WILDFIRE RISK ACROSS THE EASTERN REGION

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1 EXECUTIVE SUMMARY

The Eastern Region of the U.S. Forest Service contracted with Pyrologix in April 2019 to conduct a wildfire risk assessment for all land ownerships across the Eastern Region states. The All-lands assessment was an extension of an effort already underway to assess risk to Forest Service lands within the Region, however, the need for consistent wildfire risk and hazard products for all land ownerships led to an expansion of the Forest Service to also assess risk to highly valued resources and assets in all twenty northeastern states.

Project delays, largely due to COVID-19, presented an opportunity to update the fuelscape using the LANDFIRE Remap (version 2.0.0), and to leverage improvements in fire intensity modeling. With the incorporation of these project enhancements, the Eastern Region assessment consisted of four parts: fuelscape update, wildfire hazard assessment, wildfire risk assessment, and summary of wildfire risk to the most-exposed communities in each state. Reports documenting the methods and results of the updated fuelscape[1] and wildfire hazard products[2] are available for download.

The highly valued resources and assets (HVRA) identified at the outset of this project included homes, critical infrastructure, historic buildings, and water resources. In February 2021, groups of interagency partners convened in two virtual Fire Effects workshops to determine each HVRA's response to fires of different intensity levels. In July 2021, a final virtual workshop was held with interagency line officers to establish the importance and ranking of the primary HVRAs relative to each other. These efforts provide the HVRA characterization inputs needed to calculate wildfire effects analyses described in this report.

The simulations of wildfire hazard (likelihood and intensity) were used in conjunction with the HVRA data to estimate wildfire risk across the Eastern Region and identify the most at-risk communities in each state. For the top ten at-risk communities in each state, a spatial fireshed was calculated to identify the area within which wildfires can ignite and reach homes within the community. The Wildfire Risk to Communities analysis is provided as an appendix to this report.

This report documents the wildfire risk portion of the quantitative wildfire risk assessment. While this report was generated by Pyrologix LLC, the overall analysis was developed as a collaborative effort with numerous agencies and partners providing data and feedback.

[1] ERRA Fuelscape report: http://pyrologix.com/reports/ERRA_FuelscapeReport.pdf
[2] ERRA Wildfire Hazard report: http://pyrologix.com/reports/ERRA_HazardReport.pdf

1.1 PURPOSE OF THE ASSESSMENT

The purpose of the Eastern Region Risk Assessment (ERRA) is to provide foundational information about wildfire hazard across the geographic area. Such information supports wildfire response, regional fuel management planning, and revisions to land and resource management plans. A wildfire risk assessment is a quantitative analysis of the assets and resources across a specific landscape and how they are potentially impacted by wildfire. The ERRA analysis considers:

- likelihood of a fire burning,
- the intensity of a fire if one should occur,
- the exposure of assets and resources based on their locations, and
- the susceptibility of those assets and resources to wildfire.

To manage wildfire in Eastern Region, accurate wildfire risk data must be available to inform land and fire management strategies. These risk outputs can be used to aid in the planning, prioritization, and implementation of prevention and mitigation activities. In addition, the risk data can be used to support fire operations in response to wildfire incidents by identifying those assets and resources most susceptible to fire.

1.2 QUANTITATIVE RISK MODELING FRAMEWORK

The basis for a quantitative framework for assessing wildfire risk to highly valued resources and assets (HVRAs) has been established for many years (Finney 2005; Scott 2006). The framework has been implemented across a range of scales, from an individual county (Ager et al. 2017), a portion of a national forest (Thompson et al. 2013), individual states (Buckley et al. 2014), to the entire continental United States (Calkin et al. 2010). In this framework, wildfire risk is a function of two main factors: 1) wildfire hazard and 2) HVRA vulnerability (Figure 1).

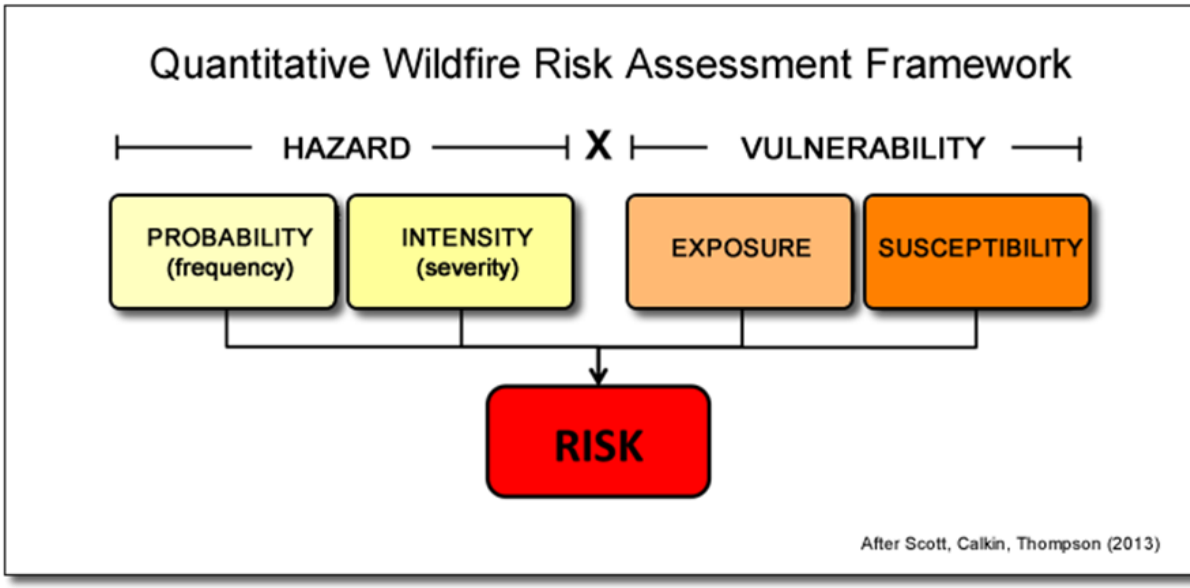

Figure 1. The components of the Quantitative Wildfire Risk Assessment Framework.

Wildfire hazard is a physical situation with the potential for causing damage to vulnerable resources or assets. Quantitatively, wildfire hazard is measured by two main factors: 1) burn probability (or likelihood of burning), and 2) fire intensity (measured as flame length, fireline intensity, or other similar measures).

HVRA vulnerability is also composed of two factors: 1) exposure and 2) susceptibility. Exposure is the placement (or coincidental location) of an HVRA in a hazardous environment—for example, building a home within a flammable landscape. Some HVRAs, like wildlife habitat or vegetation types, are not movable; they are not "placed" in hazardous locations. Still, their exposure to wildfire is the wildfire hazard where the habitat exists. Finally, the susceptibility of an HVRA to wildfire is how easily it is damaged by wildfire of different types and intensities. Some assets are fire-hardened and can withstand very intense fires without damage, whereas others are easily damaged by even low-intensity fire.

2 RISK ANALYSIS OVERVIEW

For any risk assessment, it is imperative to have spatial continuity across all aspects of project development. This ensures data alignment and logically consistent results across all ERRA data products. The project boundaries used in the Eastern Region wildfire risk assessment are described below in sections 2.1.1 – 2.1.3 and are shown in Figure 2.

2.1 LANDSCAPE ZONES

2.1.1 ANALYSIS AREA

The Analysis Area is the area for which valid burn probability results are produced. The Analysis Area for the Eastern Region project was defined as the USDA Forest Service Region 9 boundary which encompasses twenty northeastern states (Figure 2).

2.1.2 FIRE OCCURRENCE AREAS

To ensure valid Burn Probability (BP) results in the AA and prevent edge effects, it is necessary to allow FSim to start fires outside of the AA and burn into it. This larger area where simulated fires are started is called the Fire Occurrence Area (FOA). We established the FOA extent as a 20-km buffer on the AA including a 20-km buffer beyond the U.S. border and into Canada. The buffer provides sufficient area to ensure all fires that could reach the AA are simulated. The Fire Occurrence Area covers roughly 464 million acres and is characterized by diverse topographic and vegetation conditions. We divided the overall fire occurrence extent into twenty-four FOAs to model this large area where historical fire occurrence and fire weather are highly variable. Individual FOA boundaries were developed to group geographic areas that experience similar wildfire occurrence. These boundaries were generated using a variety of inputs including larger fire occurrence boundaries developed for national-level work (Short et al. 2020), aggregated level IV EPA Ecoregions, and local fire staff input. For consistency with other FSim projects, we numbered these FOAs 901 through 924.

2.1.3 FUELSCAPE EXTENT

The available fuelscape extent was delineated by adding a 20-km buffer to the FOA extent. This buffer allows fires starting within the FOA to grow unhindered by the edge of the fuelscape, which would otherwise truncate fire growth and affect the simulated fire-size distribution, potentially introducing errors in the calibration process. A map of the AA, FOA boundaries, and fuelscape extent are presented in Figure 2.

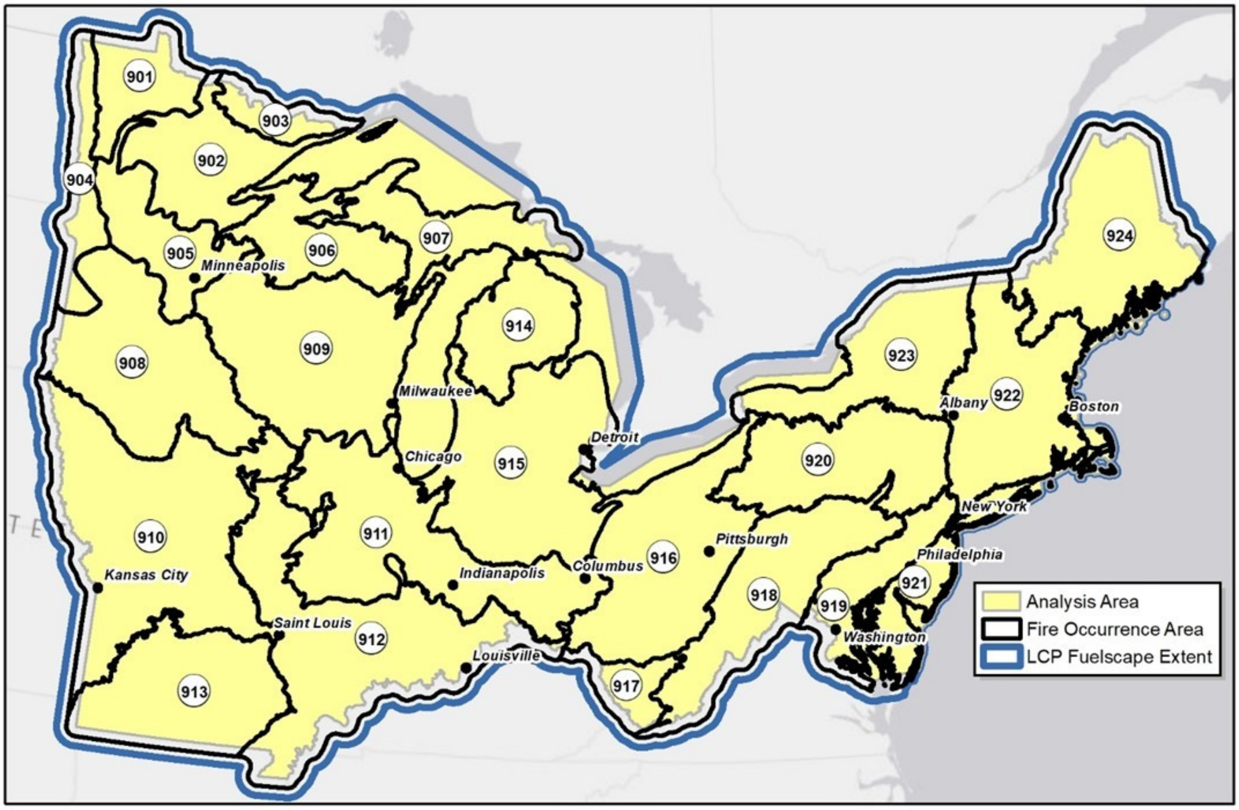

Figure 2. Overview of landscape zones for Eastern Region FSim project.

3 ANALYSIS INPUTS

Quantifying wildfire risk requires a comprehensive assessment of a focus area's high-value resources and assets, integrated with wildfire hazard (burn probability and fire intensity) to make a spatially resolved estimate of the risk. While an essential component to determining wildfire hazard is an accurate current condition fuelscape capturing the most recent disturbances and treatments. The integrated risk assessment inputs are discussed further in Sections 3.1- 3.2.

3.1 FUELSCAPE

The foundation of any wildfire hazard assessment is a current-condition fuelscape updated for recent disturbances and calibrated to reflect the fire behavior potential realized in recent historical wildfire events. LANDFIRE 2016 Remap 2.0.0 (LF Remap) data was leveraged to generate a calibrated fuelscape for this region-wide assessment.

The fuelscape consists of geospatial datasets representing surface fuel model (FM40), canopy cover (CC), canopy height (CH), canopy bulk density (CBD), canopy base height (CBH), and topography characteristics (slope, aspect, elevation). The FM40 dataset can be seen in Figure 3 in groups of similar fuel types. The fuelscape datasets can be combined into a single landscape (LCP) file and used as a fuelscape input in fire modeling programs. Further details about the methods and base data used to generate the calibrated ERRA all lands fuelscape are available in the fuelscape report.

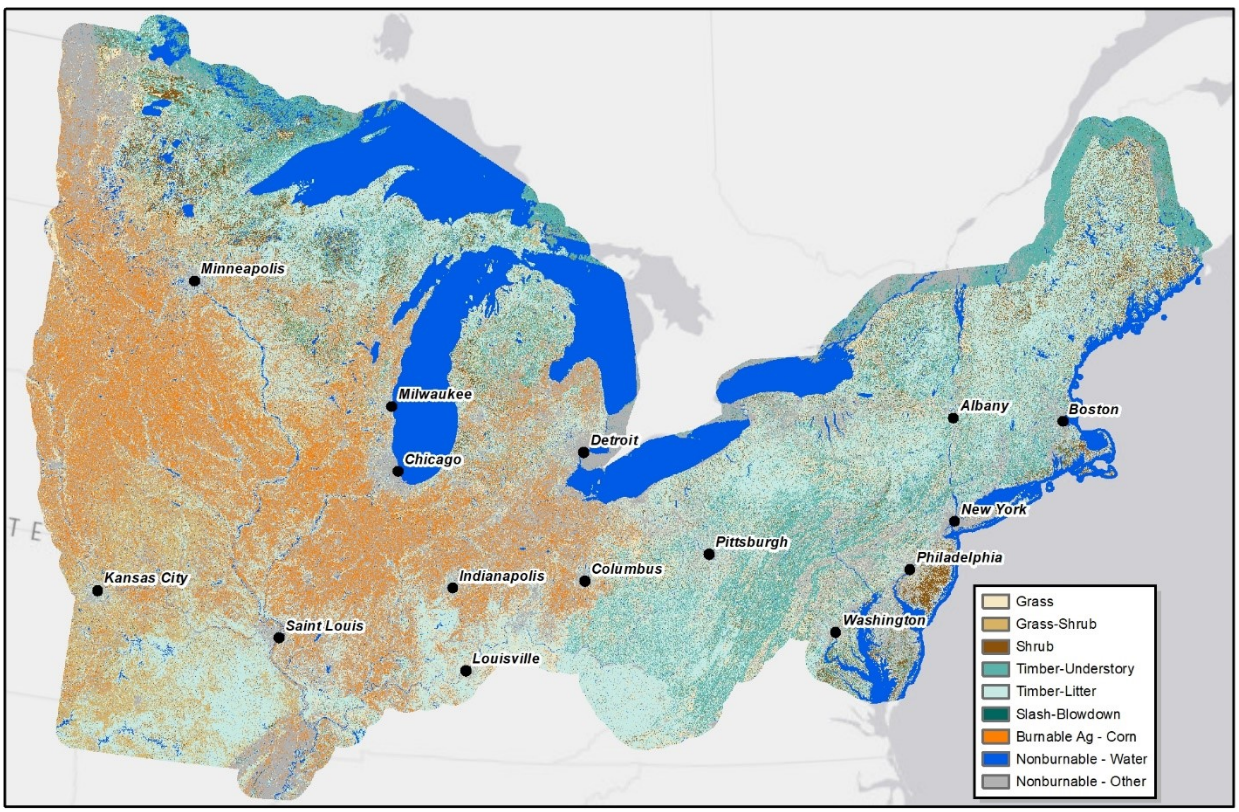

Figure 3. Map of fuel model groups across the Eastern Region LCP extent.

3.1.1 BURNABLE CORNFIELDS

The ERRA fuelscape uses a custom fuel model to represent the potential for wildfire spread into burnable cornfields. Workshop participants highlighted concerns about the underrepresentation of wildfire in agricultural areas in the western portion of the fuelscape due to the mapping of agriculture as non-burnable. Corn crops were identified as the agricultural fuel of greatest concern for the western portion of the Eastern Region. As a result, workshop participants requested a customization to portray the potential for wildfire in cornfields at certain times of the year. Pyrologix created a custom fuel model identical to the GR9 / 109 fuel model but labeled it separately as AG9 / 119 to allow for further customization.

