes from the statewide agricultural land use baseline (State of Hawaii, 2015; appendix 1). In Puerto Rico and the U.S. Virgin Islands, pasture/hay and cultivated crops were used directly from C-CAP 2010 and 2012 (National Oceanic and Atmospheric Administration, 2012). Fruit and berries (EVT 7838—coffee in this context) and tropical agroforestry plantation (EVT 9355—shade-grown coffee in this context) were delineated with elevation and LF 2014 baseline data in addition to C-CAP 2010 and 2012. Agriculture classes for American Samoa and Guam were derived from C-CAP datasets ranging from 2003 to 2006, depending on the island (National Oceanic and Atmospheric Administration, 2022). A U.S. Department of Marine and Wildlife Resources habitat map (Meyer and others, 2017) for American Samoa also provided information needed to delineate agriculture. For the remaining Pacific Islands, we used the same agriculture maps as LF 2010.

D.2.4.2. Developed Land and Roads Masks

Developed land was identified using NLCD developed classes. NLCD 2011 was used for the western contiguous United States; NLCD 2016 was used once it became available for the eastern contiguous United States (Jin and others, 2013; Homer and others, 2020). Roads were taken from the LF 2014 update product suite and were based on provisional data from the NCLD program. Roads were eliminated in high tree cover areas using NLCD canopy cover (CC) thresholds to account for canopy fuel continuity. All pixels for the following three classes were taken as-is from NLCD:

- Class 22: developed low intensity,
- Class 23: developed medium intensity, and
- Class 24: developed high intensity.

The NLCD developed open space class (21) was split into the following five classes using a supervised classification process to assign these areas the appropriate fire behavior fuel models:

- Urban deciduous forest,
- Urban evergreen forest,
- Urban mixed deciduous-evergreen forest,
- Urban herbaceous, and
- Urban shrubland.

In Alaska, roads were delineated using the NLCD 2016 developed urban descriptor layer and all primary, secondary, and tertiary NLCD road classes (urban and outside of urban) were reclassed as EVT 7299, developed roads (Jin and others, 2013; Homer and others, 2020). For developed classes in Alaska, NLCD 2016 land cover classes representing developed low intensity, medium intensity, high intensity, and open space were used with no modification and have the same EVT name as the NLCD class name. The CC adjustment for roads used in the contiguous United States was not applied in Alaska.

For Hawaii, developed land was designated using the following data sources in order of priority (for example, no. 1 trumps no. 2):

1. C-CAP 2005 developed open space, low intensity, medium intensity, high intensity (National Oceanic and Atmospheric Administration, 2005) and
2. NLCD 2001 developed open space, low intensity, medium intensity, high intensity (Homer and others, 2004).

In Puerto Rico and the U.S. Virgin Islands, roads were delineated using Topologically Integrated Geographic Encoding and Referencing lines (U.S. Census Bureau, 2017), buffered by 30 m for primary roads and 15 m for secondary roads and rasterized. Overlapping pixels of developed classes were reclassed to roads where the Topologically Integrated Geographic Encoding and Referencing lines were present. Developed classes used were from C-CAP 2010 and included developed open space, low intensity, medium intensity, and high intensity (National Oceanic and Atmospheric Administration, 2010). For St. Croix, St. John, and St. Thomas, C-CAP 2012 was used for developed open space and low intensity (National Oceanic and Atmospheric Administration, 2012). In American Samoa and Guam, low intensity developed and developed open space were derived from C-CAP datasets ranging from 2003 to 2006, depending on the island (National Oceanic and Atmospheric Administration, 2022). For the remaining Pacific Islands, we used the same developed classes as LF 2010.

D.2.4.3. Water Mask

A water mask was developed to identify open water in circa 2016 conditions. The intent was to improve upon past products that had problems with discontinuous stream channels and water on slopes, often because of rock shadows. The Landsat Dynamic Surface Water Extent (DSWE) was in development and obtained provisionally (Jones, 2019). The DSWE product uses several spectral tests to determine surface water probability from Landsat surface reflectance and topographic slope data. Classes included the following:

- Value 0: not water,
- Value 1: high confidence water,
- Value 2: moderate confidence water, and
- Value 3: partial surface water pixel.

DSWE data were obtained from the Landsat archive for a 5-year period (2011–16). Then, the frequency of high-confidence water pixels was accumulated, and pixels mapped as water more than five times were mapped by LF as water.

Fragmented segments along streams and rivers were connected using the National Hydrography Dataset (NHD; U.S. Geological Survey, 2016c) flowlines to form a continuous network. First, the high-frequency DSWE pixels were merged with the NHD artificial path flowlines to capture the center path of water bodies. The NHD lines were selected by comparing three indices computed for each seasonal composite used in LF vegetation modeling (spring, summer, and fall cloud-free imagery) and included the following:

- Soil-Adjusted Total Vegetation Index (Marsett and others 2006),
- Modified Normalized Difference Water Index (Xu, 2006), and
- Modified Soil-Adjusted Vegetation Index (Qi and others, 1994).

The three indices were merged and either the maximum of the three seasons (for Soil-Adjusted Total Vegetation Index) or the minimum (Modified Normalized Difference Water Index or Modified Soil-Adjusted Vegetation Index) was selected so that if the threshold was met in any of the three seasons, the output was positive for water.

Results required hand-editing by a team of analysts to rectify stream channels and open water extent based on a review of aerial photos, satellite imagery, and comparison to NLCD. Some common problems included the following:

- Short or disconnected stream segments, modeled paths in lake or reservoirs, and missing segments and
- Commission errors (false positives) in DSWE in urban features including asphalt roofs, parking lots, and shadows created by rocky features or mines.

The final water map represented water extent with connected streams and no water on slopes or shadows. Similar methods were used to create a water mask for Alaska; however, substantially more hand-editing was needed in Alaska than in the contiguous United States.

D.2.4.4. Barren/Sparse Mask

A mask was developed to identify barren (0-percent vegetation) and sparsely vegetated areas (1–9-percent total absolute vegetation cover). The mask was based on NDVI thresholds using the same NDVI composite used as a predictor layer in other vegetation modeling including median and maximum NDVI for 5 years (2013–17). The thresholds were calibrated by geography based on known barren and sparsely vegetated areas. The intent was to improve LF maps by capturing any clearly barren areas, especially those omitted in previous LF product versions.

An effort was made to update quarries-strip mines-gravel pits-well and wind pads (EVT 7295), which was intended to separate anthropogenic barren areas from natural barren areas represented by numerous ES or NVC groups. This update was necessary, especially for mining operations that had expanded into new areas and previously active areas that had been reclaimed. Pixel clusters of existing mines were buffered by 120 m. Then, an NDVI threshold was used to identify mining extents. Manual editing was completed to reclassify reclaimed areas (no longer barren) and water, which is often present in mining operations and gets classified as barren because of low NDVI signals.

To identify well pads in areas with expansive oil and gas mining, point data in FracTracker were used to identify areas with a concentration of oil/gas wells (FracTracker Alliance, 2016). Then, spectrally similar areas were identified and classified as barren pixels in EVT 7295. The threshold was fine tuned by comparing the barren pixels to aerial photographs in Google Earth, allowing consistent separation of well pads from adjacent naturally barren areas. Expert manual editing was done to reduce commission errors. Wind turbine locations were added as single pixels from FracTracker.

For Alaska, Hawaii, and insular areas, after applying NDVI thresholds detailed previously to identify barren areas, hand-drawn polygons were used to recode some barren areas to either developed-low intensity (EVT 7296) or quarries-strip mines-gravel pits-well and wind pads (EVT 7295) during analyst review.

D.2.4.5. Snow/Ice Mask

Snow/ice masks were obtained from the perennial ice/snow class in NLCD 2011 for the western contiguous United States and NLCD 2016 land cover (once available) for the eastern contiguous United States and Alaska (Jin and others, 2013; Homer and others, 2020).

D.2.5. Lifeform Modeling

The first step for vegetation modeling and mapping was to separate the landscape into three lifeforms: herbaceous, shrub, and treed areas. Each LFRDB plot is assigned to one of these three dominant physiognomic or lifeform types based on the assigned EVT–ES label derived from the Auto-Key.

A common occurrence that arose during the LF 2016 Remap effort was the assignment of multiple lifeforms to a given ES. These types and their associated lifeform options were identified before modeling with assistance from NatureServe and comparison to previous products. Where feasible, plots for these types were reassigned the appropriate lifeform using species absolute cover information from the LFRDB. Table and field descriptions are available in the LFRDB data dictionary (LANDFIRE, 2021b). Lifeform cover was derived from LFTreeCov, LFShrubCov, and LFHerbCov fields in the stands table using the following logic:

- If both tree and shrub lifeforms were present in a plot and tree cover was greater than or equal to (≥) 10-percent, it was assigned tree, otherwise shrub.
- If both tree and herbaceous lifeforms were present in a plot and shrub cover was ≥10-percent, it was assigned shrub, otherwise herbaceous.

- If no cover was present for the plot, then the higher lifeform of the options (the dominant lifeform) was assigned.

The modeling process began by removing sample plots collected before disturbances using LF annual disturbance products. Additionally, a recovery period (the time for vegetation in disturbed areas to recover), was assigned to each EVT class associated with a plot. In general, tree EVTs were assigned a 10-year recovery period, shrub EVTs a 5-year recovery period, and herbaceous EVTs a 1-year recovery period. Plots were removed from use in modeling for the full recovery period in high-severity disturbances, half the recovery period (rounded up) for medium-severity disturbances (for example, 3 years for shrub type with a 5-year recovery period), and 1 year for low-severity disturbances. Adjustments were made for EVTs in which rapid recovery was likely, including plantation and ruderal types. Areas without image-based change detection but containing submitted events-only disturbances were ignored for the plot removal process.

Spectral outliers were identified by summing Landsat bands 1 through 6 from the summer composite for sample plots from each lifeform class. Plots greater than two standard deviations from the average were removed. The resultant filtered plots were used to model lifeform and vegetation structure (EVC and EVH).

A classification tree model was generated with the See5 algorithm (Quinlan, 1993; RuleQuest Research, 2006) using the raster predictor layers identified in table D1. Only the spring, summer, and fall image composites and associated tasseled-cap images were used. Winter composites were used for EVT modeling rather than lifeform. The model was applied within a VPU to map vegetation to the three lifeforms with each vegetation pixel receiving a single assigned lifeform. The model output was postprocessed using a majority filter of the eight nearest neighbors (three-by-three window) to produce a smoother and more realistic output.

In some cases, the See5 algorithm performed poorly, assigning tree lifeforms to herbaceous wetlands, sagebrush steppe shrub lifeforms to herbaceous, and so on. This poor performance was usually because of underrepresentation in sampling data, when a predictor variable like tasseled-cap wetness indicated trees erroneously, or because of other false signals. In these cases, the initial lifeform model output was improved through an iterative process by adding expert-labeled training samples based on desktop review of aerial photographs in Google Earth and Landsat imagery to correct obvious lifeform modeling errors.

D.2.6. Existing Vegetation Cover and Height Modeling

D.2.6.1. Plot Cover and Height Calculations

EVC and EVH modeling started with the filtered plots for lifeform modeling described previously. Existing vegetation products were designed to nest by lifeform; for example,

Table D1. Raster inputs to mapping vegetation types per 30-meter pixel.

[3DEP, 3D Elevation Program; DEM, digital elevation model; %, percent; NDVI, Normalized Difference Vegetation Index; min, minimum; max, maximum; max-median, maximum minus median EVC, existing vegetation cover; EVH, existing vegetation height]

Dataset name	Unit of analysis	Range of values	Source (citation)
Elevation	Meters	−113–4,415	3DEP DEM (U.S. Geological Survey, 2016b)
Aspect	Degrees	0–359°	3DEP DEM derivative
Percentage slope[a]	%	0–85	3DEP DEM derivative
Topographic position index (300 and 2,000)	Index	About 900–2,330, 400–3,150	3DEP DEM derivative
Landsat imagery (seasonal) circa 2016[b]	Surface reflectance	6 (0–255 per band)	Processed Landsat scenes courtesy of the U.S. Geological Survey
Tasseled cap (seasonal) circa 2016[b]	Index	3 (−8,000–24,000 per band)	Processed Landsat scenes courtesy of the U.S. Geological Survey
NDVI 5-year statistics (min, max, median, max-median)[b]	Index	−1.0–1.0	Processed Landsat scenes courtesy of the U.S. Geological Survey
Climate (precipitation, temperature)	Millimeters and degrees	1,390–65,534, 26,000–49,494	Gradients (Rollins, 2009) Daymet (Thornton and others, 2017)[c]
Soils (percentage sand, silt, clay, organic matter, and pH)	%	0–100, 0–9	Gridded Soil Survey Geographic database (Soil Survey Staff, 2014) Polaris (Chaney and others, 2016)

[a]Used for riparian/wetland modeling in addition to layers used for lifeform, EVC, and EVH.

[b]Used for lifeform, EVC, and EVH modeling.

[c]Used in Alaska only.

pixels identified as tree in the lifeform mask were assigned a tree cover, height, and vegetation type. Training samples for vegetation percentage of cover and height were derived from field estimates of vegetation cover and height and sampled lidar data. Cover and height information for each sample plot was separated into three lifeforms: tree, shrub, and herbaceous.

Tree cover training samples were obtained from the LFTreeCovMdld field (this field is not available in the public LFRDB because of confidentiality limitations of FIA plot data) in the stands table of the LFRDB, which is derived using the stem-map method (Toney and others, 2009). Because of variability in CC collection methods, FIA stem-map plots were the only LFRDB plots used to map tree cover because the sampling methods are well documented. Shrub and herbaceous cover training samples were obtained from the DomSpCov field in the communities table, which provides the percentage of cover of the dominant taxon within the sampled unit based on highest absolute cover of species within associated lifeform of the EVT, as derived from the LF ES Auto-Key.

In Alaska, cover was calculated using the LFCovAdj attribute in the LFRDB for each lifeform, which provided the relative cover of each lifeform. Cover was modeled for each lifeform separately, and it was determined that more cover training data could be derived for the lifeform cover models using this measurement, rather than the LFRDB fields used for calculating cover in CONUS mentioned previously. In Hawaii, herbaceous cover and height were used in concert with shrub and tree estimates to better specify fuel models, but dominant lifeforms were still designated for mapping. Height in Hawaii required numerous pseudoplots from high-resolution image interpretation for modeling because of a lack of training data in the LFRDB.

Height training samples were obtained from the LFTreeHgt, LFShrubHgt, and LFHerbHgt fields in the stands table, which is height (in meters) based on the cover weighted average from the species table calculated by LF (based on NatureServe's lifeform assignments; table D2). For plots that had height measurements, relative lifeform cover is calculated for each tree, shrub, and herb on a plot and is kept as a proportion, so all values were between 0 and 1. The relative lifeform proportion is then multiplied by the height to get a weighted height; therefore, species that had higher cover had more weight in the final height value. The weighted heights were then summed for each lifeform to get the final weighted average, so in the hypothetical example in table D2, the LFTreeHgt for the plot would be 26.4 m.

FIA plot tree height calculations were determined using the stem-map method in Toney and others (2009). For FIA plots, StandHt is based on the basal area-weighted average height of trees with a diameter at breast height of ≥5.0 inches (in.) that also are classified as canopy dominant/codominants (that is, are designated with crown class codes of dominant, codominant, and open-grown). Trees with crown class codes of intermediate or overtopped are ignored in the calculation of StandHt. Seedlings and saplings are not used in the calculation unless the plot is considered to represent a sapling-stage stand. Sapling-stage plots are defined by the following procedure, which uses thresholds of CC. CC is estimated separately for trees (diameter at breast height ≥5.0 in., TreeCov) and saplings (diameter at breast height ≥1.0 in. and less than (<) 5.0 in., SaplingCov) by mapping tree crowns within the plot using stem coordinates and predicted crown widths. If a plot has TreeCov less than or equal to 10 percent and SaplingCov≥(3*TreeCov), then it is considered a sapling-stage plot, and StandHt is the average height of saplings measured in the plot.

Additionally, the 2016 NLCD fractional shrub percentage of cover was randomly sampled, and training samples were added to models where these data existed in the western contiguous United States to assist in training shrub cover (Homer and others, 2020).

D.2.6.2. Light Detection and Ranging Cover and Height Processing and Calculations

Lidar is another dataset used to help model existing vegetation cover (EVC) and EVH in addition to the LFRDB plot measurements of these data.

D.2.6.2.1. Light Detection and Ranging Processing

Lidar processing was completed using scripts incorporating Python 3.7, LASTools, the Geospatial Data Abstraction Library, and the Python Data Analysis Library on aerial lidar data obtained from The National Map, OpenTopography, and the National Aeronautics and Space Administration Goddard's LiDAR, Hyperspectral and Thermal Imager (known as

Table D2. Example of weighted height calculation for trees (not in a U.S. Department of Agriculture Forest Service Forest Inventory and Analysis plot).

Tree species	Absolute cover	Relative cover	Height (meters)	Weighted height (meters)
A	50	0.42	35	14.58
B	40	0.33	25	8.33
C	20	0.17	12	2
D	10	0.08	18	1.5
Total	**120**	**1**	**90**	**26.42**

G-LiHT). Data also included State government geographic information system and National Oceanic and Atmospheric Administration data for Alaska, the contiguous United States, Puerto Rico, American Samoa, Guam, and the Northern Mariana Islands. A full catalog was created of all data collected in Alaska, including the year and projection of data. When the lidar data were not in a recognized projection or geographic coordinate system, the data were preprocessed to a standardized coordinate system (contiguous United States and Puerto Rico European Petroleum Survey Group (EPSG) code 5070, Alaska EPSG code 3338, America Samoa EPSG code 32702, and Guam/ the Northern Mariana Islands EPSG code 32655). Lidar data were removed if collected before a disturbance as represented in LF annual disturbance layers. NLCD land cover was used to select lidar data in areas mapped as tree, shrub, and woody wetland for Alaska.

D.2.6.2.2. Calculations and Sampling

Lidar point cloud data were processed using LAStools (rapidlasso, 2019) with the lascanopy, lasheight, lasoverage, and lasgrid functions to obtain canopy height (CH) and CC values every 1 hectare across the footprint of a given point cloud file. The functions lasoverage and lasgrid were used to remove overlaps (noise) and rasterize the point cloud preprocessing steps. The lasheight function was applied to obtain a height above ground point cloud (limiting values to range between 0 and 100 m). The lasgrid function was used on this output to produce a rasterized version, which was then used in the lascanopy function to obtain CH and CC rasters per percentile and cutoff heights.

The CH values were calculated at the 50th, 60th, 70th, 80th, 90th, 95th, and 99th percentile. The 90th percentile CH, which is the 90th percentile of lidar returns, was used in model training because it most closely reflected average CH as measured in field plots and used in fire behavior fuel models.

The CC values were obtained at cutoff heights of 0.03 m, 0.04 m, 0.05 m, 0.1 m, 0.2 m, 0.3 m, 3.0 m, 4.0 m, and 5.0 m. The 3.0-m CC cutoff, which is the percentage of lidar returns greater than 3 m, was used as training data for LF vegetation modeling purposes because it provided a general rule for eliminating understory point cloud returns across the country.

From each raster produced, final CC and CH values at 1-hectare spacing were extracted and saved to output comma-separated value files, which were then converted to shapefiles for analyst review and use in modeling. Points were removed if they seemed to be collected in leaf-off conditions based on comparisons between deciduous versus evergreen tree cover in aerial photographs and deciduous and evergreen NLCD land cover classes. Lidar measurements made during leaf-off conditions largely underrepresent deciduous tree species cover and height. Lidar was not used for shrub and herb cover and height modeling.

D.2.6.3. Regression Tree Models for Cover and Height

Regression tree models predicting percentage of cover and height of dominant vegetation were generated with the Cubist algorithm (Quinlan, 1993; RuleQuest Research, 2006) using the following subset of predictor layers from table D1: seasonal Landsat imagery, tasseled-cap, and NDVI 5-year statistics. Only the spring, summer, and fall image composites and associated tasseled-cap images were used; the winter composites were used only for EVT. Models were generated within a VPU to predict continuous outputs for each lifeform layer. The layers were then combined using the lifeform mask; for example, if the lifeform mask indicated tree, then a pixel received tree cover in EVC and tree height in EVH. The following rules were used in the merge:

- Tree cover greater than 100 percent was capped at 100 percent, cover <1 percent was recoded to sparse, and cover ≥1 and <10 was set to the lowest cover option (10 percent).
- Shrub and herb cover greater than 100 percent was capped at 100 percent, cover <5 percent was recoded to sparse, and cover ≥5 and <10 was set to the lowest cover option (10 percent).
- Shrub height greater than 3 m was capped at 3 m, and no height was set to lowest height option (10 centimeters).
- Herb height greater than 1 m was capped at 1 m, and no height was set to lowest height option (10 centimeters).

EVC and EVH were modeled independently of EVT, which resulted in some illogical combinations with cover and height; for example, height and (or) percentage of cover for some types were too high for the dominant species of that EVT. Therefore, the following rules were applied:

- Tree cover and height were capped at the 97th percentile per EVT to address fuel model needs.
- Shrub cover and height were capped at the 99th percentile per EVT.

D.2.6.4. Recently Disturbed Vegetation Type Classes

Recently disturbed areas (within previous 3 years) did not model well for cover and height because the satellite image composites spanned multiple years and consisted of a mixture of pre- and postdisturbance pixels. Ruleset-based disturbance, severity, and TSD and the information in the LF historical disturbance layer were used to adjust lifeform and modeled post-disturbance cover and height (fig. D2). This adjustment was an effort to address the known issue of pre- and postdisturbance

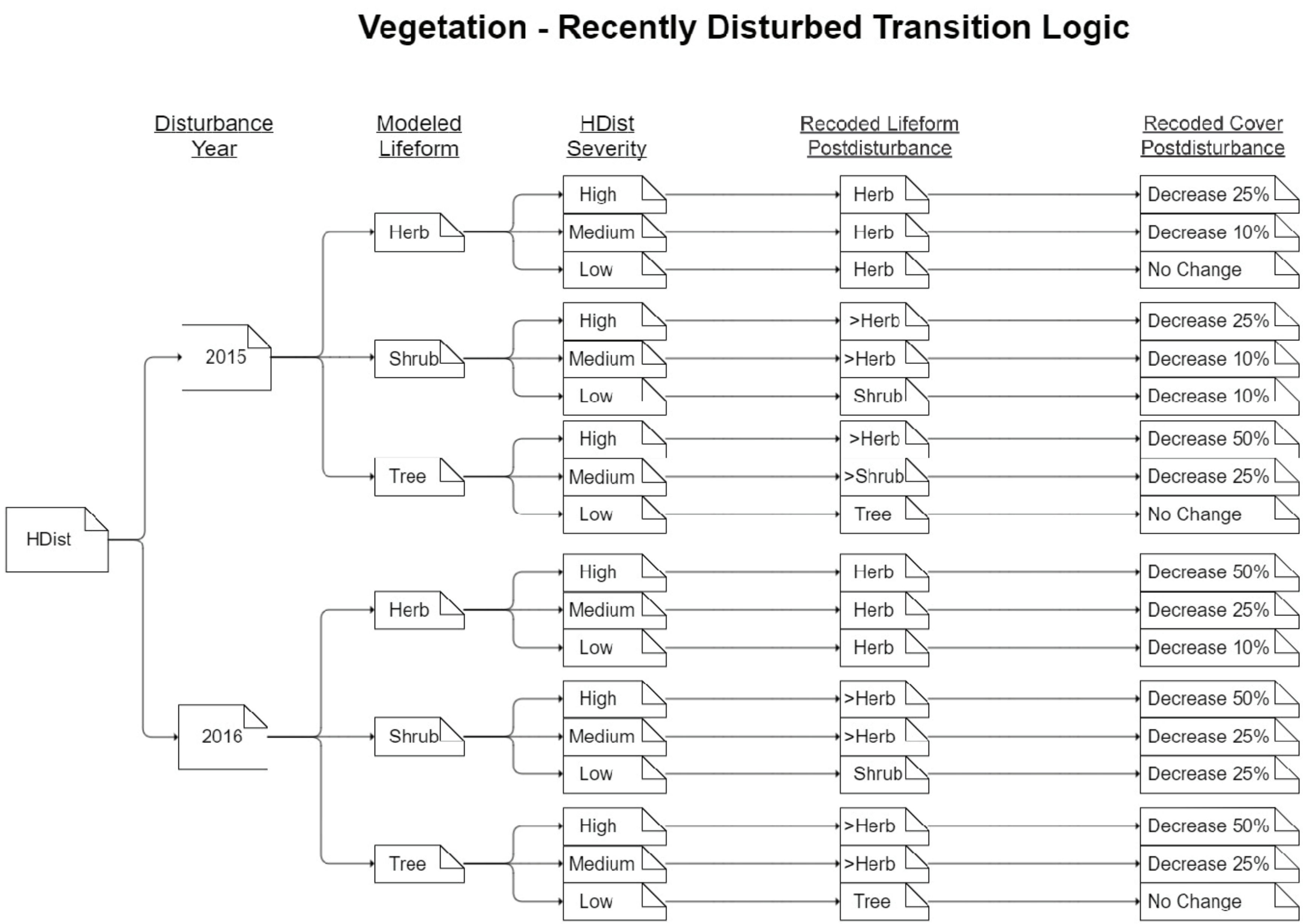


Figure D2. Recently disturbed class adjustments to lifeform, cover, and height (same reductions as indicated for cover). [HDist, historical disturbance; %, percent] imagery present in vegetation composites. The recently disturbed adjustments also included 2014, when trees and shrubs experienced a high-severity disturbance. Recently disturbed areas before 2014 were not adjusted for cover and height but, depending on lifeform and severity, were still labeled recently disturbed (see section D.2.7 for more details).

D.2.7. Existing Vegetation Type Mapping

The first step in mapping EVT was to create masks to identify ecoregions, riparian/wetland vegetation, and alpine areas where specific vegetation types are only found at high elevations to restrict mapping of these specialized types within the correct areas.

D.2.7.1. Vegetation Modeling Masks

D.2.7.1.1. Ecoregion Modeling Mask

A key factor in ecosystem modeling is determining the boundaries within which to build and apply models for EVTs. Initial prototyping determined that Omernik level III ecoregions (Omernik and Griffith, 2014) provided a more ecologically meaningful framework for modeling EVTs than mapzones used in previous LF mapping efforts (Picotte and others, 2019). The ecoregions were grouped to create 13 VPUs (fig. D1) across the contiguous United States. These VPUs created areas of a manageable size for efficiently preparing satellite imagery and georeferenced sample inputs and were similar, but not identical, to the ecoregion clusters used for design and implementation of Auto-Keys.

4.2.7.1.2. Riparian/Wetland Mask

The riparian/wetland mask was created to restrict mapping of riparian/wetland types to identified locations. The first step was to create a sampling mask that determined where riparian/wetland sample plots versus upland sample plots could be selected for generating a model. The sampling mask was created using several data sources, including an NLCD generated Wetland Potential Index (WPI) layer made up of a combination of three wetland data sources at a 30-m scale including gridded Soil Survey Geographic database hydric soils (Soil Survey Staff, 2014), National Wetlands Inventory (U.S. Fish and Wildlife Service, 2014), and NLCD 2011 wetlands (class 90 and 95; Jin and others, 2013). These three sources were combined to create raster values indicated in table D3 to better identify wetland areas.

The sampling mask was created using the following rules:

- For riparian vegetation types, no samples were allowed for agriculture, developed land, or water;
- No riparian samples were allowed in WPIs 2–4;
- Riparian samples were allowed in WPIs 5–8; and
- Upland samples were not allowed in WPIs 2–8.

Then, a random sample was taken based on percentage of wetland versus nonwetland pixels in the sampling mask, resulting in tens of thousands of training samples across the VPU. Riparian/wetland samples were given a training value of 100 and upland samples a training value of 0. The Cubist regression tree model and the same predictor layers used for the lifeform mask and the variable percentage of slope were used to model riparian types. The final mask was created using thresholds on the model output for different values of WPI combined with other data sources including the valley bottom zone from LF National for the western contiguous United States and Alaska (Rollins, 2009) or an external floodplain mask developed by Baynes and others (2018) when it became available for the eastern contiguous United States. A high threshold was used outside the masks to capture wetlands absent from the masks, and areas mapped as wetland by multiple high-confidence sources (WPIs 7 and 8) were brought through regardless of the Cubist output to capture areas absent from the model. The thresholds were adjusted for each VPU to calibrate the model based on high-confidence riparian/wetland areas using high-resolution imagery in Google Earth.

Table D3. Combinations of data sources used to develop riparian/wetland mask.

[NWI, National Wetlands Inventory; NLCD, National Land Cover Database]

Raster index value	Wetland potential sources and combinations
8	Hydric soils + NWI wetlands + NLCD wetlands
7	NWI wetlands + NLCD wetlands
6	Hydric soils + NLCD wetlands
5	Hydric soils + NWI wetlands
4	NLCD wetlands
3	NWI wetlands
2	Hydric soils

D.2.7.1.3. Alpine Mask

The alpine mask was used to help restrict the mapping of alpine EVTs to alpine areas. The digital elevation model was reclassed into 100-m increments to make a raster of elevation classes. The elevation class raster was combined with rasters of hydrologic unit code 12 subbasins and Omernik IV ecoregions (Omernik and Griffith, 2014). The resulting raster was then combined with GAP/LF 2011 land cover data. For each unique combination, the percentage covered by alpine EVTs was calculated. If a region was determined to be more than 25-percent alpine in the GAP/LF 2011 land cover map (U.S. Geological Survey, 2016a), it was coded 1 for inclusion in the alpine zone. Once this field was fully attributed, a binary raster with 1 indicating areas within the alpine mask and 0 indicating areas outside of it was created.

D.2.7.2. Existing Vegetation Type Modeling

EVT modeling began with the filtered plots from the lifeform mask and structure (EVC and EVH) described previously. Subsequently, a spectral outlier test was completed separately for ES and NVC vegetation types.

