CHUGACH ALL-LANDS WILDFIRE RISK ASSESSMENT: METHODS AND RESULTS

PREPARED FOR:  
USFS Alaska Region, R10  
Chugach National Forest

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1 OVERVIEW OF THE ASSESSMENT

1.1 PURPOSE OF THE ASSESSMENT

The purpose of the Chugach All-Lands Wildfire Risk Assessment (hereafter called ARRA) is to provide foundational information about wildfire hazard and risk to highly valued resources and assets for the Chugach National Forest and surrounding areas in Southcentral Alaska. Such information supports wildfire response, 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 ARRA analysis considers several different components, each resolved spatially across the region, including:

- 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.

Assets are human-made features, such as commercial structures, critical facilities, housing, etc., that have specific importance or value. Resources are natural features, such as wildlife habitat, vegetation type, or water, etc. These also have specific importance or value. Generally, the term “values at risk” has been used to describe both assets and resources. For the ARRA assessment, the term Highly Valued Resources and Assets (HVRA) is used to describe what has previously been labeled values at risk. There are two reasons for this change in terminology. First, resources and assets are not themselves “values” in any way that term is conventionally defined—they have value (importance). Second, while resources and assets may be exposed to wildfire, they are not necessarily “at-risk”—that is the purpose of the assessment.

To manage wildfire in Southcentral Alaska, accurate wildfire risk data are essential 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 (HVRA$s$) 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, 2017), a portion of a national forest (Thompson et al., 2013b), individual states (Buckley et al., 2014), to the entire

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ARRA is an acronym for the original title of the project—Alaska Region Risk Assessment.
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).

![Quantitative Wildfire Risk Assessment Framework](image)

**Figure 1.** The components of the Quantitative Wildfire Risk Assessment Framework used for ARRA.

**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 HVRA's, 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.

1.3 **LANDSCAPE ZONES**

1.3.1 **ANALYSIS AREA**

The Analysis Area is the area for which valid burn probability results are produced. The Analysis Area for the ARRA project was defined as the great Chugach National Forest area, including the Kenai Peninsula (ARRA).

1.3.2 **FIRE OCCURRENCE AREAS**

To prevent edge effects and ensure valid BP results, it is necessary to allow FSim fires to also start outside of the Analysis Area and burn inwards. This larger area where simulated fires are started is
called the Fire Occurrence Area (FOA). We established the FOA extent as a 30 km buffer on the Analysis Area. The buffer provides sufficient area to ensure that all fires capable of reaching the Analysis Area are simulated. The Fire Occurrence Area covers roughly 36.2 million acres characterized by diverse topographic and vegetation conditions. Such a large and diverse area will have highly variable historical fire occurrence and fire weather. To model the area’s diversity more accurately, the overall fire occurrence area was divided into two FOAs. 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, 2020), aggregated level IV EPA Ecoregions, and local fire staff input. For consistency with other FSim projects, we numbered these FOAs 101 and 102.

1.3.3 FUELSCAPE EXTENT
The available fuelscape extent was determined by adding a 30 km buffer to the FOA extent. This buffer allows fires starting within the FOA to grow unhindered by the edge of the fuelscape. Without such a buffer, fire growth would be artificially truncated and affect the fire-size distribution introducing errors in the calibration process. A map of the Analysis Area, FOA boundaries, and fuelscape extent are presented in Figure 2.
2 ANALYSIS METHODS AND INPUT DATA

The FSim large-fire simulator was used to quantify wildfire likelihood across the Analysis Area at a pixel size of 120 meters. 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).

FSim focuses on the relatively small fraction of wildfires that escape initial attack and become "large" (>100 acres). Since the occurrence of large fires is relatively rare, FSim generates many thousands of years of simulations to capture a sample size large enough to generate burn probabilities for the entire landscape. An FSim iteration spans one entire year. All FOAs within the ARRA project area were run with 100,000 iterations.

There is no temporal component to FSim beyond a single wildfire season, consisting of up to 365 days. FSim performs independent (and varying) iterations of one year, defined by the fuel, weather, topography, and wildfire occurrence inputs provided. FSim does not account for how a simulated wildfire might influence the likelihood or intensity of future wildfires (even within the same simulation year). Each year represents an independent realization of how fires might burn given the current fuelscape and historical weather conditions. FSim integrates all simulated iterations into a probabilistic result of wildfire likelihood.

2.1 FUELSCAPE

A fuelscape is a quantitative raster representation of the fuels and topography of a landscape. 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). These datasets can be combined into a single landscape (LCP) file and used as a fuelscape in fire modeling programs.

In the following sections, we discuss the process of generating and updating the fuelscape. After development, the fuelscape was resampled to 120 meters for wildfire simulation. Additional information on customizing a fuelscape can be found in the LANDFIRE data modification guide (Helmbrecht and Blankenship, 2016).

2.1.1 FUELSCAPE INPUTS

The vegetation and disturbance inputs for the ARRA Fuelscape were derived from a combination of LANDFIRE 2014 (LF2014) 30 m raster data\(^2\) and the Kenai Vegetation Mapping Project\(^3\). Capitalizing on the new Kenai Peninsula data release, Pyrologix developed a custom fuelscape methodology. The approach is discussed in the following two sections. Although a custom approach

\(^2\) Additional information can be found on the LANDFIRE website at www.LANDFIRE.org.
\(^3\) Additional information can be found on the Kenai Vegetation Mapping Project at https://www.arcgis.com/apps/MapSeries/index.html?appid=4e21c25d5eac421babaef3222004cccf
was used to integrate the Kenai Peninsula vegetation data, the LANDFIRE Total Fuel Change Toolbar (LFTFCT, Smail et al., 2011) was used to generate the surface fuel (FM40) dataset.

### 2.1.1.1 ARRA FUELSCAPE

The ARRA fuelscape was created using the LANDFIRE Total Fuel Change Toolbar (LFTFCT). LFTFCT allows users to input existing vegetation and disturbance data, define fuel rulesets, and generate fuel grids. See the LFTFCT Users Guide for more information (Smail et al., 2011). The resulting LFTFCT output fuel grids can then be combined into a single landscape (LCP) file and used as a fuelscape input in various fire modeling programs.

### 2.1.2 FUELSCAPE CALIBRATION

The LANDFIRE fuel mapping process assigns fuel model and canopy characteristics using two primary input layers: Existing Vegetation Type (EVT) and LANDFIRE map zone. Using these inputs (and information about the fuel disturbance(s), vegetation height and cover, and biophysical setting), a surface fuel model assignment is queried from the LANDFIRE ruleset database and, if applicable, canopy characteristics for the given EVT and map zone. When working with a large project extent, such as ARRA, numerous map zones are present. The challenge in fuelscape calibration is to produce a fuelscape without artificial and often arbitrary seamlines. To do so, the rules from multiple zones must be reconciled and filtered to one rule set per EVT. As an unbiased approach to reconciling rules from multiple map zones, we determined which zone holds the greatest share of each EVT on the landscape and applied those rules across the entire fuelscape. These rulesets were then unified to produce a preliminary Fuelscape. A Fuelscape calibration workshop was then conducted to further customize and calibrate rulesets to the project’s area of interest.

Prior to the fuel calibration workshop, we produced an initial set of fire behavior results with gNexus\(^4\) using the preliminary fuelscape. The gNexus results include maps of Rate of Spread (ROS), Heat Per Unit Area (HPUA), Flame Length (FL), Fireline Intensity (FIL), Crown Fraction Burned (CFRB), Torching Index (TI), and Crowning Index (CI). These maps were then summarized by rule in the LFTFCT database for landscape critique and evaluation by workshop participants.

From this analysis, a prioritized list of EVTs was determined to focus calibration efforts. The set of EVTs reviewed in the fuel calibration workshop were identified as being among the top ten most abundant EVTs, EVTs that encompass a large portion of the Analysis Area, and EVTs with inconsistencies in fire behavior across the range of vegetation cover and height values (i.e. passive crown fire is possible at all windspeeds for part of the rule while the remainder of the rule could only experience surface fire under all observable windspeeds).

The ARRA fuel calibration workshop was held on September 24-25, 2019 in Anchorage, AK. At the workshop, we solicited feedback from local fire and fuels staff from the Chugach National Forest as well as interagency partners across the Southcentral AK. The intent of the workshop was to review

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\(^4\) gNexus is a custom spatial implementation of the fire behavior calculator software, NEXUS 2.1 (available at http://pyrologix.com/downloads/)
the preliminary gNexus fire modeling results and refine the rulesets to produce fire behavior results consistent with the experience of workshop participants.

In addition to calibrating fuel rulesets, both the surface and canopy inputs were updated to reflect fuel disturbances occurring between 2015 and 2019, inclusively. Pyrologix gathered fuel disturbances across the region and assigned appropriate disturbance codes. Fuel disturbances included events such as mechanical treatments, prescribed fire, wind events, insect mortality, and wildfires. Datasets were collected from a variety of sources but included sources such as the USFS Forest Service Activity Tracking System (FACTS) and the Department of Interior National Fire Plan Operations & Reporting System (NFPORS).

