WILDFIRE RISK TO COMMUNITIES

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Wildfire Risk to Communities 2.0:

Methods for creating Community Wildfire Risk Reduction Zones for the United States

A white paper included with:

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INTRODUCTION

Background

The Wildfire Risk to Communities project (WRC) 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 develop the necessary data and build a website for effective delivery of information to communities. The team consisted of wildfire analysts from the Fire Modeling Institute (FMI), part of the Forest Service's Rocky Mountain Research Station (RMRS), and wildfire modeling and geospatial data experts at Pyrologix, LLC. A non-profit partner, Headwaters Economics, also became a critical player in developing the public-facing website with interactive maps and charts, and clear communication targeted to local government officials and private citizens who could take actions to mitigate risks in their communities.

The result of those initial efforts was the Wildfire Risk to Communities website (www.wildfirerisk.org) that was launched in April 2020. The data products published in that initial rollout were built on the nationwide wildfire hazard data from Short et al. (2020a), and they represented the first time wildfire risk to communities had been mapped nationally with consistent methodology down to the level of individual communities. The data provided foundational information for comparing the relative wildfire risk among communities in the United States.

Data Overview

There are two types of data included in this publication: 1) a new spatial dataset that delineates Community Wildfire Risk Reduction Zones for all populated areas in the United States; and 2) tabular summaries by communities, counties, tribal areas, and states of wildfire hazard and risk datasets produced as part of the WRC project.

When the first version of WRC data were published in 2020 (WRC 1.0), the landscape-wide data publication (Scott et al. 2020) included tabular summaries of hazard and risk by states, counties, communities and expanded community zones. The accompanying white paper included descriptions of the summary fields and methods. In those summaries, we chose to focus only on areas with housing units and we also gave greater weight to areas with greater relative housing-unit density. As such, we excluded any area where housing-unit density was zero from summary calculations and many of our summary measures were calculated as housing-unit-weighted means.

In the years since that initial release, the Forest Service launched the Community Wildfire Defense Grant (CWDG) program that offers grants to at-risk communities for community-focused wildfire risk mitigation work. Data from WRC have been used to help determine if communities meet the criteria to be considered at risk. In the process of designing data summaries to meet the needs of the CWDG program, we realized that it can be important to consider not only the hazard and risk specifically where housing units exist, but also within a distance from those housing units where fuel reduction activities could directly result in mitigating the hazard to a community. This concept

aligns with other efforts to delineate zones for the purpose of prioritizing wildfire management activities. For example, Wilmer and Aplet (2005) mapped "Community Fire Planning Zones" intended to help communities prioritize wildfire risk mitigation efforts using a simple buffer around communities, and the Southern Group of State Foresters Wildfire Risk Assessment Portal[1] includes a map theme called "Community Protection Zones" representing a variable width band around homes depending on wildfire rate of spread, also intended to identify areas where mitigation efforts will benefit communities.

When evaluating methods to map risk reduction zones, we built on our experience creating wildfire exposure areas adjacent to communities for the CWDG program. We chose an approach that employs standard spatial analysis smoothing and buffering processes to produce more precise and spatially explicit characterizations of map categories, similar to efforts others have used to map Wildland Urban Interface classes (Bar-Massada et al. 2013, Carlson et al. 2022). We were also influenced by a product that analysts at Pyrologix developed after the initial release of WRC 1.0 datasets. As part of the Montana Wildfire Risk Assessment[2], Pyrologix combined the Building Exposure Type raster from WRC 1.0 with spatial buffering to produce the "Functional WUI", a depiction of zones similar to those in Wildland-Urban Interface (WUI) maps (e.g., Radeloff et al. 2023, Carlson et al. 2022).

This new product we are introducing as part of a second edition of Wildfire Risk to Communities data (WRC 2.0) is the Community Wildfire Risk Reduction Zones (CWiRRZ) dataset. Like the Functional WUI, the CWiRRZ effectively integrates the refined spatial buffering techniques with spatial information describing wildfire exposure to map risk reduction zones specifically relevant for wildfire managers. We wanted this dataset to serve two purposes: 1) provide a nationally-consistent spatial dataset that could be used to summarize hazard and risk to populated areas and take into consideration areas with housing units as well as adjacent areas with wildland fuels; and 2) provide communities with a way to spatially identify where different types of risk mitigation activities are likely to be most effective.

The purpose of this white paper is to provide detailed descriptions of the methods used to create the new Risk Reduction Zones, methods for summarizing WRC data by these zones, and the fields included in the tabular data summaries. There are two companion data publications that are part of the WRC 2.0 data update: one that includes datasets for landscape-wide characteristics of wildfire hazard and risk (Scott et al. 2024), and one that includes datasets of wildfire hazard and risk for populated areas of the nation, where housing units are currently present (Jaffe et al. 2024). Each publication includes a white paper that describes methods for creating the datasets.

[1] https://www.southernwildfirerisk.com/
[2] https://mwra-mtdnrc.hub.arcgis.com/

COMMUNITY WILDFIRE RISK REDUCTION ZONES

The Community Wildfire Risk Reduction Zones (CWiRRZ) product is a 30-m raster delineating areas where mitigation activities can be most effective at reducing the risk of structure losses from wildfire. The zones are determined by the spatial coincidence of wildfire likelihood (Burn Probability), and populated areas. Generally, there are four Risk Reduction Zones: Minimal Exposure Zone, Indirect Exposure Zone, Direct Exposure Zone, and Wildfire Transmission Zone. However, the CWiRRZ raster can be further deconstructed into ten zones, wherein the Wildfire Transmission Zone is separated into the following surface fuel types: Tree, Shrub, Grass, Agriculture, Non-Vegetated, Water, and Outlying Wildlands (area beyond 2.4 km from buildings) (Figure 1).

Effective wildfire risk-reduction activities will vary depending on the zone. In the Indirect Exposure Zone, activities should make homes ignition resistant, reducing places for embers to land and ignite[3,4]. In the Wildfire Transmission Zone, fuel reduction treatments can help reduce the continuity of vegetative fuels to slow fire spread and reduce ember exposure to communities; the specifics of fuel reduction work will vary depending on the type of vegetation. In the Direct Exposure Zone, all of these activities are necessary for the most effective risk reduction.

Minimal Exposure Zone

The Minimal Exposure Zone is where homes are unlikely to be subjected to wildfire from either direct or indirect sources. This zone is more than 1,500 m (1 mile) from a large, contiguous area of flammable wildland vegetation. Because of this, homes are unlikely to be exposed to wildfire from direct sources such as flame contact or from indirect sources such as embers or home-to-home spread. In the event of an urban or suburban conflagration, minimally exposed homes could be ignited, but in such cases, the event is no longer a wildfire and is outside of current capabilities of wildfire modeling to estimate.

Indirect Exposure Zone

The Indirect Exposure Zone is where homes may be subjected to wildfire from indirect sources such as embers and home-to-home ignition. This zone is within 1,500 m (1 mile) from a large, contiguous area covered by flammable wildland vegetation, but has land cover that is not considered conducive to wildland fire spread (for example urban land cover). Because of this, homes are unlikely to be directly exposed to wildfire through direct contact or radiant heat from burning wildland vegetation but may still be exposed to ignition from indirect sources such as embers or home-to-home ignition.

Effective mitigation in the Indirect Exposure Zone will reduce places where embers can land and ignite. This includes building ignition-resistant homes and having a 5-foot noncombustible area immediately around homes.

