Northern Region Wildfire Risk Assessment: methods and results

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Table of Contents

List of Tables

List of Figures

1. Overview of NoRRA

1.1 Purpose of the assessment

The purpose of the USFS Northern Region Wildfire Risk Assessment (NoRRA) is to provide foundational information about wildfire hazard and risk to highly valued resources and assets across the Region. Such information supports regional fuel management planning decisions as well as 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 NoRRA 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 man-made features, such as commercial structures, critical facilities, housing, etc., that have a specific importance or value. Resources are natural features, such as wildlife habitat, federally threatened and endangered species (wildlife and vegetation), etc. These also have a specific importance or value. Generally, the term “values at risk” has previously been used to describe both assets and resources. For NoRRA, 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 the Northern Region, it is essential that accurate wildfire risk data is available to drive fire management strategies. These risk outputs can be used to inform the planning, prioritization and implementation of prevention and mitigation activities, such as prescribed fire and mechanical fuel treatments. 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. This can aid in decision making for prioritizing and positioning of firefighting resources.

1.2 Landscape zones

1.2.1 Analysis area

The Analysis Area (AA) is the area for which valid burn probability (BP) results are produced. The AA for the Northern Region (NoRRA) FSim project was developed using a 30-km buffer of the Regional boundary west of the continental divide and a 30-km buffer of administrative forest boundaries east of the divide (Figure 1). The NoRRA analysis includes 10 national forests (NF): the Beaverhead-Deerlodge, Bitterroot, Custer Gallatin, Flathead, Helena, Idaho Panhandle, Kootenai, Lewis and Clark, Lolo, and Nez Perce-Clearwater and the Dakota Prairie grasslands.

1.2.2 Fire Occurrence Areas

To ensure valid BP results in the AA and prevent edge effects, it is necessary to allow FSim to start fires outside of the AA and burn into it. This larger area where simulated fires are started is called the Fire Occurrence Area (FOA). We established the FOA extent as a 20-km buffer on the Analysis Area (Figure 1). The 20-km buffer provides a sufficient area to make sure that all fires that could reach the AA are simulated. The buffered Fire Occurrence Area covers 114 million acres characterized by diverse topographic and vegetation conditions. To more accurately model this large area, where historical fire occurrence, and fire weather are highly variable, we divided the overall fire occurrence area into 18 FOAs. Individual FOA boundaries were generated using elevation-based ecozones, aggregated where appropriate for fire modeling purposes. For consistency with other FSim projects, we numbered these FOAs 305 through 322.

1.2.3 Fuelscape extent

The available fuelscape extent was determined by adding an additional 20-km buffer to the FOA. This buffer allows fire starting within the FOA to grow unhindered by the edge of the fuelscape, which would otherwise truncate fire growth and affect the simulated fire-size distribution and potentially introduce errors into the calibration process. A map of the Analysis Area, Fire Occurrence Area boundaries and fuelscape extent can be seen below in Figure 1.

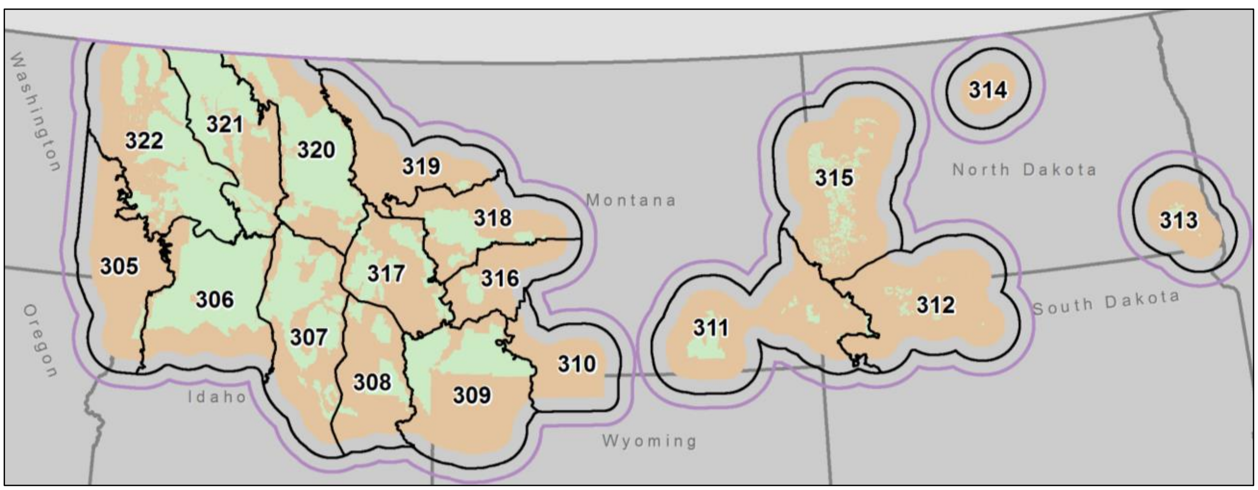

Figure 1. Overview of landscape zones for NoRRA FSim project. USFS administrative forests are shown in green, and the Analysis Area (AA) is shown in tan. The project produces valid BP results within this AA. To ensure valid BP in the AA, we started fires in the eighteen numbered fire occurrence areas (FOAs), outlined in black. To prevent fires from reaching the edge of the fuelscape, a buffered fuelscape extent was used, which is represented by the purple outline.

1.3 Quantitative risk modeling framework

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

Wildfire hazard is a physical situation with 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 measure). For this analysis, we used the large fire simulator (FSim) to quantify wildfire hazard across the landscape at a pixel size of 180 m (approximately 8 acres per pixel).

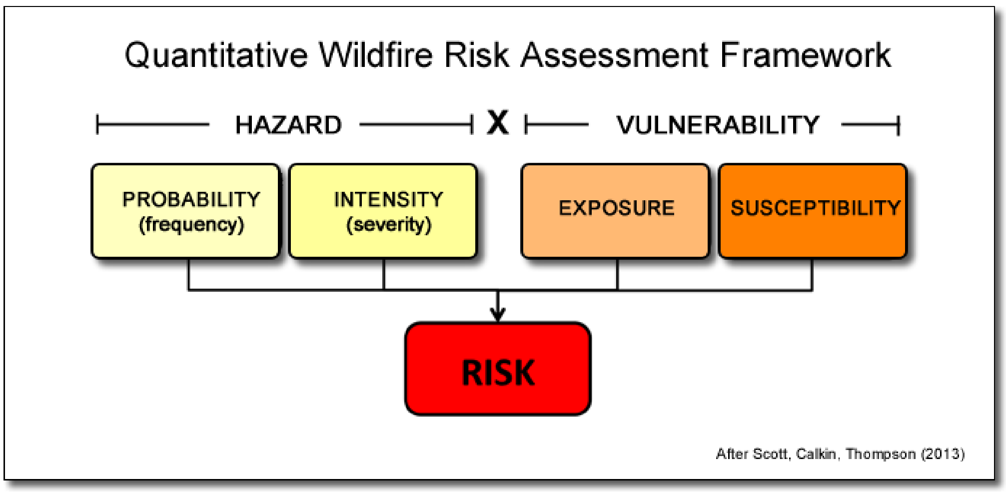

Figure 2. The components of the quantitative Wildfire Risk assessment framework used for NoRRA

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

2. Analysis methods and input data

The FSim large-fire simulator was used to quantify wildfire hazard across the Analysis Area at a pixel size of 180 m. 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).

2.1 Fuelscape

The fuelscape consists of geospatial data layers representing surface fuel model, canopy base height, canopy bulk density, and topography characteristics (slope, aspect, elevation). The fuelscape was developed from LANDFIRE 2012 (LF_1.3.0) 30-m raster data and was updated based on resource staff input at the fuel review workshop on July 6-7, 2016 in Missoula, MT. Additionally, the fuelscape was updated using RAVG, MTBS, and GeoMac datasets to account for wildfire disturbances occurring between 2013 and 2015. The resulting fuelscape by fuel model group is shown in Figure 3.

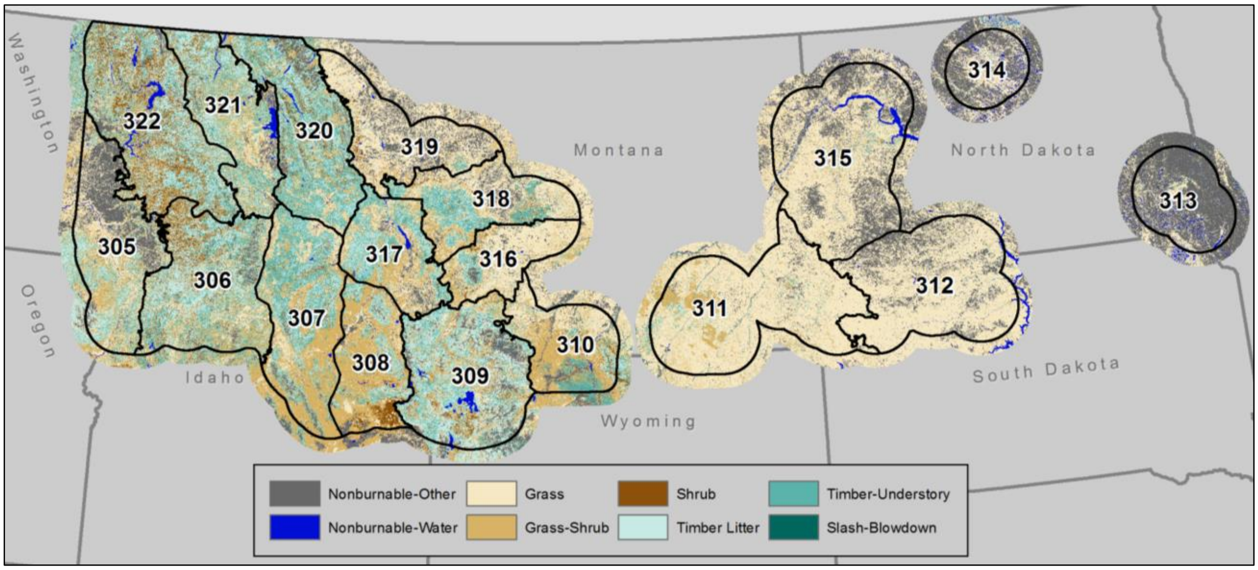

Figure 3. Map of fuel model groups across the NoRRA analysis area

The fuelscape was edited to mitigate underprediction of crown fire potential inherent in the native LANDFIRE 2012 fuelscape, where canopy base height values were too high to produce crown fire behavior under any modeled weather conditions. Due to the very large landscape size, multiple map zones, and regional focus of the project, a more general approach than the traditional LANDFIRE Total Fuel Change Tool project was needed. We evaluated the most commonly occurring combinations of existing vegetation type (EVT) models, fuel model and canopy base height (CBH) to determine where edits were needed to accurately reflect fire behavior potential. Figure 4 maps the extent of the fuel edits and fire disturbance updates applied to the original LANDFIRE 2012 grids. A summary of the edits made based on the combination of EVT_fuel code, fuel model and CBH is outlined in Table 1.

To bring the fuelscape to the current condition, we updated the fuelscape to reflect 2013-2015 fire disturbances (the work was performed in July 2016). We gathered severity data available from RAVG and MTBS and where severity data was unavailable, relied on final perimeters from the R1 fire history database (1985-2015) and downloaded perimeters from Geospatial Multi-Agency Coordination (GeoMac). We crosswalked RAVG, and MTBS to the appropriate disturbance code (112,122, or 132) corresponding with fire disturbances of low, moderate, or high severity, occurring in the last two to five years. Because perimeter data were lacking information about fire severity, we assigned a moderate severity disturbance code to all pixels coincident with recently burned fire perimeters. RAVG provides a percent canopy cover (CC) reduction value, from which a severity level was determined. For MTBS fires, we used the CC reduction midpoint values of 12 for low severity fire, 50 for moderate severity, and 80 for high severity fires. We then used these percent reduction value to increase CBH. For example, a CBH of 0.2 m with a 25 percent CC reduction would be reclassified as 0.25 m and rounded to the nearest integer. This method was used for low severity fires, but for moderate and high severity, CBH was set to 10 m to prevent any torching. We reduced canopy bulk density (CBD) by a factor equivalent to the percent CC reduction, with a minimum value of 1 (or 0.01 kg/m3)[1]. Post-disturbance fuel models varied by pre-disturbance fuel model, EVT, fire severity, and to a degree, map zone and generally slowed spread rate to reflect reduced fire behavior observed in previously burned areas.

Table 1. Table of applied edits developed at fuelscape review workshop.

<table>
<tr><th>EVT</th><th>All Map Zones, FM40=122 and EVH>109</th><th>All Map Zones, FM40=183 and CBH>2 (0.2 meters)</th><th>Map Zone 10, FM40=183 and CBH>2 (0.2 meters)</th><th>All Map Zones, FM40=188</th></tr>
<tr><td>2011</td><td></td><td rowspan="15">FM40=185, CBH = 2</td><td></td><td></td></tr>
<tr><td>2013</td><td></td><td></td><td></td></tr>
<tr><td>2016</td><td></td><td></td><td></td></tr>
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<tr><td>2057</td><td></td><td rowspan="8">FM40=185, CBH = 2</td><td></td><td></td></tr>
<tr><td>2061</td><td></td><td></td><td></td></tr>
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<tr><td>2365</td><td></td><td></td><td></td></tr>
<tr><td>2385</td><td></td><td></td><td></td><td>CBH=4</td></tr>
</table>

[1] Additional documentation on methodology used for recent fire update can be found in “NoRRA Fuel Updates.docx” along with the full rule set of post-disturbance fuel model assignments included in the spreadsheet “PostDisturbanceFMUpdates-Rules.xlsx.” These documents are included with project deliverables.

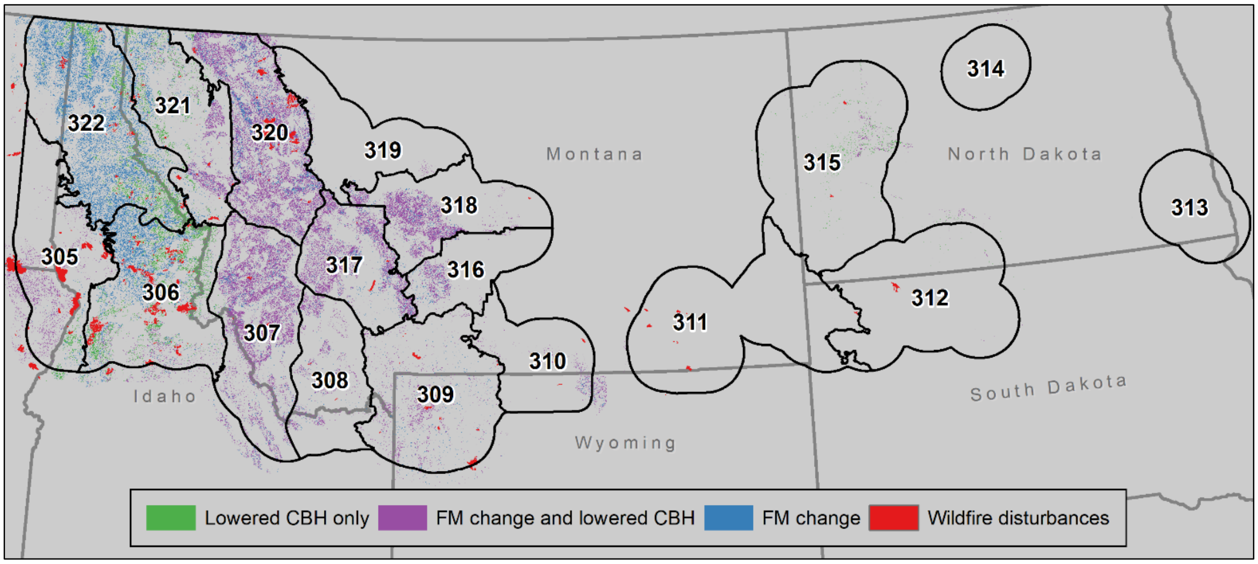

Figure 4. Map of the location of edits made to LANDFIRE 2012 (LF_1.3.0) 30-m raster data based on resource staff input at the fuel review workshop on July 6-7, 2016 in Missoula, MT.

2.2 Historical wildfire occurrence

Historical wildfire occurrence data were used to develop model inputs (Fdist and IDG) as well as for model calibration. For historical large-fire occurrence we used the (Short, 2017) Fire Occurrence Database (FOD), which spans the 24-year period 1992-2015 . Table 2 summarizes the annual number of large fires per million acres, along with mean large-fire size, and annual area burned by large fires per million acres. For this analysis, we defined a large fire, as one greater than 100 hectares (247.1 ac).

Table 2. Historical large-fire occurrence, 1992-2015, in the NoRRA FSim project FOAs.

FOA	Mean annual number of large fires	FOA area (M ac)	Mean annual number of large fires per M ac	Mean large-fire size (ac)	Mean annual large-fire area burned (ac)	FOA-mean burn probability
305	6.1	6.59	0.930	7,609	46,607	0.0071
306	21.0	7.88	2.660	6,652	139,423	0.0177
307	3.9	7.28	0.532	6,982	27,055	0.0037
308	1.8	4.71	0.371	3,266	5,716	0.0012
309	4.5	7.99	0.558	7,345	32,749	0.0041
310	2.6	4.26	0.606	1,477	3,814	0.0009
311	9.7	9.89	0.977	5,709	55,187	0.0056
312	4.6	8.76	0.523	1,873	8,586	0.0010
313	2.3	13.58	0.166	674	1,515	0.0001
314	2.3	10.62	0.212	915	2,058	0.0002
315	1.8	10.25	0.179	2,382	4,367	0.0004
316	1.2	3.35	0.348	2,991	3,489	0.0010
317	1.5	4.40	0.341	6,903	10,354	0.0024
318	1.3	4.98	0.251	1,224	1,530	0.0003
319	2.0	5.21	0.375	2,303	4,502	0.0009
320	6.3	6.96	0.899	7,740	48,375	0.0070
321	4.8	5.78	0.837	3,695	17,861	0.0031
322	4.2	9.15	0.455	2,179	9,080	0.0010

Historical wildfire occurrence varied widely by FOA, with FOA 306 experiencing the highest frequency, with an annual average of 2.66 large wildfires per million acres. FOA 313 had the least frequent rate of occurrence, with an annual average of 0.166 large wildfires per million acres. The size of wildfires ranged from an average large fire size of 674 ac in FOA 313 to 7,609 ac in FOA 305. In addition to the spatial variability, the largest wildfire year, in terms of acres burned, was 2000 with a total of 1,703,955 acres burned and the lowest was 1993 with 11,801 acres burned.

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 simulation. Ignition Density Grids (IDG) were generated using a mixed methods approach, combining with a mean the grids resulting from both the Kernel Density tool and the Point Density tool within ArcGIS for a 2-km cell size and 30-km search radius. All fires equal to or larger than 247.1 acres (100 ha) reported in the FOD were used as inputs to the IDG. One IDG was developed for the entire project area and divided up for each FOA by setting to zero all area outside of the fire occurrence boundary of that FOA. This allows for a natural blending of results across adjacent FOA boundaries. The IDG enables FSim to produce a spatial pattern of large-fire occurrence consistent with what was observed historically. Figure 5 below shows the ignition density grid for the fire occurrence area.

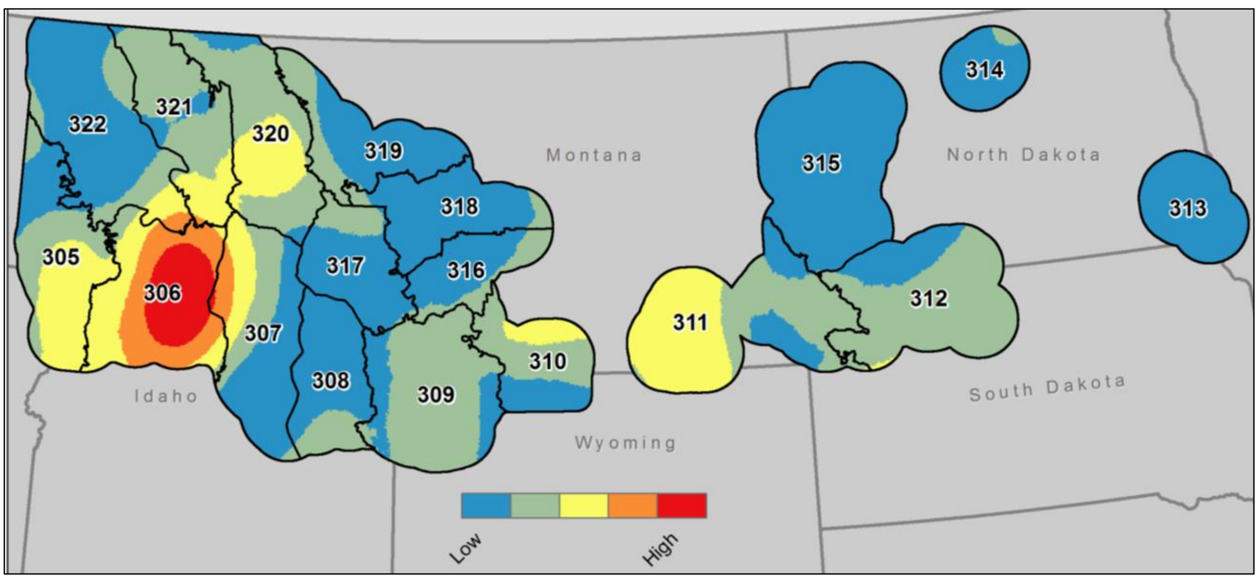

Figure 5. Ignition density grid used in FSim simulations.

2.3 Historical weather

FSim requires three weather-related inputs: monthly distributions of wind speed and direction, live and dead fuel moisture content by year-round percentile of the Energy Release Component 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 recorded at selected RAWS stations. Station selection was informed by information provided by R1 fire and fuels personnel. Stations with relatively long and consistent records and moderate wind activity were preferentially selected to produce the most reasonable and stable FSim results.

Rather than rely on ERC values produced from RAWS data which may be influenced by periods of station inactivity outside of the fire season, we extracted ERC values from Dr. Matt Jolly's historical, gridded ERC rasters for the period 1992-2012.

The map of RAWS stations selected for winds is shown in Figure 6. The point within each FOA boundary represents the station used except for FOAs 311 and 312 that used the Sand Creek RAWS station and FOA 315 which used data from Watford, Painted Canyon, and Sand Creek in a Special Interest Group (SIG), as suggested by Regional fire and fuels personnel.

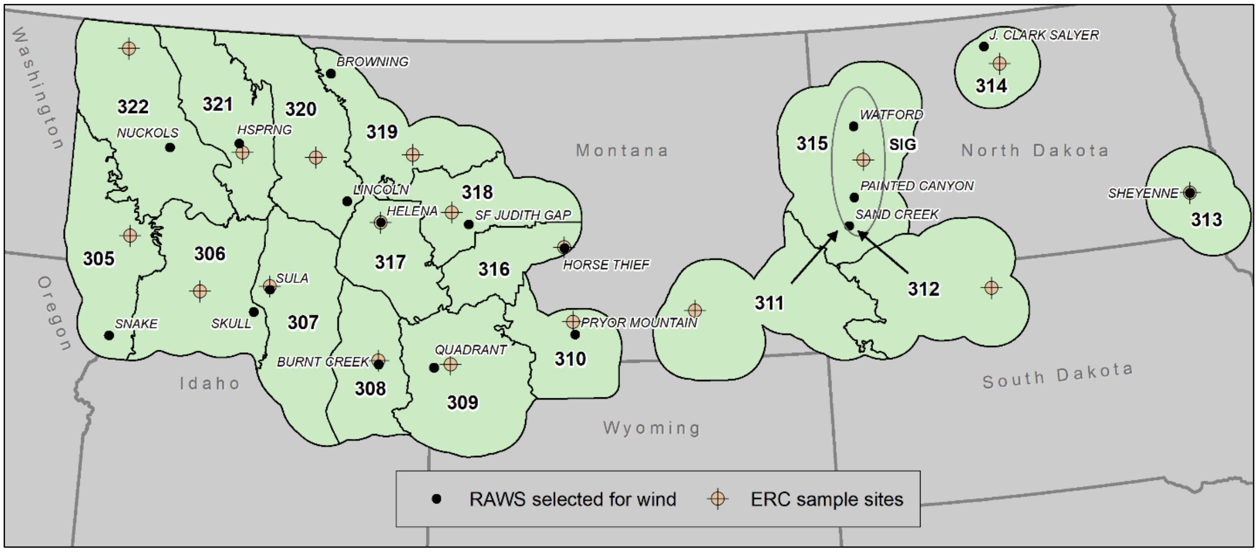

Figure 6. Name and location of RAWS used for the NoRRA FSim project. RAWS data were used for hourly sustained wind speed.

2.3.1 Fire-day distribution file (FDist)

Fire-day Distribution files (FDist) are used by FSim to generate stochastic fire ignitions as a function of ERC. 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:

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

Coefficient *a* describes the likelihood of a large fire at the lowest ERCs, and coefficient *b* determines the relative difference in likelihood of a large fire at lower versus higher ERC values.

2.3.2 Fire risk file (Frisk)

Fire risk files (Frisk) were generated for each RAWS using FireFamilyPlus (FFPlus). These files summarize percentile values for ERC, live and dead fuel moisture content, and wind speed and direction data for a RAWS. The FRISK file is used in the FSim simulation system.

2.3.3 Fuel moisture file (FMS)

Model fire behavior is not very sensitive to 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. The standard stylized set was used in sixteen of the eighteen FOAs**.** In FOAs 306 and 322 an updated FMS file was used to increase fuel moisture values on sheltered fuel model 142, where a fuel model edit was used to represent timbered understory rather than shrub canopy.

2.3.4 Energy Release Component file (ERC)

We sampled historical ERC-G values from a spatial dataset derived from North American Regional Reanalysis (NARR) 4-km ERC-G dataset for the period 1992-2012 (Freeborn *et al.*, 2016). This dataset does not include years after 2012. We did not use years prior to 1992 because our fire occurrence database record begins in 1992, though the historical grids range from 1979-2012. These gridded ERC values are year-round and match the years represented in the fire occurrence database, two factors affecting the logistic regression of the probability of a large-fire day in relation to ERC-G.

ERCs were sampled at an advantageous location within each FOA. Those locations are found on relative flat ground with little or no canopy cover, in the general area within the FOA that large-fires have historically occurred. These historical ERC values were used in conjunction with the FOD to generate FSim's FDist input file, but not for the FRISK file. ERC percentile information in the FRISK file was generated from the simulated ERC stream, described below. This approach ensures consistency between the simulated and historical ERCs.

