

Wildfire Risk to Residential Structures in the Island Park Sustainable Fire Community

Caribou-Targhee National Forest

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Contents

1	Assessment Overview	1
1.1	Purpose and background of the assessment.....	1
1.2	Assessment area.....	1
1.3	Risk concepts and framework	2
1.4	Perimeter-based analyses.....	3
2	Data preparation	4
2.1	Fuelscapes	4
2.1.1	Current Fuelscape.....	4
2.1.2	Future Fuelscapes.....	6
2.2	Historical wildfire occurrence	7
2.3	Historical weather.....	8
2.4	Structure location and susceptibility.....	9
2.5	Response functions.....	10
3	Analysis Methods and Results.....	12
3.1	Wildfire hazard.....	12
3.2	Risk to residential structures	14
3.2.1	Fireshed analysis	16
3.2.2	Exceedance probability	18
4	Future hazard, exposure and effects	20
5	Summary and Discussion	21
6	References	23
Appendix A: Field Report		1
Background:		1
LANDFIRE Vegetation & Surface Fuel Data Review:		1
Sagebrush		1
Lodgepole pine		4
Douglas-fir.....		6
LANDFIRE Canopy Fuel Data Review:.....		7
Canopy Base Height.....		7
Canopy Bulk Density		7
Summary of changes to be made:		9

Tables

Table 1. Comparison of torching index for fire behavior fuel model TU1 across a range of slope and canopy cover values and two weather scenarios.....	6
Table 2. Live and dead fuel moisture content values used for each ERC percentile bin.	9
Table 3. Dynamic response function for damage to residential structures as a function of fire intensity (flame length) and structure susceptibility rating.	11
Table 4. Flame length ranges associated with the six fire intensity levels (FILs).....	12
Table 5. Summary of risk-source to residential structures within the IPSFC fireshed based on distance from a structure. Distance zone width increases beyond 7 km because of the relatively small number of fires that reach a structure from beyond that distance.....	17
Table 6. Summary of landscape-scale effects on simulated fire occurrence.....	20
Table 7. Summary of local-scale effects of the current condition and three future fuelscapes on wildfire hazard.....	20
Table 8. Mean number of structures exposed and affected for the current condition and three future fuelscapes.....	21

Figures

Figure 1. Map of the 303,500-ha IPSFC project area and associated 2.2 million ha fire modeling area.	2
Figure 2. LANDFIRE map zones intersecting the IPSFC fire modeling area.....	5
Figure 3. Location of susceptibility rating of 4,007 residential structures within the IPSFC project area.	10
Figure 4. Current-condition burn probability.	13
Figure 5. Current-condition six-panel FLP map.....	14
Figure 6. Conditional net value change (<i>cNVC</i>) for residential structures in the IPSFC.	15
Figure 7. Scatterplot of burn probability versus conditional net value change at each of 4007 residential structures in the IPSFC project area. Reference lines indicate percentile values of expected net value change.	16
Figure 8. Start locations of simulated fires in the IPSFC project area symbolized according to the number of structures affected by the fire.....	17
Figure 9. Annual number of structures exposed and affected by wildfire per 1000 ha by fires originating various distances from a structure.....	18
Figure 10. Exceedance probability curves for structures exposed and structures affected for the current-condition landscape.....	19

1 Assessment Overview

1.1 Purpose and background of the assessment

The Island Park Sustainable Fire Community (IPSFC) Project is a collaborative working group of citizens, businesses, non-profit organizations, and local, state, and federal government agencies (www.islandparkfirecommunity.com) working to create fire-resilient ecosystems in and around the human communities of West Yellowstone, Montana and Island Park, Idaho. The IPSFC is guided in part by the Federal Land Assistance, Management, and Enhancement Act of 2009, and by the National Cohesive Wildland Fire Management Strategy, often known simply as the “Cohesive Strategy” (www.forestsandrangelands.com/strategy). Fostering sustainable, fire-adapted human communities is one of three fundamental goals of the Cohesive Strategy.