3.2 WILDFIRE HAZARD

3.2.1 WILDFIRE SIMULATION (BURN PROBABILITY)

The FSim large-fire simulator was used to quantify wildfire hazard across the landscape at a pixel size of 120 m (3.5 acres per pixel). FSim is a comprehensive fire occurrence, growth, behavior, and suppression simulation system that uses locally relevant fuel, weather, topography, and historical fire occurrence information to make a spatially resolved estimate of the contemporary likelihood and intensity of wildfire across the landscape (Finney et al. 2011). To enable greater resolution on HVRA mapping, we chose to upsample the FSim burn probability (BP) raster from its native resolution of 120 m to 30 m. Further details regarding methods and hazards results are available in the hazard report[1].

3.2.2 INTENSITY CALCULATIONS

In addition to estimates of wildfire likelihood, FSim produces measurements of predicted wildfire intensities. Due to the inherent challenges of estimating intensity with a stochastic simulator, estimates of fire intensity were instead developed using a custom Pyrologix utility called WildEST (Scott et al. 2020). WildEST is a deterministic wildfire modeling tool that integrates spatially continuous weather input variables, weighted based on how they will likely be realized on the landscape. This makes the deterministic intensity values developed with WildEST more robust for use in effects analysis than the stochastic intensity values developed with FSim. This is especially true in low wildfire occurrence areas where predicted intensity values from FSim are reliant on a very small sample size of potential weather variables. The WildEST methodology is further described in Section 3 of the Hazard report[2].

3.3 HVRA CHARACTERIZATION

Highly Valued Resources and Assets (HVRA) are the resources and assets on the landscape most likely to warrant protection if found to be at risk of wildfire. The key criteria for inclusion in the ERRA assessment is an HVRA must be of greatest importance to the region, the spatial data must be readily available, and the spatial extent of the identified HVRA must be complete.

There are three primary components to HVRA characterization: HVRAs must be identified and their spatial extent mapped, their response to fire (negative, or neutral) must be characterized, and their relative importance to each other must be determined.

3.3.1 HVRA IDENTIFICATION

A set of HVRA was identified based on readily available spatial datasets for the entire Northeast. The complete list of HVRA and their associated data sources are listed in Table 1.

Table 1. HVRA and sub-HVRA identified for the ERRA Wildfire Risk Assessment and associated data sources.

HVRA & Sub-HVRA	Data Source
People and Property	
People and Property	This data set represents housing unity density data (HUDen) produced by Pyrologix using the building footprints and U.S. Census - Census Block population data.
Infrastructure	
Electric transmission lines – high & low voltage	Geo-spatial data represents electric power transmission lines acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD) program.
Communication Sites	Communication sites were acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD) program including cellular towers, land mobile towers, FM/AM transmission towers, microwave service towers, paging transmission towers, antenna structure, TV analog/digital transmitters, broadband radio transmitters, internet service providers, and internet exchange points.
Power Plants	Data representing the geo-spatial location of power plant locations was acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD) program.
Substations	Substation locations were acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD) program.
Oil & Gas Wells	Oil and Gas well locations were acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD) program.
Natural Gas Pipelines	Data representing natural gas pipelines was acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD) program.
Railroads	Railroad lines were acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD) program.
Cultural	
Historical Buildings, Sites & Structures	Data representing historic buildings, sites, and structures were acquired from the National Register of Historic Places (NRHP) program.
Drinking-Water	
Surface Drinking Water	Surface drinking water (24-hour) protection areas were acquired from the EPA Source Water Protection Area program.

To the degree possible, HVRA are mapped to the extent of the Analysis Area boundary (Figure 2). This is the boundary used to summarize the final risk results.

3.3.1.1 RESPONSE FUNCTIONS

Each HVRA selected for the assessment must also have an associated response to wildfire, whether neutral or negative. We relied on input from a group of interagency representatives, and additional fire and resource staff in two virtual Fire Effects workshops held in February 2021. In the workshop, the group discussed each resource or asset's response to fires of different intensity levels and characterized the HVRA response using values ranging from -100 to 100. The flame-length values corresponding to the fire intensity levels used in risk calculations are shown in Table 2. The response functions (RFs) used in the risk results are shown in Table 3 thru Table 12 below.

Table 2. Flame-length values corresponding to Fire Intensity Levels used in assigning response functions.

Fire Intensity Level (FIL)	**1**	**2**	**3**	**4**	**5**	**6**
Flame Length Range (feet)	0-2	2-4	4-6	6-8	8-12	12+

3.3.1.2 RELATIVE IMPORTANCE

The relative importance (RI) assignments are needed to integrate results across all HVRA. Without this input from leadership to prioritize among HVRA, the default is to assume equal-weighting among HVRA – a result that is never a desired outcome. A virtual RI workshop was held on July 27th, 2021, for Line Officers, Area Fire Management Officers, and interagency representatives. The focus of this workshop was to establish the importance and ranking of the primary HVRAs relative to each other. The People and Property HVRA received the greatest share of RI at 62 percent, followed by the Infrastructure (25%) and Water (13%) HVRA. The remaining share of RI is composed of the Culture (<1%) HVRA (Figure 4). These importance percentages reflect the overall importance of the primary HVRA relative to each other.

Sub-HVRA relative importance was also determined at the RI workshop. Sub-RIs consider both the relative importance per unit area and the mapped extent of the Sub-HVRA layers within the primary HVRA category. These calculations need to account for the relative extent of each HVRA to avoid overemphasizing HVRA covering many acres. This was accomplished by normalizing the calculations by the relative extent of each HVRA in the assessment area. Here, relative extent refers to the number of 30-m pixels mapped in each HVRA. In using this method, the relative importance of each HVRA is spread out over the HVRA's extent. An HVRA with few pixels can have a high importance per pixel; an HVRA with a great many pixels can have a low importance per pixel. A weighting factor (called Relative Importance Per Pixel [RIPP]) representing both the relative importance per unit area and overall importance was calculated for each HVRA.

In Table 3 thru Table 12, we provide the share of HVRA relative importance within each primary HVRA.

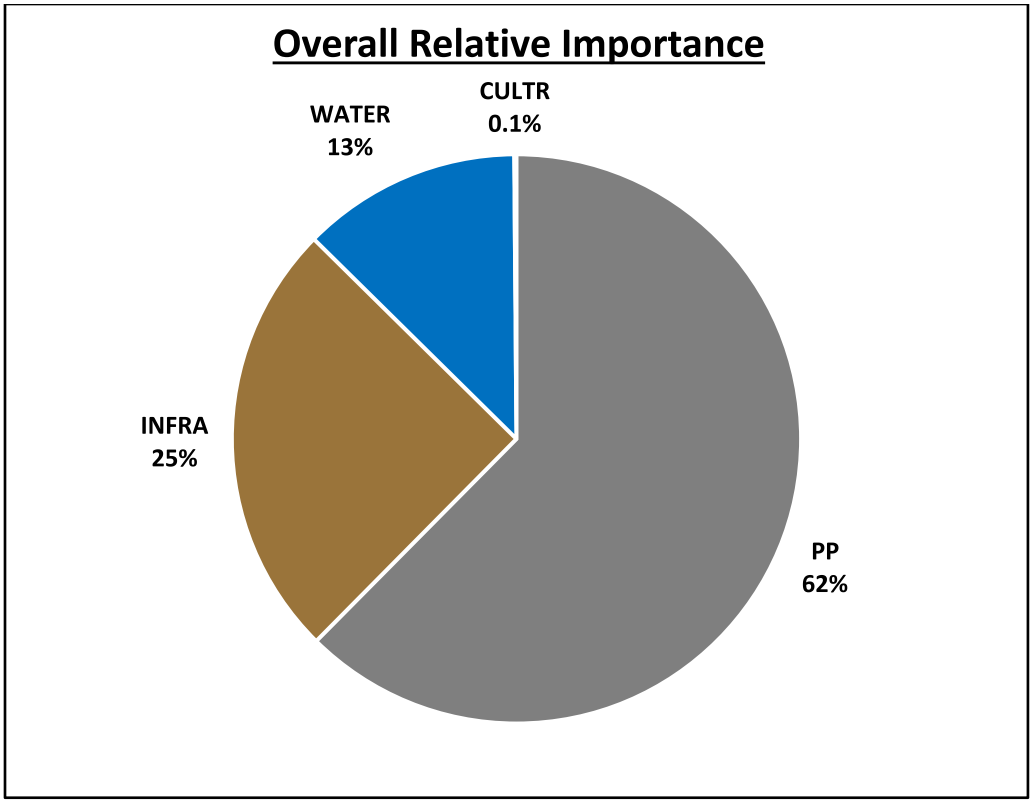

Figure 4. Overall HVRA Relative Importance for the primary HVRA.

3.3.2 HVRA CHARACTERIZATION RESULTS

Each HVRA was characterized by one or more data layers of sub-HVRA and, where necessary, further categorized by an appropriate covariate. Covariates separate HVRA by their response to wildfire, such as different response functions for transmission lines by voltage classes. The main HVRA in ERRA are mapped below along with a table containing the assigned response functions, the within-HVRA share of relative importance, and total acres for each sub-HVRA. These components are used along with fire behavior results from FSim and WildEST in the wildfire risk calculations described in section 4.1.

3.3.2.1 PEOPLE AND PROPERTY

3.3.2.1.1 HOUSING UNIT DENSITY (HUDEN)

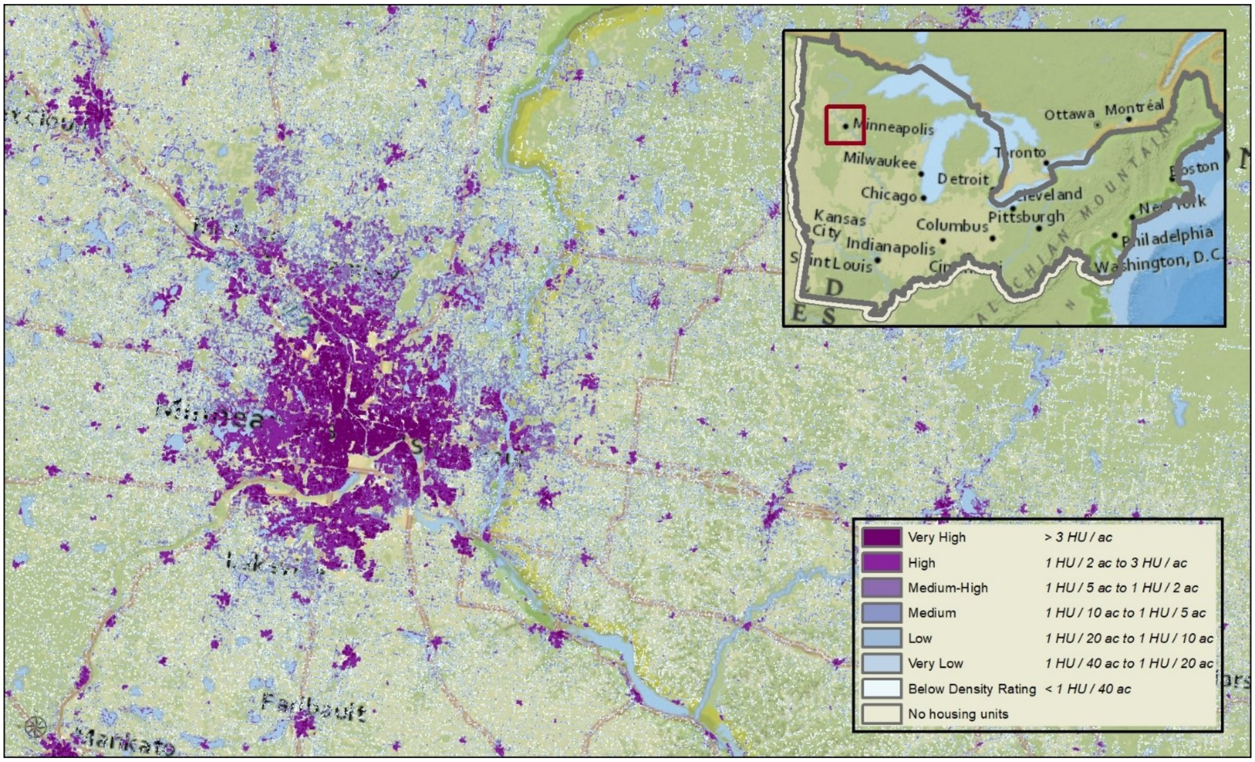

Figure 5. Map of Housing Unit Density within the Analysis Area.

The HUDen raster was produced by Pyrologix using the Microsoft Building Footprints and U.S. Census - Census Block population data. Population estimates were brought forward to 2018 county population estimates. Our approach estimates housing-unit count for a census block then allocates that count to the portions of the block likely to contain those housing units, identified as where the buildings are located within the block. This methodology was developed for the Wildfire Risk to Communities project (Scott et al. 2020). The same set of response functions was applied to all HU density classes.

The People and Property (HUDen) HVRA received negative response functions for all fire intensity levels (Table 3). The RF assignments demonstrate a pattern of increasing loss with increasing fire intensity, reaching near-total loss by FIL6.

Table 3. Response functions for the People and Property HVRA to highlight HUDen.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
P&P – HUDen, Very High	-20	-30	-50	-70	-80	-95	6%	576,756
High	-20	-30	-50	-70	-80	-95	52%	7,328,406
Medium-High	-20	-30	-50	-70	-80	-95	18%	10,626,164
Medium	-20	-30	-50	-70	-80	-95	11%	14,712,807
Low	-20	-30	-50	-70	-80	-95	7%	18,662,994
Very Low	-20	-30	-50	-70	-80	-95	4%	18,252,184
Below Density Rating	-20	-30	-50	-70	-80	-95	2%	21,864,243

[1] Within-HVRA relative importance.

3.3.2.2 INFRASTRUCTURE

3.3.2.2.1 COMMUNICATION SITES

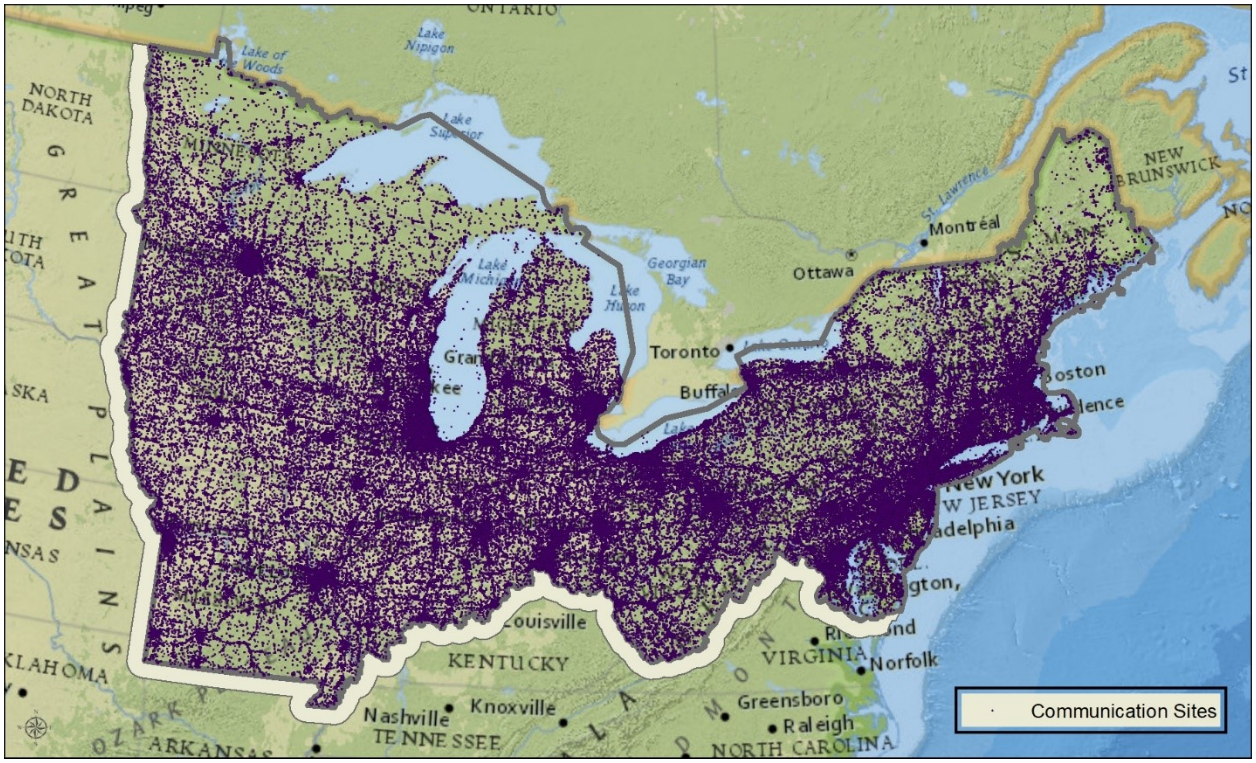

Figure 6. Map of Communication Sites within the Analysis Area.