Pyrologix incorporated recent wildfire disturbances using three different sources: Monitoring Trends in Burn Severity (MTBS) data, Burned Area Reflectance Classification (BARC), and Alaska Interagency Coordination Center (AICC) perimeter data. We gathered severity data as available from MTBS and BARC, where severity data were unavailable, we relied on final perimeters from AICC. We cross-walked MTBS/BARC severity to the appropriate LANDFIRE disturbance code (112, 122, or 132) corresponding with fire disturbances of low, moderate, or high severity, occurring in the past one to five years. AICC perimeters were assigned a severity disturbance code of 122.

After disturbances were incorporated into the final calibrated fuelscape, we generated the ARRA fuel raster shown by the fuel-model group in Figure 3.

Figure 3. Map of fuel-model groups across the ARRA LCP extent.
An additional ARRA fuelscape edit warrants highlighting: the development of a “Ghost Canopy” for EVT 2604 (Western North American Boreal Mesic Black Spruce Forest). The edit involved a ‘Ghost Canopy’ adjustment for the Western North American Boreal Mesic Black Spruce Forest vegetation type, EVT 2604. This adjustment better captures fire behavior associated with the vegetation type through the use of the appropriate surface fuel model, but with canopy fuel parameters to allow for embers without the wind reduction influence on the rate of spread. To achieve this effect, specific surface and canopy fuel values were hardwired to mimic the desired wind reduction (FM40 = SH5/145, Set CC = 5%; CH = 17.5 m; CBH = 1.5 m; CBD = 0.01 kg/m3). These canopy adjustments allow the EVT loft embers but keep the rate of spread and fire intensity unchanged.

The complete set of calibrated EVTs are listed in the final ‘Fuel Boxes’ spreadsheet provided with the project deliverables.

### 2.1.3 CUSTOM FUEL MODELS

The 40 Scott and Burgan Fire Behavior Fuel Models (FBFM40) represent distinct distributions of fuel loading found among surface fuel components, size classes, and fuel types. The spatial representation of fuel model assignments serves as input into wildfire simulation modeling systems like FARSITE, FlamMap, and FSim. Such spatial wildfire simulation systems associate certain simulation inputs to a fuel model assignment. Although the FBFM40 fuel models cover a wide array of fuel bed scenarios, it is sometimes necessary to develop custom fuel model assignments to simulate fire behavior not reflected in the standard fuel models.

For example, FSim allows for adjustments to the rate of spread (adjustment factor) and live/dead fuel moisture content to vary by fuel model. The use of a custom fuel model in this instance allows for specified locations to be given different simulation inputs. For example, certain high-elevation locations may be characterized by a standard fuel model, but with different fuel moisture inputs. In that case, a custom fuel model can be made with the same parameters as the standard fuel model but a different fuel model number. Then, because the fuel model number is different, it can be given different fuel moisture inputs.

The ARRA fuelscape applied such a custom fuel model assignment for a specific scenario related to burnable urban areas. By assigning these areas custom fuel models (using different fuel model numbers than the standard model FBFM40), we were able to control the weather scenarios during which simulated fire spread could take place.

Burnable urban areas were originally mapped by LANDFIRE as non-burnable, and therefore, do not allow simulated wildfire spread into urban areas as observed in past wildfire events. In this application of custom fuel models, the parameters are identical to standard FBFM40 fuel models but are labeled with custom numbers allowing for additional customization within FSim. The burnable urban custom fuel models were spatially identified using the LANDFIRE EVT(s designated as low and moderate-intensity developed and represented with 251/BU1; identical to TL9. The addition of the custom burnable urban fuel models allows for the transmission of wildfire in simulation across these areas. To not overestimate the likelihood of wildfire in custom fuel models,
fuel moisture inputs were edited to allow for wildfire only under 97th percentile ERC conditions. Fuel moisture inputs are further detailed in section 2.3.3.

2.1.4 KENAI PENINSULA FUELSCAPE ADJUSTMENTS

The ARRA fuelscape was initially developed using LANDFIRE 2014 (LF 2014 - LF 1.4.0) data products. In the Spring of 2020, Pyrologix updated the fuelscape with data from the Kenai Peninsula Vegetation Map and calibrated fuel model assignments from the ARRA Fuelscape. During the September 2019 ARRA calibration workshop, held at the Chugach National Forest Supervisor’s Office, a Kenai dominant vegetation type-to-LF14 EVT crosswalk was developed by local experts. This document served as the foundation of the Kenai Peninsula fuelscape.

The Kenai Peninsula Vegetation Map provided data for tree cover, tall shrub cover, and vegetation height. To incorporate the data into the fuelscape, they were resampled from 5 m to 30 m and crosswalked to the LF14 vegetation codes for EVT, EVC, and EVH. A spatial review of the tree cover and tall shrub cover showed the two datasets to be mutually exclusive. They were subsequently merged and cross-referenced against EVT/dominant lifeform ensuring alignment with LANDFIRE’S 2-digit codes for water, snow/ice, barren, and developed.

A review of the merged cover and height data highlighted areas of tree or tall shrub cover lacking height assignments. The ESRI ArcGIS Focal Statistics tool was used to perform two filters at the 30 m resolution, calculating the mean height value, within a 3-pixel by 3-pixel moving window. This allowed us to “backfill” height pixels that were coincident with tree and shrub cover. A vegetation lifeform mask was used during processing to ensure cover and height vegetation type alignment. Any remaining areas mapped with herbaceous or other non-tree/shrub vegetation types (EVTs) were backfilled using LF14 cover and height.

The resulting vegetation type, cover, and height data layers were used as inputs to create a Kenai Peninsula fuelscape. The fuelscape used calibrated rules from the ARRA calibration workshop and was processed using the LANDFIRE Total Fuel Change Toolbar (LFTFCT). The resulting Kenai Peninsula fuelscape was mosaicked along the boundaries of ice, barren, water, or rock with the calibrated ARRA fuelscape to eliminate seamlines.

It is important to highlight two Kenai Peninsula fuelscape post-processing adjustments implemented before the final mosaic. A review of the ARRA and Kenai Peninsula fuelscapes revealed differences in the mapping of developed spaces. The LANDFIRE existing vegetation type for developed areas has more detailed classes, capturing developed areas of high intensity, moderate intensity, low intensity, and open space. Developed areas in the Kenai Peninsula were mapped into a single class, high intensity developed. While this difference does not seem hugely significant, only having a single developed classification does cause difficulties in representing burnable urban areas of a fuelscape. Due to this difference, develop areas (high intensity developed) within Kenai Peninsula were adjusted to reflect the LANDFIRE classes in areas overlap.

The second adjustment involved the use of a spatial ‘wildcard’ to differentiate the vegetation characteristics (and associated fuel model assignment) for EVT 2611 (Western North American Sub-boreal Mesic Bluejoint Meadow) within the Kenai Peninsula. Areas with this vegetation type outside of the Kenai Peninsula are assumed to have more of a shrub component and received a
GS2/122 fuel model assignment; while areas within the peninsula are assumed to have more of a grass component and were assigned a GR2/102 fuel model assignment.

The ARRA-Kenai Peninsula mosaicked fuelscape was then updated to include disturbances from treatment activities and past wildfire events occurring in 2015 through 2018, rendering this fuelscape capable for use in 2019. Because 2019 was an influential fire year on this landscape, we added 2019 wildfire perimeters and fuel disturbance information available through the Fall of 2019. In terms of timing, the landscape is ‘dated’ current to 2019 with a bonus year of disturbances from 2019 added in. Disturbances occurring in the time since disturbance block two (TSD2) of zero to five years include the years 2014 through 2019. All disturbances before 2014 are in TSD3 (2005-2013). The standard LANDFIRE approach is to keep only the past 10 years of disturbance information, but that would cause fire scars like the 2007-Caribou Hill fire to be mapped as non-disturbed fuel. To prevent the aging out of these fires’ influence on fuel and fire behavior, we chose to keep the additional four years of disturbance history in TSD3.

### 2.2 HISTORICAL WILDFIRE OCCURRENCE

The Fire Occurrence Database (FOD) that spans the 26 years from 1992-2017 was used to quantify historical large-fire occurrence (Short, 2017). Historical wildfire occurrence data were used to develop model inputs (the fire-day distribution file [FDist] and ignition density grid [IDG]) as well as model calibration targets. Table 1 summarizes the annual number of large fires per million acres, mean large-fire size, and annual area burned by large fires per million acres for each FOA. For this analysis, we defined a large fire as one greater than 100 acres.

<table>
<thead>
<tr>
<th>FOA</th>
<th>Mean annual number of large fires</th>
<th>FOA area (M ac)</th>
<th>Mean annual number of large fires per M ac</th>
<th>Mean large-fire size (ac)</th>
<th>Mean annual large-fire area burned (ac)</th>
<th>FOA-mean burn probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>0.9</td>
<td>18.07</td>
<td>0.05</td>
<td>2,899</td>
<td>2,564</td>
<td>0.0001</td>
</tr>
<tr>
<td>102</td>
<td>1.0</td>
<td>18.49</td>
<td>0.05</td>
<td>13,963</td>
<td>13,963</td>
<td>0.0008</td>
</tr>
</tbody>
</table>

Historical wildfire occurrence varied substantially by FOA (Table 1). While FOA 101 and 102 experienced a similar number of large fires per million acres per year the average size of those fires was 13,963 acres in FOA 102 and only 2,899 in FOA 101.