[3] https://wildfirerisk.org/reduce-risk/ignition-resistant-homes/
[4] https://wildfireprepared.org/

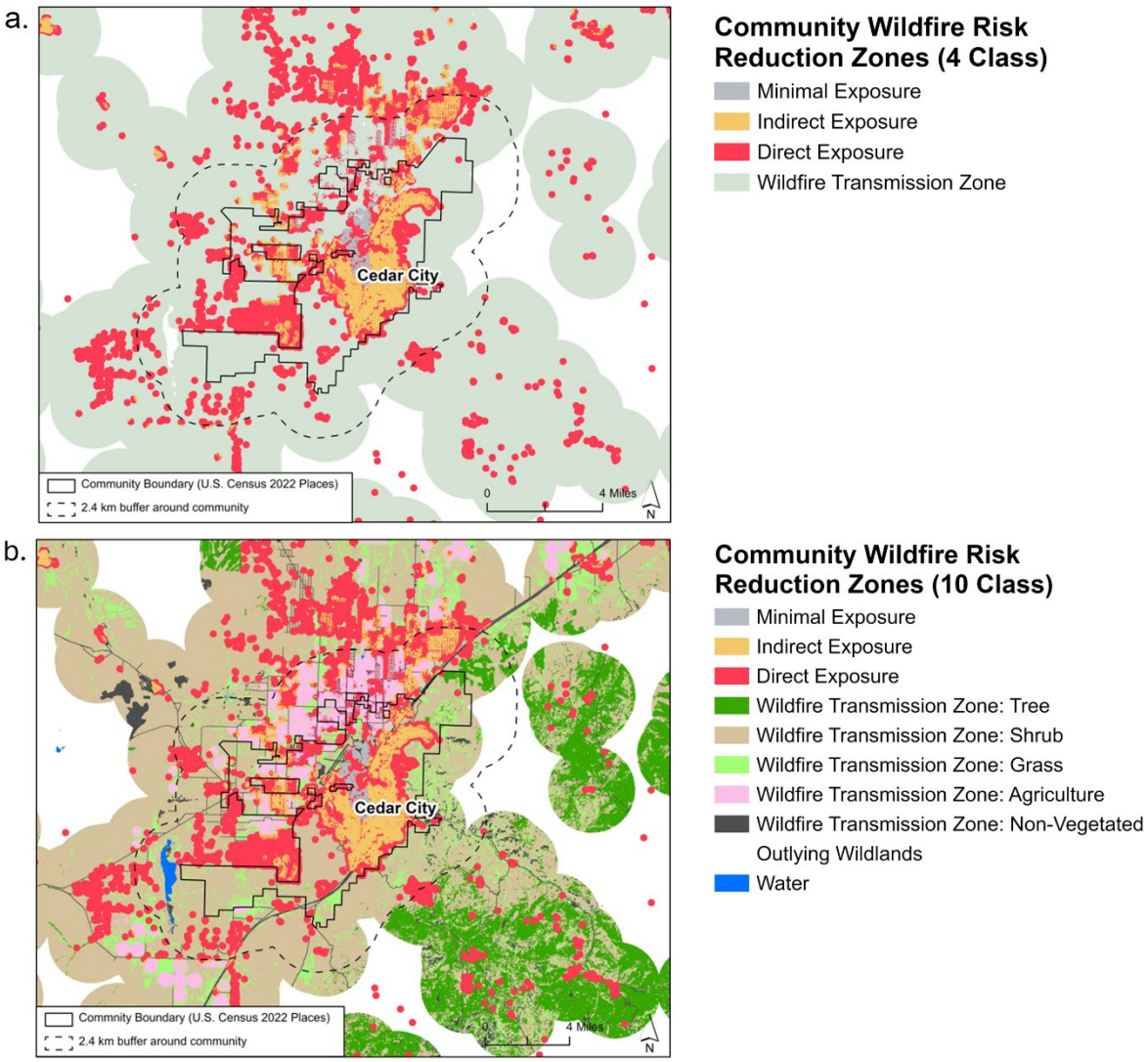

Figure 1. Example of Community Wildfire Risk Reduction Zones displayed for Cedar City, Utah: a. 4-Class CWiRRZ and b. 10-Class CWiRRZ.

Direct Exposure Zone

The Direct Exposure Zone is where homes may be subjected to wildfire from adjacent flammable wildland vegetation and from indirect sources such as embers. This zone is 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, buildings, or other materials burning nearby.

Effective mitigation activities in the Direct Exposure Zone will reduce places where embers can land and ignite and reduce the continuity of vegetation to slow fire spread and change fire behavior. Activities should include building ignition-resistant homes and conducting hazardous fuel treatments like thinning and prescribed fire.

Wildfire Transmission Zone

The Wildfire Transmission Zone is the vegetated area up to 2.4 km (approximately 1.5 miles) from building clusters (where building density is greater than 1 building per 40 acres; see methods section for details). In this zone, flammable vegetation may expose homes and other structures to wildfire and create embers that can travel into communities. While research and observations from wildfires across North America and Australia have shown that ember transport distances can vary widely depending on vegetation type and weather conditions, a reasonable approximation of typical maximum distances is about 2.4 km, or 1.5 miles, in most conditions (Filkov et al. 2023, Blunck et al. 2019, Page et al. 2019, Radeloff et al. 2005).

In the Wildfire Transmission Zone, hazardous fuel treatments such as thinning and prescribed fire can help reduce the continuity of fuels to slow or contain the spread of surface fire toward homes, minimize the potential for high intensity crown fire, and reduce the likelihood of embers being carried from burning vegetation into the built environment. These activities can also create defensible spaces to anchor safe and effective wildfire response.

We consider the Wildfire Transmission Zone as a single map category characterizing the entire vegetated area that is within 2.4 km of buildings, as described above. This results in a 4-class CWiRRZ map, which is what appears in the Wildfire Risk to Communities web application and what we used for our tabular summaries of wildfire hazard and risk metrics (described in the tabular area methods summary below). However, we also stratify the Wildfire Transmission Zone into subcategories based on dominant fuel types, enabling refinement of suggested mitigation activities. These subcategories are listed below.

Wildfire Transmission Zone: Tree

The Tree Wildfire Transmission Zone is the area up to 2.4 km from buildings where surface fuels are predominantly made up of timber understory or timber litter, as mapped in the LANDFIRE Scott and Burgan Fire Behavior Fuel Model (FBFM40) dataset[5].

Mitigation activities in this zone may include thinning or prescribed fire to reduce fuel loads and continuity to moderate wildfire spread rates, intensity, and the potential for ignited trees to loft embers towards communities.

Wildfire Transmission Zone: Shrub

The Shrub Wildfire Transmission Zone is the area up to 2.4 km from buildings where fuels are predominantly made up of shrubs, as mapped in the LANDFIRE FBFM40 dataset.

Mitigation activities in this zone may include mechanical fuel breaks, and in some cases prescribed fire, to reduce fuel continuity and moderate wildfire spread and intensity near communities.

[5] https://landfire.gov/fbfm40.php

Wildfire Transmission Zone: Grass

The Grass Wildfire Transmission Zone is the area up to 2.4 km from buildings where fuels are predominantly made up of grass, as mapped in the LANDFIRE FBFM40 dataset.

Mitigation activities in this zone may include mechanical fuel breaks or mowing, and in some cases prescribed fire, to reduce fuel continuity and moderate wildfire spread and intensity near communities.