Communication sites for the analysis area (Figure 6) were acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD)[3]. The types of communication sites compiled for the assessment include cellular towers, land mobile towers, FM/AM transmission towers, microwave service towers, paging transmission towers, antenna structure, TV analog/digital transmitters, broadband radio transmitters, internet service providers, and internet exchange points. All communication sites were merged into a single feature class and converted to 30-m pixels using the ArcGIS Focal Statistics tool. Focal statistics were calculated using the sum of an annulus neighborhood with an inner radius of zero and an outer radius of two, resulting in a point feature being represented by thirteen, 30-m pixels.

The response functions for communication sites demonstrate a pattern indicative of their generally hardened structures and defensible space, showing a neutral response at lower flame lengths, with an increasingly negative response to fires of increasing intensity (Table 4).

Communication sites were allocated 17 percent of the share of the Infrastructure HVRA importance. The share of HVRA importance is based on relative importance per unit area and mapped extent.

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[3] HIFLD data downloaded from https://hifld-geoplatform.opendata.arcgis.com/

Table 4. Response functions for the Infrastructure HVRA to highlight Communication Sites.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Communication Sites - High	0	0	-10	-20	-40	-50	17%	262,622

[1] Within-HVRA relative importance.

3.3.2.2.2 TRANSMISSION LINES

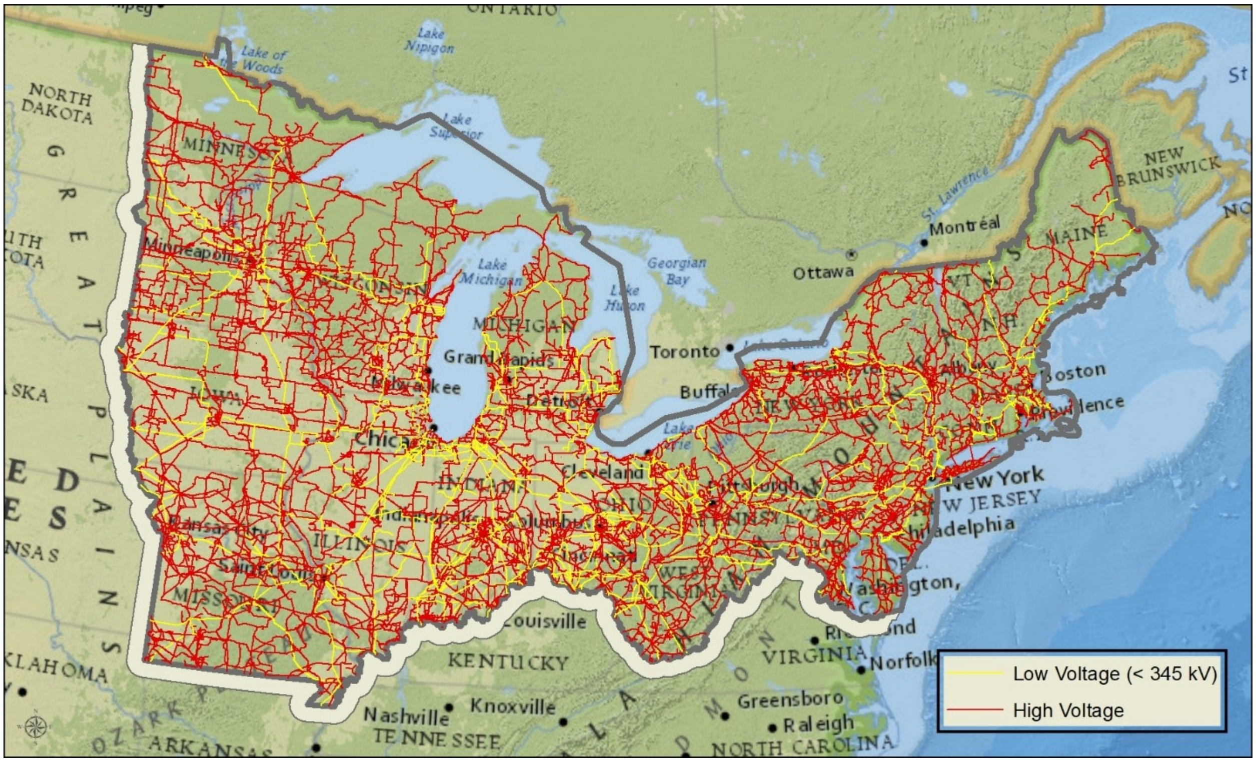

Figure 7. Map of Transmission Lines within the Analysis Area.

Transmission Lines within the analysis area (Figure 7) were acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD)[3]. The lines were classified using a voltage break of 345 volts (transmission lines carrying less than 345 volts classified as ‘1’, and those greater than 345, classified as ‘2’). The data were classified, converted to a 30-m raster based on voltage classification, expanded out one additional pixel (per side) using the ArcGIS Expand tool, and mosaiced back together to capture more of the area impacted by wildfire.

Low voltage lines (<345 kV) are mostly wooden poles, and therefore, demonstrate a strongly negative response to all fire intensities. Total loss was expected for fires greater than FIL4 (Table 5). High voltage transmission lines (≥345 kV) are expected to be constructed of largely non-burnable materials that can withstand exposure to lower fire intensities and experience less loss at the higher intensity classes (Table 5).

Due to the number of acres mapped on the landscape and their importance to infrastructure, electric transmission lines received 56 percent of the share of the Infrastructure HVRA importance. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 5. Response functions for the Infrastructure HVRA to highlight Transmission Lines.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
High Volt (>=345)	0	0	0	-10	-30	-30	12%	712,686
Low Volt (wooden poles)	-30	-50	-70	-90	-100	-100	44%	2,694,248

[1] Within-HVRA relative importance.

3.3.2.2.3 POWER PLANTS

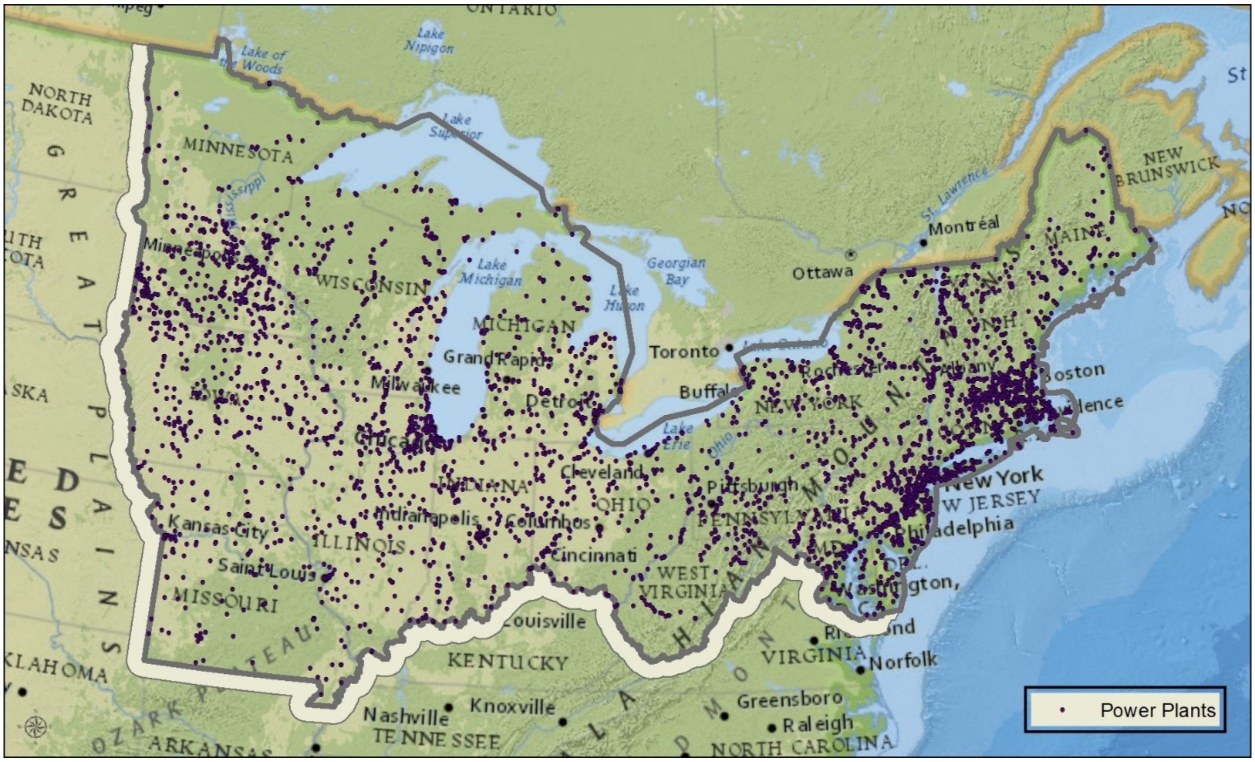

Figure 8. Map of Power Plants within the Analysis Area.

The locations of power plants within the analysis area (Figure 8) were derived from the Homeland Infrastructure Foundation-Level Data (HIFLD)[3]. The acquired data was converted to 30-m pixels using the ArcGIS Focal Statistics tool. Focal statistics were calculated using the sum of an annulus neighborhood with an inner radius of zero and an outer radius of two, resulting in a point feature being represented by thirteen, 30-m pixels.

Due to the hardened nature of the structures and defensible space, the response function assignments for power plants demonstrate a neutral response to nearly all fire intensities. They demonstrate a response only to fires of higher intensity and show minimal loss (Table 6).

Power plants were allocated less than one percent of the share of the Infrastructure HVRA importance. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 6. Response functions for the Infrastructure HVRA to highlight Power Plants.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Power Plants	0	0	0	0	-10	-20	0.2%	3,325

[1] Within-HVRA relative importance.

3.3.2.2.4 SUBSTATIONS

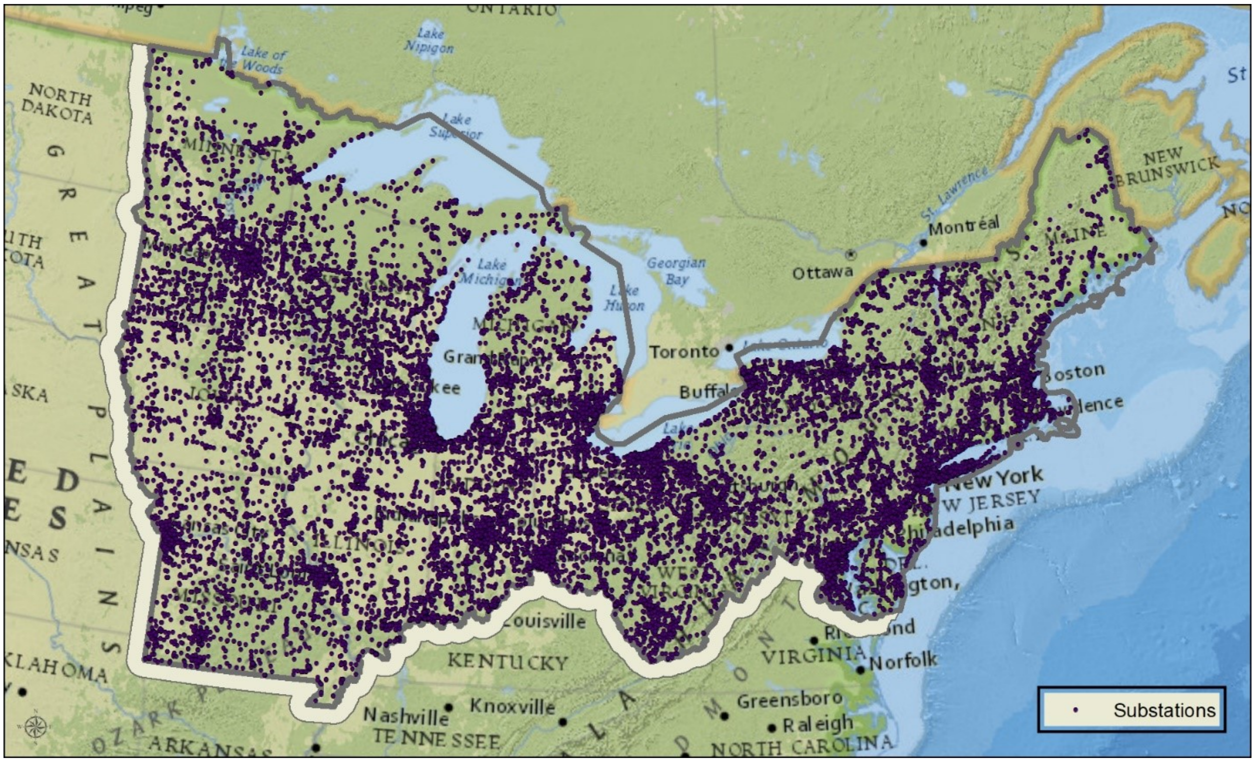

Figure 9. Map of Substations within the Analysis Area.

Substations within the analysis area (Figure 9) were derived from the Homeland infrastructure Foundation-Level Data (HIFLD)[3]. The acquired data was converted to 30-m pixels using the ArcGIS Focal Statistics tool. Focal statistics were calculated using the sum of an annulus neighborhood with an inner radius of zero and an outer radius of two, resulting in a point feature being represented by thirteen, 30-m pixels.

Due to the established, defensible space surrounding substations, the response functions are similar to that of power plants. Fires of low intensity will have little to no effect and not until FIL3 will they demonstrate a very low negative response to fire (Table 7). This negative trend continues as fire intensity increases but never surpasses mild loss.

Substations were allocated one percent of the share of the Infrastructure HVRA importance. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 7. Response functions for the Infrastructure HVRA to highlight Substations.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Substations	0	0	-10	-20	-30	-40	0.7%	21,784

[1] Within-HVRA relative importance.

3.3.2.2.5 OIL & GAS WELLS

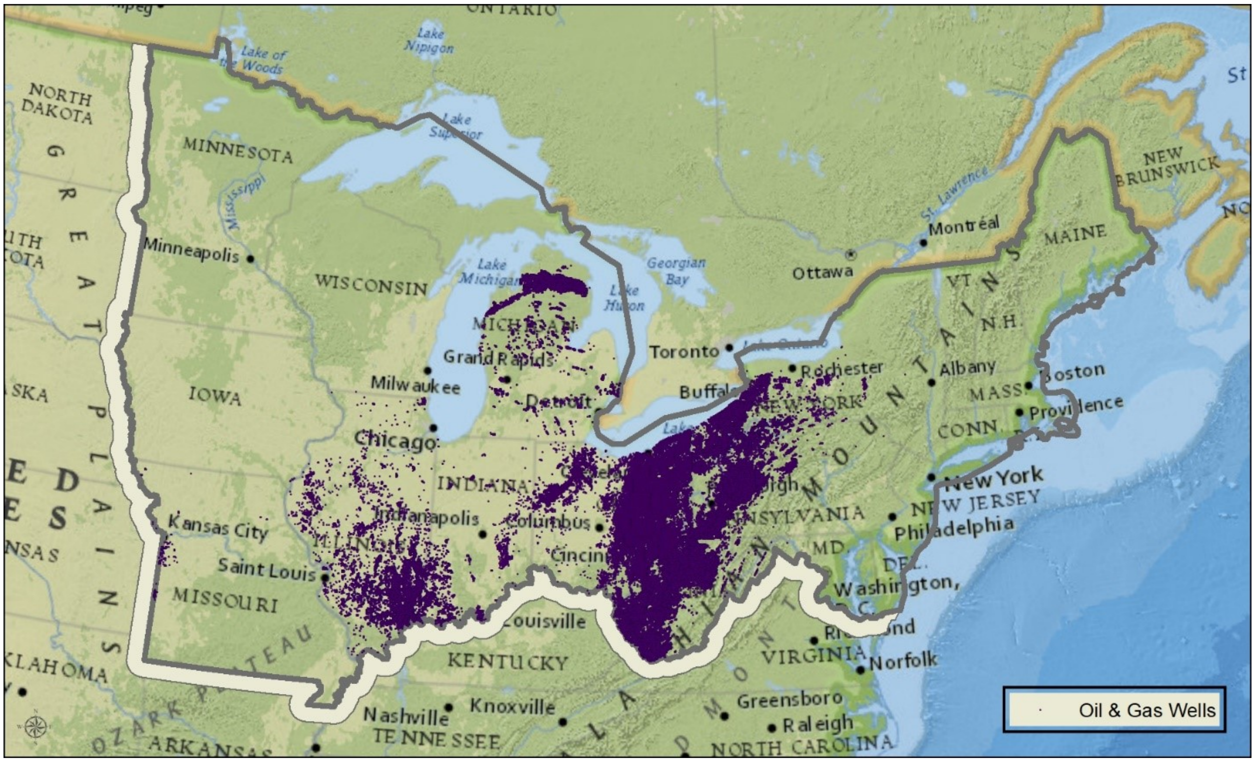

Figure 10. Map of Oil & Gas Wells within the Analysis Area.

The locations of Oil and Gas Wells for the analysis area (Figure 10) were derived from the Homeland Infrastructure Foundation-Level Data (HIFLD)[3]. The acquired data was converted to 30-m pixels using the ArcGIS Focal Statistics tool. Focal statistics were calculated using the sum of an annulus neighborhood with an inner radius of zero and an outer radius of two, resulting in a point feature being represented by thirteen, 30-m pixels.

The response function assignments for oil and gas wells show a neutral response for nearly all fire intensities. Not until 6-8-foot flame lengths (FIL4) is there a transition to a negative response. As fire intensity increases, the response functions show an increasingly negative response but remain relatively low (Table 8).

