WILDFIRE RISK TO COMMUNITIES

Interactive maps, charts, and data to help communities understand, explore, and reduce wildfire risk.

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Wildfire Risk to Communities:

Methods for geospatial and tabular datasets

A white paper included with:

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INTRODUCTION

Background

The Wildfire Risk to Communities project was created in response to direction by the U.S. Congress in the 2018 Consolidated Appropriations Act (i.e., 2018 Omnibus Act, H.R. 1625, Section 210: Wildfire Hazard Severity Mapping). That legislation directed the USDA Forest Service to develop and publish, within two years, national geospatial products depicting wildfire hazard and risk for communities across the United States. The focus of the legislation was firmly on communities. The intent was to help U.S. communities understand components of their relative wildfire risk profile, the nature and effects of wildfire risk, and actions they can take to mitigate risk.

To meet the intent of the Omnibus Act, the Forest Service formed a team of experts to both develop the necessary data and build an interactive website for effective delivery of information to communities. The Forest Service's Rocky Mountain Research Station (RMRS) has invested many years developing wildfire simulation models to generate the types of geospatial data needed to map wildfire hazard and risk. Given the short timeframe of this project, the team was able to leverage modeling work already underway with the large fire simulation system, FSim, to model probabilistic components of wildfire risk for the U.S. (Short et al. 2020a). The contractor already engaged with RMRS in completing that work, Pyrologix LLC, was able to transition into being part of the Wildfire Risk to Communities team for geospatial data development. The data included in this publication were developed by Pyrologix under the direction of the Fire Modeling Institute, part of RMRS's Missoula Fire Sciences Lab. The accompanying Wildfire Risk to Communities website and community outreach material were developed by another partner in the project, Headwaters Economics, with interactive web maps and charts completed by the web development firm, Azavea.

The data published in the initial rollout of the Wildfire Risk to Communities project are built on the geospatial data from Short et al. (2020a). But they are also different in some very important ways. The project team took the direction to produce data that would be relevant and actionable at the community scale seriously. As a result, the team devised and implemented innovative solutions to modify relatively coarse-scale national datasets for this project. The Wildfire Risk to Communities data represent the first time wildfire risk to communities has been mapped nationally with consistent methodology to the level of detail presented here. These data provide foundational information for comparing the relative wildfire risk among populated communities in the United States.

This purpose of this white paper is to provide a detailed description of the methods used to: 1) develop spatial data for the Wildfire Risk to Communities project, and 2) to summarize those data for communities in the United States.

Data Overview

Because of the short time available for data analysis and production, the methods for the Wildfire Risk to Communities project were designed to leverage existing national datasets. Our methods generally follow the raster-based methods used in a similar assessment of wildfire risk to human communities in the Pacific Northwest (Gilbertson-Day et al. 2018). However, we made some important adjustments in both the geospatial data processing and the summary of data by communities, counties, and states that make this set of data products unique.

The data included in this publication depict components of wildfire risk for all lands in the United States that: 1) are landscape-wide (i.e., measurable at every pixel across the landscape); and 2) represent *in situ* risk – risk at the location where the adverse effects take place on the landscape. The focus is on risk to housing units in communities, and we do not consider risks to other assets or resources that might be affected by wildfire. Related assessments of risk just where housing units are currently present, and of transmitted risk to housing units from the locations where damaging fires originate will be documented and delivered at a later date.

DATA AND METHODS

Input Datasets

The input datasets used in the Wildfire Risk to Communities project include datasets related to land cover, communities, and wildfire hazard. We describe those input datasets in the following sections.

Land Cover – LANDFIRE

We used LANDFIRE raster data to identify burnable vs non-burnable and habitable vs uninhabitable land covers. We used the most recent version of LANDFIRE data available at the time of processing. The data cover three different extents; each extent used a different spatial reference (projection) (see table below).

Raster extent	LANDFIRE version		Projection
Conterminous U.S. (CONUS)	1.4.0	LF 2014	Albers CONUS
Alaska (AK)	1.4.0	LF 2014	Albers AK
Hawaii (HI)	1.4.0	LF 2014	Albers HI

Non-burnable land cover was defined as areas mapped by LANDFIRE as any of the non-burnable fuel models in the Scott and Burgan Fire Behavior Fuel Models (FBFM40) raster: urban (91), permanent snow/ice (92), non-burnable agriculture (93), open water (98) and bare ground (99) (LANDFIRE 2017, Scott and Burgan 2005). We considered everything else burnable land cover. The burnable land cover raster was used at both 30-m and 270-m resolution in our raster processing described below.

Habitable land cover was defined as all land cover types except open water and permanent snow/ice. We used the habitable land cover raster in producing the housing-unity density raster described below.

Communities – LandScan USA 2017

The LandScan USA Population Database is produced by the Oak Ridge National Laboratory at a grid size of 3 arc-seconds (approx. 90-m cell size) for the Conterminous United States, Alaska, and Hawaii (Rose et al. 2017). Population data are based on the 2010 Census and updated to 2016 population from estimates provided by the American Community Survey (ACS). LandScan attempts to spatially resolve population information reported at the Census block level (Bhaduri et. al 2007) by distributing population to raster cells using dasymetric modeling and numerous spatial data sources including daytime and nighttime imagery, administrative boundaries, topography, land cover, and coastlines (Rose et al. 2017).

Communities – U.S. Census Bureau 2018 ACS 5-year population estimates

We used the U.S. Census Bureau's 2018 American Community Survey 5-year population estimates for states, counties and places. These population estimates correspond to the TIGER/Line summary polygons described in a later section.

Communities – U.S. Census Bureau Places

Generally speaking, a "place" is an area of the landscape associated with a specific name. The Wildfire Risk to Communities project used the U.S. Census Bureau's 2018 Places dataset, which includes both legally bounded incorporated places (cities, boroughs, towns, villages, etc.) and unincorporated Census Designated Places (CDPs) (https://www2.census.gov/geo/tiger/TIGER2018/PLACE/). A CDP is a concentration of population outside of an incorporated area yet still identifiable by name.