After plot filtering, some plots were withheld or set aside for map validation. The holdout process began by generating a list of plot counts for each EVT class within the VPU. For classes with total plot counts between 300 and 3,000, plots were withheld at a rate of 10 percent of total plots. A maximum of 300 plots were withheld for classes with more than 3,000 total plots, and no plots were withheld for classes with less than 300 plots. Plots withheld for validation purposes were stratified by Omernik level III ecoregion (Omernik and Griffith, 2014); that is, the total holdout plot count was divided by the percentage of total plots within each Omernik level III ecoregion. A class, for example, with a total of 1,200 plots in a VPU and 200, 400, and 600 plots in ecoregions A, B, and C would have a total of 120 holdout plots with 20, 40, and 60 holdout plots in ecoregions A, B, and C, respectively. The process was not repeated for NVC. Instead, the same plots were withheld for NVC regardless of the total number of plots that for each NVC class.

EVT sample plots were separated into three primary lifeforms: tree, shrub, and herbaceous vegetation types, as well as barren or sparsely vegetated types (defined as <10-percent total cover). Plots were further separated into wetland versus nonwetland EVT categories, and alpine versus nonalpine EVT categories where they existed. Classification tree models were generated with the See5 algorithm using many of the raster predictor variables in table D1. Models typically included the seasonal Landsat image composites, topography (elevation, percentage of slope, and aspect), and climate variables (average annual precipitation and temperature). Models were generated within individual Omernik level III ecoregions (Omernik and Griffith, 2014) to produce categorical outputs for each lifeform layer. Model outputs from individual Omernik level III ecoregions were mosaiced together to the VPU extent. Single pixels surrounded by a different class were considered "noise" and removed using a majority filter to produce a more smooth and realistic output.

Layers were then distinguished using the lifeform mask; for example, the tree EVT model output was brought through where the lifeform model had identified tree pixels. Layers were then combined using the riparian/wetland mask, barren/sparse mask, and alpine mask to restrict the mapping of certain vegetation to appropriate geographic locations; for example, the wetland EVT layer was brought through to designated wetland areas so that xeric or other vegetation would not be mistakenly mapped there.

After modeling, forest types that consisted of a mix of conifer and broadleaf dominant/codominant species were split three ways into evergreen, deciduous, and mixed EVT variants using NLCD 2011 for the western contiguous United States and NLCD 2016 when it became available for the eastern contiguous United States (Jin and others, 2013; Homer and others, 2020). This was done to account for strong differences in fire behavior fuel models; for example, pine-oak types were split based on total cover because each of these types has a different fire behavior fuel model. Fire in pine-dominant stands can spread via active crowning, whereas fire in oak-dominant stands tends to spread by surface fuels rather than canopy fuels. Pixels were reclassified using the following rules:

- Pixels overlapping NLCD class 41 (deciduous forest—more than 75-percent deciduous trees) were reclassified to the deciduous or broadleaf variant.
- Pixels overlapping NLCD class 43 (mixed forest—neither deciduous nor evergreen species were greater than 75 percent of total tree cover) were reclassified to the mixed variant.
- Pixels overlapping NLCD class 42 (evergreen forest—more than 75-percent evergreen trees) were reclassified to the evergreen or conifer variant. Pixels that did not overlap NLCD class 41, 42, or 43 were kept in this variant.

The draft thematic map was edited using rulesets based on geography or topography or manual pixel reclassification with hand-drawn polygons based on expert opinion and extensive review by local experts via the NatureServe network. Draft maps also were revised by removing problematic plots identified during the modeling process, reclassifying plots to a better fit for modeling purposes, or adding sample plots based on expert review of high-resolution imagery in Google Earth. This approach was used to correct modeling errors and improve mapping of problematic classes. The reclassified plots and plot additions were used for internal vegetation mapping and modeling purposes only, but LF added an adjusted EVT attribute reflecting these changes to the LFRDB for LF 2016 Remap. Although these reclassifications improved the accuracy of LF's ES and NVC plot labels, issues remained for a few dominant types in which LF 2014 data were used instead of modeled classes because there was no clear resolution even after attempts to improve the model. Additional editing was completed to smooth out model differences where individual Omernik level III ecoregions or VPU boundaries met.

Some difficult classes were not modeled but instead added using hand-drawn polygons. Other difficult classes had custom models using only that type; then, the model output was brought into the map using custom masks created with ancillary layers (for example, sandy soils, buffers on known locations of indicator species, or hand-drawn masks). Some difficult classes were taken from the GAP 2011 land cover map within the appropriate lifeform (U.S. Geological Survey, 2016a). Floodplain types were restricted using a floodplain mask in addition to the wetland mask mentioned previously. A minimum patch size of four or five contiguous pixels was used for plantation types because there was less confidence in the accuracy of the smaller pixel clusters. Some types were modified using EVC; for example, a savanna type with greater than a certain percentage of tree cover was assumed to be a woodland or forest type. Several rare types were restricted by proximity to plot locations because most locations where the rare types have been documented and were included in the program LFDRB with latitude/longitude coordinates from State natural heritage element occurrence data (NatureServe, 2015).

In Puerto Rico and the U.S. Virgin Islands, several difficult to model EVT classes were crosswalked from the Puerto Rico 2000 GAP land cover product (Gould and others, 2008; appendix 1). Across the Pacific insular areas, EVT mapping required the investigation of high-resolution imagery to add approximate pseudoplots for vegetation mapping of island groups in a similar geography such as Micronesia and the Marshall Islands. In American Samoa, a U.S. Department of Marine and Wildlife Resources habitat map (Meyer and others, 2017) was generalized to LF EVT classes via a crosswalk (appendix 1).

D.2.7.3. Wildland Urban Interface Adjusted Classes

Wildland urban interface (WUI) maps produced by the University of Wisconsin SILVIS Laboratory (Radeloff and others, 2018) were used in combination with the following rulesets based on EVT to identify ruderal vegetation in proximity to developed areas.

- Within medium and high density WUI values 8–13, all modeled natural EVT classes were changed to developed ruderal according to lifeform.
- Within low density WUI values 5–13, all modeled ruderal EVT classes were changed to developed ruderal according to lifeform.

These areas subsequently received less intense fire behavior fuel models during fuels mapping.

D.2.7.4. Recently Disturbed Adjusted Classes

Recently disturbed areas were identified using LF disturbance products to appropriately label transitional vegetation using the classes shown in table D4 because modeled outputs for these areas could be misleading; for example, it was more appropriate to label regenerating clearcuts in the Pacific Northwest as recently disturbed, herb and grass cover, than a native montane grassland EVT. Disturbance information was taken from historical disturbance (chap. C) using the year and type of disturbance.

Only disturbances detected by RSLC and fire program data were used to label a pixel as recently disturbed; thus, events data were not used for this purpose. Low-severity disturbances were not changed to recently disturbed classes. Labels were assigned as follows:

- Locations with harvest disturbances and identified as tree lifeform in LF National were labeled as recently logged along with the modeled lifeform.
- Locations with fire disturbances were labeled as recently burned with the modeled lifeform.
- Locations with unknown disturbances were labeled as recently disturbed with the modeled lifeform.

The lifeform in the label represents the circa 2016 lifeform for recently burned and disturbed areas. Recently disturbed areas were identified and labeled according to severity and timing of disturbance as indicated in table D5. TSD was shortened in the southeast VPU (11) from 10 to 8 years and from 5 to 3 years due to the rapid regrowth of conifers in the region.

The entire modeling process was repeated using the NVC labeled plots to produce a separate, additional map. The ES map was created first and given priority with improvement

Table D4. Recently disturbed classes and lifeforms in LANDFIRE 2016 Remap.

Existing vegetation type code	Existing vegetation type name	Lifeform
7191	Recently logged—herb and grass cover	Herb
7192	Recently logged—shrub cover	Shrub
7193	Recently logged—tree cover	Tree
7195	Recently burned—herb and grass cover	Herb
7196	Recently burned—shrub cover	Shrub
7197	Recently burned—tree cover	Tree
7198	Recently disturbed other—herb and grass cover	Herb
7199	Recently disturbed other—shrub cover	Shrub
7200	Recently disturbed other—tree cover	Tree

Table D5. Number of years pixel is labeled recently disturbed.

LANDFIRE National lifeform	Disturbance severity	Years
Tree	High	10
Tree	Medium	5
Shrub	High	5
Shrub	Medium	2
Herb	High	1
Herb	Medium	1

efforts because it was used to create fuels products. The ES map became the best available reference for difficult classes; therefore, classes in the ES map were sometimes used for the NVC map, using a crosswalk where the concepts and class definitions were almost identical. Explicit relations between NVC group-level legend classes and ES legend classes had been determined before mapping and rectification even began (see section D.2.1).

D.2.7.5. Draft Map Review Process

Draft maps of EVT–ES and EVT–NVC were separately reviewed by experts involved in the NatureServe natural heritage network. This network includes governmental and nongovernmental experts throughout the country. Each review was completed by VPU for LF 2016 Remap. The review occasionally resulted in the removal of entire classes, the addition of classes, or the modification of classes in the legend (for example, splitting of lifeforms). When necessary, to address reviewer comments, postprocessing was completed to refine EVT classes either by applying decision rules to relabel pixels or by running new classification tree models based on new information, additional plot data, or changes to plot data. This resulted in an iterative process whereby maps would be adjusted, reviewed again, then adjusted again, and so on, until the map was finalized.

D.2.7.6. Modeling Results

The mapping process for EVT resulted in maps with hundreds of natural, seminatural, and anthropogenic classes summarized in table D6 and table D7. Before distribution of the map layers, a pixel quality assurance and quality control check was completed to ensure the data matched with respect to lifeform, common classes (for example, water, snow/ice, barren/sparse, developed, and agriculture classes), and data extent.

D.2.8. The 90-Kilometer Buffer in Alaska

Fire does not typically respect international borders; therefore, LF included a buffer of 90 kilometers (km) into Canada for the Alaska release of LF 2016 Remap. Modeling and methods were the same as Alaska itself; however, no plots were located in Canada for training. All model variables were the same, including imagery and most ancillary data inputs. Agriculture, developed, and snow/ice masks were derived from the North American Land Change Monitoring System (NALCMS) land cover for 2015 (cropland [15], urban [17], snow and ice [19]; Latifovic and others, 2012). The 90-km buffer was not created for any other areas during LF 2016 Remap.

D.2.9. Agreement Assessment

The LF vegetation production team ran an agreement assessment for EVT–ES and EVT–NVC and provided results to The Nature Conservancy (TNC) LF team for review. The goal was to provide assessment results in tandem with data delivery. The assessment sampling strategy for LF 2016 Remap used the plots withheld during the modeling of EVT–ES and EVT–NVC for each VPU. Withdrawn plots were never used in the modeling process, so they represent an independent assessment sample.

Confusion tables were created for each of the six LF delivery packages (geographic areas [GeoAreas]) across the contiguous United States by cross-tabulating the Auto-Key ES or NVC group assignment for each assessment plot against the LF ES or NVC group assignment for mapped pixels at the plot location. Category-agreement focused tables were then generated from each GeoArea confusion table. No stratification, spatial buffering, or category weighting was used. A summary report was then generated and posted for each GeoArea on the LF website (LANDFIRE, 2021c).

The assessment sample was based on plots previously available to the LF program, so the sample size and distribution reflected the overall plot numbers and categorical distribution present in each GeoArea. Across the contiguous United States, sample sizes were too small to support assessment of most EVT classes, primarily because of the geographically small extent of these systems. The overall agreement results per GeoArea were generally low, but there was variation in results among GeoAreas, and results were not necessarily linked to the number of categories assessed; for example, the southeast GeoArea had the lowest number of EVTs assessed and greater than 70-percent agreement. If the plot assignment did not match the map assignment exactly, the plot was designated as an error, so errors between similar groups were counted the same as errors between dissimilar groups.

Table D6. Number of existing vegetation type ecological system mapped classes by type and geography.

[--, no data or not applicable]

Type	Contiguous United States	Alaska	Hawaii	Insular areas
Developed	25	4	4	4
Agriculture	39	2	4	2
Modeled natural	703	118	29	54
—Tree	339	37	10	28
—Shrub	145	42	10	9
—Herb	157	26	6	7
—Sparse	62	13	3	10
Modeled ruderal	35	--	5	15
—Tree	8	--	3	5
—Shrub	12	--	--	5
—Herb	15	--	2	5
Modeled cultural (plantations)	2	--	--	3
Developed ruderal	40	--	--	--
Recently disturbed	9	--	--	--
Other (water, snow/ice)	2	2	1	1
Total	849	118	38	73

Table D7. Number of existing vegetation type classes of U.S. National Vegetation Classification groups by type and geography.

[--, no data or not applicable]

Type	Contiguous United States	Alaska	Hawaii	Insular areas
Developed	25	4	4	4
Agriculture	39	2	4	2
Modeled natural	395	39	24	45
—Herb	93	8	6	6
—Shrub	113	14	7	9
—Sparse	34	7	4	9
—Tree	155	10	7	21
Modeled ruderal	35	--	5	14
—Herb	15	--	2	5
—Shrub	12	--	--	5
—Tree	8	--	3	4
Modeled cultural	2	--	--	2
Developed ruderal	40	--	--	--
Recently disturbed	9	--	--	--
Other (water, snow/ice)	2	2	1	1
Total	541	39	33	62

D.2.10. Biophysical Settings

Biophysical settings (BpS), or pre-European conditions of vegetation, were considered a vegetation product for LF 2016 Remap because they represent how vegetation may have grown and been disturbed before European colonization of North America.

Information on the development of BpS, or the vegetation models and descriptions for pre-European colonization conditions, is available in Blankenship and others (2021) and has largely been developed and improved upon by the TNC LF team. For LF 2016 Remap, BpS models and descriptions were updated for the contiguous United States but spatial BpS locations were not. Some corrections to the former BpS spatial data were made to account for updated layers to nonvegetated areas such as water, barren, snow, and ice. Where a pixel was one of these classes in the LF 2014 update but was no longer, it was filled with neighboring BpS values using concentric circles to assign a BpS value to pixels with missing data.

As a result of BpS model review by TNC LF, a few map edits were identified and shared with the Earth Resources Observation and Science LF team. These edits mostly involved the splitting or grouping of a few BpS classes, but in some cases, BpS classes could be reassigned to more appropriate BpS models based on geography using established LF mapzones developed by the Multi-Resolution Land Characteristics Consortium. The edits were made to the spatial data attributes as well; for example, some old map codes were retired (for new groupings), some new codes were assigned (for splits), and for other mapzones, their BpS names were changed (table D8).

Attribute updates for BpS codes were linked with the existing raster values. Some of the changes included adding LF mapzones to BpS model codes; for example, BpS code 10110 became 10110_16_23_24 if it was in mapzones 16, 23, and 24. Another change was to include fire regime fields in the BpS attribute table rather than to present them as separate layers (see chap. F).

D.2.11. LANDFIRE 2019 Limited Update Vegetation Transitions

The LF 2019 Limited update incorporated the same vegetation transition rules used in previous updates, translated to apply to updated LF 2016 Remap EVT codes. As mentioned, many new EVT classes were developed and split for LF 2016 Remap; thus, a lookup table was created by partners at the University of Idaho to apply updated codes to pre-Remap transition rules. Only areas that were disturbed between 2017 and 2019 were transitioned and only EVC and EVH changed. No

Table D8. Old and new (LANDFIRE 2016 Remap) biophysical settings name changes.

Mapzone	Old biophysical settings name	New biophysical settings name
2	Mediterranean California Mixed Evergreen Forest	Mediterranean California Mixed Evergreen Forest – Coastal
3	Mediterranean California Mixed Evergreen Forest	Mediterranean California Mixed Evergreen Forest – Coastal
6	Mediterranean California Mixed Evergreen Forest	Mediterranean California Mixed Evergreen Forest – Interior
7	Mediterranean California Mixed Evergreen Forest	Mediterranean California Mixed Evergreen Forest – Interior
6	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Shrubland – Semi-Desert
12	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Shrubland – Semi-Desert
15	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Shrubland – Semi-Desert
16	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Shrubland – Semi-Desert
17	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Shrubland – Semi-Desert
18	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Shrubland – Semi-Desert
23	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Shrubland – Semi-Desert
24	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Shrubland – Semi-Desert
25	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Shrubland – Semi-Desert
28	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Shrubland – Basin Big Sagebrush
31	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Steppe
33	Inter-Mountain Basins Big Sagebrush Shrubland	Inter-Mountain Basins Big Sagebrush Steppe
27	Inter-Mountain Basins Mixed Salt Desert Scrub – South	Inter-Mountain Basins Mixed Salt Desert Scrub
27	Inter-Mountain Basins Mixed Salt Desert Scrub – North	Inter-Mountain Basins Mixed Salt Desert Scrub
41	Laurentian-Acadian Northern Hardwoods Forest	Laurentian-Acadian Northern Hardwoods Forest – Hemlock
50	Laurentian-Acadian Northern Hardwoods Forest	Laurentian-Acadian Northern Hardwoods Forest – Hemlock
51	Laurentian-Acadian Northern Hardwoods Forest	Laurentian-Acadian Northern Hardwoods Forest – Hemlock

EVTs changed for LF 2019 Limited. In some cases, there was a mismatch between EVT lifeform and EVC/EVH lifeform because of LF 2019 Limited rules in disturbed areas.

Millions of rules in the vegetation transition database were applied to LF 2016 Remap data with University of Idaho and Apex cooperators using the ST-Sim functionality of SyncroSim, a state and transition model platform that can apply rules to spatial data inputs and help visualize outputs. LF received rulesets by GeoArea and ran ST-Sim with LF Remap 2016 EVT, EVC, EVH, and capable FDist inputs. Outputs included changes to EVC and EVH based on disturbance type, severity, and TSD codes from FDist (see chap. C); for example, a code of 122 represents a fire (1), with medium severity (2), in a 2–5-year TSD category (2). Only the 2–5-year TSD category was imposed on LF 2016 Remap inputs since 2016 and earlier years already had disturbances accounted for either in natural vegetation modeled EVTs or with the recently disturbed class label along with modeled cover and height reduced by a ruleset (see section D.2.7.4). All recently disturbed class labels remained for LF 2019 Limited because transition rules for these EVTs were not available.

For the final 2019 Limited product, no missing rules were detected, and outputs were assessed for logical change in randomly selected disturbed areas by TNC LF staff for the South Central GeoArea. The FDist TSD category of 2–5 years also included the year 2016; therefore, any low-severity disturbance for 2016 in the fifth year of the 2–5-year FDist category was reenacted on Remap data layers; that is, these disturbances were already accounted for in LF 2016 Remap modeled natural EVTs for cover and height. Low-severity disturbances from 2016 were the only disturbances that were not labeled as recently disturbed and therefore were not excluded from the transition ruleset application. These areas were evaluated in the South Central GeoArea to understand the effect on the final map. Effects to cover or height for reenacted low-severity 2016 disturbances were deemed minor because most happened in herbaceous ecosystems that regenerate quickly.

D.2.12. LANDFIRE 2020 Improvements

Revisions to what LF terms the “base vegetation layer” are typical for a LF update and incorporate vegetation transition rules to account for growth and disturbance, as well as land-use focused updates. For LF 2020, vegetation transitions in areas that were disturbed between 2017 and 2020 were based on the ST-Sim application of the same transition rulesets that were used for LF 2019 Limited (Apex Resource Management Solutions, 2019) that adjust for lifeform, cover, and height using the cause, severity, and the time since the disturbance. The ST-Sim application of the rulesets was only applied to the 2–5 years since disturbance (post-LF 2016 Remap disturbances). The 2019 Limited disturbances only included fire program data and the events in the Events Geodatabase for 2017–19 and did not include RSLC, which is why the update was called limited. This means that the LF 2020 product, which uses the same vegetation transition rules but also includes more disturbances for 2017–19 and includes an additional year of disturbance (2020), replaces the 2019 Limited vegetation transitions in disturbed areas. This methodology also implies that the disturbances that were recent to LF 2016 Remap (for example, 2014–16) have had about 5 years of growth postdisturbance and this growth is not represented in LF 2020. Vegetation products for LF 2020 pixels not mapped as disturbed by LF from 2017 to 2020 are not different from LF 2016 Remap vegetation (but see developed ruderal and recently disturbed updates later in this chapter). Vegetation products for LF 2020 pixels mapped as disturbed by LF from 2017 to 2020 have been transitioned to estimate 2022 vegetation cover and height in the LF 2020 version using vegetation transition rulesets within the ST-Sim state and transition rule framework. These products include capable vegetation, bringing the data to a 2022 effective condition in disturbed areas. Disturbances from 2021 and 2022 are not included in LF 2020 disturbed vegetation transitions.

Additionally, improvements to the vegetation classes, such as replacing recently disturbed and developed ruderal classes with modeled EVTs from the LF 2016 Remap, are included in the LF 2020 update. Pixels remained unchanged for the following classes (the pixels match LF 2016 Remap):

- Water (11),
- Snow/ice (12),
- Barren and sparse (31 and 100), and
- Quarries-strip mines-gravel pits-well and wind pads (32).

LF base vegetation layer updates also include using more recent datasets to define changes in locations to roads, agriculture, and developed land to reflect the human-affected environment more accurately. Additionally, a 90-km buffer into Canada and Mexico was mapped for EVT, EVC, and EVH in a highly aggregated manner to assist in cross-border fire behavior mapping. All updates to vegetation and land-use classes filter through to apply to fuels layers as well; for example, if a road changed position in the base vegetation layer, it also changed in the fuel layers.

Specifically, LF 2020 developed classes were identified using NLCD 2019 land cover for the contiguous United States using the same methods as LF 2016 Remap (with additional improvements detailed later in this chapter). Roads were identified using the NLCD 2019 impervious descriptor for the contiguous United States (U.S. Geological Survey, 2021a). All pixels for primary and secondary roads were used. Tertiary roads were used where there was less than 75-percent tree CC in NLCD 2016 U.S. Department of Agriculture Forest Service tree canopy cover (Coulston and others, 2012; U.S. Geological Survey, 2021d). In general, priority was given to developed classes except when the tree cover superseded the roads. Agriculture classes were identified using 2020 CDL. The various classes in CDL were crosswalked to the

LF 2016 Remap-era agriculture classes. California maintains a detailed agricultural layer that was used in LF 2016 Remap and for LF 2020.

These numerous updates (described in detail later in this chapter) serve to create a product that better reflects vegetation, roads, development, and agriculture and adds a 90-km buffer of base vegetation information to the contiguous U.S. region. Although not all datasets reflect the year 2020, they are the most recent available and are more recent than what was available for LF 2016 Remap. LF continues to use the most recent and relevant geospatial data available to offer a map that reflects current conditions as much as possible.

D.2.12.1. Updating Existing Vegetation Classes

A new EVT base layer was prepared by removing recently disturbed classes (7191–7200) and developed ruderal classes (7920–7959) and filling with modeled data from the LF 2016 Remap process. Details for each category of classes are described later in this chapter.

D.2.12.1.1. Recently Disturbed

The first step to updating the vegetation layer for LF 2020 was to fill in modeled EVTs for LF 2016 Remap recently disturbed classes. This effort was started because vegetation transition rules for LF 2020 were not designed to be applied to recently disturbed classes. Initially, in the process of creating LF 2016 Remap, recently disturbed areas contained modeled EVTs, but these data were known to often be mislabeled as shrub or herb EVTs when they could represent areas of recovery toward treed systems (for example, saplings). Similar to previous LF versions, LF 2016 Remap methodology labeled these areas as recently disturbed classes and distinguished them only by lifeform and disturbance type. Additionally, rulesets were applied in LF 2016 Remap to decrease cover and height from modeled cover and height to for the presumed effects of disturbance (fig. D2). The “recent” pixels removed in LF 2020 (see table D5 for the LF 2016 Remap definition of “recent” for different lifeforms and disturbance severities), were replaced with LF 2016 Remap modeled EVTs. Errors in modeling postdisturbance EVTs for LF 2016 Remap were deemed acceptable because the transition rules did not account for recently disturbed labels for areas disturbed between 2017 and 2020, creating a situation where LF 2016 Remap “recent” became older than transitioned areas. The recently disturbed classes that were replaced with LF 2016 Remap modeled EVTs are listed in table D4. The adjusted EVC and EVH values in recently disturbed areas were retained for LF 2020 because the LF update transition rulesets were applied only for new disturbances post-Remap.

D.2.12.1.2. Developed Ruderal

The second step to updating EVTs in LF 2020 was to fill in modeled EVTs from LF 2016 Remap for the developed ruderal classes. In 2021, several stakeholders notified LF that the developed ruderal classes in LF 2016 Remap were encompassing too much natural vegetation in the WUI (table D9). Developed ruderal classes are different from Auto-Key assigned “natural” ruderal classes because they were assigned after modeling using the SILVIS WUI layer (Radeloff and others, 2018) during the creation of LF 2016 Remap (table D10). There was a concern that these classes were not representing natural vegetation near developed land in terms of fire behavior in large fire hazard simulations and compared to previous LF products for these areas. The developed ruderal classes had been assigned less intense fuel models in the surface fuels layers to represent the WUI and presumed reduction of surface fuels near habitation for LF 2016 Remap. In discussions with stakeholders, it was apparent that the SILVIS WUI layer used to designate developed ruderal areas relies partially on census tracts to delineate WUI classes, which was too broad for fuels applications. Use of the census tracts to designate WUI classes included land that was not actually developed or did not demonstrate indications of differences in fire behavior.

A similar process was used in the creation of developed ruderal classes for LF 2016 Remap as had been used with recently disturbed classes, where first the area was modeled similarly to other natural vegetation (for EVT, EVC, and EVH), the developed ruderal designation was imposed on top of initial modeled vegetation type classes (retaining forest type, lifeform, EVC, and EVH information) with the use of the SILVIS WUI layer and other inputs; therefore, the second step to updating vegetation classes for LF 2020 was to fill in the original modeled LF 2016 Remap EVTs for the developed ruderal pixels. For LF 2020, developed ruderal classes reflect LF 2016 Remap modeled EVTs before the imposition of the developed ruderal label.

D.2.12.2. Updating Land-Use Classes

For LF 2020, several new land-use layers were available to update the human-altered landscape. These updates are important for representing areas of habitat fragmentation, fuels continuity, and burnable versus nonburnable lands. A new NLCD 2019 layer was used with updates to roads and urban areas (U.S. Geological Survey, 2021b, c). A new CDL 2020 also was released and incorporated for LF 2020 (Boryan and others, 2011). Additionally, a new requirement to identify nonburnable agriculture on Federal lands and shift those lands to a burnable type was implemented using the Protected Areas Database (PAD), version 2.1 (U.S. Geological Survey Gap

Table D9. Developed ruderal classes in LANDFIRE 2016 Remap but not in LANDFIRE 2020.

Value	Existing vegetation type name
7920	Western Cool Temperate Developed Ruderal Deciduous Forest
7921	Western Cool Temperate Developed Ruderal Evergreen Forest
7922	Western Cool Temperate Developed Ruderal Mixed Forest
7923	Western Cool Temperate Developed Ruderal Shrubland
7924	Western Cool Temperate Developed Ruderal Grassland
7925	Western Warm Temperate Developed Ruderal Deciduous Forest
7926	Western Warm Temperate Developed Ruderal Evergreen Forest
7927	Western Warm Temperate Developed Ruderal Mixed Forest
7928	Western Warm Temperate Developed Ruderal Shrubland
7929	Western Warm Temperate Developed Ruderal Grassland
7930	Eastern Cool Temperate Developed Ruderal Deciduous Forest
7931	Eastern Cool Temperate Developed Ruderal Evergreen Forest
7932	Eastern Cool Temperate Developed Ruderal Mixed Forest
7933	Eastern Cool Temperate Developed Ruderal Shrubland
7934	Eastern Cool Temperate Developed Ruderal Grassland
7935	Eastern Warm Temperate Developed Ruderal Deciduous Forest
7936	Eastern Warm Temperate Developed Ruderal Evergreen Forest
7937	Eastern Warm Temperate Developed Ruderal Mixed Forest
7938	Eastern Warm Temperate Developed Ruderal Shrubland
7939	Eastern Warm Temperate Developed Ruderal Grassland
7940	Western Cool Temperate Developed Ruderal Deciduous Forested Wetland
7941	Western Cool Temperate Developed Ruderal Evergreen Forested Wetland
7942	Western Cool Temperate Developed Ruderal Mixed Forested Wetland
7943	Western Cool Temperate Developed Ruderal Shrub Wetland
7944	Western Cool Temperate Developed Ruderal Herbaceous Wetland
7945	Western Warm Temperate Developed Ruderal Deciduous Forested Wetland
7946	Western Warm Temperate Developed Ruderal Evergreen Forested Wetland
7947	Western Warm Temperate Developed Ruderal Mixed Forested Wetland
7948	Western Warm Temperate Developed Ruderal Shrub Wetland
7949	Western Warm Temperate Developed Ruderal Herbaceous Wetland
7950	Eastern Cool Temperate Developed Ruderal Deciduous Forested Wetland
7951	Eastern Cool Temperate Developed Ruderal Evergreen Forested Wetland
7952	Eastern Cool Temperate Developed Ruderal Mixed Forested Wetland
7953	Eastern Cool Temperate Developed Ruderal Shrub Wetland
7954	Eastern Cool Temperate Developed Ruderal Herbaceous Wetland
7955	Eastern Warm Temperate Developed Ruderal Deciduous Forested Wetland
7956	Eastern Warm Temperate Developed Ruderal Evergreen Forested Wetland
7957	Eastern Warm Temperate Developed Ruderal Mixed Forested Wetland
7958	Eastern Warm Temperate Developed Ruderal Shrub Wetland
7959	Eastern Warm Temperate Developed Ruderal Herbaceous Wetland

Table D10. Auto-Key designated (nondeveloped) ruderal classes that remain in LANDFIRE 2020.