To account for the spatial variability in historical wildfire occurrence across the landscape, FSIm uses a geospatial layer representing the relative, large-fire ignition density. FSIm stochastically places wildfires according to this density grid during a simulation. The entire landscape is saturated with wildfire over the 100,000 simulated iterations, but more ignitions are simulated in areas that have previously allowed for large-fire development.

The Ignition Density Grid (IDG) was generated using a mixed-methods approach by averaging the two grids resulting from the Kernel Density and Point Density tools within ArcGIS, using a 120 m, output cell size, and a 75 km search radius. All fires equal to or larger than 100 acres reported in the
FOD were used as inputs to the IDG. The IDG was divided up for each FOA by setting to zero all areas outside of the fire occurrence boundary of that FOA. This allows for a natural blending of results across adjacent FOA boundaries by allowing fires to start only within a single FOA but burn onto adjacent FOAs. Additionally, all burnable urban, and small burnable areas less than 50 acres within other non-burnable or urban areas were masked out of the IDG layer. The IDG enables FSim to produce a spatial pattern of large-fire occurrence consistent with what was observed historically. Figure 4 shows the ignition density grid for the ARRA Fire Occurrence Area.

2.2.1 TRENDS IN WILDFIRE OCCURRENCE

The FSim model was calibrated using the USFS Fire Occurrence Database (FOD; 1992-2017). Wildfire occurrence within the ARRA analysis area was observed to be non-stationary and therefore not accurately represented by the 26-year FOD mean. A linear model was fit to fire size and frequency with time as the dependent variable (Figure 5). FSim model results were then calibrated to the predicted 2020 mean fire size and frequency.
Calibrating to the 2020 FOD trend resulted in an increase of 1.28X in the annual number of simulated fires and a 2.28X increase in mean large fire size. The FSim model was calibrated to the 2020 FOD trend to generate the most accurate estimate possible of wildfire likelihood.

### 2.3 HISTORICAL WEATHER

FSim requires three weather-related inputs: monthly distribution of wind speed and direction, live and dead fuel moisture content by year-round percentile of the Energy Release Component (ERC) variable of the National Fire Danger Rating System (NFDRS, 2002) for fuel model G (ERC-G) class, and seasonal trend (daily) in the mean and standard deviation of ERC-G. We used two data sources for these weather inputs. For the wind speed and direction distributions, we used the hourly (1200 to 2000 hours), 10-minute average values (2 mph calm wind), recorded at selected Remote Automatic Weather Stations (RAWS). Stations with relatively long and consistent records and moderate wind activity were preferentially selected to produce the most stable FSim results.

Energy Release Component (ERC) values were extracted from a Special Interest group (SIG) of four RAWS. Issues with downtime within the RAWS record required that multiple stations be used to have a sufficient sample of ERCs to cover all historical fire events. The RAWS stations selected for winds and ERC sample sites are shown in Figure 6 and discussed further in the following sections.
2.3.1 FIRE-DAY DISTRIBUTION FILE (FDIST)

Fire-day Distribution files are used by FSim to generate stochastic fire ignitions as a function of ERC. The FDist files were generated using an R script that summarizes historical ERC and wildfire occurrence data, performs logistic regression, and then formats the results into the required FDist format.

The FDist file provides FSim with logistic regression coefficients that predict the likelihood of a large-fire occurrence based on the historical relationship between large fires and ERC and tabulates the distribution of large fires by large-fire day. A large fire day is a day when at least one large fire occurred historically. The logistic regression coefficients together describe large-fire day likelihood $P(LFD)$ at a given ERC($G$) as follows:

$$P(LFD) = \frac{1}{1 + e^{B_a + B_b \cdot ERC(G)}}$$

Coefficient $a$ describes the likelihood of a large fire at the lowest ERCs, and coefficient $b$ determines the relative difference in the likelihood of a large fire at lower versus higher ERC values.
2.3.2 FIRE RISK FILE (FRISK)

Fire risk files were generated for each RAWS using FireFamilyPlus version 4.1 and updated to incorporate simulated ERC percentiles (as described in section 2.3.4). These files summarize the historical ERC stream for the FOA, along with wind speed and direction data for the selected RAWS.

2.3.3 Fuel Moisture File (FMS)

Modeled fire behavior is robust to minor changes in dead fuel moisture, so a standardized set of stylized FMS input files (representing the 80th, 90th, and 97th percentile conditions) for 1-, 10-, 100-hour, live herbaceous, and live woody fuels was developed (Table 2).

<table>
<thead>
<tr>
<th>Fuel Model Group</th>
<th>1-hr</th>
<th>10-hr</th>
<th>100-hr</th>
<th>Live-Herb</th>
<th>Live-Woody</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass / Shrub</td>
<td>7 / 5 / 4</td>
<td>8 / 6 / 5</td>
<td>9 / 7 / 6</td>
<td>90 / 60 / 40</td>
<td>110 / 80 / 60</td>
</tr>
<tr>
<td>Timber / Slash</td>
<td>9 / 7 / 6</td>
<td>10 / 8 / 7</td>
<td>11 / 9 / 8</td>
<td>90 / 60 / 40</td>
<td>110 / 80 / 60</td>
</tr>
<tr>
<td>Burnable Urban</td>
<td>45 / 45 / 6</td>
<td>45 / 45 / 7</td>
<td>45 / 45 / 8</td>
<td>120 / 120 / 40</td>
<td>110 / 110 / 60</td>
</tr>
</tbody>
</table>

Fuel moistures in the custom, Burnable Urban (FM 251) fuel models were set above the moisture of extinction for the 80th and 90th percentile ERC bins. This was done to restrict simulated wildfires to burn within these fuel groups only under the most extreme weather conditions (97th percentile). This method maintains the potential for fire intensity while not vastly over-predicting burn probability. The custom fuel models are further described above in section 2.1.3.

2.3.4 Energy Release Component File (ERC)

We sampled historical ERC-G values from a Special Interest group (SIG) of four RAWS (Big Lake, PT Mac, Kenai NWR, and Broadview). A 1,000 iteration FSIm was simulated to generate a sample of 365,000 days of ERCs. The generated ERC stream was used in both FOA 101 and FOA 102 to provide a “coordinated” ERC stream across the analysis area. The simulated ERC values are “coordinated” so a given year and day for one FOA corresponds to the same year and day in all FOAs. This coordination permits the analysis of fire-year information across all FOAs.

2.4 WILDFIRE SIMULATION

The FSIm large-fire simulator was used to quantify wildfire hazard across the landscape at a pixel size of 120 m (4 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). Figure 7 diagrams the many components needed as inputs to FSIm.

Due to the highly varied nature of weather and fire occurrence across the large landscape, we ran FSIm for each of the two FOAs independently and then compiled the two runs into a single data
product. For each FOA, we parameterized and calibrated FSIm based on the location of historical fire ignitions within the FOA, which is consistent with how the historical record is compiled. We then used FSIm to start fires only within each FOA but allowed those fires to spread outside of the FOA. This, too, is consistent with how the historical record is compiled.

Figure 7. Diagram showing the primary elements used to derive burn probability.

2.4.1 MODEL CALIBRATION

FSIm simulations for each FOA were calibrated to a 2020 trend analysis of historical large fire occurrence including mean historical large-fire size, and mean annual area burned per million acres. Calibration targets were adjusted upward from the mean values over the historical record based on methods outlined in section 2.2.1. Additionally, care was taken to match simulated wildfire size distributions to the historical record and allow for the occurrence of simulated fires larger than any observed historically. While only large-fire sizes (>100 acres) were considered in calibration, numerous small fires were also simulated. However, the impact of small fires on landscape-level burn probability is negligible.
To calibrate each FOA, we started with baseline inputs and a starting rate-of-spread adjustment (ADJ) factor file informed by experience on previous projects. The final model inputs can be seen below in Table 3. All runs were completed at 120 m resolution. Each FOA was calibrated separately, and final simulations were run with 100,000 iterations. The two FOAs were then integrated into an overall result for the analysis area.

Table 3. Summary of final-run inputs for each FOA

<table>
<thead>
<tr>
<th>Final run</th>
<th>Number of Iterations</th>
<th>ADJ file</th>
<th>Trimming factor</th>
<th>Frisk</th>
<th>FDist file</th>
<th>LCP file</th>
</tr>
</thead>
<tbody>
<tr>
<td>101r15</td>
<td>100,000</td>
<td>Foa101v8</td>
<td>2.5</td>
<td>Foa101v3</td>
<td>Foa101v4</td>
<td>FOA_101_120v6</td>
</tr>
<tr>
<td>102r15</td>
<td>100,000</td>
<td>Foa102v8</td>
<td>2.5</td>
<td>Foa102v3</td>
<td>Foa102v4</td>
<td>FOA_102_120v6</td>
</tr>
</tbody>
</table>

2.4.2 INTEGRATING FOAS

We used the natural-weighting method of integrating adjacent FOAs that we developed on an earlier project (Thompson et al., 2013a). With this method, well within the boundary of FOA (roughly 30 km from any boundary), the results are influenced only by that FOA. Near the border with another FOA, the results will be influenced by that adjacent FOA. The weighting of each FOA is in proportion to its contribution to the overall burn probability at each pixel.
Figure 8. Map of integrated FSim burn probability results for the ARRA Analysis Area at 120 m resolution.
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 ARRA 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: HVRA 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.

