UrbanFootprint

TECHNICAL DOCUMENTATION

UrbanFootprint Wildfire Probability and Loss Methodology

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Overview

Wildfire is an unplanned and unwanted fire burning in a natural area. Wildfires can spread to developed lands and pose a severe risk to life and property. The US has seen a billion-dollar wildfire disaster every year since 2015. Wildfires such as Los Angeles, Lahaina, Marshall, and Paradise have wiped out entire communities and seen unprecedented losses of life and property. Disasters such as these may become more common due to a mix of factors such as global warming and the expansion of development into the wildland-urban interface. UrbanFootprint addresses the need of organizations to capture the risk of wildfire by geospatially intersecting the best available models of wildfire risk (the Wildfire Risk to Communities datasets produced by the USDA Forest Service) with the people and property that are threatened. UrbanFootprint ingests publicly available wildfire risk datasets and intersects them with the people and property that are threatened. We estimate risk of financial loss due to wildfire by applying structure independent damage functions from the USFS that estimate relative risk to structures. This ground up approach allows for aggregating risk on arbitrary geometries. We compare our estimates to FEMA National Risk Index at the county level and find very close agreement in the estimated annual loss to buildings (EALB) between these datasets.

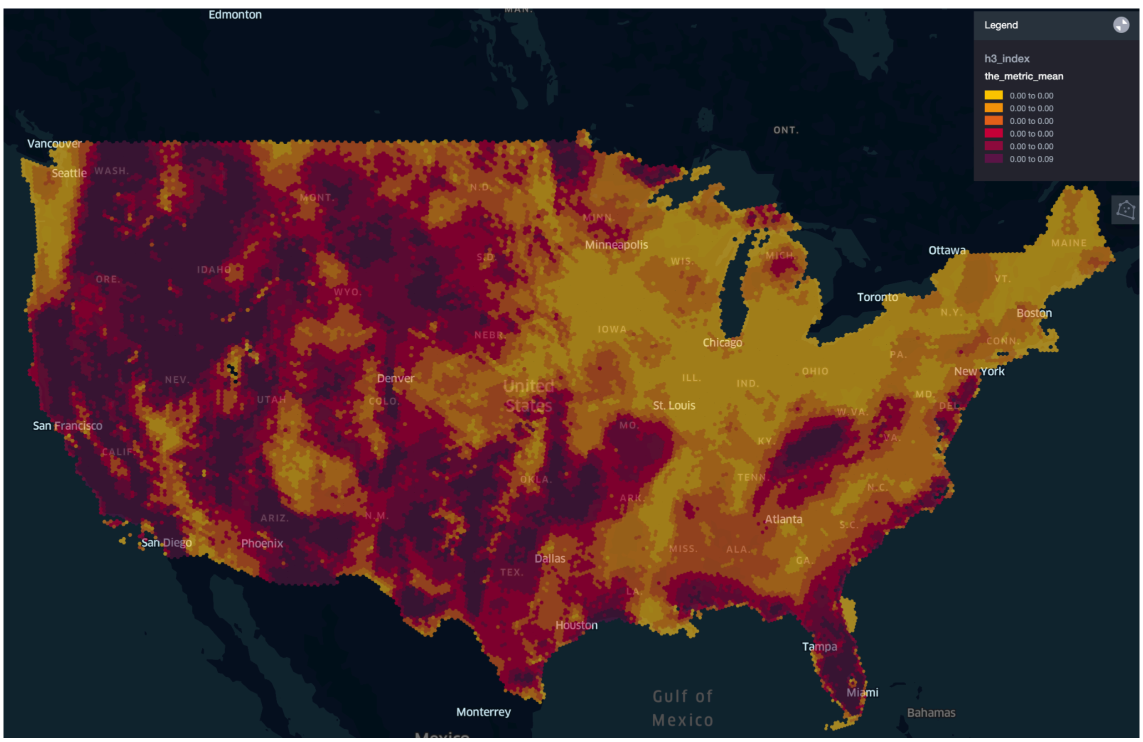

Figure 1. Current burn probability at H3 Zoom Level 5 across the contiguous United States.