In 2013, a team from the Missoula Fire Sciences Laboratory, a wildfire research and development program of the USDA Forest Service, and the Fire Modeling Institute, a wildfire science delivery program of the USDA Forest Service, completed a pilot assessment of wildfire risk to residential structures (Hollingsworth and Parsons 2013) for the IPSFC at the request of the Ashton/Island Park Ranger Districts of the Caribou-Targhee National Forest and the Hebgen Lake Ranger District of the Gallatin National Forest. The work described in this paper is an extension of that pilot project, entailing a more in-depth and comprehensive analysis of fire simulation outputs, structure exposure and loss potential, and mitigation options.

1.2 Assessment area

The effort described in this paper extends the aforementioned pilot project, to enhance the assessment of wildfire risk to the 4,007 residential structures in the 303,500 ha IPSFC project area (Figure 1). The local economy of the IPSFC is heavily dependent on both summer and winter recreation and tourism. However, relatively few residential structures in the IPSFC are occupied year round; the summertime population grows considerably with visitors and part-time residents. Residential structures in the IPSFC exhibit a wide range of compliance with FireWise principles of defensible space (see www.firewise.org). Many structures are built with combustible siding and roofing materials. Road access into many of the subdivisions is inadequate to simultaneously accommodate both egress for evacuation and ingress for firefighting; in some cases, the road system may even be inadequate for evacuation alone.

To produce valid wildfire likelihood results in the project area, we created a 2.2 million ha fire modeling area so that simulated wildfires could originate well outside of the project area and spread into it if fuel and weather conditions were conducive to such fire growth.

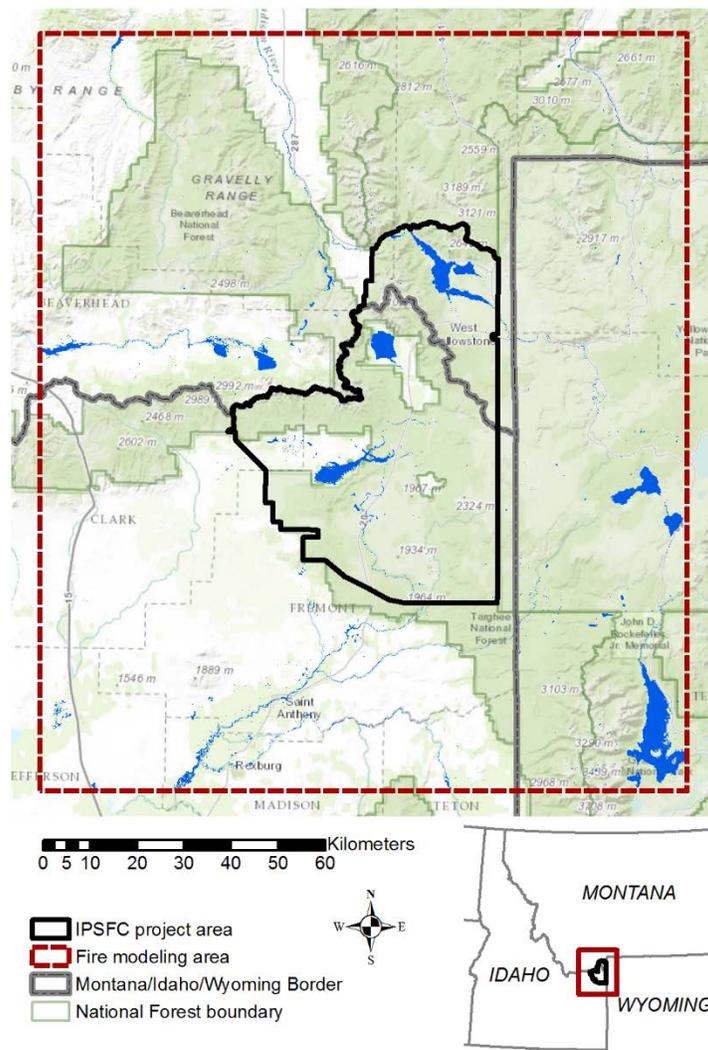


Figure 1. Map of the 303,500-ha IPSFC project area and associated 2.2 million ha fire modeling area.