For simulated ERCs in FSim, we used a new feature of FSim that allows the user to supply a stream of ERC values for each FOA. Isaac Grenfell, statistician at the Missoula Fire Sciences Lab, has generated 1,000 years of daily ERC values (365,000 ERC values) on the same 4-km grid as Jolly's historical ERCs. The simulated ERC values Grenfell produces are "coordinated" in that a given year and day for one FOA corresponds to the same year and day in all other FOAs—their values only differ due to their location on the landscape. This coordination permits analysis of fire-year information across all FOAs.

2.3 Wildfire simulation

The FSim large-fire simulator was used to quantify wildfire hazard across the landscape at a pixel size of 180 m (~8 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 eighteen FOAs independently, and then compiled the 18 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.

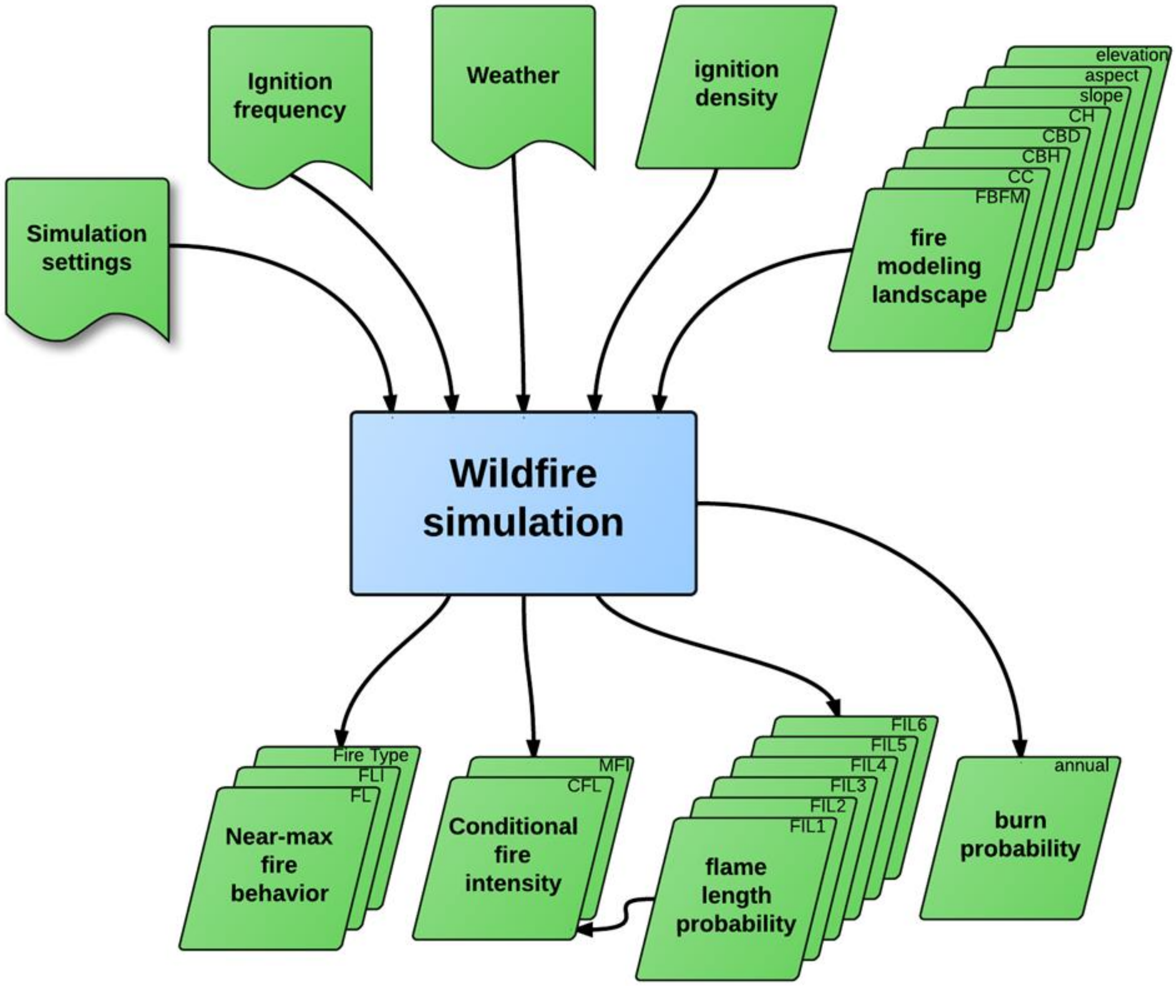

Figure 7. Diagram showing the primary elements used to derive Burn Probability.

2.3.1 Model calibration

FSim simulations for each FOA were calibrated to historical measures of large fire occurrence including: mean historical large-fire size, mean annual burn probability, mean annual number of large fires per million acres, and mean annual area burned per million acres. From these measures, two calculations are particularly useful for comparing against and adjusting FSim results: 1) mean large fire size, and 2) number of large fires per million acres.

To calibrate each FOA, we started with baseline inputs, and a starting ADJ file informed by experience on previous projects. The final model inputs can be seen below in Table 3. All runs were completed at 180-m resolution. Each FOA was calibrated separately to well within the 70% confidence interval and final simulations were run with a minimum of 10,000 iterations. The eighteen FOAs were then integrated into an overall result for the analysis area.

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

Final run	Number of Iterations	ADJ file	Trimming factor	FRISK	FDist file	LCP file
305r7	10,000	NoRRAv15	2.5	foa305v3	foa305v4	foa305v1_180
306r6	10,000	NoRRAv16	3.0	foa306v2	foa306v2	foa306v1_180
307r7	20,000	NoRRAv25	2.7	foa307v1	foa307v4	foa307v1_180
308r8	20,000	NoRRAv28	1.5	foa308v1	foa308v4	foa308v1_180
309r6	10,000	NoRRAv1	5.0	foa309v1	foa309v2	foa309v1_180
310r6	20,000	NoRRAv19	1.0	foa310v1	foa310v5	foa310v1_180
311r7	10,000	NoRRAv27	2.0	foa311v2	foa311v3	foa311v1_180
312r5	10,000	NoRRAv5	1.0	foa312v1	foa312v4	foa312v1_180
313r6	20,000	NoRRAv5	1.0	foa313v3	foa313v4	foa313v1_180
314r6	20,000	NoRRAv5	1.0	foa314v3	foa314v4	foa314v1_180
315r6	20,000	NoRRAv21	2.0	foa315v1	foa315v3	foa315v1_180
316r4	10,000	NoRRAv7	2.0	foa316v1	foa316v3	foa316v1_180
317r4	10,000	NoRRAv22	2.0	foa317v1	foa317v3	foa317v1_180
318r8	10,000	NoRRAv23	1.0	foa318v3	foa318v5	foa318v1_180
319r4	10,000	NoRRAv6	1.5	foa319v1	foa319v3	foa319v1_180
320r3	10,000	NoRRAv2	3.0	foa320v1	foa320v2	foa320v1_180
321r5	10,000	NoRRAv14	2.0	foa321v1	foa321v3	foa321v1_180fix4
322r9	20,000	NoRRAv21	1.5	foa322v2	foa322v5	foa322v1_180

2.3.2 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 a 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 BP at each pixel.

3. HVRA characterization

Highly Valued Resources and Assets (HVRA) are the resources and assets on the landscape most likely to be protected from or enhanced by wildfire and those considered in the Land and Resource Management Plan and/or Fire Management Plan. The key criterion is that they must be of high value to warrant inclusion in this type of assessment, both for the sake of keeping the assessment Regional in focus and to avoid valuing everything to the point nothing is truly *highly* valued.

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

3.1 HVRA identification

A set of HVRA were identified through a workshop held at the Northern Region Regional Office on October 25, 2016. A group consisting of the Fire/Fuel Planners, Resource Specialists, Wildlife Biologists, Geospatial Analysts, and Information Specialists identified nine HVRA in total: three highly valued assets and six resources. The complete list of HVRA and their associated data sources are listed in Table 4.

To the degree possible, HVRA are mapped to the extent of the Analysis Area boundary (Figure 1). This is the boundary used to summarize the final risk results. Some HVRA are limited to the Forest boundary, due to the nature of the data (e.g. extracted from Regional Vegetation Mapping; (VMAP) or FS assets mapped only on FS land only).

3.2 Response functions

Each HVRA selected for the assessment must also have an associated response to fire, whether it is positive or negative. We relied on input from Regional Resource Specialists, the Fuels Program Staff and various program managers in a series of mini-workshops held in March 2017 at the Regional Office. In these workshops, the group discussed how each resource or asset responded to fires of different intensity levels and characterized the HVRA response using values ranging from -100 to +100. The response functions (RFs) used in the risk results are shown in Table 6 through Table 23 below.

3.3 Relative importance

The relative importance (RI) assignments are needed to integrate results across all HVRAs, without this input from leadership, all HVRAs would be weighted equally. The RI workshop was held at the Regional Office on June 16, 2017 and was attended by Line Officers, Regional Leadership, and Regional Fuel Management Staff. The focus of this workshop was to establish the importance and ranking of the primary HVRA relative to each other. The initial HVRA rankings were revised from the original assignments, as requested by Regional Fuel Management Staff in August 2018. The changes were implemented by Pyrologix in September 2018 and the following sections reflect those revisions. HVRAs People and Property and Municipal Watersheds each received 22.2 percent of the total importance, followed by Aquatic Wildlife with 13.9 percent and T&E Terrestrial Wildlife with 11.1 percent. Timber and Vegetation Structure each received 8.3 percent, Major Infrastructure and Important Vegetation both received 5.6 percent, and Recreation received 2.8 percent (**Error! Reference source not found.**). These i mportance percentages reflect the importance per unit area of all mapped HVRA.

Sub-HVRA relative importance was determined by the Regional Fuels Program Manager and Resource Specialists. Sub-RIs are based on relative importance per unit area and mapped extent of the Sub-HVRA layers within the primary HVRA category. In Table 6 through Table 23, we provide the share of HVRA relative importance which is a function of both the mapped extent and relative importance of the Sub-HVRA of interest, within the primary HVRA.

Relative importance values were developed by first ranking the HVRAs then assigning an RI value to each. The most important HVRA was assigned RI = 100. Each remaining HVRA was then assigned an RI value indicating its importance relative to that most-important HVRA

The RI values apply to the overall HVRA on the assessment landscape as a whole. The calculations need to account for the relative extent of each HVRA to avoid overemphasizing HVRAs that cover many acres. This was accomplished by normalizing the calculations by the relative extent (RE) of each HVRA in the assessment area. Here, relative extent refers to the number of 30-m pixels mapped to 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; and an HVRA with a great many pixels has a low importance per pixel. A weighting factor (RIPP) representing the relative importance per unit area was calculated for each HVRA.

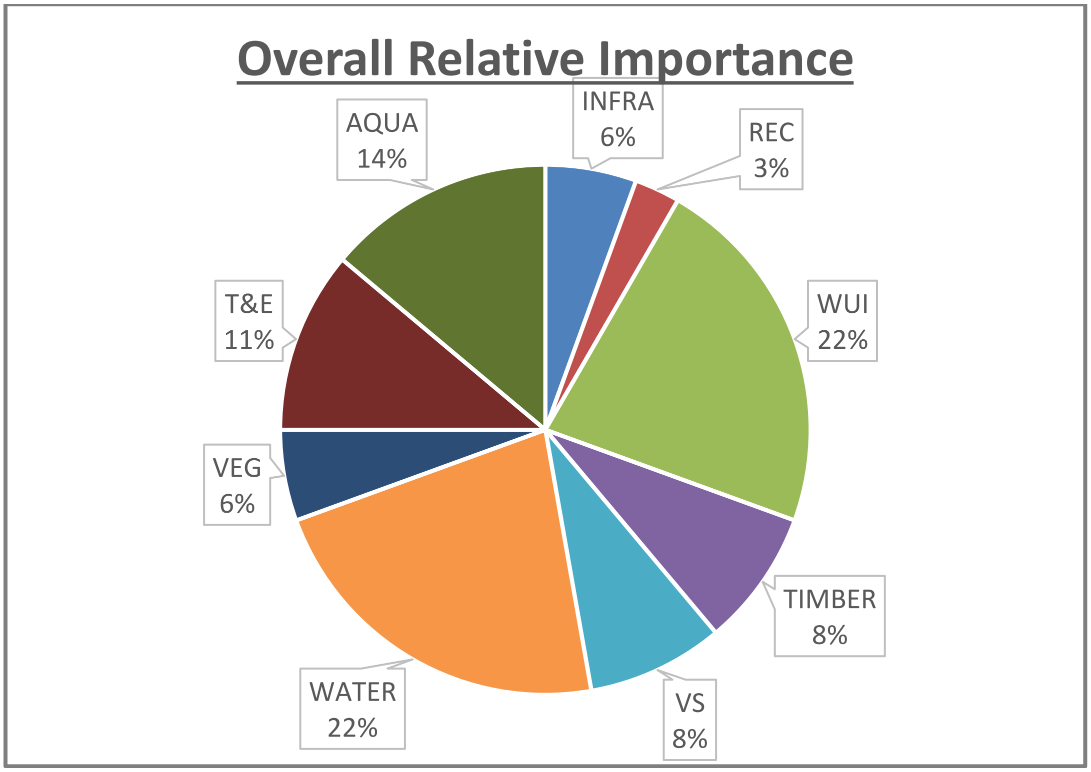

Figure 8. Overall HVRA Relative Importance for the primary HVRA included in NoRRA.

Table 4. HVRA and sub-HVRA identified in NoRRA and associated data sources.

HVRA & Sub-HVRA	Data source
Infrastructure	
Cell towers	Cell tower locations recorded by Federal Communications Commission and extracted from Homeland Security Information Network; Homeland Infrastructure Foundation Level Database.
FS Repeaters	Repeater locations from CIO Telecommunications
Other communication sites	Microwave Service Towers, Private Transmission Towers, and FM Transmission Towers extracted from Homeland Security Information Network; Homeland Infrastructure Foundation
Electric transmission lines	Transmission line locations extracted from Homeland Security Information Network; Homeland Infrastructure Foundation Level Database.
Wooden bridges	Bridges that contain wooden material from "R1 - Bridges and Culverts from Lat-Long" visualization extracted from the NRM Geospatial Interface.
Recreation and administrative infrastructure	
Developed rec sites	Developed recreation sites with Development Scale 3, 4, or 5 from EDW, S_USA.RecreationSite. Development Scale 2 extracted from INFRA.
FS Ski area infrastructure	Downhill ski areas compiled from SDE and Forest Unit Datasets

Recreation residences	Recreation residences using lat/long from SUDs database and new GPS information where lat/long not available
WUI	
WPL	Housing density classes as developed by the West Wide Wildfire Risk Assessment project
Private inholdings	Private ownership within FS admin boundaries
Timber	
FS Suitable Timber Base	Timber suitable timber lands based on R1 Forest Plan and Forest Plan Revision analysis
Non-Agency Timber	State lands from comprehensive state layers and private timberlands derived from ownership and forest visitor maps of unknown source and not comprehensive / less reliable
Experimental Forest	Experimental forests from USFS special interest management area
Vegetation	
Imp. veg types (seed source)	Potential high value seed source locations from Jones PVT and R1 VMap
Plus trees-WBP	Whitebark pine seed source trees from Regional Geneticist
Whitebark pine	Habitat suitability from R1 PVT 90m (2004)
Watershed resources	Municipal watersheds and estimates of population served by these systems in MT and ID; Erosion Potential from RSAC
Aquatic habitat	
Dense Dry Forest	LF2012 - Dry BpS Groups with Canopy Cover <=45%
Bull trout	Critical Habitat – U.S. Fish and Wildlife Service, Endangered Species Program, ECOS Joint Development
Steelhead	Critical Habitat – National Marine Fisheries Service (NOAA Fisheries)
Westslope cutthroat	Westslope Cutthroat Trout (WCT) Assessment Range-wide Database Update 2009
Yellowstone cutthroat	Yellowstone Cutthroat Trout (WCT) Assessment 2016
Redband trout	Western Native Trout Initiative – Redband Trout Assessment
T&E Terrestrial habitat	
Sage grouse habitat	SG significant units within greater SG habitat from national SG EIS and combined with NRCS-Index of Relative Ecosystem Resilience and Resistance
Lynx habitat	2017 potential lynx habitat and R1 LAU layers
Vegetation Structure	
Forest/Non-Forest vegetation structure	LANDFIRE 1.3.0 Fire Regime Group by vegetation type

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 include data such as erosion potential or habitat age/ quality/disturbance level, and population density classes. The main HVRAs in the NoRRA Assessment are mapped below along with a table with the set of response functions assigned, the within-HVRA relative importance score, and total acres for each sub-HVRA. These components are used along with fire behavior results from FSim in the wildfire risk calculations introduced in section 4.2.

3.4.1 Infrastructure

3.4.1.1 Cell towers and USFS Repeaters

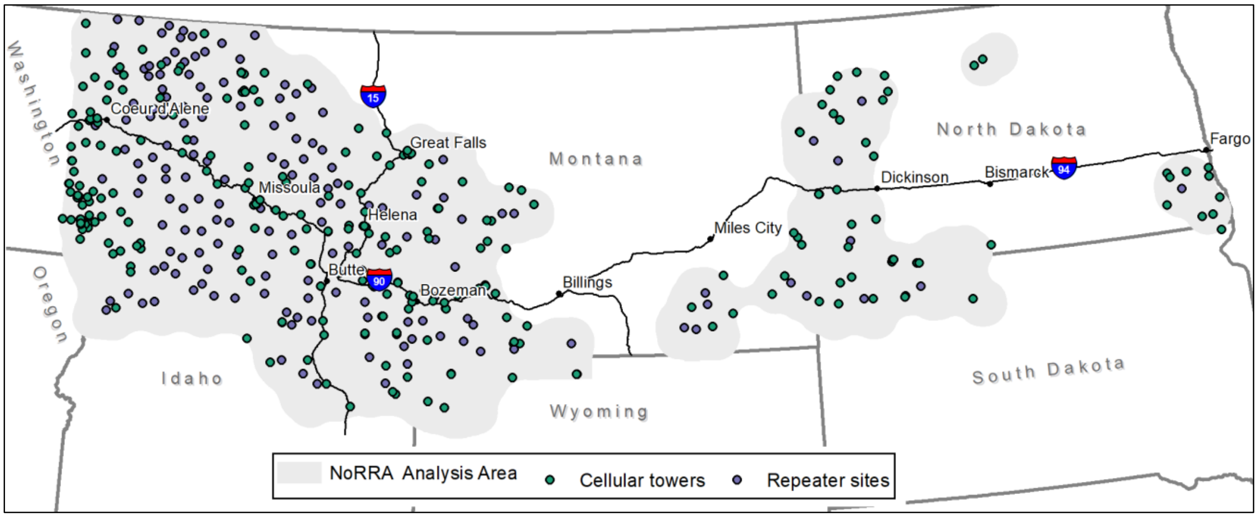

Figure 9. Map of cellular towers and repeater sites in the NoRRA analysis area.

Mapped location of cellular towers and USFS repeater site locations within the NoRRA analysis area are shown in Figure 9. Cell towers and USFS repeaters respond increasingly negatively to fire in all FIL classes. Cell towers make up 13% of the share of Infrastructure HVRA importance, while repeaters make up 7% (Table 6). The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 6. Response functions for the Infrastructure HVRA.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Cell towers	-10	-20	-40	-60	-80	-100	13%	2,218
Electric transmission lines	20	20	0	-20	-60	-100	45%	760,356
FS Repeaters	-10	-20	-40	-60	-80	-100	7%	1,433
Wooden bridges	-40	-50	-60	-70	-80	-100	1%	9,247
Other communication sites	-10	-20	-40	-60	-80	-100	35%	58,710

[1] Within-HVRA relative importance.

3.4.1.2 Other communication sites

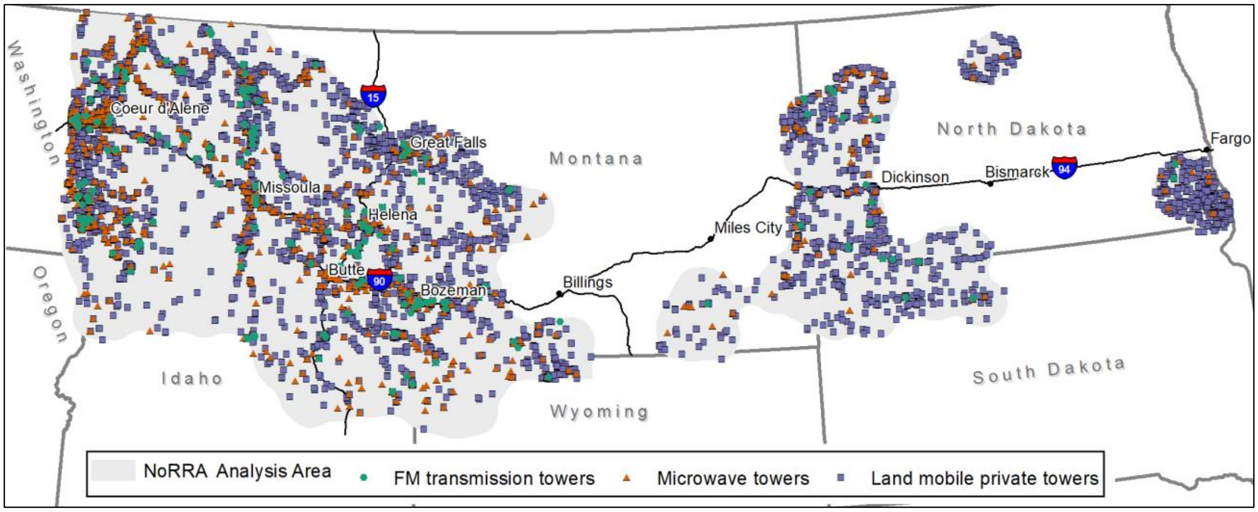

Figure 10. Map of other communication sites in the NoRRA analysis area.

Other communication sites were added to the assessment after cell towers and repeaters and were therefore labeled "other." The locations of other communication sites are mapped in Figure 10. They include microwave towers, land mobile transmission towers, and FM transmission towers recorded in the FCC database. They received the same response function as cell towers and repeaters above, characterized by an increasingly negative response to fire of increasing intensity (Table 7). Due to their abundance on the landscape, they received 35% of the share of Infrastructure HVRA importance. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 7. Response functions for the Infrastructure HVRA.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Cell towers	-10	-20	-40	-60	-80	-100	13%	2,218
Electric transmission lines	20	20	0	-20	-60	-100	45%	760,356
FS Repeaters	-10	-20	-40	-60	-80	-100	7%	1,433
Wooden bridges	-40	-50	-60	-70	-80	-100	1%	9,247
Other communication sites	-10	-20	-40	-60	-80	-100	35%	58,710

[1] Within-HVRA relative importance.

3.4.1.3 Electric transmission lines

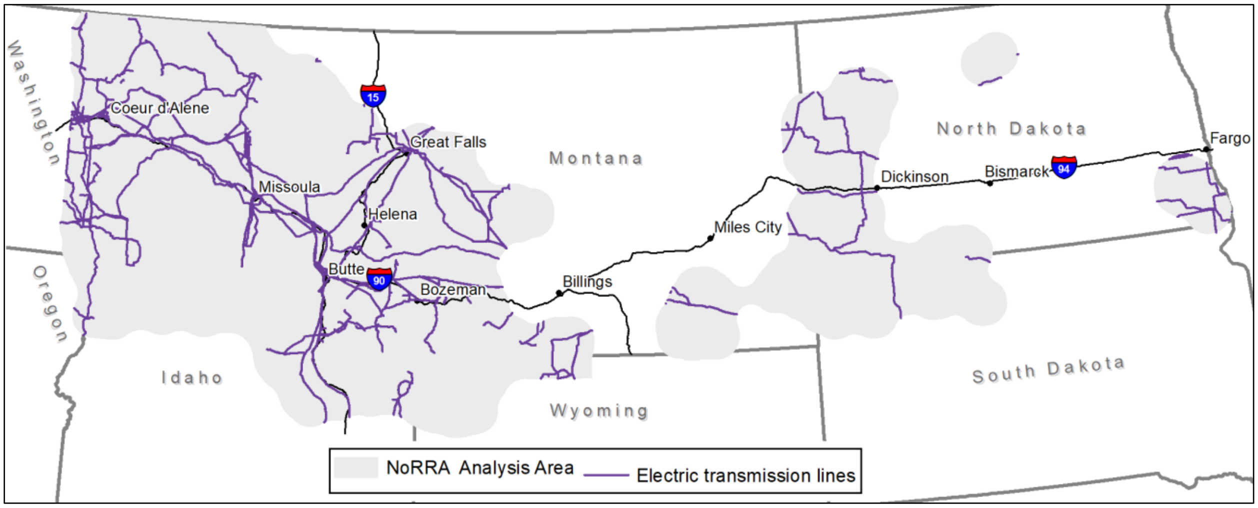

Figure 11. Map of electric transmission lines in the NoRRA analysis area.

Electrical transmission lines mapped for NoRRA are shown in Figure 11. In this assessment, electric transmission lines respond favorably to fire at FILs 1-2 and have a neutral response at FIL3. An increasingly negative response occurs at FILs 4-6 (Table 8). Due to the number of acres mapped on the landscape and their importance to infrastructure, electric transmission lines received 45% 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.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Cell towers	-10	-20	-40	-60	-80	-100	13%	2,218
Electric transmission lines	20	20	0	-20	-60	-100	45%	760,356
FS Repeaters	-10	-20	-40	-60	-80	-100	7%	1,433
Wooden bridges	-40	-50	-60	-70	-80	-100	1%	9,247
Other communication sites	-10	-20	-40	-60	-80	-100	35%	58,710

[1] Within-HVRA relative importance.

3.4.1.4 Wooden bridges

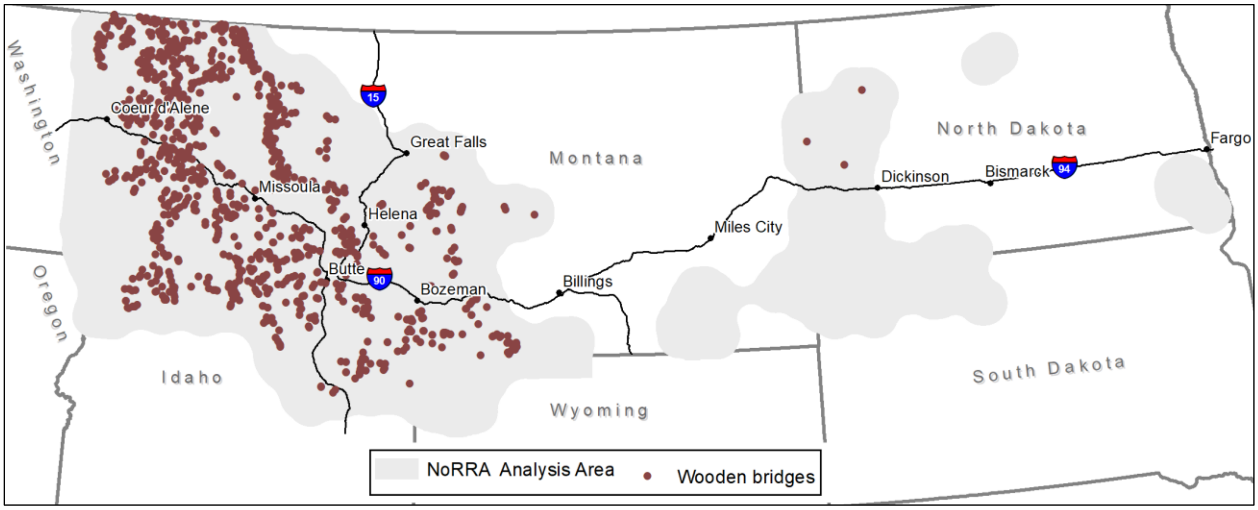

Figure 12. Map of the location of bridges that contain wooden material in the NoRRA analysis area.