Wildfire Hazard – Nationwide FSim Outputs

The input datasets related to wildfire hazard were developed by the Forest Service at RMRS's Missoula Fire Sciences Lab. Short et al. (2020a) used the large fire simulation system (FSim) to simulate at least 10,000 fire season iterations in each of 136 distinct regions of contemporary wildfire activity (pyromes) across the United States (Short et al. 2020ab). In each pyrome, modeling outputs were calibrated to fire occurrence records from recent decades (Short 2017). The resulting national datasets of annual burn probability and conditional flame-length probability (the likelihood of different fire intensities) have a spatial resolution of 270 m, and were used as primary inputs to the Wildfire Risk to Communities data products. In the national 270-m datasets, all burnable pixels at the 270-m cell size have valid non-zero values, and all non-burnable pixels have a value of zero.

Downscaling National Wildfire Hazard Datasets

Nationally-available datasets depicting the components of wildfire hazard and risk datasets—burn probability and fire intensity—are produced at a relatively coarse cell size of 270 m (Short et al. 2020a). This spatial resolution is necessary to complete simulation modeling for all areas across the United States in a reasonable amount of time, and for most national-scale applications 270-m resolution is appropriate and sufficient. To be most useful to communities, however, it was necessary to downscale the national results to a finer spatial resolution. The downscaling method we developed for this project involved resampling to a finer resolution, a process we refer to as raster upsampling. We did not re-simulate wildfire hazard at finer resolution than the native national FSim resolution of Short et al. (2020a) or use statistical downscaling methods common with broad-scale climate data. Our raster upsampling approach, described in detail below, instead used a series of iterative resampling steps. We chose to upsample to the native 30-m resolution of the nationally-available LANDFIRE fuel and vegetation data (LANDFIRE 2017).

Step 1: Downscale the 270-m wildfire hazard datasets to 30-m resolution

We used the following six-step process to downscale the national 270-m BP raster to 30-m resolution (Figure 1). The intensity downscaling process varies slightly and is covered separately.

1. Convert zero values to nodata in 270-m data
2. Two 3x3 moving-window averages at 270 m
3. Revert remaining nodata pixels back to zero at 270 m

4. Resample to 30-m resolution (cubic convolution method)
5. Set BP to zero for open water and snow/ice land covers at 30 m
6. Set negative BP to zero

The first step in downscaling was to convert the 270-m pixels with a BP value of zero to nodata. This is to enable the second step to work as desired. In step 2, we used two successive 3x3 moving-window means on the 270-m raster to smooth the data and fill in the 270-m cells for which BP was initially zero. This process replaced many zero values in the 270-m data with the mean of the non-zero cells immediately surrounding them. The two low-pass filters at 270-m resolution filled in pixels within 540 m of a burnable pixel. In step 3, we then reverted the remaining nodata values back to zero and then, in step 4, resampled the resulting raster to 30 m using cubic convolution. The cubic convolution resampling method does some interpolation among the upsampled 30-m cells within each 270-m cell. In step 5, we used a processing mask derived from the 30-m LANDFIRE fuels data to set the BP to zero for open water and snow/ice land covers. The cubic convolution also resulted in some BP values below zero, and we set these back to zero in step 6. The result of this six-step upsampling process is shown in Panel B of Figure 1.

For raster layers representing fire intensity (CRPS, WHP, MFI, FLEP4 and FLEP8), we used a slightly different process.

A. Convert zero-intensity values to nodata in 270-m data
B. Two 3x3 moving-window averages at 270 m
C. Stamp original intensity values on top of the filtered data (retain the filling but not the smoothing)
D. Resample to 30-m resolution (bilinear interpolation method)
E. Set intensity values to zero for open water and snow/ice land covers at 30 m

In Step A, zero-intensity values were converted to nodata exactly as they were for BP. The two moving-window averages in step B are identical to those in step 2. As implemented in the BP upsampling process, the two low-pass filters on the 270-m data (step 2) have the effect of slightly smoothing the spatial patterns in the data. While this is acceptable, and even helpful, for the BP data, it is undesirable for the intensity data. This is because intensity is often closely tied to spatial distribution of fuels, and smoothing of the intensity rasters can uncouple them with the underlying fuels. So, to prevent this, we stamped the 270-m intensity data back on top of the output of the low-pass filters (step C). This preserved the original intensity patterns, while achieving the goal of filling in areas without values. In step D we upsampled to 30-m resolution using bilinear interpolation, again to preserve as much fidelity with original intensity value as possible. In step E we set intensity values to zero for open water and snow/ice land covers.

Step 2: Estimating wildfire hazard in developed areas

The fire modeling used to produce the national 270-m wildfire hazard datasets does not simulate fire spread into developed housing areas. LANDFIRE data show most developed areas as “non-burnable” because those areas are not covered by wildland fuel and are therefore not appropriate for simulation with wildland fire spread models. As a result, the simulated wildfires do not penetrate into developed housing areas. Wildfires have been known to ignite urban conflagrations that spread through developed areas for quite some distance. These events are rare, but their effects are devastating. Fire scientists are working toward the ability to simulate fire spread in both wildland and developed urban and suburban fuels. Until such models are available for use within a Monte

Carlo simulator such as FSim, post-processing of modeling results can emulate penetration of wildfire into otherwise non-burnable developed urban areas.