Oil and gas wells were allocated 7 percent of the share of the Infrastructure HVRA importance. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 8. Response functions for the Infrastructure HVRA to highlight Oil & Gas Wells.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Oil and Gas Wells	0	0	0	-10	-10	-20	7%	688,518

[1] Within-HVRA relative importance.

3.3.2.2.6 NATURAL GAS PIPELINES

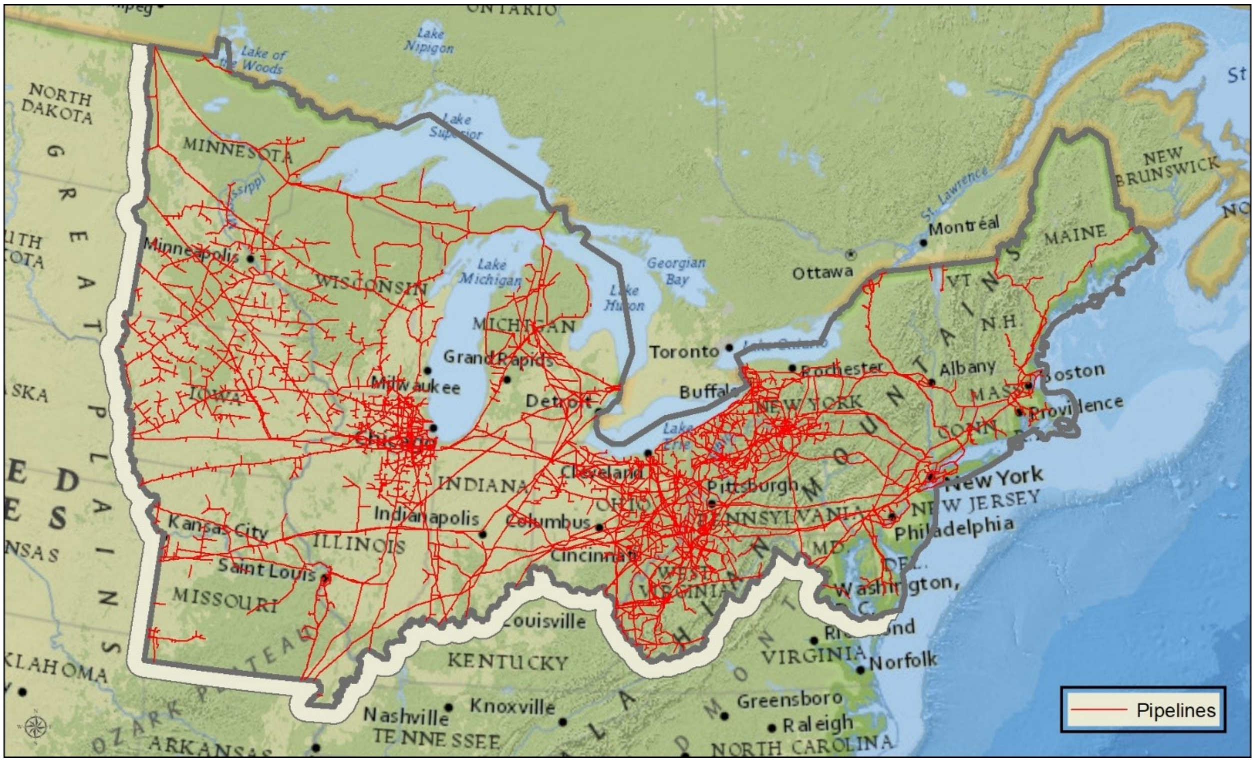

Figure 11. Map of Natural Gas Pipelines within the Analysis Area.

Natural Gas Pipelines within the analysis area (Figure 11) were acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD)[3]. For use in this analysis, the data were converted to a 30-m raster and expanded out one additional pixel (per side) using the ArcGIS Expand tool to capture more of the area impacted by wildfire.

The response functions for pipelines show a neutral response at the lower flame lengths. Starting at the 6–8-foot flame lengths (FIL4) there is a transition to a negative response. As fire intensity increases, the response functions show an increasingly negative response but remain relatively low (Table 9).

Natural gas pipelines were allocated ten percent of the share of the Infrastructure HVRA importance. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 9. Response functions for the Infrastructure HVRA to highlight Natural Gas Pipelines.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Natural Gas Pipelines	0	0	0	-10	-10	-20	10%	1,471,140

[1] Within-HVRA relative importance.

3.3.2.2.7 RAILROADS

Figure 12. Map of Railroads within the Analysis Area.

Railroads for the analysis area (Figure 12) were acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD)[3]. For use in this analysis, the data were converted to a 30-m raster and expanded out one additional pixel (per side) using the ArcGIS Expand tool to capture more of the area impacted by wildfire.

Due to the mixed construction materials (both wooden and steel railroad) represented in this layer, and our inability to identify which features use which materials at this scale, their response function assignments demonstrate a minimal, moderated response to nearly all fire intensities. It is not until fires reach high intensities that the RFs demonstrate a moderate response and show minimal loss (Table 10).

Railroads were allocated ten percent of the share of the Infrastructure HVRA importance. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 10. Response functions for the Infrastructure HVRA to highlight Railroads.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Railroads	-5	-10	-15	-20	-25	-35	10%	1,553,808

[1] Within-HVRA relative importance.

3.3.2.3 CULTURAL

3.3.2.3.1 HISTORIC BUILDINGS, SITES & STRUCTURES

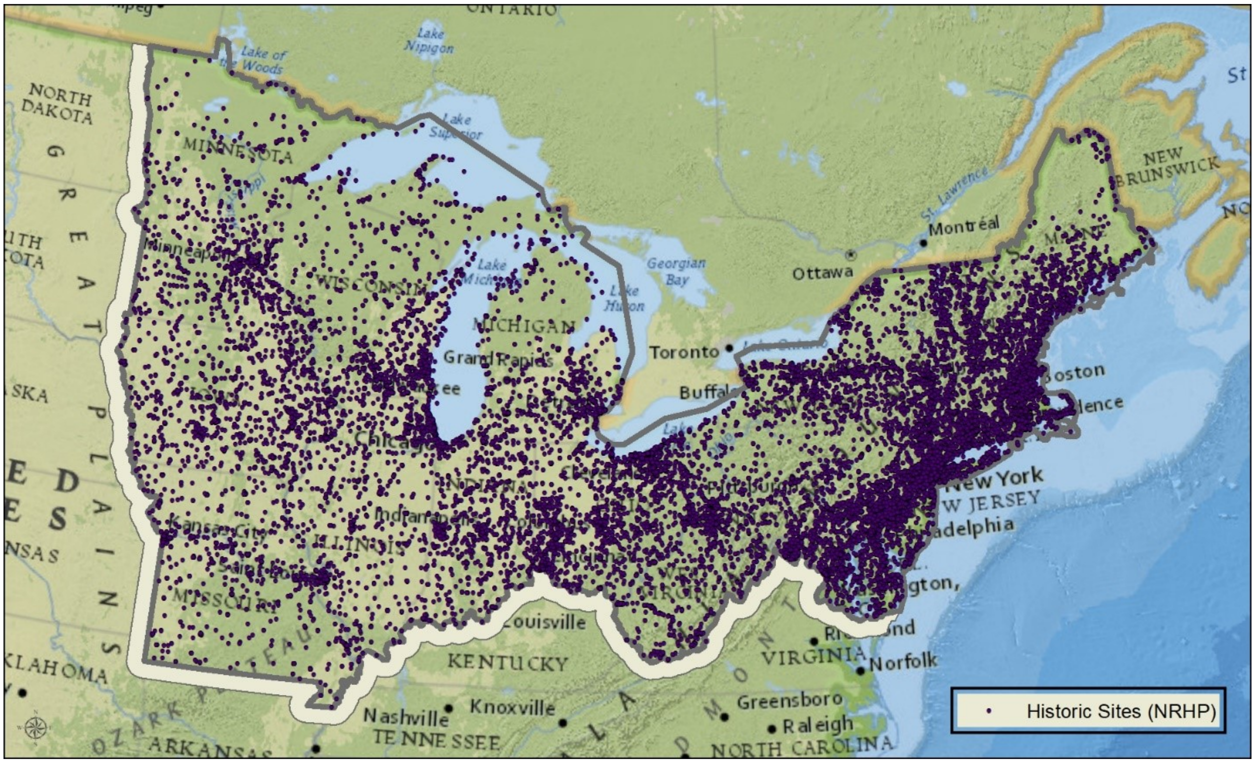

Figure 13. Map of Historical Buildings, Sites, and Structures within the Analysis Area.

Cultural sites (historic buildings, sites, or structures) within the analysis area (Figure 13) were acquired from the National Register of Historic Places (NRHP)[4]. The acquired data was converted to 30-m pixels using the ArcGIS Focal Statistics tool. Focal statistics were calculated using the sum of an annulus neighborhood with an inner radius of zero and an outer radius of two, resulting in a point feature being represented by thirteen, 30-m pixels.

Due to the susceptibility and intrinsic value of historic sites, the response function assignments for historic buildings, sites, and structures, demonstrate an initial negative response to fire higher than that assigned in the response function for the People and Property HVRA (section 3.3.2.1). The inability to replace such structures causes this trend to continue as fire intensity increases, reaching near-total loss by 6-foot flame lengths (Table 11).

Table 11. Response functions for the Cultural HVRA to highlight Historic Buildings, Sites and Structures.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Historic Buildings, Sites, Structures	-30	-40	-60	-80	-90	-100	100.0%	21,129

[1] Within-HVRA relative importance.

[4] https://www.nps.gov/subjects/nationalregister/data-downloads.htm

3.3.2.4 DRINKING WATER

3.3.2.4.1 SURFACE DRINKING-WATER

Figure 14. Map of Drinking Water Protection Areas within the Analysis Area.

Drinking water protection areas were mapped using data from the EPA's Source Water Protection Area program[5]. The dataset includes surface drinking water protection areas (24-hour critical water basins) and their associated intake facilities. Basins were limited to those with an associated intake, being careful to not truncate basins at project boundaries during processing. The resulting critical watershed map is shown in Figure 14.

For the ERRA, watershed resources were analyzed using a custom approach to determine the importance of each pixel within a basin, based on population served and distance to intake. We calculated the Euclidean distance to the drinking water intake for each pixel within its associated watershed. We then divided the result by the Euclidean distance to create a proportion of importance based on the distance to the intake, and to prevent values from decaying as rapidly we divided the distance by 1/3. We then multiplied by the intake's population served. The sum of the importance for each watershed was then normalized to the total population served to prevent overweighting the largest watersheds. A single pixel can belong to one or more overlapping watersheds; therefore values are cumulative across overlapping watersheds.

[5] https://www.epa.gov/sourcewaterprotection/delineate-source-water-protection-area

Table 12. Response functions for the Critical Watersheds HVRA.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Drinking Water	0	-10	-20	-30	-40	-50	100.0%	27,605,648

[1] Within-HVRA relative importance.

4 EFFECTS ANALYSIS

An effects analysis quantifies wildfire risk as the expected value of net response (Finney 2005; Scott et al. 2013) also known as expected net value change (eNVC). Effects analysis relies on input from resource specialists to produce response functions for Highly Valued Resources and Assets (HVRA) occurring in the analysis area. A response function is a tabulation of the relative change in the value of an HVRA if it were to burn in each of six WildEST flame-length classes. A positive value in a response function indicates a benefit or increase in value; a negative value indicates a loss or decrease in value.

For the ERRA assessment, the term Highly Valued Resources and Assets (HVRA) is used to describe what has previously been labeled "values at risk." This change in terminology is important to highlight because resources and assets are not themselves "values" in a way that the term is conventionally defined—they *have* value (importance). For example, assets are human-made features, such as commercial structures, critical facilities, housing, etc., that have specific importance or value. Similarly, resources are natural features, such as wildlife habitat, vegetation type, or water, etc., also with specific importance or value. While such resources and assets may be exposed to wildfire, they are not necessarily "at-risk"—that is the purpose of the assessment.

4.1 CALCULATIONS

Integrating HVRAs with differing units of measure (for example, habitat vs. homes) requires relative importance (RI) values for each HVRA/sub-HVRA. These values were identified in the RI workshop, as discussed in section 3.3.1.2. The final importance weight used in the risk calculations is a function of overall HVRA importance, sub-HVRA importance, and relative extent (pixel count) of each sub-HVRA. This value is therefore called relative importance per pixel (RIPP).

The RF and RIPP values were combined with estimates of the flame-length probability (FLP) in each of the six flame-length classes to estimate conditional NVC (cNVC) as the sum-product of flame-length probability (FLP) and response function value (RF) over all the six flame-length classes, with a weighting factor adjustment for the relative importance per unit area of each HVRA, as follows:

$$cNVC_j = \sum_{i}^{n} FLP_i * RF_{ij} * RIPP_j$$

where *i* refers to flame length class (n = 6), *j* refers to each HVRA, and RIPP is the weighting factor based on the relative importance and relative extent (number of pixels) of each HVRA. The cNVC calculation shown above places each pixel of each resource on a common scale (relative importance), allowing them to be summed across all resources to produce the total cNVC at a given pixel:

$$cNVC = \sum_{j}^{m} cNVC_j$$

where cNVC is calculated for each pixel in the analysis area. Finally, eNVC for each pixel is calculated as the product of cNVC and annual BP:

$$eNVC = cNVC * BP$$

4.1.1 BURNABLE CORN CALCULATION ADJUSTMENTS

The ERRA fuelscape (section 3.1) included the use of a custom fuel model to represent the potential for wildfire spread into burnable cornfields. This customization is necessary because fire behavior associated with cornfields is dependent on the time of year relative to harvest. Discussions during the fuelscape calibration workshop highlighted this difference, suggesting the use of a GR2 fuel model to represent corn in its stubble form, but GR9 to represent fire behavior before harvest. Since only one fuel model can be assigned, the fuelscape customization portrays the potential for wildfire in cornfields at certain times of the year via a custom fuel model identical to the GR9 / 109 fuel model but labeled as AG9 / 119 to allow for further customization in FSim modeling. More information on the fuelscape calibration is available in the ERRA Fuelscape report[1].

The WildEST fire intensity calculations resulting from the fuelscape adjustment express the full fire behavior potential of burnable cornfields mapped with the custom fuel model, AG9. The fire behavior shown in these products may overrepresent the potential in the months outside of the peak growing season. When determining the integrated hazard and risk it is necessary to make adjustments reflecting fire behavior associated with different stages of corn relative to harvest

The wildfire risk results presented in this report were adjusted in pixels mapped with fuel model AG9 to reduce intensity proportional to the split between GR2 and GR9. This adjustment compensates for the difference in expected fire behavior depending on the time of year relative to corn-crop harvest. This involved a reduction factor of 50 percent from the calculated risk value. Without this adjustment, burnable cornfields appear as the most hazardous fuel type in the Eastern Region despite the moderate fire behavior expected for approximately half of the fire season.

4.2 UPSAMPLING FSIM RESULTS

FSim's stochastic simulation approach can be computationally intensive and time constraining on large landscapes. The challenge is to determine a resolution sufficiently fine to retain detail in fuel and terrain features while producing calibrated results in a reasonable timeframe. Moreover, HVRA are often mapped at the same resolution as the final BP produced by FSim. To enable greater resolution on HVRA mapping, we chose to upsample the FSim burn probability (BP) rasters to 30-m, consistent with HVRA mapping at 30-m. More information on probability upsampling is available in the ERRA Wildfire Hazard report[2].

4.3 WILDFIRE TRANSMISSION (RISK-SOURCE)

The potential for wildfires to transmit risk is a function of the spatial variation in fire occurrence and fire growth potential, in conjunction with spatial variation in HVRA location. To evaluate this potential, the total cNVC – the sum of all HVRA (People and Property, Infrastructure, Culture, and Critical Watersheds) – was determined for each simulated FSim fire perimeter. The sum of total cNVC within each fire perimeter was then attributed to its associated ignition point. Summaries were limited to "large" fire perimeters, defined here as perimeters greater than the Lorenz curve large-fire threshold. Below this perimeter size, simulated fire-size distributions do not match historical distributions. More information on the Lorenz curve large-fires threshold is available in the ERRA Wildfire Hazard report[2].

The final raster dataset created from the perimeter overlay exercise (risk-source) represents the expected annual risk per km^2 (or total wildfire transmission risk) for all HVRA from ignitions across the landscape. We refer to this raster as Expected Transmitted Risk (eRiskSource_allHVRA.tif).

The Expected Transmitted Risk raster was generated using a multi-stage process. The ERRA analysis area includes twenty-four Fire Occurrence Areas (FOAs) with a varying number of iterations. The number of iterations used in the simulation was added to the attribute table for each fire and a new attribute representing cNVC per iteration was generated. Including the number of iterations in the calculation provides the "expected" or likelihood component of risk-source. Using the ArcGIS Point Statistics tool, the sum of cNVC per iteration within 5-km and 10-km moving window was calculated and the results were combined by taking the larger negative value or minimum using ArcGIS Cell Statistics. This approach retains the ignition impact nearer the ignition source (with the 5-km window) but uses the results of the broader focal raster (10-km) to fill missing values and to more gradually decrease wildfire risk values in areas with fewer ignitions.