1.3 Risk concepts and framework

A quantitative framework for assessing wildfire risk to highly valued resources and assets (HVRAs) was first proposed by Finney (2005). That framework measures wildfire risk as the expected net value change ($eNVC$) to an HVRA due to wildfire. The fundamental components of the wildfire risk framework are wildfire likelihood and intensity, HVRA exposure to wildfire, and HVRA response to fire given its susceptibility (Finney 2005; Miller and Ager 2012; Scott 2006; Scott et al. 2013). Estimating HVRA response to wildfire—called effects analysis—is a crucial step for assessing wildfire risk and prioritizing mitigation efforts (Fairbrother and Turnley 2005). Analyzing the susceptibility of HVRAs to varying levels of fire intensity relies on a combination of fire effects modeling and expert judgment. The three primary data requirements to assess $eNVC$ to an HVRA include: (1) geospatial representations of wildfire likelihood and intensity, (2) a geospatially characterized HVRA, and (3) a response function that describes the susceptibility of the HVRA over a range of fire intensity levels (FILs). Although several measures of fire intensity are available, FILs are typically expressed in terms of flame length.

Calculating *eNVC* for a discrete element of an HVRA—a pixel, point or polygon—is a two-step process. First, the conditional *NVC*, or *cNVC*, is calculated as the sum-product of *FLP_i* and *NVC_i* over a range of flame length classes

$$cNVC = \sum_i (FLP_i * NVC_i)$$

where *cNVC* is the conditional response of the HVRA to wildfire, given that one occurs, *FLP_i* is the conditional probability of observing flame-length class *i*, and *NVC_i* is the *NVC*—the response function value—for flame-length class *i*.

In the second step, *eNVC* is the product of *cNVC* and burn probability (*BP*)

$$eNVC = cNVC * BP$$

1.4 Perimeter-based analyses

Planning and assessment efforts are increasingly using individual perimeters as well, to capture variation in the size, shape, and location of simulated fires (Thompson et al. 2013a; Kuhlmann et al. 2015). Exposure and risk assessment methods that use simulated fire perimeters involve overlaying the simulated fire perimeters with spatial data representing the HVRA in point, line, polygon, or raster data. The spatial data representing the HVRA can be simply the location of the HVRA, without consideration for its susceptibility, or it can be *cNVC* as calculated above. Direct calculation of individual fire-level effects at any given pixel based on intensity is not possible due to limitations of existing simulation systems; hence reliance on aggregate *FLP* and *cNVC* values (Thompson et al. 2015).

The results of perimeter-HVRA overlays can be used to summarize information about potential fire impacts in a variety of ways. Scott et al. (2012a) quantified the conditional distribution of the amount of HVRA burned in a single wildfire event, focusing on municipal watersheds. The same information can be used to produce an exceedance probability curve that relates the magnitude of an effect to its likelihood of occurring (Thompson et al. 2015).

Perimeter-based analyses can further associate the effects of simulated fires with their ignition locations to explore spatial patterns in the transmission of wildfire risk across landscapes. For instance, by identifying the locations of all ignitions associated with simulated fires that ultimately reached an identified critical wildlife habitat polygon, Thompson et al. (2013a) delineated a biophysical fireshed as the area within which a wildfire could ignite and impact the habitat. Related applications have examined the potential for ignitions to reach delineated residential communities or to impact human populations. After tying simulated wildfire impacts to communities and human populations back to their ignition locations, areas of high risk-source potential can be identified (Ager et al. 2014; Haas et al. 2015; Scott et al. 2012b).

2 Data preparation

2.1 Fuelscapes

The LANDFIRE Program (www.landfire.gov) produces and maintains, for the extent of the United States, the geospatial data required for spatial fire behavior modeling. We acquired version 1.2 (also referred to as LANDFIRE 2010) of these data for the 2.2 million ha IPSFC fire modeling area. Although designed for national to regional applications, LANDFIRE data may be appropriately applied at more local scales given proper review and adjustment where necessary (Rollins 2009). Applicability varies by location and specific use.

2.1.1 Current Fuelscape

A field visit and preliminary fire behavior modeling were conducted to validate the LANDFIRE data for use in this analysis. Although LANDFIRE mapping methodologies are consistent across the United States, products are produced on a map zone-by-map zone basis. Differences may occur at map zone boundaries due to inconsistencies in, or the amount of, source data (e.g., field plots, remotely sensed imagery) and/or differences in expert-opinion based mapping rules, such as those used for mapping fire behavior fuel model. Furthermore, modeling landscape fire behavior is a balancing act between multiple data variables, each with its own set of nuances. In-depth knowledge of how fire behavior modeling inputs interact with one another and their relationship to real-world phenomena is critical to producing informative results. The findings of our data critique and modifications are summarized in the following paragraphs and discussed in more depth in Appendix A.