Wooden bridges are located predominantly in the north-western section of the analysis area (Figure 12). The wooden bridge Sub-HVRA responds negatively to fire in all FIL classes (Table 9) due to the susceptibility of wooden material to fire. Wooden bridges comprise one percent of the Infrastructure HVRA importance because of their relative scarcity on the landscape. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 9. Response functions for the Infrastructure HVRA.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Cell towers	-10	-20	-40	-60	-80	-100	13%	2,218
Electric transmission lines	20	20	0	-20	-60	-100	45%	760,356
FS Repeaters	-10	-20	-40	-60	-80	-100	7%	1,433
Wooden bridges	-40	-50	-60	-70	-80	-100	1%	9,247
Other communication sites	-10	-20	-40	-60	-80	-100	35%	58,710

[1] Within-HVRA relative importance.

3.4.2 Recreation infrastructure

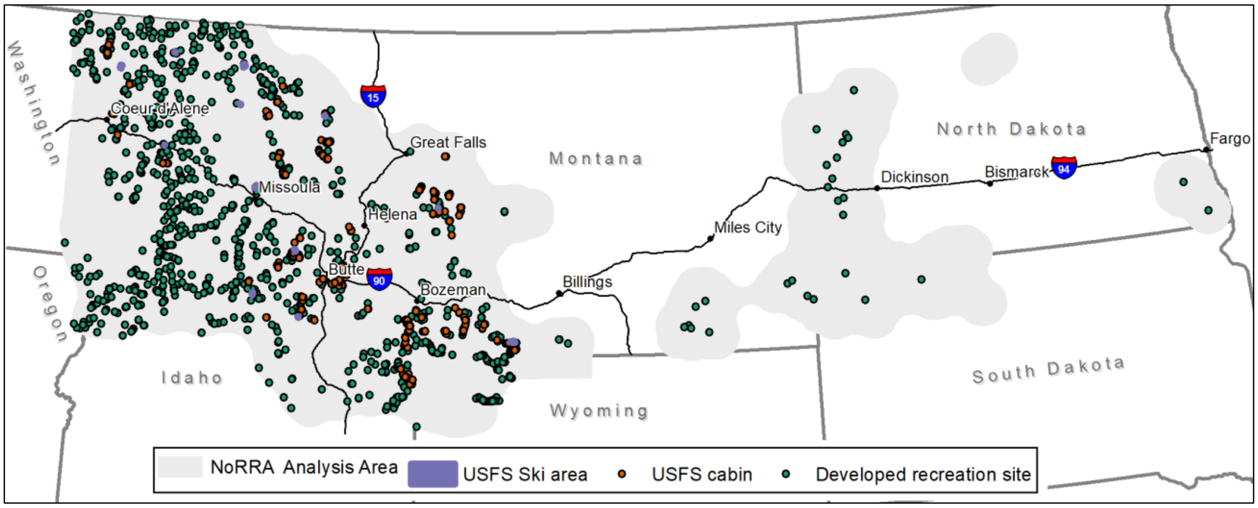

Figure 13. Map of USFS ski areas, USFS cabins and developed recreation sites in the NoRRA analysis area.

Recreation and administrative infrastructure are located throughout the study area (Figure 13). All Recreation Sub-HVRAs were assigned a negative response function in all FILs, increasingly so with increasing intensities (Table 10). Developed recreation sites Scale 2-5 were separated in the analysis so that their relative importance ranks would be tied to their investment level. The share of RI importance in Table 10 is a balance of the number of acres mapped for a given resource and the relative importance within the HVRA. The Sub-RI value assigned to Scale-2 sites was the lowest value and Scale-5, the highest. Scale-2 sites received one percent of the share of the Recreation HVRA relative importance. Scale-3 received a larger share at 18 percent than Scale-4 (12 percent) due to their abundance on the landscape. Scale-5 received four percent because of its relative scarcity compared with the lower level recreation sites. USFS ski areas represent downhill (lift service) ski areas and associated infrastructure and received 44 percent of the Recreation HVRA relative importance. This is due to both the number of acres mapped to this Sub-HVRA and their value to the Region. Finally, recreation residences received 21 percent of the Recreation HVRA relative importance because of their value to the Region and the number of acres mapped in the assessment area. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 10. Response functions for the Recreation HVRA.

Sub-HVRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Developed recreation sites – 2	-10	-20	-40	-60	-80	-100	1%	1,065
Developed recreation sites – 3	-10	-20	-40	-60	-80	-100	18%	6,109
Developed recreation sites – 4	-10	-20	-40	-60	-80	-100	12%	2,458
Developed recreation sites – 5	-10	-20	-40	-60	-80	-100	4%	584
USFS ski area infrastructure	-10	-20	-40	-60	-80	-100	44%	20,059
Recreation residences	-10	-20	-40	-60	-80	-100	21%	3,675

[1] Within-HVRA relative importance.

3.4.3 People and property

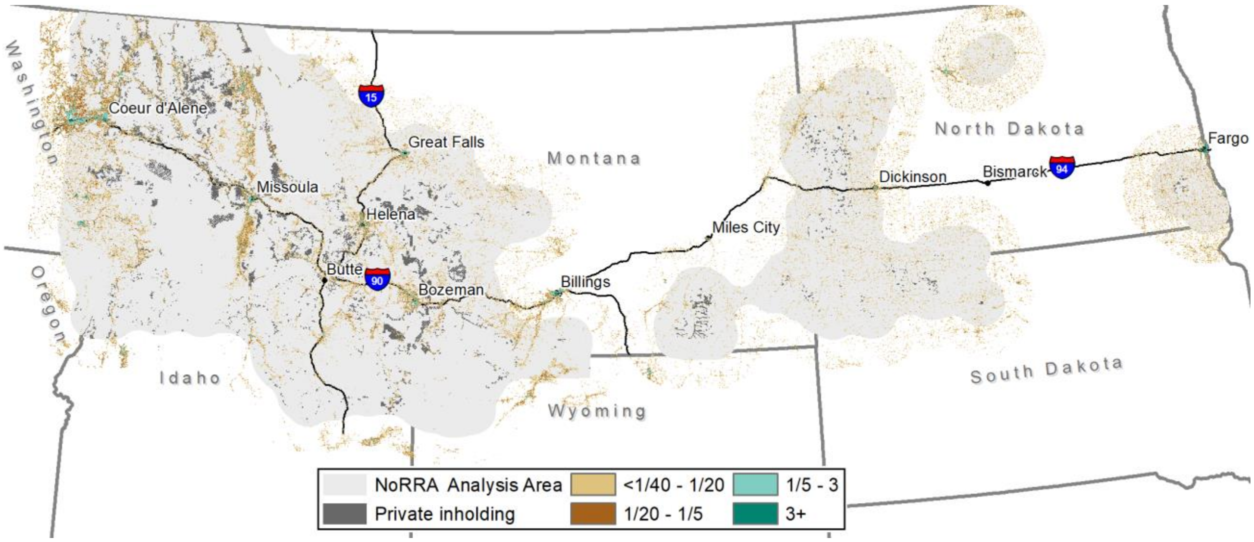

Figure 14. Map of housing density and private inholdings within USFS administered lands in the NoRRA analysis area.

The People and Property HVRA consisted of both the Where People Live (WPL) dataset and the Private inholdings within USFS administered lands Sub-HVRA (Figure 14). We classified WPL into seven housing density classes ranging from very dense (>3 housing units per acre) to very sparse (<1 housing unit per 40 acres). Pixels in the lower density classes (tan and brown) are scattered throughout the project area, but the more densely populated pixels (turquoise) are concentrated around the major cities. Private inholdings (mapped in dark gray) are privately owned parcels within the administrative boundaries of the U.S. Forest Service. Response functions were increasingly negative for all housing densities across FILs 1-6 (Table 11). Because private inholding parcels may contain seasonal dwellings or structures not represented by WPL, they were given the same response function as the WPL classes.

The relative importance per unit area was in proportion to the housing density class, but the share of the People and Property HVRA importance held by the most-densely populated class (WPL 3+ housing units per acre) is only 5 percent, while the next density class holds the greatest share at 36 percent (Table 11). The remaining classes each hold a decreasing share of RI. Private inholdings received eight percent of the share of RI because their sub-RI was less than the lowest density class due to the greater uncertainty of housing unit presence on the parcel. In total, 1.8 million acres were mapped across the project area.

Table 11. Response functions for People and Property HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
WPL <1 housing unit/ 40 acres	-10	-20	-40	-60	-80	-100	6%	1,057,641
WPL 1/40 – 1/20	-10	-20	-40	-60	-80	-100	7%	487,501
WPL 1/20 – 1/10	-10	-20	-40	-60	-80	-100	10%	391,956
WPL 1/10 – 1/5	-10	-20	-40	-60	-80	-100	14%	279,024
WPL 1/5 – 1/2	-10	-20	-40	-60	-80	-100	22%	194,722
WPL 1/2 - 3	-10	-20	-40	-60	-80	-100	36%	96,012
WPL 3+	-10	-20	-40	-60	-80	-100	5%	3,129
Private Inholdings	-10	-20	-40	-60	-80	-100	8%	1,818,345

[1] Within-HVRA relative importance.

3.4.4 Timber

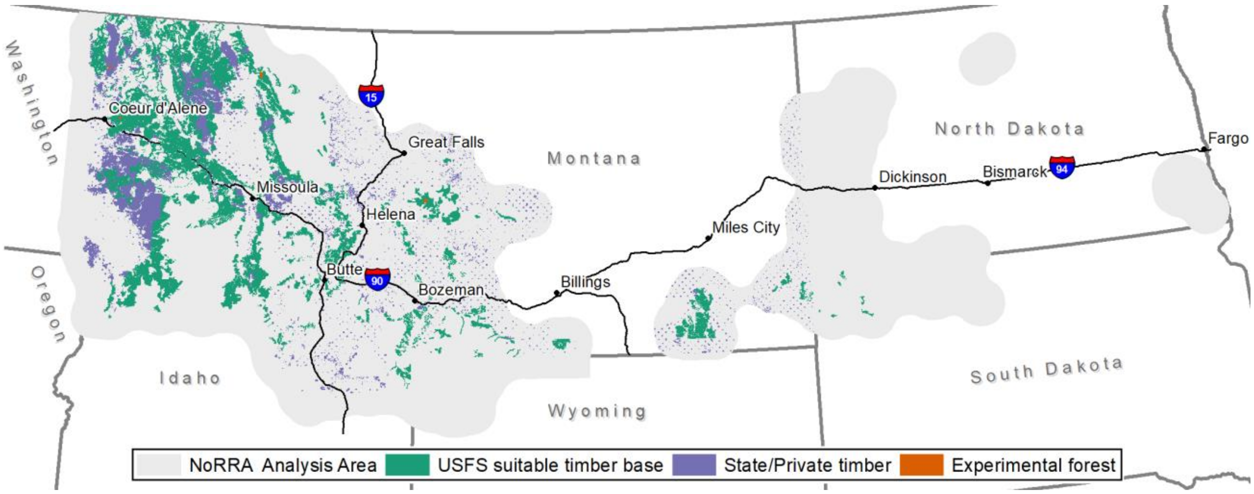

Figure 15. Map of USFS, State, and Private suitable timber lands and designated experimental forests in the NoRRA analysis area.

The Timber HVRA includes suitable timber base for USFS, timber values for state, private, and University lands, and USFS experimental forests (Figure 15). USFS Suitable Timber Base was stratified by vegetation type and size to allow for more refinement on the fire effects on timber values. Non-Agency Timber values include state, private, and University-owned lands but information on vegetation type and size were not available.

Response to fire varied by size class in the USFS Timber sub-HVRA with the larger (greater than 15in. diameter), warm-climate classes responding very favorably to fire in FILs1-3, but negatively in FILs4-6 (Table 12). The smaller (greater than 10in. diameter), cooler-climate classes responded less favorably, but still positively to fire in FILs1-2, neutral in FIL3, and negatively to FILs4-6. Other USFS Timber was assumed to be of smaller diameter, and therefore less resistant to fire, and received a slightly positive RF in FIL1, but increasingly negative RFs in FILs2-6. Non-Agency Timber was shown to be neutral to fire in FILs1-2 but responded negatively to fire in FILs3 and greater. Finally, unplanned fire can destroy ongoing experiments in the Experimental Forests and therefore, all FILs received the maximum -100 response.

Relative importance between the two different timber ownerships (USFS and Non-Agency) was split nearly equally with 52 percent of the share going to USFS and 48 percent to Non-Agency timber. Because there are so few acres across the project area, especially with respect to the other timber sub-HVRA, Experimental Forests received just 0.5 percent of the Timber HVRA relative importance. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 12. Response functions for the Timber HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
USFS Timber Other	10	-10	-40	-60	-100	-100	44%	5,279,872
USFS Timber WM GT 15	75	75	50	-25	-50	-100	4%	428,243
USFS Timber Cold GT 10	25	25	0	-20	-100	-100	1%	104,788
USFS Timber CM GT 10	25	25	0	-20	-100	-100	1%	109,057
USFS Timber WD GT 15	75	75	50	-25	-50	-100	2%	278,578
Non-Agency Timber	0	0	-40	-60	-100	-100	48%	2,882,066
Experimental Forests	-100	-100	-100	-100	-100	-100	0.5%	27,848

[1] Within-HVRA relative importance.

3.4.5 Important vegetation

3.4.5.1 Important vegetation types - seed sources

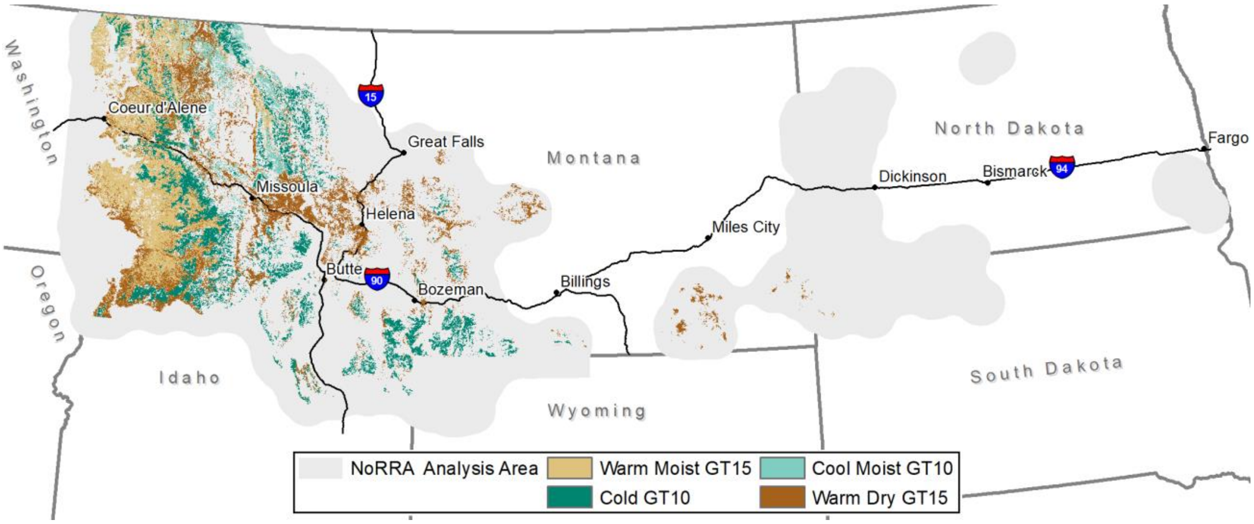

Figure 16. Map of important vegetation type seed sources in the NoRRA analysis area.

The Important Vegetation-seed sources sub-HVRA is mapped in Figure 16 and depicts the location of mature trees of desirable species by climate type.

Response to fire varied by size class in the different seed source classes with the larger (greater than 15in. diameter), warm-climate classes responding very favorably to fire in FILs1-4, but negatively in FILs5-6 (Table 13). The smaller (greater than 10in. diameter), cooler-climate classes responded less favorably, but still positively to fire in FILs1-5, and negatively in FILs5-6.

All classes of Seed Source trees were weighted equally, but due to difference in numbers of acres had a different share of the Important Vegetation HVRA relative importance. In total, Seed Source received 64 percent of the share of RI. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 13. Response functions for Important Vegetation HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Seed Source – WM GT 15	75	75	75	50	-50	-100	24%	1,851,012
Seed Source – Cold GT 10	25	25	25	25	-100	-100	16%	1,239,718
Seed Source – CM GT10	25	25	25	25	-100	-100	3%	222,480
Seed Source – WD GT 15	75	75	75	50	-50	-100	20%	1,529,183
WBP – Plus trees	0	-50	-100	-100	-100	-100	0.3%	5,084
WBP – Potential habitat	25	25	60	40	0	-10	36%	2,744,994

[1] Within-HVRA relative importance.

3.4.5.2 Whitebark pine

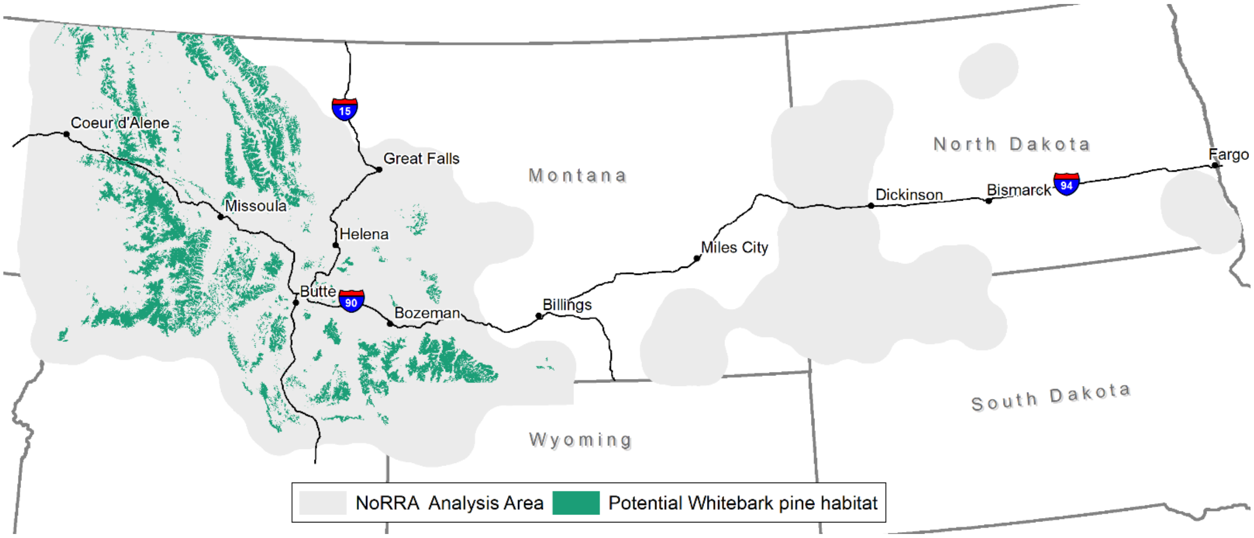

Figure 17. Map of the location of potential habitat in the NoRRA analysis area. Resistant Whitebark pine seed sources not shown due to data sensitivity.

Map of suitable environments for Whitebark pine within the NoRRA analysis area (Figure 17). Due to data sensitivity, the locations of disease tolerant Whitebark pine Plus trees are not shown. Whitebark pine habitat and Plus trees are located only in the western, higher elevation, and forested portion of the analysis area.

Whitebark pine potential habitat was characterized as relatively fire tolerant, with the response to fire described as slightly benefial in FILs1-2, strongly postive in FILs3-4, neutral in FIL5 and only sligtly negative in FIL6 (Table 14). Whitebark pine Plus trees, on the other hand, are neutral to fire only in FIL1 and strongly adverse in FILs2-6 where fire might damage trees and root structure to the point they are no longer viable.

Though they were given a high per pixel importance, Plus trees only received 0.3 percent of the total Important Vegetation HVRA relative importance because there are so few acres mapped. Potential habitat received 36 percent of the Important Vegetation HVRA relative importance due to the abundance of acres mapped in the analysis area. The share of HVRA importance is based on relative importance per unit area and mapped extent.

Table 14. Response functions for Important Vegetation HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Seed Source – WM GT 15	75	75	75	50	-50	-100	24%	1,851,012
Seed Source – Cold GT 10	25	25	25	25	-100	-100	16%	1,239,718
Seed Source – CM GT10	25	25	25	25	-100	-100	3%	222,480
Seed Source – WD GT 15	75	75	75	50	-50	-100	20%	1,529,183
WBP – Plus trees	0	-50	-100	-100	-100	-100	0.3%	5,084
WBP – Potential habitat	25	25	60	40	0	-10	36%	2,744,994

[1] Within-HVRA relative importance.

3.4.6 Watershed resources

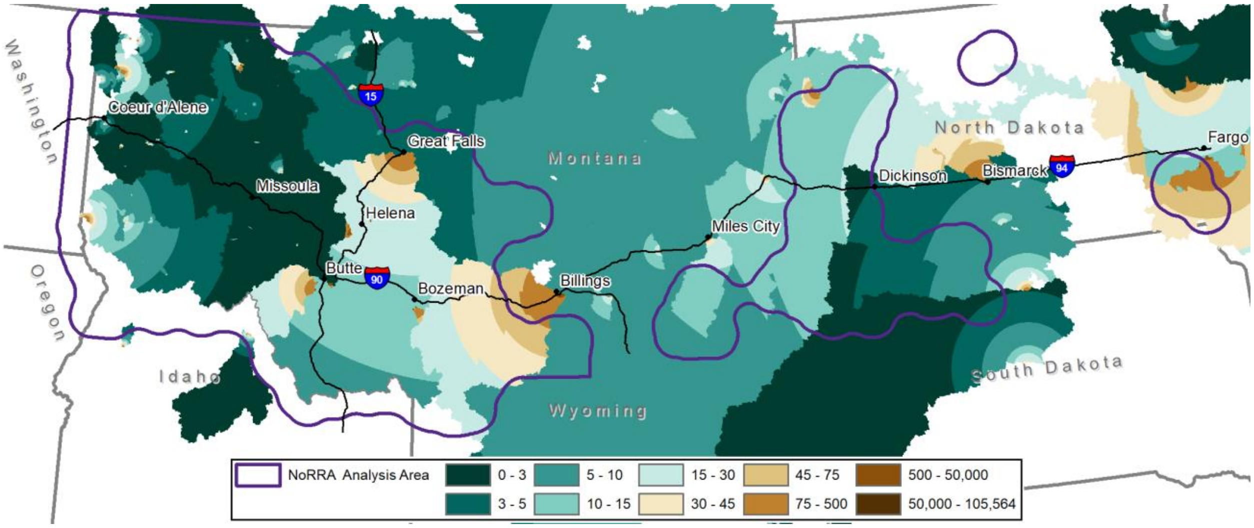

Figure 18. Map of watershed importance index developed based on the distance to a municipal drinking water intake and the population that it serves.

Watershed resources were mapped 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 raster resolution (30 meters) of each pixel by the distance to the intake and multiplied by the population served by that intake. Because a single pixel can belong to one or more overlapping watersheds, the values are cumulative across any overlapping watersheds. The resulting importance map is shown in Figure 18.

The response functions used for erosion cannot be shown in Table 15 because response to fire was determined spatially according to erosion modeling results for the analysis area. The Remote Sensing Applications Center (RSAC) produced a set of modeled erosion and deposition potential maps based on a current condition (no-fire) situation and low and high severity fire scenarios. We used only erosional pixels that were negative values in the modeled results and converted them to positive integers. Using the differences between the no-fire scenario and the low fire severity scenario, we applied a logarithmic base-ten transformation. We applied the same transformation to the difference values between the no-fire scenario and the high fire severity scenario, and determined the 95th percentile value. We set this value as the maximum loss value (response function of -100) for both scenarios and scaled all other values relative to this. This resulted in two grids ranging from 0 to -100 for low severity fire and high severity fire. The RSAC model used a c-factor value to determine the change in cover due to wildfire, and cover types were derived from the National Land Cover Dataset (NLCD). Where the c-factor value was constant across low and high severity fire, we assigned the low severity RF values. These pixels were generally associated with grass and shrub-type vegetation. Where c-factor increased from low to high severity, typically in timbered vegetation, we used the low severity RF values for FILs1-3 and the high severity RF values for FILs4-6. The municipal watersheds HVRA had just one sub-HVRA, which received the full share of the HVRA importance.

Table 15. Response functions for Municipal Watershed HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Municipal Watershed	x	x	x	x	x	x	100%	77,847,403

[1] Within-HVRA relative importance.

3.4.7 Aquatic habitat

3.4.7.1 Bull trout

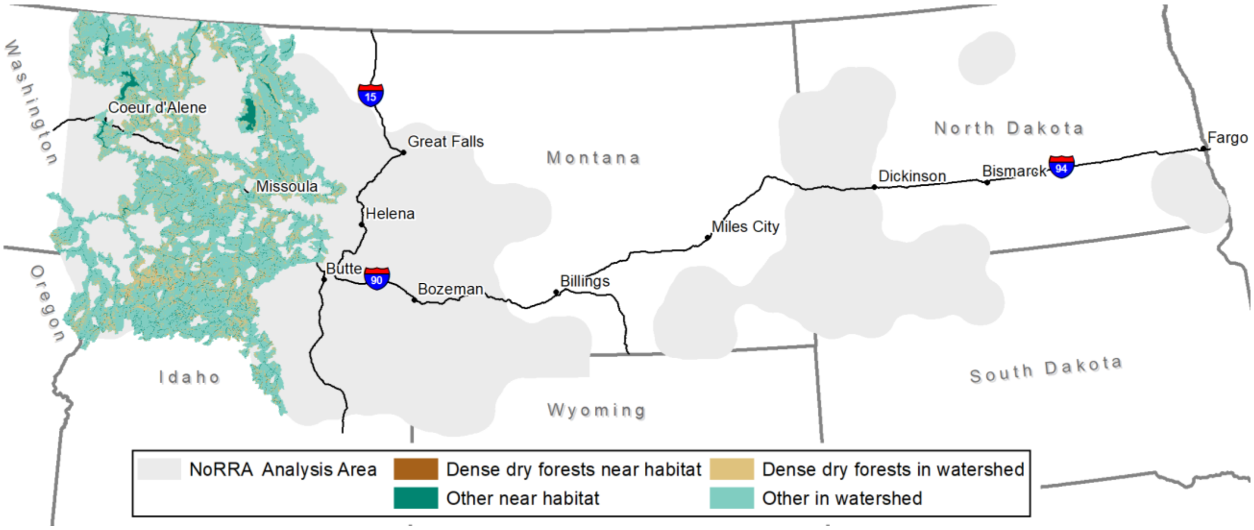

Figure 19. Map of Bull trout habitat and surrounding forest types in the NoRRA analysis area.