Value	Existing vegetation type name
9301	California Ruderal Grassland and Meadow
9337	California Ruderal Scrub
9302	Californian Ruderal Forest
9307	Great Basin & Intermountain Introduced Annual and Biennial Forbland
9308	Great Basin & Intermountain Introduced Annual Grassland
9309	Great Basin & Intermountain Introduced Perennial Grassland and Forbland
9336	Great Basin & Intermountain Ruderal Shrubland
9825	Great Plains Comanchian Ruderal Grassland
9325	Great Plains Comanchian Ruderal Shrubland
9327	Interior West Ruderal Riparian Forest
9827	Interior West Ruderal Riparian Scrub
9828	Interior Western North American Temperate Ruderal Grassland
9328	Interior Western North American Temperate Ruderal Shrubland
9810	North American Warm Desert Ruderal & Planted Grassland
9310	North American Warm Desert Ruderal & Planted Scrub
9811	North Pacific Maritime Coastal Sand Dune Ruderal Herb Vegetation
9311	North Pacific Maritime Coastal Sand Dune Ruderal Scrub
9314	Northern & Central Native Ruderal Flooded & Swamp Forest
9315	Northern & Central Native Ruderal Forest
9816	Northern & Central Plains Ruderal & Planted Grassland
9316	Northern & Central Plains Ruderal & Planted Shrubland
9817	Northern & Central Ruderal Meadow
9317	Northern & Central Ruderal Shrubland
9318	Northern & Central Ruderal Wet Meadow & Marsh
9332	Southeastern Exotic Ruderal Flooded & Swamp Forest
9319	Southeastern Exotic Ruderal Forest
9320	Southeastern Native Ruderal Flooded & Swamp Forest
9321	Southeastern Native Ruderal Forest
9823	Southeastern Ruderal Grassland
9323	Southeastern Ruderal Shrubland
9324	Southeastern Ruderal Wet Meadow & Marsh
9826	Southern Vancouverian Lowland Ruderal Grassland
9326	Southern Vancouverian Lowland Ruderal Shrubland
9829	Western North American Ruderal Wet Meadow & Marsh
9329	Western North American Ruderal Wet Shrubland

Analysis Project, 2020). Finally, the availability of two building cover datasets derived from the Microsoft building footprint dataset (Microsoft, 2021)—one 30-m rasterized version of the Microsoft vector version (Heris and others, 2020) and one value-added layer used for Wildfire Risk to Communities (WRC) from Pyrologix (2021)—provided the opportunity to add detail to the NLCD-based nonburnable developed classes and create new burnable developed classes based on building densities. Detailed later in this chapter are the specific methods for each update. They are presented in order of the prioritization in the following list, where a no. 1 layer would trump a no. 2 layer and so on.

1. Roads, modified for canopy fuels continuity from NLCD 2019 impervious surface/roads layer;
2. New developed high, medium, and low intensity (from NLCD 2019 urban classes 22, 23, 24) and burnable urban (derived from NLCD 2019 developed open space class 21 and split into five classes);
3. New burnable developed (7920–7939, 2908–2912), derived from two new building cover layers (described later in this chapter); and
4. New agriculture, derived from CDL 2020 (Federal burnable agriculture updates used LF 2016 Remap agricultural classes on PAD Federal lands, not new CDL 2020 agriculture).

Considering the burnable urban classes were derived from NLCD 2019 and the burnable developed classes were derived from the Microsoft building total footprint coverage layer (Heris and others, 2020; Microsoft, 2021) and WRC layer from Pyrologix (2021), it was determined that these similar concept classes should maintain different labels. Additionally, burnable urban classes did not have modeled cover and height but were assigned a generic range, whereas burnable developed areas maintained modeled cover and height. The new burnable developed classes represent a much more detailed version or restricted concept of the previous developed ruderal classes, whereas the NLCD-derived burnable urban classes are produced in the same manner as LF 2016 Remap, just using updated NLCD from 2019. Note that nonburnable urban from NLCD 2019 and nonburnable developed derived from the building cover layers were placed into the developed classes traditionally used only for low, medium, and high intensity developed areas derived from NLCD classes because these concepts are similar in terms of the source data and do not affect differences in fuel assignments. The following sections detail the methods for deriving each land-use update in the order of the highest priority assigned to each pixel from the previously provided list.

D.2.12.2.1. Road Mask

The roads layer in LF represents two important aspects of fire: (1) fuels continuity for fire behavior and (2) access for operations and firefighting. Historically, LF roads have focused on incorporating fuels continuity in our base vegetation layer to accurately reflect fire behavior, and we have continued this approach for LF 2020 by using the NLCD 2016 tree canopy cover layer to “erase” NLCD 2019 roads where there is greater than 75-percent CC. This canopy continuity carries through to the fuel layers.

The roads for the LF 2020 vegetation and fuels layers were created from the NLCD 2019 impervious descriptor layer (U.S. Geological Survey, 2021b) using pixels of primary road (value 20), secondary road (value 21), and tertiary road (value 22) that were <75 percent CC from the NLCD 2016 U.S. Department of Agriculture Forest Service tree canopy cover layer (U.S. Geological Survey, 2021d). (Pixels that were labeled as roads (7299) in LF 2016 Remap and were not identified in the new road mask were designated to burnable urban classes (7900–7919, 2913–2917) according to the burnable urban mask.

For Hawaii, Puerto Rico, American Samoa, and Guam, 2017 U.S. Census Bureau Topologically Integrated Geographic Encoding and Referencing lines were used to delineate roads in the vegetation and fuel layers (U.S. Census Bureau, 2017). A crosswalk was created using the Master Address File/Topologically Integrated Geographic Encoding and Referencing feature class code listed in appendix 1 (table 1.6). Roads were added to the base EVT layer by first selecting the named primary, secondary, and tertiary roads, buffering the primary roads by 30 m and the secondary and tertiary roads by 15 m, converting to raster using the center point of overlapping pixels, then recoding overlapping pixels of developed open space, low intensity, medium intensity, and high intensity to roads (EVT class 7299).

D.2.12.2.2. New Operational Roads Layer

For LF 2020, a second roads layer including all NLCD 2019 roads and including all pixels of tertiary roads (value 22) and thinned roads (value 23) is available. This layer should address the need to provide this information for operations purposes on large fires or incidents so that the spatial data can quickly be “burned in” on top of other geospatial operations data. The NLCD 2019 roads layer was favorably compared to (and incorporates) other road layers such as HERE transportation data available via the Department of Homeland Security (2020) to eligible users.

In Alaska, the NLCD 2016 urban descriptor for Alaska and HERE roads were combined by buffering the HERE roads by 15 m, rasterizing them, and adding them to the NLCD roads. Where NLCD and HERE roads overlapped, NLCD was used. HERE classes were translated to NLCD primary, secondary, tertiary, and thinned roads based on the descriptions, whether a road was paved, and speed categories.

The new operational roads layers for Hawaii, Puerto Rico, American Samoa, and Guam were derived from the 2017 U.S. Census Bureau Topologically Integrated Geographic Encoding and Referencing lines (U.S. Census Bureau, 2017) and include pixels within 15 m of the road lines. The lines were buffered by 15 m and then converted to raster using the “recode” field to designate the new pixel values.

D.2.12.2.3. Developed Land Mask and New Burnable Developed Classes

Developed nonburnable classes for LF 2020 were derived from different sources. Where layers overlapped, NLCD 2019 was assigned the highest priority layer, then the USGS raster version of the Microsoft building area second priority (Heris and others, 2020), and the WRC building cover layer third priority (Pyrologix, 2021).

D.2.12.2.3.1. Developed Nonburnable Classes Derived from National Land Cover Database 2019

The most recently released NLCD 2019 land cover was used to label nonburnable developed classes in a manner identical to the LF 2016 Remap where NLCD 24 was designated as developed-high intensity (7298), NLCD 23 as developed-medium intensity (7297), and NLCD 22 as developed-low intensity (7296).

D.2.12.2.3.2. Developed Nonburnable Classes Derived from Building Cover Datasets

The USGS building total footprint coverage raster (Heris and others, 2020) derived from the Microsoft building cover vector layer (Microsoft, 2021) was used to provide further detail on developed nonburnable areas to delineate natural vegetation more accurately from developed ruderal areas in LF 2016 Remap. For nonburnable developed classes, the following thresholds were used with the Heris and others (2020) building area raster layer:

- Values ≥90 (10 percent of a pixel) are 7296 (developed-low intensity),
- Values ≥225 (25 percent of a pixel) are 7297 (developed-medium intensity), and
- Values ≥450 (50 percent of a pixel) are 7298 (developed-high intensity).

Nonburnable developed classes also were labeled using the WRC building cover layer (Pyrologix, 2021). This layer is a value-added version of the Microsoft building vector layer (version 1.0 and version 1.1) rasterized with a moving window using a 75-m radius. This layer was designed specifically for wildland fire risk to communities applications and provides a smoother gradient from developed to nondeveloped areas along with fixes to the Microsoft footprint layer anomalies such as missing data. The following percentage of cover thresholds were used to designate nonburnable urban classes using the WRC building cover (Pyrologix, 2021):

- Values ≥25 are 7296 (developed-low intensity),
- Values ≥50 are 7297 (developed-medium intensity),
- Values ≥75 are 7298 (developed-high intensity), and
- Values ≥1 are 7296 (developed-low intensity in low NDVI for desert areas only in shrub and herb lifeforms in the western contiguous United States).

D.2.12.2.3.3. Developed/Urban Burnable Classes Derived from National Land Cover Database 2019

NLCD class 21 (developed open space) was made “burnable” by splitting it into five “burnable urban” classes that capture the variety of lifeform (herb, shrub, tree) and leaf form (deciduous, evergreen, mixed) across the open space designation and emulate NLCD classes 41, 42, 43, 52, and 71 and are further stratified by geography as follows:

- 41 is urban deciduous forest (7900, 7905, 7910, 7915),
- 42 is urban evergreen forest (7901, 7906, 7911, 7916),
- 43 is urban mixed forest (7902, 7907, 7912, 7917),
- 52 is urban shrubland (7904, 7909, 7914, 7919), and
- 71 is urban herbaceous (7903, 7908, 7913, 7918).

The five burnable urban classes were modeled by VPU for every pixel by randomly sampling 120 points in each processing block (1,024 x 1,024 pixels) from NLCD 2019 classes 41, 42, 43, 52, and 71 based on the proportion of each class in the block. A See5 model (Quinlan, 1993; RuleQuest Research, 2006) was generated from these samples using imagery generated during LF 2016 Remap to predict the five classes for all pixels. Imagery included temporal NDVI composites (2013–17 minimum, maximum, median, and difference between maximum and medium) along with a summer composite, a summer tasseled-cap composite, and a winter tasseled-cap composite (only for VPU 8–13). The resultant five burnable urban classes were used to update pixels within NLCD 2019 class 21 and retired roads and previously mapped developed areas from LF 2016 Remap for use with the LF 2020 update. Burnable urban classes from LF 2016 Remap were not changed, but they were overwritten if new roads, developed, or agriculture designations were present.

D.2.12.2.3.4. New Burnable Developed Classes

The new building footprint data layers were used to help replace the developed ruderal classes (see section D.2.12.1.2). The building footprint layers capture a more nuanced concept of low-density developed areas that could easily carry a fire but that may represent less continuous fuels and a lower rate of spread in average fire season conditions. Additionally, more detailed building cover information can assist firefighters in understanding where isolated homes and businesses may be located. Burnable developed lands were designated as follows where the USGS building area layer trumped the WRC building cover values where there was overlap:

- USGS building area values ≥10 (1 percent of pixel) and
- WRC building cover values ≥5 (percentage of building cover).

A new series of burnable developed classes with low building density was added to the EVT legend based on the previously provided criteria, and a look-up table was developed to relate EVTs to the new burnable developed classes based on the EVT_Phys field (for example, deciduous, evergreen, mixed, shrubland, and herbaceous). The new burnable developed classes created for the LF 2020 vegetation and fuels update are listed in table D11. EVC and EVH were not changed, and LF 2016 Remap modeled EVC and EVH data were used for the new burnable developed classes. The lifeform designations between the two layers also is consistent because they were labeled by EVT_Phys.

D.2.12.2.4. Agriculture Mask

A new agricultural mask was created for LF 2020 because a new CDL 2020 was available from the National Agricultural Statistics Service (Boryan and others, 2011). In the past, stakeholders from California have expressed that their crop layer is preferred to the national layer, and we used the California layer in LF 2016 Remap; therefore, we repeated that methodology for LF 2020 using the 2018 version of the California Statewide Crop Mapping geodatabase (California Department of Water Resources, 2021). To create the agriculture update, the CDL 2020 was crosswalked to LF classes using a lookup function similar to the crosswalk for LF 2016 Remap with slight changes because of added CDL classes (appendix 1). For California, the California Statewide Crop Mapping geodatabase was used. A new field was created combining class 2

Table D11. New developed classes added to the base vegetation layer and corresponding fuel vegetation type labels.

[Dtd, developed tree deciduous; Dtc, developed tree coniferous; Dtm, developed tree mixed; Dgr, developed grass; Dsh, developed shrub]

Value	Existing vegetation type name	Ecological systems code used for fuel product development	Ecological systems class name used for fuel product development
7920	Western Cool Temperate Developed Deciduous Forest	2908	Dtd Developed Deciduous Forest
7921	Western Cool Temperate Developed Evergreen Forest	2909	Dtc Developed Evergreen Forest
7922	Western Cool Temperate Developed Mixed Forest	2910	Dtm Developed Mixed Deciduous-Evergreen Forest
7923	Western Cool Temperate Developed Herbaceous	2911	Dgr Developed Herbaceous
7924	Western Cool Temperate Developed Shrubland	2912	Dsh Developed Shrubland
7925	Eastern Cool Temperate Developed Deciduous Forest	2908	Dtd Developed Deciduous Forest
7926	Eastern Cool Temperate Developed Evergreen Forest	2909	Dtc Developed Evergreen Forest
7927	Eastern Cool Temperate Developed Mixed Forest	2910	Dtm Developed Mixed Deciduous-Evergreen Forest
7928	Eastern Cool Temperate Developed Herbaceous	2911	Dgr Developed Herbaceous
7929	Eastern Cool Temperate Developed Shrubland	2912	Dsh Developed Shrubland
7930	Western Warm Temperate Developed Deciduous Forest	2908	Dtd Developed Deciduous Forest
7931	Western Warm Temperate Developed Evergreen Forest	2909	Dtc Developed Evergreen Forest
7932	Western Warm Temperate Developed Mixed Forest	2910	Dtm Developed Mixed Deciduous-Evergreen Forest
7933	Western Warm Temperate Developed Herbaceous	2911	Dgr Developed Herbaceous
7934	Western Warm Temperate Developed Shrubland	2912	Dsh Developed Shrubland
7935	Eastern Warm Temperate Developed Deciduous Forest	2908	Dtd Developed Deciduous Forest
7936	Eastern Warm Temperate Developed Evergreen Forest	2909	Dtc Developed Evergreen Forest
7937	Eastern Warm Temperate Developed Mixed Forest	2910	Dtm Developed Mixed Deciduous-Evergreen Forest
7938	Eastern Warm Temperate Developed Herbaceous	2911	Dgr Developed Herbaceous
7939	Eastern Warm Temperate Developed Shrubland	2912	Dsh Developed Shrubland

and subclass 2 attributes and each combination was assigned a unique value because the combination provided additional information for the California crosswalk (appendix 1). The polygon layer was converted to raster based on the unique value. A lookup table based on descriptions in the metadata was used to assign LF codes to pixels via the combined unique field. All CDL 2020 data in California were erased and replaced with California Statewide Crop Mapping data. NLCD 2019 pasture/hay (81) also was added to the agriculture layer, but it was trumped by CDL 2020 and the California Statewide Crop Mapping layer where data were available.

In burnable agriculture areas (see table D12), EVC and EVH were universally assigned for certain classes where height and cover were not already modeled in LF 2016 Remap. Cover and height were based on the following:

- Orchards—45-percent tree cover, 10-m height;
- Bush fruit and berries—45-percent shrub cover, 0.5-m height;
- Fallow/idle cropland and pasture/hay—55-percent herbaceous cover, 0.3-m height; and
- Fallow/idle cropland and pasture/hay—15-percent herbaceous cover, 0.3-m height in low NDVI.

Areas that were agriculture in LF 2016 Remap but were not present in the new agriculture mask using CDL 2020 and California crop maps were reclassified to fallow/idle cropland (EVT 7966, 7976, 7986, 7996). What was fallow/idle cropland or pasture/hay (EVT 7967, 7977, 7987, 7997) in LF 2016 Remap was left as is.

D.2.12.2.4.1. Burnable Federal Lands

Federal stakeholders had expressed a need for all Federal lands to be of a burnable type. In previous versions of LF, mapped agriculture data sources identified substantial amounts of nonburnable agriculture on Federal lands (see table D12 for nonburnable and burnable agricultural types). For LF 2020, the CDL 2020-derived agricultural mask mentioned previously was not imposed on Federal lands. Almost all LF 2016 Remap nonburnable agriculture lands on federally managed or federally owned lands, were changed to burnable, a fallow/idle cropland type with default cover and height values. Irrigated agricultural lands identified by the Landsat based irrigation dataset, (Xie and Lark, 2021) were not changed to a burnable type. Federal land was identified by merging two layers derived from the PAD, version 2.1 (U.S. Geological Survey Gap Analysis Project, 2020):

1. For layer 1,
    a. Queried and exported: Own_Type = ‘FED’ or Own_Type = ‘TRIB’;
    b. From a, queried and exported: “Mang_Type” = ‘FED’ OR “Mang_Type” = ‘TRIB’;
        i. Note that no agriculture easements were in these queries.
2. For layer 2,
    a. Queried and exported: Unit_Nm LIKE ‘%National Wildlife Refuge’.
3. Merged layer 1 and layer 2, converted polygon to raster on cell center.

D.2.12.3. The 90-Kilometer Buffer for LANDFIRE 2020 (Contiguous United States)

The 90-km buffer for the contiguous United States is included for LF 2020; however, it is a generalized version of vegetation type, cover, and height based on a relation between the NALCMS (Latifovic and others, 2012) and LF EVTs. The approach for the 90-km buffer into Canada and Mexico is considered a first pass using 2015 NALCMS (Commission for Environmental Cooperation, 2020) classes. Spatial combines relating NALCMS classes to EVT, EVC, and EVH on the U.S. side of the border (90 km within) were produced, then LF vegetation values from the combines were applied to NALCMS classes outside of the border in a 90 km buffer.

The general methods were to label EVT within the 90-km buffer based on NALCMS class, topography, and Daymet. The mapzone boundaries were extended into the 90-km buffer outside of the contiguous United States using a straight line (fig. D3).

D.2.12.3.1. The 90-Kilometer Buffer Within the Contiguous United States

An analysis area was established 90 km into the contiguous United States by mapzone to understand the relation between NALCMS classes and LF products within the U.S. border (fig. D3). This resulted in the creation of an EVT lookup and corresponding EVC/EVH for use in mapping the 90-km buffer outside of the contiguous United States. To create the EVT lookup for the 90-km buffer into the contiguous United States, the total area of each EVT was tabulated within each NALCMS class. The most common EVT classes were reviewed and formed the basis of the lookup for assigning EVT within the 90-km buffer outside of the contiguous United States discussed later in this chapter. EVTs were selected by expert opinion according to the most appropriate EVT based on lifeform and geography. Additional EVT splits were made using LF elevation and aspect, along with Daymet values for maximum temperature and precipitation (Thornton and others, 2020).

To create EVC/EVH lookup by mapzone, the following steps were taken:

1. Reclassed aspect according to table D13,
2. Combined EVT and reclassed aspect, and

Table D12. Agricultural types in LANDFIRE.

[Da, developed agriculture; Dab, developed agriculture burnable]

Existing vegetation type code	Existing vegetation type name	Ecological systems code used for fuel product development	Ecological systems class name used for fuel product development	Existing vegetation type lifeform
		Nonburnable		
7979	Eastern Cool Temperate Aquaculture	2969	Da Aquaculture	Agriculture
7989	Western Warm Temperate Aquaculture	2969	Da Aquaculture	Agriculture
7999	Eastern Warm Temperate Aquaculture	2969	Da Aquaculture	Agriculture
7965	Western Cool Temperate Close Grown Crop	2965	Da Close Grown Crop	Agriculture
7975	Eastern Cool Temperate Close Grown Crop	2965	Da Close Grown Crop	Agriculture
7985	Western Warm Temperate Close Grown Crop	2965	Da Close Grown Crop	Agriculture
7995	Eastern Warm Temperate Close Grown Crop	2965	Da Close Grown Crop	Agriculture
7964	Western Cool Temperate Row Crop	2964	Da Row Crop	Agriculture
7974	Eastern Cool Temperate Row Crop	2964	Da Row Crop	Agriculture
7984	Western Warm Temperate Row Crop	2964	Da Row Crop	Agriculture
7994	Eastern Warm Temperate Row Crop	2964	Da Row Crop	Agriculture
7963	Western Cool Temperate Row Crop – Close Grown Crop	2963	Da Row Crop – Close Grown Crop	Agriculture
7973	Eastern Cool Temperate Row Crop – Close Grown Crop	2963	Da Row Crop – Close Grown Crop	Agriculture
7983	Western Warm Temperate Row Crop – Close Grown Crop	2963	Da Row Crop – Close Grown Crop	Agriculture
7993	Eastern Warm Temperate Row Crop – Close Grown Crop	2963	Da Row Crop – Close Grown Crop	Agriculture
7961	Western Cool Temperate Vineyard	2961	Da Vineyard	Agriculture
7971	Eastern Cool Temperate Vineyard	2961	Da Vineyard	Agriculture
7981	Western Warm Temperate Vineyard	2961	Da Vineyard	Agriculture
7991	Eastern Warm Temperate Vineyard	2961	Da Vineyard	Agriculture
7968	Western Cool Temperate Wheat	2968	Da Wheat	Agriculture
7978	Eastern Cool Temperate Wheat	2968	Da Wheat	Agriculture
7988	Western Warm Temperate Wheat	2968	Da Wheat	Agriculture
7998	Eastern Warm Temperate Wheat	2968	Da Wheat	Agriculture
		Burnable		
7962	Western Cool Temperate Bush fruit and berries	2962	Dab Bush Fruit and Berries	Shrub
7972	Eastern Cool Temperate Bush fruit and berries	2962	Dab Bush Fruit and Berries	Shrub
7982	Western Warm Temperate Bush fruit and berries	2962	Dab Bush Fruit and Berries	Shrub
7992	Eastern Warm Temperate Bush fruit and berries	2962	Dab Bush Fruit and Berries	Shrub
7966	Western Cool Temperate Fallow/Idle Cropland	2966	Dab Fallow/Idle Cropland	Herb
7976	Eastern Cool Temperate Fallow/Idle Cropland	2966	Dab Fallow/Idle Cropland	Herb
7986	Western Warm Temperate Fallow/Idle Cropland	2966	Dab Fallow/Idle Cropland	Herb

Table D12. Agricultural types in LANDFIRE. —Continued

[Da, developed agriculture; Dab, developed agriculture burnable]

Existing vegetation type code	Existing vegetation type name	Ecological systems code used for fuel product development	Ecological systems class name used for fuel product development	Existing vegetation type lifeform
		Burnable—Continued		
7996	Eastern Warm Temperate Fallow/Idle Cropland	2966	Dab Fallow/Idle Cropland	Herb
7960	Western Cool Temperate Orchard	2960	Dab Orchard	Tree
7970	Eastern Cool Temperate Orchard	2960	Dab Orchard	Tree
7980	Western Warm Temperate Orchard	2960	Dab Orchard	Tree
7990	Eastern Warm Temperate Orchard	2960	Dab Orchard	Tree
7967	Western Cool Temperate Pasture and Hayland	2967	Dab Pasture and Hayland	Herb
7977	Eastern Cool Temperate Pasture and Hayland	2967	Dab Pasture and Hayland	Herb
7987	Western Warm Temperate Pasture and Hayland	2967	Dab Pasture and Hayland	Herb
7997	Eastern Warm Temperate Pasture and Hayland	2967	Dab Pasture and Hayland	Herb

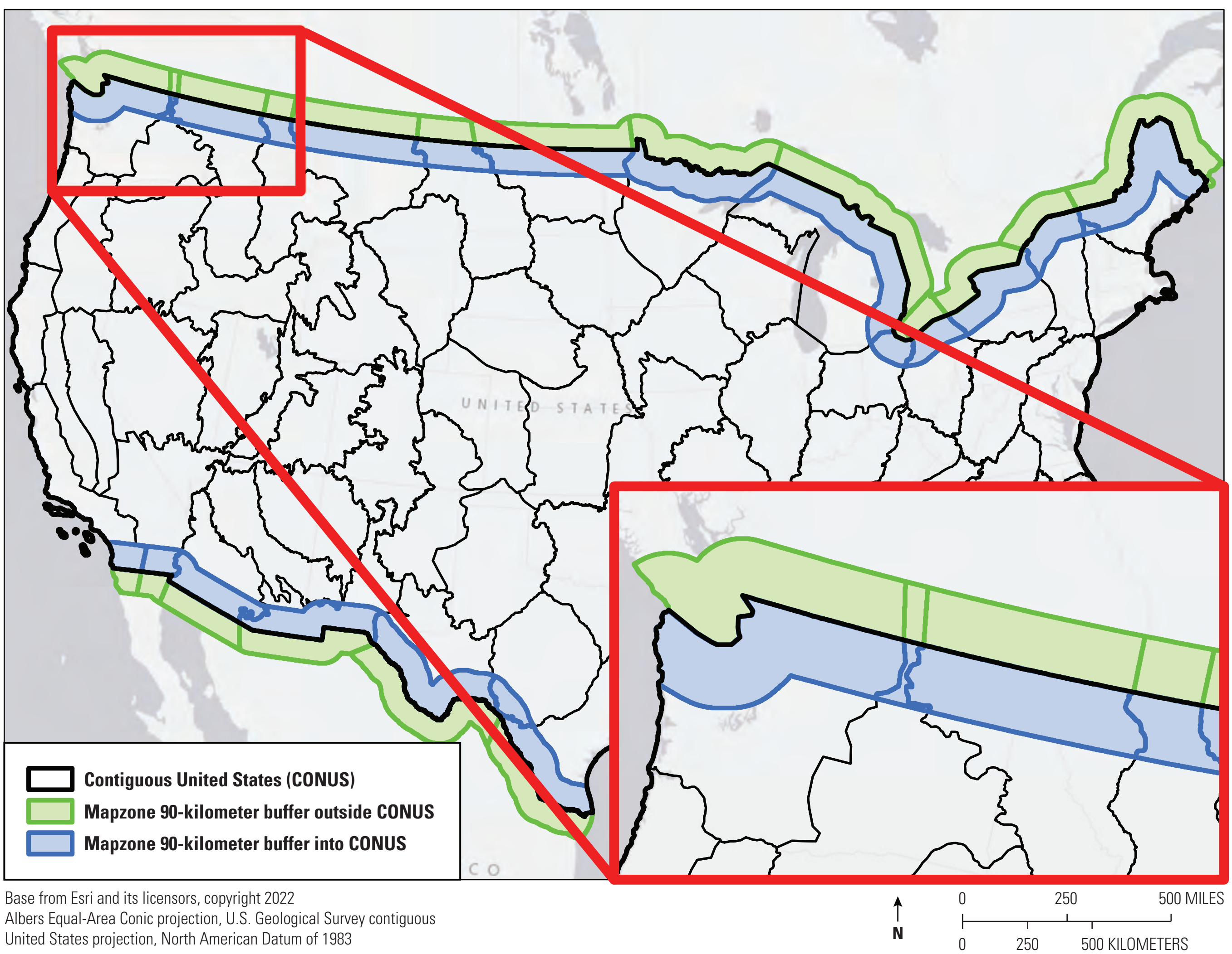


Figure D3. The 90-kilometer buffer area for development (blue) and application (green) by mapzone.

Table D13. Reclassed aspect used for existing vegetation cover and existing vegetation height assignments in the 90-kilometer buffer.

Raster value	Direction	Bin range
0	North	338–22
45	Northeast	23–67
90	East	68–112
135	Southeast	113–157
180	South	158–202
225	Southwest	203–247
270	West	248–292
315	Northwest	293–337

3. Calculated the median value for EVC and EVH on each unique combination.

Aspect was available on both sides of the border and added variability to cover and height within the NAL-CMS classes.

D.2.12.3.2. The 90-Kilometer Buffer Outside the Contiguous United States

Within the 90-km buffer outside the contiguous United States, elevation data were obtained from the Canadian digital elevation model mosaic (Natural Resources Canada, 2013) and 3D Elevation Program elevation data downloaded from The National Map viewer (U.S. Geological Survey, 2021e). The Canadian digital elevation model mosaic had a few 10-pixel-wide gaps along the border that were filled with 3D Elevation Program elevation data. The digital elevation models were projected to the Albers Equal-Area Conic projection. Aspect was calculated on the digital elevation model layer using the planar method to reflect true north and then reclassed as in table D13.

For each mapzone in the 90-km buffer outside of the border:

1. EVTs were labeled based on NALCMS, topography, and Daymet using lookups defined within the U.S. border;
2. EVT was combined with reclassed aspect; and
3. EVC/EVH were labeled based on EVT/reclassed aspect combine using the lookup.

D.3. Conclusion

LF vegetation layers are an important baseline for landscape level analyses of vegetation type, cover, and height. With 856 EVT–ES classes mapped at the 30-m pixel level, it is the most detailed land cover map available for the contiguous United States. Additionally, several other LF 30-m resolution layers are directly derived from the vegetation layers, including surface fire behavior fuel models, CC, and CH used in fire behavior modeling, along with vegetation departure and succession class. Numerous data sources were gathered and used in the modeling and mapping of vegetation, which were considered the best available. LF's commitment to using the best data and methods available, along with reviewer input and assessment, means that the products are comprehensive and consistent across the landscape. Additionally, comparisons between different landscapes and prioritization within a landscape for restoration or other measures is more straightforward, even if local adjustments are needed. Methods used in LF 2016 Remap, LF 2019 Limited, and LF 2020 for modeling and mapping vegetation characteristics has created a strong base for future improvements and reduction in latency. For further information, please reference the LF website (https://www.landfire.gov).

D.4. References Cited

Apex Resource Management Solutions, 2019, SyncroSim: Apex Resource Management Solutions web page, accessed October 8, 2021, at https://apexrms.com/.

Baynes, J., Woznicki, S., Panlasigui, S., Mehaffey, M., and Neale, A., 2018, A floodplain map of the conterminous United States developed using random forest classification: Proceedings of the 2019 Esri User Conference: San Diego, Calif., July 8–12, 2018 [presentation].

Blankenship, K., Swaty, R., Hall, K.R., Hagen, S., Pohl, K., Shlisky Hunt, A., Patton, J., Frid, L., and Smith, J., 2021, Vegetation dynamics models—A comprehensive set for natural resource assessment and planning in the United States: Ecosphere, v. 12, no. 4, art. e03484, 22 p., accessed February 8, 2022, at https://doi.org/10.1002/ecs2.3484.

Boryan, C., Yang, Z., Mueller, R., and Craig, M., 2011, Monitoring US agriculture—The US Department of Agriculture, National Agricultural Statistics Service, Cropland Data Layer Program: Geocarto International, v. 26, no. 5, p. 341–358. [Also available at https://doi.org/10.1080/10106049.2011.562309.]