For the Wildfire Risk to Communities project, we attempted to mimic the effects of wildfire penetration into communities by estimating burn probability and fire intensity in otherwise non-burnable areas adjacent to burnable fuels. We accomplished this by using GIS methods for spatially smoothing data. Fires originating in smaller blocks of contiguous fuel have less ability to ignite urban conflagrations. To account for this, we identified and set aside patches of burnable fuel less than 500 ha in size (Stewart et. al, 2007) that were wholly surrounded by non-burnable fuels. These islands often represent urban parks and other relatively small remnants of natural vegetation interspersed in mostly developed settings. We identified these areas using the ArcGIS Region Group tool on the 30-m, burnable-fuel raster. We then temporarily set the non-zero BP values within the patches to nodata. For burn probability, we expanded BP values into adjacent non-burnable areas by first setting nodata pixels in the 30-m upsampled BP raster to zero, except in areas of open water, snow/ice, and the small burnable patches identified in the previous step. We then ran three successive 510-m moving-window averages (i.e., 510-m radius, circular focal means). This effectively allowed BP values to spread into developed areas, bare ground, and agricultural areas, but not into water, snow, ice, and small burnable patches. This method results in BP values that rapidly diminish with increasing distance into non-burnable areas.

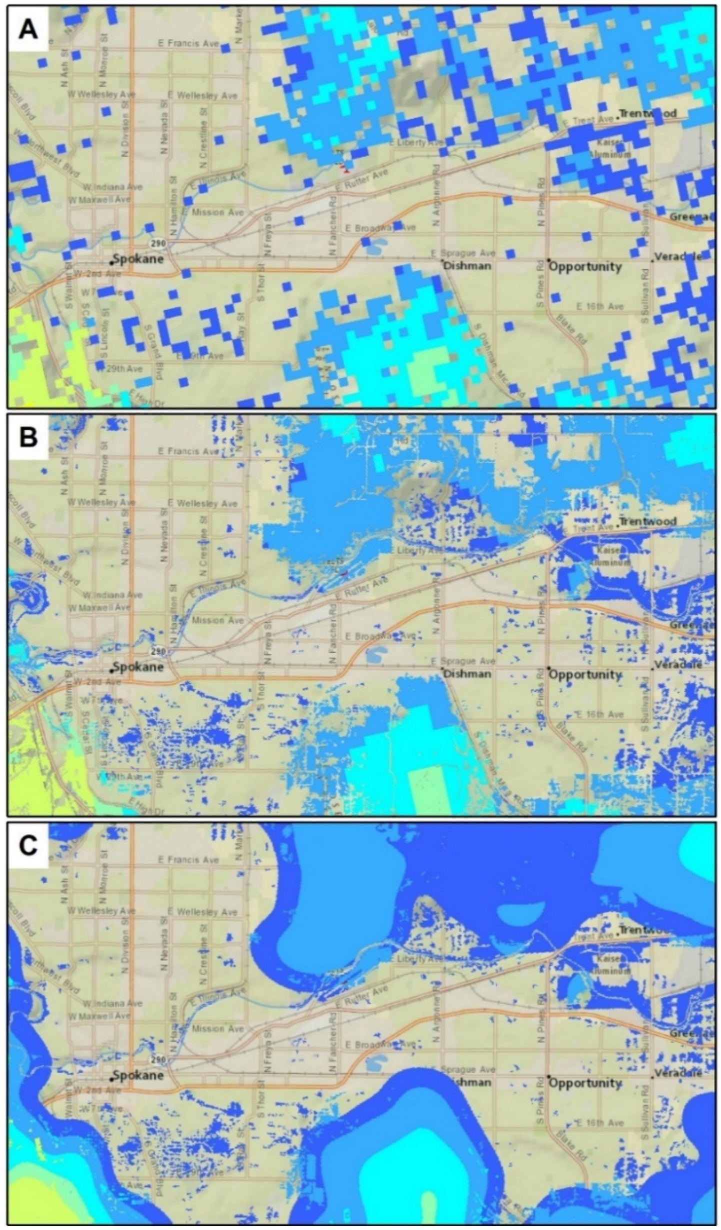

Figure 1. Comparison of burn probability maps in Spokane, Washington at A) the native, 270-m resolution, B) upsampled to 30 m, and C) upsampled to 30 m and smoothed into adjacent, non-burnable fuel.

After smoothing, we set the final BP value in small isolated patches to the larger of their original value and the smoothed value.

The total distance BP values are spread into non-burnable areas using this approach is 1,530 m (approximately 1 mile), as the cumulative result of three iterative focal mean operations. This total distance is slightly less than the 1.5 mile (2.4 km) distance from large, contiguous areas of wildland vegetation currently used to map the “interface” category of Wildland Urban Interface (WUI) in the United States (Martinuzzi et al. 2015). We feel our distance of approximately 1 mile strikes a balance between being conservative and pragmatic, and is generally consistent with the distance that at least one urban conflagration—the Coffee Park portion of the 2017 Tubbs Fire—spread into developed housing areas.

For fire intensity rasters, we used a slightly different approach for the spatial smoothing. As with BP, we set nodata pixels in the 30-m upsampled intensity data to zero, with the same exceptions for water, snow, ice, and small burnable patches. To retain the integrity of original intensity patterns in burnable fuel areas, we first used two iterative 150-m moving window averages (i.e., 150-m radius, circular focal means) to create the primary smoothed intensity rasters. This approach, however, only expanded intensity values 300 m into non-burnable fuels, and we needed to ensure intensity values everywhere that the expanded BP values were non-zero. Therefore, we also created an alternate version of smoothed intensity using the BP approach (three iterative 510-m focal means). We generated the final set of 30-m intensity rasters by using cell values produced with the tighter window where they exist (up to 300-m into nonburnable fuels) and the alternate version everywhere else with non-zero BP (between 300-m and 1,530-m into non-burnable fuels). Again, we stamped the upsampled values in small isolated patches back into the final products.

Methods for Specific Raster Datasets

For this release of the Wildfire Risk to Communities data, we produced a series of eight nationwide raster datasets, all at 30-m spatial resolution. They all build off of the downscaling process described above, and specifics for each dataset are described in the sections that follow.