Bull trout (*Salvelinus confluentus*) critical habitat (streams and lakes) and the watersheds that intersect them are mapped in Figure 19. In this analysis, fish habitat was stratified into Dense Dry Forest (DDF) habitat and other forest types. DDF was defined as dry-climate, LANDFIRE version 1.3.0 Biophysical Groups, where canopy cover values met or exceeded 45 percent. In DDF nearest the fish habitat, response function values were highly positive in FILs1-2, neutral in FIL3, and becoming increasingly negative in FILs4-6 (Table 16). In the other forest types nearest the habitat, fire was neutral in FILs1-3 and increasingly beneficial in FILs4-6. In DDF farther from the stream, fire was decreasingly positive in FILs1-2 switching to neutral in FILs3-4 and becoming negative in FILs5-6. Finally, in other forest types farther from the stream, fire was neutral in FILs1-3, switching to increasingly beneficial in FILs4-6 (Table 16).

Because bull trout are a listed species, they received a higher relative importance score than the non-listed species. Combined with the relative extent of both "near" and "other" habitat, bull trout habitat received 45 percent of the relative importance share of the Aquatic Habitat HVRA.

Table 16. Response functions for the Bull trout Sub-HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Dense-dry forest near habitat	80	60	0	-20	-60	-80	1%	101,285
Other forest near habitat	0	0	0	20	60	80	8%	1,119,780
Dense-dry forest in HUC	40	20	0	0	-20	-40	6%	3,422,360
Other forest in HUC	0	0	0	20	40	60	30%	16,616,190

[1] Within-HVRA relative importance.

3.4.7.2 Steelhead

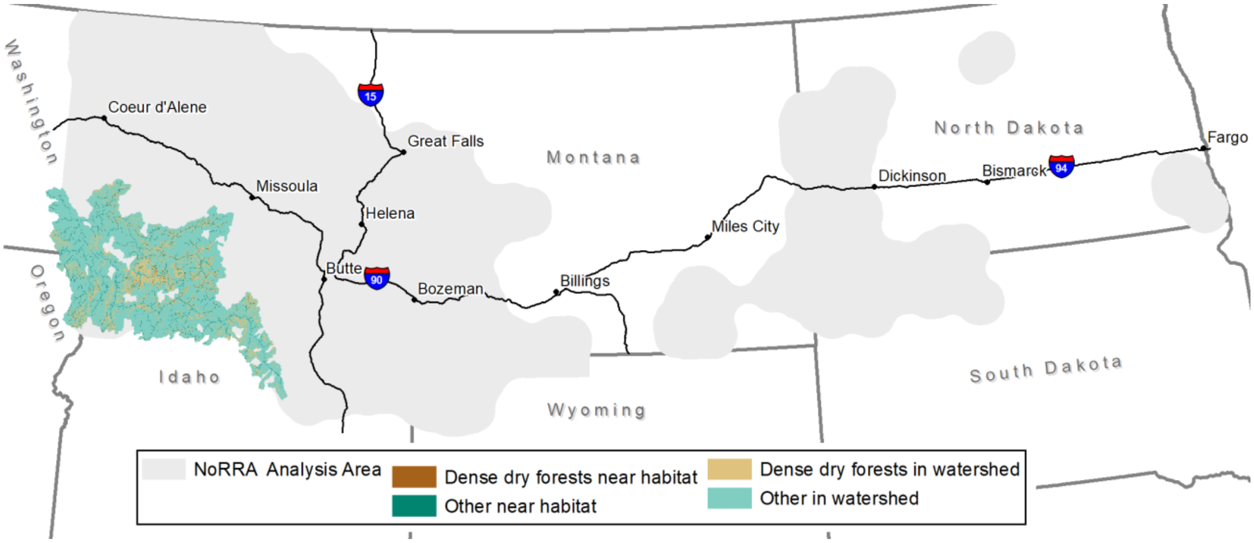

Figure 20. Map of Steelhead habitat and surrounding forest types in the NoRRA analysis area.

Steelhead (*Oncorhynchus mykiss*) critical habitat (streams and rivers) and the watersheds that intersect them are mapped in Figure 20. In this analysis, fish habitat was stratified into Dense Dry Forest (DDF) habitat and other forest types. DDF was defined as dry-climate, LANDFIRE version 1.3.0 Biophysical Groups, where canopy cover values met or exceeded 45 percent. In DDF nearest the fish habitat, response function values were highly positive in FILs1-2, neutral in FIL3, and becoming increasingly negative in FILs4-6 (Table 17). In the other forest types nearest the habitat, fire was neutral in FILs1-3 and increasingly beneficial in FILs4-6. In DDF farther from the stream, fire was decreasingly positive in FILs1-2 switching to neutral in FILs3-4 and becoming negative in FILs5-6. Finally, in other forest types farther from the stream, fire was neutral in FILs1-3, switching to increasingly beneficial in FILs4-6 (Table 17).

Because steelhead are a listed species, they received a higher relative importance score than the non-listed species. Combined with the relative extent of both “near” and “other” habitat, steelhead habitat received 19 percent of the relative importance share of the Aquatic Habitat HVRA.

Table 17. Response functions for the Steelhead Sub-HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Dense-dry forest near habitat	80	60	0	-20	-60	-80	1%	74,142
Other forest near habitat	0	0	0	20	60	80	3%	355,037
Dense-dry forest in HUC	40	20	0	0	-20	-40	2%	1,314,910
Other forest in HUC	0	0	0	20	40	60	14%	7,539,109

[1] Within-HVRA relative importance.

3.4.7.3 Westslope cutthroat

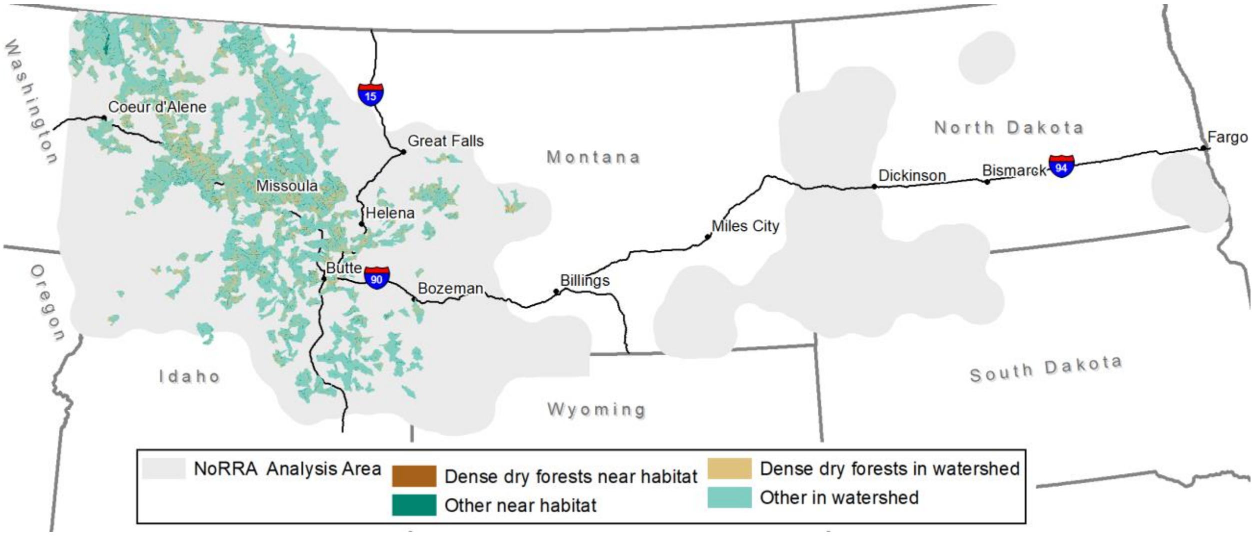

Figure 21. Map of Westslope cutthroat trout habitat and surrounding forest types in the NoRRA analysis area.

Westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) habitat (streams and lakes) and the watersheds that intersect them are mapped in Figure 21. We applied a selection for genetic status [GENSTATID in (1, 2)] to limit mapping to populations with genetic integrity. In this analysis, fish habitat was stratified into Dense Dry Forest (DDF) habitat and other forest types. DDF was defined as dry-climate, LANDFIRE version 1.3.0 Biophysical Groups, where canopy cover values met or exceeded 45 percent. In DDF nearest the fish habitat, response function values were highly positive in FILs1-2, neutral in FIL3, and becoming increasingly negative in FILs4-6 (Table 18). In the other forest types nearest the habitat, fire was neutral in FILs1-3 and increasingly beneficial in FILs4-6. In DDF farther from the stream, fire was decreasingly positive in FILs1-2 switching to neutral in FILs3-4 and becoming negative in FILs5-6. Finally, in other forest types farther from the stream, fire was neutral in FILs1-3, switching to increasingly beneficial in FILs4-6 (Table 18).

Westslope cutthroat are not a listed species, and therefore they received a lower relative importance score than the listed species. However, because their habitat is widespread across the analysis area, their combined share of relative importance including the "near" and "other" habitat is 28 percent of the relative importance share of the Aquatic Habitat HVRA.

Table 18. Response functions for the Westslope cutthroat Sub-HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Dense-dry forest near habitat	80	60	0	-20	-60	-80	1%	102,997
Other forest near habitat	0	0	0	20	60	80	3%	567,930
Dense-dry forest in HUC	40	20	0	0	-20	-40	4%	2,736,559
Other forest in HUC	0	0	0	20	40	60	20%	13,765,577

[1] Within-HVRA relative importance.

3.4.7.4 Yellowstone cutthroat

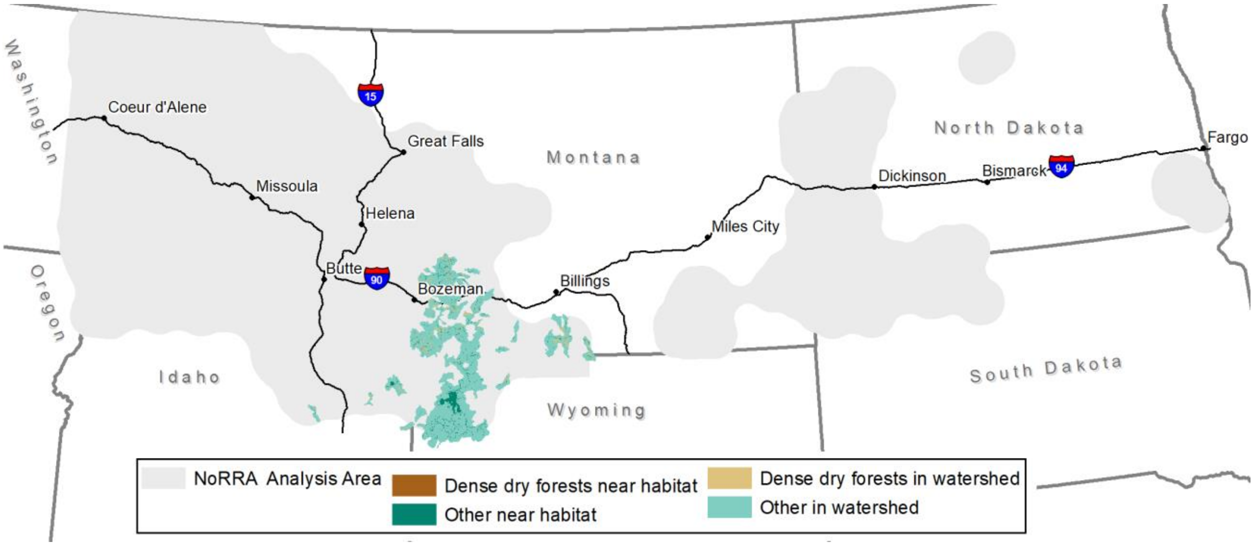

Figure 22. Map of Yellowstone cutthroat trout habitat and surrounding forest types in the NoRRA analysis area.

Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) habitat (streams and lakes) and the watersheds that intersect them are mapped in Figure 22. We applied a selection for genetic status [GENETICSTATUS IN ('>1% and <=10%', 'Unaltered (< 1%)')] to limit mapping to populations with genetic integrity. In this analysis, fish habitat was stratified into Dense Dry Forest (DDF) habitat and other forest types. DDF was defined as dry-climate, LANDFIRE version 1.3.0 Biophysical Groups, where canopy cover values met or exceeded 45 percent. In DDF nearest the fish habitat, response function values were highly positive in FILs1-2, neutral in FIL3, and becoming increasingly negative in FILs4-6 (Table 19). In the other forest types nearest the habitat, fire was neutral in FILs1-3 and increasingly beneficial in FILs4-6. In DDF farther from the stream, fire was decreasingly positive in FILs1-2 switching to neutral in FILs3-4 and becoming negative in FILs5-6. Finally, in other forest types farther from the stream, fire was neutral in FILs1-3, switching to increasingly beneficial in FILs4-6 (Table 19).

Yellowstone cutthroat are not a listed species, and therefore they received a lower relative importance score than the listed species. Their habitat is limited across the analysis area, and therefore, their combined share of relative importance including the "near" and "other" habitat is 6 percent of the relative importance share of the Aquatic Habitat HVRA.

Table 19. Response functions for the Yellowstone cutthroat Sub-HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Dense-dry forest near habitat	80	60	0	-20	-60	-80	0.1%	9,163
Other forest near habitat	0	0	0	20	60	80	1.3%	227,302
Dense-dry forest in HUC	40	20	0	0	-20	-40	0.2%	172,824
Other forest in HUC	0	0	0	20	40	60	4.7%	3,239,429

[1] Within-HVRA relative importance.

3.4.7.5 Redband trout

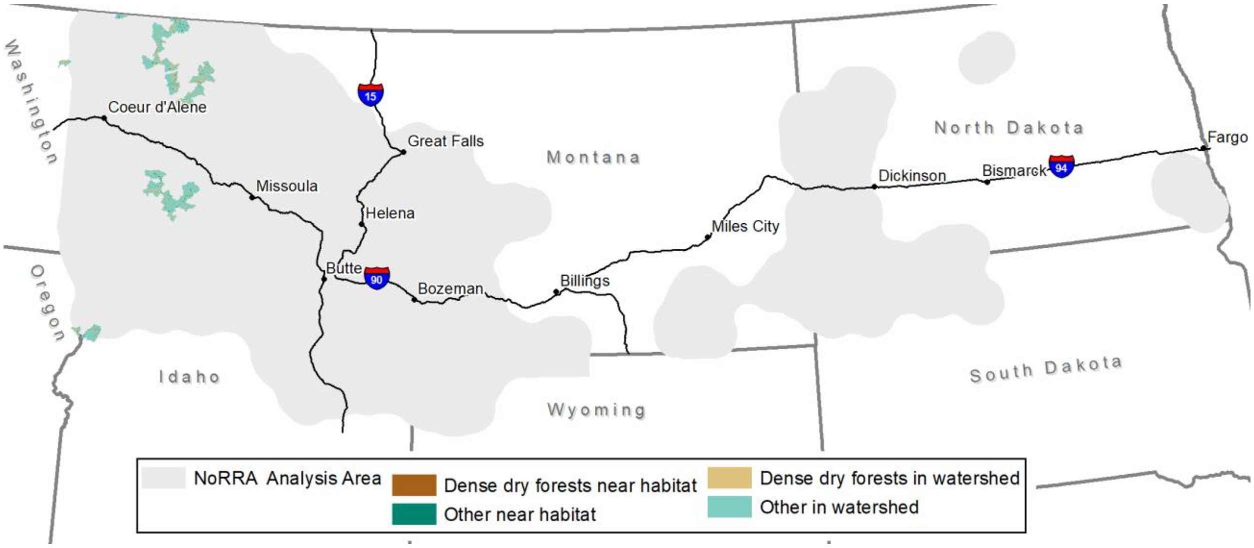

Figure 23. Map of Redband trout habitat and surrounding forest types in the NoRRA analysis area.

Redband trout (*Oncorhynchus mykiss subsp.*) habitat (streams and lakes) and the watersheds that intersect them are mapped in Figure 23. We applied a selection for genetic status [GeneticSta IN ('>1% and <=10%', 'Unaltered (< 1%)')] to limit mapping to populations with genetic integrity. In this analysis, fish habitat was stratified into Dense Dry Forest (DDF) habitat and other forest types. DDF was defined as dry-climate, LANDFIRE version 1.3.0 Biophysical Groups, where canopy cover values met or exceeded 45 percent. In DDF nearest the fish habitat, response function values were highly positive in FILs1-2, neutral in FIL3, and becoming increasingly negative in FILs4-6 (Table 20). In the other forest types nearest the habitat, fire was neutral in FILs1-3 and increasingly beneficial in FILs4-6. In DDF farther from the stream, fire was decreasingly positive in FILs1-2 switching to neutral in FILs3-4 and becoming negative in FILs5-6. Finally, in other forest types farther from the stream, fire was neutral in FILs1-3, switching to increasingly beneficial in FILs4-6 (Table 20).

Redband trout are not a listed species, and therefore they received a lower relative importance score than the listed species. Their habitat is limited across the analysis area with fewer total acres than all other fish species. Therefore, their combined share of relative importance including the "near" and "other" habitat is two percent of the relative importance share of the Aquatic Habitat HVRA.

Table 20. Response functions for the Redband Sub-HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Dense-dry forest near habitat	80	60	0	-20	-60	-80	0.03%	4,576
Other forest near habitat	0	0	0	20	60	80	0.1%	25,638
Dense-dry forest in HUC	40	20	0	0	-20	-40	0.3%	235,771
Other forest in HUC	0	0	0	20	40	60	1.5%	1,007,798

[1] Within-HVRA relative importance.

3.4.8 T&E Terrestrial habitat

3.4.8.1 Sage grouse priority habitat

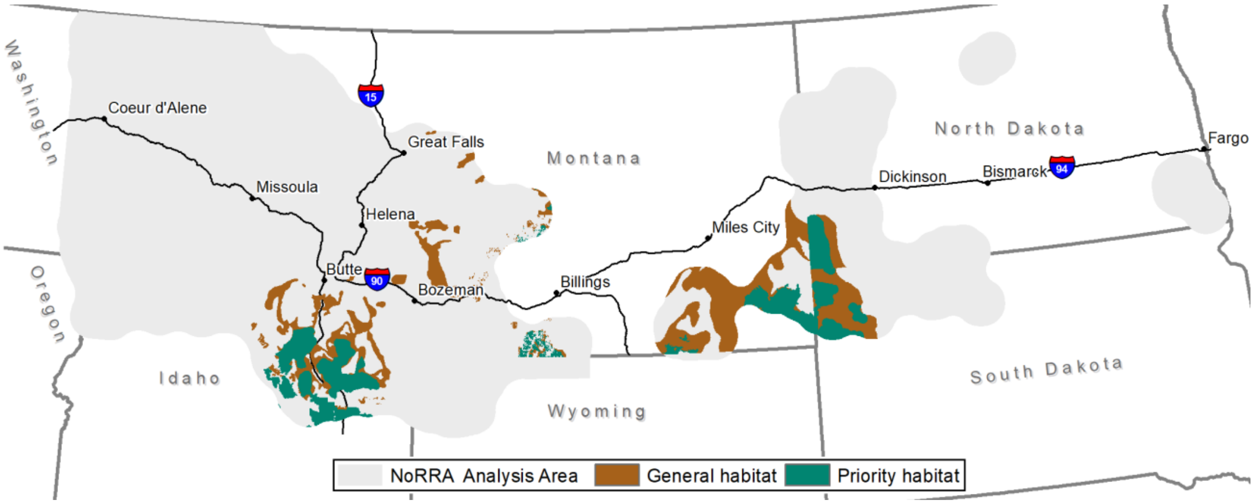

Figure 24. Map of Sage grouse habitat management zones in the NoRRA analysis area.

Greater sage-grouse (*Centrocercus urphasianus*) habitat mapped based on the Final Environmental Impact Statement for the project area states is mapped in Figure 24. Habitat was categorized by Priority Habitat Management Areas (PHMA) and General Habitat Management Areas (GMHA) and further classified by NRCS Ecosystem Index of Resistance and Resilience (RR) to better define sage grouse habitat response to fire (Table 21). The same set of response functions were used for both priority and general habitat, but varied by RR class. Low RR is the most susceptible and was habitat response to fire was described as uninformely, highly negative across all FILs. Moderate RR benefits from fire at low FILs (FILs1-2) but becomes increasingly negative in FILs3-6. High RR experiences more benefit from fire in FILs1-3 but switches to increasintly negative in FILs4-6. Where PHMA/GHMA was identified but no RR information was available, a moderate RR response function was used.

PHMA received a greater share of the sub-HVRA importance than did GHMA at 25 and 22 percent, respectively. The remainder of the T&E Terrestrial Wildlife importance is allocated to lynx habitat and discussed in the next section.

Table 21. Response functions for the Sage grouse habitat HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Priority 0 – No RR Class	50	20	-40	-80	-100	-100	0.9%	138,106
Priority 3 – Low RR	-100	-100	-100	-100	-100	-100	0.2%	30,236
Priority 2 – Moderate RR	50	20	-40	-80	-100	-100	13.2%	2,074,877
Priority 1 – High RR	60	30	10	-60	-100	-100	10.5%	1,655,576
General 0 – No RR Class	50	20	-40	-80	-100	-100	0.3%	74,412
General 3 – Low RR	-100	-100	-100	-100	-100	-100	0.0%	5,072
General 2 – Moderate RR	50	20	-40	-80	-100	-100	12.1%	3,179,806
General 1 – High RR	60	30	10	-60	-100	-100	9.5%	2,488,675

[1] Within-HVRA relative importance.

3.4.8.2 Lynx habitat

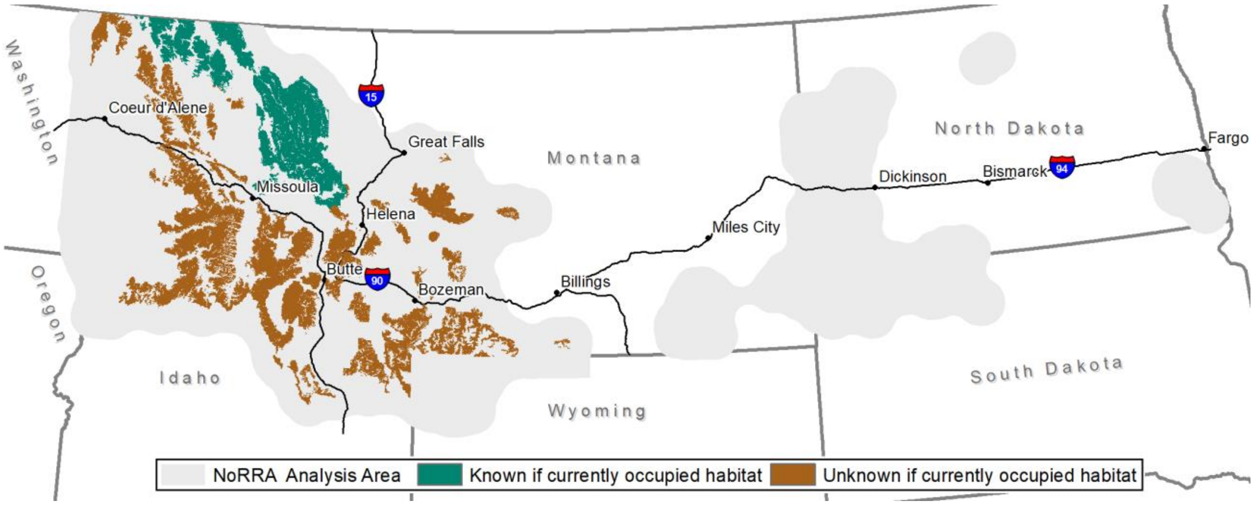

Figure 25. Map of known and potentially occupied Lynx habitat and in the NoRRA analysis area

Lynx (*Lynx canadensis*) habitat is mapped in Figure 25 for the NoRRA project area. Habitat was divided into two categories: known to be currently occupied (occupied) and unknown if currently occupied (unk-occupied). Each habitat category was then sub-divided into Lynx Activity Units (LAUs) where greater than 30 percent of the LAU was disturbed in the past 20 years and LAUs with less than 30 percent recent disturbance. Finally, these combinations were further divided into time-since-disturbance classes: Young regen (0-20 years since disturbance), Young forest (21-40 years since disturbance), and Mature forest (greater than 40 years since disturbance).

These categories were used to determine lynx habitat response to fire (Table 22). In LAUs with greater than 30 percent disturbance, young regen habitat responded favorably to fire in FILs1-2, neutral in FIL3, and became increasingly negative in FILs4-6. In young forest habitat, FILs1-3 were neutral, and became increasingly negative in FILs4-6. In mature forest, fire was negative at all FILs, particularly FIL4 and greater. LAUs with less than 30 percent recent disturbance had different responses to fire. Young regen habitat was neutral to fire in FILs1-2 and became increasingly negative in FILs3-6. Young forest was slightly more fire tolerant with a neutral response in FILs1-3, and negative in FILs4-6. Finally, mature forest was described as intolerant of fire in all FILs, however FILs3-4 were less harmful than FILs1-2.

Habitat known to be currently occupied was given a greater share of the sub-HVRA importance, however, because fewer acres of occupied exist on the landscape, it received 44 percent of the T&E habitat importance while unk-occupied received 9.4 percent.