Wildfire Transmission Zone: Agriculture

The Agriculture Wildfire Transmission Zone is the area up to 2.4 km from buildings where fuels are predominantly made up of non-burnable agricultural land, as mapped in the LANDFIRE FBFM40 dataset.

Wildfire mitigation activities may be unnecessary in some areas within this zone if they are consistently irrigated. However, in areas where crops or crop residue may be burnable (e.g., wheat fields and other agricultural grasses), mechanical fuel breaks or mowing may be warranted.

Wildfire Transmission Zone: Non-Vegetated

The Non-Vegetated Wildfire Transmission Zone is the area up to 2.4 km from buildings where land cover is predominantly non-vegetated. These areas include land cover types mapped as urban, permanent snow/ice, and bare ground in the LANDFIRE FBFM40 dataset.

Wildfire mitigation activities are generally unnecessary in this zone.

Water

This zone includes any area within the Wildfire Transmission Zone that is mapped as water in the LANDFIRE FBFM40 dataset.

Outlying Wildlands

The area outside the Wildfire Transmission Zone, labeled Outlying Wildlands, is anywhere beyond 2.4 km from building clusters and without isolated buildings or water. This area is considered far enough from a community that fuels are unlikely to pose a threat to buildings.

Land managers or landowners responsible for isolated buildings outside the Wildfire Transmission Zone may consider reducing nearby hazardous fuels to reduce wildfire exposure, using best practices for creating ignition-resistant structures[6]. Mitigation activities targeted toward resources and assets other than buildings/communities may also be warranted in these areas.

[6] https://wildfirerisk.org/reduce-risk/ignition-resistant-homes/

DATA AND METHODS

Input Datasets

The input datasets used to produce the data products described here include datasets related to population, building sizes and locations, land cover, and wildfire likelihood. We describe the sources of those input datasets in the following sections.

Building Footprints

3DBuildings—We acquired a commercially available building footprint dataset, 3DBuildings from ONEGEO[7], in January 2023. This dataset covers all 50 states and the District of Columbia, and represents building footprints as of 2022.

USA Structures—We acquired a publicly available building footprint dataset for all 50 states and the District of Columbia from USA Structures[8], a collaboration of Oak Ridge National Laboratory (ORNL) and the Federal Emergency Management Agency (FEMA). This dataset is limited to buildings with a calculated footprint area of 450 ft^2 (41.8 m^2). We acquired USA Structures data in December 2022 to represent building footprints as of 2022. A simple analysis showed that the USA Structures dataset contains buildings not present in the 3DBuildings dataset.

Integrated Building Footprints—Each of the source building footprint datasets had benefits and drawbacks; neither dataset on its own appeared to fully represent the full extent of building locations across the country. We therefore made an integrated building footprint (IBF) dataset designed to reduce the number of missed buildings that could exist within each source on its own. To make the IBF dataset, we started with all buildings in the 3DBuildings dataset and added buildings from the USA Structures dataset whose footprints did not intersect with a 3DBuildings footprint.

Qualifying Buildings—Another drawback to building footprint datasets is the presence of false-positives – footprint polygons that don't actually represent buildings. Often these are very small polygons that may reflect rocks, shadows, and other imagery features mistaken for buildings. To reduce the prevalence of these in our data, and to also keep our focus on primary residential, commercial, and industrial buildings (as opposed to sheds and other small outbuildings), we eliminated buildings with a footprint area smaller than 40 m^2 (430 ft^2). As this was below the minimum size for the USA Structures data (41.8 m^2 or 450 ft^2), this only eliminated small building footprints coming from the 3DBuildings dataset. We also eliminated a building footprint if its centroid fell on a pixel of uninhabitable land cover (i.e., open water and permanent snow/ice; see below). We refer to the resulting, filtered version of the IBF dataset as the qualifying buildings dataset (QBF).

[7] https:/onegeo.co
[8] https://gis-fema.hub.arcgis.com/pages/usa-structures

Protected Areas

In addition to the filtering of buildings for our QBF dataset, we also used a protected areas mask to remove more false positives from our population and housing unit products. In doing so, we assumed that very few people live inside of legally designated Wilderness or Roadless areas and created our protected area mask from the following datasets: Department of Interior wilderness areas (Craig Thompson, DOI Office of Wildland Fire, personal communication), and USDA Forest Service Wilderness Area boundaries, Other National Designated-Area boundaries, and Roadless Area boundaries. We acquired all datasets in September 2023.

We considered Wilderness and Wilderness Study Areas a first step in filtering out false positives. We merged all Wilderness and Wilderness Study Area polygons into a combined dataset. We visually inspected these polygons with aerial imagery available in ArcGIS and found that true buildings existed directly on the edge of designated areas. To prevent losing those buildings when converting the polygons to a raster mask, we first did an inverse buffer of 200m (i.e. shrunk the polygons inwards by 200m). We then removed any potential buildings from inside the inverted mask.

Next, we visually inspected Roadless Areas with aerial imagery and found that some states appeared to have true buildings (possibly housing units) inside Roadless areas. Therefore, we subjectively chose specific states where we felt also removing potential buildings from inside Roadless Areas would be beneficial. The states where we removed potential buildings from Roadless Areas were: Arizona, California, Colorado, Florida, Idaho, Kentucky, Montana, Nevada, New Mexico, North Dakota, Oregon, Pennsylvania, South Dakota, Texas, Utah, Washington, and Wyoming.

Land Cover – LANDFIRE Fire Behavior Fuel Models

We used the LANDFIRE 2.2.0 (LANDFIRE 2020) Scott and Burgan Fire Behavior Fuel Model (FBFM40) raster dataset to identify burnable vs non-burnable and habitable vs uninhabitable land covers. The FBFM40 dataset represents the primary vegetation layer likely to carry fire, which is different than a typical land cover map that represents the dominant overstory. It is used as a primary input to the fire behavior modeling that generates burn probability and flame-length probability rasters, so using it to also represent land cover maintains logical consistency between the WRC datasets. The data cover three different extents; each extent used a different spatial reference (see table below).

Spatial domain	LANDFIRE version		Projection
Conterminous U.S. (CONUS)	2.2.0	LF 2020	Albers CONUS
Alaska (AK)	2.2.0	LF 2020	Albers AK
Hawaii (HI)	2.2.0	LF 2020	Albers HI

Non-burnable land cover was defined as areas mapped by LANDFIRE as any of the non-burnable fuel models in the FBFM40 raster: urban (91), permanent snow/ice (92), non-burnable agriculture (93), open water (98) and bare ground (99) (Scott and Burgan 2005). We considered everything else burnable land cover. We used both 30-m and 270-m resolution versions of the burnable land cover raster at different stages of data processing for Wildfire Risk to Communities. We defined habitable land cover as all land cover types except open water and permanent snow/ice.

Exposure Type

The Exposure Type raster from Scott et al. (2024) is a primary input to the CWiRRZ dataset. Exposure Type characterizes the way that a structure could be exposed to wildfire with values ranging 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 structure would be "directly exposed" to wildfire. Where land cover is non-burnable developed, agricultural, or bare ground and the upsampled and oozed Burn Probability (BP) is non-zero (i.e., within approximately 1 mile of a 500-ha contiguous area of burnable vegetation), structures would be "indirectly exposed" to wildfire. The value of Exposure Type in these areas is between 1 and 0, varying by distance to burnable fuels, with pixel values decreasing toward 0 as they get further from burnable fuel. 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 structure would have little-to-no exposure to wildfire due to its distance from a large contiguous patch of burnable vegetation.