Burn Probability (BP)

Burn probability is a 30-m raster representing the *circa* 2015 annual likelihood of burning in a given location. BP is referred to as Wildfire Likelihood in the Wildfire Risk to Communities web application.

We generated the Wildfire Risk to Communities BP raster using the multi-stage upsampling and smoothing processes described above, applied to the most recent nationwide 270-m BP results from Short et al. (2020a). The BP results produced by Short et al. (2020a) were generated using the FSim large fire simulator (Finney et al. 2011) with fuel data from LANDFIRE 2014 (version 1.4.0) that represent fuel characteristics for the 2015 fire season.

Conditional Flame Length (CFL)

Conditional Flame Length is a 30-m raster representing the most likely flame length at a given location if a fire occurs, based on wildfire simulation modeling. It is an average measure of wildfire intensity. As with all raster products presented here, it represents fuel characteristics for the 2015 fire season.

We generated the Wildfire Risk to Communities CFL raster by first upsampling and smoothing the Mean Fireline Intensity (MFI) raster from Short et al. (2020a) using the multi-stage process described above for fire intensity data. MFI is a direct output of FSim modeling and depicts the mean intensity from all simulated fires that occurred on any given pixel in units of kilowatts/meter (kW/m). We then calculated CFL from the 30-m upsampled MFI raster using the following equation (Byram 1959) for CFL measured in feet as a proxy for mean flame length.

$$CFL = 0.45 * (MFI/3.45914)^{0.46}$$

Calculating CFL from MFI is not identical to a direct calculation of mean flame length calculated internally within FSim each time a pixel burns (using the same calculation of MFI). Because the functionality does not exist in FSim to calculate mean flame length directly, CFL is often calculated as the sum-product of flame-length probability (FLP) and midpoint flame length of each FLP class. That approach relies on the accuracy of using the midpoint flame length for each FLP class; because the highest FLP class is open ended (greater than 12 feet), it is not possible to know what “midpoint” to use for that class. Also, unlike other spatial fire modeling systems, FSim uses the Byram (1959) relationship for all types of fire, rather than for surface fires only. Furthermore, CFL is only used for graphical display and tabular summaries, not as an intermediate variable for input to another model. For those reasons, calculating CFL directly from MFI is reasonable.

Flame Length Exceedance Probability—4 feet (FLEP4)

FLEP4 is a 30-m raster representing the conditional probability that flame length at a pixel will exceed 4 feet if a fire occurs. FLEP4 indicates the potential for moderate to high wildfire intensity. Because 4 feet is considered the limit of manual fire control, FLEP4 represents the likelihood that fire intensity will be beyond the ability of hand crews to control. As with all raster products presented here, it represents fuel characteristics for the 2015 fire season.

We generated the Wildfire Risk to Communities FLEP4 by first calculating FLEP4 at 270-m resolution from the nationally-available flame length probability (FLP) rasters from Short et al. (2020a). FLP rasters each represent the conditional probability of seeing flame lengths within certain ranges if a fire occurs. FLEP4 is simply calculated by adding the conditional probability for all classes representing flame lengths above 4 feet. The equation is:

$$FLEP4 = FLP3 + FLP4 + FLP5 + FLP6$$

Where,

FLP3 = conditional probability of 4 to 6 foot flames

FLP4 = conditional probability of 6 to 8 foot flames

FLP5 = conditional probability of 8 to 12 foot flames

FLP6 = conditional probability of 12+ foot flames.

After calculating FLEP4 at 270-m resolution, we created a 30-m resolution version using the multi-stage upsampling and smoothing process described above for fire intensity data.

Flame-length exceedance probability—8 feet (FLEP8)

FLEP8 is a 30-m raster representing the conditional probability that flame length at a pixel will exceed 4 feet if a fire occurs. FLEP8 indicates the potential for moderate to high wildfire intensity. Because 4 feet is considered the limit of manual fire control, FLEP8 represents the likelihood that fire intensity will be beyond the ability of hand crews to control. As with all raster products presented here, it represents fuel characteristics for the 2015 fire season.

We generated the Wildfire Risk to Communities FLEP8 by first calculating FLEP8 at 270-m resolution from the nationally-available flame length probability (FLP) rasters from Short et al. (2020a). FLP rasters each represent the conditional probability of seeing flame lengths within certain ranges if a fire occurs. FLEP8 is simply calculated by adding the conditional probability for all classes representing flame lengths above 4 feet. The equation is:

$$FLEP8 = FLP5 + FLP6$$

Where,

FLP5 = conditional probability of 8 to 12 foot flames

FLP6 = conditional probability of 12+ foot flames.

After calculating FLEP8 at 270-m resolution, we created a 30-m resolution version using the multi-stage upsampling and smoothing process described above for fire intensity data.

Exposure Type

Exposure Type is a 30-m raster that delineates where homes would be directly exposed to wildfire from adjacent wildland vegetation, indirectly exposed to wildfire from indirect sources such as embers and home-to-home ignition, or not exposed to wildfire due to distance from direct and indirect ignition sources (> 1 mile).

We generated the Wildfire Risk to Communities Exposure Type raster by applying the process described above for estimating wildfire hazard in developed areas, and using the LANDFIRE 2014 fuels data as the primary input (LANDFIRE 2017). First, we assigned a value of one to all burnable pixels in the original 30-m resolution LANDFIRE data. Then we applied the spatial smoothing used for BP (three iterative 510-m focal means) to spread values into otherwise non-burnable areas, using the same steps described above to handle small patches of burnable vegetation and other land cover types.