Table 22. Response functions for Lynx currently occupied habitat Sub-HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Occupied >30% Class 20, Young regen (0-20)	50	25	0	-50	-100	-100	4.9%	388,366
Occupied >30% Class 20, Young forest (21-40)	0	0	0	-50	-100	-100	0.5%	38,048
Occupied >30% Class 20, Mature forest (40+)	-50	-50	-50	-75	-100	-100	4.6%	359,173
Occupied <30% Class 20, Young regen (0-20)	0	0	-25	-50	-100	-100	2.6%	204,936
Occupied <30% Class 20, Young forest (21-40)	0	0	0	-50	-75	-75	1.8%	142,553
Occupied <30% Class 20, Mature forest (40+)	-50	-50	-25	-25	-75	-75	29.5%	2,316,814
Unk-occupied >30% Class 20, Young regen (0-20)	50	25	0	-50	-100	-100	0.7%	388,366
Unk-occupied >30% Class 20, Young forest (21-40)	0	0	0	-50	-100	-100	0.02%	38,048
Unk-occupied >30% Class 20, Mature forest (40+)	-50	-50	-50	-75	-100	-100	0.6%	359,173
Unk-occupied <30% Class 20, Young regen (0-20)	0	0	-25	-50	-100	-100	0.4%	204,936
Unk-occupied <30% Class 20, Young forest (21-40)	0	0	0	-50	-75	-75	0.3%	142,553
Unk-occupied <30% Class 20, Mature forest (40+)	-50	-50	-25	-25	-75	-75	7.4%	2,316,814

[1] Within-HVRA relative importance.

3.4.9 Vegetation structure

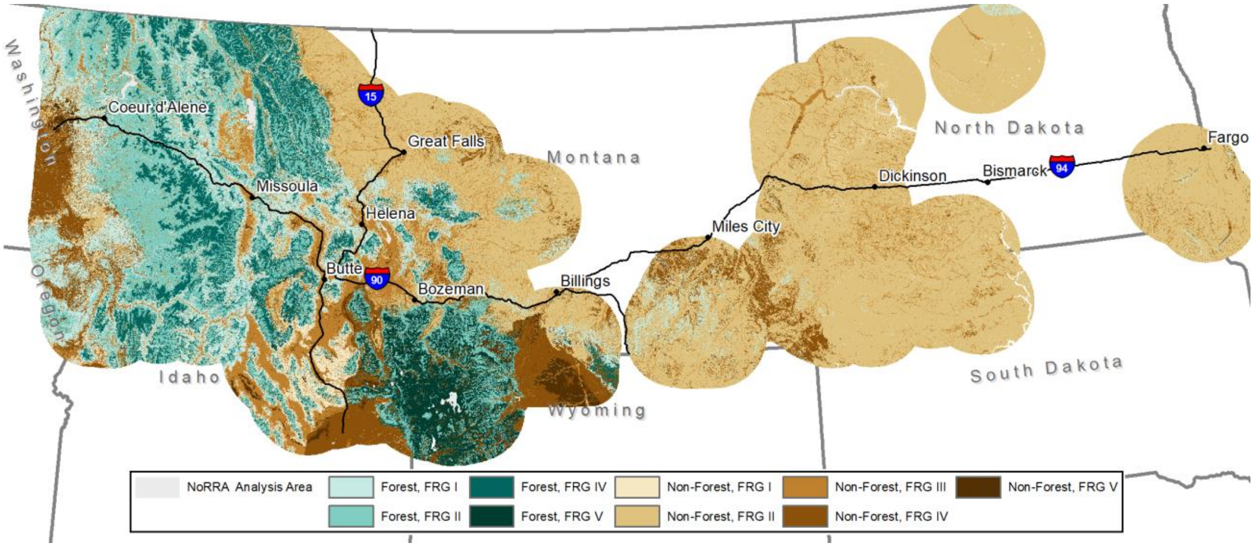

Figure 26. Map of forested and non-forested areas by Fire Regime Group in the NoRRA analysis area.

Map of forested and non-forested lands by fire regime group (FRG) within the NoRRA project area (Figure 26). Fire Regime Groups are categorized as follows:

1. FRG I <= 35 Year Fire Return Interval, Low and Mixed Severity
2. FRG II <= 35 Year Fire Return Interval, Replacement Severity
3. FRG III 35 - 200 Year Fire Return Interval, Low and Mixed Severity
4. FRG IV 35 - 200 Year Fire Return Interval, Replacement Severity
5. FRG V > 200 Year Fire Return Interval, Any Severity

The Vegetation structure HVRA provides an opportunity to capture the ecological role of fire in fire-adapted landscapes. The response functions in Table 23 are largely beneficial apart from where low and mixed severity are the desired fire regime. The response functions generally reflect the FILs most desirable in the given vegetation type and fire regime group.

All sub-HVRA of vegetation type and FRG were weighted equally and the share of the Vegetation structure relative importance allocated to each varies only by the number of acres mapped on the landscape.

Table 23. Response functions for Vegetation structure HVRA.

Covariate	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	Share of RI[1]	Acres
Forest, FRG I	100	100	60	25	-25	-75	14%	12,151,411
Forest, FRG III	100	100	60	30	0	-25	16%	14,530,657
Forest, FRG IV	25	25	50	75	75	75	11%	9,262,627
Forest, FRG V	50	50	50	50	50	50	5%	4,050,781
Non-Forest, FRG I	70	40	20	0	-50	-50	3%	2,369,357
Non-Forest, FRG II	50	50	75	100	100	100	33%	29,286,800
Non-Forest, FRG III	70	40	20	0	-50	-50	11%	9,659,119
Non-Forest, FRG IV	50	50	75	100	100	100	7%	5,973,990
Non-Forest, FRG V	50	50	50	50	50	50	1%	867,285

[1] Within-HVRA relative importance.

3.5 Effects analysis methods

An effects analysis quantifies wildfire risk as the expected value of net response (Finney, 2005; Scott *et al.*, 2013b) also known as expected net value change (eNVC). This approach has been applied at a national scale (Calkin *et al.*, 2010), in regional and sub-regional assessments (Thompson *et al.*, 2015; Thompson *et al.*, 2016) and several forest-level assessments of wildfire risk (Scott and Helmbrecht, 2010; Scott *et al.*, 2013a). 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 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 ranged from -100 (greatest possible loss of resource value) to +100 (greatest increase 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:

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

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

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

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

$$eNVC = cNVC * BP$$

3.5.2 Downscaling FSim results for effects analysis

FSim's stochastic simulation approach can be computationally intensive and therefore, time constraining on large landscapes. A challenge, therefore, is to determine a resolution sufficiently fine to retain detail in fuel and terrain features, yet produce calibrated results in a reasonable timeframe. Moreover, HVRA are often mapped at the same resolution as the final BP and FLPs produced by FSim. To enable greater resolution on HVRA mapping, we chose to downscale the FSim results to 30 m, consistent with HVRA mapping at 30 m.

We downscaled FSim results using a multi-step process. First, we resampled the original, 180-m BP and FLP grids to 30 m. Next, we used the Focal Statistics tool in ESRI's ArcGIS to calculate the mean BP and FLP, of burnable pixels only, within a 7-pixel by 7-pixel moving window. Finally, we used the smoothed BP and FLP values to "backfill" burnable pixels at 30 m that were coincident with non-burnable fuel at 180 m. The final smoothed grids resulted in original FSim values for pixels that were burnable at both 180 m and 30 m, non-zero burn probability values in burnable pixels that were non-burnable at 180m, and a BP of zero in non-burnable, 30 m pixels.

4. Analysis Results

4.1 Model calibration to historical occurrence

Due to the highly varied nature of weather and fire occurrence across the large landscape, we ran FSim for each of the eighteen FOAs independently, and then compiled the 18 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 27, Figure 28, and Figure 29 shown below, illustrate the level of model calibration as compared with the historical large-wildfire record from 1992-2015. Figure 27 depicts the mean annual number of large fires and their size in the historical record for the entire NoRRA analysis area as well as the grouped modeled wildfire perimeters for the eighteen simulated FOAs. The teal bars represent the 70% and 90% confidence intervals around the historical mean. Model simulations were calibrated well within the 70% confidence interval.

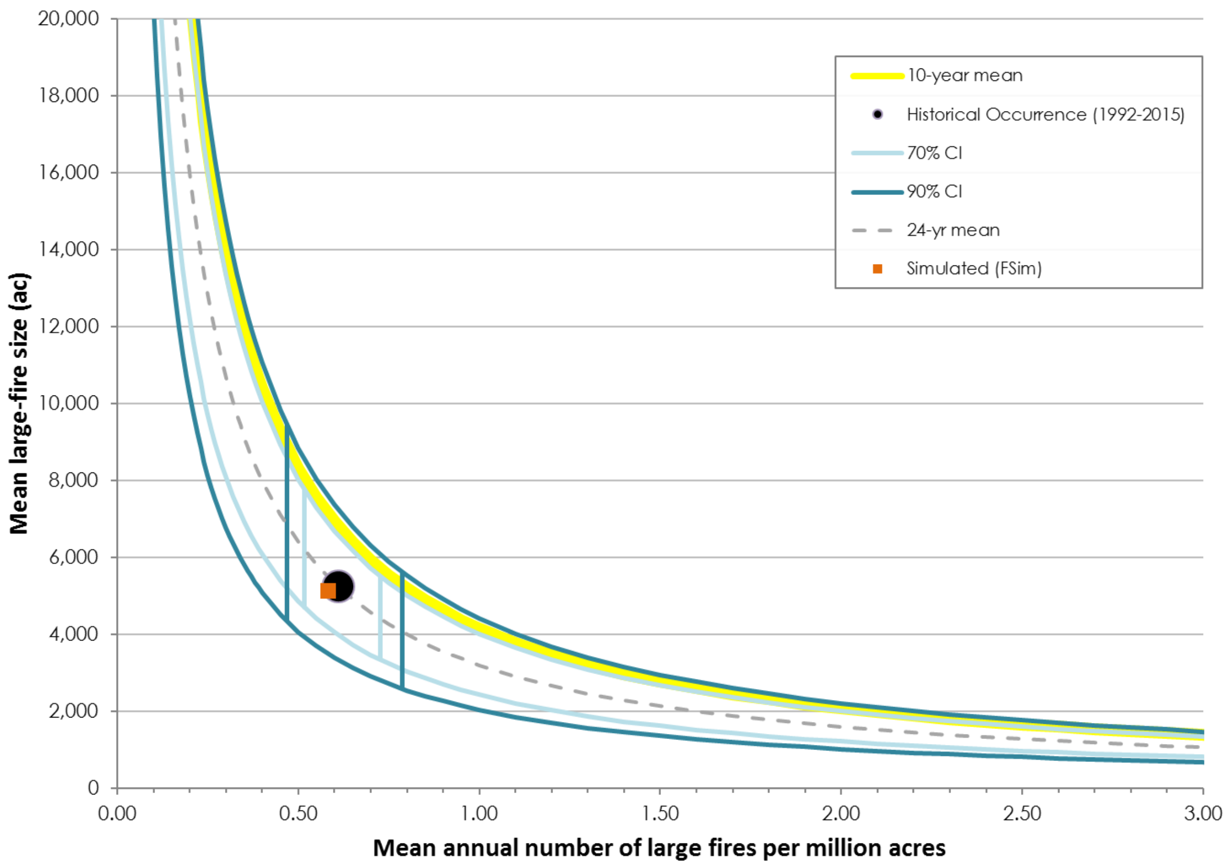

Figure 27. Calibration of FSim to the historical occurrence for the NoRRA FSim project. The above chart shows the mean number and size of large fires. Simulated results match well to historical occurrence. In Figure 28, we show that the distribution of simulated large-fire sizes across the landscape resembles historical distribution, providing confidence in the perimeter outputs and fire-size distribution results.

Figure 28 represents the fire size exceedance probability for both the historical record and simulated wildfires grouped from the 18 independently modeled FOAs. In order to generate future fireshed, WUI housing risk, or other types of analysis that would utilize the perimeter event set, an accurate distribution of wildfire sizes that mimics the historical record is required. Figure 28 shows that the modeled wildfire perimeters closely resembles the distribution of wildfire sizes from the historical record. Additionally, the upper range of simulated perimeters exceed the fire sizes observed in the historical record – important for capturing the previously unobserved, yet not impossible, rare-event.

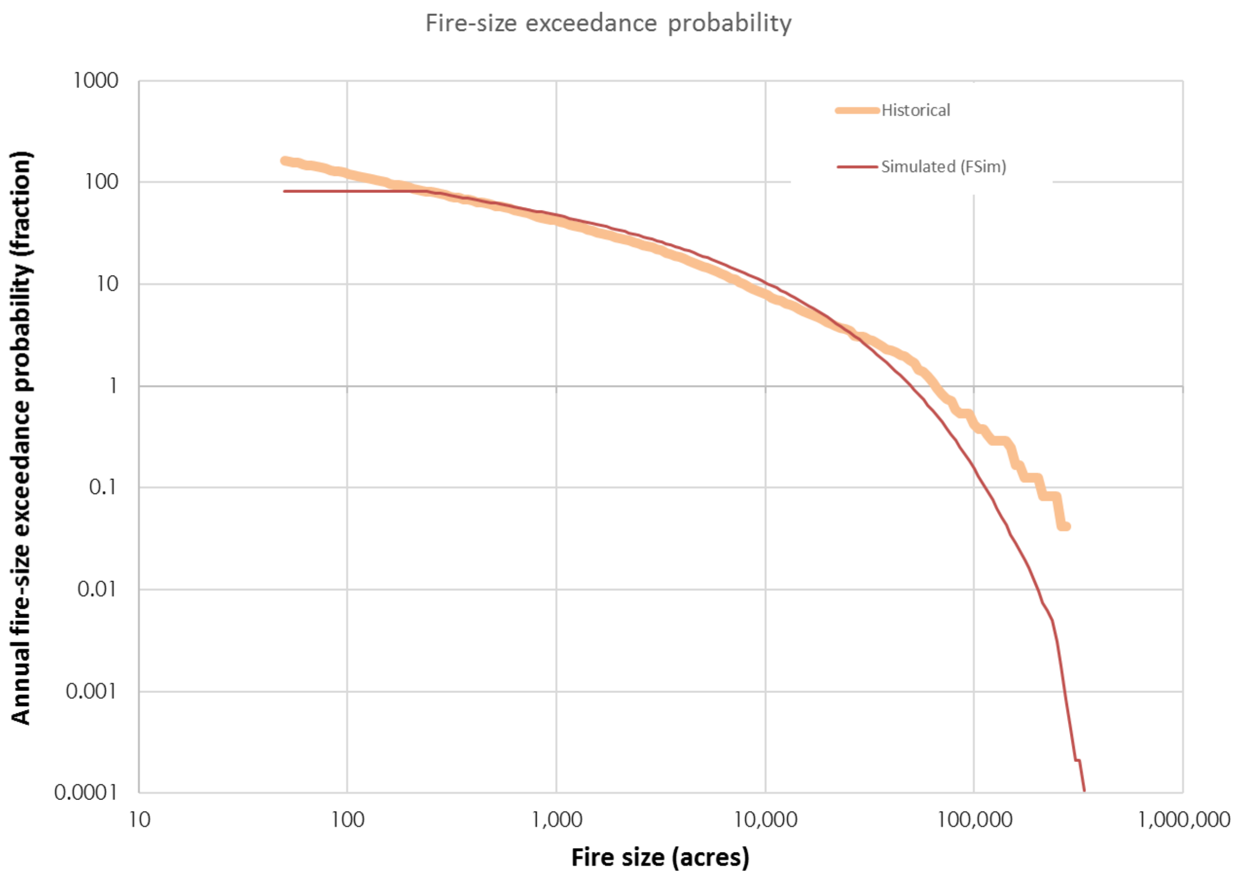

Figure 28 Fire-size exceedance probability chart (log-log scale) for the NoRRA FSim project.

Figure 29 depicts the historical mean large-fire size and mean annual number of large-fires per million acres for each of the eighteen FOAs in the NoRRA analysis area. The triangles represent the simulated fire perimeters for each of the eighteen FOAs. All FOAs were calibrated to well within the 70% confidence interval. FOAs where the simulated size and frequency appears further away from the historical mean, is a result of greater variability in the historical record. Figure 29 also allows for the analysis of the relative burn probability (likelihood of wildfire occurrence) between the 18 simulated FOAs. The colored curving lines represent lines of equal burn probability.

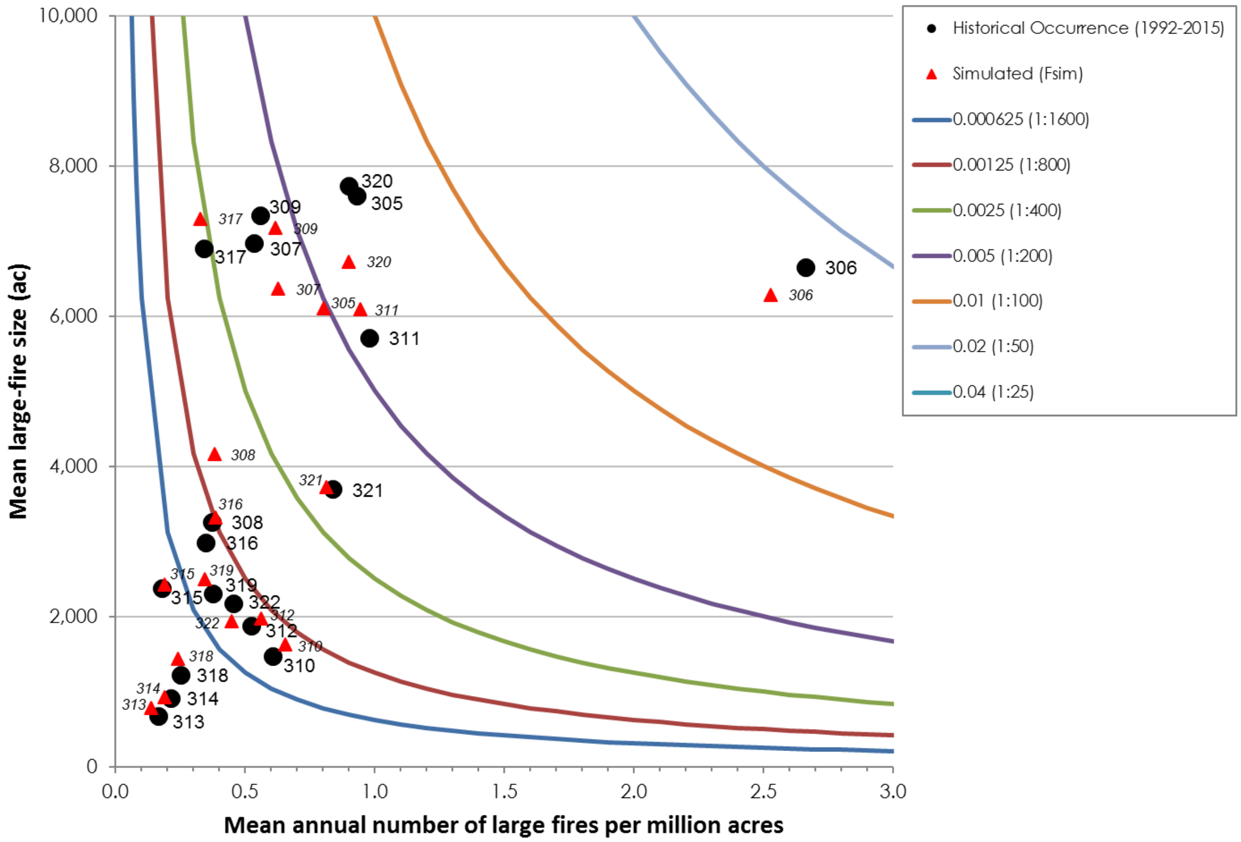

Figure 29. Mean large-fire size and mean annual number of large fires per million acres in each of the eighteen FOAs within the NoRRA analysis area for both the historical record and the simulated fire perimeters.

4.2 FSim results

FSim model results are presented for the NoRRA analysis area in sections 4.2.1 and 4.2.2. Additionally, all FSim results are presented in the deliverables folder and are described in further detail in Section: 6. Data dictionary. FSim produced wildfire hazard results for each FOA, including burn probability and conditional flame length probability. From the base FSim outputs flame-length exceedance probabilities were calculated for each FOA (Figure 31-Figure 35). The eighteen FOAs were combined using the calculations described above to produce integrated maps of wildfire hazard for the entire analysis area.

4.2.1 Burn probability

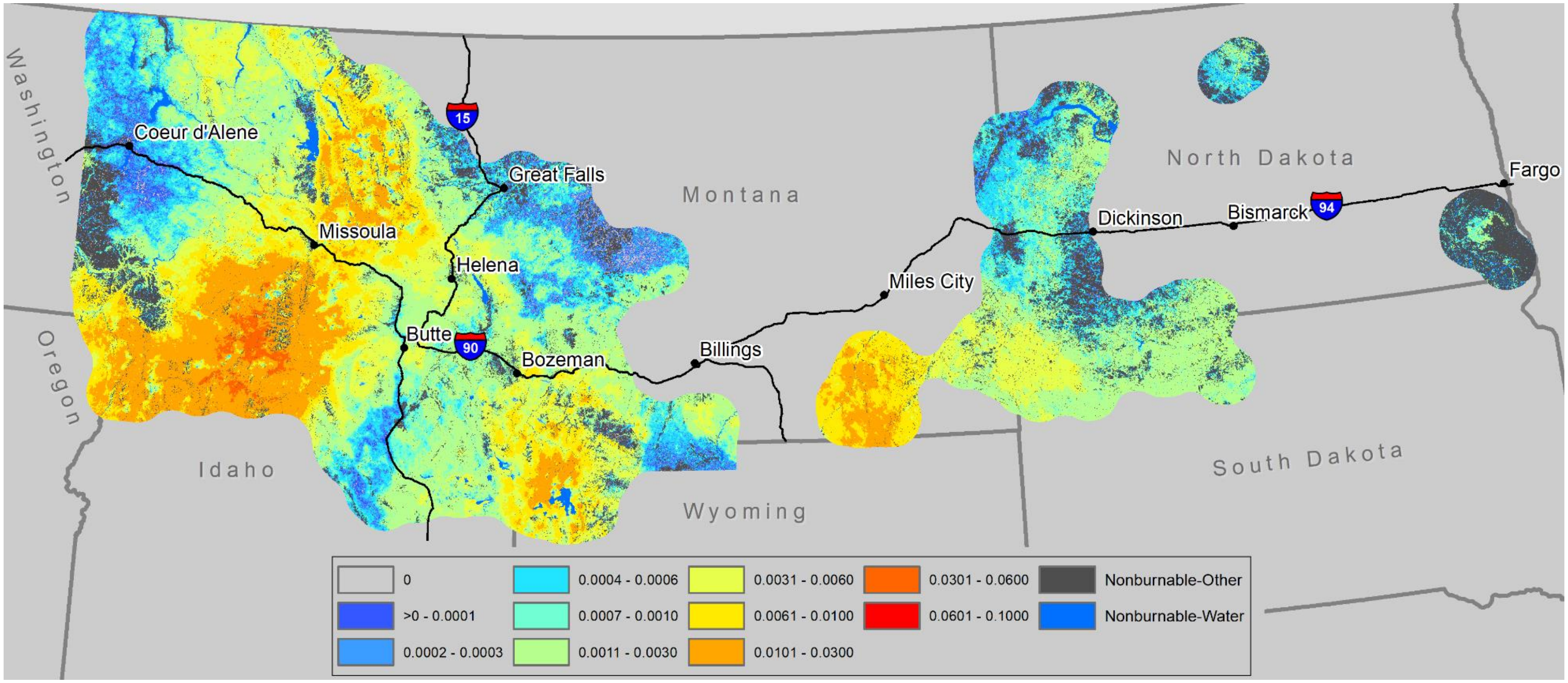

Figure 30. Map of integrated FSim burn probability results for NoRRA study area.

4.2.2 Flame length exceedance probability

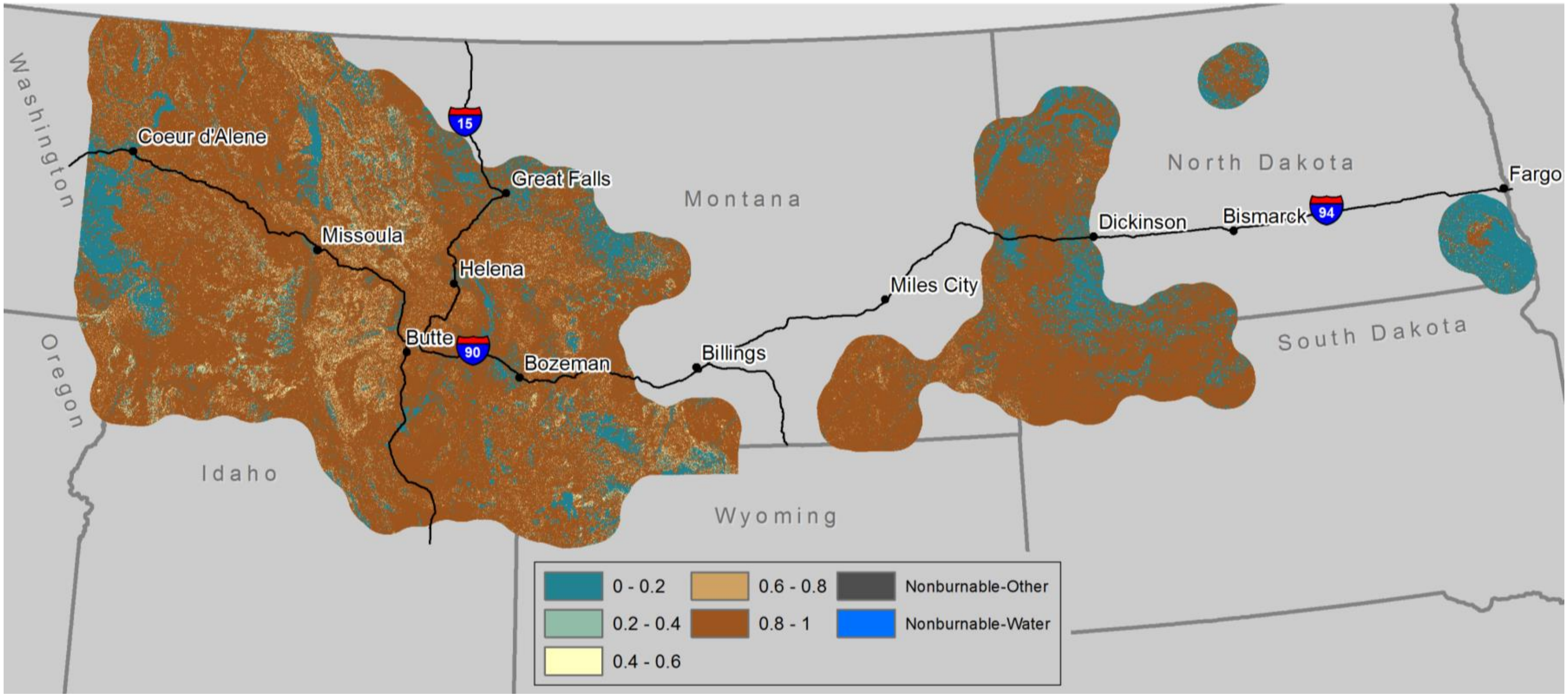

Figure 31. Map of FSim flame-length exceedance probability: 2-ft results for the USFS Northern Region.