The second step involved calculating the sum of the ignitable[6] land area using the same tool and parameters on a point feature class differentiating ignitable and nonignitable fuel models. Finally, the sum of cNVC per iteration was divided by the sum of ignitable land area per km^2 to get the expected risk-source per km^2 of source-area. These results can be used to look at the relative likelihood and consequence of ignitions occurring across the landscape.

This same process was completed for estimated population as mapped by PopDen (Scott et al. 2020). The result of that overlay exercise is a raster called Expected Impact to Population (eImpact_Population.tif) and represents the expected annual impacts to people per km^2 from ignitions across the ERRA analysis area. The Data Products list in section 8 identifies where this product is located within the project deliverables.

4.4 RELATIVE SUPPRESSION COST INDEX

We evaluated the spatial variability of the potential for producing fires that are costly to suppress by calculating a *relative* suppression cost index. By holding constant the variables that do not pertain to landscape characteristics, we can identify the locations across the analysis area with potential for producing larger, costly wildfires. The Suppression Cost Index (SCI) was originally developed by Gebert et al. (2007) at the U.S. Forest Service, Rocky Mountain Research Station who used historical fire characteristics and suppression expenditures to develop regression models to predict the cost of wildfires. Their regressions were based on fire size, fire environment, distance to cities, Census-based housing value, distance to roadless areas, Region of the National Forest System, and additional variables such as detection time, suppression strategy and resource availability (Gebert et al. 2007).

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[6] Ignitable fuel includes burnable fuel, but not the custom burnable-urban fuel model.

Calculating suppression costs for simulated wildfires is a time-intensive process and the predicted cost is sensitive to fire size (Gebert et al. 2007). Simulated fire sizes and numbers of simulated ignitions vary drastically across the Eastern Region. Rather than cost each simulated fire in the ERRA assessment and generalize the resulting suppression cost predictions, we instead generalized large-fire potential in a regular grid spacing across the project extent. We call this product relative Suppression Cost Index (rSCI) because rather than costing every fire, we are comparing fire size and landscape characteristics relative to other points on the landscape and holding constant the other variables that influence predicted costs.

To generalize fire size, we calculated the 90th percentile large-fire size by using a moving window approach within a 5-km search radius. To address missing data in low fire occurrence areas, we applied the ArcGIS Nibble tool to assign adjacent values to burnable pixels missing a fire-size assignment. Each grid-cell centroid was assigned a fire size value (in acres) associated with the 90th percentile. At each point in the 1080-m grid, we also identified surface fuel model (FM40), slope, aspect, and elevation – required inputs for computing suppression costs (Gebert et al. 2007). We used a constant, 90th percentile ERC input to hold the ERC variable constant across "ignitions."

We then relied on scripts provided by Jessica Haas (personal communication, August 28, 2018) used to calculate the cost of simulated fires. The scripts automate calculations of distance to cities, housing values, and distance to wilderness and then calculate a predicted Cost per Fire and Cost per Acre for each 1080-m grid centroid using the USFS regression model for the eastern region ('R9' was used as a variable input).

Finally, we smoothed the resulting Cost per Fire surface using the ArcGIS Point Statistics tool with a 5-km window and output cell size of 240 m.

5 RESULTS

5.1 EFFECTS ANALYSIS RESULTS

The cumulative results of the wildfire risk calculations described in section 4.1 are the spatial grids of cNVC and eNVC, representing both the conditional and expected change in value from wildfire disturbance to all HVRAs included in the analysis. Results are limited to those pixels that have at least one HVRA and a non-zero burn probability. Both cNVC and eNVC reflect an HVRA's response to fire and their relative importance within the context of the assessment, while eNVC additionally captures the relative likelihood of wildfire disturbance. Cumulative effects of wildfire across the landscape vary by HVRA (Figure 15) with a net negative eNVC for all the HVRA. Results are scaled to cumulative eNVC values for the People and Property HVRA in the ERRA analysis area. People and Property show the greatest cumulative wildfire losses (eNVC) result followed by Infrastructure, Drinking Water, and Cultural as the HVRA with the greatest cumulative risk.

Figure 16 shows cNVC results at a 30-m resolution across the analysis area. The most adverse effects are shown in dark red and are largely concentrated around ERRA communities. Adjusting cNVC by fire likelihood (i.e., burn probability) narrows the range of values for negative outcomes and highlights areas more likely to be visited by wildfire as seen in the eNVC map in Figure 18.

Figure 17 shows the upsampled BP, as discussed in section 4.1.1. Figure 19 shows the wildfire transmission results, as discussed in section 4.3.

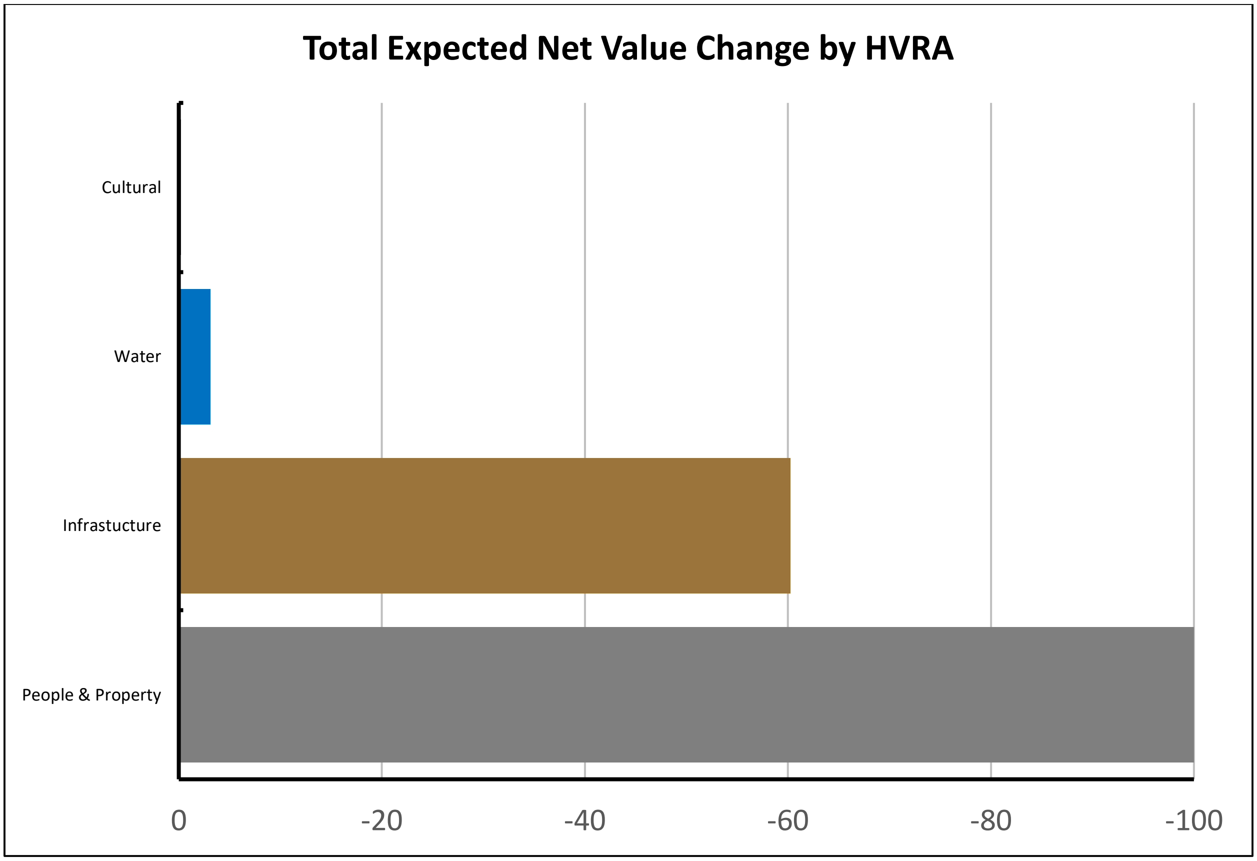

Figure 15. Weighted net response overall highly valued resources and assets (HVRAs) in the assessment. The HVRAs are listed in order of net value change and scaled to eNVC values for the People and Property HVRA.

5.1.1 CONSEQUENCE – CONDITIONAL NET VALUE CHANGE (CNVC)

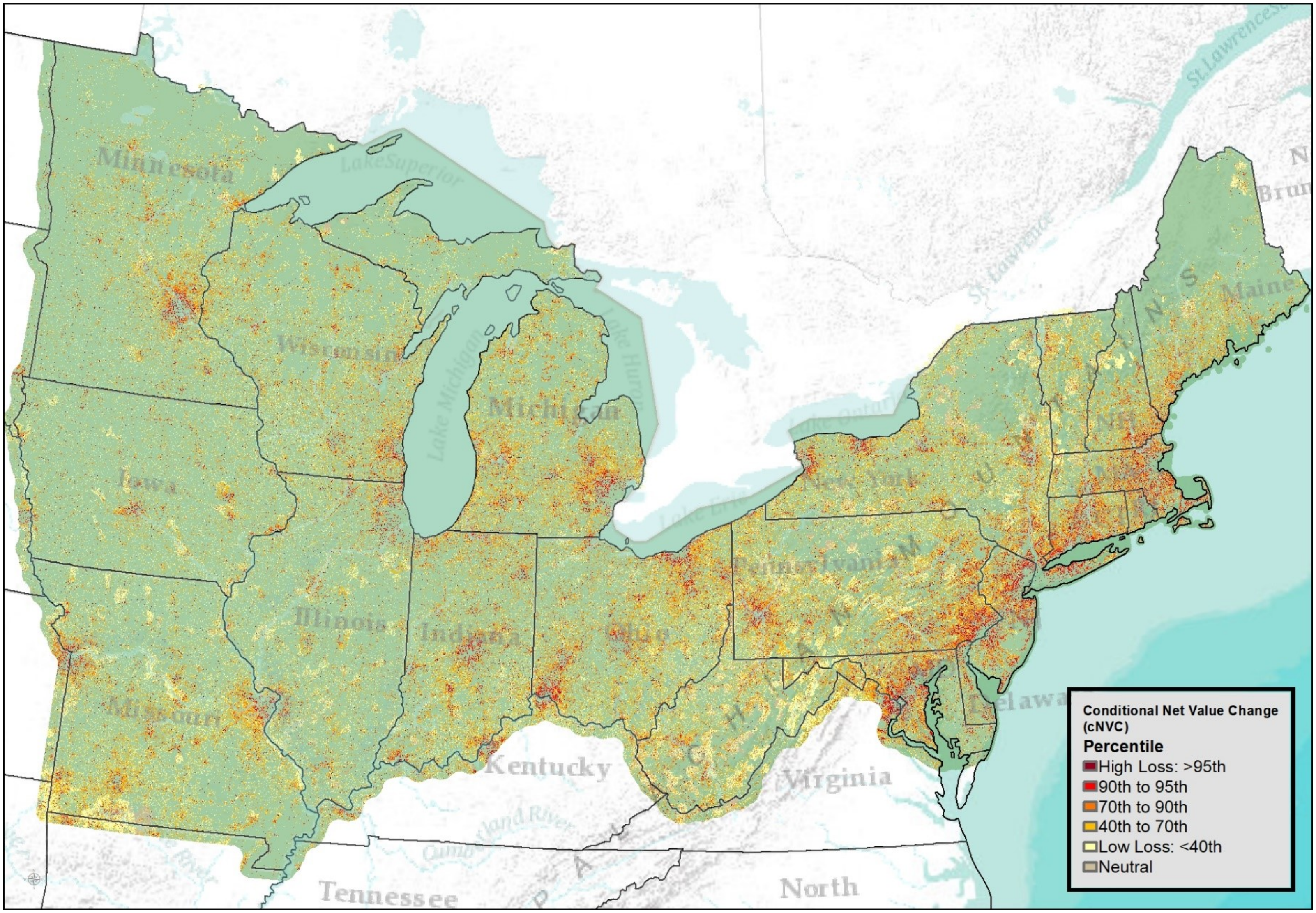

Figure 16. Map of Conditional Net Value Change (cNVC) at 30-m for the analysis area.

5.1.2 LIKELIHOOD – ANNUAL BURN PROBABILITY (BP)

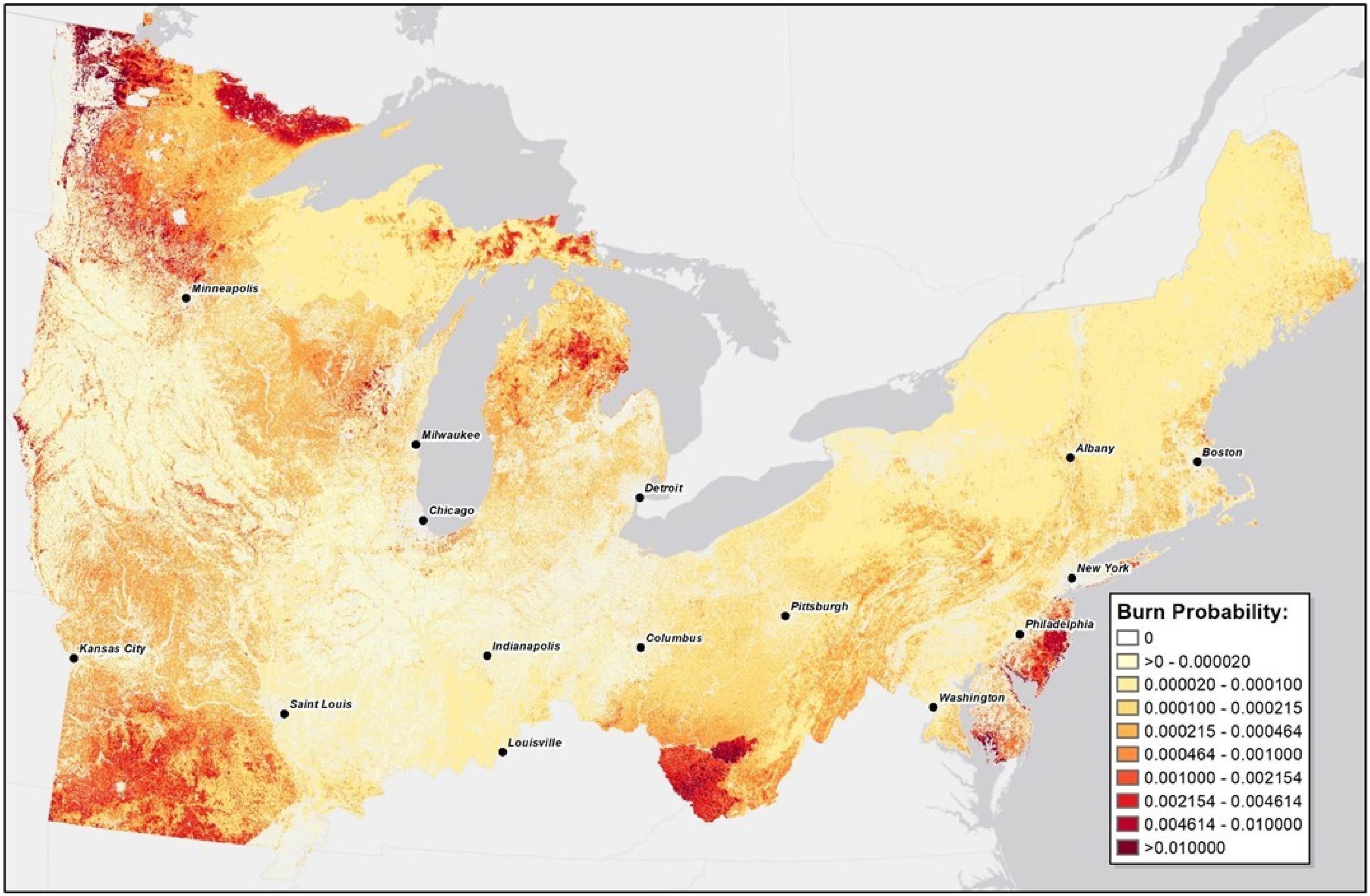

Figure 17. Map of integrated FSim burn probability results for the Eastern Region study area at 30-m resolution.