Wildfire Methodology

We use Wildfire Risk to Communities, a high-resolution (270 x 270 m), vetted national dataset of fire risk that includes 8 layers that give different perspectives on fire risk. The layer methodologies describe how each layer was calculated. Specifically, the layers include:

- **Risk to potential structures (RPS)**
  - A measure that combines wildfire intensity and likelihood and answers the question, "What would be the relative risk to a house if one existed here?". The metric is given as a *national percentile rank*.
- **Burn probability (BP)**
  - Annual *probability* of wildfire burning at a specific location.
- **Exposure type (Exposure)**
  - *Categorical* variable (direct, indirect, or not exposed) indicating exposure to wildfire from adjacent wildlands.
- **Conditional risk to potential structures (CRPS)**
  - National *percentile rank* of wildfire impact if a fire occurs and if a structure were to exist at that location.
- **Conditional flame length (CFL)**
  - Most likely flame length (in feet) at a given location if a fire occurs. This is a measure of wildfire *intensity* or severity.
- **Flame length exceedance probability 4ft (and 8ft) (FLEP4, FLEP8)**
  - *Probability* of having flame lengths greater than 4ft (and 8ft) if a fire occurs. This indicates the potential for moderate to high wildfire intensity.
- **Wildfire hazard potential (WHP)**
  - A *categorical* risk level ranging from "very low" to "very high".

Wildfire Metrics

To quantify the risk of population, household, job and property exposure to wildfire, UrbanFootprint utilizes the annualized burn probabilities at severities of 0ft, 4ft, and 8ft. We resample the Wildfire Risk to Communities datasets on H3 grid cells at Zoom level 9, which is the most similar H3 resolution to the source data. We use mean values for burn probability, risk to potential structures, and flame length exceedance probabilities for 4 and 8ft. The mean burn probability represents the likelihood of a wildfire burning at any length greater than 0 feet. Using the burn probability along with the (conditional) flame length exceedance probabilities, we can calculate the probability of wildfire exceedance for moderate severity wildfires (4 foott flame lengths) and high severity wildfires (8 foot flame lengths):

- Probability of wildfire with flames exceeding 4 ft = BP (burn probability) x FLEP4 (flame length exceedance probability 4ft)
- Probability of wildfire with flames exceeding 8 ft = BP (burn probability) x FLEP8 (flame length exceedance probability 8ft).

Extrapolating to Different Time Horizons and Climate Scenarios

Wildfire Risk to Communities datasets are current scenario estimates and lack information on future changes to wildfire risk in the future due to climate change. However, the literature suggests a strong correlation between high temperatures and increased burn probabilities in future.

For example, Peng Gao et al. in Robust projections of future fire probability for the conterminous United States project wildfire risk changes over CONUS using the Physical Chemistry Fire Frequency Model (PC2FM) under two RCP scenarios (4.5 and 8.5). Their research suggests nearly universal increases in wildfire probability at mid-century under both RCP scenarios driven primarily by higher temperatures. While existing high-risk areas, such as the Cascades, Rocky Mountains, Coastal California Mountains and Sierra Nevadas, are projected to experience greater annual fire occurrence probabilities, regions not currently associated with frequently occurring wildfires, such as New England and the Great Lakes, are projected to experience a doubling of occurrence probabilities by 2100 under RCP 8.5.

Karin L. Riley and Rachel A. Loehman in Mid-21st-century climate changes increase predicted fire occurrence and fire season length, Northern Rocky Mountains, United States look at projected changes in annual burn probability in Idaho using the large fire simulation model FSIM and modifying weather data based on project mid-century climate averages. They find that annual burn probability increases by approximately 50% by ~2045 (see their Table 1 on page 10) due to warmer temperatures and longer fire seasons. Aurora A. Gutierrez, et al. in Wildfire response to changing daily temperature extremes in California's Sierra Nevada reviews historical fire data in the Sierra Nevada from 2001 to 2020, finding that higher summer temperatures are driving changes, with a 1°C increase leading to a 19-22% increase in fire occurrence. Under projected climate change the authors find a more than 50% increase by 2050 in the Sierras relative to the 2010s.

To provide future wildfire risk estimates, UrbanFootprint scales the current probabilities for different severity thresholds based on LOCA downscaled temperature data. In particular, given the literature findings suggesting that the major driver of future fire risk is from increasing temperature, we extrapolate current risk probabilities using the forecasted number of days over 95°F. We identified this threshold as an approximate breakpoint above which the likelihood of significant fire activity increases substantially. We apply the empirical function

$$P_{\text{scenario}} = P_{\text{current}} \times \min\left(1 + \left(\frac{t_{\text{scenario}} + 1}{t_{\text{historical}} + 1} - 1\right) \times \frac{1}{19.4}, 2.25\right)$$

where

- P_{scenario} is the burn probability in scenario, expressed as a decimal,
- t_{scenario} is the number of days above 95F in scenario, and
- $t_{\text{historical}}$ in the number of days historically above 95°F,

for scenario time periods 2030 and 2050 under climate scenarios SSP2-4.5 and SSP5-8.5. Comparing results from the extrapolation to published maps of future annual fire probability, such as Gao et al. (2021), we see similar spatial patterns in future risk (Figure 2b).