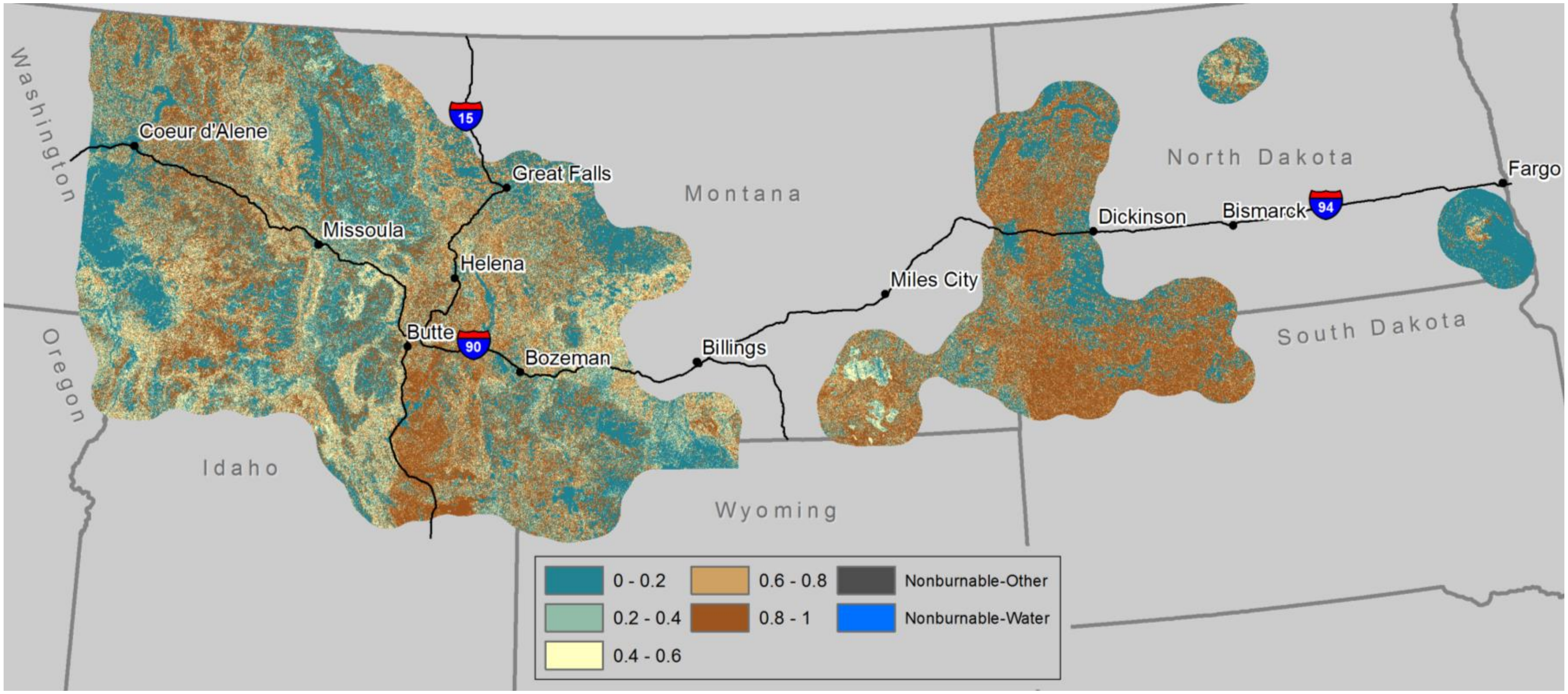

Figure 32. Map of FSim flame-length exceedance probability: 4-ft results for the USFS Northern Region.

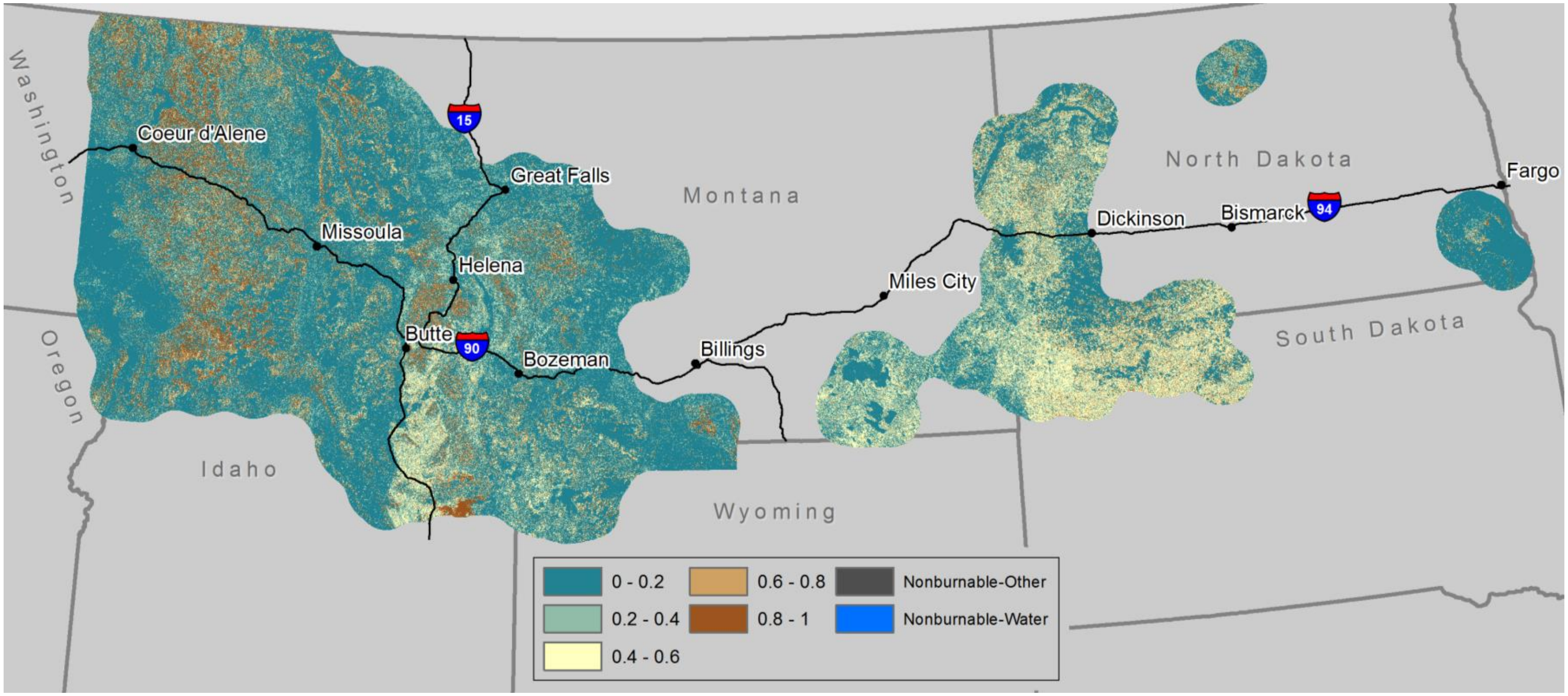

Figure 33. Map of FSim flame-length exceedance probability: 6-ft results for the USFS Northern Region.

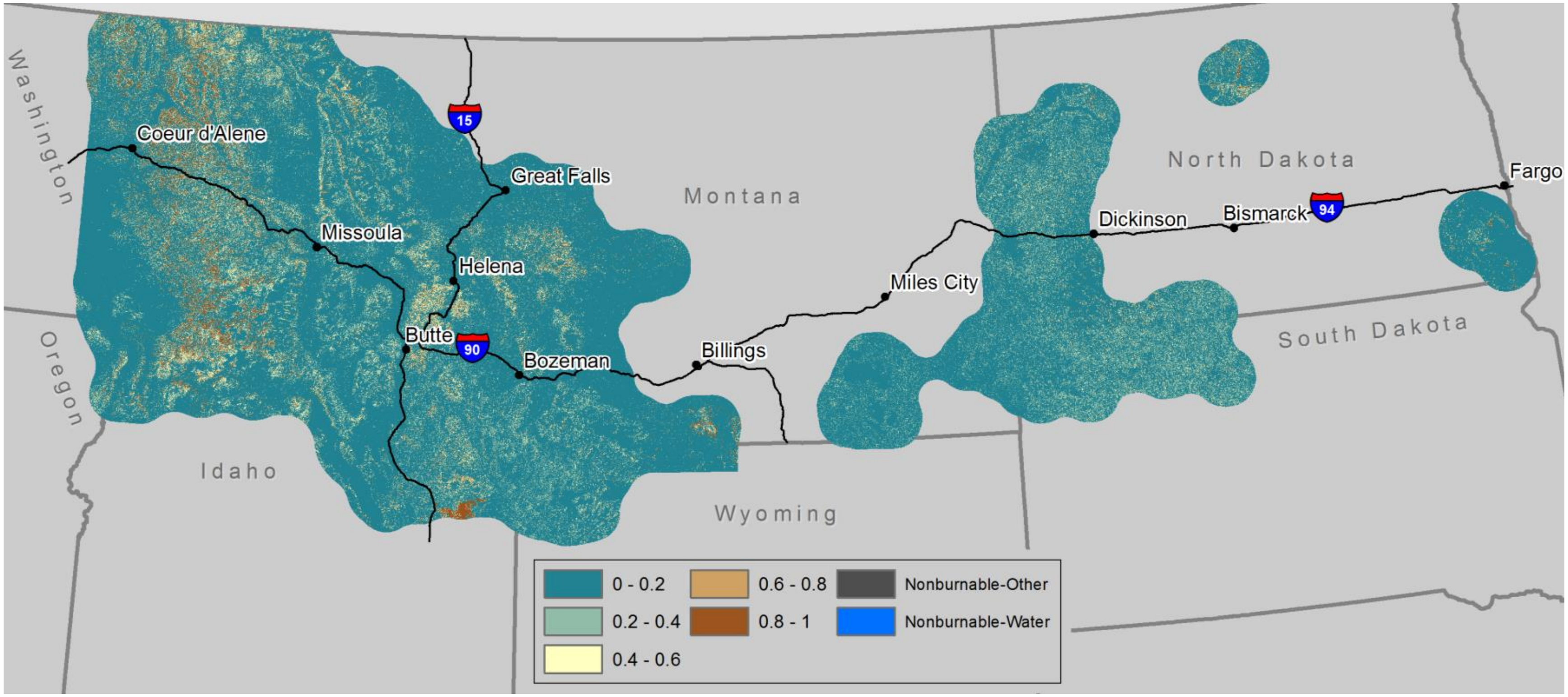

Figure 34. Map of FSim flame-length exceedance probability: 8-ft results for the USFS Northern Region.

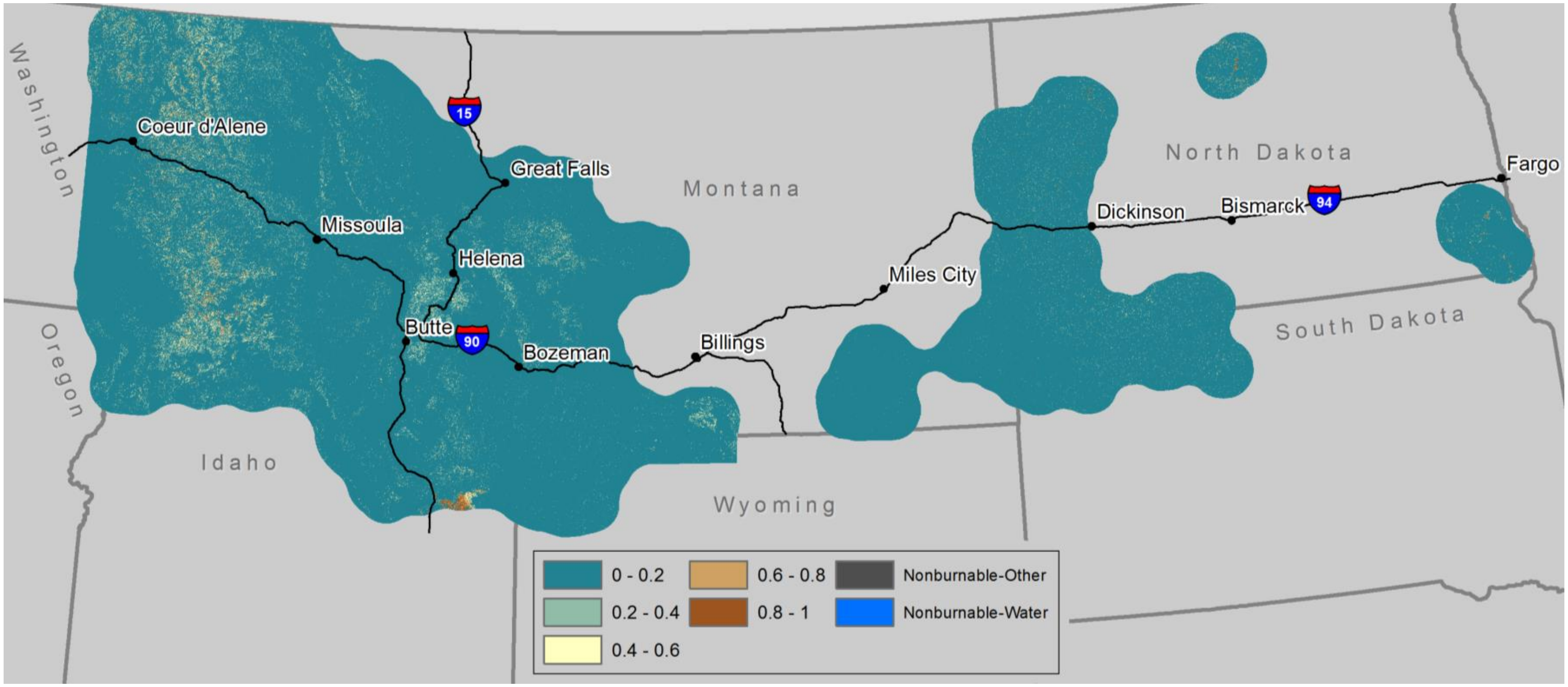

Figure 35. Map of FSim flame-length exceedance probability: 12-ft results for the USFS Northern Region.

4.2.3 FSim zonal summary results

FSim results were summarized using zonal statistics for the 10 national forests in the NoRRA analysis area as well as for a 2-km buffer between each of those forests and lands administered by other ownerships. Figure 37 below demonstrates the 2-km buffer surrounding the Bitterroot National Forest that was used in the zonal summary analysis. Note that the buffer does not include areas where two national forests are adjoining. The 2-km buffer can be viewed as a surrogate for the national forest / Wildland Urban Interface although this analysis does not consider the relative density of structures. Figure 38, Figure 40, and Figure 42 depict zonal summaries of the FSim results for the 10 national forests in the NoRRA analysis area while Figure 39, Figure 41, and Figure 43 depict zonal summaries for the 2-km buffer around those forests.

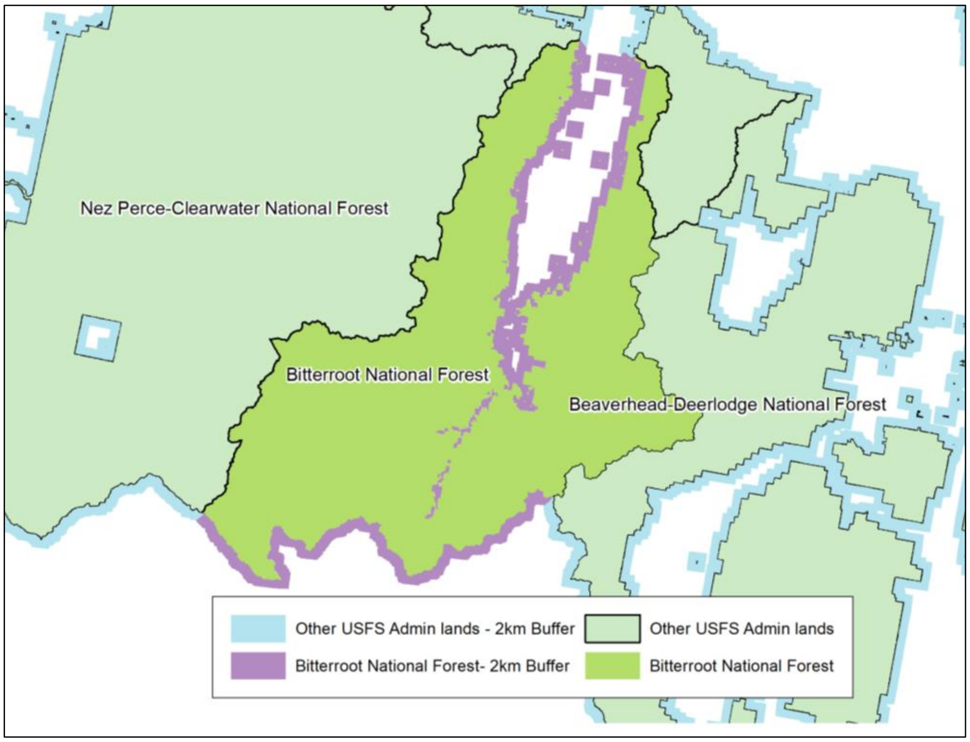

Figure 37. Map illustrating the 2-km buffer area used in the zonal summaries. The 2-km buffer represents the area between USFS lands and non-USFS lands. The area where two national forests meet is not included.

Additionally, Appendices A1-A3 provide numerical data summaries of FSim results for individual national forests, the 2-km buffer around national forests, and individual ranger districts. These summaries allow for the comparison between forests of the relative likelihood of wildfire occurrence, probability of high intensity wildfire behavior, as well as effects analysis described below in section 4.3.

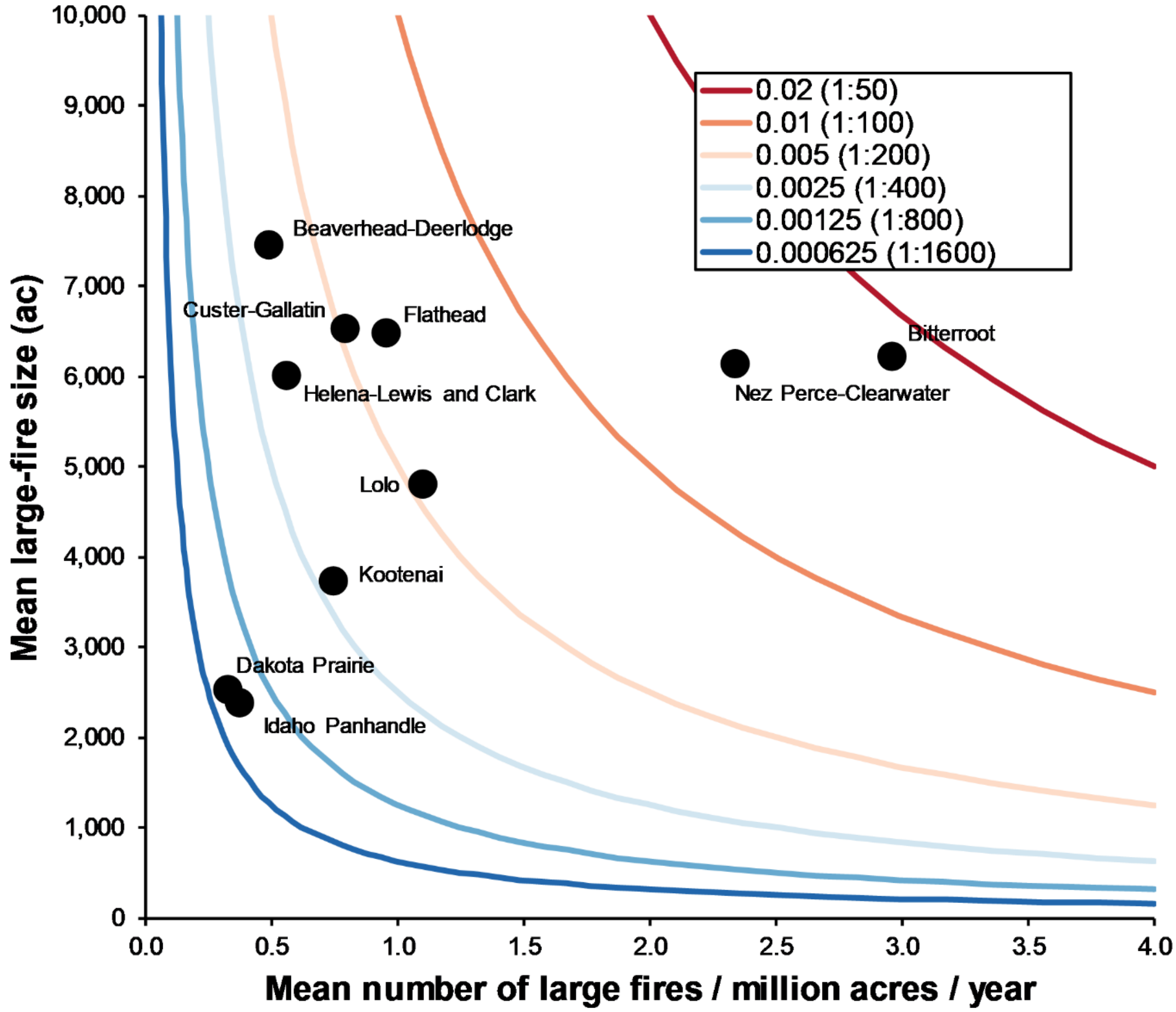

Figure 38. Simulated mean large-fire size and mean number of large fires per million acres per year for the ten forests in the NoRRA study area. The curved lines represent lines of equal burn probability.

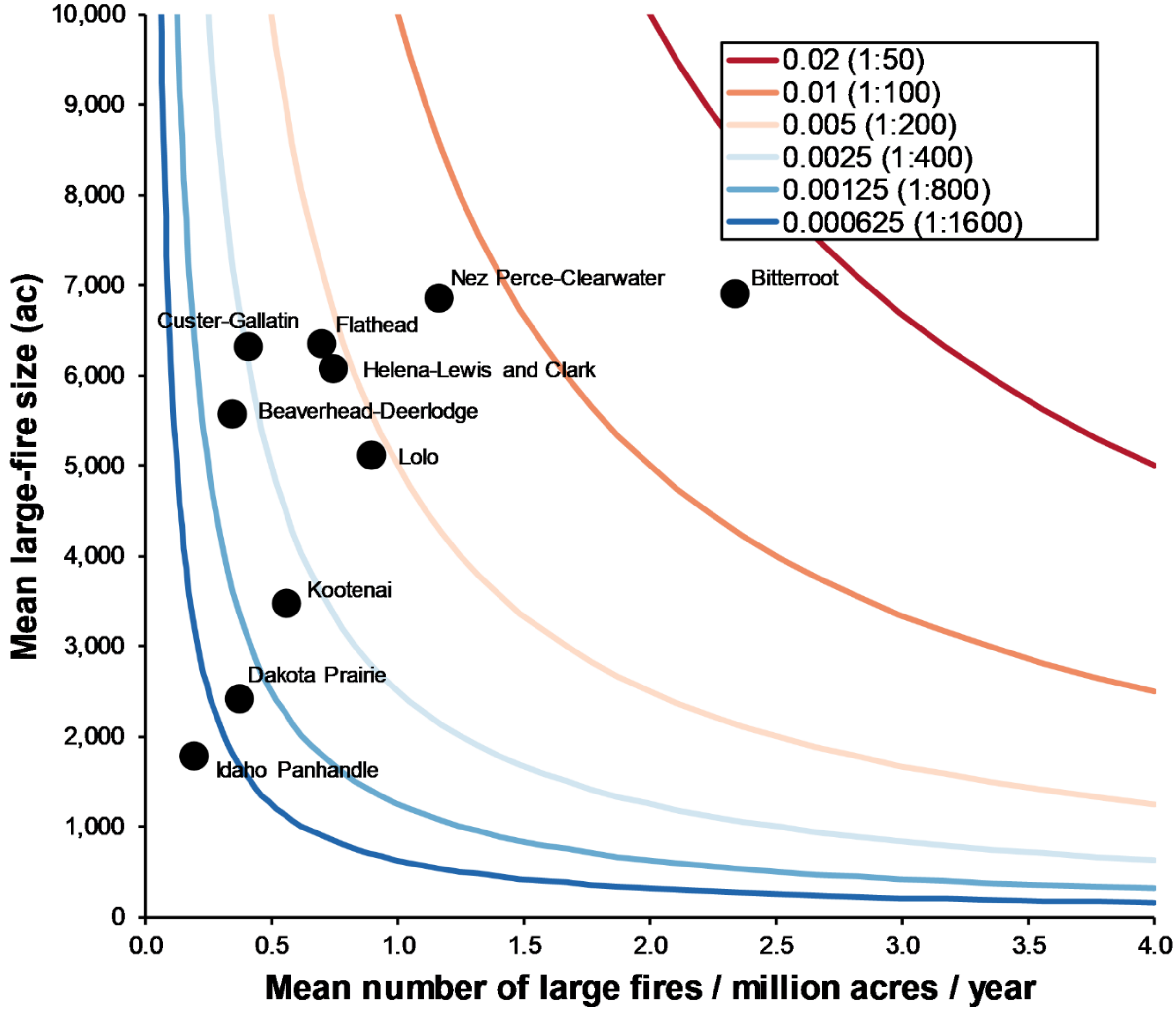

Figure 39. Simulated mean large-fire size and mean number of large fires per million acres per year for a 2-kilometer buffer around the ten forests in the NoRRA study area. The curved lines represent lines of equal burn probability.