Housing Unit Count (HUCount)

Housing Unit count is a 30-m raster representing the number of housing units in each pixel. It is produced to facilitate data analysis (summarizing housing unit count for any geography) rather than map display (Housing Unit Density is preferred for map display). HUCount was generated from the U.S. Census Bureau redistricting data from 2020 and the building footprint data from the Qualifying Building Footprint Dataset filtered by protected areas. For details, see the WRC 2.0 companion paper describing populated areas datasets (Jaffe et al. 2024).

Methods for Creating Community Wildfire Risk Reduction Zones

The approach we took to create the CWiRRZ was to map wildfire exposure surrounding buildings and delineate an area around building clusters (groups of buildings of a specified density, further defined below) where wildfire may pose a threat to communities. The process involved a set of geoprocessing steps described below and diagrammed in Figure 2.

Step 1: Create Exposure Zones

a. ***Remove additional potentially erroneously mapped buildings***

Though the protected areas mask removed many of the false positives in the Qualified Building Footprints (QBF) dataset, while examining the filtered QBF points against aerial imagery, we found that buildings were also mapped erroneously on lands outside of protected areas. Assuming that true buildings are not likely to exist far from roads and populated areas, we further minimized false positives by employing the following logic: Building Count pixels were eliminated if they were greater than 500 m from a road or greater than 2400 m from a housing unit as mapped in the HUCount raster. There is no way to guarantee that 500 m adequately represents the distance beyond which true buildings could exist; however, we found that 80% of mapped potential buildings on all land jurisdictions (99% on private lands) were within 500-m of a road, and that distance seemed reasonable based on visual comparisons of true buildings with aerial imagery. We chose to exclude mapped buildings greater than 2400 m from HUCount pixels with at least 1 housing unit because that distance is consistent with the buffer distance we selected to define the area around a community within which to summarize wildfire risk metrics (see Tabular Summaries section below).

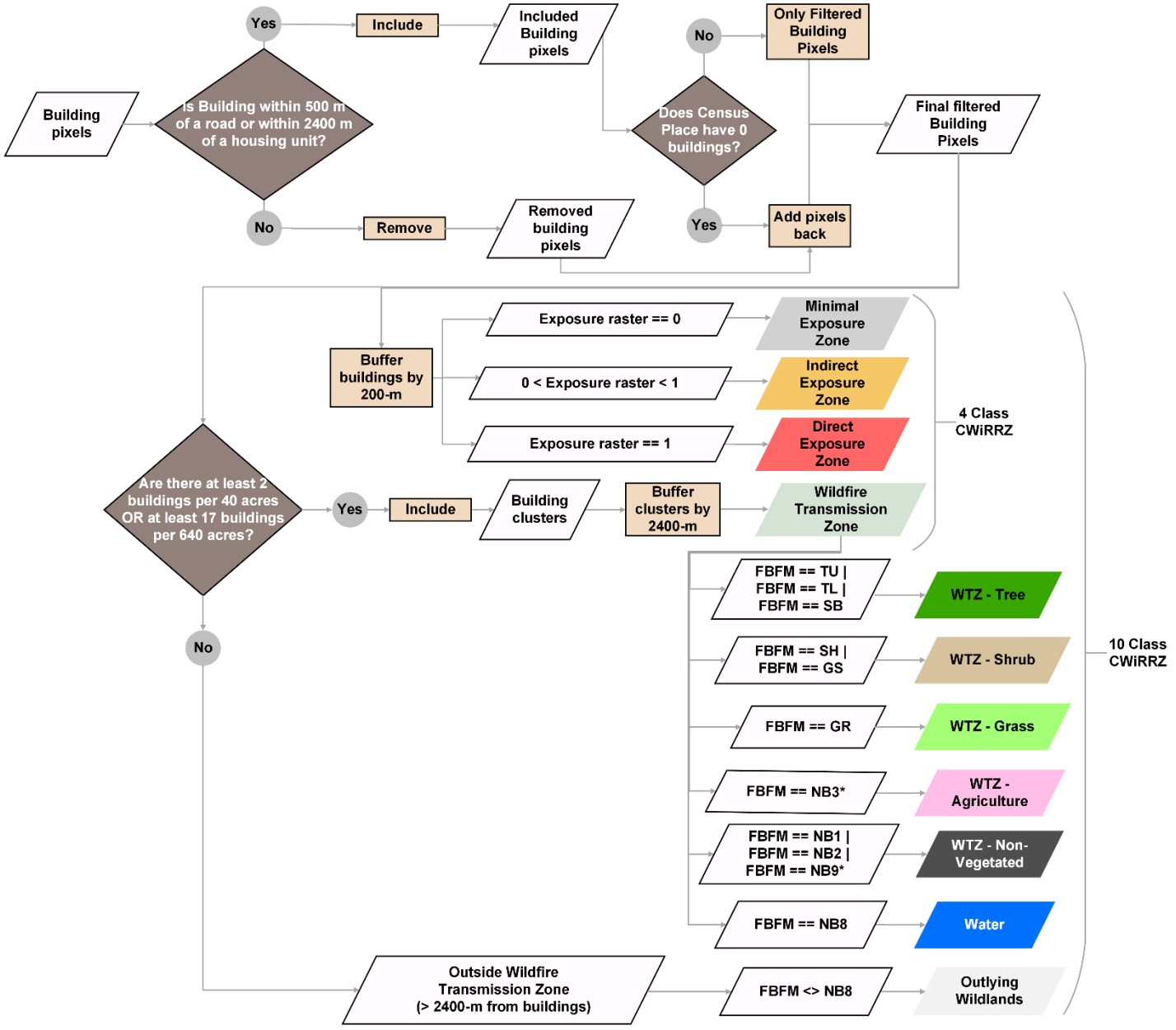

Figure 2. Community Wildfire Risk Reduction Zones geoprocessing workflow.

b. Restore potential buildings within Census Places

Because Step 1.a. removed several building pixels that were true buildings, we checked to see if any Census Designated Places (CDPs) had no buildings after that step, and if so, we added them back into the set of filtered building pixels within that CDP. This ensured that buildings were included within communities where roads were sparsely mapped, and Census data did not adequately count population.

c. Create exposure area around buildings

We buffered filtered buildings by 200 m to approximate an exposure area (~30 acres) surrounding structures where wildfire risk reduction actions may be warranted. This area represents a conservative home ignition zone around buildings where the exposure type is characterized.

d. Characterize exposure zones

Within the buffered area surrounding buildings, we reclassified the Exposure Type raster where:

Exposure Type is 0 = Minimal Exposure,

Exposure type is between 0 and 1 = Indirect Exposure, and

Exposure Type is 1 = Direct Exposure.

We then used a 200-m radius moving window majority filter on the classified Exposure Types to define boundaries between exposure zones and represent the influence of adjacent fuels on a pixel's exposure type. For instance, a road may be mapped as having indirect or minimal exposure due to being non-burnable; however, if it is completely surrounded by wildland fuels, the pixel will take on the Direct Exposure class to show the influence of these adjacent fuels. To maintain the spatial precision of the Direct Exposure class, we returned pixels originally in the Direct Exposure class to Direct Exposure in the final exposure zone raster.