California Department of Water Resources, 2017, 2014 California statewide agricultural land use: California Department of Water Resources digital data, accessed October 8, 2021, at https://data.cnra.ca.gov/dataset/statewide-crop-mapping.

California Department of Water Resources, 2021, 2018 California statewide agricultural land use: California Department of Water Resources digital data, accessed February 8, 2022, at https://data.cnra.ca.gov/dataset/statewide-crop-mapping.

Carter, S.K., Burris, L.E., Domschke, C.T., Garman, S.L., Haby, T., Harms, B.R., Kachergis, E., Litschert, S.E., and Miller, K.H., 2021, Identifying policy-relevant indicators for assessing landscape vegetation patterns to inform planning and management on multiple-use public lands: Environmental Management, v. 68, no. 3, p. 426–443. [Also available at https://doi.org/10.1007/s00267-021-01493-8.]

Chaney, N.W., Wood, E.F., McBratney, A.B., Hempel, J.W., Nauman, T.W., Brungard, C.W., and Odgers, N.P., 2016, POLARIS—A 30-meter probabilistic soil series map of the contiguous United States: Geoderma, v. 274, p. 54–67. [Also available at https://doi.org/10.1016/j.geoderma.2016.03.025.]

Comer, P., Faber-Langendoen, D.R., Evans, S.G., Gawler, S.C., Josse, C., Kittel, G., Menard, S., Pyne, M., Reid, M., Schulz, K., Snow, K., and Teague, J., 2003, Ecological systems of the United States—A working classification of U.S. terrestrial systems: Arlington, Va., NatureServe, 75 p.

Commission for Environmental Cooperation, 2020, North American Environmental Atlas—Land cover 2015, 30 m: Commission for Environmental Cooperation web page, accessed October 8, 2021, at http://www.cec.org/nalcms.

Coulston, J.W., Moisen, G.G., Wilson, B.T., Finco, M.V., Cohen, W.B., and Brewer, C.K., 2012, Modeling percent tree canopy cover—A pilot study: Photogrammetric Engineering and Remote Sensing, v. 78, no. 7, p. 715–727.

Department of Homeland Security, 2020, Roads and routing data—HERE 2020: Department of Homeland Security web page, accessed April 4, 2023, at https://hifld-geoplatform.hub.arcgis.com.

Dixon, G.E., 2002, Essential FVS—A user's guide to the Forest Vegetation Simulator (revised February 2013): Fort Collins, Colo., Forest Service, Forest Management Service Center, 226 p., accessed October 8, 2021, at https://www.fs.usda.gov/fmsc/ftp/fvs/docs/gtr/EssentialFVS.pdf.

Federal Geographic Data Committee, 2008, FGDC endorses national vegetation classification standard (version 2) FGDC–STD–005–2008: Federal Geographic Data Committee web page, accessed October 8, 2021, at https://www.fgdc.gov/standards/projects/FGDC-standards-projects/vegetation/fgdc-endorse-NVCS-V2.

FracTracker Alliance, 2016, National energy and petrochemical map: FracTracker Alliance web page, accessed October 8, 2021, at https://www.fractracker.org/data/.

Gould, W., Alarcón, C., Fevold, B., Jiménez, M., Martinuzzi, S., Potts, G., Quiñones, M., Solórzano, M., and Ventosa, E., 2008, The Puerto Rico Gap Analysis Project volume 1—Land cover, vertebrate species distributions, and land stewardship: Forest Service General Technical Report IITF–39, 189 p., accessed October 8, 2021, at https://doi.org/10.2737/IITF-GTR-39.

Heris, M.P., Foks, N.L., Bagstad, K.J., Troy, A., and Ancona, Z.H., 2020, A rasterized building footprint dataset for the United States: Scientific Data, v. 7, no. 1, art. 207, 10 p. [Also available at https://doi.org/10.1038/s41597-020-0542-3.]

Homer, C., Dewitz, J., Jin, S., Xian, G., Costello, C., Danielson, P., Gass, L., Funk, M., Wickham, J., Stehman, S., Auch, R., and Riitters, K., 2020, Conterminous United States land cover change patterns 2001–2016 from the 2016 National Land Cover Database: ISPRS Journal of Photogrammetry and Remote Sensing, v. 162, p. 184–199. [Also available at https://doi.org/10.1016/j.isprsjprs.2020.02.019.]

Homer, C., Huang, C., Yang, L., Wylie, B., and Coan, M., 2004, Development of a 2001 National Land Cover Database for the United States: Photogrammetric Engineering and Remote Sensing, v. 70, no. 7, p. 829–840. [Also available at https://doi.org/10.14358/PERS.70.7.829.]

Jin, S., Yang, L., Danielson, P., Homer, C., Fry, J., and Xian, G., 2013, A comprehensive change detection method for updating the National Land Cover Database to circa 2011: Remote Sensing of Environment, v. 132, p. 159–175. [Also available at https://doi.org/10.1016/j.rse.2013.01.012.]

Jones, J.W., 2019, Improved automated detection of subpixel-scale inundation—Revised Dynamic Surface Water Extent (DSWE) partial surface water tests: Remote Sensing, v. 11, no. 4, art. 374, 26 p. [Also available at https://doi.org/10.3390/rs11040374.]

Kauth, R.J., and Thomas, G.S., 1976, The tasselled cap—A graphic description of the spectral-temporal development of agricultural crops as seen by Landsat: LARS Symposia, paper 159, 13 p.

LANDFIRE, 2008, Forest Vegetation Simulator disturbance database: LANDFIRE digital data, accessed October 8, 2021, at https://landfire.gov/lf_fvs.php.

LANDFIRE, 2021a, Comparing LANDFIRE vegetation type, cover, and height across versions: LANDFIRE Technical Report LF–OPS–014, 4 p., accessed October 8, 2021, at https://landfire.gov/documents/Comparing_LF_Vegetation_Type_Cover_and_Height_Across_Versions.pdf.

LANDFIRE, 2021b, LANDFIRE reference database—LF 2016 remap (LF 2.0.0) public data dictionary: LANDFIRE Technical Document LF–PRD–014, 16 p., accessed May 1, 2022, at https://landfire.gov/DataDictionary/LF2016_LFRDB_DataDictionary.pdf.

LANDFIRE, 2021c, LANDFIRE 2016 Remap EVT agreement assessment: LANDFIRE web page, accessed October 8, 2021, at https://landfire.gov/remapevt_assessment.php.

Latifovic, R., Homer, C., Ressl, R., Pouliot, D.A., Hossian, S., Colditz, R., Olthof, I., Giri, C., and Arturo, V., 2012, North American land change monitoring system, in Giri, C.P., ed., Remote sensing of land use and land cover—Principles and applications: Boca Raton, Fla., CRC Press, p. 303–324.

Macfarlane, W.W., Gilbert, J.T., Jensen, M.L., Gilbert, J.D., Hough-Snee, N., McHugh, P.A., Wheaton, J.M., and Bennett, S.N., 2017, Riparian vegetation as an indicator of riparian condition—Detecting departures from historic condition across the North American West: Journal of Environmental Management, v. 202, p. 447–460. [Also available at https://doi.org/10.1016/j.jenvman.2016.10.054.]

Marsett, R.C., Qi, J., Heilman, P., Biedenbender, S.H., Watson, M.C., Amer, S., Weltz, M., Goodrich, D., and Marsett, R., 2006, Remote sensing for grassland management in the arid southwest: Rangeland Ecology and Management, v. 59, no. 5, p. 530–540. [Also available at https://doi.org/10.2111/05-201R.1.]

Meyer, R., Seamon, J., Fa'aumu, S., and Lalogafuafua, I., 2017, Classification and mapping of wildlife habitat in American Samoa—An object-oriented approach using high resolution orthoimagery and LIDAR remote sensing data: Department of Marine and Wildlife Resources Technical Report, 131 p.

Microsoft, 2021, Building footprints: Microsoft web page, accessed February 8, 2022, at https://www.microsoft.com/en-us/maps/building-footprints.

National Oceanic and Atmospheric Administration, 2005, Hawaii regional land cover data: National Oceanic and Atmospheric Administration digital data, accessed October 8, 2021, at https://coast.noaa.gov/digitalcoast/data/.

National Oceanic and Atmospheric Administration, 2010, Puerto Rico regional land cover data: National Oceanic and Atmospheric Administration digital data, accessed October 8, 2021, at https://coast.noaa.gov/digitalcoast/data/.

National Oceanic and Atmospheric Administration, 2011, Hawaii regional land cover data: National Oceanic and Atmospheric Administration digital data, accessed October 8, 2021, at https://coast.noaa.gov/digitalcoast/data/.

National Oceanic and Atmospheric Administration, 2012, US Virgin Islands regional land cover data: National Oceanic and Atmospheric Administration digital data, accessed October 8, 2021, at https://coast.noaa.gov/digitalcoast/data/.

National Oceanic and Atmospheric Administration, 2022, Guam and American Samoa regional land cover: National Oceanic and Atmospheric Administration digital data, accessed September 10, 2022, at https://www.fisheries.noaa.gov/inport/item/47841.

Natural Resources Canada, 2013, Canadian digital elevation model, 1945–2011: Government of Canada web page, accessed October 8, 2021, at https://open.canada.ca/data/en/dataset/7f245e4d-76c2-4caa-951a-45d1d2051333.

NatureServe, 2009, International ecological classification standard—Terrestrial ecological classifications: Arlington, Va., NatureServe, 1,172 p. [Also available at http://downloads.natureserve.org/get_data/data_sets/veg_data/nsDescriptions.pdf.]

NatureServe, 2015, NatureServe network species occurrence data: NatureServe digital data, accessed October 8, 2021, at http://services.natureserve.org/ipt/resource?r=occurrences&v=8.3.

NatureServe, 2017, International ecological classification standard—Terrestrial ecological classifications—NVC groups of the western U.S. on the LANDFIRE legend: NatureServe Technical Report, 453 p., accessed October 8, 2021, at https://landfire.gov/documents/LANDFIRE_Natural_NVC_Groups_Descriptions_WesternUS.pdf.

NatureServe, 2018, International ecological classification standard—Terrestrial ecological classifications—NVC groups of the eastern U.S. on the LANDFIRE legend: NatureServe Technical Report, 699 p., accessed October 8, 2021, at https://landfire.gov/documents/LANDFIRE_Natural_NVC_Groups_Descriptions_EasternUS.pdf.

Nelson, K.J., and Steinwand, D., 2015, A Landsat data tiling and compositing approach optimized for change detection in the conterminous United States: Photogrammetric Engineering and Remote Sensing, v. 81, no. 7, p. 573–586. [Also available at https://doi.org/10.14358/PERS.81.7.573.]

Omernik, J.M., and Griffith, G.E., 2014, Ecoregions of the conterminous United States—Evolution of a hierarchical spatial framework: Environmental Management, v. 54, no. 6, p. 1249–1266. [Also available at https://doi.org/10.1007/s00267-014-0364-1.]

Picotte, J.J., Dockter, D., Long, J., Tolk, B., Davidson, A., and Peterson, B., 2019, LANDFIRE remap prototype mapping effort—Developing a new framework for mapping vegetation classification, change, and structure: Fire, v. 2, no. 2, art. 35, 26 p., accessed October 8, 2021, at https://doi.org/10.3390/fire2020035.

Prichard, S.J., Kennedy, M.C., Andreu, A.G., Eagle, P.C., French, N.H., and Billmire, M., 2019, Next-generation biomass mapping for regional emissions and carbon inventories—Incorporating uncertainty in wildland fuel characterization: Journal of Geophysical Research Biogeosciences, v. 124, no. 12, p. 3699–3716. [Also available at https://doi.org/10.1029/2019JG005083.]

Pyrologix, 2021, Wildfire risk to California communities: Pyrologix, 24 p., accessed October 8, 2021at http://pyrologix.com/reports/Wildfire-Risk-to-California-Communities.pdf.

Qi, J., Chehbouni, A., Huete, A.R., Kerr, Y.H., and Sorooshian, S., 1994, A modified soil adjusted vegetation index: Remote Sensing of Environment, v. 48, no. 2, p. 119–126. [Also available at https://doi.org/10.1016/0034-4257(94)90134-1.]

Quinlan, J.R., 1993, Combining instance-based and mode-based learning: Proceedings of the 10th International Conference on Machine Learning, Amherst, Md., June 27, 1993, 8 p.

Radeloff, V.C., Helmers, D.P., Kramer, H.A., Mockrin, M.H., Alexandre, P.M., Bar-Massada, A., Butsic, V., Hawbaker, T.J., Martinuzzi, S., Syphard, A., and Stewart, S.I., 2018, Rapid growth of the US wildland-urban interface raises wildfire risk: Proceedings of the National Academy of Sciences, v. 115, no. 13, p. 3314–3319, accessed October 8, 2021, at https://doi.org/10.1073/pnas.1718850115.

rapidlasso, 2019, LAStools (version 191018, academic): rapidlasso software release, accessed October 8, 2021, at https://rapidlasso.com/LAStools.

Reid, M., Comer, P., Lundberg, B., Smith, J., Drake, J., Faber-Langendoen, D., Harkness, M., Kittel, G., Menard, S., Nordman, C., Pyne, M., Schulz, K., Sneddon, L., and Teague, J., 2015, Developing Auto-Keys for LANDFIRE vegetation mapping—2014–2015 CONUS project report: Arlington, Va., prepared by NatureServe, 69 p. plus appendixes, accessed August 27, 2021, at https://landfire.gov/lf_improvements.php.

Rollins, M.G., 2009, LANDFIRE—A nationally consistent vegetation, wildland fire, and fuel assessment: International Journal of Wildland Fire, v. 18, no. 3, p. 235–249. [Also available at https://doi.org/10.1071/WF08088.]

RuleQuest Research, 2006, Data mining tools: RuleQuest Research web page, accessed October 8, 2021, at https://www.rulequest.com/.

Soil Survey Staff, 2014, Soil Survey Geographic database (SSURGO): U.S. Department of Agriculture web page, accessed October 8, 2021, at https://data.nal.usda.gov/dataset/soil-survey-geographic-database-ssurgo.

State of Hawaii, 2015, 2015 Hawaii statewide agricultural land use baseline: State of Hawaii digital data, accessed October 8, 2021, at https://planning.hawaii.gov/gis/download-gis-data-expanded/.

Thornton, M.M., Shrestha, R., Wei, Y., Thornton, P.E., Kao, S., and Wilson, B.E., 2020, Daymet—Annual climate summaries on a 1-km grid for North America, version 4: Oakridge National Laboratory digital data, accessed October 8, 2021, at, https://doi.org/10.3334/ORNLDAAC/1852.

Thornton, M.M., Thornton, P.E., Wei, Y., Mayer, B.W., Cook, R.B., and Vose, R.S., 2017, Daymet—Annual climate summaries on a 1-km grid for North America, version 3: Oakridge National Laboratory digital data, accessed October 8, 2021, at https://doi.org/10.3334/ORNLDAAC/1343.

Toney, C., Shaw, J.D., and Nelson, M.D., 2009, A stem-map model for predicting tree canopy cover of Forest Inventory and Analysis (FIA) plots, in McWilliams, W., Moisen, G., and Czaplewski R., comps., Proceedings of the Forest Inventory and Analysis (FIA) Symposium 2008, Park City, Utah, October 21–23, 2008: Fort Collins, Colo., Forest Service, Rocky Mountain Research Station, 19 p.

U.S. Census Bureau, 2017, TIGER/Line shapefiles: U.S. Census Bureau digital data, accessed October 8, 2021, at https://www.census.gov/cgi-bin/geo/shapefiles/index.php.

U.S. Department of Agriculture, 2008, Common land unit: U.S. Department of Agriculture web page, accessed October 8, 2021, at https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-products/common-land-unit-clu/index.

U.S. Fish and Wildlife Service, 2014, National Wetlands Inventory: U.S. Fish and Wildlife Service web page, accessed October 8, 2021, at https://www.fws.gov/wetlands/.

U.S. Geological Survey, 2015, National Gap Analysis Program (GAP) and LANDFIRE: LANDFIRE technical document, 6 p., accessed October 8, 2021, at https://landfire.cr.usgs.gov/documents/2014-2015_GAP_LANDFIRE_Report_Final.pdf.

U.S. Geological Survey, 2016a, GAP/LANDFIRE National Terrestrial Ecosystems 2011: U.S. Geological Survey data release, accessed October 8, 2021, at https://doi.org/10.5066/F7ZS2TM0.

U.S. Geological Survey, 2016b, 3D Elevation Program 1-meter resolution digital elevation model: U.S. Geological Survey web page, accessed May 5, 2023, at https://www.usgs.gov/3d-elevation-program.

U.S. Geological Survey, 2016c, USGS TNM hydrography (NHD): U.S. Geological Survey web page, accessed October 8, 2021, at https://hydro.nationalmap.gov/arcgis/rest/services/nhd/MapServer.

U.S. Geological Survey, 2021a, NLCD imperviousness (CONUS) 2016: Multi-Resolution Land Characteristics Consortium digital data, accessed February 8, 2022, at https://www.mrlc.gov/data/nlcd-imperviousness-conus-all-years.

U.S. Geological Survey, 2021b, NLCD imperviousness (CONUS) 2019: Multi-Resolution Land Characteristics Consortium digital data, accessed February 8, 2022, at https://www.mrlc.gov/data/nlcd-imperviousness-conus-all-years.

U.S. Geological Survey, 2021c, NLCD land cover (CONUS) 2019: Multi-Resolution Land Characteristics Consortium digital data, accessed February 8, 2022, at https://www.mrlc.gov/data/nlcd-land-cover-conus-all-years.

U.S. Geological Survey, 2021d, NLCD 2016 USFS tree canopy cover (CONUS): Multi-Resolution Land Characteristics Consortium digital data, accessed February 8, 2022, at https://www.mrlc.gov/data/nlcd-2016-usfs-tree-canopy-cover-conus.

U.S. Geological Survey, 2021e, The National Map 3D Elevation Program 1-Meter resolution digital elevation model: U.S. Geological Survey web page, accessed May 5, 2023, at https://www.usgs.gov/3d-elevation-program.

U.S. Geological Survey Gap Analysis Project, 2020, Protected Areas Database of the United States (PAD-US) 2.1: U.S. Geological Survey data release, accessed October 8, 2021, at https://doi.org/10.5066/P92QM3NT.

Xie, Y., and Lark, T., 2021, LANID-US—Landsat-based irrigation dataset for the United States (3.0): Zenodo digital data, accessed October 8, 2021, at https://doi.org/10.5281/zenodo.5548555.

Xu, H., 2006, Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery: International Journal of Remote Sensing, v. 27, no. 14, p. 3025–3033. [Also available at https://doi.org/10.1080/01431160600589179.]

Zhu, Z., Woodcock, C.E., Holden, C., and Yang, Z., 2015, Generating synthetic Landsat images based on all available Landsat data—Predicting Landsat surface reflectance at any given time: Remote Sensing of Environment, v. 162, p. 67–83. [Also available at https://doi.org/10.1016/j.rse.2015.02.009.]

Chapter E. Fuels Mapping

By Inga P. La Puma,[1] Charley Martin,[1] and Tobin Smail[1]

E.1. Introduction to LANDFIRE Fuels Mapping

E.1.1. The Need for LANDFIRE Fuels

Fuel layers in LANDFIRE (LF) help determine how a fire will behave. Most spatial fire behavior models in use operationally on large wildland fires are designed to directly ingest LF fuel and topography layers (table E1; Wildland Fire Decision Support System, 2021); for example, the Wildland Fire Decision Support System (WFDSS) uses LF fuel and topographic layers to run its Basic Fire Behavior, Short-Term Fire Behavior and Near-Term Fire Behavior tools (Calkin and others, 2011; Wildland Fire Decision Support System, 2021), and Fire Spread Probability (Finney and others, 2011a). WFDSS is typically used for all large Federal wildland fires for decision support by fire behavior analysts and long-term analysts. The FlamMap 6.0 fire behavior model (table E1) used for regional fire behavior modeling incorporates LF fuel layers and is used in the Interagency Fuels Treatment Decision Support System, a fuels treatment and planning interface designed for multiagency use (Drury and others, 2016). In addition to fire behavior applications for specific fires and regional planning, LF fuel layers also are used in larger landscape models such as FSim (Finney and others, 2011b) for estimating fire hazard and risk. FSim results have been used in the Wildfire Risk to Communities project (Scott and others, 2020), the wildland fire potential map (Dillon and others, 2014), numerous regional wildfire risk assessments (Scott and others, 2013; Southern Group of State Foresters, 2021) and community wildfire protection plans (National Fire Protection Association, 2008). LF fuel layers for obtaining FSim results also are used in the delineation of potential wildfire operations delineations via the rate of spread and suppression difficulty index (O'Connor and others, 2016). Other important uses of LF fuel data layers include prioritizing areas for fuel reduction projects (Ager and others, 2021) and assessing the results of those treatments (Prichard and others, 2020). National fire models use LF fuel layers as base level information about the rate of spread, intensity, and canopy characteristics that comprehensively cover every 30-meter (m) pixel of the United States, including insular areas.

[1]KBR, Inc., under contract to the U.S. Geological Survey.

E.1.2. LANDFIRE Fuel Mapping Background

LF fuel layers have been mapped since the LF national effort began with circa 2001 products released in 2009 (Reeves and others, 2009). LF fuel layers consist of three primary foci: surface fuels, canopy fuels, and layers used to account for fuel disturbances. Fuel layers are generally based on vegetation type, cover, and height (see chap. D) while also accounting for disturbances in all but the most recent of the last 10 years (see section E.4.2). Surface fuel related layers provided by LF include Anderson Fire Behavior Fuel Models (FBFM13; Anderson, 1981), Scott and Bergan Fire Behavior Fuel Models (FBFM40; Scott and Burgan, 2005), the Canadian Forest Fire Danger Rating System (CFFDRS; used in Alaska only; Wotton and others, 2009; Ziel, 2014), and the Fuel Characteristic Classification System (FCCS; Ottmar and others, 2003). Canopy-related structure attributes include canopy height (CH), canopy cover (CC), canopy bulk density (CBD), and canopy base height (CBH). Fuel vegetation layers account for predisturbance vegetation information where disturbances happened during most of the previous 10 years and include fuel vegetation type (FVT), fuel vegetation cover (FVC), and fuel vegetation height (FVH). Fuel vegetation layers are primarily used to calculate capable fuels (see section E.4.2). Fuel disturbance (FDist) accounts for disturbances during the last 10 years. These disturbances are grouped by disturbance type, severity, and time since disturbance (TSD) categories.

E.1.3. LANDFIRE Fuel Versions

This document focuses primarily on the LF 2016 Remap fuel layers; however, there are some important differences between the LF 2016 Remap fuel layers and the LF 2019 Limited and LF 2020 updates. A brief description of these updates follows, but further details are available in section E.6.7 and section E.6.8.

E.1.3.1. LANDFIRE 2016 Remap

Fuel layers for the LF 2016 Remap release were substantially improved from previous LF update versions in several ways, including the use of the capable fuels shift (where fuel layers were processed in a way that most closely represents present day) representing the capable year associated with the release for known disturbed areas (see section E.4.2).

Table E1. Fire behavior models that use LANDFIRE data (adapted from Wildland Fire Decision Support System [2021]).

[WFDSS, Wildland Fire Decision Support System; IFTDSS, Interagency Fuels Treatment Decision Support System; LCP, landscape file]

Tools	Included in WFDSS				Stand alone/included in IFTDSS
	Basic Fire Behavior	Short-Term Fire Behavior	Near-Term Fire Behavior	Fire Spread Probability	FlamMap 6.0 with FARSITE
Spread model	FlamMap grid	Minimum travel time	FARSITE	Minimum travel time	Minimum travel time
Duration	Snapshot in time	1–3 days	1–7 days	7–30 days	1–3 days
Weather	Daily, constant	Daily, constant	Hourly, variable	Hourly, variable	Daily, constant
Data source	LANDFIRE LCP	LANDFIRE LCP	LANDFIRE LCP	LANDFIRE LCP	LANDFIRE LCP
Output	Raster display of fire behavior	Major flow paths, arrival times	Perimeter, fire behavior rasters	Probability surface	Major flow paths, arrival times, perimeter, fire behavior rasters

Additionally, all nondisturbed fuel layers were based on modeled vegetation type, cover, and height using circa 2016 imagery (see chap. D). Improvements in vegetation modeling are reflected in fuel layers estimates as well.

E.1.3.2. LANDFIRE 2019 Limited Update

Fuel layers for the LF 2019 Limited update reflect similar methods as the LF 2016 Remap process. The main difference for LF 2019 Limited fuel layers is the methods in which disturbances were recorded. The FDist used in calculating capable fuels for LF 2019 Limited used the Events Geodatabase and fire program data available at the time of production (see section C.1.4.2). Disturbances detected from LF's remote sensing of landscape change (RSLC) process were not incorporated into the 2019 Limited fuel products. This may have resulted in an underreporting of disturbances accounted for in the 2021 capable 2019 Limited fuel products. Nondisturbed fuel layers of LF 2019 Limited were identical to those of LF 2016 Remap.

E.1.3.3. LANDFIRE 2020 Update

The LF 2020 update includes all detectable disturbances (including RSLC, events, and fire program annual disturbances) from 2012 to 2020 and represents 2022 capable fuels for release in June 2022. Improvements in fuel assignments for those areas that were assigned to the developed ruderal and recently disturbed classes in LF 2016 Remap have been addressed. A new set of developed classes using the Microsoft building footprint derived building cover dataset accounts for previously unmapped developed areas, and Normalized Difference Vegetation Index (NDVI) thresholds determine whether these areas are burnable. Additionally, all Federal agricultural lands were assigned to a burnable fuel model. Nondisturbed fuel layers that were not in these classes are identical to LF 2016 Remap.

E.2. Fuel Mapping Production

The most important layers for fuel mapping production are vegetation type, cover, height, and annual and aggregated 10-year disturbance layers. Biophysical settings also are used primarily in the Northeast, Southeast, and North Central geographic areas (GeoAreas). These data layers feed directly into how fuel layers are mapped across the landscape. The process flow for surface and canopy layers that is detailed later in this section is shown in figure E1.

E.3. Nondisturbed Fuel Vegetation

Nondisturbed areas in LF 2016 Remap were assigned FVT, FVC, and FVH values from EVT–ES, existing vegetation cover (EVC), and existing vegetation height (EVH) modeling and mapping. These fuel vegetation layers were new for LF 2016 Remap and are key components in creating the capable fuels layers. FVT, FVC, and FVH values represent LF 2016 Remap vegetation in nondisturbed areas and predisturbance vegetation in disturbed areas (see section E.5). EVT–ES was translated via a lookup table to the closest pre-Remap 2000 series EVT code based on past relations and consultation between fuel and vegetation subject matter experts at LF for newly developed LF 2016 Remap EVT–ES codes. This lookup is available in the LF 2016 Remap EVT attribute table by comparing the Remap EVT code to the EVT_Fuel code. For nondisturbed areas, the EVT_Fuel code is the same code in the FVT layer. Additionally, continuous EVC and EVH vegetation layers for LF 2016 Remap are binned for FVC and FVH as they were for pre-Remap EVC and EVH (table E2). LF 2016 Remap continuous EVC and EVH values for nondisturbed areas fall within the bins in the FVC and FVH layers.

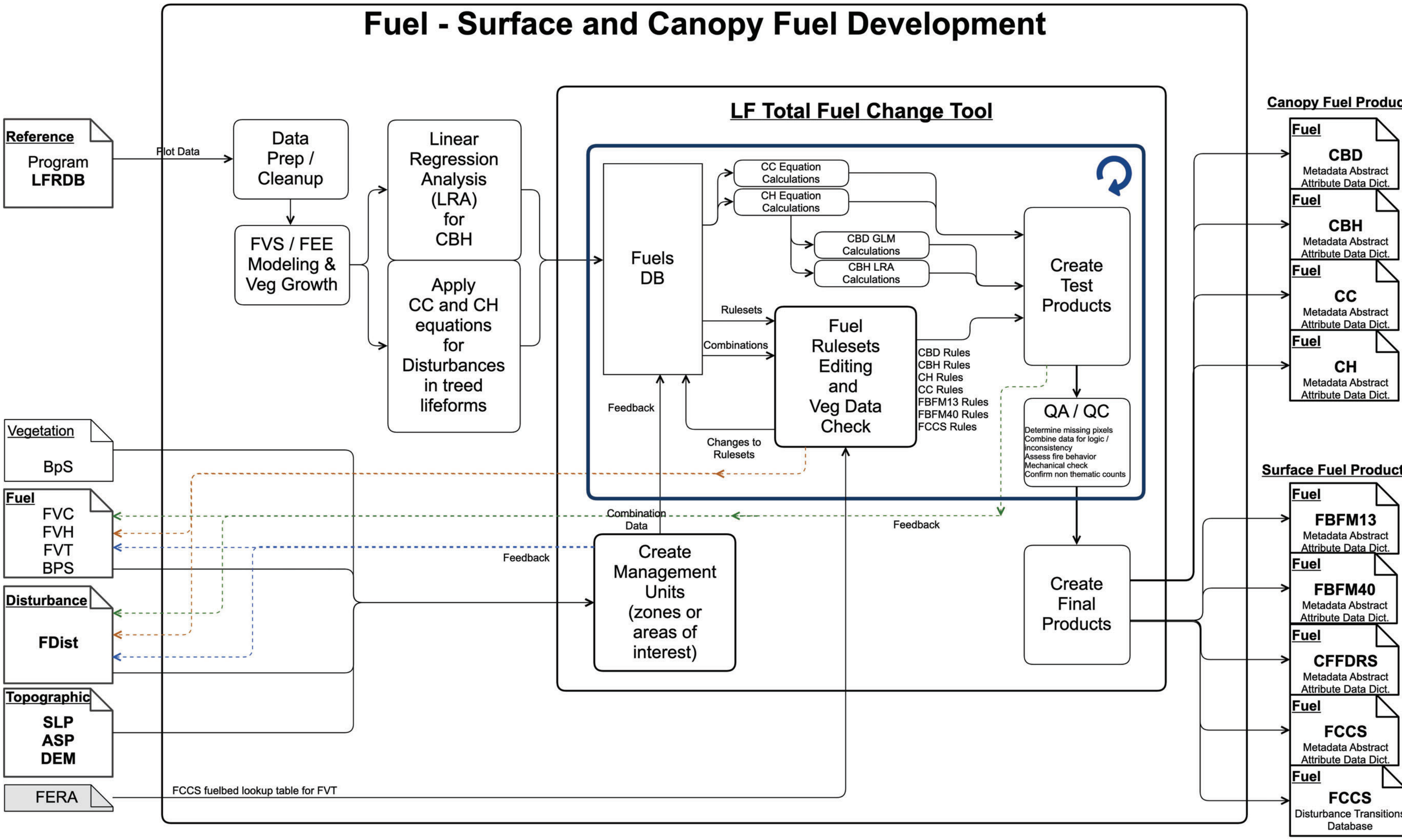


Figure E1. Inputs, process flow, and output fuel development. [LFRDB, LANDFIRE reference database; BpS, biophysical setting; FVC, fuel vegetation cover; FVH, fuel vegetation height; FVT, fuel vegetation type; FDist, fuel disturbance; SLP, slope; ASP, aspect; DEM, digital elevation model; FERA, fire and environmental research applications; FCCS, Fuel Characteristic Classification System; FVS, Forest Vegetation Simulator; FEE, fire and fuel effects extension; Veg, vegetation; CBH, canopy base height; CC, canopy cover; CH, canopy height; DB, database; CBD, canopy bulk density; GLM, general linear model; FBFM13, Anderson Fire Behavior Fuel Models; FBFM40, Scott and Bergan Fire Behavior Fuel Models; QA/QC, quality assurance/quality control; Dict., dictionary; CFFDRS, Canadian Forest Fire Danger Rating System]

E.4. Disturbance for Fuel Layers

E.4.1. Fuel Disturbance

For LF 2016 Remap, FDist links historical disturbance (see section C.1.3) to 6 types, 3 severities, and 3 TSD categories (that is, 0–1 year since disturbance, 2–5 years since disturbance, and 6–10 years since disturbance). The disturbance of each pixel is assigned via a hierarchy of rules, but before disturbances are assigned, illogical combinations of vegetation types and disturbance types are filtered out; for example, shrub- and herb-dominated vegetation types do not typically undergo wind disturbance; therefore, these categories are dropped from FDist. If there is more than one valid disturbance for a given pixel after the 10 years of disturbance have been filtered for illogical combinations, then the disturbances are assigned in this order (with 1 the highest and 5 the lowest priority):

1. High-severity fire,
2. High-severity mechanical remove,
3. All other fires,
4. Most recent of the remaining disturbances, and
5. Any other one-time disturbance occurrence.