5.1.3 RISK – EXPECTED NET VALUE CHANGE (ENVC) - TOTAL

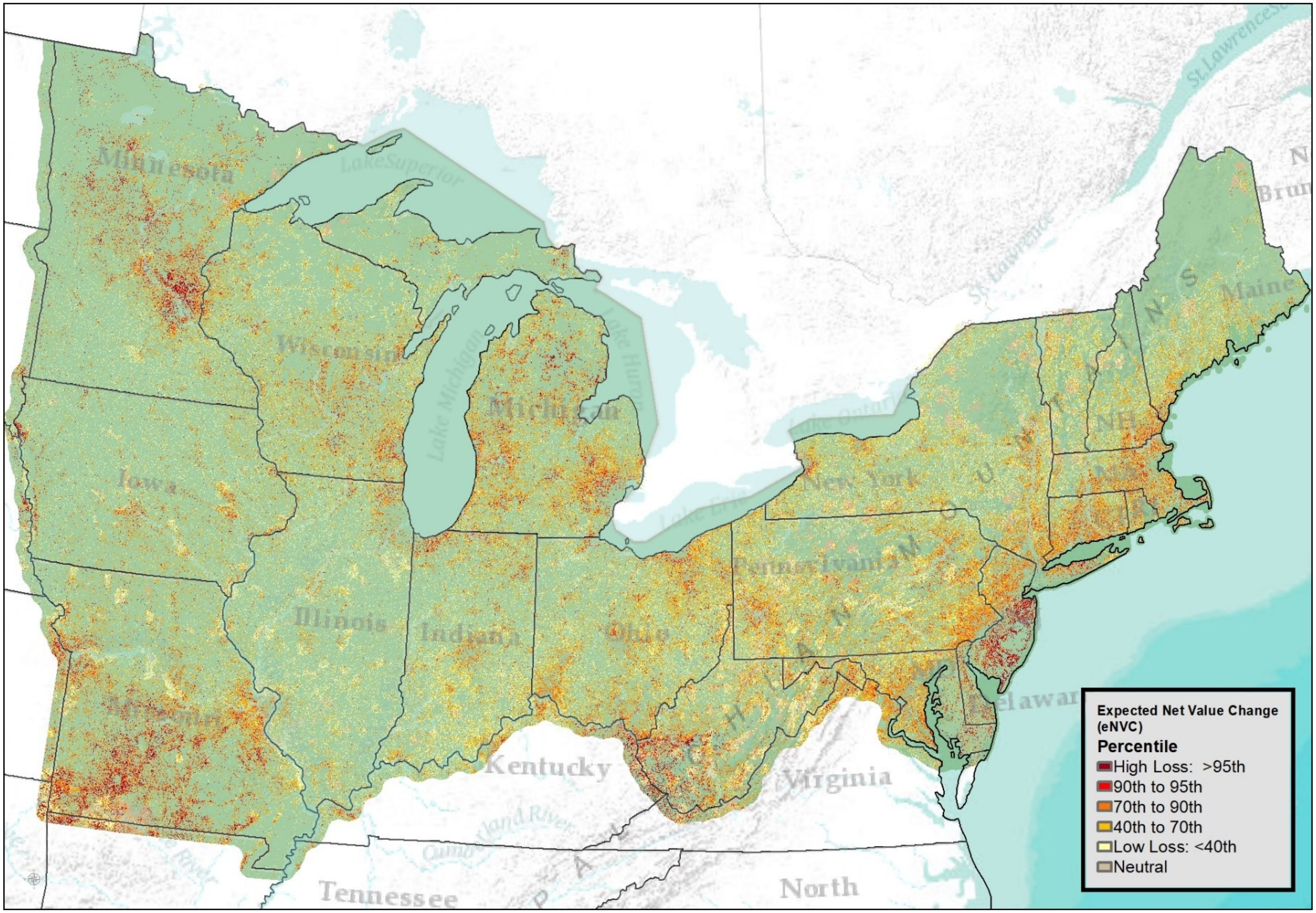

Figure 18. Map of Expected Net Value Change (eNVC) at 30-m for the analysis area.

5.1.4 WILDFIRE TRANSMISSION (RISK-SOURCE ANALYSIS)

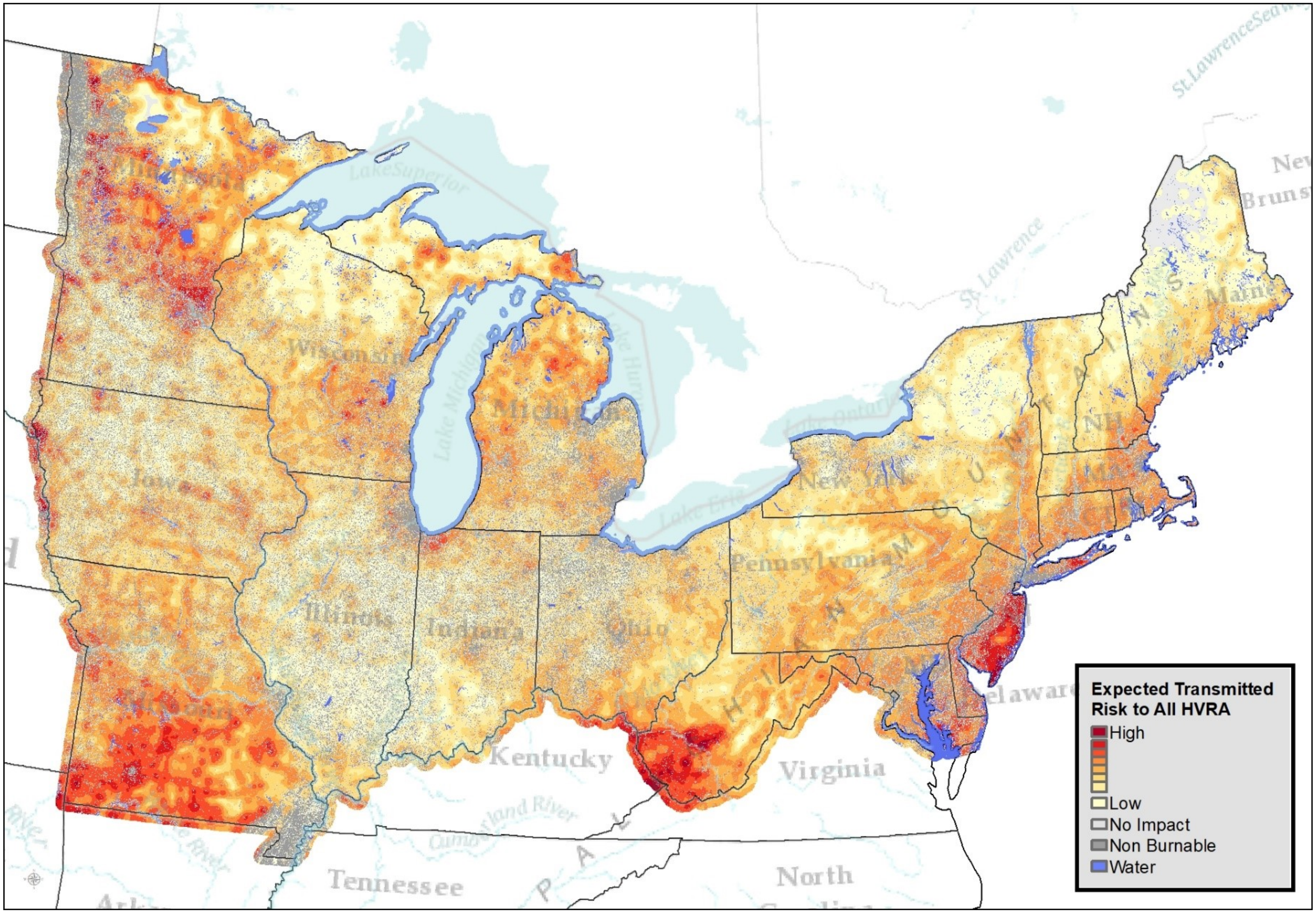

Figure 19. Map of the annual wildfire transmission risk (eRiskSource_allHVRA.tif) to all HVRA from ignitions across the landscape.

5.1.5 RELATIVE SUPPRESSION COST INDEX

The rSCI map (Figure 20) shows the relative estimated cost of the 90th percentile fire size generalized across the landscape. In general, the map of rSCI shows that portions of the landscape with the potential for the most costly wildfires are also generally the areas with the potential for larger fires (as identified in the burn probability map (Figure 17) and ERRA Wildfire Hazard Report[2]).

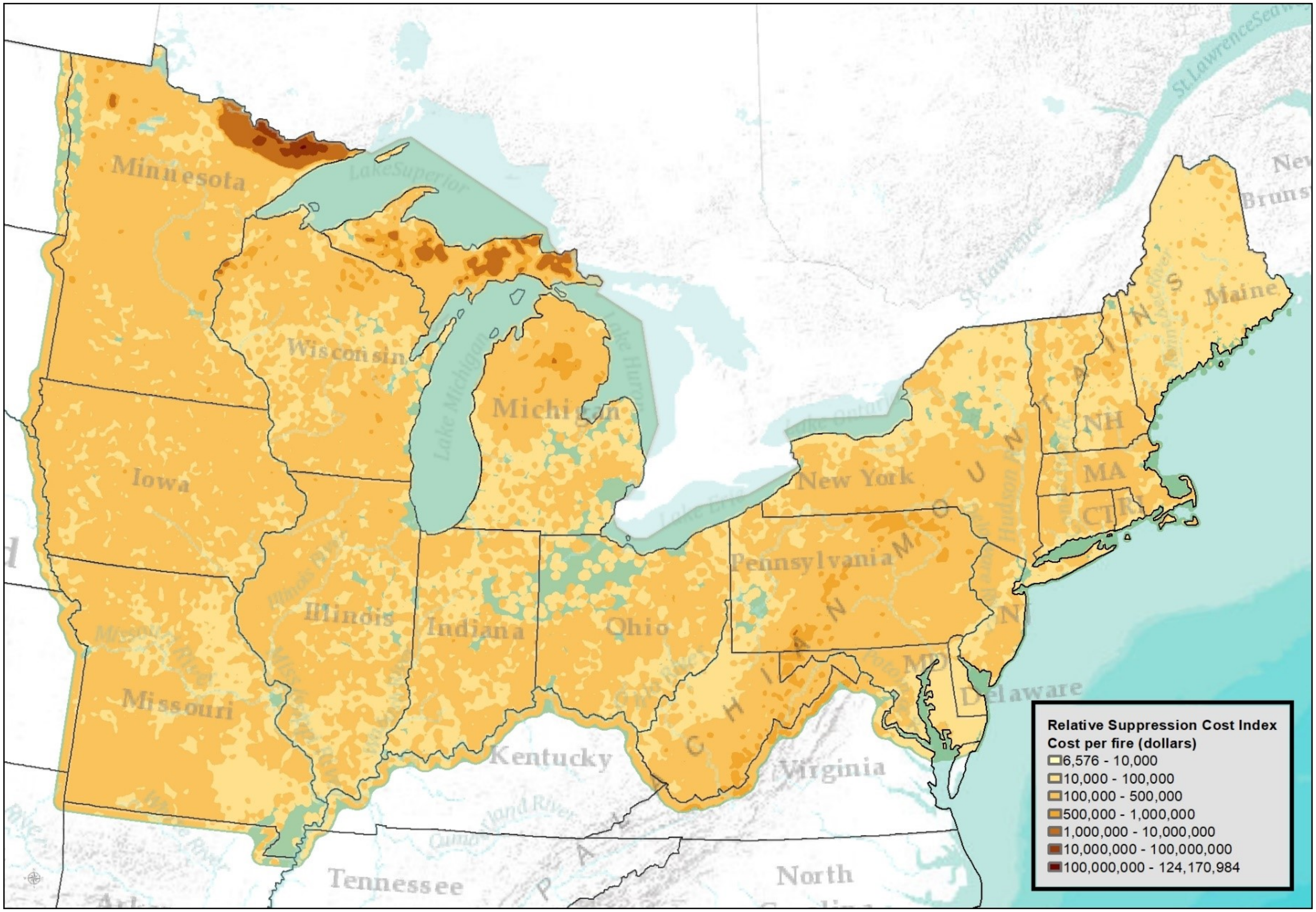

Figure 20. Relative Suppression Cost Index based on 90th percentile ERC values and 90th percentile large-fire size.

6 ANALYSIS SUMMARY

The ERRA Wildfire Risk Assessment provides foundational information about wildfire hazard and risk across the Eastern Region. The results represent the best available science across a range of disciplines. While this report was generated by Pyrologix LLC, the overall analysis was developed as a collaborative effort with numerous agencies, across a range of disciplines. This analysis can provide great utility in a range of applications including resource planning, prioritization and implementation of prevention and mitigation activities, and wildfire incident response planning. Lastly, this analysis should be viewed as a living document. While the effort to parameterize and calibrate model inputs should remain static, the landscape file should be periodically revisited and updated to account for future forest disturbances.

7 REFERENCES

Ager, A, Evers, C., Paleologos, P., Bunzel, K., Ringo, C., 2017. An Assessment of Community Wildfire Risk in Chelan County. In. USDA Forest Service, Online Report.

Buckley, M., Beck, N., Bowden, P., Miller, M.E., Hill, B., Luce, C., Elliott, W.J., Enstice, N., Podolak, K., Winford, E., Smith, S.L., Bokach, M., Reichert, M., Edelson, D., Gaither, J., 2014. Mokelumne Watershed Avoided Cost Analysis: Why Sierra Fuel Treatments Make Economic Sense. In. The Nature Conservancy, USDA Forest Service, and Sierra Nevada Conservancy, Auburn, California. https://sierranevada.ca.gov/our-work/mokelumne-watershed-analysis/macafullreport.

Bunzel, K; Ager, A.A. Day, M.A..; Dillon, G.K. 2021. Community Zones For Assessing Wildfire Exposure in the United States. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/rds-2021-0046

Calkin, D., Ager, A., Gilbertson-Day, J., eds. 2010. Wildfire Risk and Hazard: Procedures for the First Approximation. In, Gen. Tech. Rep. RMRS-GTR-235. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, p. 62.

Finney, M.A., 2005. The Challenge of Quantitative Risk Analysis for Wildland Fire. Forest Ecology and Management 211, 97-108.

Finney, M.A., McHugh, C., Grenfell, I.C., Riley, K.L., Short, K.C., 2011. A Simulation of Probabilistic Wildfire Risk Components for the Continental United States. Stochastic Environmental Research and Risk Assessment 25.7, 973-1000.

Gebert, K.M, Calkin, D.E., Yoder, J. 2007. Estimating suppression expenditures for individual large wildland fires. Western Journal of Applied Forestry 22(3),188-196.

Park, J.S. and Oh, S.J. (2013). A New Concave Hull Algorithm and Concaveness Measure for n-dimensional Datasets. Journal of Information Science and Engineering. 29. 379-392.

Scott, J., 2018. A Deterministic Method for Generating Flame-Length Probabilities. In: U.S. Department of Agriculture, F.S., Rocky Mountain Research Station (Ed.), Proceedings of the Fire Continuum – Preparing for the Future of Wildland Fire; 2018 May 21-24, Missoula, MT. Proceedings RMRS-P. Fort Collins, CO.

Scott, Joe H.; Brough, April M.; Gilbertson-Day, Julie W.; Dillon, Gregory K.; Moran, Christopher. 2020. Wildfire Risk to Communities: Spatial datasets of wildfire risk for populated areas in the United States. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2020-0060.

Scott, J., Thompson, M., Calkin, D., 2013. A Wildfire Risk Assessment Framework for Land and Resource Management. In, Gen. Tech. Rep. RMRS-GTR-315. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, p. 92.

Scott, J.H., 2006. An Analytical Framework for Quantifying Wildland Fire Risk and Fuel Treatment Benefit. USDA Forest Service Proceedings RMRS-P-41.

Short, K., Grenfell. I., Riley, K.; Vogler, K., 2020. Pyromes of the Conterminous United States. In. Forest Service Research Data Archive, Fort Collins, CO. https://doi.org/10.2737/RDS-2020-0020.

Thompson, M.P., Scott, J.H., Helmbrecht, D., Calkin, D.E., 2013. Integrated Wildfire Risk Assessment: Framework Development and Application on the Lewis and Clark National Forest in Montana, USA. Integrated environmental assessment and management 9, 329-342.

8 DATA PRODUCTS

The Eastern Region Wildfire Risk Assessment required the development of a wide range of data products. The section below outlines those datasets, with a brief description, based on provided data deliverables. More detailed descriptions of data product background and development procedures can be found in the metadata of each data product.

Deliverable Folder	Data Product	Description
	HVRA Characterization	
1.1	HVRA Spatial Data	The subfolder contains an ESRI 10.7 geodatabase that contains ten, 30-m HVRA rasters used as inputs for the risk calculations: Drinking water, communication sites, natural gas pipelines, oil & gas wells, power plants, substations, railroads, transmission lines, people & property, and historic buildings/sites/structures.
1.2	Table of final RFs/RIs	The subfolder contains an Excel file containing a table of response functions and relative importance values for each assessed HVRA.

Deliverable Folder	Data Product	Description
	Effects Analysis	
2.1.3	Risk and consequence results (e/cNVC)	The subfolder contains two ESRI ArcMap geodatabases that contain rasters representing conditional and expected NVC results for all assessed HVRA individually (people & property, infrastructure, cultural/historic, and drinking water), and in total.

2.9	Relative Suppression Cost Index (rSCI)	The subfolder contains a 240-m rSCI raster in TIFF format representing the relative cost of suppressing fires across the landscape as a function of general landscape and wildfire characteristics. The subfolder also contains an ESRI ArcMap 10.3 layer file for recommended rSCI symbology.
2.10	Risk Source Analysis	The subfolder contains two 30-m risk source rasters in TIFF format representing the *Expected Impact to Population* and *Expected Transmitted Risk to all HVRA*. The subfolder also contains an ESRI ArcMap 10.3 layer file for recommended symbology
2.11	Risk to Communities (Community Exposure)	This subfolder contains community summaries – spreadsheets and spatial data – for all communities in the analysis extent. The top 20 most exposed communities are highlighted in a separate spatial layer.
2.12	Community Firesheds	This subfolder contains one feature class identifying the spatial extent of the firesheds associated with the top 10 most at-risk communities in each state. The attribute table identifies each community's rank in the state and in ERRA.