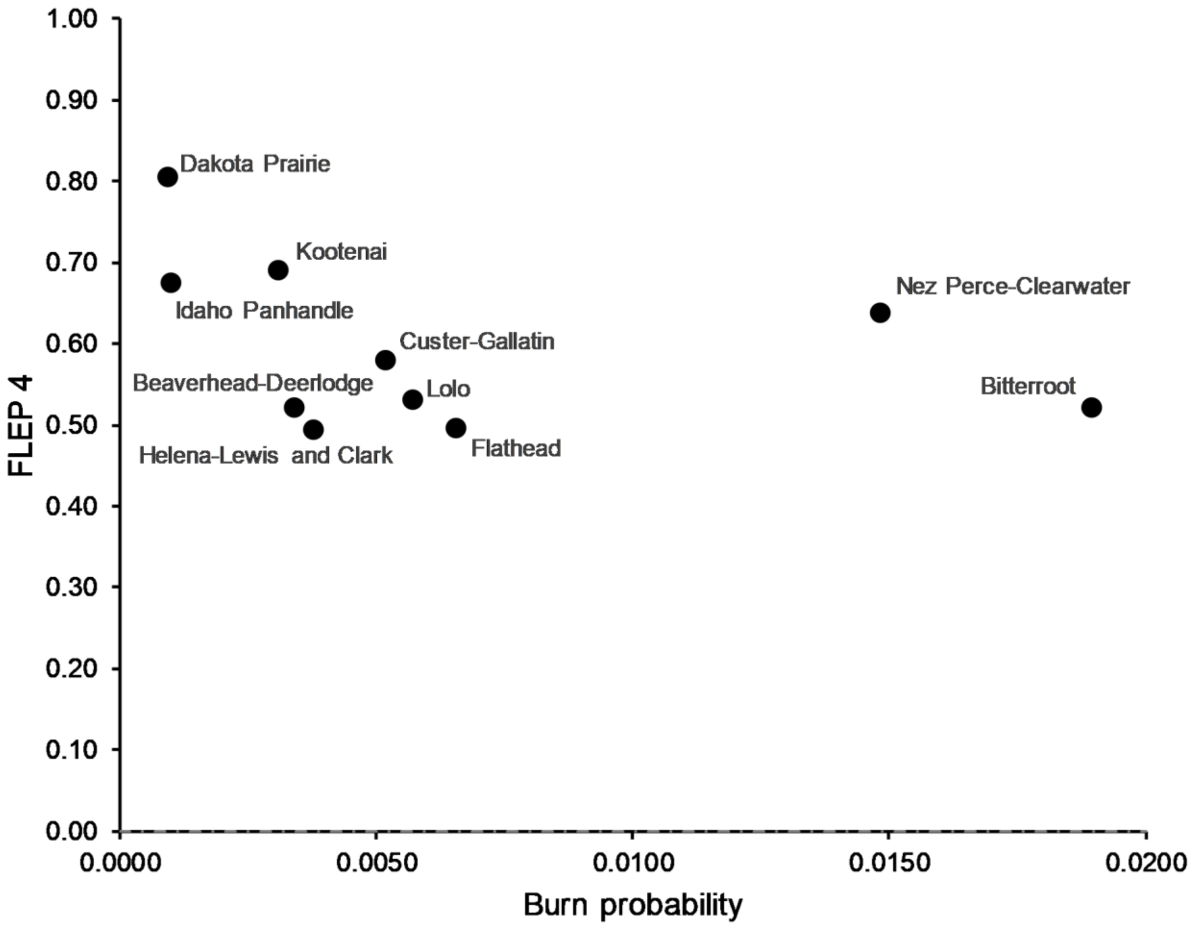

Figure 40. Graph of the 4-foot flame length exceedance probability and burn probability for the 10 forests in the NoRRA study area.

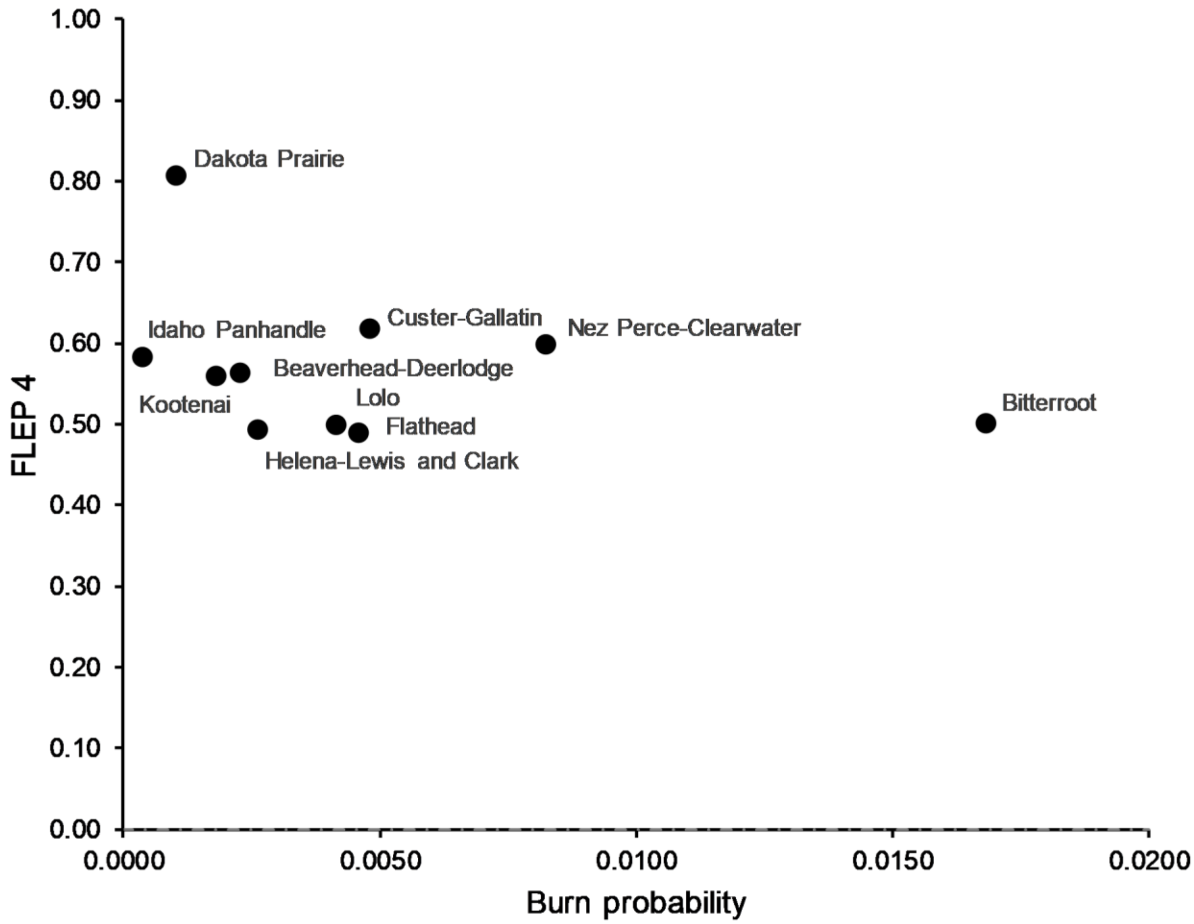

Figure 41. Graph of the 4-foot flame length exceedance probability and burn probability for a 2-kilometer buffer around the 10 forests in the NoRRA study area.

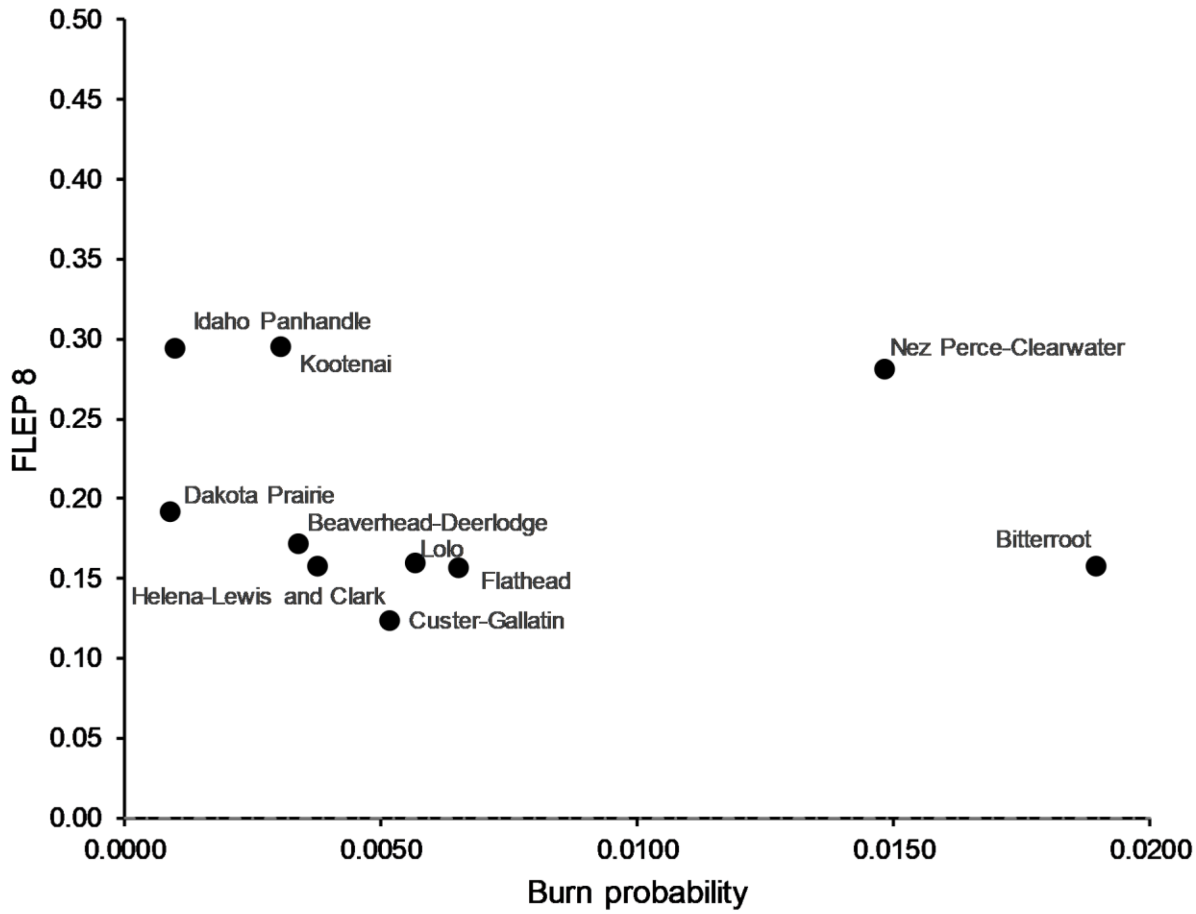

Figure 42 . Graph of the 8-foot flame length exceedance probability and burn probability for the 10 forests in the NoRRA study area.

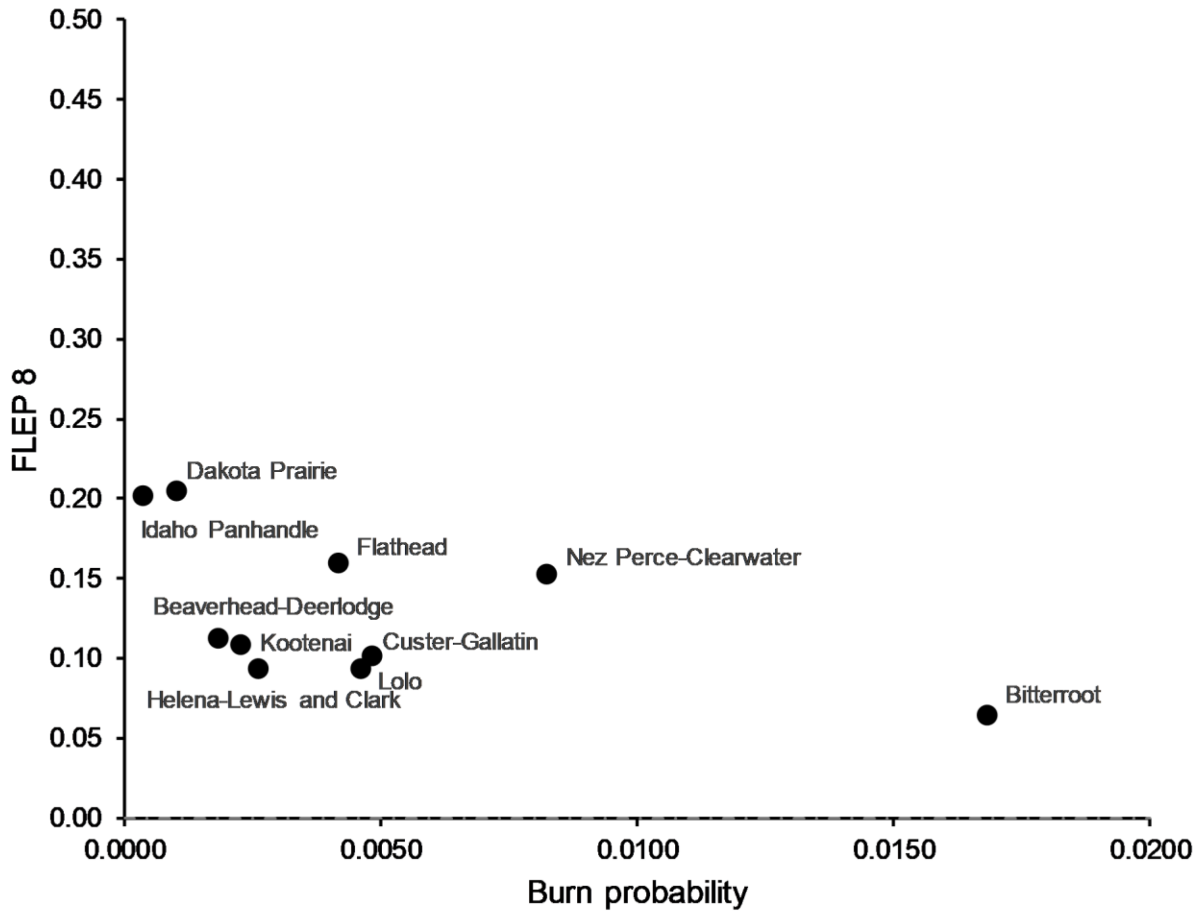

Figure 43. Graph of the 8-foot flame length exceedance probability and burn probability for a 2-kilometer buffer around the 10 forests in the NoRRA study area.

4.3 Effects analysis

The cumulative result of the calculations presented in Section 3 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 therefore limited to those pixels that have at least one HVRA and a non-zero burn probability. Both cNVC and eNVC reflect an HVRAs' response to fire and their relative importance within the context of the assessment, while eNVC additionally captures the relative likelihood of disturbance. Cumulative effects of wildfire vary by HVRA (Figure 44) with a net positive eNVC for Vegetation structure, Important vegetation, and Aquatic wildlife; a relatively minimal net negative eNVC for Major infrastructure, Municipal watersheds, and Recreation; and a more strongly negative net eNVC for Timber, People and Property, and T&E Terrestrial wildlife. Figure 45 shows cNVC results across the analysis area, with beneficial effects shown in light blue and negative in dark red. Adjusting cNVC by fire likelihood (i.e. burn probability) narrows the range of values for both negative and positive outcomes as seen in the eNVC map in Figure 46.

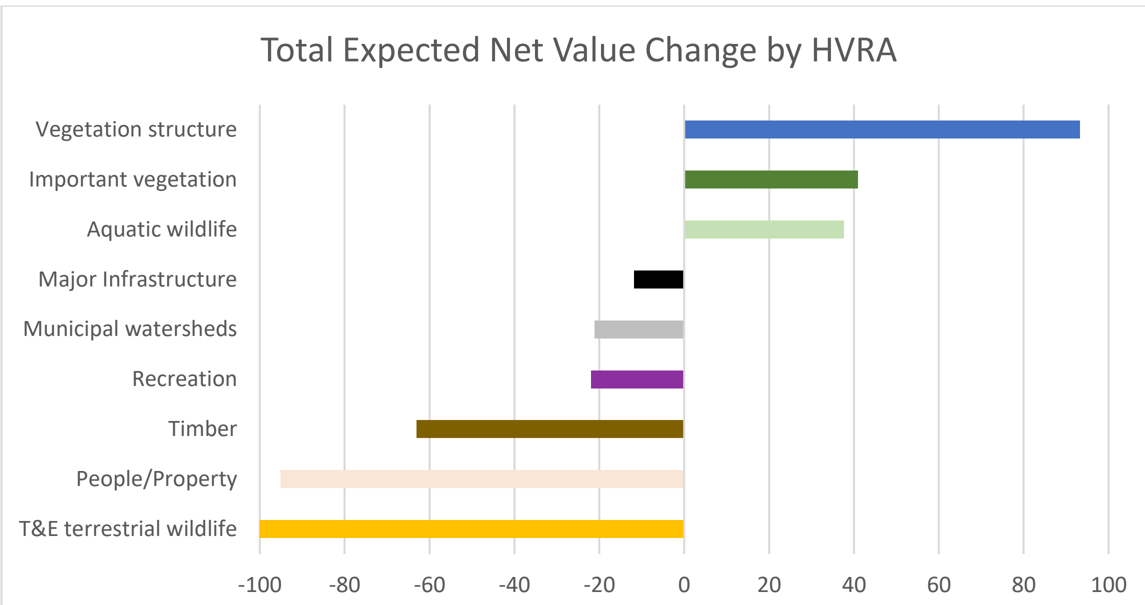

Figure 44: Weighted net response over all highly valued resources and assets (HVRAs) in the assessment. HVRAs are listed in order from greatest expected positive net response at the top to greatest net negative at the bottom.

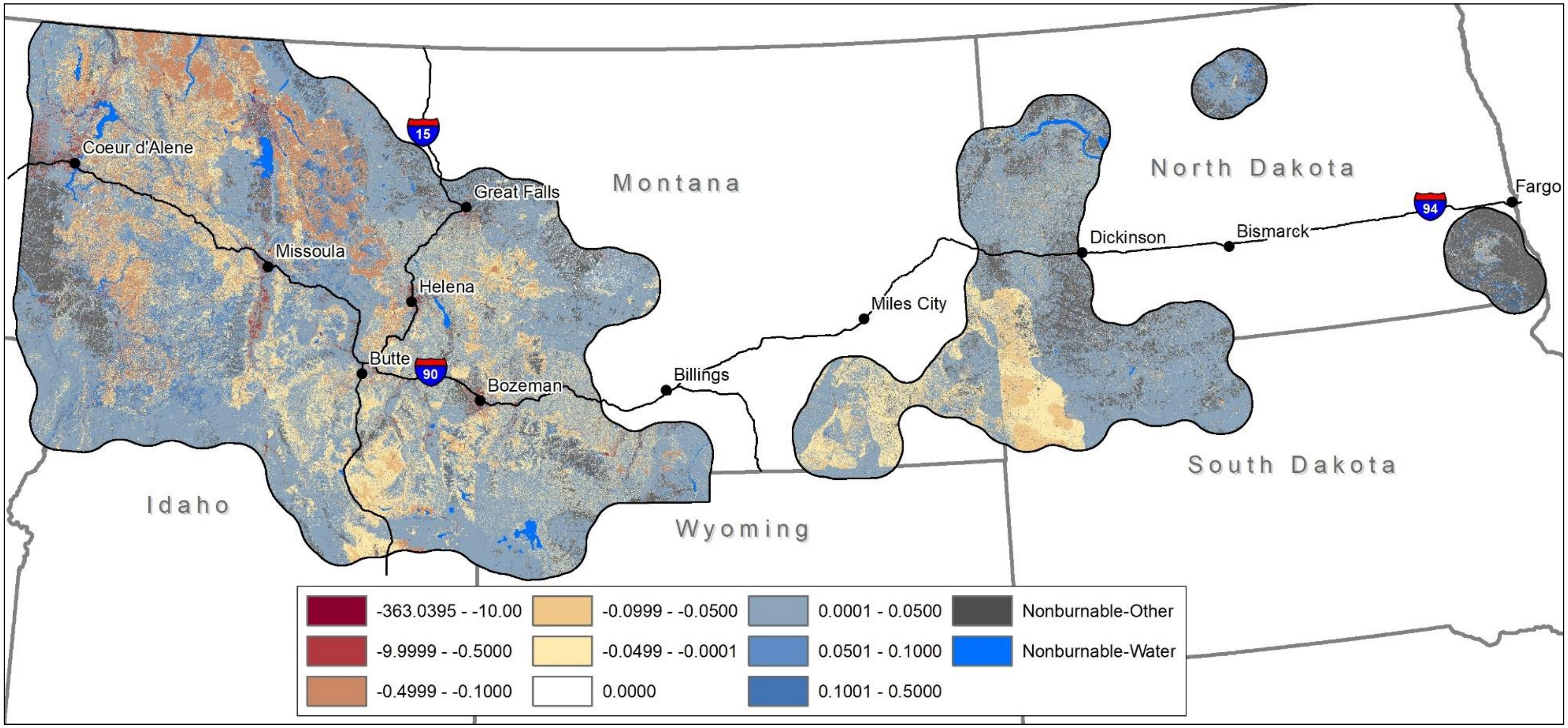

Figure 45: Map of Conditional Net Value Change cNVC for the NoRRA analysis area.

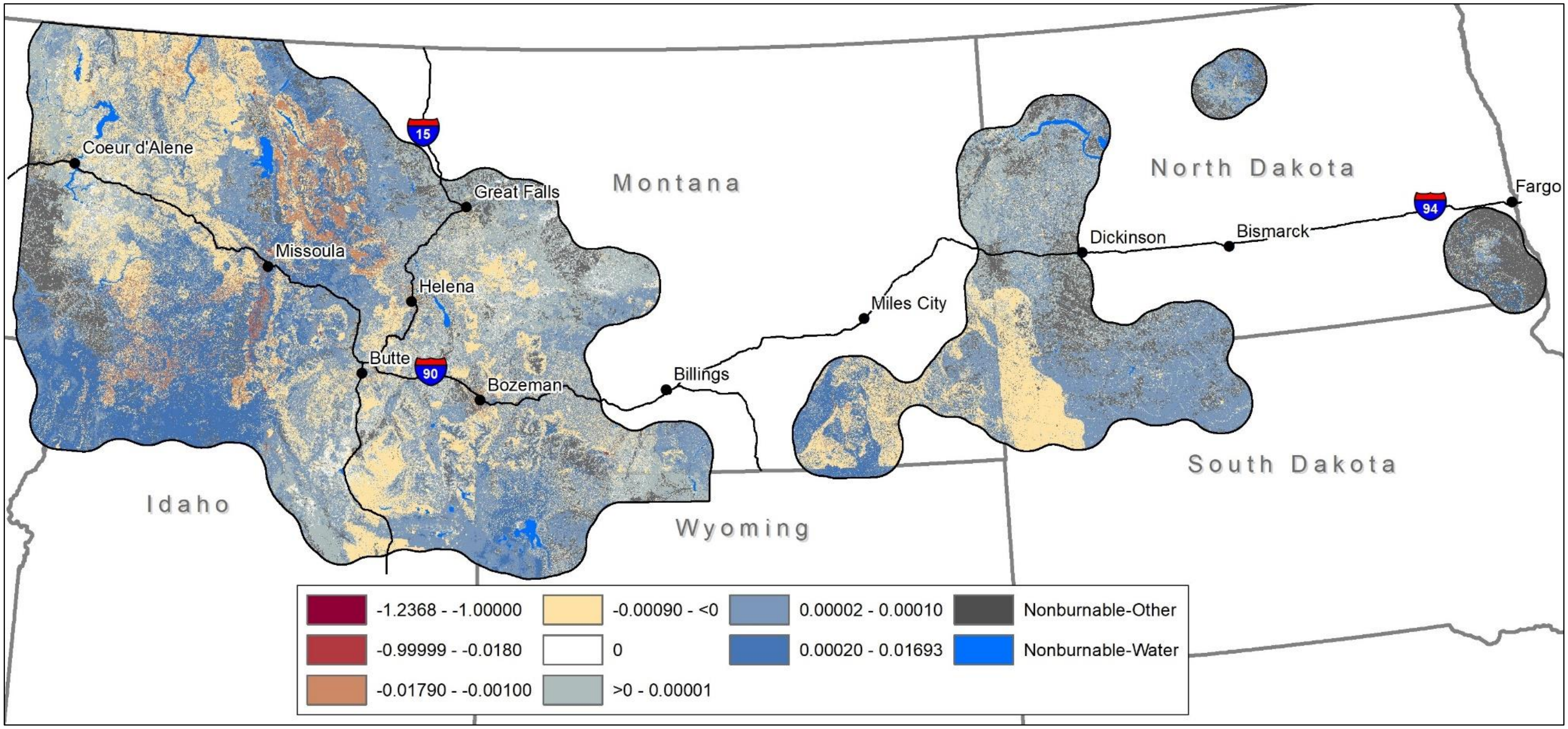

Figure 46: Map of Expected Net Value Change eNVC for the NoRRA analysis area.

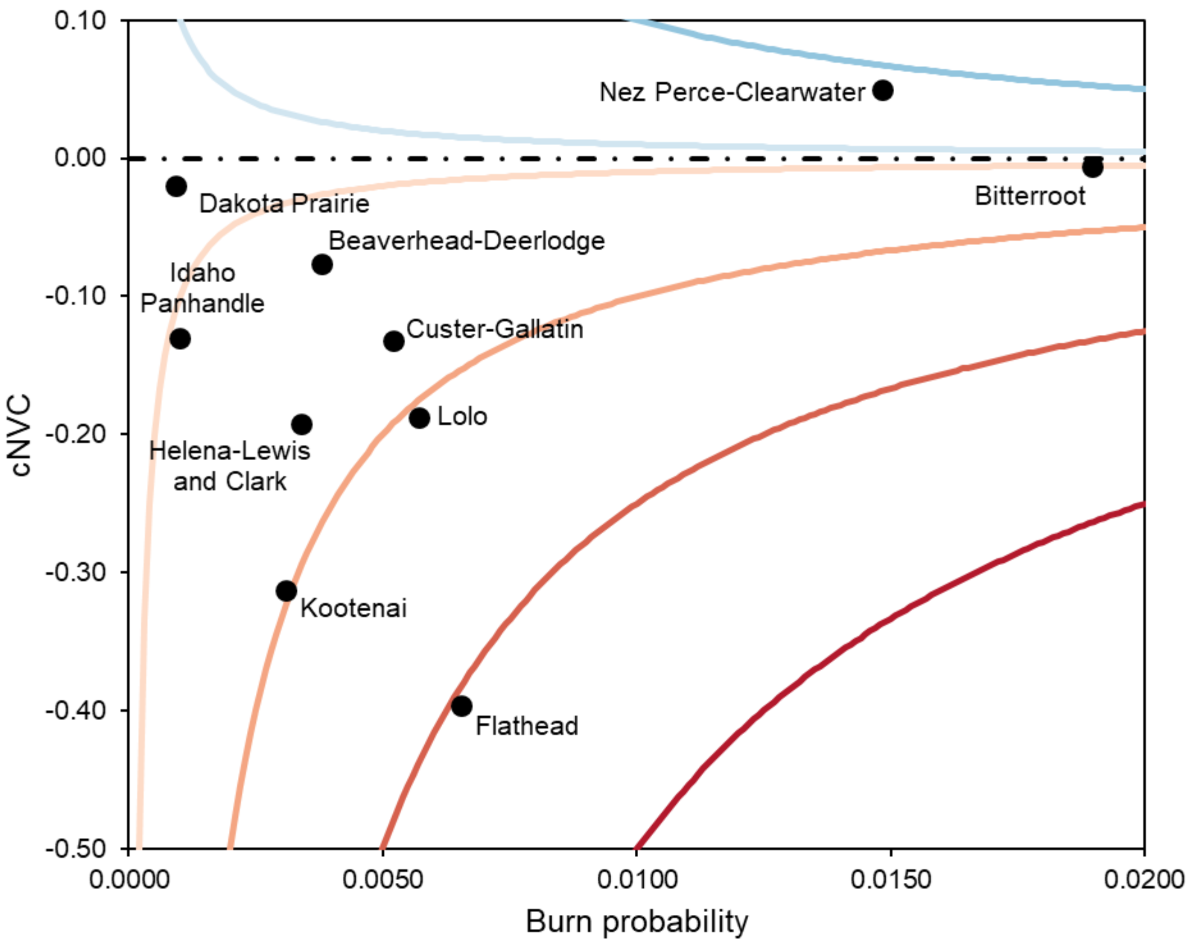

Figure 47. Graph of conditional net value change and burn probability for the ten forests in the NoRRA study area. The curved lines represent lines of equal expected net value change.