The resulting exposure type values range from 0 to 1. Where the underlying land cover is considered burnable in the LANDFIRE fuels data, the value of the Exposure Type raster is 1 indicating pixels where a home would be “directly exposed” to wildfire. Where land cover is non-burnable urban, agricultural, or bare ground and the upsampled and smoothed BP is non-zero (i.e., within approximately 1 mile of a 500 ha contiguous area of burnable vegetation), homes would be “indirectly exposed” to wildfire. The value Exposure Type in these areas is between 0 and 1. Finally, where the land cover is non-burnable and the upsampled and smoothed BP is zero, the value of the Exposure Type raster is 0 indicating pixels where a home would be “non-exposed” to wildfire.

Conditional Risk to Potential Structures (cRPS)

Conditional Risk to Potential Structures is a 30-m raster that represents the potential consequences of fire to a home at a given location, if a fire occurs there and if a home were located there. It is a measure that integrates wildfire intensity with generalized consequences to a home on every pixel, but does not account for the actual probability of fire occurrence. It is analogous to conditional Net Value Change (cNVC) described by Scott and Thompson (2015), if the only highly-valued resource and asset (HVRA) is homes and we assume a home is on every pixel. cRPS is referred to as Wildfire Consequence in the Wildfire Risk to Communities web application.

We calculated the cRPS raster at 270-m by applying a response function representing the relative effect of wildfire on structures (i.e., relative degree of damage or loss) at different intensities to the 270-m flame-length probability (FLP) rasters produced by Short et al. (2020a). The response function values used were: 25, 40, 55, 70, 85, and 100 for FLP1 through FLP6 respectively. A value of 0 means no damage to a structure, and a value of 100 means complete loss. We applied the response function to all pixels across the landscape, even if no structures are present, as follows:

$$cRPS = (FLP1 * 25) + (FLP2 * 40) + (FLP3 * 55) + (FLP4 * 70) + (FLP5 * 85) + (FLP6 * 100)$$

We then created the 30-m Wildfire Risk to Communities cRPS raster by using the upsampling and smoothing approach described above for measures of wildfire intensity.

Risk to Potential Structures (RPS)

Risk to Potential Structures is a 30-m raster that integrates wildfire likelihood and intensity with generalized consequences to a home on every pixel. For every place on the landscape, it poses the hypothetical question, "What would be the relative risk to a house if one existed here?" It asks that question whether a home actually exists at that location or not. This allows comparison of wildfire risk in places where homes already exist to places where new construction may be proposed. This dataset is referred to as Risk to Homes in the Wildfire Risk to Communities web application.

We calculated the RPS raster at 30-m resolution by multiplying the 30-m cRPS raster (representing the intensity and susceptibility components of risk) by the 30-m BP raster (representing wildfire likelihood). Just as cRPS is analogous to conditional Net Value Change (cNVC), RPS is analogous to the expected Net Value Change (eNVC) presented by Scott et al. (2013), if the only HVRA is homes and we assume a home is on every pixel. The equation for RPS is simply:

$$RPS = cRPS * BP$$

It is important to note that by using a consistent response function for all homes, we assume that all homes are equally susceptible to wildfire. In reality, an individual home’s ability to survive wildfire is driven largely by local conditions that can be highly affected by a homeowner’s or community’s efforts toward mitigating wildfire susceptibility. The condition of vegetation in the immediate area around a home (known as the “Home Ignition Zone”) and the construction materials used in building a home (Quarles et al. 2010) could result in very different response function values for individual homes (Cohen 2019). Consideration of this local variation in susceptibility is well beyond the scope of the Wildfire Risk to Communities project, and RPS should be considered a landscape metric rather than specific to any one home.

Wildfire Hazard Potential (WHP)

Wildfire Hazard Potential is a 30-m raster that quantifies the relative potential for wildfire that may be difficult to control. It is an index developed by the Forest Service to inform prioritization of fuel treatment needs at a national scale (Dillon et al. 2015). WHP integrates wildfire likelihood and intensity with additional factors including historic ignition density of small fires and the relative resistance to control posed by wildfire in different fuel types. Similar to the response function used in calculating cRPS, WHP also applies weights to different fire intensities. Complete description of the WHP methods are available in Dillon et al. (2015) and previous national 270-m versions of WHP are available at Dillon (2018a) and Dillon (2018b).

We first calculated the WHP raster at 270-m, using the most recent nationwide 270-m BP and FLP rasters from Short et al. (2020) as input. Other input data included the Existing Vegetation Type and Scott and Burgan Fire Behavior Fuel Model rasters from LANDFIRE Version 1.4.0 (LANDFIRE 2017), as well as the most recent national Fire Occurrence Database (Short 2017). We then generated the 30-m Wildfire Risk to Communities WHP raster by using the upsampling and smoothing approach described above for measures of wildfire intensity.

Methods for Tabular Summaries

Summary polygons

We generated statistics for three nationwide sets of summary polygons—states, counties, and communities.

State

There are 51 polygons in the "States" set of summary polygons—50 U.S. States plus the District of Columbia. We used the U.S. Census Bureau's "2018 TIGER/Line Shapefiles: States (and equivalent)" to delineate U.S. States (and equivalent).

County

There are 3,141 summary polygons in the "Counties" set. We used the U.S. Census Bureau's "2018 TIGER/Line Shapefiles: Counties (and equivalent)" to delineate counties (and equivalent) covering the 50 U.S. States.

Community core

We used the U.S. Census Bureau's "2018 TIGER/Line Shapefiles: Places" dataset to represent populated places, which we call community cores. A census populated place is an incorporated area (city, town, etc) or a Census Designated Place (CDP). There are 29,318 community cores across the 50 U.S. States.

Fields

Each set of summary polygons has certain attributes that originated with the source data. We retained those fields in the final database. In addition, we summarized the WRC raster datasets to produce the following additional fields that characterize a community's exposure to wildfire.

Total Number of Housing Units (HU_{total})

HU_{total} is the estimated number of housing units within a summary polygon. This total includes all housing units in the zone regardless of wildfire exposure. This value was calculated as the total population of a zone divided by a nationwide mean number of persons per housing unit of 2.53. The population data was taken from the 2018 American Community Survey population estimates for states, counties and communities (i.e., U.S. Census Populated Places).