The IPSFC fire modeling area intersects three LANDFIRE map zones—18, 19, and 21—with the majority of the project area in zone 21 (Figure 2). We modified the mapped fuel characteristics for five existing vegetation types (EVTs) in the fire modeling extent. The first modification was to EVT 3220 (*Artemisia tridentata* ssp. *vaseyana* Shrubland Alliance). A significant amount of this sagebrush EVT is mapped within all three zones, however the fire behavior fuel model mapping rules vary between zones. The zone 18 mapping rules assign fuel model SH7 to the majority of the EVT, whereas the zone 19 and 21 rules assign fuel model GS2. We concluded that fuel model SH7 would over predict flame length and rate of spread in this vegetation type based on our field observations and therefore applied the zone 19/21 rules to the EVT across all three zones.

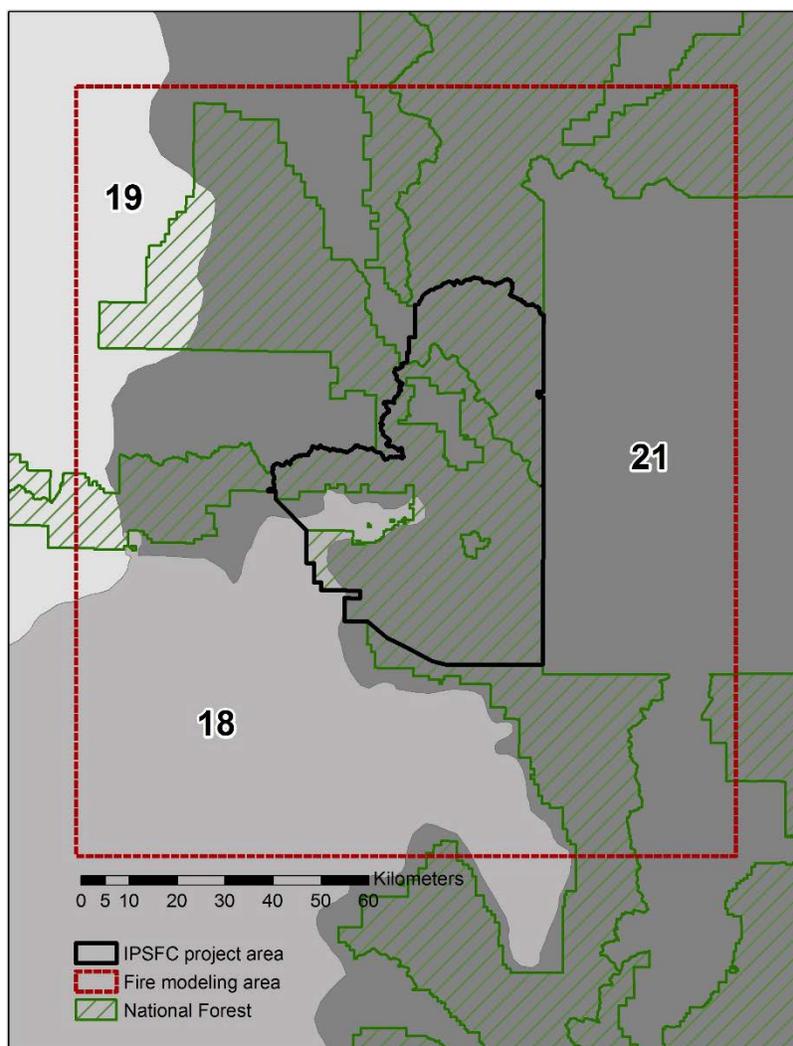


Figure 2. LANDFIRE map zones intersecting the IPSFC fire modeling area.