Table E2. Fuel vegetation cover and fuel vegetation height codes along with representative values and bin ranges from existing vegetation cover and existing vegetation height.

[FVC, fuel vegetation cover; EVC, existing vegetation cover; FVH, fuel vegetation heigh; EVH, existing vegetation type; ≥, greater than or equal to; <, less than; %, percent; >, greater than; ≤, less than or equal to; --, no data or not applicable]

FVC code	Percentage of cover	EVC binned range	FVH code	Height (meters)	EVH binned range
100	0	Sparse vegetation canopy	100	0	Sparse vegetation height
101	15	Tree cover ≥10 and <20%	425	0.25	Herb height 0–<0.5 meter
102	25	Tree cover ≥20 and <30%	475	0.75	Herb height 0.5–<1.0 meter
103	35	Tree cover ≥30 and <40%	499	1.00	Herb height ≥1.0 meter
104	45	Tree cover ≥40 and <50%	502	0.25	Shrub height 0–<0.5 meter
105	55	Tree cover ≥50 and <60%	507	0.75	Shrub height 0.5–<1.0 meter
106	65	Tree cover ≥60 and <70%	520	2.00	Shrub height 1.0–<3.0 meters
107	75	Tree cover ≥70 and <80%	530	3.00	Shrub height ≥3.0 meters
108	85	Tree cover ≥80 and <90%	603	3.50	Forest height 1.8–<5 meters
109	95	Tree cover ≥90 and ≤100%	607	7.50	Forest height 5–<9 meters
111	15	Shrub cover ≥10 and <20%	611	11.50	Forest height 9–<13 meters
112	25	Shrub cover ≥20 and <30%	615	15.50	Forest height 13–<17 meters
113	35	Shrub cover ≥30 and <40%	619	19.50	Forest height 17–<21 meters
114	45	Shrub cover ≥40 and <50%	623	23.50	Forest height 21–<25 meters
115	55	Shrub cover ≥50 and <60%	627	27.50	Forest height 25–<29 meters
116	65	Shrub cover ≥60 and <70%	631	31.50	Forest height 29–<33 meters
117	75	Shrub cover ≥70 and <80%	635	35.50	Forest height 33–<37 meters
118	85	Shrub cover ≥80 and <90%	639	39.50	Forest height 37–<41 meters
119	95	Shrub cover ≥90 and ≤100%	643	43.50	Forest height 41–<45 meters
121	15	Herb cover ≥10 and <20%	647	47.50	Forest height 45–<49 meters
122	25	Herb cover ≥20 and <30%	651	50.00	Forest height ≥ 49 meters
123	35	Herb cover ≥30 and <40%	--	--	--
124	45	Herb cover ≥40 and <50%	--	--	--
125	55	Herb cover ≥50 and <60%	--	--	--
126	65	Herb cover ≥60 and <70%	--	--	--
127	75	Herb cover ≥70 and <80%	--	--	--
128	85	Herb cover ≥80 and <90%	--	--	--
129	95	Herb cover ≥90 and ≤100%	--	--	--

Of the six disturbance type categories (table E3), “mechanical unknown” was added to describe mechanical disturbances where there was not enough information to distinguish the type of the disturbance detected via RSLC remote sensing detections. All “mechanical unknown” disturbances are treated as “mechanical remove” in LF 2016 Remap fuel rules. FDist is considered capable, in that the TSD is calculated from the capable year (or the year in which it is intended to be used), not the last year of disturbance, and is directly used in the development of capable surface and canopy fuels (table E4).

The FDist codes listed in table E3 can be broken down as follows: for an FDist code of 111, the first “1” indicates fire, the second “1” indicates low severity, and the third “1” indicates 0–1 year since the disturbance. There are 6 disturbance type codes, 3 severity codes, and 3 TSD codes.

E.4.2. Capable Fuels

Capable fuels for the LF 2016 Remap fuel products have updated TSD assignments to reflect the time since the capable year; for example, if the capable year is 2020 (table E4), then disturbances from 2010 to 2016 are included and transitioned to represent 2020 conditions (that is, surface and canopy fuels reflect the disturbance plus recovery to 2020). This transition made the products ready for use in 2020 without the need for users to account for the difference in time; however, LF users still needed to add any disturbances that were not included in LF 2016 Remap products. In LF 2016 Remap, for example, disturbance years 2017–19 were not yet accounted for in the 2020 capable FDist product and, as such, would need to be added to the 2020 capable fuels product, have the disturbance and recovery accounted for, and output a new map to gain a complete understanding of recent disturbance effects on fuel conditions in any study region. This updating process can be done with LF’s Total Fuels Change (LFTFC) tool in a standardized manner using the same update rules that LF uses with the available disturbances at the time of production. Disturbances older than 10 years are given a code of “0,” meaning nondisturbed.

LF chose a 10-year time frame for the maximum TSD period in capable fuels based on the available literature and results of Forest Vegetation Simulator (FVS) model runs (Reinhardt and Crookston, 2003). This 10-year period addresses the need to account for vegetation succession within a production scope that can reasonably be managed and executed. This general approach provides that surface fuels will return or are within an average range of variability of the predisturbance vegetation/fuel assignment within 10 years. LF recognizes that canopy fuels are on a similar trajectory during this 10-year period but do not recover to original vegetation/fuel conditions; however, canopy fuels would generally be tall enough to be included in the canopy fuel profile for the area. LF also recognizes that a wide range of variability and complexity exists in landscapes across the United States. Varied successional responses, interacting disturbances, and climate change may not be accounted for. The ecological succession response in some areas can take decades for regrowth/colonization to happen as vegetation changes and it may not ever return to what it was before the disturbance, depending on local conditions and seed source. Additional research in postdisturbance vegetation and fuel detection and modeling in different vegetation types will help refine postdisturbance fuel estimations.

E.5. Disturbed Fuel Vegetation

Having knowledge of the predisturbance vegetation conditions informs the LF fuel assignment process. Predisturbance information helps determine the type of vegetation and amount of vegetation remaining on the landscape after the disturbance. The vegetation type and the structure that was acted upon by the disturbance at a site also can be accounted for as the vegetation regrows with time.

For disturbed areas that are accounted for in FDist (see table E4 for disturbance years included), the fuel vegetation layers represent pre-Remap vegetation; for example, if a disturbance happened in 2014, the FVT, FVC, and FVH pixels overlying that area of disturbance would represent vegetation from the LF update year that happened before the disturbance, in this case the LF 2012 EVT, EVC, and EVH. FVT values are represented by the original 2000 series EVT codes. FVC is divided into classes of 10-percent increments that reach a maximum of 90 to 100 percent. FVH is depicted using meters and is classified into 3 herb, 4 shrub, and 13 tree bins. Disturbed areas that have surpassed the 10-year TSD window also reflect circa LF 2016 Remap conditions.

E.6. Fuel Assignment Rules

E.6.1. Surface Fuel Models

Surface fuel models typically represent the first 6 feet of fuels above the ground and are used in Rothermel’s fire spread model (Rothermel, 1972), which is the spread model used in many spatial fire behavior models. Surface fuel models typically represent size classes of fuels, live and dead fuels, fuelbed depth estimations, moisture of extinction for dead fuels, and heat content of all fuels (Scott and Burgan, 2005). When surface fuel models are used in concert with fuel moisture and weather variables in fire behavior models such as FARSITE, key outputs can be obtained. These outputs include the rate of spread of the fire across the landscape through different types of fuels, the flame lengths that can be expected for each pixel (a measure of intensity), the potential for a fire to transition into the crown, and its potential to create spot fires outside of the main fire (Finney, 2004).

Table E3. Fuel disturbance codes, disturbance type codes, and time since disturbance codes for LANDFIRE 2016 Remap.

Fuel disturbance code	Disturbance type code	Severity	Time since disturbance code
111	Fire	Low	1 year
112	Fire	Low	2–5 years
113	Fire	Low	6–10 years
121	Fire	Moderate	1 year
122	Fire	Moderate	2–5 years
123	Fire	Moderate	6–10 years
131	Fire	High	1 year
132	Fire	High	2–5 years
133	Fire	High	6–10 years
211	Mechanical add	Low	1 year
212	Mechanical add	Low	2–5 years
213	Mechanical add	Low	6–10 years
221	Mechanical add	Moderate	1 year
222	Mechanical add	Moderate	2–5 years
223	Mechanical add	Moderate	6–10 years
231	Mechanical add	High	1 year
232	Mechanical add	High	2–5 years
233	Mechanical add	High	6–10 years
311	Mechanical remove	Low	1 year
312	Mechanical remove	Low	2–5 years
313	Mechanical remove	Low	6–10 years
321	Mechanical remove	Moderate	1 year
322	Mechanical remove	Moderate	2–5 years
323	Mechanical remove	Moderate	6–10 years
331	Mechanical remove	High	1 year
332	Mechanical remove	High	2–5 years
333	Mechanical remove	High	6–10 years
411	Windthrow	Low	1 year
412	Windthrow	Low	2–5 years
413	Windthrow	Low	6–10 years
421	Windthrow	Moderate	1 year
422	Windthrow	Moderate	2–5 years
423	Windthrow	Moderate	6–10 years
431	Windthrow	High	1 year
432	Windthrow	High	2–5 years
433	Windthrow	High	6–10 years
511	Insects-disease	Low	1 year
512	Insects-disease	Low	2–5 years
513	Insects-disease	Low	6–10 years
521	Insects-disease	Moderate	1 year
522	Insects-disease	Moderate	2–5 years
523	Insects-disease	Moderate	6–10 years
531	Insects-disease	High	1 year

Table E3. Fuel disturbance codes, disturbance type codes, and time since disturbance codes for LANDFIRE 2016 Remap.—Continued

Fuel disturbance code	Disturbance type code	Severity	Time since disturbance code
532	Insects-disease	High	2–5 years
533	Insects-disease	High	6–10 years
611	Mechanical unknown	Low	1 year
612	Mechanical unknown	Low	2–5 years
613	Mechanical unknown	Low	6–10 years
621	Mechanical unknown	Moderate	1 year
622	Mechanical unknown	Moderate	2–5 years
623	Mechanical unknown	Moderate	6–10 years
631	Mechanical unknown	High	1 year
632	Mechanical unknown	High	2–5 years
633	Mechanical unknown	High	6–10 years

Table E4. The 2010–16 disturbances represented in the 2020 capable fuels layers from LANDFIRE 2016 Remap.

[TSD, time since disturbance; --, no data or not applicable]

2010	2011	2012	2013	2014	2015	[1]2016	2017	2018	2019	2020
TSD3	TSD3	TSD3	TSD3	TSD3	TSD2	TSD2	TSD2	TSD2	TSD1	Capable year
6–10 years					2–5 years				0–1 year	--

[1]LANDFIRE 2016 Remap last disturbance year included was 2016 for capable fuels 2020.

Surface fuel models are assigned using a modified version of the original LF stakeholder calibrated rulesets (Reeves and others, 2006), which are now available in the LFTFC (Smail and others, 2020). These rulesets were calibrated in a concerted effort with experts in workshops across the country under the assumption of an average fire season. The average fire season statistics (number of fires, fire season start, stop, and length) were calculated for the years 1999–2010 within Fire Program Analysis Fire Protection Units. Each Fire Protection Unit was assigned one weather station, and an average fire season was calculated by date, climate, and stakeholder input (appendix 2, table 2.1).

The calibrated rulesets based on the average fire season are directly applied to FVT, FVC, FVH, biophysical settings, and FDist information for each pixel. This means that the fire behavior fuel model, either FBFM13 (Anderson, 1981) or FBFM40 (Scott and Burgan, 2005), is applied to fuel vegetation layers that represent LF 2016 Remap in nondisturbed areas and predisturbance LF vegetation layers in disturbed areas. If no FDist information is present for a pixel, then the LFTFC is used to assign fuels based on LF 2016 Remap codes translated to pre-Remap EVT codes. If there was a disturbance in FDist, then the FVT, FVC, and FVH representing predisturbance vegetation has a calibrated disturbance fuel rule applied and a postdisturbance FBFM40 or FBFM13 assigned. All surface fuel models through LF 2020 are considered capable fuels. Disturbances in the FDist TSD1 are assumed to be the same as TSD2. This was done so that disturbances do not remain in TSD1 (0–1 year) until the next update, which for most LF updates, has taken at least 2 years. Plans to account for the previous year's disturbances and use rules developed specifically for the TSD1 time step are underway for updates after LF 2020. The LFTFC and associated rules for assigning surface fire behavior fuel models are available on the LF fuel tab on the LF website (https://landfire.gov/download_lftfc.php) by downloading the tool itself for use in ArcMap or by downloading the database of rules that are accessed by the tool (see fig. E2 for example set of rules). The LFTFC also is used by those wishing to update the disturbances that happened on their local sites, thus accounting for more recent disturbances not included in the capable FDist.

Fuel rules specifying the FVC and FVH required for each surface fuel model assignment (for example, cover 10–39 percent and height 1.8–4.9 m is assigned GS2 FBFM40) for nondisturbed Mediterranean California dry-mesic mixed conifer forest and woodland are shown in figure E2. See section E.6.2.5 for explanation of canopy guide (CG) applications.

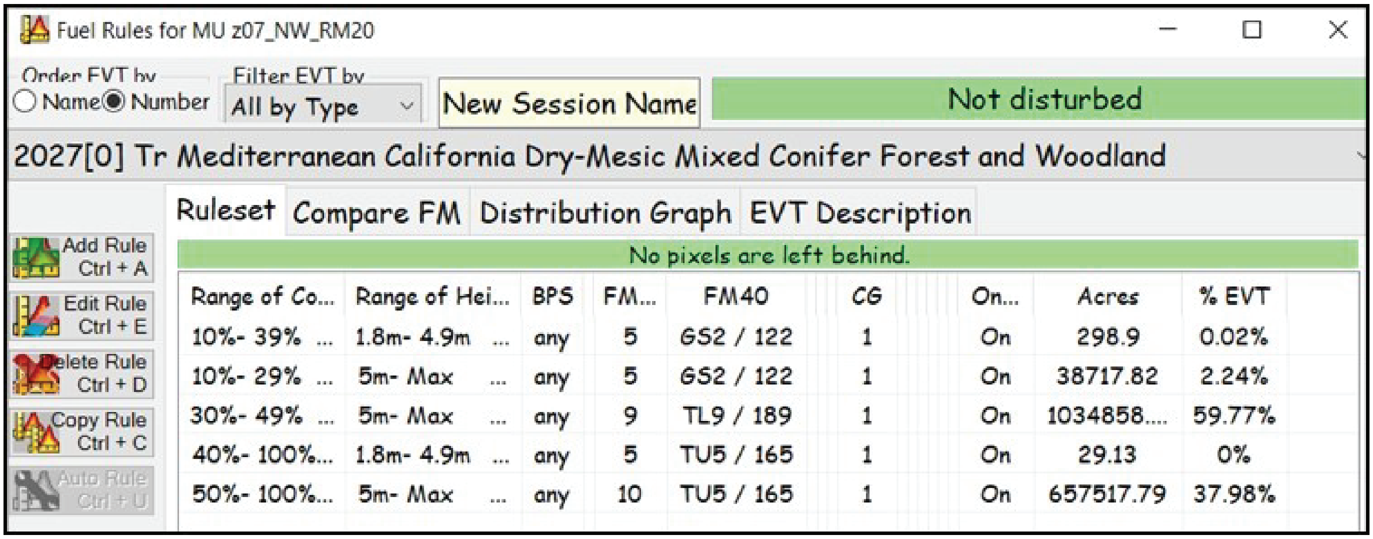


Figure E2. Image of fuel rules in LANDFIRE's Total Fuels Change ArcMap tool (version 3.19).

E.6.2. Canopy Fuels

Canopy fuels also are used in fire behavior models via crown fire initiation and spread models, which can vary with different model choices such as the Van Wagner (1977) and Scott and Reinhardt (2001) crown fire modeling systems (table E5). The space between surface fuels and CBH helps determine whether crown fire initiation can happen along with fuel moisture content; and CC, CH, and CBD along with wind speeds inform rate of spread, the potential for passive crowning (torching trees), or active crown fires (treetop to treetop spread), and spotting ahead of the main fire (Finney, 2004).

The origins of crown fire initiation, spread, and active crown fire models, adapted from the National Wildfire Coordinating Group (2021) are listed in table E5. LF data are designed to work with the Scott and Reinhardt crown fire modeling system.

A series of linear models developed from Forest Inventory and Analysis plot data were obtained via the Fire and Fuels Extension (FFE) of FVS (Reinhardt and Crookston, 2003). FFE–FVS scenarios account for the effects of disturbance type, severity, and the time since disturbance when applied to FVT, FVC, and FVH (table E6). Accounting for changes to canopy fuels postdisturbance is critical in understanding crown fire initiation and behavior on an incident, for hazard mapping, or when planning fire management priorities. All canopy fuels are considered capable fuels.

E.6.2.1. Canopy Cover

CC is assigned the midpoint of the FVC-binned forested classes at nondisturbed locations. For disturbed areas, FDist, predisturbance vegetation FVT, FVC midpoints, and FVH midpoints are used to calculate disturbance effects on CC via FFE–FVS disturbance scenario outputs. These linear equations inform cover acted on by the disturbance, and results are available in the FVS disturbance database ((LANDFIRE, 2008).

E.6.2.2. Canopy Height

CH is assigned the midpoint of the binned FVH forested classes at nondisturbed locations. For disturbances, FDist, predisturbance vegetation FVT, FVC, and FVH are used to calculate CH via linear equations derived from FFE–FVS scenario outputs. FFE–FVS scenario outputs for CH are available in the FVS disturbance database (LANDFIRE, 2008).

E.6.2.3. Canopy Base Height

CBH represents the distance from surface fuels to the base of the canopy and is partially determined by the species of tree being considered. Different tree species grow limbs lower on the bole (trunk) than others. The process for CBH development in LF 2016 Remap used plot and species information in FFE–FVS, which considers multiple traits of the tree species of interest based on the geography of the variants. Forest Inventory and Analysis tree plot data were input into the FFE–FVS program and analyzed by variant with information on the six primary disturbance types and a no-disturbance scenario. Outputs from FFE–FVS for the change in ecological traits included the change in CBH by disturbed type, severity, TSD, and regrowth. Once the CBH change information was produced by FVT and variant, a linear regression model was developed to relate the change in plot-level CBH to the change in CC and CH. The linear relations within FFE–FVS variants were grouped, and CBH was regressed against CC and CH such that whenever CC or CH changed, a new CBH was designated.

E.6.2.4. Canopy Bulk Density

CBD is a volume measure of the amount and arrangement of aerial fine fuels in tree canopies (Reinhardt and Crookston, 2003). The general linear model method for calculating CBD for LF 2016 Remap was the same as previous versions of LF (Reeves and others, 2009), but the values that go into

Table E5. National Wildfire Coordinating Group models and modeling systems used.

[CFFBP, Canadian Forest Fire Behavior Prediction System]

Model used	CFFBP, Van Wagner (1977) modeling system	Surface fire control, Finney (1998) modeling system	Crown fire control, Scott and Reinhardt (2001) modeling system
Surface fire	Van Wagner (1977) integrated, empirical model	Rothermel (1972)	Rothermel (1972)
Crown fire spread	Van Wagner (1977) integrated, empirical model	Rothermel (1972)	Rothermel (1972)
Crown fire (torching) initiation threshold spread rate	Van Wagner (1977)	Van Wagner (1977)	Van Wagner (1977)
Active crown fire propagation threshold spread rate	Van Wagner (1977)	Van Wagner (1977)	Van Wagner (1977)

Table E6. Example of Fire and Fuels Extension-Forest Vegetation Simulator inputs and change for a plot undergoing high-severity fire.

[ft, foot; PCC, percentage of canopy cover; CBD, canopy bulk density; CBH, canopy base height; PCCDELTA, change in percentage of canopy cover; HTDELTA, change in height; CBDDELTA, change in CBD]

LANDFIRE plot identifier	Year	Variant	Height (ft)	PCC	CBD	CBH	PCCDELTA	HTDELTA	CBDDELTA	CBHDELTA
LF201010	2010	Blue Mountains	22.43	11.5	0	3	−11.47	−22.43	−0.03	−4
LF2010100	2010	Blue Mountains	22.54	17	0	3	−2.46	4.06	−0.02	−4

the computation were refined. The model is sensitive to CH inputs. Because CBD is a measure of volume, the height of a stand of trees would either expand or compress the area that the amount of fuel is calculated within. The previous versions of LF had only 5 classes of CH, whereas LF 2016 Remap has 13, which allows the general linear model to assess the volume of fuel in a more detailed manner for the canopy. The CH in relation to CC determines CBD in the general linear model, so regardless of the height, if the canopies of trees are too open, the heat transfer process from crown to crown will not happen in crown fire spread models.

E.6.2.5. LANDFIRE Total Fuels Change Canopy Guide

A final step in assigning CBH or CBD for each pixel is the CG assigned to each FVT used in the LFTFC. The CG creates an adjustment to CBH and CBD values based on whether it is likely to torch or crown. Generally, under average fire season circumstances, deciduous trees will not torch or crown, and coniferous trees will torch if mixed with deciduous and have the potential for crown fire spread if pure conifer. Unfortunately, fire behavior models in use today are not able to adjust whether certain vegetation types torch or crown; therefore, an adjustment is made to LF CBD and CBH layers to account for these trends in fire behavior. To emulate these general trends, the CG is set as follows:

- 0: no canopy,
- 1: torching and crown fire possible (CBD and CBH unchanged),
- 2: no torching or crown fire possible (CBD=0.012 kilogram per cubic meter and CBH = 10 m), and
- 3: only torching possible (CBD=0.05 kilogram per cubic meter).

E.6.3. Surface and Canopy Fuels Review and Refinement

An important step in fuel layer creation is reviewing how the fuel layers produced by LF perform compared to previous years' fuel layers using gNexus (Scott, 1999) and FlamMap (Finney, 2006) by mapzone. If large discrepancies are detected, actual fires are modeled to try to emulate fire behavior and help adjust fuel layers when needed. To model the fires, a landscape file (LCP), which includes surface and canopy fuels and topographic layers from LF, must be created. LCPs are typically the format in which fire behavior and hazard models use the layers and are available in that format for download if specified. Once an LCP has been created for an area of interest, numerous model runs are created to attempt to emulate known fire spread with available LF fuel layers and local weather inputs. If modeled results are substantially different from known fire spread perimeters, then expert adjustments to fuel models are considered. This workflow represents a feedback loop in fuel production efforts where fuels adjustments are made and models are rerun to better calibrate fuel layers (fig. E3).

An example of FlamMap 6.1 2021 FARSITE run of fire spread using LF fuel layers (colors) compared to actual fire spread (in black) is shown in figure E3. The final fire perimeter calculated in the model was similar to the actual area burned using LF 2016 Remap fuels.

E.6.4. Fuel Characteristic Classification System

The FCCS is used with Fuel and Fire Tools software to describe fuel characteristics of different types of vegetation related to spread, intensity, and consumption and describes fuel loading, in tons per acre, for six forest strata within each FCCS class (Fire and Environmental Research Applications Team, 2021). The FCCS classes in combination with the Fuel and Fire tools can also estimate carbon flux during fire. LF collaborated with the Fire and Environmental Research Applications Team of the Forest Service’s Pacific Northwest Research Station for creation of the FCCS product. Rule-based methods for crosswalks and mapping the FCCS fuel layer are constructed from the FVT and FDist products. The FVT-to-FCCS crosswalk rules often allow for several possibilities; therefore, expert opinion is used to assign the most representative FCCS and to determine where additional development is necessary. FCCS mapping should be considered a starting point and customized to represent a project area. FCCS is a capable fuels product.

E.6.5. Canadian Forest Fire Danger Rating System

The CFFDRS product depicts fuel types as an identifiable association of fuel elements of distinctive species, form, size, arrangement, and continuity. CFFDRS demonstrates characteristic fire behavior under the specified burn conditions. In LF 2016 Remap, Canadian fuel models are derived from the “Fuel Model Guide to Alaska Vegetation” (Alaska Fuel Model Guide Task Group, 2018), which was specifically designed for translating FBFM13 and FBFM40 surface fuel layers from LF maps to Canadian fuel models. The LF CFFDRS layer is only created for Alaska and contains the fuel models used for the fire behavior prediction system fuel type inputs (fig. E4 [red circle]; table E7). Default values assigned to the Canadian fuel models required to run the Prometheus fire behavior software (W.I.S.E. Development Team, 2021) are added as attributes to the LF CFFDRS layer.

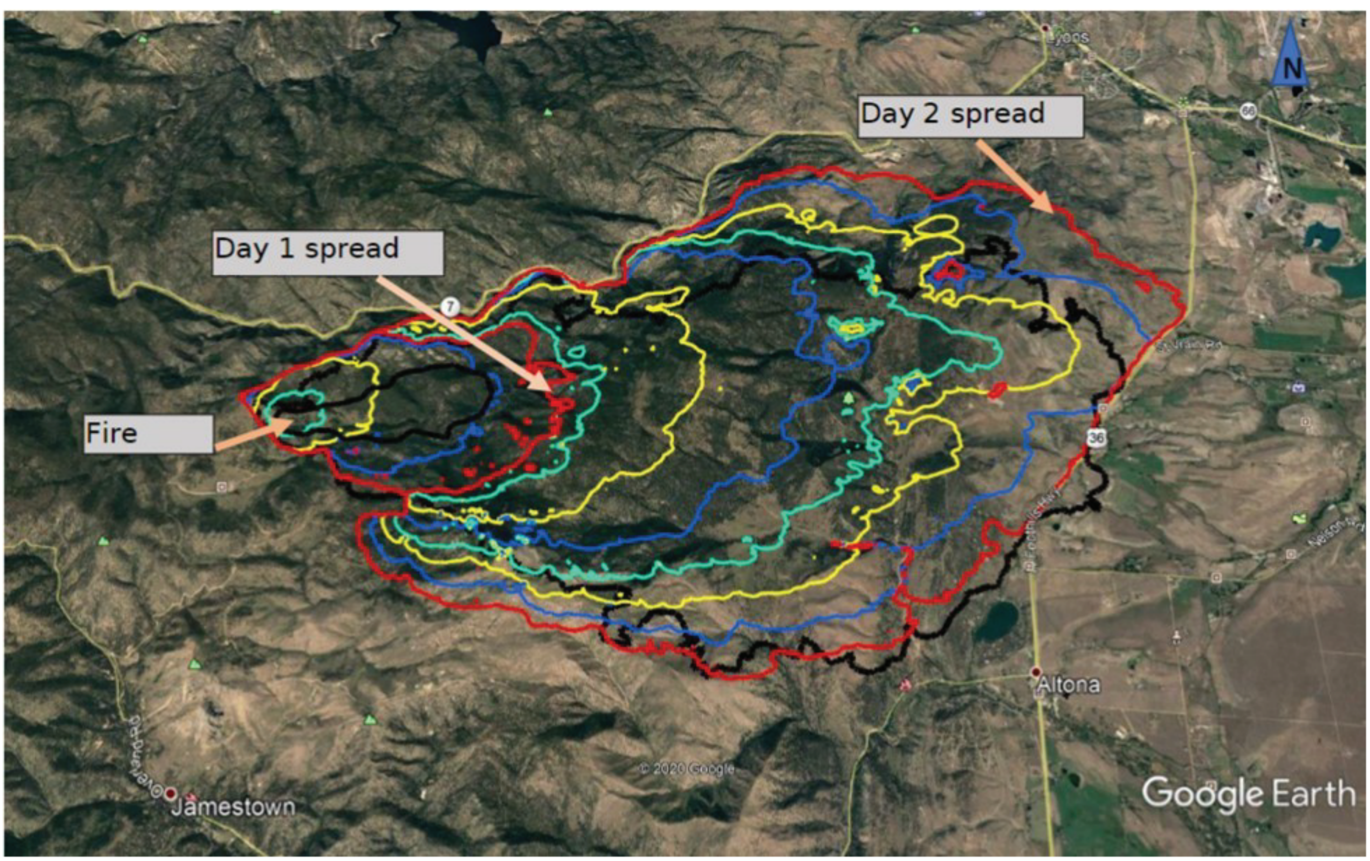


Figure E3. Example of FlamMap 6.1 2021 FARSITE run of fire spread.