9 APPENDIX A - WILDFIRE RISK TO COMMUNITIES

In addition to the wildfire risk assessment analysis, we completed an assessment of hazard and risk to communities in the Eastern Region. The concept of summarizing wildfire risk to homes within a set of pre-defined communities is well-established. In 2018, Pyrologix produced a report titled "Exposure of human communities to wildfire in the Pacific Northwest" for the Pacific Northwest Region of the U.S. Forest Service[7]. That report identified the most at-risk communities in terms of 1) the mean risk to all housing units in a community, and 2) the cumulative risk within the community, which increases with community size (population). Following that analysis, the Wildfire Risk to Communities[8] project was established by the U.S. Forest Service; it produced a nationwide summary of wildfire risk to communities by generating nationally consistent web maps, summary statistics, downloadable spatial data and tables, and more for the conterminous U.S., Alaska, and Hawaii.

Using many of the same metrics established in previous, similar efforts, we summarized wildfire risk and hazard for all communities in the twenty northeastern states within the Eastern Region. The datasets and methods used and resulting community rankings are discussed in the sections below.

9.1 DATASETS USED

9.1.1 HOUSING-UNIT DENSITY

The housing-unit density (HUDen) map used here is the same source dataset that was introduced in section 3.3.2.1.1 above. Here, housing-unit density was converted to a count of homes by multiplying by the area in square kilometers of a 30-m pixel (0.0009). We use continuous values of housing units rather than grouping by a density class as was done for the HUDen HVRA used in the risk assessment analysis.

For this assessment, housing units were considered *directly* exposed to wildfire if they were located on burnable land cover[9] and otherwise, considered *not exposed*.

9.1.2 COMMUNITIES

For this assessment, a community "core" was defined as a Populated Place Area (PPA) as identified by the U.S. Census Bureau. PPAs include incorporated cities and towns as well as Census Designated Places (CDPs). A CDP is an unincorporated concentration of population—a statistical counterpart to incorporated cities and towns.

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[7] See report titled "Exposure of human communities to wildfire in the Pacific Northwest"

[8] www.wildfirerisk.org

[9] Burnable and nonburnable land cover is characterized by the LANDFIRE Remap 2016 FBFM40 data layer (www.landfire.org), with calibration edits informed by local expert knowledge. Burnable land cover includes land covered by grasses, forbs, shrubs, tree litter, understory trees, or logging slash. Nonburnable land cover includes urban areas, irrigated agricultural land, permanent snow or ice, bare ground, and open water.

We refer to the U.S. Census PPA delineation as the community "core", but the summary unit of interest is the "Expanded Community" which includes the populated area and structures surrounding the PPAs. Bunzel et al. (2021) used a travel-time analysis to delineate the land areas closest by drive-time to each PPA core, up to a maximum of 45 minutes travel time.

Approximately 99.9 percent of the housing units identified by HUDen within the project's Analysis Area extent can be found within these Expanded Community areas (Figure 21). Less than one percent of the total housing units are not within 45-minutes travel time of any expanded community (hereafter, "community") identified in the Eastern Region.

9.1.3 BURN PROBABILITY

This assessment relies on wildfire behavior simulations produced using a comprehensive wildfire occurrence, growth, and behavior simulation system called FSim (Finney et al. 2011). The FSim model works by simulating 10,000 or more "iterations" to produce spatial data representing annual burn probability—the annual likelihood that a wildfire will reach a given point on the landscape. Each iteration is a possible realization of a complete calendar year. More details on the FSim methods for the Eastern Region can be found in the full report.

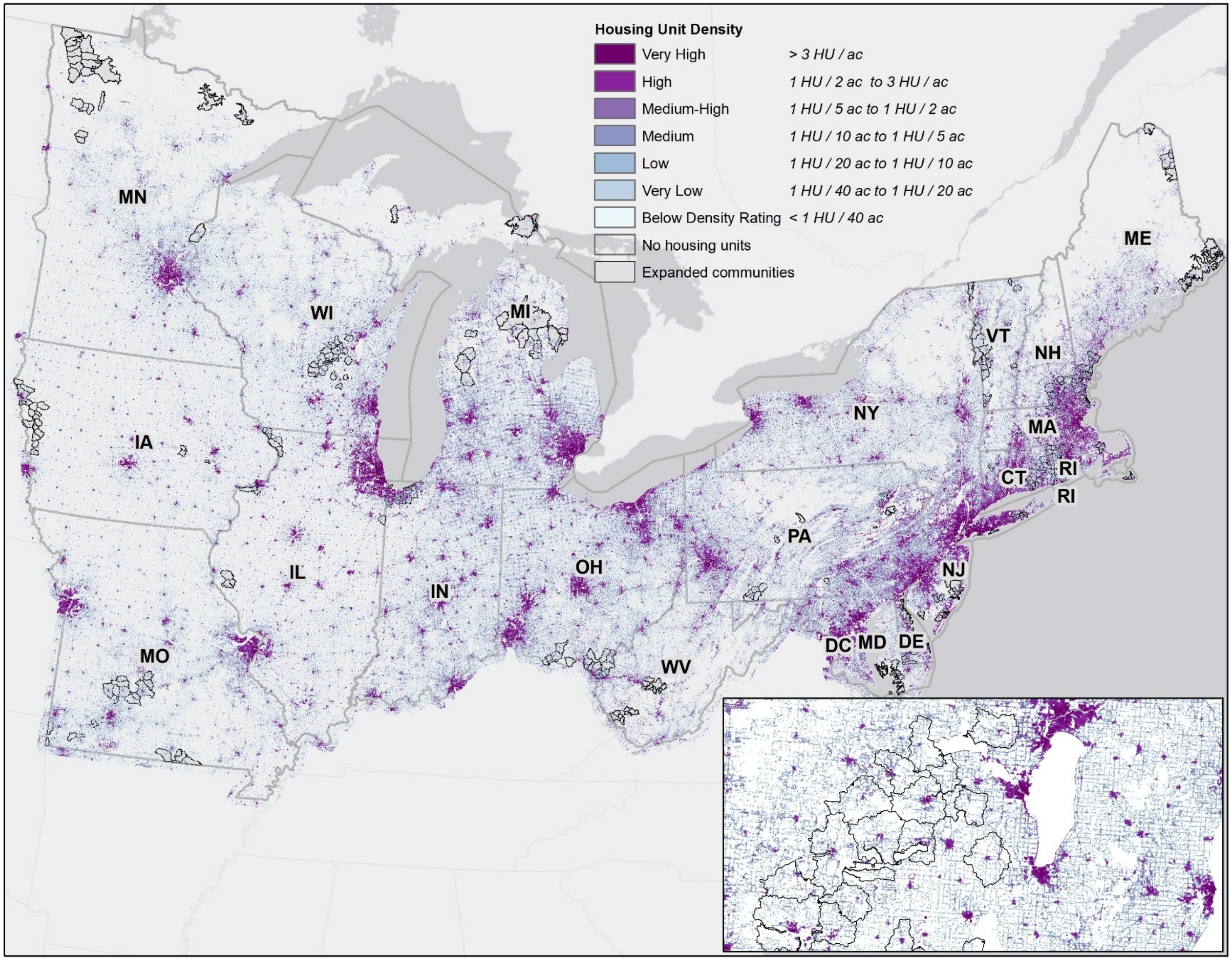

Figure 21. Housing units mapped in ERRA and the expanded community boundaries with which they are associated. Only the top 20 most at-risk community boundaries are shown.

9.1.4 CONDITIONAL RISK TO POTENTIAL STRUCTURES

For this assessment, we use an index of wildfire consequence that measures fire intensity in the context of its potential for damage to a generic residential structure. That is, we apply a stylized, generic response function (RF) to characterize the potential for housing-unit damage from wildfire as a function of fire intensity. The RF is not specific to any type of structure, construction materials, community mitigation measures, or home ignition zone fuel complexes. Instead, we simply attempt to capture the range of home losses possible at different intensities or flame lengths. The response function characterizing potential consequences to an exposed structure was applied to all exposed fuel types on the landscape regardless of whether an actual structure is present. The response function values applied are shown in Table 13.

Table 13. Table of response function (RF) values used by Fire Intensity Level (flame-length class) to calculate Conditional Risk to Potential Structures (cRPS). This effect of wildfire on homes is *adverse* at any Fire Intensity Level; the larger the response-function value, the greater the potential for adverse effects.

Fire Intensity Level	Response Function value
0<FL<2	25
2<FL<4	40
4<FL<6	55
6<FL<8	70
8<FL<12	85
12<FL	100

A given location on the landscape can burn at a range of intensity values depending on the weather and spread direction at the time of burning. Spread direction refers to the alignment of the flaming fire front relative to the direction of maximum spread. When aligned, fire intensity is at its peak. This occurs at the "head" of the fire, and fire simulation models inherently estimate fire intensity for the head. But the alignment of the flame front with respect to the direction of maximum spread varies around the perimeter of a fire. Fire intensity is lowest where the flame front is spreading opposite the direction of maximum spread—a backing fire.

Given the wide range of fire intensity that can be produced for the same fuel complex from different weather conditions and spread directions, the estimation of cRPS comes by first estimating the relative probabilities of the flame-length classes occurring—called flame-length probability (FLP). For a given location, the FLPs for the six Fire Intensity Levels defined above must always sum to 1 (unless the location is not exposed to wildfire).

For this assessment of risk to homes, the FLPs were developed at a 30-m resolution from the WildEST wildfire behavior results. Please reference the full ERRA Wildfire Hazard Report[2] for more information on WildEST methods and products.

9.1.5 RISK TO POTENTIAL STRUCTURES (RPS)

Risk to Potential Structures (RPS) is the simple product of BP and cRPS; that is, it represents risk to homes as the product of likelihood and consequence. Because we map RPS across all land—not just land near homes—it can be used to assess wildfire risk in places where development may be considered but is not yet built. RPS incorporates spatial data regarding the fire environment—fuel, weather, and topography—as well as spatial and temporal data regarding historical wildfire occurrence. The map of RPS is located in section 4.1 of the ERRA Wildfire Hazard Report.

9.1.6 HOUSING-UNIT RISK (HURISK)

The product of housing-unit count and RPS is called housing-unit risk (HURisk). This raster layer incorporates all of the risk elements including burn probability and intensity information, susceptibility characterized by the response function in Table 13, and exposure by identifying where homes are along with an estimated count in each pixel. It takes *both* the presence of non-zero burn probability and intensity and the presence of housing units to have a value of HURisk greater than zero.

9.2 METHODS AND RESULTS

9.2.1 SUMMARIZING BY COMMUNITIES

We summarize numerous population, housing-unit, hazard, and risk attributes to produce the assessment we call Wildfire Risk to Communities. The results of this analysis are spreadsheet tables of attributes by community name and associated GEOID and a feature class of Community "zones" with these attributes joined back to each feature. The feature class can be used to make maps of the top at-risk communities, overlay wildfire hazard or risk maps, or make thematic maps of mean hazard or risk by community. These attributes provide a wealth of information to sort and rank communities by the various metrics. The second tab in the supplemental data table provides a short description of each field to assist users with navigating the many community and wildfire hazard metrics. Table 14 provides a subset of attributes to highlight the top 30 communities at risk sorted by mean RPS. The complete summary for all communities in the Eastern Region is available as a supplemental data table[10].

9.2.2 MEAN RPS WHERE HOMES EXIST

We calculated the mean RPS where housing units are located within each community. This measure represents the mean likelihood that a given housing unit in a community will experience loss to wildfire in one year. The higher this value, the more likely it is that an individual housing unit within the community will experience a wildfire. Mean RPS is not a cumulative measure for a community, so it does not necessarily increase as the number of housing units increases. Instead, this measure is sensitive to the general location of a community relative to the mapped wildfire hazard and the specific locations of housing units with each community.

Ranking communities by RPS highlights the communities with the greatest potential for wildfire losses but does not consider the population or number of housing units residing in the community. The hazard rating provides information useful in prioritizing mitigation efforts – i.e. this community is most likely to experience losses – but without the magnitude of wildfire impacts, the scope of needed mitigation is unknown.

Figure 22 displays a scatterplot showing the relationship between mean burn probability and mean Conditional Risk to Structures (cRPS) – the components of mean Risk to Potential Structures.

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[10] ERRA Risk to Communities data table:
http://pyrologix.com/reports/ERRA_Risk_to_Communities_All_States.xlsx

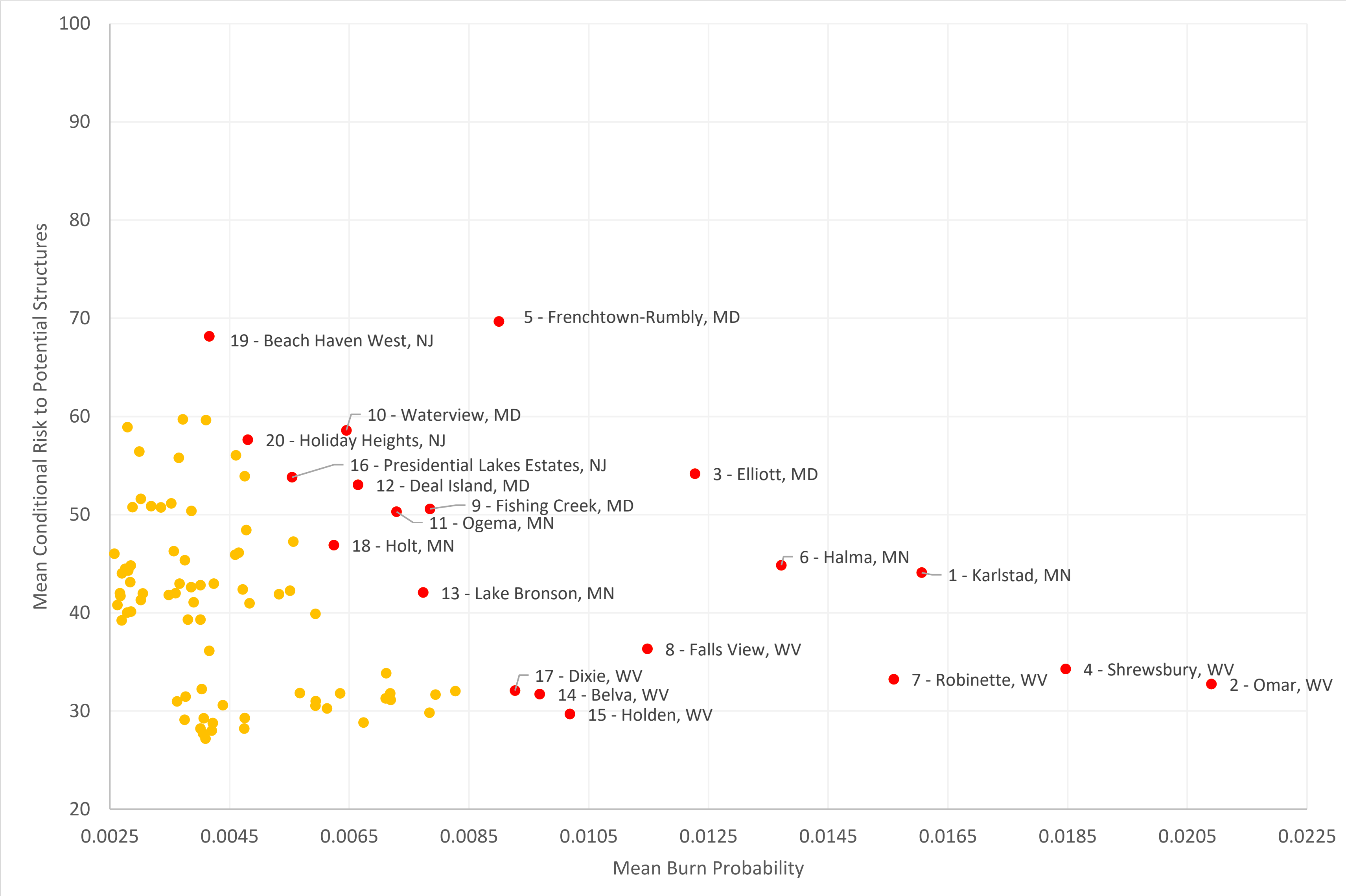

Figure 22. Scatterplot for the top 100 most at-risk communities across the Northeast of Mean Burn Probability and Mean Conditional Risk to Potential Structures - the product of which is Risk to Potential Structures (RPS). The top 20 communities are shown in red.

Table 14. The top 30 communities across the Northeast as ranked by greatest mean Risk to Potential Structures (RPS) where structures are found in the community.