Exclusion

The Exclusion field is a binary indicator of Census Populated Places for which there are insufficient LandScan data to produce reliable estimates of exposure type and housing-unit weighted mean hazard and risk values. A value of 0 indicates the data are sufficient; a value of 1 indicates the data are not sufficient and the community is excluded from the Wildfire Risk to Communities interactive web application.

Fraction of Housing Units Directly Exposed ($FractionHU_{DE}$)

Using the exposure type and relative housing-unit density rasters, we determined, within each summary polygon, the percentage of the total number of housing units that are directly exposed to wildfire. Directly exposed homes are located in an area considered to be covered by flammable wildland vegetation. Because of this, homes may be exposed to wildfire through direct flame contact or radiant heat from burning wildland vegetation, as well as indirect sources such as embers transported through the air from vegetation or homes burning nearby. For any summary polygon, the sum of $FractionHU_{DE}$, $FractionHU_{IE}$, and $FractionHU_{NE}$ necessarily equals 100 percent.

$$FractionHU_{DE} = \frac{\sum(r(HUden_{DE}) * .0009)}{HU_{total}}$$

Fraction of Housing Units Indirectly Exposed ($FractionHU_{IE}$)

Using the exposure type and relative housing-unit density rasters we determined, within each summary polygon, the percentage of the total number of housing units that are indirectly exposed to wildfire. Indirectly exposed homes are located within 1500 meters (1 mile) of a large area (at least two square miles) considered to be covered by flammable wildland vegetation, but are located on land cover otherwise considered to be not subject to wildland fire spread (for example, urban land cover). Because of this, homes are unlikely to be directly exposed to wildfire through direct flame contact or radiant heat from burning wildland vegetation but may still be exposed to ignition from indirect sources such as embers transported through the air from vegetation or homes burning nearby. For any summary polygon, the sum of $FractionHU_{DE}$, $FractionHU_{IE}$, and $FractionHU_{NE}$ necessarily equals 100 percent.

$$FractionHU_{IE} = \frac{\sum(r(HUden_{IE}) * .0009)}{HU_{total}}$$

Fraction of Housing Units Not Exposed ($FractionHU_{NE}$)

Using the exposure type and relative housing-unit density rasters we determined, within each summary polygon, the percentage of the total number of housing units that are not exposed to wildfire. Nonexposed homes are located more than 1500 m (1 mile) from a large area (at least two square miles) considered to be covered by flammable wildland vegetation. Because of this, homes are unlikely to be directly exposed to wildfire through direct flame contact or indirect sources of ignition such as embers originating from a wildfire. In the event of an urban or suburban conflagration, nonexposed homes could still be ignited, but in such cases the event is no longer a wildfire and is outside of current capabilities of wildfire modeling to estimate. For any summary polygon, the sum of $FractionHU_{DE}$, $FractionHU_{IE}$, and $FractionHU_{NE}$ necessarily equals 100 percent.

$$FractionHU_{NE} = \frac{\sum(r(HUden_{NE}) * .0009)}{HU_{total}}$$

Total number of exposed Housing Units ($HU_{exposed}$)

The estimated number of housing units directly or indirectly exposed to wildfire in a summary polygon. Calculated as

$$HU_{exposed} = HU_{total} * \ (FractionHU_{DE} + FractionHU_{IE})$$

$HU_{exposed}$ is used in later calculations.

Fraction of Exposed Housing Units Directly Exposed ($FractionExHU_{DE}$)

The fraction of exposed housing units directly exposed to wildfire is calculated as

$$FractionExHU_{DE} = \frac{FractionHU_{DE}}{(FractionHU_{DE} + FractionHU_{IE})}$$

Fraction of Exposed HUs Indirectly Exposed ($FractionExHU_{IE}$)

The fraction of exposed housing units indirectly exposed to wildfire is calculated as

$$FractionExHU_{IE} = \frac{FractionHU_{IE}}{(FractionHU_{DE} + FractionHU_{IE})}$$

Mean Burn Probability

Mean Burn Probability (BP) is the arithmetic mean annual BP across all exposed housing units (direct or indirect). Nonexposed housing units, for which BP is zero, are not included in the calculation. The mean is weighted by housing-unit density so that it represents the mean BP of housing units in the summary polygon rather than the mean BP of the land area where housing units exist. The housing-unit-weighted mean is calculated from the BP and rHUden rasters as follows:

$$Mean\ BP = \frac{\sum\big(r(BP) * r(HUden)\big)}{\sum r(HUden)}$$

Mean BP percentile within state

This field represents the percentile rank of a summary polygon's mean BP within its state, calculated on an exposed housing-unit basis. The percentile rank of a summary polygon is calculated as the fraction of *exposed housing units* within the state that exist in polygons with a mean BP value less than or equal to the summary polygon's mean BP value. This calculation is slightly different than the percentile reported in the Wildfire Risk to Communities web application, where the percentile represents the percent of polygons (counties, communities) with a lower mean BP than the summary polygon's mean BP value. This field applies to the county and community summaries, but it has no meaning for the statewide summaries.

We calculate percentiles in this fashion because the higher-risk communities tend to have a smaller number of exposed housing units. Whereas the traditional calculation of percentile rank might identify a polygon as being in the 95th percentile (for example), 98% of the exposed housing units might be less than or equal to the polygon's value. This calculation approach uses the latter as the percentile.

Mean BP percentile within nation

This field represents the percentile rank of a summary polygon's mean BP within the nation, calculated on an exposed housing-unit basis. The percentile rank of a summary polygon is calculated as the fraction of *exposed housing units* within the nation that exist in polygons with a mean BP value less than or equal to the summary polygon's Mean BP value. This calculation is slightly different than the percentile reported in the Wildfire Risk to Communities web application, where the percentile represents the percent of polygons (states, counties, communities) with a lower mean BP than the summary polygon's mean BP value. This field applies to the state, county and community summaries.