Two lodgepole pine EVT, 3050 (Rocky Mountain lodgepole pine forest) and 3167 (Rocky Mountain poor-site lodgepole pine forest), are mapped to 14 percent and 6 percent of the IPSFC project area, respectively; both EVT reside almost exclusively in map zone 21. Under the default LANDFIRE zone 21 mapping rules, over 70 percent of EVT 3050 is mapped to fuel model TU5 in the IPSFC project area and nearly 80 percent of EVT 3167 is mapped to TL5. Fuel model TU5 is designed to characterize fire behavior where the primary carrier of fire is heavy forest litter with a shrub or small tree understory (Scott and Burgan 2005) and predicts high flame lengths under typical fire weather conditions (Appendix A). We were unable to validate the TU5 fuel model assignment based on field observation, concluding that it would over predict flame length and rate of spread. Fuel model TL5 is designed to characterize fire behavior where the primary carrier of fire is a high load of forest litter, or light slash or mortality fuel. Although fuel model TL5 predicts lower flame lengths than TU5, we still felt it was not the best fit based on field observation and discussion of fire behavior with local fire and fuel specialists. After comparison with other timber-litter and timber-understory fuel models we determined that fuel model TU1 best represented the expected surface fire behavior in each of these EVT and mapped it as such. Fuel model TU1 is a “dynamic” fuel model, meaning that its herbaceous load shifts between live and dead depending on the live herbaceous moisture content. This allows us to model with better precision the availability, or more so, the lack thereof, the grass and sedge fuels that are very characteristic of these EVT.

The Douglas-fir EVT, 3235 (xeric montane Douglas-fir Forest) and 3166 (middle Rocky Mountain montane Douglas-fir forest and woodland), are mapped to 12 percent and 10 percent of the IPSFC project area, respectively; both reside almost exclusively in map zone 21. Across both EVTs, 43 percent of the area is mapped to fuel model TU5. Although more productive than the lodgepole pine sites, we felt fuel model TU5 would still over predict fire behavior in the Douglas-fir vegetation types and decided that fuel model TU1 best represented the range of expected fire behavior across a range of fire environment conditions.

Canopy base height is defined as the lowest height above the ground at which there is significant fuel to propagate fire vertically into the crowns of overstory trees. This variable is difficult to map at the landscape scale because it is not well related to characteristics that can be measured via remote sensing techniques. It is therefore best to assign canopy base height based on the range of local fire environment conditions—surface fuels, fuel moisture, slope, wind speed and direction—that lead to crown fire initiation. We modeled the torching index (the 20-foot wind speed at which crown fire initiation is possible), using fuel model TU1, across a range of slope and canopy cover values found within the IPSFC fire modeling area. With a canopy base height of 0.4 m the torching index ranged from 8 to 23 mph under the 97th and 90th percentile ERC based fuel moisture scenarios that would be used in the wildfire simulation modeling (Table 1). We concluded that this appropriately characterized the conditions required for crown fire initiation under current vegetation conditions in the lodgepole pine and Douglas-fir vegetation types.

The above adjustments were only applied to non-disturbed areas as mapped in the LANDFIRE fuel disturbance geospatial data. LANDFIRE uses a different set of mapping rules for areas that have been disturbed in the last ten years based on the disturbance type, severity, and time since occurrence; we did not critique or adjust these rules. We also made no adjustments canopy to bulk density as we felt crowning indices (the 20-foot wind speed at which active crown fire is possible) seemed reasonable.

Table 1. Comparison of torching index for fire behavior fuel model TU1 across a range of slope and canopy cover values and two weather scenarios.

		97 th Percentile Fuel Moisture Scenario					90 th Percentile Fuel Moisture Scenario				
		Percent Canopy Cover					Percent Canopy Cover				
		15	25	35	45	55	15	25	35	45	55
Percent Slope	5	10.5	14.8	18.0	19.4	22.9	11.6	15.1	18.3	19.7	23.3
	10	10.2	14.5	17.6	18.9	22.4	11.4	14.7	17.9	19.2	22.7
	15	9.8	13.9	16.8	18.1	21.4	10.9	14.1	17.1	18.4	21.8
	20	9.1	13.0	15.8	17.0	20.1	10.2	13.2	16.1	17.3	20.5
	25	8.1	11.9	14.4	15.5	18.3	9.4	12.1	14.7	15.8	18.7

2.1.2 Future Fuelscapes

In addition to assessing wildfire risk to structures under current conditions, an objective of this project was to assess alternative mitigation measures that proactively manage for a more fire-resilient landscape in the future. We developed and assessed three alternative future fuelscapes to accomplish this task.