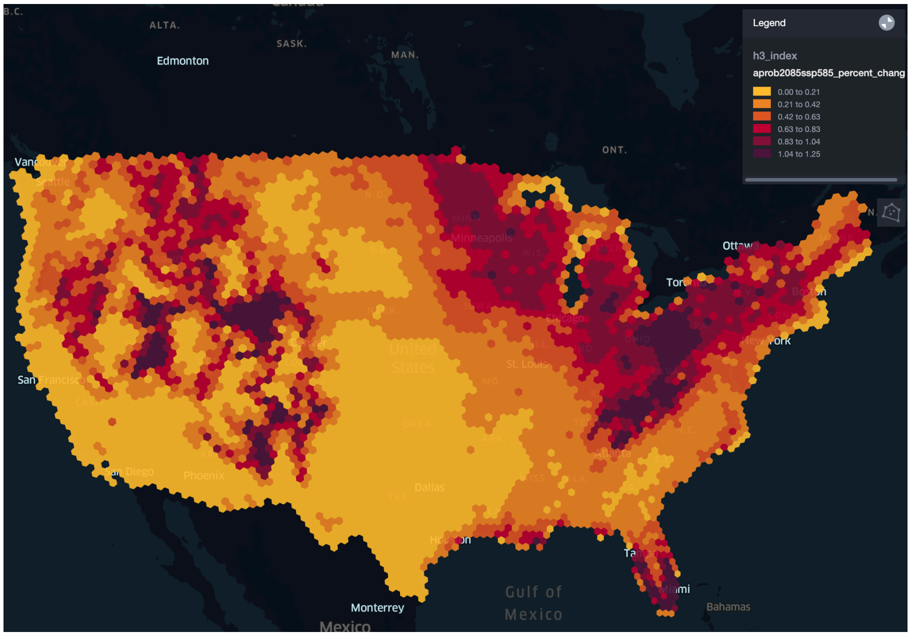

Figure 2. UrbanFootprint's estimated increase in annual probability of wildfire in 2085 under SSP5-8.5 based on increasing temperature.

Quantifying Exposure

To quantify wildfire risk exposure, we intersect the wildfire risk metrics with the UrbanFootprint parcel Base Canvas. Parcels may be exposed to different risk probabilities. UrbanFootprint provides a conservative estimate of risk by assigning the parcel the most adverse risk to which it is exposed. For example, if a parcel spans two grid cells with 1% and 2% annual burn probabilities, the parcel will be assigned a value of 2%. We aggregate these adverse probabilities at different census geographies to get the estimated mean wildfire risk exposure and use Base Canvas parcel-level data, such as property value, estimated population or employment, to quantify the annualized exposure of property value, people and jobs to different severities of wildfire.

Loss Methodology

Wildfire risk to communities provides a column called 'Risk to potential structures' (RPS), which is a "measure that integrates wildfire likelihood and intensity with generalized consequences to a home on every pixel". It calculates the annualized structural damage fraction by multiplying the annual burn probability and the conditional structural damage derived from the flame length probabilities. UrbanFootprint utilizes RPS as an annualized structural damage metric and calculates annualized loss (EALB) by multiplying this value by the parcel assessed improvement value. Per USDA Forest Service, this is a measure of 'generalized consequences', and as such is not structure dependent. Actual wildfire damage to a structure depends on several structure and landscaping factors that make some structures more likely to burn than others. This structure-agnostic metric serves as a starting point to understand damage from wildfires.

To estimate future wildfire damage and structural loss, we make the naive assumption that future vegetation, and thus conditional flame length distributions, remain constant and that only the overall probability of wildfire is increasing. Under this assumption we scale the RPS by the ratio of future to present annual burn probability.