3.1 HVRA IDENTIFICATION

A set of HVRA was identified through a workshop held in Anchorage, Alaska, on September 26, 2019. A group consisting of the Forest Service employees, Resource Specialists, Geospatial Analysts, and Interagency Partners from USFS Region 10 identified eleven HVRA in total: nine assets and two resources. The complete list of HVRA and their associated data sources are listed in Table 4.
Table 4. HVRA and sub-HVRA identified for the Chugach All-Lands Wildfire Risk Assessment and associated data sources.

<table>
<thead>
<tr>
<th>HVRA &amp; Sub-HVRA</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>People and Property</strong></td>
<td>Represents housing unity density data produced by Pyrologix using the building footprints and U.S. Census - Census Block population data. Data depicting building locations was provided by Chugach NF and adjusted by Pyrologix.</td>
</tr>
<tr>
<td>Native Allotments</td>
<td>The data was provided by the Bureau of Land Management, Alaska State Office, representing areas designated as ‘Conveyed Native Allotments’ within Alaska.</td>
</tr>
<tr>
<td><strong>Infrastructure</strong></td>
<td></td>
</tr>
<tr>
<td>Electric transmission lines – high &amp; low voltage</td>
<td>The provided linear features represent electric power transmission lines. Data was provided by Chugach NF and supplemented with data from the Homeland Infrastructure Foundation-Level Data (HIFLD) program.</td>
</tr>
<tr>
<td>Communication Sites</td>
<td>Data represents the location of communication sites. Data was provided by Chugach NF and supplemented with data from the Homeland Infrastructure Foundation-Level Data (HIFLD) program.</td>
</tr>
<tr>
<td>Power: Power Plants &amp; Substations</td>
<td>The provided data represents the locations of power plants and substations. Data was provided by Chugach NF and supplemented with data from the Homeland Infrastructure Foundation-Level Data (HIFLD) program.</td>
</tr>
<tr>
<td>Oil &amp; Gas Wells</td>
<td>The data contains the location of surface wells &amp; structures. Well locations were limited to those designated as active wells; structures were limited to items designated as oil/gas buildings. Data was provided by Chugach NF.</td>
</tr>
<tr>
<td>Pipelines</td>
<td>The data depicts pipeline locations in Alaska as digitized from USGS maps. Ancillary source documentation was provided by the AK DNR and used as necessary for updates.</td>
</tr>
<tr>
<td>Fish Hatcheries</td>
<td>These sport subsistence sites represent the known locations of sport and commercial fish rearing facilities (commercial salmon fishery) located in Southcentral AK. Data was provided by Chugach NF.</td>
</tr>
<tr>
<td>Recreation &amp; Administrative Sites</td>
<td>The data contains the locations of administrative buildings, offices, recreation sites, and service/utility structures on lands owned by Alaska State Parks, USDA (Forest Service) lands, and the National Park Service. Data was provided by Chugach NF.</td>
</tr>
<tr>
<td><strong>Carbon</strong></td>
<td></td>
</tr>
<tr>
<td>Carbon Credits</td>
<td>Mapped areas represent forested land used in carbon trading markets and identify areas of biomass (forest) marketable as carbon credits. Data provided by Chugach NF.</td>
</tr>
<tr>
<td><strong>Watershed</strong></td>
<td></td>
</tr>
<tr>
<td>Critical Watersheds</td>
<td>Surface drinking water protection areas (Zone C, G boundaries) were delineated from local topography and anticipated effects on the drinking water source intake. Data provided by Chugach NF and Alaska DEC Open Data.</td>
</tr>
</tbody>
</table>

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.
3.2 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 the Forest Service and interagency representatives, and additional fire and resource staff at a virtual Fire Effects workshop held on January 27, 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 reported by FSIm are shown in Table 5. The response functions (RFs) used in the risk results are shown in Table 6 thru Table 16 below.

Table 5. Flame-length values corresponding to Fire Intensity Levels used in assigning response functions.

<table>
<thead>
<tr>
<th>Fire Intensity Level (FIL)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame Length Range (feet)</td>
<td>0-2</td>
<td>2-4</td>
<td>4-6</td>
<td>6-8</td>
<td>8-12</td>
<td>12+</td>
</tr>
</tbody>
</table>

3.3 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. The virtual RI workshop was held on March 2, 2021, and was attended by the 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 69 percent, followed by the Infrastructure (14%) and Water (11%) HVRA. The remaining share of RI is composed of the Carbon (6%) HVRA (Figure 9). 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 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 6 thru Table 16, we provide the share of HVRA relative importance within each primary HVRA.
3.4 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 and different response functions for people and property by vegetation lifeform. The main HVRA in ARRA 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 in the wildfire risk calculations described in section 3.5.1.

Figure 9. Overall HVRA Relative Importance for the primary HVRAAs included in ARRA.
3.4.1 PEOPLE AND PROPERTY

3.4.1.1 HOUSING UNIT DENSITY (HUDEN)

The HUDen raster was produced by Pyrologix using data depicting building locations provided by Chugach National Forest 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 where the buildings are located within the block. This methodology was developed for the Wildfire Risk to Communities project (Scott et. al, 2020) and refined in this project by removing false positives and duplicates from the provided data.

Response Functions were applied in conjunction with burnable vegetation types derived from the LANDFIRE Existing Vegetation Type (EVT). A value of ‘1’ was assigned to sites associated with deciduous tree or shrub lifeforms, a value of ‘2’ for sites designated as grass, and a value of ‘3’ for Spruce/Mixed-wood sites. The same set of response functions was applied to all HU density classes within each vegetation classification.

The People and Property (HUDEN) HVRA received negative response functions for all vegetation types and fire intensity levels (Table 6). People and Property HVRA located in spruce and mixed-wood lifeforms were assigned a stronger negative response due to the likelihood of ember-cast from these fuel types and the suppression difficulty presented with such fire behavior. Conversely, People and Property HVRA located in grass pixels may present fewer challenges to fire suppression efforts—resulting in less loss overall.

Figure 10. Map of Housing Unit Density within the ARRA Analysis Area
Table 6. Response functions for the People and Property HVRA to highlight HUDEN.

<table>
<thead>
<tr>
<th>Sub-HVRA</th>
<th>FIL1</th>
<th>FIL2</th>
<th>FIL3</th>
<th>FIL4</th>
<th>FIL5</th>
<th>FIL6</th>
<th>Share of RI¹</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>P&amp;P - HUDEN Tree/Shrub</td>
<td>-5</td>
<td>-15</td>
<td>-30</td>
<td>-50</td>
<td>-80</td>
<td>-95</td>
<td>16.1%</td>
<td>128,537</td>
</tr>
<tr>
<td>P&amp;P - HUDEN Grass</td>
<td>-10</td>
<td>-30</td>
<td>-40</td>
<td>-60</td>
<td>-70</td>
<td>-80</td>
<td>5.8%</td>
<td>50,236</td>
</tr>
<tr>
<td>P&amp;P - HUDEN Spruce/Mixed</td>
<td>-20</td>
<td>-40</td>
<td>-50</td>
<td>-80</td>
<td>-90</td>
<td>-95</td>
<td>70.9%</td>
<td>309,352</td>
</tr>
</tbody>
</table>

¹ Within-HVRA relative importance.
Native allotment delineations for the analysis area (Figure 11) were provided by Chugach National Forest. The provided data represents mapped areas within the PLSS native allotment network. Data were extracted from the Conveyed Native Allotments within the Alaska\(^6\) data set and converted to a 30 m raster. Due to the sensitive/protected nature of Native Allotments and a variety of land-uses applications, the response function assignments for Native Allotments demonstrate a negative response to fire (Table 7). At low flame lengths, Native Allotments demonstrate moderate loss that quickly increases as fire intensity increases, reaching total loss by FIL5. Native Allotment delineations were allocated 7 percent of the share of the People and Property HVRA. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 7. Response functions for the People and Property HVRA to highlight Native Allotments.

<table>
<thead>
<tr>
<th>Sub-HVRA</th>
<th>FIL1</th>
<th>FIL2</th>
<th>FIL3</th>
<th>FIL4</th>
<th>FIL5</th>
<th>FIL6</th>
<th>Share of RI(^1)</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native Allotments</td>
<td>-30</td>
<td>-60</td>
<td>-70</td>
<td>-80</td>
<td>-100</td>
<td>-100</td>
<td>7.1%</td>
<td>20,715</td>
</tr>
</tbody>
</table>

\(^1\)Within-HVRA relative importance.