Step 2: Create Wildfire Transmission Zone

a. Identify building clusters

Though we built an exposure zone around every building across the landscape, the Wildfire Transmission Zone is created only around building clusters. This decision aligns with the Wildland Urban Interface definition[9] wherein WUI is classified in areas with densities greater than 1 building per 40 acres. This density threshold is a very conservative representation of where multiple adjacent structures can face a collective threat from wildfire and where collective mitigation actions will be required.

To implement this logic, we created a raster processing mask extending from buildings where either of the following conditions apply:

[9] "Urban Wildland Interface within the vicinity of federal lands that are at high risk from wildfire." (Notice). Federal Register 66:3(January 4, 2001): 751-777.

1. A building is within a 227 m radius of one or more buildings,

   OR

2. A building is within a 908 m radius of 16 or more buildings.

Both conditions, when implemented in a raster focal sum operation, generated an area around a building equivalent to 1 building per 40 acres, however the first condition captured buildings that are within 40 acres of another building but in an otherwise sparsely populated area, while the second condition captured buildings near the edges of more densely populated areas. We combined the masks created from these two conditions and selected buildings that fell within the combined area as the starting point from which to build the Wildfire Transmission Zone. We identify the buildings selected with this process as belonging to a "building cluster", as each one is in a group with other buildings. Our intention with this approach was to select buildings inclusively, while aligning with how the Federal Register classifies low housing density.

b. *Create buffer surrounding building clusters*

From the building clusters selected in Step 2.a., we created a 2.4 km buffer to delineate the Wildfire Transmission Zone.

Step 3: Create CWiRRZ Product

The CWiRRZ raster product included in the data publication can be displayed in two ways:

- 4-class CWiRRZ – This raster includes the three exposure zones and the entire Wildfire Transmission Zone mapped with a single value.
- 10-class CWiRRZ – This raster includes the three exposure zones and separate values for each of the fuel categories in the Wildfire Transmission Zone. It also includes the Outlying Wildlands and Water categories.

a. *Define fuel categories within Wildfire Transmission Zone*

Several geoprocessing steps were required to define each of the categories within the Wildfire Transmission Zone (WTZ):

1. **WTZ-Tree** is mapped as the area 200m – 2400m from building clusters, where LANDFIRE FBFM40 is equal to either a Timber Understory (161, 162, 163, 164, 165), Timber Litter (181, 182, 183, 184, 185, 186, 187, 188, 189), or Slash-Blowdown (201, 202, 203, 204) fuel model.
2. **WTZ-Shrub** is mapped as the area 200m – 2400m from building clusters, where LANDFIRE FBFM40 is equal to either a Grass-Shrub (121, 122, 123, 124) or Shrub (141, 142, 143, 144, 145, 146, 147, 148, 149) fuel model.
3. **WTZ-Grass** is mapped as the area 200m – 2400m from building clusters, where LANDFIRE FBFM40 is equal to a Grass fuel model (101, 102, 103, 104, 105, 106 ,107, 108, 109).
4. **WTZ-Agriculture** is mapped as the area 200m – 2400m from building clusters, where LANDFIRE FBFM40 is equal to the non-burnable Agricultural fuel model (93); or where

exposure is minimal, FBFM40 is 93, and there are no buildings. The second part of this mapping rule eliminated areas of minimal exposure around buildings surrounded by larger regions of non-burnable agriculture, resulting in a more conservative and intuitive characterization for this Wildfire Transmission Zone category.

5. **WTZ-Non-Vegetated** is mapped as the area 200m – 2400m from building clusters, where LANDFIRE FBFM40 is equal to a non-burnable Urban, Snow/Ice, or Barren fuel model (91, 92, 99); or where exposure is minimal, FBFM40 is either 91, 92, or 99, there are no buildings, and the majority of pixels within a 200 m radius are non-burnable Agriculture. The second part of this mapping rule is a minor fix that maintains logical consistency by stamping in the WTZ-Non-Vegetated class where Minimal Exposure pixels are surrounded by agriculture.

b. Delineate ancillary zones

1. **Outlying Wildlands** is mapped as the area beyond 2400 m from building clusters, where an Exposure Zone is not assigned, or water is not present.

2. **Water** is mapped as any area where LANDFIRE FBFM40 is water (98).

c. Create final raster

The final step in creating the CWiRRZ product is to stamp the Exposure Zone raster on top of the Wildfire Transmission Zone and ancillary zones resulting in a raster with the final classes. A raster attribute table was created so a 4-class version can be displayed where the Wildfire Transmission Zone is a single class and Outlying Wildlands and Water are set to NA. The following is the raster attribute table for the final TIFF:

10 Class CWiRRZ			4 Class CWiRRZ		
Value	**Name**	**Abbr.**	**Value**	**Name**	**Abbr.**
0	Minimal Exposure	ME	0	Minimal Exposure	ME
1	Indirect Exposure	IE	1	Indirect Exposure	IE
2	Direct Exposure	DE	2	Direct Exposure	DE
3	Wildfire Transmission Zone: Tree	WTZ_T	3	Wildfire Transmission Zone	WTZ
4	Wildfire Transmission Zone: Shrub	WTZ_S	3	Wildfire Transmission Zone	WTZ
5	Wildfire Transmission Zone: Grass	WTZ_G	3	Wildfire Transmission Zone	WTZ
6	Wildfire Transmission Zone: Agriculture	WTZ_A	3	Wildfire Transmission Zone	WTZ
7	Wildfire Transmission Zone: Non-Vegetated	WTZ_N	3	Wildfire Transmission Zone	WTZ
8	Outlying Wildlands	OW	NA	NA	NA
9	Water	W	NA	NA	NA

Methods for Tabular Summaries

Overview of Summary Methods and Differences from WRC 1.0

A key aspect of the WRC website is the summary of wildfire risk by jurisdictions – states, counties, tribal areas, and communities. For WRC 1.0, we calculated these summaries as housing unit weighted means within the political boundaries of the different jurisdictions. Using this approach, we summarized risk

only where Housing Unit Density is greater than zero, focusing in on the location of homes and the surrounding 200-m radius area used in creating the density raster. As we subsequently began considering how summaries would be used in the Community Wildfire Defense Grant (CWDG) program, we realized that including broader spatial context that captures the hazard characteristics of the surrounding landscape would be helpful. For the new summaries in WRC 2.0, we shifted to summarizing hazard and risk within three zones defined in the CWiRRZ: the Indirect Exposure Zone, Direct Exposure Zone, and Wildfire Transmission Zone. To capture the full extent of these zones relative to any jurisdiction, we include all area within these three zones that is within 2.4 km of the jurisdictional boundary (Figure 3)[10]. This results in overlapping summary areas for neighboring jurisdictions, but means that the wildfire hazard within 2.4 km of all buildings in any jurisdiction is considered in its summary statistics.

The metrics reported in the WRC 2.0 tables are also land area based rather than weighted by housing units as in the previous version. This means that averages for this version were calculated with all pixels within the summary area weighted evenly, as opposed to previous calculations that were weighted by the relative housing-unit density at each pixel. As expected, based on these differences in calculation methods, summary statistics computed for variables in WRC 2.0 differ from those calculated for WRC 1.0. For example, the mean absolute deviation for National Risk to Potential Structures (RPS) percentiles is 12.8, 11.1 and 9.9 points for census places, counties, and states respectively (Figure 4).

Summary Polygons

We generated wildfire hazard and risk statistics for four nationwide sets of jurisdictional boundaries – states, counties, tribal areas, and communities.