Calculating conditional losses

Structural damage depends on flame length and vegetation types (lifeforms) as shown in Table 1 below. The flame length probability categories (FLPs) correspond to the following flame lengths (in feet):

- FLP1: $\text{flame length} \leq 2$
- FLP2: $2 < \text{flame length} \leq 4$
- FLP3: $4 < \text{flame length} \leq 6$
- FLP4: $6 < \text{flame length} \leq 8$
- FLP5: $8 < \text{flame length} \leq 12$
- FLP6: $12 < \text{flame length}$

We calculate the conditional loss at three flame lengths, 2, 4, and 8ft corresponding to low, moderate, and high wildfire activity. Those lengths are at the borders of the FLPs below, so we average the loss from the two surrounding bins for each vegetation type.

Table 1. The damage functions at specific flame lengths from Wildfire Risk to Communities. A value of -100 represents a total loss, a value of 0 indicates no damage.

Vegetation type	FLP1	FLP2	FLP3	FLP4	FLP5	FLP6
Tree	-25	-40	-55	-70	-85	-100
Shrub	-20	-35	-50	-65	-80	-95
Grass	-10	-25	-40	-55	-70	-85

We use the National Land Cover Dataset to map each location to the vegetation types above: tree, shrub, and grass. Many vegetation types map sensibly, such as deciduous forest or shrub, however, we make two broad assumptions. First, we need to make an assumption about developed land. Wildfire Risk to Communities uses a methodology that propagates burn probability and flame length into developed areas from adjacent wild lands. For these developed areas, we use the 'tree' vegetation type, which has the highest damage. We make this assumption because the majority of residential homes are made of wood and of comparable heights to trees as opposed to shrubs. The second assumption is what to do with lands that we don't expect to burn, such as water or barren land. Here we assign the lowest damage vegetation category (grass). The lack of burnable material should be reflected in the burn probabilities and in the annualized loss. We use the lowest category because there may be flammable structures on that land that have a non-zero burn probability. In those cases we want to estimate some level of conditional damage rather than assuming no damage. Thus we assign it the lowest damage category.

Table 2. Mapping between Wildfire Risk to Communities lifeform types and NLCD categories.

Lifeform type	NLCD category names (codes)
Tree	Deciduous Forest (41), Evergreen Forest (42), Mixed Forest (43), Developed High Intensity(24), Developed Medium Intensity (23), Developed Low Intensity (22), Developed Open Space (21)
Shrub	Shrub/Scrub (52), Dwarf Scrub (51), Woody Wetlands (90)
Grass	Lichens (73), Emergent Herbaceous Wetlands (95), Cultivated Crops (82), Unclassified (0), Pasture/Hay (81), Perennial Ice/Snow (12), Barren Land (Rock/Sand/Clay) (31), Grassland/Herbaceous (71), Open Water (11), Moss (74), Sedge/Herbaceous (72)

Model Validation

Because UrbanFootprint estimates loss at the parcel level these loss estimates can be aggregated to any spatial resolution, enabling comparisons with other public resources, such as FEMA's National Risk Index (NRI). The NRI provides data on natural hazard risk and losses at the county and Census tract levels. For wildfire, the NRI's Expected Annual Loss to Buildings (EALB) metric represents the estimated average annualized economic loss to buildings in a specific area. This EALB value is derived by considering the total value of buildings, the exposure of buildings to wildfire (defined as areas having a non-zero probability of a wildfire with more than 12 foot flame lengths), and assuming a historical loss ratio of 0.4 in those areas.

Figure 3 shows the UrbanFootprint EALB under current conditions and the NRI EALB at the county level. Overall, we predict an annual total loss of $5.1B compared to $3.4B from NRI. Given the very different methodologies employed by these two approaches, this difference is easily understood. In general, while the overall UrbanFootprint estimate is higher than that from NRI, the overall spatial patterns observed are similar, with higher loss areas in the west and southwest (particularly southern California) and parts of Hawaii. There are no major spatial or numerical discrepancies between UrbanFootprint and NRI. The loss distributions are similar for both approaches and a linear fit at the county level gives an r^2 of 0.87, while a much better looking fit to the log transformed data gives an r^2 of 0.65 (Figure 4).