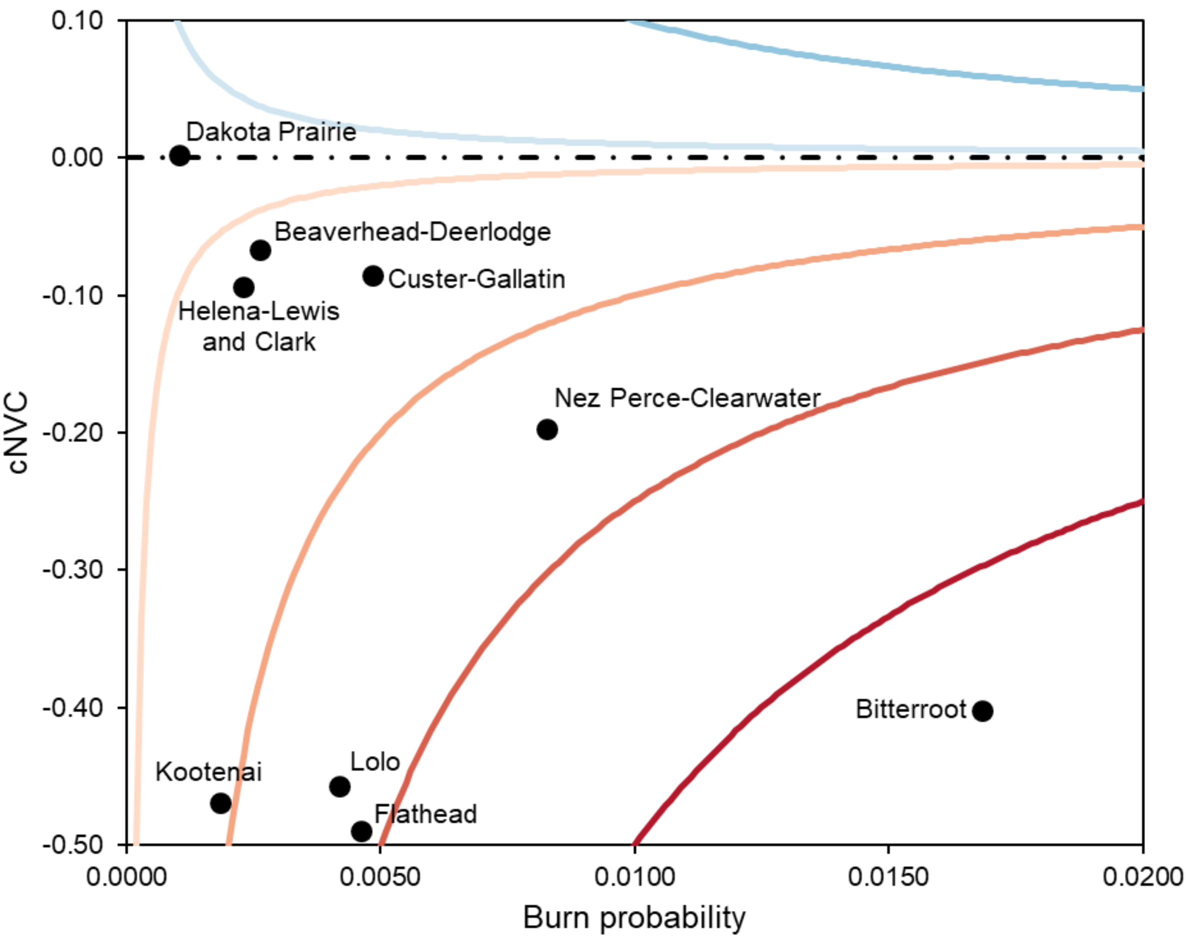

Figure 48. Graph of conditional net value change and burn probability for a 2-kilometer buffer around the ten forests in the NoRRA study area. The curved lines represent lines of equal expected net value change.

5. Analysis summary

The USFS Northern Region Wildfire Risk Assessment (NoRRA) provides foundational information about wildfire hazard and risk to highly valued resources and assets across the Region. The results represent the best available science across a range of disciplines. While this report was generated by Pyrologix LLC, the overall analysis was developed as a collaborative effort with numerous USFS the Fire/Fuel Planners, Resource Specialists, Wildlife Biologists, Geospatial Analysts, and Information Specialists. 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. Finally, 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. Additionally, the HVRA mapping may also need to be updated to account for forthcoming resource challenges and needs within the Region.

6. Data dictionary

- FSim modeling results are presented in three geodatabases:
  - **NoRRA_FSim_180_vFinal.gdb** – Mosaic FSim results for the eighteen FOAs in the NoRRA project area.
  - **NoRRA_AllPerims.gdb** – Event set outputs from FSim that includes all simulated wildfire perimeters.
  - **NoRRA_AllIgnitions.gdb** – Event set outputs from FSim that include the start location of all simulated wildfire perimeters.

1. **NoRRA_FSim_180_vFinal.gdb** – This geodatabase contains 13 rasters representing mosaic data results from the FSim simulations in the 18 FOAs within the NoRRA project area:
   a. **FLEP_2 –**
      This dataset represents the conditional probability of exceeding a nominal flame-length value (also known as flame-length exceedance probability, or FLEP). There are five FLEP rasters. FLEP_GT2 is the conditional probability of exceeding a flame length of 2 feet; it is calculated as the sum of iFLP_FIL2 through iFLP_FIL6. FLEP_GT4 is the conditional probability of exceeding a flame length of 4 feet; it is calculated as the sum of iFLP_FIL3 through iFLP_FIL6. FLEP_GT6 is the conditional probability of exceeding a flame length of 6 feet; it is calculated as the sum of iFLP_FIL4 through iFLP_FIL6. FLEP_GT8 is the conditional probability of exceeding a flame length of 8 feet; it is calculated as the sum of iFLP_FIL5 and iFLP_FIL6. There is no raster for FLEP_GT0 because, by definition, for all burnable pixels there is a 100 percent probability that flame length will exceed 0, given that a fire occurs.
      The iFLP_FILx rasters are the integrated (project wide) conditional probabilities of observing flame length in each of six classes: iFLP_FIL1 represents flame lengths from 0 - 2 ft., iFLP_FIL2 represents flame lengths from 2 - 4 ft., iFLP_FIL3 represents flame lengths from 4 - 6 ft., iFLP_FIL4 represents flame lengths from 6 - 8 ft., iFLP_FIL5 represents flame lengths from 8 - 12 ft., and iFLP_FIL6 represents flame lengths >12 ft.

   b. **FLEP_4** – see FLEP_2 description above
   c. **FLEP_6** – see FLEP_2 description above
   d. **FLEP_8** – see FLEP_2 description above
   e. iBP –
      This dataset is a 180-m cell size raster representing annual burn probability across the project area. The individual-FOA BPs were integrated into this overall result for the project area using a natural-weighting method that Pyrologix developed on an earlier project and subsequently published (Thompson and others 2013; "Assessing Watershed-Wildfire Risks on National Forest System Lands in the Rocky Mountain Region of the United States"). With this method, BP values for pixels well within the boundary of a FOA are influenced only by that FOA. Near the border with another FOA the results are influenced by that adjacent FOA. The weighting of each FOA is in proportion to its contribution to the overall BP at each pixel.

   f. **iCFL –**

      This dataset is a 180-m cell size raster representing the mean conditional flame length (given that a fire occurs). It is a measure of the central tendency of flame length. This raster was calculated as the sum-product of iFLP_FILx and the midpoint flame length of each of the six iFLP_FILs. For iFLP_FIL6, for which there is no midpoint, we used a surrogate flame length of 100 feet (representing torching trees).

g. **iFLP_FIL1 –**

This dataset is a 180-m cell size raster representing the mean conditional flame length (given that a fire occurs). This is also called the flame-length probability (FLP) and is a measure of the central tendency of flame length. This raster was calculated as the sum-product of the probability at each flame-length class and the midpoint flame length value of each of the six FILs. For FIL6, for which there is no midpoint, we used a surrogate flame length of 100 feet (representing torching trees) in timber fuel models and a flame length of 20 feet in all in grass, grass-shrub and shrub fuel types.

The individual-FOA iFLP_FILx rasters were integrated into this overall result for the project area using a natural-weighting method that Pyrologix developed on an earlier project and subsequently published (Thompson and others 2013; "Assessing Watershed-Wildfire Risks on National Forest System Lands in the Rocky Mountain Region of the United States"). With this method, the iFLP_FILx values for pixels well within the boundary of a FOA are influenced only by that FOA. Near the border with another FOA the results are also influenced by that adjacent FOA. The weighting of each FOA is in proportion to its contribution to the overall BP at each pixel.

h. **iFLP_FIL2** – see iFLP_FIL1 description above
i. **iFLP_FIL3** – see iFLP_FIL1 description above
j. **iFLP_FIL4** – see iFLP_FIL1 description above
k. **iFLP_FIL5** – see iFLP_FIL1 description above
l. **iFLP_FIL6** – see iFLP_FIL1 description above
m. **iMFI –**

This dataset is a 180-m cell size raster representing the mean conditional fireline intensity (kW/m) given that a fire occurs. It is a measure of the central tendency of fireline intensity. The individual-FOA MFI rasters were integrated into this overall result for the project area using a natural-weighting method that Pyrologix developed on an earlier project and subsequently published (Thompson and others 2013; "Assessing Watershed-Wildfire Risks on National Forest System Lands in the Rocky Mountain Region of the United States"). With this method, the iMFI values for pixels well within the boundary of a FOA are influenced only by that FOA. Near the border with another FOA the results are also influenced by that adjacent FOA. The weighting of each FOA is in proportion to its contribution to the overall BP at each pixel.

2. **NoRRA_AllPerims.gdb –** This dataset represents the simulated wildfire perimeters within each of the eighteen Fire Occurrence Areas (FOA) that comprise the NoRRA project area. Each _Perims feature class includes an attribute table with the following attributes:

a. **FIRE_NUMBE -** the unique fire number for a simulation
b. **THREAD_NUM -** the thread number that simulated the fire (the number of threads is determined by the number of CPUs in the workstation, the number of processing cores per CPU, and whether the cores are hyperthreaded.)
c. **ERC_STARTD -** the ERC(G) value on the start day of the fire
d. **ERC_PERCEN -** the ERC(G) percentile associated with ERC_STARTD. The ERC_PERCEN is a simple lookup from the ERC_STARTD from the "percentiles" section of the .frisk file.
e. **NUM_BURNDA -** the number of days the fire burned during the simulation. This does not include any no-burn days (days below the 80th percentile ERC
f. **START_DAY -** the Julian day of the fire start

g. **YEAR -** the iteration number (year) for which the fire was simulated
h. **Xcoord/Ycoord -** the coordinates of the fire's ignition point
i. **CONTAIN -** the reason for the cessation of fire growth on the simulated fire
j. **FOA** – the FOA number where the ignition is located
k. **UNQ_ID** – concatenation of FOA number and FIRE_NUMBE
l. **NumIterations** – the number of iterations within a simulation. Individual FOAs were run with 10,000 iterations. When generating additional analytical products from the FSim event set, results must be weighted by iteration number to avoid introducing error
m. **GIS_SizeAc** – the final wildfire size (acres) generated as an ArcGIS calculation based on feature geometry
n. **GIS_SizeHa** – the final wildfire size (hectares) generated as an ArcGIS calculation based on feature geometry
o. **FSim_SizeAc -** is the final fire size (acres) generated within FSim based on raster count. Best-practice is to calculate GIS acres for each perimeter instead of relying on SizeAc, especially if subsequent analyses will be based on GIS acres
p. **NumParts** – Number of geometry parts in the simulated wildfire perimeter
q. **ContainsIgn** – True/False value (1,0) that describes if the location of the ignition point is contained within the simulated wildfire perimeter polygon. The ignition may not be included within the simulated perimeter due to how FSIM converts pixel geometry to polygon geometry or as a result of a post processing script that removed small artifacts generated from the FSim trimming suppression algorithm.

3. **NoRRA_AllIgnitions.gdb –** This dataset represents the simulated fire start locations within each of the eighteen Fire Occurrence Areas (FOA) that comprise the NoRRA project area. Each _AllIgnitions feature class includes an attribute table with the following attributes:

a. **FIRE_NUMBE -** the unique fire number for a simulation
b. **THREAD_NUM -** the thread number that simulated the fire (the number of threads is determined by the number of CPUs in the workstation, the number of processing cores per CPU, and whether the cores are hyperthreaded.)
c. **ERC_STARTD -** the ERC(G) value on the start day of the fire
d. **ERC_PERCEN -** the ERC(G) percentile associated with ERC_STARTD. The ERC_PERCEN is a simple lookup from the ERC_STARTD from the "percentiles" section of the .frisk file.
e. **NUM_BURNDA -** the number of days the fire burned during the simulation. This does not include any no-burn days (days below the 80th percentile ERC
f. **START_DAY -** the Julian day of the fire start
g. **YEAR -** the iteration number (year) for which the fire was simulated
h. **Xcoord/Ycoord -** the coordinates of the fire's ignition point
i. **CONTAIN -** the reason for the cessation of fire growth on the simulated fire
j. **FOA** – the FOA number where the ignition is located
k. **UNQ_ID –** concatenation of FOA number and FIRE_NUMBE
l. **NumIterations** – the number of iterations within a simulation. Individual FOAs were run with 10,000 iterations. When generating additional analytical products from the FSim event set, results must be weighted by iteration number to avoid introducing error
m. **GIS_SizeAc** – the final wildfire size (acres) generated as an ArcGIS calculation based on feature geometry
n. **GIS_SizeHa** – the final wildfire size (hectares) generated as an ArcGIS calculation based on feature geometry

o. **FSim_SizeAc -** is the final fire size (acres) generated within FSim based on raster count. Best-practice is to calculate GIS acres for each perimeter instead of relying on SizeAc, especially if subsequent analyses will be based on GIS acres
p. **NumParts** – Number of geometry parts in the simulated wildfire perimeter
q. **ContainsIgn** – True/False value (1,0) that describes if the location of the ignition point is contained within the simulated wildfire perimeter polygon. The ignition may not be included within the simulated perimeter due to how FSim converts pixel geometry to polygon geometry or as a result of a post processing script that removed small artifacts generated from the FSim trimming suppression algorithm.

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8. Appendices

Table A1. Zonal summaries of FSim and HVRA data for the 10 national forests within the NoRRA analysis area.

Forest	Area_AC (Million)	Lrg-Fire/ mill ac/yr	Mean BP	Avg 4' FLEP/BP	Avg 8' FLEP/BP	Mean cNVC	Sum eNVC	Mean HVRA Import	Maj Import HVRA	% of Ovrl Import
Beaverhead-Deerlodge	3.48	0.49	0.0038	0.49	0.16	-0.0767	-1097	0.0113	WATER	0.36
Bitterroot	1.54	2.96	0.0190	0.52	0.16	-0.0062	-182	0.0110	AQUA	0.40
Custer-Gallatin	2.99	0.79	0.0052	0.58	0.12	-0.1323	-1764	0.0136	WATER	0.39
Dakota Prairie	2.41	0.33	0.0009	0.80	0.19	-0.0199	-36	0.0061	WATER	0.56
Flathead	2.51	0.96	0.0065	0.50	0.16	-0.3960	-6777	0.0207	TERR	0.45
Helena-Lewis and Clark	3.05	0.56	0.0034	0.52	0.17	-0.1922	-2838	0.0131	WATER	0.27
Idaho Panhandle	2.84	0.37	0.0010	0.67	0.29	-0.1298	-259	0.0129	TIMBER	0.25
Kootenai	2.56	0.74	0.0031	0.69	0.30	-0.3129	-3093	0.0157	TERR	0.27
Lolo	2.59	1.10	0.0057	0.53	0.16	-0.1879	-3017	0.0149	TIMBER	0.26
Nez Perce-Clearwater	3.96	2.34	0.0148	0.64	0.28	0.0499	3178	0.0132	AQUA	0.35

Table A2. Zonal summaries of FSim and HVRA data for a 2-km buffer around the 10 national forests within the NoRRA analysis area.

Forest	Area_AC (Million)	Lrg-Fire/ mill ac/yr	Mean BP	Avg 4' FLEP/BP	Avg 8' FLEP/BP	Mean cNVC	Sum eNVC	Mean HVRA Import	Maj Import HVRA	% of Ovrl Import
Beaverhead-Deerlodge	1.43	0.34	0.0023	0.56	0.11	-0.0935	-218	0.0119	WUI	0.28
Bitterroot	0.27	2.34	0.0168	0.50	0.06	-0.4022	-1780	0.0207	WUI	0.62
Custer-Gallatin	1.11	0.74	0.0048	0.62	0.10	-0.0855	-442	0.0096	WATER	0.41
Dakota Prairie	0.69	0.37	0.0010	0.81	0.20	0.0027	9	0.0055	WATER	0.64
Flathead	0.47	0.70	0.0042	0.50	0.16	-0.4565	-530	0.0222	WUI	0.55
Helena-Lewis and Clark	1.07	0.41	0.0026	0.49	0.09	-0.0667	-164	0.0098	WATER	0.32
Idaho Panhandle	1.03	0.19	0.0004	0.58	0.20	-0.5645	-200	0.0264	WUI	0.53
Kootenai	0.33	0.56	0.0018	0.56	0.11	-0.4690	-271	0.0244	WUI	0.50
Lolo	0.58	0.89	0.0046	0.49	0.09	-0.4899	-993	0.0261	WUI	0.57
Nez Perce-Clearwater	0.55	1.16	0.0083	0.60	0.15	-0.1972	-390	0.0167	TIMBER	0.27

Table A3. Zonal summaries of FSim and HVRA data for each USFS ranger district within the NoRRA analysis area.

Forest / Ranger District	Area_AC (Million)	Lrg-Fire/ mill ac/yr	Mean BP	Avg 4' FLEP/BP	Avg 8' FLEP/BP	Mean cNVC	Sum eNVC	Mean HVRA Import	Maj Import HVRA	% of Ovrl Import
Beaverhead-Deerlodge										
Butte	0.21	0.30	0.0029	0.65	0.28	-0.2672	-161	0.0209	WATER	0.61
Dillon	0.56	0.25	0.0017	0.52	0.13	0.0001	-41	0.0096	TERR	0.26
Jefferson	0.46	0.29	0.0024	0.68	0.32	-0.1400	-169	0.0094	WATER	0.35
Madison	0.70	0.37	0.0020	0.69	0.21	-0.0318	-48	0.0085	WATER	0.28
Pintler	0.71	0.77	0.0064	0.44	0.13	-0.0996	-376	0.0116	AQUA	0.27
Wisdom	0.42	0.88	0.0069	0.38	0.10	-0.0455	-155	0.0108	WATER	0.53
Wise River	0.42	0.47	0.0041	0.48	0.15	-0.0843	-147	0.0154	WATER	0.65
Bitterroot										
Darby	0.33	2.53	0.0155	0.43	0.10	-0.0283	-231	0.0112	AQUA	0.38
Stevensville	0.22	1.92	0.0106	0.51	0.15	-0.0104	-61	0.0088	AQUA	0.31
Sula	0.25	1.78	0.0135	0.41	0.08	-0.1202	-486	0.0155	TIMBER	0.27
West Fork	0.75	3.83	0.0247	0.57	0.19	0.0419	596	0.0101	AQUA	0.50
Custer-Gallatin										
Ashland	0.50	1.59	0.0104	0.56	0.07	-0.0404	-225	0.0079	WATER	0.30
Beartooth	0.43	0.73	0.0030	0.58	0.16	-0.2647	-576	0.0171	WATER	0.45
Bozeman	0.54	0.51	0.0041	0.57	0.16	-0.2823	-607	0.0179	WATER	0.33
Gardiner	0.35	0.75	0.0061	0.60	0.14	-0.0617	-90	0.0134	WATER	0.47
Hebgen Lake	0.31	0.54	0.0048	0.61	0.14	-0.0821	-85	0.0106	WATER	0.22
Sioux	0.18	0.57	0.0035	0.78	0.15	-0.0614	-35	0.0059	WATER	0.27
Yellowstone	0.68	0.66	0.0038	0.54	0.15	-0.0762	-145	0.0145	WATER	0.46
Dakota Prairie										
Grand River	0.41	0.55	0.0015	0.84	0.20	0.0228	13	0.0028	WATER	0.33
Mckenzie	0.77	0.24	0.0008	0.80	0.19	-0.0061	-5	0.0052	WATER	0.58
Medora	1.11	0.29	0.0008	0.80	0.18	-0.0413	-40	0.0063	WATER	0.47
Sheyenne	0.11	0.48	0.0010	0.67	0.21	-0.0599	-6	0.0212	WATER	0.87
Flathead										
Glacier View	0.34	0.55	0.0045	0.46	0.13	-0.4523	-732	0.0257	TERR	0.43
Hungry Horse	0.41	0.88	0.0068	0.56	0.20	-0.5263	-1470	0.0233	TERR	0.43
Spotted Bear	0.98	1.19	0.0079	0.47	0.14	-0.2047	-2262	0.0172	TERR	0.55
Swan Lake	0.49	1.09	0.0076	0.49	0.16	-0.4572	-1749	0.0210	TERR	0.35
Tally Lake	0.29	0.55	0.0024	0.63	0.21	-0.6795	-565	0.0227	TERR	0.35

Table A3. (Continued) Zonal summaries of FSim and HVRA data for each USFS ranger district within the NoRRA analysis area.

Forest / Ranger District	Area_AC (Million)	Lrg-Fire/ mill ac/yr	Mean BP	Avg 4' FLEP/BP	Avg 8' FLEP/BP	Mean cNVC	Sum eNVC	Mean HVRA Import	Maj Import HVRA	% of Ovrl Import
Helena-Lewis and Clark										
Belt Creek	0.20	0.38	0.0010	0.58	0.22	-0.1650	-32	0.0103	REC	0.19
Helena	0.45	0.41	0.0036	0.64	0.26	-0.2654	-428	0.0190	WATER	0.57
Judith	0.37	0.27	0.0007	0.63	0.27	-0.0816	-30	0.0070	TIMBER	0.26
Lincoln	0.34	0.83	0.0072	0.52	0.18	-0.3217	-889	0.0183	TERR	0.52
Musselshell	0.30	0.27	0.0008	0.54	0.18	-0.0515	-24	0.0060	TIMBER	0.26
Rocky Mountain	0.69	0.99	0.0058	0.44	0.11	-0.2137	-1186	0.0139	TERR	0.56
Townsend	0.37	0.40	0.0032	0.59	0.20	-0.1505	-173	0.0111	WATER	0.43
White Sulphur Springs	0.33	0.45	0.0011	0.58	0.20	-0.2261	-75	0.0148	WATER	0.45
Idaho Panhandle										
Bonners Ferry	0.48	0.45	0.0014	0.70	0.32	-0.1753	-169	0.0128	TIMBER	0.24
Coeur d'Alene River	0.80	0.21	0.0005	0.70	0.33	-0.1585	-55	0.0116	TIMBER	0.32
Priest Lake	0.36	0.17	0.0004	0.70	0.34	-0.2159	-27	0.0153	AQUA	0.29
Sandpoint	0.34	0.49	0.0012	0.66	0.33	-0.1810	-43	0.0161	AQUA	0.28
St. Joe	0.87	0.52	0.0014	0.65	0.25	-0.0228	35	0.0117	TIMBER	0.29
Kootenai										
Cabinet	0.46	0.49	0.0015	0.73	0.37	-0.0674	-33	0.0132	AQUA	0.31
Fortine	0.28	0.70	0.0040	0.62	0.22	-0.4639	-536	0.0183	TERR	0.46
Libby	0.86	0.77	0.0030	0.67	0.26	-0.2905	-927	0.0153	TIMBER	0.32
Rexford	0.31	0.85	0.0040	0.70	0.28	-0.5241	-739	0.0179	TERR	0.46
Three Rivers	0.66	0.85	0.0034	0.73	0.36	-0.3491	-859	0.0160	TERR	0.36
Lolo										
Missoula	0.61	1.31	0.0083	0.52	0.14	-0.1928	-1038	0.0153	TIMBER	0.23
Ninemile	0.47	1.49	0.0058	0.62	0.19	-0.1466	-397	0.0118	AQUA	0.31
Plains/Thompson Falls	0.57	0.57	0.0020	0.63	0.21	-0.1867	-194	0.0132	TIMBER	0.38
Seeley Lake	0.43	1.27	0.0100	0.41	0.11	-0.2147	-1094	0.0201	TERR	0.31
Superior	0.51	0.94	0.0030	0.67	0.25	-0.1988	-295	0.0148	TIMBER	0.31
Nez Perce-Clearwater										
Lochsa/Powell	0.93	2.45	0.0156	0.60	0.26	0.0504	653	0.0133	AQUA	0.35
Moose Creek	0.79	3.39	0.0218	0.61	0.28	0.0833	1404	0.0126	AQUA	0.41
North Fork	0.76	1.61	0.0075	0.66	0.29	0.0748	297	0.0109	VEG	0.35
Palouse	0.20	0.28	0.0007	0.68	0.29	-0.1560	-27	0.0133	TIMBER	0.44
Red River	0.76	2.92	0.0200	0.67	0.29	0.0650	780	0.0149	AQUA	0.39
Salmon River	0.52	1.60	0.0119	0.68	0.29	0.0210	72	0.0148	AQUA	0.33

4. Report Change Log

Table A4. Change log for edits made to this report after the original 9-28-2017 release date.

Date	Author	Changes made
8/22/2018	JGD-Per R1	Changed overall RI of Veg. Structure HVRA from 15 to 30
	JGD-Per R1	Changed sub-RI of Unknown if Occupied Lynx habitat from 60 to 10
	JGD-Per R1	Changed RFs for all AQUA species (see section 3.4.7 for updates)
	JGD-Per R1	Changed response function for FIL6 to -100 for all WUI, REC, and INFRA (sections 3.4.1-3.4.3)
	JGD-Per R1	Changed response function for FS Timber-All Other (see section 3.4.4)
	JGD-Per R1	Renamed Terrestrial to T&E Terrestrial
9/13/2018	JGD	Update relative importance in HVRA tables to reflect changes, update chart and maps of cNVC and eNVC in Section 4.3
9/18/18	KV	Update charts in Section 4.3 and tables in Appendices
9/20/18	JGD	Minor copy edits after final review of updated document