---

6 https://navigator.blm.gov/data?keyword=allotments&fs_publicRegion=Alaska
Communication sites for the analysis area (Figure 12) were provided by Chugach National Forest (covering Forest Service and non-Forest Service lands) and supplemented using data acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD)\(^7\). The types of communication sites compiled for the assessment include cellular towers, FS repeaters, aviation navigation aids, web cameras, RAWs, seismic stations, 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 hardened structures and defensible space, showing a neutral response at lower flame lengths, with increasing negativity to fires of increasing intensity (Table 8). Each communication site was also assigned a type classification (high value or other), giving those sites designated as 'high' more importance per pixel (cell towers, radio transmission, and navigational aids) relative to the ‘other’ sites (general

\(^7\) HIFLD data on communication sites was downloaded from [https://hifld-geoplatform.opendata.arcgis.com/](https://hifld-geoplatform.opendata.arcgis.com/) on 5/12/2020
Communication sites were allocated 43 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 Communication Sites.

<table>
<thead>
<tr>
<th>Sub-HVRA</th>
<th>FIL1</th>
<th>FIL2</th>
<th>FIL3</th>
<th>FIL4</th>
<th>FIL5</th>
<th>FIL6</th>
<th>Share of RI</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication Sites - High</td>
<td>0</td>
<td>0</td>
<td>-20</td>
<td>-30</td>
<td>-40</td>
<td>-50</td>
<td>40.6%</td>
<td>2,503</td>
</tr>
<tr>
<td>Communication Sites</td>
<td>0</td>
<td>0</td>
<td>-20</td>
<td>-30</td>
<td>-40</td>
<td>-50</td>
<td>2.7%</td>
<td>1,994</td>
</tr>
</tbody>
</table>

1. Within-HVRA relative importance.
Transmission Lines within the analysis area (Figure 13) were acquired from the Homeland Infrastructure Foundation-Level Data (HIFLD). Ancillary data were provided by Copper Valley Electric to supplement the data and capture missing features. The lines were classified using a voltage break of 230 volts (transmission lines carrying less than 230 volts classified as ‘1’, and those greater than 230, classified as ‘2’). 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.

Low voltage lines (<230 kV) are mostly wooden poles, and therefore, respond with a strongly negative response to all fire intensities. Total loss was expected for fires greater than FIL4 (Table 9). High voltage transmission lines (≥230 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. Therefore, high voltage transmission lines have an initial neutral response at lower intensities and transition to moderate loss as intensity increases due to the associated heat damage to lines (Table 9).

Due to the number of acres mapped on the landscape and their importance to infrastructure, electric transmission lines received 32 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 Transmission Lines.

<table>
<thead>
<tr>
<th>Sub-HVRA</th>
<th>FIL1</th>
<th>FIL2</th>
<th>FIL3</th>
<th>FIL4</th>
<th>FIL5</th>
<th>FIL6</th>
<th>Share of RI(^1)</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Volt (&gt; 230)</td>
<td>0</td>
<td>0</td>
<td>-20</td>
<td>-30</td>
<td>-50</td>
<td>-60</td>
<td>3.3%</td>
<td>4,041</td>
</tr>
<tr>
<td>Low Volt (wooden poles)</td>
<td>-40</td>
<td>-50</td>
<td>-70</td>
<td>-90</td>
<td>-100</td>
<td>-100</td>
<td>28.7%</td>
<td>35,280</td>
</tr>
</tbody>
</table>

\(^1\) Within-HVRA relative importance.
Figure 14. Map of Power Plants and Substations within the ARRA analysis area.

The location of power plants and substations within the analysis area (Figure 14) was derived from a combination of data provided by Chugach National Forest (covering Forest Service and non-forest service lands) and Homeland Infrastructure Foundation-Level Data (HIFLD). 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 and substations demonstrate a neutral response to nearly all fire intensities. They only demonstrate a response to fires of higher intensity and will show minimal loss (Table 10).

Power plants and substations were allocated six 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 Power Plants and Substations.

<table>
<thead>
<tr>
<th>Sub-HVRA</th>
<th>FIL1</th>
<th>FIL2</th>
<th>FIL3</th>
<th>FIL4</th>
<th>FIL5</th>
<th>FIL6</th>
<th>Share of RI¹</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Plants</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-10</td>
<td>-20</td>
<td>-30</td>
<td>1.7%</td>
<td>62</td>
</tr>
<tr>
<td>Substations</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-10</td>
<td>-20</td>
<td>-30</td>
<td>4.3%</td>
<td>197</td>
</tr>
</tbody>
</table>

¹Within-HVRA relative importance.
Oil and gas wells for the analysis area (Figure 15) were provided by Chugach National Forest. The provided data contains the location of surface wells designated as 'active' (extracted from Alaska Oil and Gas Conservation Commission) and structures limited to those designated as 'oil/gas buildings' within the Known Sites database. 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 well pads, the response functions are similar to that of power plants and substations. 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 11). This negative trend continues as fire intensity increases but never surpasses mild loss. Oil and gas wells were allocated 4 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>
<thead>
<tr>
<th>Sub-HVRA</th>
<th>FIL1</th>
<th>FIL2</th>
<th>FIL3</th>
<th>FIL4</th>
<th>FIL5</th>
<th>FIL6</th>
<th>Share of RI(^1)</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil &amp; Gas Wells</td>
<td>0</td>
<td>0</td>
<td>-10</td>
<td>-20</td>
<td>-30</td>
<td>-30</td>
<td>4.0%</td>
<td>493</td>
</tr>
</tbody>
</table>

\(^1\)Within-HVRA relative importance.
Pipelines for the analysis area (Figure 16) were provided by Chugach National Forest. The provided data depicts pipeline locations in Alaska as digitized from USGS maps and updated using ancillary source documentation from the Alaska DNR. The pipelines 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 function assignments for pipelines show a neutral response for nearly all fire intensities. Not until 8-12-foot flame lengths (FIL3) 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 12).

Pipelines were allocated 9 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 12. Response functions for the Infrastructure HVRA to highlight Pipelines.

<table>
<thead>
<tr>
<th>Sub-HVRA</th>
<th>FIL1</th>
<th>FIL2</th>
<th>FIL3</th>
<th>FIL4</th>
<th>FIL5</th>
<th>FIL6</th>
<th>Share of RI</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipelines</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-10</td>
<td>-30</td>
<td>9.3%</td>
<td>1,716</td>
</tr>
</tbody>
</table>

1 Within-HVRA relative importance.
3.4.2.6 FISH HATCHERIES

The location of fish hatcheries within the analysis area (Figure 17) was provided by Chugach National Forest via the Alaska Department of Fish & Game. The provided data represents the known locations of sport and commercial fish rearing facilities (commercial salmon fisheries) located in Southcentral Alaska. For use in this analysis, the data were 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.

In this assessment, sites designated as hatcheries were associated with commercial locations. Due to the established, developed, and defensible space associated with these hatcheries, the response function assignments demonstrate neutral response at lower fire intensities. Although remaining moderate, the response functions do show increasingly negative responses as fire intensity increases (Table 13).

Fish hatcheries 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 13. Response functions for the Infrastructure HVRA to highlight Fish Hatcheries.

<table>
<thead>
<tr>
<th>Sub-HVRA</th>
<th>FIL1</th>
<th>FIL2</th>
<th>FIL3</th>
<th>FIL4</th>
<th>FIL5</th>
<th>FIL6</th>
<th>Share of RI¹</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish Hatcheries</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-10</td>
<td>-20</td>
<td>-30</td>
<td>0.2%</td>
<td>14</td>
</tr>
</tbody>
</table>

¹Within-HVRA relative importance.
Recreation and administrative sites for the analysis area (Figure 18) were provided by Chugach National Forest and the National Park Service (Alaska Region GIS Team). The provided data contains the locations of administrative buildings, offices, recreation sites, and service/utility structures on lands owned by Alaska State Parks, USDA (Forest Service) lands, and the National Park Service. For use in this analysis, the data were extracted to the analysis area, assigned a rank (high or low) based on the locations associated importance level (all sites are assumed to have the same wildfire susceptibility), 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.

Due to their susceptibility to fire, the response function assignments for all recreation and administrative sites demonstrate a pattern of increasing loss as fire intensity increases (Table 14). Those sites designated as high importance show a greater loss across all fire intensities due to their associated investment level. For instance, sites such as regional headquarters or district offices show greater losses relative to campgrounds or day-use areas.

Recreation and administrative sites were allocated 5 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 14. Response functions for the Infrastructure HVRA to highlight Recreation and Administrative Sites.

<table>
<thead>
<tr>
<th>Sub-HVRA</th>
<th>FIL1</th>
<th>FIL2</th>
<th>FIL3</th>
<th>FIL4</th>
<th>FIL5</th>
<th>FIL6</th>
<th>Share of RI$^1$</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rec Admin Sites - High</td>
<td>-20</td>
<td>-40</td>
<td>-50</td>
<td>-80</td>
<td>-90</td>
<td>-95</td>
<td>4.2%</td>
<td>310</td>
</tr>
<tr>
<td>Rec Admin Sites - Low</td>
<td>-10</td>
<td>-30</td>
<td>-40</td>
<td>-60</td>
<td>-70</td>
<td>-80</td>
<td>1.0%</td>
<td>378</td>
</tr>
</tbody>
</table>

$^1$Within-HVRA relative importance.
3.4.3 CARBON

3.4.3.1 CARBON CREDITS

Carbon credit delineations within the analysis area (Figure 19) were provided by Chugach National Forest and the Chugachmiut Native Corporation. The mapped areas represent forested land used in carbon trading markets, identifying forested areas of biomass marketable as carbon credits. The provided data was converted to a 30 m raster for use in the analysis.