States

There are 51 polygons in the "States" set of polygons – 50 states plus the District of Columbia. We used the U.S. Census Bureau's 2022 States and Equivalent Entities TIGER/Line Shapefile dataset to delineate U.S. states.

Counties

There are 3,144 polygons in the "Counties" set of polygons, excluding District of Columbia. We used the U.S. Census Bureau's 2022 Counties and Equivalent Entities TIGER/Line Shapefile dataset to delineate counties (and equivalent) covering the 50 U.S. states.

Tribal Areas

There are 736 polygons in the Tribal Areas set of polygons. We used the U.S. Census Bureau's 2022 American Indian/Alaska Native/Native Hawaiian Areas (AIANNH) TIGER/Line Shapefiles. These files include Federal American Indian Reservations, Off-Reservation Trust Lands (ORTL), State American Indian Reservations, Hawaiian Home Lands (HHL), Alaska Native Village Statistical Areas (ANVSA), Oklahoma Tribal Statistical Areas (OTSA), State Designated Tribal Statistical Areas (SDTSA), Tribal Designated Statistical Areas (TDSA), American Indian Joint-Use Areas (AIJUA), and Joint-Use Oklahoma Tribal Statistical Areas. For WRC, tribal areas that cross state boundaries are divided by

[10] States are the one exception to this. Summaries for states are within the state boundary.

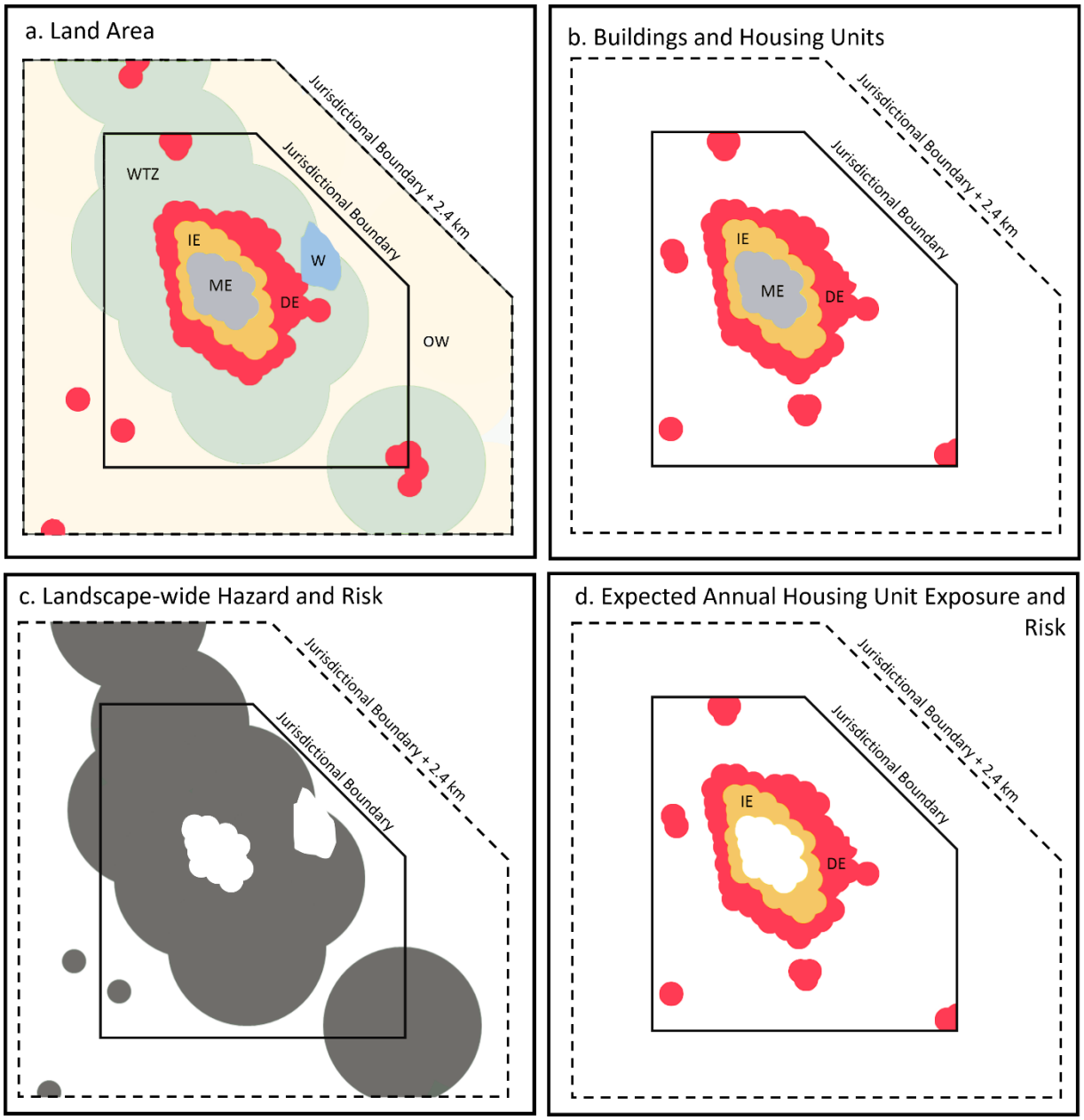

Figure 3. Summary zones for four categories of Wildfire Risk to Community tabular metrics: a. Land Area, b. Buildings and Housing Units, c. Landscape-Wide Hazard and Risk, and d. Expected Annual Housing Unit Exposure and Risk.