The first fuelscape, represents a future condition where no vegetation or fuels management is conducted. Under this “No-action” scenario, we assumed an increase in canopy cover and canopy bulk density. We modeled these changes by increasing the current canopy cover by one, 10-percent, cover class and then recalculating canopy bulk density using the LANDFIRE methodology (Reeves et al. 2009). We assumed a

rise in canopy base height in lodgepole pine stands due to self-thinning and crown lift and therefore increased the current condition canopy base height from 0.4 m to 1 m. Conversely, we assumed a lowering of canopy base height in Douglas-fir stands due to an increase in biomass of shade-tolerant understory trees and therefore decreased canopy base height to 0.3 m. In both lodgepole pine and Douglas-fir we assumed a slight increase in surface fuel loading and changed fuel model TU1 to TU2. Fuel model TU2 has a higher load of 1- and 10-hr time-lag class fuels and a higher fuelbed depth, resulting in higher fire intensity and rate of spread than TU1.

Recent studies on wildfire exposure of residential areas suggest that treatments are most effective if placed in close proximity to those areas (Gibbons et al., 2012; Haas et al., 2015; Scott et al., 2015). We created two “treated” fuelscapes (NEAR and REMOTE) to assess the proximity of treatments on wildfire risk to residential structures in the IPSFC area. For both of the treated fuelscapes we set the post-treatment canopy cover to 25 percent in lodgepole pine and 35 percent in Douglas-fir (unless the existing condition values were already lower) and then recalculated canopy bulk density. We set the post-treatment canopy base height to 1 m in lodgepole pine and 0.6 m in Douglas-fir (unless the existing condition values were higher). We left the fire behavior fuel model as TU1. Areas of the fire modeling landscape that were not treated maintained the values of the “No-action” scenario discussed above.

The “NEAR” treatment scenario restricted treatment to National Forest System (NFS) land within two kilometers of the outermost residential structures and treated 9,826 ha of lodgepole pine and 2,472 ha of Douglas-fir. The “REMOTE” treatment scenario restricted treatment to NFS land 1-5 kilometers from the outermost residential structures and treated 8,663 ha of lodgepole pine and 2,613 ha of Douglas-fir. Both scenarios also included 2,239 ha of prescribed fire to represent management of conifer encroachment on aspen habitat types. These treatments were restricted to NFS land, greater than one kilometer from the outermost structures, and not to the west or southwest (direction of the prevailing wind) of the structures. Pixels selected for prescribed fire treatment were those mapped as a conifer or conifer-hardwood existing vegetation type and an aspen biophysical setting in the LANDFIRE data, thus representing an encroachment situation. In addition to being important habitat for a number of wildlife species, aspen can also act as a barrier to crown fire spread.

The end point of the scenarios is meant to estimate a point in time where the lodgepole pine stands within the IPSFC project area would be reaching around 80 years of age (roughly the year 2055). These scenarios were intentionally designed to assume an increase in fire hazard in untreated areas, as described above, however stand-level analysis indicates there are many variables that will dictate the level of future fire hazard (Schantz et al. 2016). As such, the future scenarios should be thought of as one of many potential future situations. There are several other caveats to the future fuelscapes that should be considered, including, but not limited to; we assume no natural disturbance from wildfire, insects, or disease between now and circa 2055; the amount of treatment (based on estimates by the Ashton/Island Park District Ranger) and the location of treatments may be affected by socio-political, environmental, or economic factors not considered in this analysis; we assume the modeled post-treatment conditions can be achieved; and we assume treatments implemented early in the scenario would be maintained through the circa 2055 end point. Despite these potential limitations, the relative comparison of current and potential future conditions can provide useful information for the mitigation of wildfire risk.

2.2 Historical wildfire occurrence

Fire occurrence data were provided by the local units; in addition, a national fire occurrence database (Short 2013) produced for Fire Program Analysis (FPA), wildfire polygons from the Wildland Fire Decision Support System (WFDSS), and regional databases were consulted to attempt to compile

complete records. Fire occurrence data prior to 1970 are generally not as complete as later records. Although numerous fires have occurred within the project area, most have been less than 100 acres.