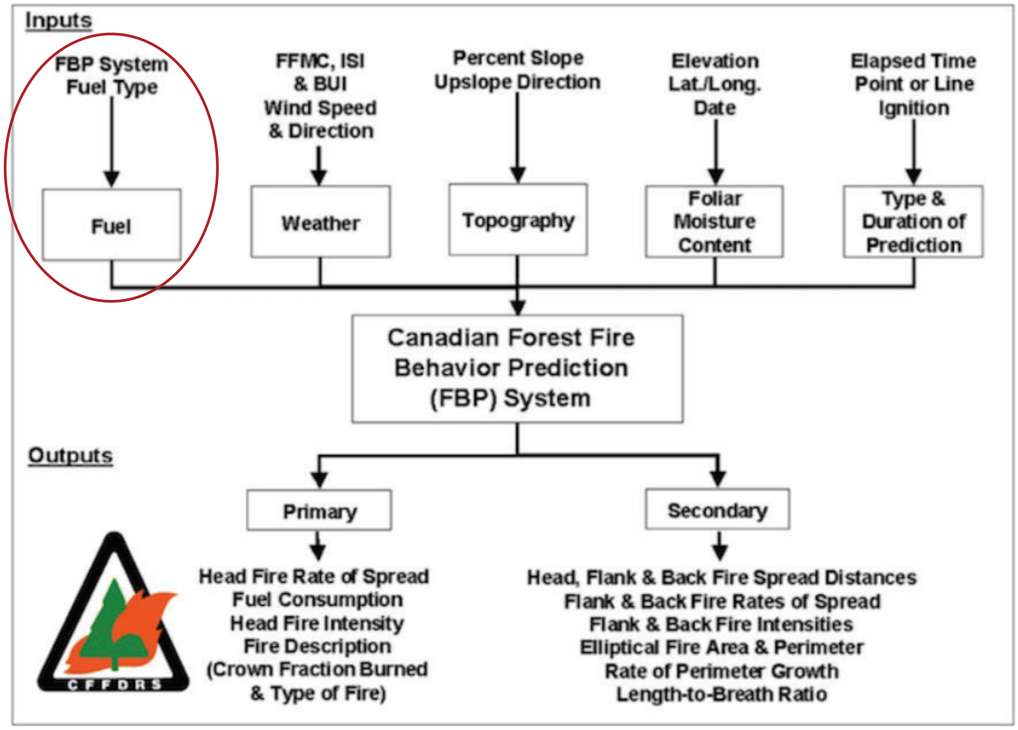


Figure E4. Canadian Forest Fire Danger Rating System inputs. The red circle indicates the fuel layers needed to run the fire behavior prediction system provided for Alaska by LANDFIRE. [FBP, Fire Behavior Prediction; FFMC, fine fuel moisture content; ISI, initial spread index; BUI, build up index; Lat./Long., latitude/longitude; CFFDRS, Canadian Forest Fire Danger Rating System]

Table E7. Canadian Forest Fire Danger Rating System fire behavior prediction fuel types provided in LANDFIRE 2016 Remap for Alaska.

Fuel type	Description
C–1	Spruce-lichen woodland
C–2	Boreal spruce
C–3	Mature jack or lodgepole pine
C–4	Immature jack or lodgepole pine
C–5	Red and white pine
C–6	Conifer plantation
C–7	Ponderosa pine-Douglas-fir
D–1/D-2	Aspen
S–1	Jack or lodgepole pine slash
S–2	White spruce-balsam slash
S–3	Coastal cedar-hemlock-Douglas-fir slash
O–1a	Matted grass
O–1b	Standing grass
O–1a/O–1b	Grass
M–1/M–2	Boreal mixed wood
M–3/M–4	Dead balsam fir mixed wood
M–1/M–2 (80 PC)	Boreal mixed wood (80-percent conifer)

The CFFDRS inputs and red circle indicating the fuel layers needed to run the fire behavior prediction system. The CFFDRS fuel types provided for Alaska by LF (National Wildfire Coordinating Group, 2021) are shown in figure E4.

E.6.6. Modeling Fuels with an Index System

Modeling Fuels with an Index System (MoD–FIS) was created in response to user needs for fuel adjustments mainly on systems where fire is driven by variations in herbaceous cover from season to season and with varying weather regimes (LANDFIRE, 2017). The changes in available fuel layers are critical in areas of *Bromus tectorum* L. (cheatgrass) and *Cenchrus ciliaris* L. (buffelgrass) invasion to help understand the resources that may be needed during the fire season. This product is created seasonally in the Southwest and Northern Great Basin, along with parts of the Northwest (labeled as Northern) United States (as much as three times annually; fig. E5). It indicates the difference in the live fuel cover for that season compared to a 10-year average. The index for adjusting surface fuels for MoD–FIS used a 10-year average NDVI value for each pixel, then the index relates the median average NDVI value within each mapzone to EVC at each pixel. To obtain seasonal fuel model adjustments, seasonal NDVI was used to assign an adjusted cover value based on the established NDVI and cover relation. The adjusted cover

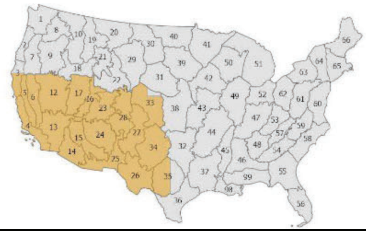
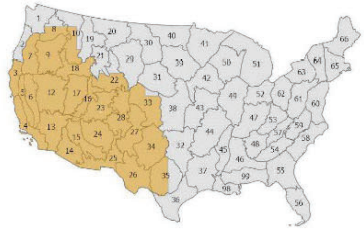
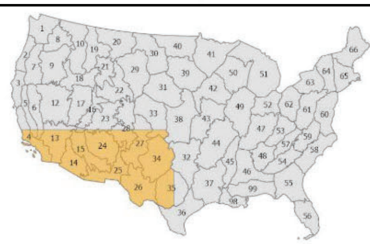
Overview Area	Season	Region	Date Range
	Spring	Southwest Northern Great Basin	Feb. 1–May 15
	Summer	Southwest Northern Great Basin Northern	Mar. 1–June 30
	Fall	Southwest	July 1–Sept. 15

Figure E5. Modeling Fuels with an Index System release seasons, regions, and date ranges.

value was used within the LFTFC tool to assign each season's adjusted surface fuel model (FBFM40). MoD–FIS data are considered capable and are based on the latest version of annual FBFM40 data available within LF.

LF also assisted in developing the Southeast MoD–FIS product distributed by WFDSS. That product was released weekly by WFDSS and was based on a crosswalk between LF fuel layers and changes to the Keetch-Byram Drought Index, which is a measure of soil dryness (Keetch and Byram, 1968). WFDSS no longer provides the Southeast MoD-FIS product.

E.6.7. LANDFIRE 2019 Limited Fuel Approach

Fuel layers in LF 2019 Limited were 2021 capable and included limited disturbances similar to vegetation updates for LF 2019 Limited. Only fire program data and events from the Events Geodatabase were available to use in the creation of the 2021 capable FDist. Additionally, the 2021 capable FDist was transitioned forward 1 year from the 2020 capable FDist that was available with LF 2016 Remap. This translates to FDist disturbances recorded from 2011 to 2016 having complete disturbance and those from 2017 to 2019 having only limited disturbances recorded. Disturbances from 2020 were not available for the 2019 Limited release. All nondisturbed surface and canopy fuels were identical to LF 2016 Remap, and disturbed areas went through the same assignment processes noted for LF 2016 Remap surface and canopy fuel rules described previously. Additionally, the 2019 Limited fuel layers were created for the contiguous United States but not for Alaska, Hawaii, or the insular areas.

E.6.8. LANDFIRE 2020 Fuel Approach

For LF 2020, complete disturbances including RSLC, fire program data, and events were mapped for 2017–20. This means that when the 2022 capable FDist was created, only 1 year of full disturbance mapping was missing and disturbances covered 2012–20; 2021 was unrecorded but accounted for in the TSD shift for capable fuels. The general approach to mapping fuel layers was similar to the previously mentioned descriptions and any nondisturbed pixels still reflect LF 2016 Remap fuel layers assignments; however, updates to developed ruderal fuels reflect modeled vegetation from LF 2016 Remap to assign fuel layers instead. Additionally, updates to developed areas, urban areas, and roads also are incorporated into the fuel layers. Finally, agricultural lands were updated for LF 2020, and Federal agricultural lands were assigned a burnable fuel model. The 2022 capable fuels with LF 2020 are for the contiguous United States, Alaska, Hawaii, and the insular areas that have recorded disturbances. Alaska used the limited disturbance paradigm used in previous updates that only includes fire program data available and recorded

recorded events from the Events Geodatabase. Puerto Rico and the U.S. Virgin Islands had full disturbance with RSLC. Fuel layers for LF 2020 in the western GeoAreas reflect more recent fuel calibrations gathered by Pyrologix for a California wildfire risk assessment and another recent fuel calibration in the Northwest GeoArea.

For LF 2020, a new disturbance cause was added in the fuel rules for mastication (new 700 series FDist codes) to better distinguish masticated areas from the mechanical other class (200 series). The mechanical other class is typically interpreted as "mechanical add" for postdisturbance fuel model designations. Mastication was easy to separate out of the mechanical other class based on disturbance codes and was separated because mastication creates smaller fuels that tend to be spread across the surface. Masticated fuels also tend to be less flammable compared to an area that has had a different type of mechanical treatment where the fuels have been left on.

Finally, a 90-kilometer buffer into Canada at the northern border of the contiguous United States and into Mexico at the southern border of the contiguous United States uses vegetation type, cover, and height derived from the North American Land Change Monitoring System (Latifovic and others, 2012) data and aspect to assign fuel layers in these buffer areas (see section D.2.12.3 for more information about the 90-kilometer buffer). Although a coarse assessment, it provides a way to model fire ignition and spread across the U.S. border with fire behavior models.

E.7. Conclusion

LF fuel products are important datasets for those involved in fire management or planning. Having detailed fuel information for every 30-m pixel on the landscape for the United States and insular areas, and having this information regularly updated to account for disturbances, overcomes a huge hurdle for landscape planning and fire response. LF fuel products are designed to be customized at the local level, allowing users to account for the most recent disturbances. Feedback mechanisms are provided to continue improving LF's fuel calibrations via outreach, help desk, and stakeholder efforts supporting large-scale modeling. Although incorporating all local calibrations into the larger LF project is difficult, in some cases, improvements can be implemented for entire vegetation types or mapzones. The surface and canopy fuel models used in many fire behavior models at all scales show the versatility of mapping fuels at the 30-m pixel scale and for all lands in the United States. With the ability of LF fuel production staff to run fire behavior models and compare model outputs using LF data to actual fire behavior and extent, surface and canopy fuels are continuously updated and reflect the latest fuel information available.

The many uses of LF fuel layers detailed herein are varied and wide reaching. Using the FDist layer, stakeholders have access to 10 years of categorized disturbance information for any project. Surface fuels are used for modeling fire behavior on incidents during intense fire years, and smoke modeling and air quality studies can begin with the LF FCCS fuel-bed layer. For more information on canopy structure for wildlife or to gain another proxy for biomass, users can use the CBD layer. Overall, the LF fuel layers are an important resource for the health, safety, and security of those who live in the United States. For further information, please reference the LF website (https://www.landfire.gov).

E.8. References Cited

Ager, A.A., Evers, C.R., Day, M.A., Alcasena, F.J., and Houtman, R., 2021, Planning for future fire—Scenario analysis of an accelerated fuel reduction plan for the western United States: Landscape and Urban Planning, v. 215, art. 104212, 12 p. [Also available at https://doi.org/10.1016/j.landurbplan.2021.104212.]

Alaska Fuel Model Guide Task Group, 2018, Fuel model guide to Alaska vegetation: Alaska Wildland Fire Coordinating Group Fire Modeling and Analysis Committee report, 105 p., accessed November 1, 2021, at https://www.frames.gov/catalog/56055.

Anderson, H.E., 1981, Aids to determining fuel models for estimating fire behavior: Forest Service General Technical Report INT–122, 22 p.

Calkin, D.E., Thompson, M.P., Finney, M.A., and Hyde, K.D., 2011, A real-time risk assessment tool supporting wildland fire decisionmaking: Journal of Forestry, v. 109, no. 5, p. 274–280.

Dillon, G.K., Menakis, J.P., and Fay, F., 2014, Wildland fire potential—A tool for assessing wildfire risk and fuels management needs, in Keane, R.E., Jolly, M., Parsons, R., and Riley, K., comps., Proceedings of the large wildland fires conference, May 19–23, 2014, Missoula, Mont.: Fort Collins, Colo., Forest Service, Rocky Mountain Research Station, p. 60–76.

Drury, S.A., Rauscher, H.M., Banwell, E.M., Huang, S., and Lavezzo, T.L., 2016, The interagency fuels treatment decision support system—Functionality for fuels treatment planning: Fire Ecology, v. 12, no. 1, p. 103–123. [Also available at https://doi.org/10.4996/fireecology.1201103.]

Finney, M.A., 1998, FARSITE—Fire Area Simulator-model development and evaluation (revised February 2004): Ogden, Utah, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Research Paper RMRS-RP-4, 47 p.

Finney, M.A., 2004, FARSITE—Fire area simulator—Model development and evaluation: Ogden, Utah, Forest Service, Rocky Mountain Research Station Research Paper RMRS–RP–4, 47 p.

Finney, M.A., 2006, An overview of FlamMap fire modeling capabilities, in Andrews, P.L., and Butler, B.W., eds., Fuels management—How to measure success: Fort Collins, Colo., Forest Service, Rocky Mountain Research Station, p. 213–220.

Finney, M.A., Grenfell, I.C., McHugh, C.W., Seli, R.C., Trethewey, D., Stratton, R.D., and Brittain, S., 2011a, A method for ensemble wildland fire simulation: Environmental Modeling and Assessment, v. 16, no. 2, p. 153–167. [Also available at https://doi.org/10.1007/s10666-010-9241-3.]

Finney, M.A., McHugh, C.W., Grenfell, I.C., Riley, K.L., and Short, K.C., 2011b, A simulation of probabilistic wildfire risk components for the continental United States: Stochastic Environmental Research and Risk Assessment, v. 25, no. 7, p. 973–1000. [Also available at https://doi.org/10.1007/s00477-011-0462-z.]

Fire and Environmental Research Applications Team, 2021, Fuel and fire tools: Forest Service web page, accessed November 1, 2021, at https://www.fs.usda.gov/pnw/tools/fuel-and-fire-tools-fft.

Keetch, J.J., and Byram, G.M., 1968, A drought index for forest fire control: Forest Service Research Paper SE–38, 33 p.

LANDFIRE, 2008, Forest Vegetation Simulator disturbance database: LANDFIRE web page, accessed November 1, 2021, at https://landfire.gov/lf_fvs.php.

LANDFIRE, 2017, Modeling dynamic fuels with an index system—Fine fuels based process in the Great Basin and Southwest United States: LANDFIRE Technical Report, 8 p., accessed November 1, 2021, at https://landfire.gov/documents/GB-SW_MoD-FIS_White-Paper.pdf.

Latifovic, R., Homer, C., Ressl, R., Pouliot, D.A., Hossian, S., Colditz, R., Olthof, I., Giri, C., and Arturo, V., 2012, North American land change monitoring system, in Giri, C.P., ed., Remote sensing of land use and land cover—Principles and applications: Boca Raton, Fla., CRC Press, p. 303–324.

National Fire Protection Association, 2008, Community guide to preparing and implementing a community wildfire protection plan: National Fire Protection Association, 26 p., accessed November 1, 2021, at https://www.nfpa.org/-/media/Files/Training/certification/CWMS/CWPP_Report_Aug2008.ashx.

National Wildfire Coordinating Group, 2021, Fire Behavior Field Reference Guide, PMS 437: National Wildfire Coordinating Group web page, accessed May 5, 2023, at https://www.nwcg.gov/publications/pms437.

O'Connor, C.D., Thompson, M.P., and Rodríguez y Silva, F., 2016, Getting ahead of the wildfire problem—Quantifying and mapping management challenges and opportunities: Geosciences, v. 6, no. 3, art. 35, 18 p., accessed November 1, 2021, at https://doi.org/10.3390/geosciences6030035.

Ottmar, R.D., Sandberg, D.V., Prichard, S.J., and Riccardi, C.L., 2003, Fuel characteristic classification system: Proceedings of the 2nd International Wildland Fire Ecology and Fire Management Congress, Orlando, Fla., November 16–20, 2003, 6 p., accessed November 1, 2021, at http://ams.confex.com/ams/FIRE2003/techprogram/paper_67236.htm.

Prichard, S.J., Povak, N.A., Kennedy, M.C., and Peterson, D.W., 2020, Fuel treatment effectiveness in the context of landform, vegetation, and large, wind-driven wildfires: Ecological Applications, v. 30, no. 5, art. e02104, 22 p., accessed November 1, 2021, at https://doi.org/10.1002/eap.2104.

Reeves, M.C., Kost, J.R., and Ryan, K.C., 2006, Fuels products of the LANDFIRE Project, in Andrews, P.L., and Butler, B.W., eds., Fuels management—How to measure success: Fort Collins, Colo., Forest Service, Rocky Mountain Research Station, p. 239–252.

Reeves, M.C., Ryan, K.C., Rollins, M.G., and Thompson, T.G., 2009, Spatial fuel data products of the LANDFIRE Project: International Journal of Wildland Fire, v. 18, no. 3, p. 250–267. [Also available at https://doi.org/10.1071/WF08086.]

Reinhardt, E., and Crookston, N.L., eds., 2003, The fire and fuels extension to the forest vegetation simulator: Ogden, Utah, Forest Service, Rocky Mountain Research Station General Technical Report RMRS–GTR–116, 209 p., accessed November 1, 2021, at https://doi.org/10.2737/RMRS-GTR-116.

Rothermel, R.C., 1972, A mathematical model for predicting fire spread in wildland fuels: Ogden, Utah, U.S. Department of Agriculture Intermountain Forest and Range Experiment Station Research Paper INT–115, 40 p.

Scott, J.H., 1999, NEXUS—A system for assessing crown fire hazard: Fire Management Notes, v. 59, no. 2, p. 20–24.

Scott, J.H., and Burgan, R.E., 2005, Standard fire behavior fuel models—A comprehensive set for use with Rothermel's surface fire spread model: Fort Collins, Colo., Forest Service, Rocky Mountain Research Station General Technical Report RMRS–GTR–153, 81 p., accessed November 1, 2021, at https://doi.org/10.2737/RMRS-GTR-153.

Scott, J.H., Gilbertson-Day, J.W., Moran, C.J., Dillon, G.K., Short, K.C., and Vogler, K.C., 2020, Wildfire risk to communities—Spatial datasets of landscape-wide wildfire risk components for the United States: Forest Service Research Data Archive, accessed November 1, 2021, at https://doi.org/10.2737/RDS-2020-0016.

Scott, J.H., and Reinhardt, E.D., 2001, Assessing crown fire potential by linking models of surface and crown fire behavior: Fort Collins, Colo., Forest Service, Rocky Mountain Research Station Research Paper RMRS–RP–29, 59 p., accessed November 1, 2021, at https://doi.org/10.2737/RMRS-RP-29.

Scott, J.H., Thompson, M.P., and Calkin, D.E., 2013, A wildfire risk assessment framework for land and resource management: Fort Collins, Colo., Forest Service, Rocky Mountain Research Station General Technical Report RMRS–GTR–315, 83 p., accessed November 1, 2021, at https://doi.org/10.2737/RMRS-GTR-315.

Smail, T., Martin, C., and Napoli, J., 2020, The LANDFIRE Total Fuel Change Tool (LFTFC) user guide: LANDFIRE Technical Document LF–OPS–007, 67 p., accessed November 1, 2021, at https://landfire.cr.usgs.gov/documents/LFTFC_User_Guide_2020.pdf.

Southern Group of State Foresters, 2021, Wildfire risk assessment portal: Southern Group of State Foresters web page, accessed November 1, 2021, at https://www.southernwildfirerisk.com/About.

Van Wagner, C.E., 1977, Conditions for the start and spread of crown fire: Canadian Journal of Forest Research, v. 7, no. 1, p. 23–34. [Also available at https://doi.org/10.1139/x77-004.]

Wildland Fire Decision Support System, 2021, WFDSS 101, lesson 9—Fire behavior analysis: U.S. Geological Survey, 7 p., accessed November 1, 2021, at https://wfdss.usgs.gov/wfdss/pdfs/WFDSS_101_Lesson_9.pdf.

W.I.S.E. Development Team, 2021, Promethius—The Canadian wildland fire growth simulation model (version 2021.12.03): W.I.S.E. Development Team software release, accessed November 1, 2021, at http://www.firegrowthmodel.com.

Wotton, B.M., Alexander, M.E., and Taylor, S.W., 2009, Updates and revisions to the 1992 Canadian Forest Fire Behavior Prediction System: Ontario, Natural Resources Canada, Information Report GLC–X–10, 55 p.

Ziel, R., 2014, Field guide for CFFDRS Fire Weather Index (FWI) system: Canadian Forest Service, 34 p., accessed November 1, 2021, at https://www.frames.gov/documents/nwcg/fbfrg/mn_2014_cffdrs-fwi-field-guide_glesener.pdf.

Chapter F. Fire Regime

By Daryn Dockter,[1] Inga P. La Puma,[1] Paul Bourget,[1] and Erica J. Degaga[1]

F.1. Introduction to LANDFIRE Fire Regime Data

F.1.1. The Need for LANDFIRE Fire Regime Data

Fire regime data from LANDFIRE (LF) represent what is presumed to be the pre-European colonization fire regime and includes the fire return intervals for all fire along with the percentage of low-severity, mixed-severity, and replacement-severity fire. Another aspect of the fire regime data is the fire regime group, which consists of a combination of the fire return interval and the percentage of different severity fires. These data are attached to the biophysical settings (BpS) attribute table (see chap. D) and are directly associated with the BpS of pre-European colonization vegetation. Fire regime data are a useful starting place for managers attempting to assess how to implement a prescribed fire program on their lands; for example, researchers in the Monongahela National Forest compared LF fire regime group maps to fire regime group maps that they derived from witness tree records (tree records from surveys in the late 1700s and the 1800s). They noted overall agreement between the maps but also noted areas in which disagreement indicated that further research was needed (Thomas-Van Gundy, 2019). Other researchers have used LF fire return intervals as a comparison to fire return intervals under expected climate effects (Parks and others, 2018).

The LF fire regime category also includes vegetation assessment layers that relate to BpS, such as succession class (SClass), vegetation departure from historical conditions (departure from BpS), and the vegetation condition class, a classification of the vegetation departure from historical conditions.

F.1.2. LANDFIRE Fire Regime Data Background

BpS maps and fire regime attributes indicate the presumed state of the vegetation with pre-European colonization vegetation and fire regimes along with late 20th century climate inputs. Spatial BpS and fire regime data were originally mapped using the Vegetation Dynamics Development Tool model using modern climate data inputs and a mapped estimate of environmental site potential without disturbance for each pixel for LF National (Rollins, 2009). The BpS descriptions and fire regimes associated with the original mapped BpS layer have since been refined using ST-Sim (a package of SyncroSim, described in detail in chap. D) and extensive expert review, but the spatial BpS data have not changed except to reflect updates in barren and water layers (Blankenship and others, 2021).

In LF 2016 Remap, fire regime groups, the percentage of low-severity fire, the percentage of mixed-severity fire, the percentage of replacement-severity fire, and the fire return interval are included as attributes in the BpS mapped product rather than stand-alone spatial layers.

All vegetation assessment layers, including vegetation SClass, departure, and condition class, are derived from the BpS mapped models and descriptions and LF 2016 Remap vegetation information. No updates were made in LF 2019 Limited or LF 2020 to fire regime products.

F.2. Fire Regime Production

F.2.1. Fire Return Intervals, Percentage of Severity, and Fire Regime Groups

The fire return intervals and percentage of expected severity for pre-European fire regimes were revised from LF National with updated BpS descriptions. The descriptions were updated with the input of more than 800 experts around the country during 5 years of workshops (Blankenship and others, 2021). The fire regime group classification is a combination of the return interval and the percentage of replacement fire (table F1).

F.2.2. Vegetation Assessment Layers

F.2.2.1. Succession Class

SClass is assigned based on combinations of BpS, existing vegetation type (EVT)/ecological system, existing vegetation cover (EVC), and existing vegetation height (EVH). The Nature Conservancy LF team produced the SClass assignments in a spreadsheet. The rules were updated to reflect BpS map splits and updated BpS code formatting with the mapzone added. In addition, the rules were expanded from previous LF product versions by adding leaf-form designations for mixed broadleaf-conifer types. A custom tool was produced by Don Helmbrecht and Michelle Hawks with U.S. Department

[1]KBR, Inc., under contract to the U.S. Geological Survey.

Table F1. Fire regime group labels and definitions.

[%, percent]

Fire regime group label	Definition
I–A	Percentage of replacement fire less than 66.7%, fire return interval 0–5 years
I–B	Percentage of replacement fire less than 66.7%, fire return interval 6–15 years
I–C	Percentage of replacement fire less than 66.7%, fire return interval 16–35 years
II–A	Percentage of replacement fire greater than 66.7%, fire return interval 0–5 years
II–B	Percentage of replacement fire greater than 66.7%, fire return interval 6–15 years
II–C	Percentage of replacement fire greater than 66.7%, fire return interval 16–35 years
III–A	Percentage of replacement fire less than 80%, fire return interval 36–100 years
III–B	Percentage of replacement fire less than 66.7%, fire return interval 101–200 years
IV–A	Percentage of replacement fire greater than 80%, fire return interval 36–100 years
IV–B	Percentage of replacement fire greater than 66.7%, fire return interval 101–200 years
V–A	Any severity, fire return interval 201–500 years
V–B	Any severity, fire return interval 501 or more years

of Agriculture Forest Service and provided to the Earth Resources Observation and Science Center to help assign SClass. The tool ingested the LF 2016 Remap BpS, EVT, EVC, and EVH rasters along with the SClass rules from the spreadsheet. Primary processing steps included the following:

- Binning EVC and EVH according to SClass rules (similar to previous LF version bins) and
- Combining BpS, EVT, EVC, and EVH into 1 layer containing all 4 attributes.

Then, LF used the SClass tool to assign an SClass to every pixel according to rules. The tool used the following EVT attributes:

- EVT_Phys (hardwood = brdlf; conifer = con; hardwood-conifer = mix) to get leaf form for mixed types and split out rules based on leaf form (brdlf, mix, con),
- Subclass for riparian/wetland types to get appropriate leaf form because these are all "riparian" in EVT_Phys, and
- BpS or EVT to assign "barren or sparse."

Unique rules were developed for a few specific BpS classes such as Sagebrush, Lodgepole, Oak, and Maple-Basswood based on feedback from regional review and workshops. The following changes to SClass also happened for LF 2016 Remap:

- Burnable and nonburnable designations for urban and agriculture were dropped because they are not relevant to SClass, and
- "Barren" and "sparsely vegetated" classes were combined into one "barren or sparse" class because they are not differentiated in EVT.

F.2.2.2. Vegetation Departure

Vegetation departure is assigned based on combinations of SClass and BpS codes (for example, BpS models detected within certain mapzones). The Nature Conservancy provided BpS codes in a spreadsheet. A custom tool was produced by the Earth Resources Observation and Science Center that ingested the LF 2016 Remap BpS codes, SClass, and mapzone rasters along with the reference conditions spreadsheet. Primary processing steps included the following:

- Combining BpS code, SClass, and mapzone into one layer.
- Extracting attribute tables to text files.
- Using SClass_Counts for a given SClass within a given BpS code combination, (the total count in the combination was calculated).
- Using SClass_Total for each BpS code (the total count for all SClass counts present was calculated).
- Determining current percentage for a given SClass within a BpS code (the percentage of each SClass counts against the total that was calculated using this equation: current percentage = [SClass_Counts/SClass_Total]*100).

- Determining minimum of reference and current for a given SClass label within a BpS mapzone combination (the corresponding [classes A–E] reference percentage column value was compared with the derived current percentage value, and the minimum of the two was designated; if not a number in both, the value was left blank in the final output [given a weight of 0 in calculations]). As an example, for a BpS code with an SClass label A, the current percentage value of 27 was compared to the class A reference percentage column value of 10; thus, the minimum of reference and current was 10 for that given row.
- Determining similarity for each BpS code (the total minimum of reference and current in existence was calculated; if the calculated value was negative, then the given value was blank in the final output [given a weight of 0 in calculations]).
- Determining departure for each BpS code (the difference between 100 and the given similarity value was calculated; if the calculated value was negative, then the given value was blank in the final output [given a weight of 0 in calculations]: departure=100–similarity).

The final raster was produced with a lookup function.

F.2.2.3. Vegetation Condition Class

Vegetation condition class is a reclassification and categorization of vegetation departure. The vegetation condition class raster was produced using a lookup tool (table F2).

Table F2. Vegetation condition class based on reclassification and categorization of vegetation departure.

[Vdep, vegetation departure; VCC, vegetation condition class]

Vdep value	VCC category	VCC class
0–16	Very low	1
17–33	Low to moderate	2
34–50	Moderate to low	3
51–66	Moderate to high	4
67–83	High	5
84–100	Very high	6

F.3. Conclusion

The fire regime map layers give users the ability to understand their landscape in relation to pre-European colonization fire and vegetation conditions. Fire return intervals along with severity estimations under these conditions can help managers understand how their landscape may have looked before the substantial land-use changes and resource use associated with European colonization and how different the current landscape may be. Understanding this departure of fire regimes and vegetation compared to that baseline can be useful in land management and prioritization of restoration or fuel treatment decisions. The creation of fire regime layers involves many partners and local experts and will continue to evolve with new information on fire and vegetation history. For further information, please reference the LF website (https://www.landfire.gov).

F.4. References Cited

Blankenship, K., Swaty, R., Hall, K.R., Hagen, S., Pohl, K., Shlisky Hunt, A., Patton, J., Frid, L., and Smith, J., 2021, Vegetation dynamics models—A comprehensive set for natural resource assessment and planning in the United States: Ecosphere, v. 12, no. 4, art. e03484, 22 p., accessed February 8, 2022, at https://doi.org/10.1002/ecs2.3484.