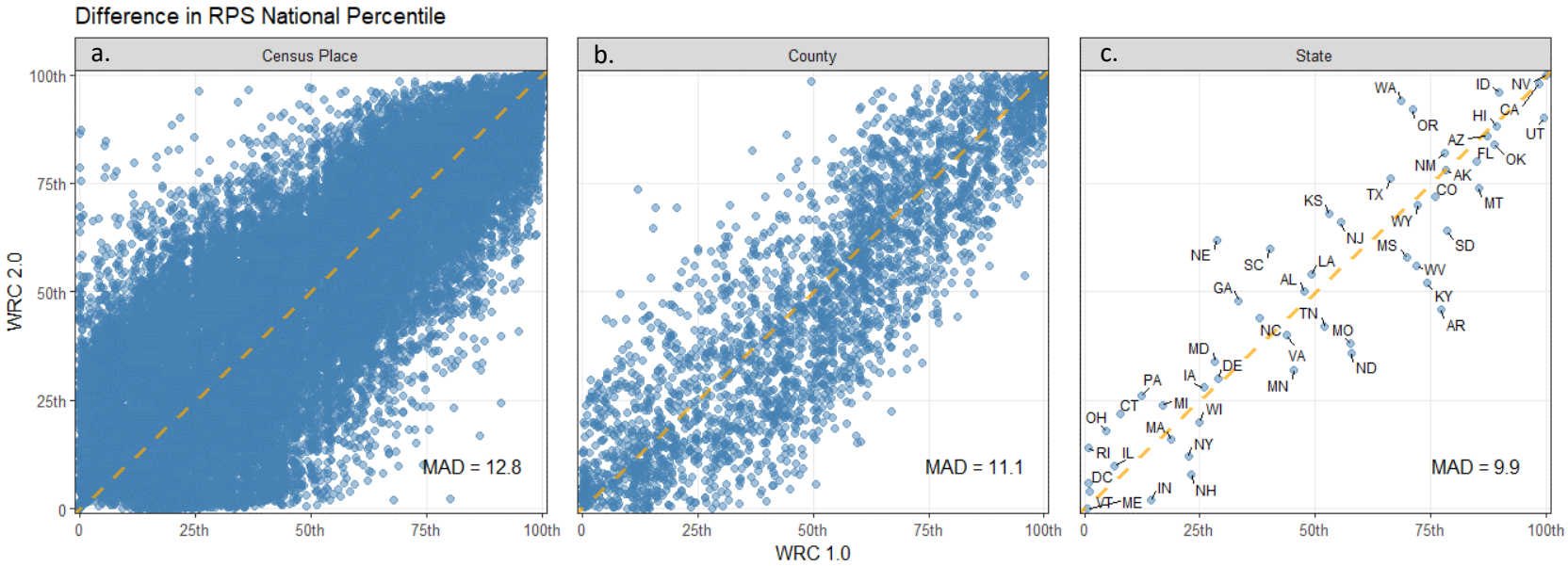

Figure 4. The national Risk to Potential Structures (RPS) percentile rankings for WRC 2.0 are plotted against WRC 1.0 for Census Places, Counties, and States. Each blue point is a community (a.), county (b.), or state (c.), and the dashed orange line is a 1:1 line. The Mean Absolute Deviation (MAD) is 12.8, 11.1, and 9.9 percentile points respectively, showing the average difference between the summarized RPS in the two WRC versions.

state and listed separately for each state they overlap. We were unable to calculate summaries for 99 Tribal Area polygons due to insufficient population or building data. Percentile rankings for Tribal Areas were calculated with counties and tribal areas included in the data distribution.

Communities

We used the U.S. Census Bureau's 2022 Places TIGER/Line Shapefile dataset to represent communities. A census populated place can be an incorporated area (city, town, etc.) or a Census Designated Place (CDP). There are 31,895 places across the 50 U.S. states. We were unable to calculate summaries for 451 CDP polygons due to insufficient population or building data.

Summary Field Descriptions

Each set of summary polygons has certain attributes that originated with the source data. We retained those fields in the final database in case users need that information. In addition, we summarized the WRC raster datasets to produce the following additional fields that characterize a community's exposure to wildfire. There are four categories of metrics: Land Area, Buildings and Housing Units, Landscape-Wide Hazard and Risk, and Expected Annual Housing Unit Exposure and Risk, each of which are calculated within different zones (Figure 3).

Category 1: Land Area

- **Total Land Area (acres):** The total land area (acres) within the buffered jurisdictional boundary.
- **Percentage of Land Area in the Minimal Exposure Zone:** Percentage of the total land area within the buffered jurisdictional boundary that is in the Minimal Exposure Zone.
- **Percentage of Land Area in the Indirect Exposure Zone:** Percentage of the total land area within the buffered jurisdictional boundary that is in the Indirect Exposure Zone.
- **Percentage of Land Area in the Direct Exposure Zone:** Percentage of the total land area within the buffered jurisdictional boundary that is in the Direct Exposure Zone.
- **Percentage of Land Area in the Wildfire Transmission Zone:** Percentage of the total land area within the buffered jurisdictional boundary that is in the Wildfire Transmission Zone.
- **Percentage of Land Area in Outlying Wildlands:** Percentage of the total land area within the buffered jurisdictional boundary that is not in any of the mapped risk reduction zones.
- **Percentage of Land Area as Water:** Percentage of the total land area within the buffered jurisdictional boundary that is water.

Category 2: Buildings and Housing Units

- **Total number of Buildings (BU_{total}):** Total number of Qualifying Buildings filtered to remove buildings within the protected areas mask that are within the jurisdictional boundary (not buffered).
- **Percentage of Total Buildings Minimally Exposed ($\%BU_{ME}$):** Percentage of the total number of Qualifying Buildings filtered to remove buildings within the protected areas mask that are within the jurisdictional boundary that are in the Minimal Exposure Zone.

$$\%BU_{ME} = \frac{BU_{ME}}{BU_{total}} \times 100$$

Where BU_{ME} = Number of Buildings Minimally Exposed

- **Percentage of Total Buildings Indirectly Exposed (%BU_{IE}):** Percentage of the total number of Qualifying Buildings filtered to remove buildings within the protected areas mask that are within the jurisdictional boundary that are in the Indirect Exposure Zone.

$$\%BU_{IE} = \frac{BU_{IE}}{BU_{total}} \times 100$$

Where BU_{IE} = Number of Buildings Indirectly Exposed

- **Percentage of Total Buildings Directly Exposed (%BU_{DE}):** Percentage of the total number of Qualifying Buildings filtered to remove buildings within the protected areas mask that are within the jurisdictional boundary that are in the Direct Exposure Zone.

$$\%BU_{DE} = \frac{BU_{DE}}{BU_{total}} \times 100$$

Where BU_{DE} = Number of Buildings Directly Exposed

- **Total number of Housing Units (HU_{total}):** Total number of housing units (identified in the Housing Unit Count raster) within the jurisdictional boundary (not buffered).

- **Percentage of Total Housing Units Minimally Exposed (%HU_{ME}):** Percentage of the total number of housing units (identified in the Housing Unit Count raster) within the jurisdictional boundary that are in the Minimal Exposure Zone.

$$\%HU_{ME} = \frac{HU_{ME}}{HU_{total}} \times 100$$

Where HU_{ME} = Number of Housing Units Minimally Exposed

- **Percentage of Total Housing Units Indirectly Exposed (%HU_{IE}):** Percentage of the total number of housing units (identified in the Housing Unit Count raster) within the jurisdictional boundary that are in the Indirect Exposure Zone.

$$\%HU_{IE} = \frac{HU_{IE}}{HU_{total}} \times 100$$

Where HU_{IE} = Number of Housing Units Indirectly Exposed

- **Percentage of Total Housing Units Directly Exposed (%HU_{DE}):** Percentage of the total number of housing units (identified in the Housing Unit Count raster) within the jurisdictional boundary that are in the Direct Exposure Zone.

$$\%HU_{DE} = \frac{HU_{DE}}{HU_{total}} \times 100$$

Where HU_{DE} = Number of Housing Units Directly Exposed

Category 3: Landscape-Wide Hazard and Risk

- **Mean Burn Probability (BP):** The arithmetic mean of annual burn probability values across all pixels in the Direct, Indirect and Wildfire Transmission zones within the buffered jurisdictional boundary. Pixels in the Minimal Exposure Zone or those not in any mapped risk reduction zone

are excluded from this calculation. BP is referred to as Wildfire Likelihood in the Wildfire Risk to Communities web application.

- **Mean BP Percentile within state:** The percentile rank of a summary polygon's mean BP within its state. The percentile rank of a summary polygon is calculated as the percent of polygons within the state that have a mean BP value less than or equal to this polygon's mean BP value. This field applies to the county and community summaries; it is not applicable for the statewide summaries.

- **Mean BP Percentile within nation:** The percentile rank of a summary polygon's mean BP within the nation. The percentile rank of a summary polygon is calculated as the percent of polygons within the nation that have a mean BP value less than or equal to this polygon's mean BP value.