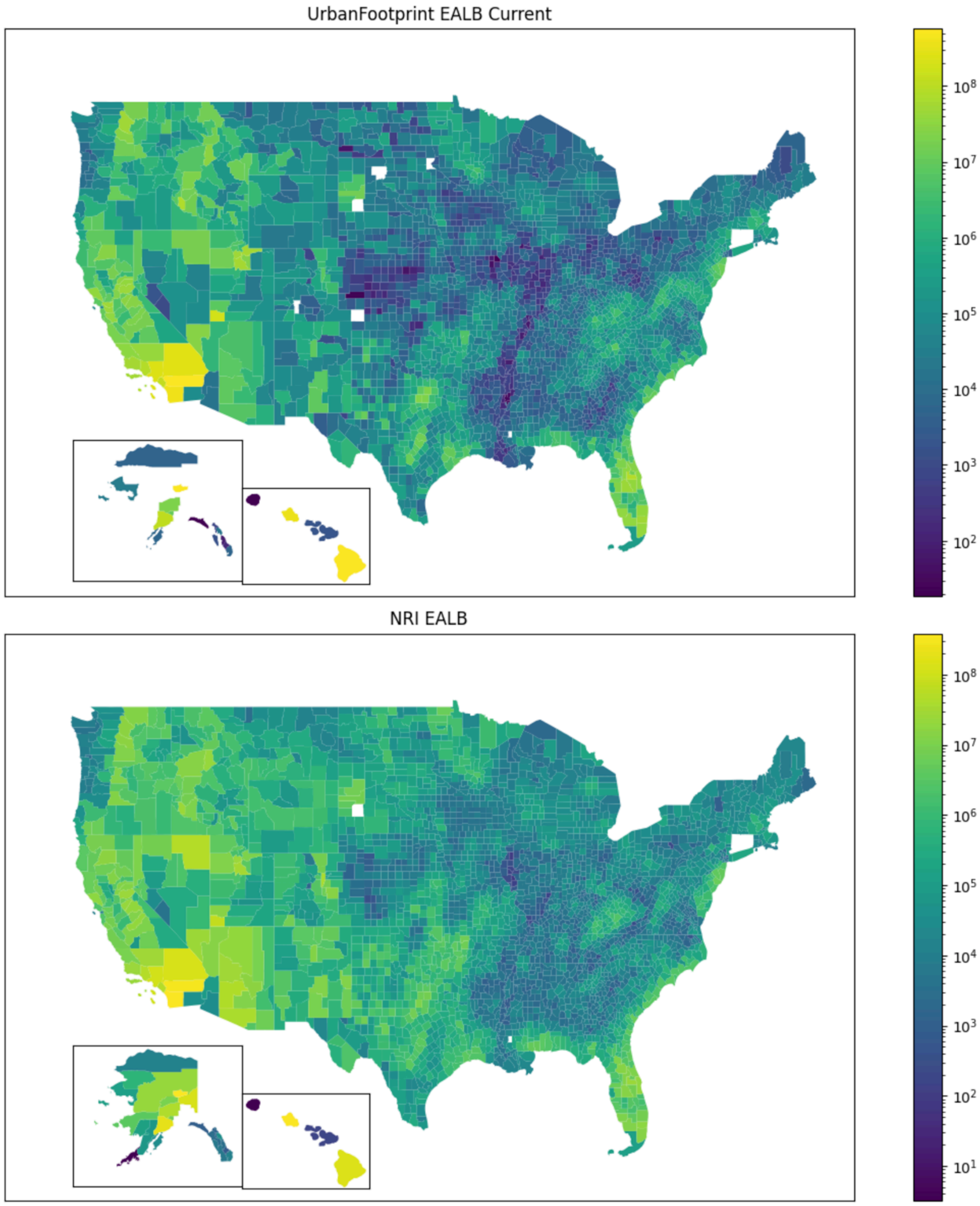

Figure 3. A county comparison of Expected Annual Loss to Buildings (ELAB) ($) between UrbanFootprint (top) and NRI (bottom).

NRI does not provide estimates for future losses for any natural hazard. Using UrbanFootprint wildfire risk extrapolations we estimate a 14% increase in annual wildfire loss to $5.8B from the current $5.1B. This increase is modest over the next quarter century, but will continue to increase throughout the century. The spatial pattern in conditional losses, such as Figure 5 showing the county level conditional loss for fires with more than 4 ft flame lengths, largely reflects population distribution across CONUS. This is expected as the conditional loss is a function of property at risk, which varies by orders of magnitude, and a (weak) function of vegetation type, which varies by 10s of percent.