Due to the susceptible and sensitive nature of forested carbon sequestration areas, the response function assignments for carbon credit delineations demonstrate an initial strong negative response to fire. This trend continues as fire intensity increases, reaching total loss by 8-foot flame lengths (Table 15).

Table 15. Response functions for the Carbon HVRA to highlight Carbon Credit delineations.

<table>
<thead>
<tr>
<th>Sub-HVRA</th>
<th>FIL1</th>
<th>FIL2</th>
<th>FIL3</th>
<th>FIL4</th>
<th>FIL5</th>
<th>FIL6</th>
<th>Share of RI¹</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Credits</td>
<td>-30</td>
<td>-50</td>
<td>-70</td>
<td>-80</td>
<td>-100</td>
<td>-100</td>
<td>100.0%</td>
<td>94,663</td>
</tr>
</tbody>
</table>

¹ Within-HVRA relative importance.
3.4.4 CRITICAL WATERSHEDS

3.4.4.1 DRINKING-WATER PROTECTION AREAS

Drinking water protection areas were mapped using Alaska DEC Open Data\(^8\) (Zone C and G), provided by Chugach National Forest. The dataset included drinking water protection areas (critical water basins) and their associated water facilities. The selected water basins were reviewed by a Forest Service hydrologist and water facilities were limited to those associated with surface water and/or groundwater under the influence of surface water. The resulting critical watershed map is shown (Figure 20).

For the QWRA, 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 the values from decaying as rapidly we divided 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 any overlapping watersheds.

\(^8\)https://hub.arcgis.com/datasets/ADEC::zone-c-surface-water-watershed-boundary?geometry=44.708%2C42.010%2C19.219%2C72.703
Table 16. Response functions for the Critical Watersheds HVRA.

<table>
<thead>
<tr>
<th>Sub-HVRA</th>
<th>FIL1</th>
<th>FIL2</th>
<th>FIL3</th>
<th>FIL4</th>
<th>FIL5</th>
<th>FIL6</th>
<th>Share of RI</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drinking Water</td>
<td>-10</td>
<td>-30</td>
<td>-50</td>
<td>-70</td>
<td>-80</td>
<td>-95</td>
<td>100.0%</td>
<td>215,696</td>
</tr>
</tbody>
</table>

1 Within-HVRA relative importance.
3.5 EFFECTS ANALYSIS METHODS

An effects analysis quantifies wildfire risk as to 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 a tabular response function for each 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 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. Response function values for the ARRA ranged from -100 (greatest possible loss of value) to 0 (no change in value).

3.5.1 EFFECTS ANALYSIS 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. 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:

\[ cNVC_j = \sum_{i} FLP_i \times RF_{ij} \times RIPP_j \]

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:

\[ cNVC = \sum_{j} cNVC_j \]

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:

\[ eNVC = cNVC \times BP \]

3.5.2 UPSAMPLING FSIM RESULTS FOR EFFECTS ANALYSIS

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) and flame-length probability (FLP) rasters to 30 m, consistent with HVRA mapping at 30 m.

As discussed in the Fuelscape section (Section 2.1) above, the fire behavior modeling in ARRA included the custom, burnable-urban fuel model. Without accounting for any potential burnability in developed areas, simulated wildfires would stop at the edge of burnable fuel. To address this issue, we allowed fires to spread through burnable-urban pixels which produced simulated fire perimeters that spread through developed areas. However, because of the many unknowns and challenges in modeling the potential for home-to-home spread in landscape-scale fire modeling, we ultimately minimized the influence of burn probability values associated with burnable-urban pixels and spread probabilities from adjacent wildlands with a series of focal window smoothing steps as described below.

We upsampled the FSim BP raster using a multi-step process. First, we used the ESRI ArcGIS Focal Statistics tool to perform two, rectangular, low-pass filters at the 120 m resolution, calculating the mean value of burnable pixels only (including burn probability values on burnable-urban pixels), within a 3-pixel by 3-pixel moving window. These steps allowed us to “backfill” burnable pixels at 30 m that were coincident with non-burnable fuel at 120 m. We subsequently resampled the 120 m FSim BP raster to 30 m using bilinear resampling. If, after running two low-pass filters, burnable pixels had BP values of zero, we set a threshold value of 1-in-10,000 to avoid assigning zero values on burnable pixels with some likelihood of burning.

As discussed above, we chose to smooth burn probability values from nearby burnable fuel onto adjacent non-burnable pixels to capture the low likelihood, but high-consequence event of wildfire spreading onto developed pixels. Before running the smoothing steps, we masked the 30 m resampled raster to burnable pixels only, removing BP values from burnable-urban pixels. Additionally, we removed BP values from small, burnable islands less than 500 ha. The purpose of removing burnable urban, non-burnable fuel, and small burnable islands is to prevent smoothing from these pixels, and in particular, to prevent golf courses and urban parks from spreading wildfires to nearby homes.

The resulting resampled raster was then smoothed again using the ESRI ArcGIS Focal Statistics tool to perform three low-pass filters at a 300 m resolution, allowing for spread from burnable pixels to nearby non-burnable pixels. Each focal smoothing operation incrementally reduces burn probability by including zero values on non-burnable pixels (other than water and ice) in the focal mean calculation. This reduces burn probability on non-burnable fuel relative to the burnable areas nearby. The 900 m smoothing distance is consistent with work by Caggiano et al. (2020) showing that all home losses to wildfire from 2000 to 2018 were within 850 m of wildland vegetation. Further, by removing burnable-urban and instead of smoothing burn probability onto those pixels, we reduce wildfire likelihood and control the distance those values are spread. As a final step, if small burnable islands were not populated through BP smoothing, they were assigned a threshold value of 1-in-100,000 (0.00001).

FSim flame-length probability (FLP) rasters were upsampled like the burn probability layer for use in effects analysis calculations. We used the ESRI ArcGIS Focal Statistics tool to perform two low-pass filters at the 120 m resolution, calculating the mean value of burnable pixels only, within a 3-pixel by 3-pixel moving window. This allowed us to “backfill” burnable pixels at 30 m that were
coincident with non-burnable fuel at 120 m. We then resampled the 120 m FSim FLP rasters to 30 m using bilinear resampling and masked the result to burnable pixels at 30 m (removing FLP values from burnable-urban pixels). To match the extent of the smoothed BP raster, we performed three, 300 m focal windows. Instead of allowing intensity values to decay with each pass, we kept only non-zero probabilities with each smoothing pass. Final values were then rescaled or normalized so the sum of all FLPs equals one.

3.5.3 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, Recreation, Range, Culture, Critical Watersheds, Aquatic Species, Wildland Species, Timber and Limited & Rare Vegetation) – 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 having at least five, 3.6-acre pixels per fire. Below this perimeter size, simulated fire-size distributions do not match historical distributions.

The final raster dataset created from the perimeter overlay exercise (risk-source) represents the expected annual risk per km² (or total wildfire transmission risk) for all HVRA from ignitions across the landscape. We refer to this raster as Expected Impact (eImpact).

The eImpact raster was generated using a multi-stage process. The ARRA analysis area includes two Fire Occurrence Areas (FOAs) that were each simulated with 100,000 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 a 5-km moving window radius was calculated for a 30 m output cell size. The second step involved calculating the sum of the ignitable⁹ 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 km² to get the expected risk-source per km² of source-area. These results can be used to look at the relative likelihood and consequence of ignitions occurring across the landscape.

The mean consequence of an ignition, given a fire starts, is called Conditional Impact (cImpact). The cImpact raster is calculated by dividing the sum of cNVC per iteration by the sum of “1/iterations” to remove the annual estimate of the number of fire-starts from the calculation. cImpact characterizes the mean impact of ignition in different parts of the landscape, without consideration of how likely they are to occur.

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⁹ Ignitable fuel includes burnable fuel, but not the custom burnable-urban fuel model.
3.5.4 TABULATED WILDFIRE RISK SUMMARIES

Summarizing wildfire risk and hazard products to a coarser summary unit facilitates comparison of risk and hazard across the landscape and between HVRA – quickly highlighting areas of concentrated risk that warrant further investigation at a more detailed, 30 m resolution. Additionally, tabulating the results in spreadsheet form facilitates sorting among and between attributes and ranking of high-risk areas.