Community Name	HU count	Fraction HUcount directly exposed	Fraction HUcount not exposed	Exposed HU count	Mean RPS all exposed	Rank Mean RPS	Rank mean RPS w/in state	Expected annual HU risk	Rank Expected annual HU risk
Karlstad - MN	686	49%	51%	333	0.71	1	1	217	37
Omar - WV	453	65%	36%	291	0.68	2	1	48	411
Elliott - MD	35	88%	12%	31	0.66	3	1	10	2,296
Shrewsbury - WV	323	32%	68%	104	0.63	4	2	45	444
Frenchtown-Rumbly - MD	31	82%	18%	26	0.63	5	2	15	1,546
Halma - MN	119	62%	38%	73	0.62	6	2	44	460
Robinette - WV	832	62%	38%	514	0.52	7	3	70	245
Falls View - WV	102	49%	51%	50	0.42	8	4	17	1,365
Fishing Creek - MD	398	73%	27%	293	0.40	9	3	80	205
Waterview - MD	17	85%	15%	15	0.38	10	4	4	4,728
Ogema - MN	264	56%	44%	148	0.37	11	3	67	257
Deal Island - MD	188	83%	17%	156	0.35	12	5	38	572
Lake Bronson - MN	258	52%	48%	133	0.33	13	4	31	698
Belva - WV	494	75%	26%	368	0.31	14	5	96	170
Holden - WV	777	69%	30%	542	0.30	15	6	111	137
Presidential Lakes Estates - NJ	1,866	79%	21%	1,466	0.30	16	1	189	54
Dixie - WV	**1,761**	**66%**	**34%**	**1,160**	**0.30**	**17**	**7**	**326**	**10**
Holt - MN	262	49%	51%	129	0.29	18	5	27	842
Beach Haven West - NJ	2,022	7%	93%	139	0.28	19	2	32	697
Holiday Heights - NJ	1,136	20%	80%	225	0.28	20	3	22	1,026
Sarah Ann - WV	497	80%	20%	397	0.27	21	8	66	262
Dames Quarter - MD	268	79%	21%	212	0.26	22	6	58	319
Ocean Acres - NJ	**14,039**	**28%**	**72%**	**3,926**	**0.26**	**23**	**4**	**319**	**13**
Cedar Glen Lakes - NJ	1,518	40%	61%	588	0.26	24	5	78	213
Stollings - WV	337	59%	42%	194	0.25	25	9	13	1,762
Mystic Island - NJ	6,529	28%	72%	1,814	0.24	26	6	203	47
Gauley Bridge - WV	352	52%	48%	184	0.24	27	10	23	989
Strathcona - MN	234	53%	47%	125	0.24	28	6	28	808
Belle - WV	1,420	37%	63%	525	0.23	29	11	101	156
Lancaster - MN	472	43%	57%	202	0.23	30	7	33	648

9.2.3 CUMULATIVE ANNUAL WILDFIRE RISK TO HOUSING UNITS

As a measure of cumulative wildfire risk to housing units, we calculated the product of housing units per pixel and RPS and summed that value for all pixels within a community. Summing HURisk within each community provides a measure of cumulative annual wildfire risk to each community. Because HURisk includes housing-unit count in addition to RPS, it is in part dependent on the "size" of a community—the population or number of housing units.

This measure is useful in resource allocation and can address the question: "In which communities are the total consequences of wildfire the greatest?" Unlike the previous measure, the total number of housing units strongly influences the Expected Annual Housing-Unit Risk (HURisk). Some communities, like Springfield, Missouri, have relatively low mean RPS but rank high in total HURisk because of the very high number of housing units. Figure 23 displays a scatterplot showing the relationship between mean Risk to Potential Structures and total exposed housing units – the components of total HURisk.

Housing-unit risk is the secondary variable by which the summary communities are ranked (Table 15). The top 30 communities ranked by total HURisk are shown in Table 15, however, all communities within the Eastern Region are summarized in the supplemental data table[10].

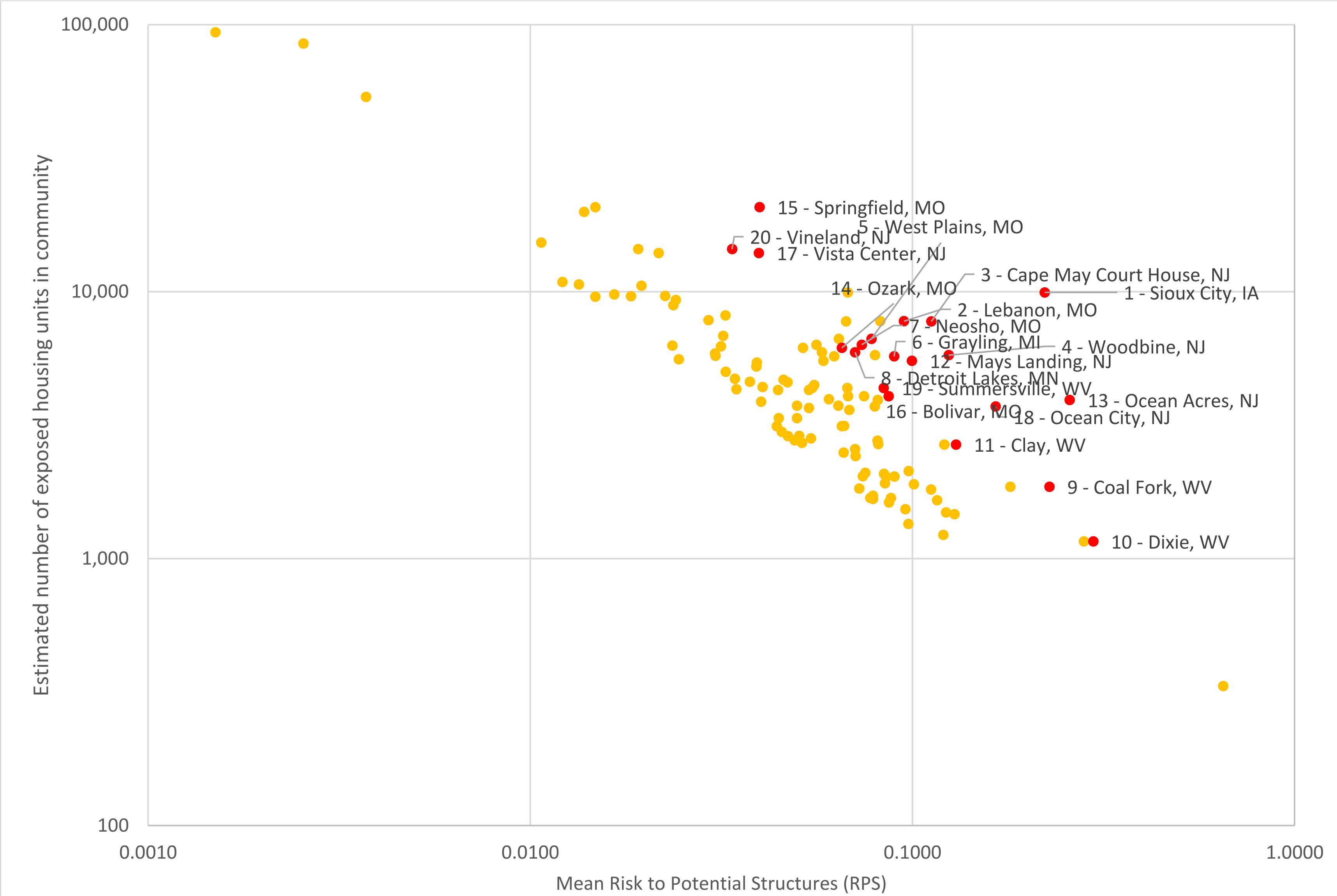

Figure 23. for the top 100 most at-risk communities across the Northeast of Mean Risk to Potential Structures (RPS) and estimated number of exposed housing units per community - the product of which is the total housing unit risk (HURisk). The top 20 communities are shown in red.

Table 15. The top 30 most at-risk communities across the Northeast as ranked by expected annual housing-unit risk.

Community Name	HU count	Fraction HUcount directly exposed	Fraction HUcount not exposed	Exposed HU count	Mean RPS all exposed	Rank Mean RPS	Expected annual HU risk	Rank Expected annual HU risk	Rank Expected annual HU risk w/in state
Sioux City - IA	38,826	26%	74%	9,935	0.22	36	673	1	1
Lebanon - MO	13,104	59%	41%	7,747	0.10	116	638	2	1
Cape May Court House - NJ	11,847	65%	35%	7,737	0.11	90	519	3	1
Woodbine - NJ	8,100	72%	29%	5,781	0.12	75	461	4	2
West Plains - MO	10,723	62%	38%	6,659	0.08	165	428	5	2
Grayling - MI	8,980	64%	36%	5,723	0.09	130	357	6	1
Neosho - MO	10,034	63%	37%	6,326	0.07	191	355	7	3
Detroit Lakes - MN	10,484	56%	43%	5,928	0.07	207	344	8	1
Coal Fork - WV	2,461	76%	24%	1,859	0.23	32	335	9	1
Dixie - WV	1,761	66%	34%	1,160	0.30	17	326	10	2
Clay - WV	3,138	85%	15%	2,674	0.13	71	324	11	3
Mays Landing - NJ	10,565	52%	48%	5,502	0.10	106	322	12	3
Ocean Acres - NJ	14,039	28%	72%	3,926	0.26	23	319	13	4
Ozark - MO	12,457	49%	51%	6,154	0.07	244	318	14	4
Springfield - MO	106,789	20%	81%	20,735	0.04	557	307	15	5
Bolivar - MO	8,084	50%	50%	4,055	0.09	136	303	16	6
Vista Center - NJ	22,894	61%	39%	13,947	0.04	560	302	17	5
Ocean City - NJ	18,476	20%	80%	3,712	0.17	55	296	18	6
Summersville - WV	6,147	71%	29%	4,355	0.08	146	294	19	4
Vineland - NJ	28,112	51%	49%	14,424	0.03	659	277	20	7
Somers Point - NJ	11,108	37%	63%	4,058	0.17	53	275	21	8
Lakewood - NJ	56,282	35%	65%	19,881	0.03	703	275	22	9
Sault Ste. Marie - MI	16,929	43%	52%	8,142	0.04	509	264	23	2
Salem - MO	6,629	68%	33%	4,471	0.06	295	247	24	7
Fair Grove - MO	4,105	88%	12%	3,605	0.07	190	246	25	8
Rogersville - MO	4,870	75%	23%	3,738	0.07	229	239	26	9
Marshfield - MO	6,055	65%	35%	3,952	0.07	195	239	27	10
Princeton - MN	7,496	61%	42%	4,357	0.06	266	238	28	2
East Bethel - MN	5,508	78%	22%	4,286	0.07	227	230	29	3
Rolla - MO	15,451	51%	49%	7,817	0.04	506	229	30	11

9.3 COMMUNITY FIRESHEDS

The sections above in the Wildfire Risk to Communities analysis assess in situ wildfire risk and exposure. We also investigated transmitted risk to the top 10 most at-risk communities in each state as defined by mean RPS in the previous section (9.2.2), by mapping the "fireshed" associated with each community.

A fireshed is defined in this analysis as the area within which wildfires can ignite and reach the population mapped within a community. The fireshed was created for each community by drawing a polygon around the simulated ignition locations associated with final perimeters that reached populated areas within the community. The final fireshed polygon was a result of a series of steps intended to control for the inherent randomness in variables such as future fire ignition locations and the inability to model fire growth at every location and in every weather scenario in the stochastic simulations. First, a concave hull[11] was drawn around simulated ignition locations. These ignition points were filtered by those that reached population within the community to identify only the locations where ignitions have the potential for damage to homes (as represented by PopDen >0). The concave hull polygon was then buffered by 300 m and smoothed using a Gaussian kernel regression to simultaneously generalize and reduce jagged edges in the fireshed boundary.

Figure 24 shows the fireshed map for Erskine, MN and associated simulated ignitions that reach population. The fireshed is plotted over the ERRA burn probably map to illustrate the location of ignitions relative to burnable fuel. Areas mapped as gray in the burn probability map are, by definition, unable to produce ignitions in the wildfire modeling. In this community's fireshed, 98 percent of the ignitions that impact the community start within one mile of the community boundary.

The fireshed boundaries resulting from this analysis are included with the final project deliverables (please see the Data Products list in section 8).

[11] Following the algorithm described in Park and Oh (2013) as implemented in the concaveman R package. We used a concavity parameter of 3.5 to generate the concave hulls.

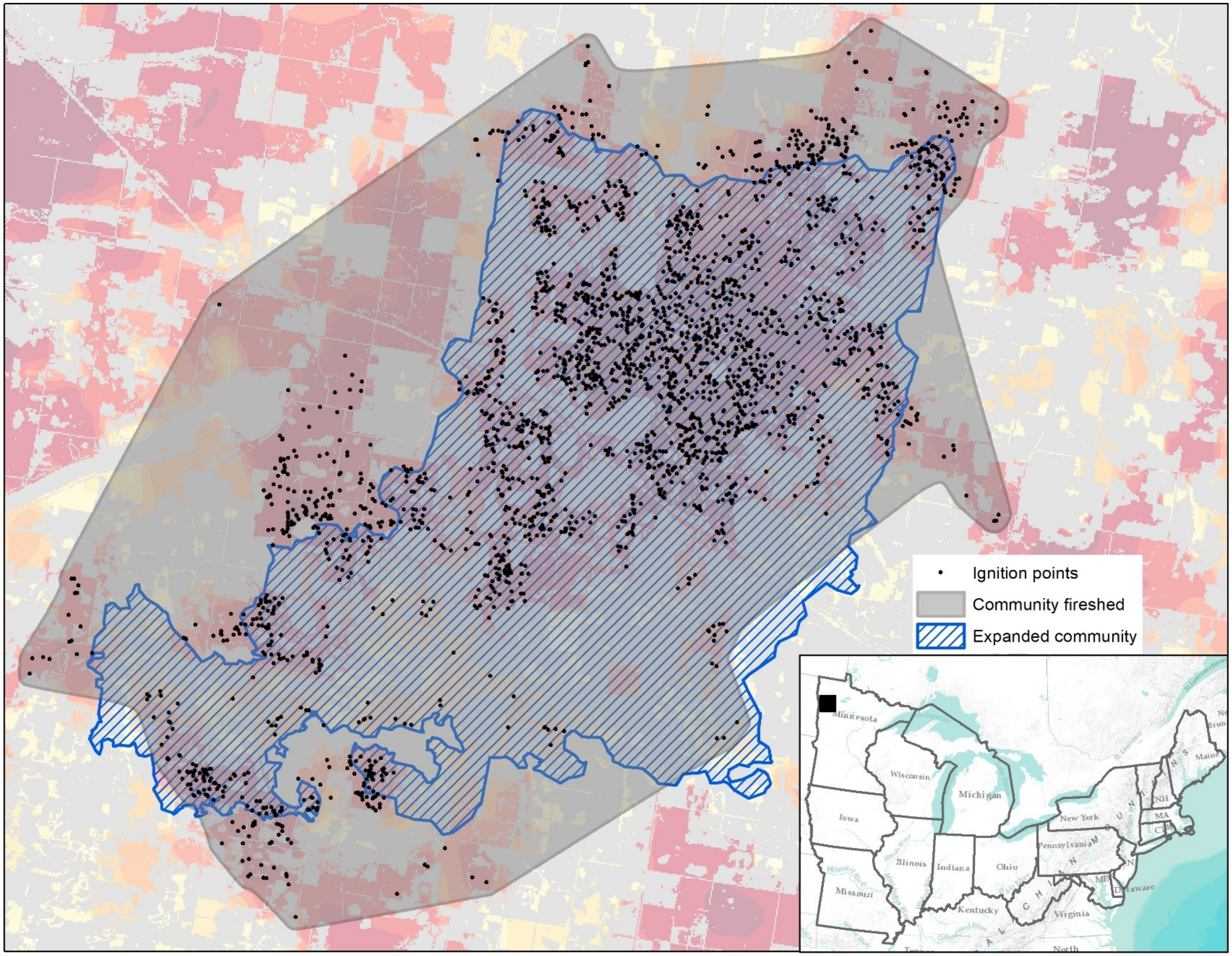

Figure 24. Example community fireshed for Eskine, MN mapped over the burn probably map for the Northeast. Ninety-eight percent of the ignitions that impact the community start within one mile of the expanded community boundary.

9.4 DISCUSSION

This assessment provides foundational information that should prove useful to a variety of organizations charged with mitigating wildfire risk to homes by allowing them to prioritize the most at-risk communities and locations on the landscape. For this application, the community-mean RPS summary is best—it highlights the communities with high exposure to wildfire, even if the population is low.

The data provided may also help in the allocation of mitigation resources. For that, the cumulative risk to homes can provide a guide because it incorporates the “size” of a community—population or housing units—in addition to its exposure to wildfire. A low-population high-priority community may not need as much mitigation effort (funding) as a lower priority but higher population community.

Among the most at-risk communities across the Eastern Region; Dixie, West Virginia, and Ocean Acres, New Jersey rank in the top 25 for both mean RPS and Expected Annual HURisk (Table 14 and Table 15, respectively). In general, homes in these communities have a higher average wildfire risk (mean RPS) and a relatively high number of homes are shown to be at-risk annually. Conversely, a community like Elliott, Maryland ranks 3rd in terms of mean RPS, but ranks as number 2,296 across ERRA in terms of cumulative HURisk, meaning fewer resources may be needed to reduce risk to homes in this community.

The wildfire hazard simulations used in this report generally represent conditions circa 2020, meaning fuelscape changes occurring after that time are not reflected in the fire modeling and community summary results. Rankings may change with updates to the fuelscape and wildfire hazard products in the future.

10 CHANGE LOG

The change log documents changes made to this document after the initial submission.

Date	Location of Change	Author	Description of Change
12/22/2021	-	-	Initial submission