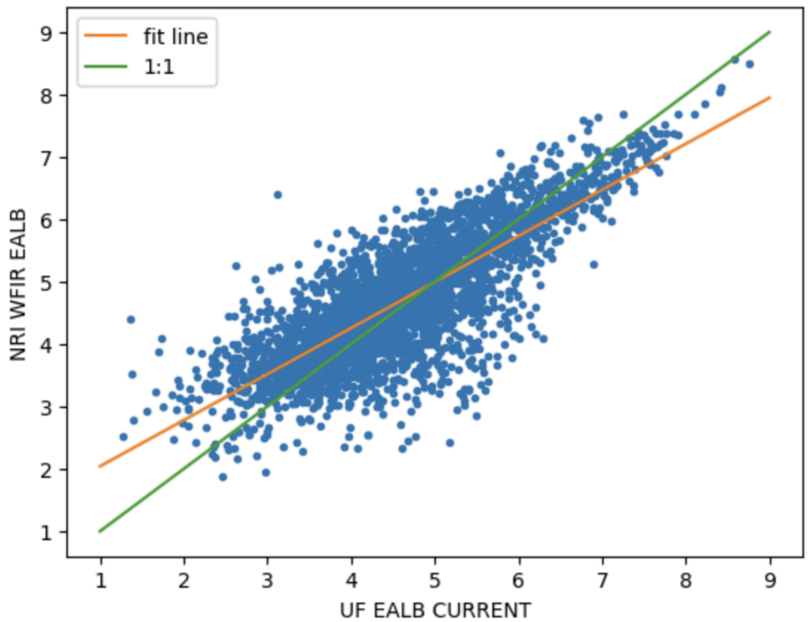

Figure 4. County level comparison between the UrbanFootprint wildfire loss estimates ($) and those of FEMA's National Risk Index Expected Annual Loss to Buildings.

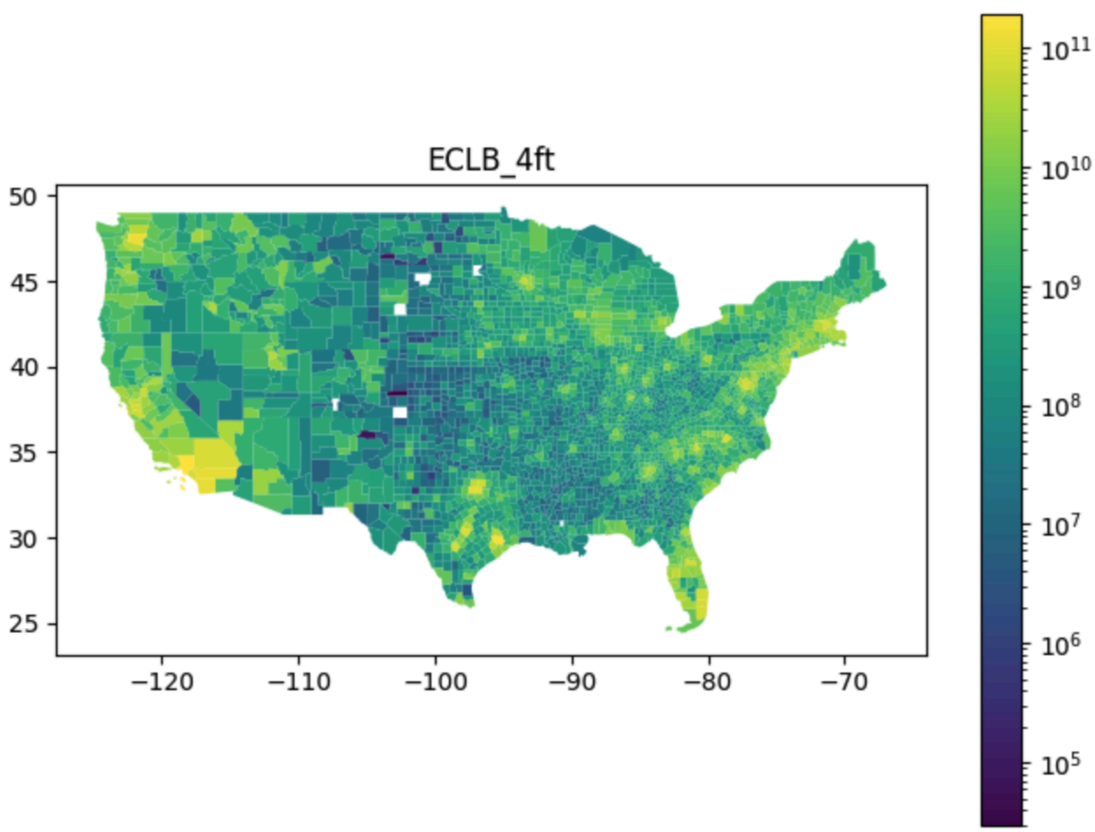

Figure 5. County level conditional loss ($) in the event of fires with 4ft flame lengths, estimated by UrbanFootprint.