For the ARRA QWRA, we summarized a set of Effects Analysis results for ARRA using 6th-level watershed polygons. Within each polygon zone we summarized exposed acres, burn probability, total eNVC (sum of all pixels) for each HVRA individually and for all HVRA combined, mean eNVC (calculated as the sum of eNVC divided by exposed acres/100 acres) for each HVRA individually and all HVRA combined, and mean cNVC (calculated as the sum of eNVC divided by the sum of burn probability) for each HVRA individually and all HVRA combined. An example of the NVC summary results for ARRA 6th-Level Watersheds is shown in Table 17.
4 RESULTS

4.1 EFFECTS ANALYSIS RESULTS

The cumulative results of the wildfire risk calculations described in section 3.5.1 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 21) with a net negative eNVC for all the HVRA. Results are scaled to cumulative eNVC values for the People and Property HVRA in the ARRA analysis area. People and Property show the greatest cumulative wildfire losses (eNVC) result followed by Infrastructure, Drinking Water, and Carbon as the HVRA with the greatest cumulative risk.

Figure 22 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 ARRA 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 23.

Figure 24 and Figure 25 show the upsampled BP and FLEPs results, as discussed in Section 3.5.2. Figure 26 shows the wildfire transmission results, as discussed in Section 3.5.3.

Total Expected Net Value Change

- People & Property: 83.1%
- Infrastructure: 14.5%
- Drinking Water: 2.4%
- Carbon: 2.3%
- 0.1%

Figure 21. 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.
4.1.1 CONSEQUENCE – CONDITIONAL NET VALUE CHANGE (CNVC)

Figure 22. Map of Conditional Net Value Change (cNVC) at 30 m for the ARRA analysis area.
4.1.2 RISK – EXPECTED NET VALUE CHANGE (ENVC) - TOTAL

Figure 23. Map of Expected Net Value Change (eNVC) at 30 m for the ARRA analysis area.
Figure 24. Map of integrated FSim burn probability results upsampled to 30 m resolution for the ARRA analysis area.
4.1.4 FLAME-LENGTH EXCEEDANCE PROBABILITIES

Flame-length exceedance probabilities (FLEP) represent the conditional probability of exceeding a nominal flame-length value. A FLEP of six is the conditional probability of a wildfire exceeding a six-foot flame length. FLEPs are a useful way to visualize individual FSim flame-length probabilities (FLPs). The FLEPs shown in Figure 23 were derived from the same FLPs used in the effects analysis calculations and upsampled to 30 m from the native 120 m using the methods outlined in section 3.5.2.

Figure 25. Map of 2, 4, 6, & 8-foot Flame-length Exceedance Probabilities (FLEPs)
Figure 26. Map of the annual wildfire transmission risk (expected impact) to all HVRA from ignitions across the landscape.
4.1.6 Tabulated Summaries for ARRA 6th-Level Watersheds

The summary of mean wildfire risk (mean eNVC) for all HVRA by 6th-level HUCs is provided in Table 17. The table highlights a sample of the risk attributes summarized for each watershed polygon outlined in Section 3.5.4. The tabular summaries provided with the complete set of project deliverables include the full list of risk attributes, but Table 17 displays a limited set of attributes to compare between mean eNVC and total eNVC for all HUCs.

The total eNVC metric highlights which HUCs have the greatest cumulative risk, but because watershed sizes are variable, it is useful to also examine risk concentration, or mean eNVC. Ranking by mean eNVC is most useful to examine which watersheds, on average, have the greatest wildfire risk. The mean eNVC by HVRA shows which HVRA are most at risk in each watershed and which contribute to the overall mean eNVC. Mean eNVC can help identify which watersheds might be prioritized for potential wildfire risk mitigation efforts, but the level of funding and mitigation efforts must be informed by the total eNVC.

Mean eNVC is a useful metric for larger summary zones, however, for smaller HUC polygons with very few burnable acres, the mean can be arbitrarily inflated by the small number of burnable acres in the denominator. Caution must be used when interpreting these results and establishing a minimum threshold for burnable acres may be needed to accurately rank mean eNVC values.

For the ARRA QWRA, we summarized a set of Effects Analysis results for ARRA using 6th-level watershed polygons (Figure 20. Map of Drinking Water Protection Areas within the ARRA analysis area. Figure 27).

\[ \text{ARRA}_6\text{th Level Watershed NVC results.xls} \]

\[ \text{For the full summaries by 6th-level watersheds please see: } \text{ARRA}_6\text{th Level Watershed NVC results.xls} \]
Figure 27. Total Mean eNVC for ARRA 6th-Level Watersheds
Table 17. Tabular summary of Mean and Total Wildfire Risk (eNVC) for ARRA 6th-Level Watersheds (Top 25).

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Exposed Acres/100 Acres</th>
<th>Total (All HVRA) Sum eNVC</th>
<th>Total (All HVRA) Mean eNVC</th>
<th>People &amp; Property Mean eNVC</th>
<th>Drinking Water Mean eNVC</th>
<th>Infrastructure Mean eNVC</th>
<th>Carbon Mean eNVC</th>
<th>Rank by Mean eNVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scout Lake-Kenai River</td>
<td>178</td>
<td>-12,480.607</td>
<td>-70.117</td>
<td>-67.007</td>
<td>0.00</td>
<td>-3.110</td>
<td>0.000</td>
<td>1</td>
</tr>
<tr>
<td>Sports Lake-Kenai River</td>
<td>120</td>
<td>-7,913.985</td>
<td>-65.815</td>
<td>-57.096</td>
<td>0.00</td>
<td>-8.718</td>
<td>0.000</td>
<td>2</td>
</tr>
<tr>
<td>Salamatof Creek-Frontal Cook Inlet</td>
<td>201</td>
<td>-10,701.659</td>
<td>-53.149</td>
<td>-49.220</td>
<td>0.00</td>
<td>-3.930</td>
<td>0.000</td>
<td>3</td>
</tr>
<tr>
<td>Slikok Creek</td>
<td>160</td>
<td>-6,995.063</td>
<td>-43.698</td>
<td>-37.130</td>
<td>0.00</td>
<td>-6.568</td>
<td>0.000</td>
<td>4</td>
</tr>
<tr>
<td>Bishop Creek</td>
<td>216</td>
<td>-9,085.223</td>
<td>-41.976</td>
<td>-39.961</td>
<td>0.00</td>
<td>-2.016</td>
<td>0.000</td>
<td>5</td>
</tr>
<tr>
<td>Soldotna Creek</td>
<td>270</td>
<td>-11,255.707</td>
<td>-41.643</td>
<td>-37.972</td>
<td>0.00</td>
<td>-3.672</td>
<td>0.000</td>
<td>6</td>
</tr>
<tr>
<td>Outlet Kenai River</td>
<td>177</td>
<td>-7,213.909</td>
<td>-40.648</td>
<td>-38.857</td>
<td>0.00</td>
<td>-1.791</td>
<td>0.000</td>
<td>7</td>
</tr>
<tr>
<td>Longmere Lake-Kenai River</td>
<td>262</td>
<td>-8,159.540</td>
<td>-31.088</td>
<td>-29.533</td>
<td>0.00</td>
<td>-1.555</td>
<td>0.000</td>
<td>8</td>
</tr>
<tr>
<td>Twitter Creek</td>
<td>103</td>
<td>-2,714.650</td>
<td>-26.452</td>
<td>-6.664</td>
<td>-17.143</td>
<td>-2.645</td>
<td>0.000</td>
<td>9</td>
</tr>
<tr>
<td>Reflection Lake-Frontal Cook Inlet</td>
<td>208</td>
<td>-5,052.861</td>
<td>-24.321</td>
<td>-23.739</td>
<td>0.00</td>
<td>-0.582</td>
<td>0.000</td>
<td>10</td>
</tr>
<tr>
<td>Star Lake-Kasilof River</td>
<td>166</td>
<td>-3,874.768</td>
<td>-23.350</td>
<td>-18.603</td>
<td>0.00</td>
<td>-4.748</td>
<td>0.000</td>
<td>11</td>
</tr>
<tr>
<td>Diamond Creek-Frontal Cook Inlet</td>
<td>212</td>
<td>-3,986.292</td>
<td>-18.774</td>
<td>-17.710</td>
<td>-0.055</td>
<td>-1.009</td>
<td>0.000</td>
<td>12</td>
</tr>
<tr>
<td>Coal Creek</td>
<td>132</td>
<td>-2,356.189</td>
<td>-17.818</td>
<td>-12.343</td>
<td>0.00</td>
<td>-5.474</td>
<td>0.000</td>
<td>13</td>
</tr>
<tr>
<td>Torpedo Lake-Kenai River</td>
<td>268</td>
<td>-4,676.165</td>
<td>-17.442</td>
<td>-15.508</td>
<td>0.00</td>
<td>-1.934</td>
<td>0.000</td>
<td>14</td>
</tr>
<tr>
<td>Lower Moose River</td>
<td>200</td>
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<td>-1.748</td>
<td>0.000</td>
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</tbody>
</table>
5 ANALYSIS SUMMARY

The Chugach All-Lands (ARRA) Wildfire Risk Assessment provides foundational information about wildfire hazard and risk for Southcentral Alaska. 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.
6 References


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 Southcentral AK. Much of the data used in this assessment is leveraged from the assessment but includes some slight modifications which warrant explanation in the sections below.

6.1 DATASETS USED

6.1.1 HOUSING-UNIT DENSITY
The housing-unit density (HUDen) map used here is the same source dataset as was introduced in Section 3.4.1.1 above. Here, housing-unit density was converted to a count of homes by multiplying by the area in square kilometers of a 30m 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.