Mean BP_{DE}

Mean BP_{DE} is the housing-unit weighted mean annual Burn Probability of the directly exposed housing units in the summary polygon. Nonexposed and indirectly exposed housing units are not included in the calculation. The housing-unit-weighted mean is calculated from the BP and rHUden rasters as follows:

$$Mean\ BP_{DE} = \frac{\sum\left(r(BP_{DE}) * r(HUden_{DE})\right)}{\sum r(HUden_{DE})}$$

Where BP_{DE} is the BP where housing units are directly exposed and $rHUden_{DE}$ is the housing-unit density where housing units are directly exposed.

Mean BP_{IE}

Mean BP_{IE} is the housing-unit weighted mean annual Burn Probability of the indirectly exposed housing units in the summary polygon. Nonexposed and directly exposed housing units are not included in the calculation. The housing-unit-weighted mean is calculated from the BP and rHUden rasters as follows:

$$Mean\ BP_{IE} = \frac{\sum\left(r(BP_{IE}) * r(HUden_{IE})\right)}{\sum r(HUden_{IE})}$$

Where BP_{IE} is the BP where housing units are indirectly exposed and $rHUden_{IE}$ is the housing-unit density where housing units are indirectly exposed.

Mean CRPS

Mean CRPS is the housing-unit weighted mean of the Conditional Risk to Potential Structures (CRPS) raster within a summary polygon. The CRPS raster represents the general consequences of fire, if it occurs, on homes and other structures as a function of fire intensity. CRPS does not include the likelihood of fire occurring, and it does not reflect mitigations done to individual structures that would influence susceptibility. CRPS is referred to in the Wildfire Risk to Communities web application as Wildfire Consequence.

Mean CRPS percentile within state

This field represents the percentile rank of a summary polygon's mean CRPS within its state, calculated on an exposed housing-unit basis. The percentile rank of a summary polygon is calculated as the percent of exposed housing units within the state that exist in polygons with a mean CRPS value less than or equal to the summary polygon's mean CRPS value. This field applies to the county and community summaries; it is not applicable for the statewide summaries.

Mean CRPS percentile within nation

This field represents the percentile rank of a summary polygon's mean CRPS within the nation, calculated on an exposed housing-unit basis. The percentile rank of a summary polygon is calculated as the percent of exposed housing units within the nation that exist in polygons with a mean CRPS value less than or equal to the summary polygon's mean CRPS value.

Mean CRPS-Direct

Mean $CRPS_{DE}$ is the housing-unit weighted mean conditional risk to potential structures of the directly exposed housing units in the summary polygon. Nonexposed and indirectly exposed housing units are not included in the calculation.

Mean CRPS-Indirect

Mean $CRPS_{IE}$ is the housing-unit weighted mean conditional risk to potential structures of the indirectly exposed housing units in the summary polygon. Nonexposed and directly exposed housing units are not included in the calculation.

Mean RPS

Mean RPS is the housing-unit weighted mean of the Risk to Potential Structures (RPS) raster within a summary polygon. The RPS raster poses the hypothetical question on every pixel, "What would be the relative risk to a house if one existed here?" It integrates wildfire likelihood and general consequences of fire on homes and other structures as a function of fire intensity. RPS does not reflect mitigations done to individual structures that would influence susceptibility. RPS is referred to in the Wildfire Risk to Communities web application as Risk to Homes.

Mean RPS percentile within state

This field represents the percentile rank of a summary polygon's mean RPS within its state, calculated on an exposed housing-unit basis. The percentile rank of a summary polygon is calculated as the percent of exposed housing units within the state that exist in polygons with a mean RPS value less than or equal to the summary polygon's mean RPS value. This calculation is slightly different than the percentile reported in the Wildfire Risk to Communities web application, where the percentile represents the percent of polygons (counties, communities) with a lower mean RPS than the summary polygon's mean RPS value. This field applies to the county and community summaries; it is not applicable for the statewide summaries.

Mean RPS percentile within nation

This field represents the percentile rank of a summary polygon's mean RPS within the nation, calculated on an exposed housing-unit basis. The percentile rank of a summary polygon is calculated as the percent of exposed housing units within the nation that exist in polygons with a mean RPS value less than or equal to the summary polygon's mean RPS value. This calculation is slightly different than the percentile reported in the Wildfire Risk to Communities web application, where the percentile represents the percent of polygons (states, counties, communities) with a lower mean RPS than the summary polygon's mean RPS value.

Mean RPS-Direct

$MeanRPS_{DE}$ is the housing-unit weighted mean risk to potential structures of the directly exposed housing units in the summary polygon. Nonexposed and indirectly exposed housing units are not included in the calculation.

Mean RPS-Indirect

$MeanRPS_{IE}$ is the housing-unit weighted mean risk to potential structures of the indirectly exposed housing units in the summary polygon. Nonexposed and directly exposed housing units are not included in the calculation.

Mean WHP

MeanWHP is the housing-unit weighted mean of the Wildfire Hazard Potential (WHP) raster within a summary polygon. The Wildfire Hazard Potential is described in Dillon et al. (2015) and Dillon (2018).

Mean WHP percentile within state

This field represents the percentile rank of a summary polygon's meanWHP within its state, calculated on an exposed housing-unit basis. The percentile rank of a summary polygon is calculated as the percent of exposed housing units within the state that exist in polygons with a meanWHP value less than or equal to the summary polygon's meanWHP value. This field applies to the county and community summaries; it is not applicable for the statewide summaries.

Mean WHP percentile within nation

This field represents the percentile rank of a summary polygon's meanWHP within the nation, calculated on an exposed housing-unit basis. The percentile rank of a summary polygon is calculated as the percent of exposed housing units within the nation that exist in polygons with a meanWHP value less than or equal to the summary polygon's meanWHP value.