- **Mean Conditional Risk to Potential Structures (cRPS):** The arithmetic mean of Conditional Risk to Potential Structures (cRPS) values across all pixels in the Direct, Indirect, and Wildfire Transmission Zones, within the buffered jurisdictional boundary. The cRPS raster represents the potential consequences of fire to a home or other structure in a given pixel if a fire were to occur there and if a home were located there. It is a measure that integrates the expected range of wildfire intensities with generalized consequences to a structure on every pixel but does not account for the annual probability of fire occurrence. Because cRPS uses a consistent response function, it does not reflect any changes to wildfire intensity afforded by efforts to mitigate individual structures.

- **Mean cRPS Percentile within state:** The percentile rank of a summary polygon's mean cRPS within its state. The percentile rank of a summary polygon is calculated as the percent of polygons within the state that have a mean *c*RPS value less than or equal to this 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:** The percentile rank of a summary polygon's mean cRPS within the nation. The percentile rank of a summary polygon is calculated as the percent of polygons within the nation that have a mean RPS value less than or equal to this polygon's mean cRPS value.

- **Mean Risk to Potential Structures (RPS):** The arithmetic mean of Risk to Potential Structures (RPS) values across all pixels in the Direct, Indirect, and Wildfire Transmission Zones, within the buffered jurisdictional boundary. For every pixel on the landscape, the RPS raster poses the hypothetical question, "What would be the relative risk to a structure if one existed here?" It integrates wildfire likelihood and general consequences of fire on homes and other structures as a function of fire intensity. Because RPS uses a consistent, response function it does not reflect any changes to susceptibility afforded by efforts to mitigate individual structures. RPS is referred to as Risk to Homes in the Wildfire Risk to Communities web application.

- **Mean RPS Percentile within state:** The percentile rank of a summary polygon's mean RPS within its state. The percentile rank of a summary polygon is calculated as the percent of polygons within the state that have a mean RPS value less than or equal to this 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:** The percentile rank of a summary polygon's mean RPS within the nation. The percentile rank of a summary polygon is calculated as the percent of

polygons within the nation that have a mean RPS value less than or equal to this polygon's mean RPS value.

- **Mean Wildfire Hazard Potential (WHP):** The arithmetic mean of Wildfire Hazard Potential (WHP) values across all pixels in the Direct, Indirect, and Wildfire Transmission Zones, within the buffered jurisdictional boundary. WHP 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)
- **Mean WHP Percentile within state:** The percentile rank of a summary polygon's mean WHP within its state. The percentile rank of a summary polygon is calculated as the percent of polygons within the state that have a mean WHP value less than or equal to this polygon's mean WHP value. This field applies to the county and community summaries; it is not applicable for the statewide summaries.
- **Mean WHP Percentile within nation:** The percentile rank of a summary polygon's mean WHP within the nation. The percentile rank of a summary polygon is calculated as the percent of polygons within the nation that have a WHP value less than or equal to this polygon's mean WHP value.

Category 4: Expected Annual Exposure and Risk

- **Expected Annual Housing Units Exposed ($EAHUexp_{Tot}$):** $EAHUexp_{Tot}$ 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. This metric is derived from the Housing Unit Exposure (HUExposure) raster that depicts the expected annual number of housing units within a pixel potentially exposed to wildfire. Those values are calculated as the product of wildfire likelihood and housing unit count at each pixel (see Jaffe et al. 2024 for more details). To calculate $EAHUexp_{Tot}$ we take the sum of HUExposure pixel values within the Indirect and Direct Exposure Zones within the unbuffered jurisdictional boundary.
- **Expected Annual Housing Units Exposed percentile within state:** The percentile rank of a summary polygon's $EAHUexp_{Tot}$ within its state. The percentile rank of a summary polygon is calculated as the percent of polygons within the state that have a $EAHUexp_{Tot}$ value less than or equal to this polygon's $EAHUexp_{Tot}$ value. This field applies to the county and community summaries; it is not applicable for the statewide summaries.
- **Expected Annual Housing Units Exposed percentile within nation:** The percentile rank of a summary polygon's $EAHUexp_{Tot}$ within the nation. The percentile rank of a summary polygon is calculated as the percent of polygons within the nation that have a $EAHUexp_{Tot}$ value less than or equal to this polygon's $EAHUexp_{Tot}$ value.
- **Percentage of Expected Annual Housing Units Exposed – Indirect ($\%EAHUExp_{IE}$):** Percentage of total expected annual housing units exposed within the jurisdictional boundary that are in the Indirect Exposure Zone.

$$\%EAHUexp_{IE} = \frac{EAHUexp_{IE}}{EAHUexp_{Tot}} \times 100$$

Where $EAHUexp_{IE}$ is the number of housing units within a summary polygon expected to be indirectly exposed to wildfire in a year.

- **Percentage of Expected Annual Housing Units Exposed – Direct (%$EAHUexp_{DE}$):** Percentage of total expected annual housing units exposed within the jurisdictional boundary that are in the Direct Exposure Zone.

$$\%EAHUexp_{DE} = \frac{EAHUexp_{DE}}{EAHUexp_{Tot}} \times 100$$

Where $EAHUexp_{DE}$ is the number of housing units within a summary polygon expected to be directly exposed to wildfire in a year.

- **Expected Annual Housing Unit Risk ($EAHUrisk_{Tot}$):** $EAHUrisk_{Tot}$ 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 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. This metric is derived from the Housing Unit Risk (HURisk) raster that integrates all four primary elements of wildfire risk - likelihood, intensity, susceptibility, and exposure - on pixels where housing unit density is greater than zero. The HURisk raster is calculated as the product of Risk to Potential Structures (RPS) and Housing Unit Count. (see Jaffe et al. 2024 for more details). To calculate $EAHUrisk_{Tot}$ we take the sum of HURisk pixel values within the Indirect and Direct Exposure Zones within the unbuffered jurisdictional boundary.

- **Expected Annual Housing Unit Risk percentile within state:** The percentile rank of a summary polygon's $EAHUrisk_{Tot}$ within its state. The percentile rank of a summary polygon is calculated as the percent of polygons within the state that have a $EAHUrisk_{Tot}$ value less than or equal to this polygon's $EAHUrisk_{Tot}$ value. This field applies to the county and community summaries; it is not applicable for the statewide summaries.

- **Expected Annual Housing Unit Risk percentile within nation:** The percentile rank of a summary polygon's $EAHUrisk_{Tot}$ within the nation. The percentile rank of a summary polygon is calculated as the percent of polygons within the nation that have a $EAHUexp_{Tot}$ value less than or equal to this polygon's $EAHUrisk_{Tot}$ value.

- **Percentage of Expected Annual Housing Unit Risk – Indirect (%$EAHUExp_{IE}$):** Percentage of the total expected annual housing unit risk within the jurisdictional boundary that is in the Indirect Exposure Zone.

$$\%EAHUrisk_{IE} = \frac{EAHUrisk_{IE}}{EAHUrisk_{Tot}} \times 100$$

Where $EAHUrisk_{IE}$ is the expected annual relative housing-unit risk for a summary polygon within the Indirect Exposure Zone.

- **Percentage of Expected Annual Housing Unit Risk – Direct (%$EAHUexp_{DE}$):** Percentage of the total expected annual housing unit risk within the jurisdictional boundary that is in the Direct Exposure Zone.

$$\%EAHUrisk_{DE} = \frac{EAHUrisk_{DE}}{EAHUrisk_{Tot}} \times 100$$

Where $EAHUrisk_{DE}$ is the expected annual relative housing-unit risk for a summary polygon within the Direct Exposure Zone.

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