6.1.2 RISK TO POTENTIAL STRUCTURES (RPS)
For this assessment, we use an integrated hazard dataset that uses burn probability, flame-length probabilities, and a response function (RF) to generally characterize loss to homes. This raster dataset is called Risk to Potential Structures (RPS) is created by calculating “loss to homes” for every pixel on the landscape, regardless of whether a home is present there. The RF used here does not vary by home and different building materials, nor does it consider nuances of each the immediate vegetation characteristics around each home.

<table>
<thead>
<tr>
<th>Fire Intensity Level</th>
<th>Response Function value</th>
</tr>
</thead>
<tbody>
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<td>0&lt;FL&lt;2</td>
<td>25</td>
</tr>
<tr>
<td>2&lt;FL&lt;4</td>
<td>40</td>
</tr>
<tr>
<td>4&lt;FL&lt;6</td>
<td>55</td>
</tr>
<tr>
<td>6&lt;FL&lt;8</td>
<td>70</td>
</tr>
<tr>
<td>8&lt;FL&lt;12</td>
<td>85</td>
</tr>
<tr>
<td>12&lt;FL</td>
<td>100</td>
</tr>
</tbody>
</table>
6.1.3 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 18, 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.

6.1.4 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.

We refer to the U.S. Census PPA delineation as the community “core”, but the summary unit of interest to us is the “Expanded Community” which includes the populated area and structures surrounding the PPAs. Ager and others (2019) 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 99.7 percent of the housing units identified by HUDen within the project’s LCP extent can be found within these Expanded Community areas (Figure 28). Less than 1 percent of the total housing units are not within 45-minutes travel time of any expanded community (hereafter, “community”) identified in southcentral AK.
Figure 28. Housing units mapped in ARRA and the community boundaries with which they are associated. Note that very few housing units are located beyond a community boundary.
6.2 RESULTS

6.2.1 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, overlaying wildfire hazard or risk maps, or to 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. Table 19 provides a subset of attributes to highlight the top communities at risk.

6.2.2 MEAN RISK TO POTENTIAL STRUCTURES
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 29 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.
Figure 29. Scatterplot of Mean Burn Probability and Mean Conditional Risk to Potential Structures - the product of which is Risk to Potential Structures (RPS).
Table 19. The top 25 communities as ranked by greatest mean Risk to Potential Structures (RPS) near where structures are found in the community.

<table>
<thead>
<tr>
<th>Community Name</th>
<th>HU count</th>
<th>Fraction HU count directly exposed</th>
<th>Fraction HU count indirectly exposed</th>
<th>Fraction HU count not exposed</th>
<th>Exposed HU count</th>
<th>Mean RPS all exposed</th>
<th>Rank Mean RPS (of 73)</th>
<th>Percentile Mean RPS</th>
<th>Expected annual HU risk</th>
<th>Rank Expected annual HU risk</th>
<th>Fraction direct expected annual HU risk</th>
<th>Fraction indirect expected annual HU risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Funny River</td>
<td>662</td>
<td>90%</td>
<td>10%</td>
<td>0%</td>
<td>662</td>
<td>1.82</td>
<td>1</td>
<td>99.6%</td>
<td>1,160</td>
<td>6</td>
<td>91%</td>
<td>9%</td>
</tr>
<tr>
<td>Sterling</td>
<td>3,141</td>
<td>82%</td>
<td>18%</td>
<td>0%</td>
<td>3,141</td>
<td>1.80</td>
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<td>5,272</td>
<td>1</td>
<td>85%</td>
<td>15%</td>
</tr>
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<td>8%</td>
<td>0%</td>
<td>308</td>
<td>1.55</td>
<td>3</td>
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<td>473</td>
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<td>93%</td>
<td>7%</td>
</tr>
<tr>
<td>Cohoe</td>
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<td>86%</td>
<td>14%</td>
<td>0%</td>
<td>760</td>
<td>1.42</td>
<td>4</td>
<td>96.9%</td>
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<td>11%</td>
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<td>9%</td>
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<td>72%</td>
<td>27%</td>
<td>1%</td>
<td>1,435</td>
<td>1.22</td>
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<td>2,910</td>
<td>0.35</td>
<td>20</td>
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<td>16%</td>
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<td>8%</td>
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<td>1,009</td>
<td>0.14</td>
<td>24</td>
<td>82.1%</td>
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<td>27</td>
<td>94%</td>
<td>6%</td>
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<td>14%</td>
<td>0%</td>
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<td>0.13</td>
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<td>81.4%</td>
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<td>16</td>
<td>89%</td>
<td>11%</td>
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</tbody>
</table>
6.2.3 TOTAL HOUSING-UNIT RISK

As a measure of cumulative wildfire risk to housing units, we calculate the product of housing units per pixel and RPS and sum that value for all pixels in a community. This measure is useful in resource allocation and can address the question: “In which communities are the total consequence of wildfire the greatest?” Unlike the previous measure, the total number of housing units strongly influences the Total Housing-Unit Risk (HURisk). Some communities, like Anchorage, have relatively low mean RPS, but rank high in total HURisk because of the very high number of housing units. Figure 30 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 20).

![Figure 30. Scatterplot 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).]
Table 20. The top 25 most at-risk communities as ranked by expected annual housing-unit risk.

<table>
<thead>
<tr>
<th>Community Name</th>
<th>HU count</th>
<th>Fraction HU count directly exposed</th>
<th>Fraction HU count indirectly exposed</th>
<th>Exposed HU count</th>
<th>Mean RPS all exposed</th>
<th>Rank Mean RPS (of 73)</th>
<th>Percentile Mean RPS</th>
<th>Expected annual HU risk</th>
<th>Rank Expected annual HU risk</th>
<th>Fraction direct expected annual HU risk</th>
<th>Fraction indirect expected annual HU risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sterling</td>
<td>3,141</td>
<td>82%</td>
<td>18%</td>
<td>0%</td>
<td>3,141</td>
<td>1.80</td>
<td>2</td>
<td>97.6%</td>
<td>5,272</td>
<td>1</td>
<td>85%</td>
</tr>
<tr>
<td>Kalifornsky</td>
<td>4,526</td>
<td>72%</td>
<td>28%</td>
<td>0%</td>
<td>4,521</td>
<td>0.93</td>
<td>10</td>
<td>95.5%</td>
<td>3,253</td>
<td>2</td>
<td>80%</td>
</tr>
<tr>
<td>Nikiski</td>
<td>2,637</td>
<td>85%</td>
<td>15%</td>
<td>0%</td>
<td>2,637</td>
<td>0.83</td>
<td>12</td>
<td>90.7%</td>
<td>2,161</td>
<td>3</td>
<td>89%</td>
</tr>
<tr>
<td>Kenai</td>
<td>4,285</td>
<td>51%</td>
<td>48%</td>
<td>1%</td>
<td>4,235</td>
<td>0.65</td>
<td>15</td>
<td>87.1%</td>
<td>1,902</td>
<td>4</td>
<td>64%</td>
</tr>
<tr>
<td>Ridgeway</td>
<td>1,446</td>
<td>72%</td>
<td>27%</td>
<td>1%</td>
<td>1,435</td>
<td>1.22</td>
<td>8</td>
<td>96.5%</td>
<td>1,310</td>
<td>5</td>
<td>87%</td>
</tr>
<tr>
<td>Funny River</td>
<td>662</td>
<td>90%</td>
<td>10%</td>
<td>0%</td>
<td>662</td>
<td>1.82</td>
<td>1</td>
<td>99.6%</td>
<td>1,160</td>
<td>6</td>
<td>91%</td>
</tr>
<tr>
<td>Cohoe</td>
<td>760</td>
<td>86%</td>
<td>14%</td>
<td>0%</td>
<td>760</td>
<td>1.42</td>
<td>4</td>
<td>96.9%</td>
<td>1,074</td>
<td>7</td>
<td>87%</td>
</tr>
<tr>
<td>Anchorage</td>
<td>123,613</td>
<td>32%</td>
<td>29%</td>
<td>39%</td>
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<td>0.02</td>
<td>52</td>
<td>54.3%</td>
<td>836</td>
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</tr>
<tr>
<td>Homer</td>
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<td>35%</td>
<td>0%</td>
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</tr>
<tr>
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<td>18</td>
<td>85.2%</td>
<td>656</td>
<td>10</td>
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</tr>
<tr>
<td>Anchor Point</td>
<td>1,123</td>
<td>86%</td>
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<td>1,123</td>
<td>0.65</td>
<td>16</td>
<td>86.4%</td>
<td>612</td>
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</tr>
<tr>
<td>Knik-Fairview</td>
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<td>90%</td>
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<td>0.09</td>
<td>28</td>
<td>77.5%</td>
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<td>12</td>
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</tr>
<tr>
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<td>487</td>
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<td>13</td>
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<td>718</td>
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<td>718</td>
<td>0.70</td>
<td>14</td>
<td>90.3%</td>
<td>480</td>
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</tr>
<tr>
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<tr>
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<tr>
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<td>22</td>
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<tr>
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<td>23</td>
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<tr>
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<tr>
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