Mean WHP-Direct

MeanWHP_{DE} is the housing-unit weighted mean Wildfire Hazard Potential of the directly exposed housing units in the summary polygon. Nonexposed and indirectly exposed housing units are not included in the calculation.

Mean WHP-Indirect

MeanWHP_{IE} is the housing-unit weighted mean Wildfire Hazard Potential of the indirectly exposed housing units in the summary polygon. Nonexposed and directly exposed housing units are not included in the calculation.

Mean CFL

MeanCFL is the housing-unit weighted mean of the conditional flame length (CFL) raster within a summary polygon. Nonexposed housing units are not included in this mean.

Mean CFL-Direct

MeanCFL_{DE} is the housing-unit weighted mean of the conditional flame length (CFL) raster in the directly exposed pixels in a summary polygon. Nonexposed and indirectly exposed housing units are not included in this mean.

Mean CFL-Indirect

MeanCFL_{IE} is the housing-unit weighted mean of the conditional flame length (CFL) raster in the indirectly exposed pixels in a summary polygon. Nonexposed and directly exposed housing units are not included in this mean.

Mean FLEP4

MeanFLEP4 is the housing-unit weighted mean of the FLEP4 raster within a summary polygon. Nonexposed housing units are not included in this mean. The FLEP4 raster represents the conditional probability that flame length will exceed the limit of manual control (4 feet).

Mean FLEP4-Direct

$MeanFLEP4_{DE}$ is the housing-unit weighted mean of the FLEP4 raster in the directly exposed pixels in a summary polygon. Nonexposed and indirectly exposed housing units are not included in this mean.

Mean FLEP4-Indirect

$MeanFLEP4_{IE}$ is the housing-unit weighted mean of the FLEP4 raster in the indirectly exposed pixels in a summary polygon. Nonexposed and directly exposed housing units are not included in this mean.

Mean FLEP8

MeanFLEP8 is the housing-unit weighted mean of the FLEP8 raster within a summary polygon. Nonexposed housing units are not included in this mean. The FLEP8 raster represents the conditional probability that flame length will exceed the limit of mechanical control (8 feet).

Mean FLEP8-Direct

$MeanFLEP8_{DE}$ is the housing-unit weighted mean of the FLEP8 raster in the directly exposed pixels in a summary polygon. Nonexposed and indirectly exposed housing units are not included in this mean.

Mean FLEP8-Indirect

$MeanFLEP8_{IE}$ is the housing-unit weighted mean of the FLEP8 raster in the indirectly exposed pixels in a summary polygon. Nonexposed and directly exposed housing units are not included in this mean.

Expected Annual HU Exposed (EAHUexp)

EAHUexp is the expected number of housing units within a summary polygon potentially exposed to wildfire in a year. This is a long-term annual average and not intended to represent the actual number of housing units exposed in any specific year. It is calculated as

$$EAHUexp = Mean\ BP * HU_{exposed}$$

Expected Annual HU Exposed percentile within state

This field represents the percentile rank of a summary polygon's EAHUexp within its state, calculated on a polygon basis (as opposed to the housing-unit basis used for other percentile calculations).

Expected Annual HU Exposed percentile within nation

This field represents the percentile rank of a summary polygon's EAHUexp within the nation, calculated on a polygon basis (as opposed to the housing-unit basis used for other percentile calculations).

Fraction $EAHUexposed_{DE}$

This field is the fraction of total EAHUexp contributed by the directly exposed housing units. The balance is contributed by indirectly exposed housing units.

$$EAHUexposed_{DE} = \frac{r(BP_{DE}) * r(HUden_{DE})}{r(BP) * r(HUden)}$$

Fraction EAHUexposed$_{IE}$

This field is the fraction of total EAHUexp contributed by the indirectly exposed housing units. The balance is contributed by directly exposed housing units.

$$EAHUexposed_{IE} = \frac{r(BP_{IE}) * r(HUden_{IE})}{r(BP) * r(HUden)}$$

Expected Annual Relative HU Risk (EAHUrisk)

This field is the expected annual relative housing-unit risk for a summary polygon. It is an index of the expected damage to, or loss of, housing units within a summary polygon due to wildfire in a year. This is a long-term annual average and not intended to represent the actual losses expected in any specific year.

EAHUrisk It is sensitive to the mean RPS and the number of exposed housing units for a summary polygon. Mean RPS is a function of mean BP and mean CRPS, so this measure incorporates all four components of risk—likelihood and intensity of wildfire, and exposure and susceptibility of housing units.

This field is calculated as

$$EAHUrisk = Mean\ RPS * HU_{exposed}$$

Expected Annual Relative HU Risk percentile within state

This field represents the percentile rank of a summary polygon's EAHUrisk within its state, calculated on a polygon basis (as opposed to the housing-unit basis used for other percentile calculations).

Expected Annual Relative HU Risk percentile within nation

This field represents the percentile rank of a summary polygon's EAHUrisk within the nation, calculated on a polygon basis (as opposed to the housing-unit basis used for other percentile calculations).

Fraction EAHUrisk$_{DE}$

This field is the fraction of total EAHUrisk contributed by the directly exposed housing units. The balance is contributed by indirectly exposed housing units.

$$EAHUrisk_{DE} = \frac{r(RPS_{DE}) * r(HUden_{DE})}{r(RPS) * r(HUden)}$$

Fraction EAHUrisk-Indirect

This field is the fraction of total EAHUexp contributed by the indirectly exposed housing units. The balance is contributed by directly exposed housing units.

$$EAHUrisk_{IE} = \frac{r(RPS_{IE}) * r(HUden_{IE})}{r(RPS) * r(HUden)} \qquad \text{or simply,} \qquad EAHUrisk_{IE} = 1 - EAHUrisk_{DE}$$

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