Parks, S.A., Holsinger, L.M., Miller, C., and Parisien, M.A., 2018, Analog-based fire regime and vegetation shifts in mountainous regions of the western US: Ecography, v. 41, no. 6, p. 910–921. [Also available at https://doi.org/10.1111/ecog.03378.]

Rollins, M.G., 2009, LANDFIRE—A nationally consistent vegetation, wildland fire, and fuel assessment: International Journal of Wildland Fire, v. 18, no. 3, p. 235–249. [Also available at https://doi.org/10.1071/WF08088.]

Thomas-Van Gundy, M.A., 2019, Inferring fire regimes from data you may already have—Assessing LANDFIRE fire regime maps using local products: Asheville, N.C., Forest Service, Southern Research Station General Technical Report SRS–237, p. 89–91.

Chapter G. Topographic Information

By Daryn Dockter,[1] Inga P. La Puma,[1] and Jacob Casey[1]

G.1. Introduction to LANDFIRE Topography Data

G.1.1. The Need for LANDFIRE Topography Data

Topographic information helps predict vegetation distribution. Certain species are known to be at certain elevations, or prefer south-facing slopes, or are only detected on cliffs or in valleys. When LANDFIRE (LF) models existing vegetation type, elevation, slope, and aspect are key inputs for training LF classification trees. LF's topographic data are not only used within the program for vegetation modeling and mapping but also for fire behavior modeling. They are seamless 30-meter (m) rasters, are ready to use, require no further processing, and are useful for numerous purposes. LF topographic layers are regularly used in research settings such as a study by Alexandre and others (2016) investigating the primary factors affecting building loss to wildfire, where, for example, building loss was higher on steeper slopes. LF topographic layers are part of the landscape files needed to run fire behavior models on large incidents within the Wildland Fire Decision Support System (see chap. E). One recent study used the topographic layers to run the fire behavior model FlamMap to investigate postfire debris flow in New Mexico (Cram and others, 2017).

G.1.2. LANDFIRE Topography Data Background

LF 2016 Remap was the first revision of the topographic layers since LF 2010 (Nelson and others, 2016). Topographic information does not change substantially from year to year; therefore, the revisions mainly incorporated advances associated with the accuracy of the source data, such as higher resolutions, light detection and ranging, and synthetic aperture radar technologies.

[1]KBR, Inc., under contract to the U.S. Geological Survey.

G.2. Elevation Production

G.2.1. Contiguous United States, Hawaii, Puerto Rico, and U.S. Virgin Islands

The U.S. Geological Survey 3D Elevation Program (3DEP) produces the data used in LF's primary elevation data product, the digital elevation model (DEM; U.S. Geological Survey, 2017). The 3DEP DEM provides the best available public domain raster elevation data of the contiguous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands in a seamless format. The 3DEP DEM, previously referred to as the "National Elevation Dataset," is derived from diverse source data including aerial light detection and ranging and is processed to a common coordinate system and unit of vertical measure. All 3DEP DEM data are distributed in geographic coordinates, in units of decimal degrees, and in conformance with the North American Datum of 1983 (NAD 83). Elevation units are in meters and are referenced to the North American Vertical Datum of 1988 across the contiguous United States. 3DEP DEM data are available nationally at a 1/3 arc-second resolution (about 10 m). For the LF elevation product, the 1/3 arc-second 3DEP DEM data were projected from a geographic coordinate system to Albers Equal-Area Conic, resampled to a 30-m spatial resolution, and clipped to the LF boundary.

G.2.2. Alaska Elevation Production

The Alaska elevation data consist of two merged datasets. Interferometric synthetic aperture radar (IFSAR) data were used over the mainland and some small islands (U.S. Geological Survey, 2012), and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data were used over the Aleutian Islands and the 90-kilometer (km) buffer across the border into Canada (National Aeronautics and Space Administration and others, 2019). IFSAR data had a 5-m resolution and were projected in NAD 83 Alaska Albers. Data were mosaicked, resampled to 30 m, and snapped to the Alaska extent. ASTER Global Digital Elevation Model (GDEM) V003 data, which have a 1 arc-second (roughly 33 m at the equator) resolution and a projection of the geographic coordinate system World Geodetic System of 1984, were mosaicked, reprojected to NAD 83 Alaska Albers, resampled to 30 m, and then snapped to the Alaska extent. The IFSAR and ASTER layers were then mosaicked and clipped to the Alaskan extent.

The DEM contained many negative values. Negative values over water were recoded to zero, whereas negative values in mines/quarries were left as is because of the proximity to the ocean and the likelihood that they are in fact below sea level. Negative values not in those areas were replaced using a focal fill process using the median values of surrounding pixels. Seamlines at the United States-Canada border, where there are different values between the ASTER and IFSAR data, are evident. These seamlines are mostly in mountainous terrain and could cause steep (possibly substantial) changes in topography, producing artificial cliffs and valleys.

G.2.3. Pacific Islands

ASTER GDEM data also were downloaded for insular areas in the Pacific. Data were mosaicked, reprojected to the World Geodetic System of 1984 Universal Transverse Mercator (UTM) zone, resampled to 30 m, and then snapped to the Pacific Islands extent.

G.3. LANDFIRE 2016 Remap Aspect

G.3.1. Contiguous United States

The aspect layer was generated from the 3DEP 1/3 arc-second DEM clipped to the LF contiguous U.S. boundary. Aspect was computed using the aspect algorithm in GDAL version 2.0.12 (GDAL/OGR contributors, 2021). The aspect layer defines downslope direction and has the following characteristics:

- If the slope is less than or equal to 4 percent after applying a focal majority using a 9-pixel by 9-pixel window, then a value of −1 is assigned.
- Aspect values range from 0 to 359.0 degrees.
- Values are adjusted to account for the Albers projection.

G.3.2. Outside Contiguous United States (Alaska, Hawaii, and Insular Areas)

Aspect was produced from the DEM layer for Alaska, Hawaii, and insular areas using the planar method in Esri's aspect tool. The DEM layer has the same characteristics as previously listed for the contiguous United States.

G.4. LANDFIRE 2016 Remap Slope

G.4.1. Contiguous United States

Slope was generated from the 3DEP DEM clipped to the LF boundary. The slope layer was created using the degree and percentage of slope algorithm in GDAL version 2.0.12. Degree of slope was distributed as a public deliverable. Percentage of slope was used as a predictor layer for vegetation modeling and for calibrating fuel models with but was not distributed.

G.4.2. Alaska, Hawaii, and Insular Areas

Slope was produced from LF's DEMs for Alaska, Hawaii, and insular areas. Output measurements for slope were degrees and percentage of rise.

G.5. LANDFIRE 2020 Topography Updates

G.5.1. Elevation

In late 2021, the LF team responded to feedback and created new topographic products (elevation, slope, and aspect) for the contiguous United States, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands. New methods were used to ensure the aspect would reflect true north. To create the new LF 2020 elevation products, the 1 arc-second (about 30 m) DEM tiles were obtained from The National Map (U.S. Geological Survey, 2021). The 1 arc-second products were selected because they cover the contiguous United States and the 90-km buffer into Canada and Mexico. The tiles were mosaicked in the native coordinate system of the geographic coordinate system NAD 83 (European Petroleum Survey Group code 4269) and projected to NAD 83 Albers (European Petroleum Survey Group code 5070) with the bilinear interpolation resampling method; cell size and spacing was set to the LF pixel grid. In Alaska, several missing locations along coastal areas and the 90-km buffer into Canada were filled using 3DEP 1/3 arc-second DEM (about 10 m), 2 arc-second DEM (about 60 m), or ASTER GDEM 1 arc-second V003 (National Aeronautics and Space Administration and others, 2019), in order of priority.

G.5.2. Aspect

Aspect was calculated from the previously mentioned elevation layers using the geodesic option in ArcGIS Desktop 10.6.1 (Esri, 2011). This methodology of using the geodesic option on the NAD 83 Albers elevation layer resulted in aspect angles reflecting true north (improvements in aspect values were observed with this methodology, especially for far western and eastern parts of the contiguous United States), accounting for the curvature of the Earth in the projection. During the creation of the LF 2020 aspect layer, a persistent processing artifact consisting of numerous, obviously errant pixel values along the boundary of UTM zones 15 and 16 was rectified by filling a 15-km-wide swath with aspect values calculated for elevation in the UTM projection using the planar option in ArcGIS. Flat pixels with a slope less than or equal to 2 degrees were assigned a value of −1. Pixels with a value of 360 were reclassified to 0.

G.5.3. Slope

After the LF 2020 elevation product was projected to Albers, slope (degree and percentage of rise) was calculated using the geodesic option in ArcGIS Desktop 10.6.1 (Esri, 2011). Percentage of rise was a new slope product release for LF 2020. For slope percentage of rise, percentage of slope values greater than 400 were reclassified to 400. Several no-data areas were assigned value 0 that overlap the LF data extent, which includes a 3-nautical-mile buffer along coastal areas.

G.6. Conclusion

LF topographic layers are used for modeling and mapping vegetation and for informing fire behavior. The LF 2016 Remap and LF 2020 updates to the topographic layers used more recent datasets, more modern processing tools, and the combination of different data sources. Having seamless 30-m resolution for elevation, slope, and aspect for all the United States and insular areas provides a ready resource for research and management applications. For further information, please reference the LF website (https://www.landfire.gov).

G.7. References Cited

Alexandre, P.M., Stewart, S.I., Mockrin, M.H., Keuler, N.S., Syphard, A.D., Bar-Massada, A., Clayton, M.K., and Radeloff, V.C., 2016, The relative impacts of vegetation, topography and spatial arrangement on building loss to wildfires in case studies of California and Colorado: Landscape Ecology, v. 31, no. 2, p. 415–430. [Also available at https://doi.org/10.1007/s10980-015-0257-6.]

Cram, D.S., Sabie, R.P., Smallidge, S.T., and Ashcroft, N.K., 2017, Assessment of postfire debris-flow hazards, La Jara Watershed, north-central New Mexico: New Mexico State University Cooperative Extension Service Publications RITF–86, accessed October 11, 2021, at https://pubs.nmsu.edu/_ritf/RITF86/index.html.

Esri, 2011, ArcGIS Desktop (release 10): Esri software release, accessed October 11, 2021, at https://desktop.arcgis.com/en/arcmap/10.6/get-started/installation-guide/installing-on-your-computer.htm.

GDAL/OGR contributors, 2021, GDAL/OGR (version 2.0.12): GDAL/OGR software release, accessed October 11, 2021, at https://gdal.org/download.html#past-releases.

National Aeronautics and Space Administration, Ministry of Economy, Trade, and Industry, National Institute of Advanced Industrial Science and Technology, Japan Space Systems, and U.S./Japan ASTER Science Team, 2019, ASTER Global Digital Elevation Model V003 [dataset]: U.S. Geological Survey digital data, accessed October 11, 2021, at https://doi.org/10.5067/ASTER/ASTGTM.003.

Nelson, K.J., Long, D.G., and Connot, J.A., 2016, LANDFIRE 2010—Updates to the national dataset to support improved fire and natural resource management: U.S. Geological Survey Open-File Report 2016–1010, 48 p., accessed October 11, 2021, at https://doi.org/10.3133/ofr20161010.

U.S. Geological Survey, 2012, USGS EROS archive—Digital elevation—Interferometric synthetic aperture radar (IFSAR)–Alaska: U.S. Geological Survey digital data, accessed October 11, 2021, at https://www.usgs.gov/centers/eros/science/usgs-eros-archive-radar-ifsar-orthorectified-radar-image-ori-alaska?qt-science_center_objects=0#qt-science_center_objects.

U.S. Geological Survey, 2017, 1/3rd arc-second Digital Elevation Models (DEM)—USGS National Map 3DEP downloadable data collection: U.S. Geological Survey digital data, accessed October 11, 2021, at https://www.sciencebase.gov/catalog/item/4f70aa9fe4b058caae3f8de5.

U.S. Geological Survey, 2021, 3D Elevation Program 1-meter resolution digital elevation model: U.S. Geological Survey web page, accessed May 5, 2023, at https://www.usgs.gov/3d-elevation-program.

Appendix 1. Vegetation Mapping

Several tables are included in this appendix that are used to map vegetation, mainly agriculture classes and roads. The following tables include the crosswalk from National Agricultural Statistics Service Cropland Data Layer 2020 to LANDFIRE 2020 updated existing vegetation type (table 1.1),the crosswalk from California agriculture classes to LANDFIRE 2020 existing vegetation types (table 1.2), the Hawaii State agriculture baseline 2015 to LANDFIRE 2016 Remap existing vegetation type crosswalk (table 1.3), the Puerto Rico Gap Analysis Project 2000 crosswalk to LANDFIRE 2016 Remap existing vegetation type (table 1.4), the American Samoa vegetation type crosswalk to LANDFIRE 2016 Remap existing vegetation type (table 1.5) and the Topologically Integrated Geographic Encoding and Referencing feature class code field crosswalk to LANDFIRE road classes (table 1.6).

Table 1.1. National Agricultural Statistics Service Cropland Data Layer 2020 to LANDFIRE 2020 updated existing vegetation type group crosswalk for agriculture classes in the contiguous United States. This crosswalk is similar to what was used in LANDFIRE 2016 Remap.

[Dbl, double; WinWht, winter wheat; Misc, miscellaneous; Vegs, vegetables]

Cropland Data Layer name	Existing vegetation type group	Existing vegetation type group name
Aquaculture	69	Aquaculture
Blueberries	62	Bush Fruit and Berries
Cranberries	62	Bush Fruit and Berries
Alfalfa	65	Close Grown Crop
Sod/Grass Seed	65	Close Grown Crop
Clover/Wildflowers	65	Close Grown Crop
Mint	65	Close Grown Crop
Buckwheat	65	Close Grown Crop
Switchgrass	65	Close Grown Crop
Fallow/Idle Cropland	66	Fallow/Idle Cropland
Almonds	60	Orchard
Oranges	60	Orchard
Pecans	60	Orchard
Pistachios	60	Orchard
Walnuts	60	Orchard
Apples	60	Orchard
Citrus	60	Orchard
Cherries	60	Orchard
Other Tree Crops	60	Orchard
Christmas Trees	60	Orchard
Peaches	60	Orchard
Olives	60	Orchard
Avocados	60	Orchard
Plums	60	Orchard
Pears	60	Orchard
Pomegranates	60	Orchard
Nectarines	60	Orchard
Apricots	60	Orchard
Prunes	60	Orchard
Other Hay/Non Alfalfa	67	Pasture and Hayland
Corn	64	Row Crop
Soybeans	64	Row Crop
Cotton	64	Row Crop
Sorghum	64	Row Crop
Rice	64	Row Crop
Dbl Crop WinWht/Soybeans	64	Row Crop
Dry Beans	64	Row Crop
Peanuts	64	Row Crop
Sunflower	64	Row Crop
Peas	64	Row Crop
Sugarcane	64	Row Crop
Sugarbeets	64	Row Crop

Table 1.1. National Agricultural Statistics Service Cropland Data Layer 2020 to LANDFIRE 2020 updated existing vegetation type group crosswalk for agriculture classes in the contiguous United States. This crosswalk is similar to what was used in LANDFIRE 2016 Remap.—Continued

[Dbl, double; WinWht, winter wheat; Misc, miscellaneous; Vegs, vegetables]

Cropland Data Layer name	Existing vegetation type group	Existing vegetation type group name
Potatoes	64	Row Crop
Lentils	64	Row Crop
Dbl Crop WinWht/Corn	64	Row Crop
Tomatoes	64	Row Crop
Sweet Corn	64	Row Crop
Chick Peas	64	Row Crop
Dbl Crop WinWht/Sorghum	64	Row Crop
Pop or Orn Corn	64	Row Crop
Herbs	64	Row Crop
Onions	64	Row Crop
Dbl Crop Triticale/Corn	64	Row Crop
Sweet Potatoes	64	Row Crop
Other Crops	64	Row Crop
Tobacco	64	Row Crop
Dbl Crop WinWht/Cotton	64	Row Crop
Hops	64	Row Crop
Dbl Crop Oats/Corn	64	Row Crop
Dbl Crop Barley/Soybeans	64	Row Crop
Carrots	64	Row Crop
Cucumbers	64	Row Crop
Lettuce	64	Row Crop
Greens	64	Row Crop
Pumpkins	64	Row Crop
Watermelons	64	Row Crop
Garlic	64	Row Crop
Dbl Crop Barley/Corn	64	Row Crop
Cabbage	64	Row Crop
Squash	64	Row Crop
Dbl Crop Soybeans/Oats	64	Row Crop
Broccoli	64	Row Crop
Peppers	64	Row Crop
Caneberries	64	Row Crop
Cantaloupes	64	Row Crop
Strawberries	64	Row Crop
Radishes	64	Row Crop
Dbl Crop Lettuce/Cotton	64	Row Crop
Misc Vegs & Fruits	64	Row Crop
Honeydew Melons	64	Row Crop
Turnips	64	Row Crop
Dbl Crop Lettuce/Cantaloupe	64	Row Crop
Dbl Crop Corn/Soybeans	64	Row Crop

Table 1.1. National Agricultural Statistics Service Cropland Data Layer 2020 to LANDFIRE 2020 updated existing vegetation type group crosswalk for agriculture classes in the contiguous United States. This crosswalk is similar to what was used in LANDFIRE 2016 Remap.—Continued

[Dbl, double; WinWht, winter wheat; Misc, miscellaneous; Vegs, vegetables]

Cropland Data Layer name	Existing vegetation type group	Existing vegetation type group name
Cauliflower	64	Row Crop
Asparagus	64	Row Crop
Eggplants	64	Row Crop
Celery	64	Row Crop
Dbl Crop Soybeans/Cotton	64	Row Crop
Dbl Crop Lettuce/Barley	64	Row Crop
Gourds	64	Row Crop
Barley	63	Row Crop - Close Grown
Oats	63	Row Crop - Close Grown
Canola	63	Row Crop - Close Grown
Millet	63	Row Crop - Close Grown
Rye	63	Row Crop - Close Grown
Flaxseed	63	Row Crop - Close Grown
Safflower	63	Row Crop - Close Grown
Mustard	63	Row Crop - Close Grown
Other Small Grains	63	Row Crop - Close Grown
Speltz	63	Row Crop - Close Grown
Vetch	63	Row Crop - Close Grown
Rape Seed	63	Row Crop - Close Grown
Camelina	63	Row Crop - Close Grown
Grapes	61	Vineyard
Winter Wheat	68	Wheat
Spring Wheat	68	Wheat
Durum Wheat	68	Wheat
Triticale	68	Wheat

Table 1.2. California agriculture classes crosswalked to LANDFIRE 2020 existing vegetation type groups. This crosswalk is similar to what was used in LANDFIRE 2016 Remap.

[**, general subcategory]

California agriculture label	Class 2, subcategory 2	Existing vegetation type group	Existing vegetation type group name
Citrus and subtropical	C**	60	Agricultural-Orchard
Dates	C 4	60	Agricultural-Orchard
Avocados	C 5	60	Agricultural-Orchard
Olives	C 6	60	Agricultural-Orchard
Miscellaneous subtropical fruit	C 7	60	Agricultural-Orchard
Kiwis	C 8	60	Agricultural-Orchard
Apples	D 1	60	Agricultural-Orchard
Cherries	D 3	60	Agricultural-Orchard
Peaches and nectarines	D 5	60	Agricultural-Orchard
Pears	D 6	60	Agricultural-Orchard
Miscellaneous deciduous	D10	60	Agricultural-Orchard
Mixed deciduous	D11	60	Agricultural-Orchard
Almonds	D12	60	Agricultural-Orchard
Walnuts	D13	60	Agricultural-Orchard
Pistachios	D14	60	Agricultural-Orchard
Pomegranates	D15	60	Agricultural-Orchard
Plums Prunes or Apricots	D16	60	Agricultural-Orchard
Flowers nursery and Christmas tree farms	T16	60	Agricultural-Orchard
Vineyards	V**	61	Agricultural-Vineyard
Wine grapes	V 2	61	Agricultural-Vineyard
Bush berries	T19	62	Agricultural-Bush fruit and berries
Field Crops	F**	64	Agricultural-Row Crop
Cotton	F 1	64	Agricultural-Row Crop
Safflower	F 2	64	Agricultural-Row Crop
Beans	F10	64	Agricultural-Row Crop
Miscellaneous field	F11	64	Agricultural-Row Crop
Sunflowers	F12	64	Agricultural-Row Crop
Corn Sorghum or Sudan	F16	64	Agricultural-Row Crop
Rice	R 1	64	Agricultural-Row Crop
Wild Rice	R 2	64	Agricultural-Row Crop
Truck nursery and berry crops	T**	64	Agricultural-Row Crop
Cole crops	T 4	64	Agricultural-Row Crop
Carrots	T 6	64	Agricultural-Row Crop
Melons squash and cucumbers	T 9	64	Agricultural-Row Crop
Onions and garlic	T10	64	Agricultural-Row Crop
Potatoes	T12	64	Agricultural-Row Crop
Tomatoes	T15	64	Agricultural-Row Crop
Miscellaneous truck	T18	64	Agricultural-Row Crop
Strawberries	T20	64	Agricultural-Row Crop
Peppers	T21	64	Agricultural-Row Crop
Greenhouse	T27	64	Agricultural-Row Crop

Table 1.2. California agriculture classes crosswalked to LANDFIRE 2020 existing vegetation type groups. This crosswalk is similar to what was used in LANDFIRE 2016 Remap.—Continued

[**, general subcategory]

California agriculture label	Class 2, subcategory 2	Existing vegetation type group	Existing vegetation type group name
Lettuce or Leafy Greens	T30	64	Agricultural-Row Crop
Potato or Sweet potato	T31	64	Agricultural-Row Crop
Young Perennial	YP**	64	Agricultural-Row Crop
Alfalfa and alfalfa mixtures	P 1	65	Agricultural-Close Grown Crop
new lands being prepared for crop production	I 2	66	Agricultural-Fallow/Idle Cropland
Unclassified fallow	X**	66	Agricultural-Fallow/Idle Cropland
Grain and hay crops	G**	67	Agricultural-Pasture and Hayland
Miscellaneous grain and hay	G 6	67	Agricultural-Pasture and Hayland
Pasture	P**	67	Agricultural-Pasture and Hayland
Mixed pasture	P 3	67	Agricultural-Pasture and Hayland
Native pasture	P 4	67	Agricultural-Pasture and Hayland
Miscellaneous grasses	P 6	67	Agricultural-Pasture and Hayland
Wheat	G 2	68	Agricultural-Wheat

Table 1.3. Hawaii State agriculture baseline 2015 to LANDFIRE 2016 Remap existing vegetation type crosswalk for agriculture classes in Hawaii.

Hawaii State agriculture name	Existing vegetation type	Existing vegetation type name
Aquaculture	7755	Cultivated Crops
Banana	7834	Tropical Pacific Orchard
Coffee	7835	Tropical Bush fruit and berries
Diversified Crop	7755	Cultivated Crops
Flowers/Foliage/Landscape	7755	Cultivated Crops
Macadamia Nuts	7834	Tropical Pacific Orchard
Papaya	7834	Tropical Pacific Orchard
Pasture	7754	Pasture/Hay
Pineapple	7835	Tropical Bush fruit and berries
Seed Production	7755	Cultivated Crops
Sugar	7837	Sugar Cane
Taro	7755	Cultivated Crops
Tropical Fruits	7834	Tropical Pacific Orchard

Table 1.4. Puerto Rico Gap Analysis Project 2000 crosswalk to LANDFIRE 2016 Remap existing vegetation type ecological system vegetation classes.

Value	Gap Analysis Project class	Existing vegetation type	Existing vegetation type ecological system name
1	Mature secondary lowland dry alluvial semideciduous forest	7881	Caribbean Semi-deciduous Lowland Forest
2	Young secondary lowland dry alluvial semideciduous forest	7881	Caribbean Semi-deciduous Lowland Forest
3	Lowland dry alluvial shrubland and woodland	7863	Caribbean Coastal Thornscrub
5	Mature secondary lowland dry limestone semideciduous forest	7881	Caribbean Semi-deciduous Lowland Forest
6	Young secondary lowland dry limestone semideciduous forest	7881	Caribbean Semi-deciduous Lowland Forest
7	Lowland dry limestone woodland and shrubland	7863	Caribbean Coastal Thornscrub
8	Lowland dry limestone shrubland	7863	Caribbean Coastal Thornscrub
9	Lowland dry cactus shrubland	7863	Caribbean Coastal Thornscrub
10	Coastal dwarf woodland and shrubland	7863	Caribbean Coastal Thornscrub
11	Lowland dry limestone cliffside semideciduous forest	7865	Caribbean Edapho-Xerophilous “Mogote” Complex
12	Lowland dry limestone cliffside shrubland and woodland	7865	Caribbean Edapho-Xerophilous “Mogote” Complex
13	Mature secondary lowland dry noncalcareous semideciduous forest	7881	Caribbean Semi-deciduous Lowland Forest
14	Young secondary lowland dry noncalcareous semideciduous forest	7881	Caribbean Semi-deciduous Lowland Forest
15	Lowland dry noncalcareous shrubland and woodland	7881	Caribbean Semi-deciduous Lowland Forest
16	Mature secondary dry and moist serpentine semideciduous forest	7870	Caribbean Lowland Moist Serpentine Woodland
17	Young secondary dry and moist serpentine semideciduous forest	7870	Caribbean Lowland Moist Serpentine Woodland
18	Dry and moist serpentine woodland and shrubland	7882	Caribbean Serpentine Dry Scrub
19	Abandoned dry forest plantation	9305	Caribbean Ruderal Dry Forest
20	Mature secondary lowland moist alluvial evergreen forest	7868	Caribbean Floodplain Forest
21	Young secondary lowland moist alluvial evergreen forest	7868	Caribbean Floodplain Forest
22	Lowland moist alluvial shrubland and woodland	7868	Caribbean Floodplain Forest
23	Mature secondary moist limestone evergreen and semideciduous forest	7883	Caribbean Submontane/Montane Karstic Forest
24	Young secondary moist limestone evergreen and semideciduous forest	7883	Caribbean Submontane/Montane Karstic Forest
25	Moist limestone shrubland and woodland	7865	Caribbean Edapho-Xerophilous “Mogote” Complex
26	Mature secondary lowland moist noncalcareous evergreen forest	7880	Caribbean Seasonal Evergreen Submontane/Lowland Forest
27	Young secondary lowland moist noncalcareous evergreen forest	7880	Caribbean Seasonal Evergreen Submontane/Lowland Forest
28	Lowland moist noncalcareous shrubland and woodland	7880	Caribbean Seasonal Evergreen Submontane/Lowland Forest
29	Lowland moist abandoned and active coffee plantations	9355	Tropical Agroforestry Plantation
30	Mature secondary montane wet alluvial evergreen forest	7880	Caribbean Seasonal Evergreen Submontane/Lowland Forest
31	Young secondary montane wet alluvial evergreen forest	7880	Caribbean Seasonal Evergreen Submontane/Lowland Forest

Table 1.4. Puerto Rico Gap Analysis Project 2000 crosswalk to LANDFIRE 2016 Remap existing vegetation type ecological system vegetation classes.—Continued

Value	Gap Analysis Project class	Existing vegetation type	Existing vegetation type ecological system name
32	Montane wet alluvial shrubland and woodland	7880	Caribbean Seasonal Evergreen Submontane/ Lowland Forest
33	Mature secondary montane wet noncalcareous evergreen forest	7884	Caribbean Wet Montane Forest
34	Mature primary Tabonuco and secondary montane wet non-calcareous evergreen forest	7880	Caribbean Seasonal Evergreen Submontane/ Lowland Forest
35	Mature primary Palo Colorado and secondary montane wet noncalcareous evergreen fore	7884	Caribbean Wet Montane Forest
36	Mature primary Sierra Palm and secondary montane wet noncalcareous evergreen forest	7884	Caribbean Wet Montane Forest
37	Mature primary elfin woodland and secondary montane wet noncalcareous evergreen cloud forest	7872	Caribbean Montane Wet Elfin Forest
38	Young secondary montane wet noncalcareous evergreen forest	7880	Caribbean Seasonal Evergreen Submontane/ Lowland Forest
39	Montane wet noncalcareous evergreen shrubland and wood-land	7874	Caribbean Montane Wet Short Shrubland
40	Mature secondary montane wet serpentine evergreen forest	7873	Caribbean Montane Wet Serpentine Woodland
41	Young secondary montane wet serpentine evergreen forest	7873	Caribbean Montane Wet Serpentine Woodland
42	Wet serpentine shrubland and woodland	7873	Caribbean Montane Wet Serpentine Woodland
43	Montane wet evergreen abandoned and active coffee planta-tion	9355	Tropical Agroforestry Plantation
44	Mangrove forest and shrubland	7867	Caribbean Estuary Mangrove
45	Freshwater Pterocarpus swamp	7868	Caribbean Floodplain Forest
46	Lowland dry riparian forest	7875	Caribbean Riparian Forest
47	Lowland dry riparian shrubland and woodland	7875	Caribbean Riparian Forest
48	Dry grasslands and pastures	7754	Agriculture-Pasture and Hay
49	Dry cactus grassland and shrubland	7863	Caribbean Coastal Thornscrub
50	Moist grasslands and pastures	7754	Agriculture-Pasture and Hay
51	Emergent herbaceous nonsaline wetlands	7869	Caribbean Freshwater Marsh
52	Emergent herbaceous saline wetlands	7866	Caribbean Emergent Herbaceous Estuary
53	Seasonally flooded herbaceous nonsaline wetlands	7869	Caribbean Freshwater Marsh
54	Seasonally flooded herbaceous saline wetlands	7866	Caribbean Emergent Herbaceous Estuary
55	Hay and row crops	7755	Agriculture-Cultivated Crops and Irrigated Agriculture
56	Woody agriculture and plantations: Palm plantations	9355	Tropical Agroforestry Plantation
57	Rocky cliffs and shelves	7862	Caribbean Coastal Rocky Shore
58	Gravel beaches and stony shoreline	7877	Caribbean Sand Beach Vegetation
59	Fine to coarse sandy beaches, mixed sand and gravel beaches	7877	Caribbean Sand Beach Vegetation
60	Riparian and other natural barrens	7875	Caribbean Riparian Forest
61	Salt and mudflats	7876	Caribbean Salt Flat and Pond
68	Lowland moist riparian forest	7868	Caribbean Floodplain Forest
69	Lowland moist riparian shrubland and woodland	7868	Caribbean Floodplain Forest

Table 1.5. American Samoa vegetation type crosswalk to LANDFIRE 2016 Remap existing vegetation type ecological system.

Code	Class	Existing vegetation type	Existing vegetation type ecological system name
4100	Upland Scrub	4620	Central and Southern Polynesian Cloud Forest
2100	Unconsolidated Shore	4617	Central and Southern Polynesian Dry Coastal Strand
4200	Coastal Scrub	4627	Central and Southern Polynesian Dry Coastal Strand Shrubland
4240	Mixed Coastal Scrub	4627	Central and Southern Polynesian Dry Coastal Strand Shrubland
2200	Exposed Volcanic Rock	4616	Central and Southern Polynesian Lava Flow
3124	Hibiscus Thicket	4621	Central and Southern Polynesian Littoral Forest
3300	Coastal Forest	4621	Central and Southern Polynesian Littoral Forest
3330	Callophyllum Coastal Forest	4621	Central and Southern Polynesian Littoral Forest
3360	Mixed Coastal Forest	4621	Central and Southern Polynesian Littoral Forest
3370	Hernandia Coastal Forest	4621	Central and Southern Polynesian Littoral Forest
3380	Pandanus Coastal Forest	4621	Central and Southern Polynesian Littoral Forest
2300	Landslips/Clearcuts	4618	Central and Southern Polynesian Lowland Rain Forest
3100	Lowland Rainforest	4618	Central and Southern Polynesian Lowland Rain Forest
4300	Successional Scrub Vegetation	4618	Central and Southern Polynesian Lowland Rain Forest
3200	Montane Forest	4606	Central and Southern Polynesian Montane Rainforest
7300	Swamp	4623	Central and Southern Polynesian Swamp Forest
7100	Marsh	4610	Polynesian Freshwater Marsh
7140	Mixed Marsh Vegetation	4610	Polynesian Freshwater Marsh
5000	Grassland/Herbaceous	9850	Polynesian Ruderal Lowland Grassland
5200	Grassland/Herbaceous	9850	Polynesian Ruderal Lowland Grassland
1200	Developed Woodlands	9349	Polynesian Ruderal Lowland Rainforest
3400	Agroforest	9355	Tropical Agroforestry Plantation
3410	Coconut Agroforest/Secondary Coastal Forest	9355	Tropical Agroforestry Plantation
3420	Coconut Plantation	4614	Central and Southern Polynesian Coastal Wooded Strand
3450	Breadfruit Agroforest	9355	Tropical Agroforestry Plantation
7200	Mangrove	4612	Western Pacific Mangrove
1100	Developed Open Space	7300	Developed - Open Space
1300	Buildings	7296	Developed - Low Intensity
1600	Impervious Surfaces	7296	Developed - Low Intensity
1700	Landfill	7296	Developed - Low Intensity
1800	Quarries and Gravel Pits	7295	Quarries-Strip Mines-Gravel Pits-Well and Wind Pads
6000	Cultivated Land	7755	Cultivated Crops

Table 1.6. Crosswalk from Topologically Integrated Geographic Encoding and Referencing line Master Address File/Topologically Integrated Geographic Encoding and Referencing feature class code field to LANDFIRE road class.

[MAF, Master Address File; TIGER, Topologically Integrated Geographic Encoding and Referencing; 4WD, four-wheel drive]

MAF/TIGER feature class code	Description	Recode	Name
S1100	Primary road	20	Primary road
S1200	Secondary road	21	Secondary road
S1400	Local neighborhood road, rural road, city street	22	Tertiary road
S1500	Vehicular trail (4WD)	23	Thinned road
S1630	Ramp	22	Tertiary road
S1640	Service drive usually along a limited access highway	22	Tertiary road
S1730	Alley	22	Tertiary road
S1740	Private road for service vehicles (logging, oil fields, ranches, and so on)	23	Thinned road
S1750	Internal U.S. Census Bureau use	23	Thinned road
S1780	Parking lot road	22	Tertiary road

Appendix 2. Fuels Mapping

This appendix includes the fire data used to determine average fire season along with associated weather stations in the region used for determining LANDFIRE fuel models in different vegetation regions (table 2.1).

Table 2.1. Fire season dates by Fire Protection Unit.

[FPU, Fire Protection Unit; GA, GeoArea; ID, identifier; AK, Alaska; CA, California; LA, Los Angeles; EA, Eastern Area; IA, Iowa; IN, Indiana; UP, Upper peninsula; MI, Michigan; LP, Lower peninsula; MN, Minnesota; MO, Missouri; NH, New Hampshire; NJ, New Jersey; OH, Ohio; PA, Pennsylvania; WI, Wisconsin; WV, West Virginia; GB, Great Basin; ID, Idaho; NV, Nevada; UT, Utah; NR, Northern Region; MT, Montana; ND, North Dakota; NW, Northwest; OR, Oregon; WA, Washington; RM, Rocky Mountain; CO, Colorado; KS, Kansas; NE, Nebraska; SD, South Dakota; WY, Wyoming; SA, Southeastern Area; AL, Alabama; AR, Arkansas; FL, Florida; GA, Georgia; KY, Kentucky; LA, Louisiana; #, number; Del_Mar_VA, Delaware Maryland Virginia; MD, Maryland; SE, Southeast; MS, Mississippi; NC, North Carolina; OK, Oklahoma; OCM, unknown; PR, Puerto Rico; SC, South Carolina; TN, Tennessee; TX, Texas; NE, Northeast; VA, Virginia; AZ, Arizona; NM, New Mexico]

FPU code	FPU name	GA	State	Number of fires	First day	Last day	Season days	Season dates (month/day)	Weather station ID	Weather station name
AK_AK_001	Alaska	AK	AK	4,973	116	224	109	4/26–8/12	500321	EAGLE LAKE
CA_CA_001	Northwest California	CA	CA	5,361	145	299	155	5/25–10/26	41005	EEL RIVER
CA_CA_002	NE California and NW Nevada	CA	CA	3,523	138	287	150	5/18–10/14	40703	BOGARD
CA_CA_003	Modoc Plateau	CA	CA	1,283	146	270	125	5/26–9/27	40221	ROUND MOUNTAIN
CA_CA_004	Northern California	CA	CA	4,768	114	302	189	4/24–10/29	40503	HAYFORK
CA_CA_005	West Sacramento Valley	CA	CA	3,286	105	311	207	4/15–11/7	41503	STONYFORD
CA_CA_006	Sacramento Tahoe Area	CA	CA	6,142	121	311	191	5/1–11/7	41806	WHITECLOUD
CA_CA_007	Yosemite Area	CA	CA	6,961	107	311	205	4/17–11/7	43605	MTELIZ
CA_CA_008	Southern Sierra	CA	CA	1,995	139	290	152	5/19–10/17	44712	UHL/HOT SPRING
CA_CA_009	Eastern Sierra	CA	CA	1,028	99	290	192	4/9–10/17	44804	OAK CREEK
CA_CA_010	Central Coast	CA	CA	6,281	89	334	246	3/30–11/30	45314	ROSE VALLEY II
CA_CA_011	The Desert	CA	CA	2,541	99	20	287	4/9–1/20	45614	LOST HORSE
CA_CA_012	LA Basin	CA	CA	2,264	109	9	266	4/19–1/9	45426	WARM SPRING
CA_CA_013	Pacific Islands	CA	CA	92	161	64	269	6/10–3/5	496009	HILUNA PALI 2
CA_CA_014	Riverside Area	CA	CA	3,471	105	6	267	4/15–1/6	45604	KEENWILD
CA_CA_015	San Diego Area	CA	CA	4,752	106	26	286	4/16–1/26	45710	OAK GROVE FIRE STA
EA_IA_001	Iowa	EA	IA	277	306	131	191	11/2–5/11	252402	BESSY
EA_IL_001	Illinois	EA	IL	543	239	121	248	8/27–5/1	119501	DIXON SPRINGS
EA_IN_001	Indiana	EA	IN	1,300	56	321	266	2/25–11/17	125701	HARDIN RIDGE
EA_MI_001	UP of Michigan	EA	MI	604	89	257	169	3/30–9/14	201002	DOE LAKE
EA_MI_002	LP of Michigan	EA	MI	2,364	85	253	169	3/26–9/10	202902	MIO
EA_MN_001	Minnesota Woodland	EA	MN	11,222	83	257	175	3/24–9/14	210509	ELY MN
EA_MN_002	Minnesota Transition and Prairie	EA	MN	9,489	61	184	124	3/2–7/3	210901	BEMIDJI
EA_MO_001	Missouri	EA	MO	2,958	301	164	229	10/28–6/13	236403	SINKIN FTS

Table 2.1. Fire season dates by Fire Protection Unit.—Continued

[FPU, Fire Protection Unit; GA, GeoArea; ID, identifier; AK, Alaska; CA, California; LA, Los Angeles; EA, Eastern Area; IA, Iowa; IN, Indiana; UP, Upper peninsula; MI, Michigan; LP, Lower peninsula; MN, Minnesota; MO, Missouri; NH, New Hampshire; NJ, New Jersey; OH, Ohio; PA, Pennsylvania; WI, Wisconsin; WV, West Virginia; GB, Great Basin; ID, Idaho; NV, Nevada; UT, Utah; NR, Northern Region; MT, Montana; ND, North Dakota; NW, Northwest; OR, Oregon; WA, Washington; RM, Rocky Mountain; CO, Colorado; KS, Kansas; NE, Nebraska; SD, South Dakota; WY, Wyoming; SA, Southeastern Area; AL, Alabama; AR, Arkansas; FL, Florida; GA, Georgia; KY, Kentucky; LA, Louisiana; #, number; Del_Mar_VA, Delaware Maryland Virginia; MD, Maryland; SE, Southeast; MS, Mississippi; NC, North Carolina; OK, Oklahoma; OCM, unknown; PR, Puerto Rico; SC, South Carolina; TN, Tennessee; TX, Texas; NE, Northeast; VA, Virginia; AZ, Arizona; NM, New Mexico]

FPU code	FPU name	GA	State	Number of fires	First day	Last day	Season days	Season dates (month/day)	Weather station ID	Weather station name
EA_NH_001	Northeastern	EA	NH	6,526	68	262	195	3/9–9/19	270301	WHITE MOUNTAIN
EA_NJ_001	New Jersey	EA	NJ	12,643	56	323	268	2/25–11/19	281501	EB FORSYTHE
EA_OH_001	Ohio	EA	OH	1,118	236	128	258	8/24–5/8	152001	TRIANGLE MTN
EA_PA_001	Pennsylvania	EA	PA	2,539	80	233	154	3/21–8/21	361002	ALLEGHENY
EA_WI_001	Northern Wisconsin	EA	WI	3,585	89	255	167	3/30–9/12	471002	WOODRUFF
EA_WI_002	Southern Wisconsin	EA	WI	5,812	86	293	208	3/27–10/20	474301	NECEDAH
EA_WV_001	West Virginia	EA	WV	3,408	287	164	243	10/14–6/13	464901	GRANDVIEW
GB_ID_001	South Central Idaho	GB	ID	1,758	153	288	136	6/2–10/15	104103	MOBERG CANYON
GB_ID_002	Southwest Idaho	GB	ID	4,033	163	278	116	6/12–10/5	101108	WEISRV
GB_ID_003	Salmon-Challis	GB	ID	1,053	162	265	104	6/11–9/22	101311	SKULL GULCH
GB_ID_004	Eastern Idaho	GB	ID	1,494	168	279	112	6/17–10/6	103703	CRYSTAL
GB_NV_001	Northwest Nevada	GB	NV	793	137	270	134	5/17–9/27	260402	SIARD
GB_NV_002	Northeast Nevada	GB	NV	1,654	148	275	128	5/28–10/2	260314	CRANE SPRINGS
GB_NV_003	Western Nevada	GB	NV	1,911	141	286	146	5/21–10/13	261204	FISH SPRINGS
GB_NV_004	Central Nevada	GB	NV	669	163	277	115	6/12–10/4	260601	COMBS
GB_NV_005	Eastern Nevada	GB	NV	2,433	163	260	98	6/12–9/17	261604	KANE SPRING
GB_NV_006	Southern Nevada	GB	NV	1,460	122	283	162	5/2–10/10	261705	RED ROCK
GB_UT_001	Central Utah	GB	UT	2,299	150	260	111	5/30–9/17	421904	SIGNAL PEAK
GB_UT_002	Color Country	GB	UT	4,482	148	273	126	5/28–9/30	422803	ENTERPRISE
GB_UT_003	Northern Utah	GB	UT	4,527	144	264	121	5/24–9/21	421101	PLEASANT GROVE
GB_UT_004	Uintah Basin	GB	UT	1,350	120	272	153	4/30–9/29	421304	FIVE MILE
GB_UT_005	Southeast Utah	GB	UT	2,427	139	260	122	5/19–9/17	422002	FLATTOP
GB_WY_001	Western Wyoming	GB	WY	880	171	291	121	6/20–10/18	481302	HOBACK
NR_ID_001	Northern Idaho	NR	ID	6,639	176	262	87	6/25–9/19	100603	POTLATCH
NR_MT_001	Billings	NR	MT	1,737	74	265	192	3/15–9/22	245106	PRYOR MOUNTAIN

Table 2.1. Fire season dates by Fire Protection Unit.—Continued

[FPU, Fire Protection Unit; GA, GeoArea; ID, identifier; AK, Alaska; CA, California; LA, Los Angeles; EA, Eastern Area; IA, Iowa; IN, Indiana; UP, Upper peninsula; MI, Michigan; LP, Lower peninsula; MN, Minnesota; MO, Missouri; NH, New Hampshire; NJ, New Jersey; OH, Ohio; PA, Pennsylvania; WI, Wisconsin; WV, West Virginia; GB, Great Basin; ID, Idaho; NV, Nevada; UT, Utah; NR, Northern Region; MT, Montana; ND, North Dakota; NW, Northwest; OR, Oregon; WA, Washington; RM, Rocky Mountain; CO, Colorado; KS, Kansas; NE, Nebraska; SD, South Dakota; WY, Wyoming; SA, Southeastern Area; AL, Alabama; AR, Arkansas; FL, Florida; GA, Georgia; KY, Kentucky; LA, Louisiana; #, number; Del_Mar_VA, Delaware Maryland Virginia; MD, Maryland; SE, Southeast; MS, Mississippi; NC, North Carolina; OK, Oklahoma; OCM, unknown; PR, Puerto Rico; SC, South Carolina; TN, Tennessee; TX, Texas; NE, Northeast; VA, Virginia; AZ, Arizona; NM, New Mexico]

FPU code	FPU name	GA	State	Number of fires	First day	Last day	Season days	Season dates (month/day)	Weather station ID	Weather station name
NR_MT_002	Bitterroot	NR	MT	1,303	176	261	86	6/25–9/18	242907	WESTFORK
NR_MT_003	Headwaters	NR	MT	1,077	170	323	154	6/19–11/19	243002	PBURG
NR_MT_004	Rocky Mountain Front	NR	MT	1,143	98	280	183	4/8–10/7	241901	BENCHMARK
NR_MT_005	Greater Yellowstone Area North	NR	MT	748	173	279	107	6/22–10/6	480115	QUADRANT
NR_MT_006	Helena	NR	MT	1,111	141	278	138	5/21–10/5	241907	HELENA
NR_MT_007	Lewistown	NR	MT	1,349	78	277	200	3/19–10/4	240704	LITTLE BULL
NR_MT_008	Miles City	NR	MT	3,680	78	260	183	3/19–9/17	245201	FORT HOWES
NR_MT_009	Northwest Montana	NR	MT	3,974	143	269	127	5/23–9/26	240207	WEST GLACIER
NR_MT_010	Southwest Montana	NR	MT	3,968	135	277	143	5/15–10/4	241206	PLAINS
NR_ND_001	North Dakota	NR	ND	6,722	90	297	208	3/31–10/24	321703	WATFORD
NW_OR_001	Northwest Oregon	NW	OR	4,315	165	284	120	6/14–10/11	352558	EMIGRANT
NW_OR_002	Central Coast Range & Cascades	NW	OR	671	174	263	90	6/23–9/20	353036	GRANDAD RAWS
NW_OR_003	Southwest Oregon	NW	OR	3,365	146	267	122	5/26–9/24	353213	SQUAW
NW_OR_004	Central Oregon	NW	OR	5,776	137	276	140	5/17–10/3	352618	LAVA BUTTE
NW_OR_005	Northeast Oregon	NW	OR	1,843	180	311	132	6/29–11/7	351202	TUPPER
NW_OR_006	Southeast Oregon	NW	OR	574	162	259	98	6/11–9/16	353614	OWYRID
NW_OR_007	Eastern Oregon	NW	OR	1,141	174	310	137	6/23–11/6	353512	P HILL
NW_OR_008	Southeast/ South Central Oregon	NW	OR	3,058	166	283	118	6/15–10/10	353343	HOYT
NW_OR_009	Wallowa-Whitman	NW	OR	1,727	170	279	110	6/19–10/6	351414	J-RIDGE
NW_OR_010	Malheur	NW	OR	1,529	166	292	127	6/15–10/19	352327	FALL MOUNTAIN
NW_OR_011	Coos Bay/Roseburg	NW	OR	1,367	129	304	176	5/9–10/31	352816	SIGNAL TREE
NW_WA_001	Northwest Washington	NW	WA	1,009	163	284	122	6/12–10/11	450911	JEFFERSON
NW_WA_002	North Washington Cascades West	NW	WA	1,586	163	266	104	6/12–9/23	451718	GREENWATER
NW_WA_003	North Central Washington	NW	WA	2,885	139	273	135	5/19–9/30	452219	SWAUK
NW_WA_004	Northeast Washington	NW	WA	4,269	103	287	185	4/13–10/14	452009	NESPELEM

Table 2.1. Fire season dates by Fire Protection Unit.—Continued

[FPU, Fire Protection Unit; GA, GeoArea; ID, identifier; AK, Alaska; CA, California; LA, Los Angeles; EA, Eastern Area; IA, Iowa; IN, Indiana; UP, Upper peninsula; MI, Michigan; LP, Lower peninsula; MN, Minnesota; MO, Missouri; NH, New Hampshire; NJ, New Jersey; OH, Ohio; PA, Pennsylvania; WI, Wisconsin; WV, West Virginia; GB, Great Basin; ID, Idaho; NV, Nevada; UT, Utah; NR, Northern Region; MT, Montana; ND, North Dakota; NW, Northwest; OR, Oregon; WA, Washington; RM, Rocky Mountain; CO, Colorado; KS, Kansas; NE, Nebraska; SD, South Dakota; WY, Wyoming; SA, Southeastern Area; AL, Alabama; AR, Arkansas; FL, Florida; GA, Georgia; KY, Kentucky; LA, Louisiana; #, number; Del_Mar_VA, Delaware Maryland Virginia; MD, Maryland; SE, Southeast; MS, Mississippi; NC, North Carolina; OK, Oklahoma; OCM, unknown; PR, Puerto Rico; SC, South Carolina; TN, Tennessee; TX, Texas; NE, Northeast; VA, Virginia; AZ, Arizona; NM, New Mexico]

FPU code	FPU name	GA	State	Number of fires	First day	Last day	Season days	Season dates (month/day)	Weather station ID	Weather station name
NW_WA_005	The Basin	NW	WA	698	112	284	173	4/22–10/11	453201	JUNIPER DUNES
NW_WA_007	Central Cascades	NW	WA	3,226	146	281	136	5/26–10/8	350913	WAMIC
RM_CO_001	South Front Range	RM	CO	2,822	90	281	192	3/31–10/8	53102	CHEESMAN
RM_CO_002	Montrose	RM	CO	1,327	137	270	134	5/17–9/27	52704	JAY
RM_CO_003	Southwest Colorado Public Lands	RM	CO	1,778	146	250	105	5/26–9/7	55901	DEVIL MOUNTAIN
RM_CO_004	San Luis Valley	RM	CO	304	94	254	161	4/4–9/11	55305	BLUE PARK
RM_CO_005	Northwest Colorado	RM	CO	2,892	149	251	103	5/29–9/8	51402	PINTO
RM_CO_006	Upper Colorado River	RM	CO	2,552	137	261	125	5/17–9/18	51504	RIFLE
RM_CO_007	North Front Range	RM	CO	828	108	301	194	4/18–10/28	50507	ESTES PARK
RM_CO_008	Ute Mountain/Southern Ute	RM	CO	1,484	139	246	108	5/19–9/3	55805	MESA MTN
RM_KS_001	Mid Plains	RM	KS	1,848	301	198	263	10/28–7/17	146501	STAFFORD
RM_NE_001	Nebraska	RM	NE	1,340	76	261	186	3/17–9/18	252402	BESSEY
RM_SD_001	Black Hills	RM	SD	2,650	51	282	232	2/20–10/9	393506	CUSTER WEST
RM_SD_002	Prairie	RM	SD	11,863	60	323	264	3/1–11/19	392602	PINNACLES
RM_SD_003	Eastern	RM	SD	4,406	58	314	257	2/27–11/10	392602	PINNACLES
RM_WY_002	Central Wyoming	RM	WY	1,986	155	254	100	6/4–9/11	481904	SNOW SPRING CREEK
RM_WY_003	Big Horn Basin	RM	WY	1,226	65	263	199	3/6–9/20	481410	ELKHORN
SA_AL_001	Alabama/Florida Panhandle	SA	AL	17,719	27	321	295	1/27–11/17	12701	TALLGA
SA_AR_001	Eastern Arkansas	SA	AR	2,618	206	113	273	7/25–4/23	32801	POINSETT
SA_AR_002	Southern Ozarks	SA	AR	12,143	209	118	275	7/28–4/28	34702	ODEN
SA_FL_001	South Florida	SA	FL	9,320	363	232	235	12/29–8/20	86401	OASIS
SA_FL_002	SEGA_NEFL	SA	FL	10,270	25	253	229	1/25–9/10	81301	OLUSTEE
SA_FL_003	Central Florida	SA	FL	12,309	362	232	236	12/28–8/20	83501	CENTRAL
SA_FL_004	Florida Big Bend	SA	FL	12,164	355	257	268	12/21–9/14	82201	SANBORN
SA_GA_001	Central Georgia	SA	GA	37,011	230	149	285	8/18–5/29	93701	OCONEE#1

Table 2.1. Fire season dates by Fire Protection Unit.—Continued

[FPU, Fire Protection Unit; GA, GeoArea; ID, identifier; AK, Alaska; CA, California; LA, Los Angeles; EA, Eastern Area; IA, Iowa; IN, Indiana; UP, Upper peninsula; MI, Michigan; LP, Lower peninsula; MN, Minnesota; MO, Missouri; NH, New Hampshire; NJ, New Jersey; OH, Ohio; PA, Pennsylvania; WI, Wisconsin; WV, West Virginia; GB, Great Basin; ID, Idaho; NV, Nevada; UT, Utah; NR, Northern Region; MT, Montana; ND, North Dakota; NW, Northwest; OR, Oregon; WA, Washington; RM, Rocky Mountain; CO, Colorado; KS, Kansas; NE, Nebraska; SD, South Dakota; WY, Wyoming; SA, Southeastern Area; AL, Alabama; AR, Arkansas; FL, Florida; GA, Georgia; KY, Kentucky; LA, Louisiana; #, number; Del_Mar_VA, Delaware Maryland Virginia; MD, Maryland; SE, Southeast; MS, Mississippi; NC, North Carolina; OK, Oklahoma; OCM, unknown; PR, Puerto Rico; SC, South Carolina; TN, Tennessee; TX, Texas; NE, Northeast; VA, Virginia; AZ, Arizona; NM, New Mexico]

FPU code	FPU name	GA	State	Number of fires	First day	Last day	Season days	Season dates (month/day)	Weather station ID	Weather station name
SA_KY_001	Cumberland	SA	KY	14,459	258	131	239	9/15–5/11	157002	SOMERSET2
SA_LA_001	Louisiana Delta	SA	LA	6,116	253	165	278	9/10–6/14	168541	BIG BRANCH MARSH
SA_LA_003	North/Central Louisiana	SA	LA	13,962	197	119	288	7/16–4/29	162303	DOVE FIELD
SA_MD_001	Del_Mar_Va	SA	MD	3,790	349	245	262	12/15–9/2	449801	GREAT DISMAL SWAMP
SA_MS_001	SE Mississippi	SA	MS	12,451	289	181	258	10/16–6/30	227802	BLACK CREEK
SA_MS_002	Mississippi	SA	MS	34,589	182	110	294	7/1–4/20	225101	BIENVILLE
SA_NC_001	North Carolina Piedmont	SA	NC	27,113	307	221	280	11/3–8/9	381201	CSNWR NORTH
SA_NC_002	North Carolina Coast	SA	NC	12,721	300	233	299	10/27–8/21	315405	ALLIGATOR RIVER
SA_OK_001	Choctaw	SA	OK	8,946	206	99	259	7/25–4/9	346303	KIAMICHI
SA_OK_002	OCM	SA	OK	6,366	295	113	184	10/22–4/23	30901	STRICKLER
SA_OK_003	Creek/Seminole	SA	OK	904	299	110	177	10/26–4/20	346303	KIAMICHI
SA_OK_005	Western Oklahoma	SA	OK	1,380	166	97	297	6/15–4/7	345801	WICHITA
SA_PR_001	Caribbean	SA	PR	122	22	120	99	1/22–4/30	511202	CABO ROJO
SA_SC_001	South Carolina/Savannah Coastal	SA	SC	41,668	301	202	267	10/28–7/21	384002	WITHERBEE
SA_TN_001	Southern Appalachian	SA	TN	21,005	284	176	258	10/11–6/25	315802	WAYAH
SA_TX_001	Northeast Texas	SA	TX	11,478	179	102	289	6/28–4/12	345801	WICHITA
SA_TX_002	Texas Hill Country	SA	TX	22,798	186	107	287	7/5–4/17	417901	BIRD
SA_TX_003	Southeast Texas	SA	TX	11,853	208	144	302	7/27–5/24	413509	LUFKIN
SA_TX_004	SW Louisiana/NE Texas Coast	SA	TX	1,828	145	62	283	5/25–3/3	165102	SABINE
SA_TX_005	South Texas Coast	SA	TX	704	320	236	282	11/16–8/24	418502	ARANSAS
SA_TX_006	Lower Rio Grande Valley	SA	TX	3,200	348	240	258	12/14–8/28	418602	SANTA ANA NWR
SA_VA_001	Northern Appalachian	SA	VA	12,858	300	226	292	10/27–8/14	444002	CRAIG VALLEY
SW_AZ_001	Southeast Arizona	SW	AZ	5,855	39	238	200	2/8–8/26	21007	MULE SHOE
SW_AZ_002	West Central Arizona	SW	AZ	1,284	84	254	171	3/25–9/11	20509	STANTON

Table 2.1. Fire season dates by Fire Protection Unit.—Continued

[FPU, Fire Protection Unit; GA, GeoArea; ID, identifier; AK, Alaska; CA, California; LA, Los Angeles; EA, Eastern Area; IA, Iowa; IN, Indiana; UP, Upper peninsula; MI, Michigan; LP, Lower peninsula; MN, Minnesota; MO, Missouri; NH, New Hampshire; NJ, New Jersey; OH, Ohio; PA, Pennsylvania; WI, Wisconsin; WV, West Virginia; GB, Great Basin; ID, Idaho; NV, Nevada; UT, Utah; NR, Northern Region; MT, Montana; ND, North Dakota; NW, Northwest; OR, Oregon; WA, Washington; RM, Rocky Mountain; CO, Colorado; KS, Kansas; NE, Nebraska; SD, South Dakota; WY, Wyoming; SA, Southeastern Area; AL, Alabama; AR, Arkansas; FL, Florida; GA, Georgia; KY, Kentucky; LA, Louisiana; #, number; Del_Mar_VA, Delaware Maryland Virginia; MD, Maryland; SE, Southeast; MS, Mississippi; NC, North Carolina; OK, Oklahoma; OCM, unknown; PR, Puerto Rico; SC, South Carolina; TN, Tennessee; TX, Texas; NE, Northeast; VA, Virginia; AZ, Arizona; NM, New Mexico]

FPU code	FPU name	GA	State	Number of fires	First day	Last day	Season days	Season dates (month/day)	Weather station ID	Weather station name
SW_AZ_003	White Mountains	SW	AZ	4,709	97	274	178	4/7–10/1	20303	LAKESIDE
SW_AZ_004	Lower Colorado River	SW	AZ	1,136	365	292	293	12/31–10/19	45801	SQUAW LAKE
SW_AZ_005	Arizona Strip	SW	AZ	2,090	157	276	120	6/6–10/3	20108	OLAF
SW_AZ_006	Central Arizona	SW	AZ	3,686	41	276	236	2/10–10/3	20604	ROOSEVELT
SW_NM_001	Northern New Mexico Mountains	SW	NM	3,684	105	276	172	4/15–10/3	290702	JEMEZ
SW_NM_002	Pecos Plains	SW	NM	3,254	360	251	257	12/26–9/8	293002	MAYHILL
SW_NM_003	Southern New Mexico Desert	SW	NM	278	25	227	203	1/25–8/15	292903	DRIPPING SPRING
SW_NM_004	Gila	SW	NM	2,411	129	243	115	5/9–8/31	292001	BEAVERHEAD
SW_NM_005	Central New Mexico	SW	NM	4,171	39	258	220	2/8–9/15	291302	GRANTS
SW_NM_006	Northwest New Mexico Plateau	SW	NM	1,909	133	242	110	5/13–8/30	290201	ALBINO
SW_NM_007	Colorado Plateau New Mexico/Arizona	SW	NM	8,948	104	281	178	4/14–10/8	20209	FLAGSTAFF
SW_TX_002	Southern Great Plains	SW	TX	5,942	302	221	285	10/29–8/9	418701	CEDAR
SW_TX_004	Southwest Texas	SW	TX	1,672	39	294	256	2/8–10/21	417401	PANTHER JUNCTION

For more information about this publication, contact:
LANDFIRE help desk
USGS Earth Resources Observation and Science Center
47914 252nd Street
Sioux Falls, SD 57198
605–594–2839

Email: helpdesk@landfire.gov

Publishing support provided by the Rolla Publishing Service Center

La Puma—**LANDFIRE Technical Documentation**—OFR 2023–1045

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20231045