There are numerous contributing factors affecting fire growth, management, and occurrence. Fire growth can be influenced by weather patterns, flammability of vegetation, horizontal and vertical fuel arrangement, topography, and landscape vegetation pattern as influenced by past disturbances and activities. Weather patterns may or may not be conducive for large fire growth; for example, some areas are consistently dry during the fire season while other areas are prone to numerous frontal passages that may increase the potential for fire growth. The flammability of vegetation is related to fuel moisture; certain compounds found within plants can also increase flammability. Horizontal and vertical fuel arrangement directly affects how a fire burns through an area. Topography affects fire spread patterns and directly influences fire behavior. Past disturbances alter vegetation structure and can also affect species composition and size class distribution. Fire management is dictated by standards and protocols within the land management plan; the fire management plan offers a more detailed guide. Wildfires may be managed for multiple resource benefit (formerly known as prescribed natural fire and wildland fire use) in identified areas if prescription criteria are met; adjacent Yellowstone National Park has had a longstanding program that allows management of wildfires to achieve resource benefits. Fire occurrence is heavily influenced by lightning patterns and patterns of human use which generally concentrate human-caused ignitions close to infrastructure.

Most fires in the project area occur in July and August and the greatest number of acres has historically burned during these months as well. Although the general fire season in this area ranges from May 1 through October 15, July and August represent the height of the fire season. While the trends in fire cause are similar between Island Park and Hebgen Lake, Island Park has far more ignitions caused by lightning (cause code 1) while Hebgen Lake has a higher proportion of human-caused ignitions (cause code 4 = campfires, cause code 9 = miscellaneous).

Historical annual area burned was calculated for the three fire program units (FPU) within the project area, including 1) GB_ID_004, Eastern Idaho, 2) NR_MT_003, Headwaters, and 3) NR_MT_005, Greater Yellowstone Area North. The Headwaters FPU is not within the project area but is part of the analysis area. Historical area burned for these three FPUs totaled 26,746,845 ac. Based on actual fire occurrence data (Short 2013) from 1992-2011, the average annual burn probability is 0.00396 (1-in-253 chance of burning) and the maximum annual burn probability is 0.01374 (1-in-73 chance of burning) for the three combined FPUs. This information was used to compare with fire occurrence simulation results.

2.3 Historical weather

For ERC inputs we used data for the Island Park RAWS (NWS ID#102105) for the period 1992 – 2012. For wind speed and direction inputs we used the 10-minute average wind speed data for the Island Park RAWS for the period 1999-2014 and the Red Rock RAWS (NWS ID#245410) for the period 1988-2014. We used hourly observations for the period 1100 – 2000 hours each day.

For dead fuel moisture content, we allowed FSim to choose default values from the FRISK for all fuel models except TU1 and TU5. For those fuel models, we added 2 percentage points to the default values to better represent the dead fuel moisture beneath a forest canopy. For live herbaceous and live woody fuel moisture contents we used values developed by the Firelab in its initial work on the study area. The final FMS values used for the 80th, 90th and 97th ERC percentile bins is shown below (Table 2).

Table 2. Live and dead fuel moisture content values used for each ERC percentile bin.

ERC percentile bin	Fuel model	1-h MC	10-h MC	100-h MC	Live herbaceous MC	Live woody MC
80 th	TU1, TU5	6	8	12	70	100
	All others	4	6	12	70	100
90 th	TU1, TU5	6	7	10	60	90
	All others	4	5	10	60	90
97 th	TU1, TU5	5	6	9	50	80
	All others	3	4	9	50	80

2.4 Structure location and susceptibility

We made use of a dataset regarding residential structure location and susceptibility that was generated during an earlier phase of the IPSFC project. A total of 4,007 residential structures were geolocated and rated, using RedZone™ software, for 36 factors affecting the susceptibility of a residential structure to wildfire, including vehicle access, defensible space, structure characteristics, and the presence of special firefighting hazards, such as above-ground propane tanks near the structure, that could limit firefighting operations during a wildfire. The distribution of susceptibility scores was slightly left-tailed (Figure 3, inset histogram). The maximum susceptibility score in the dataset was 90 (mean = 52; median = 54; mode = 56). We used this structure susceptibility rating in a dynamic response function as described in the next section.

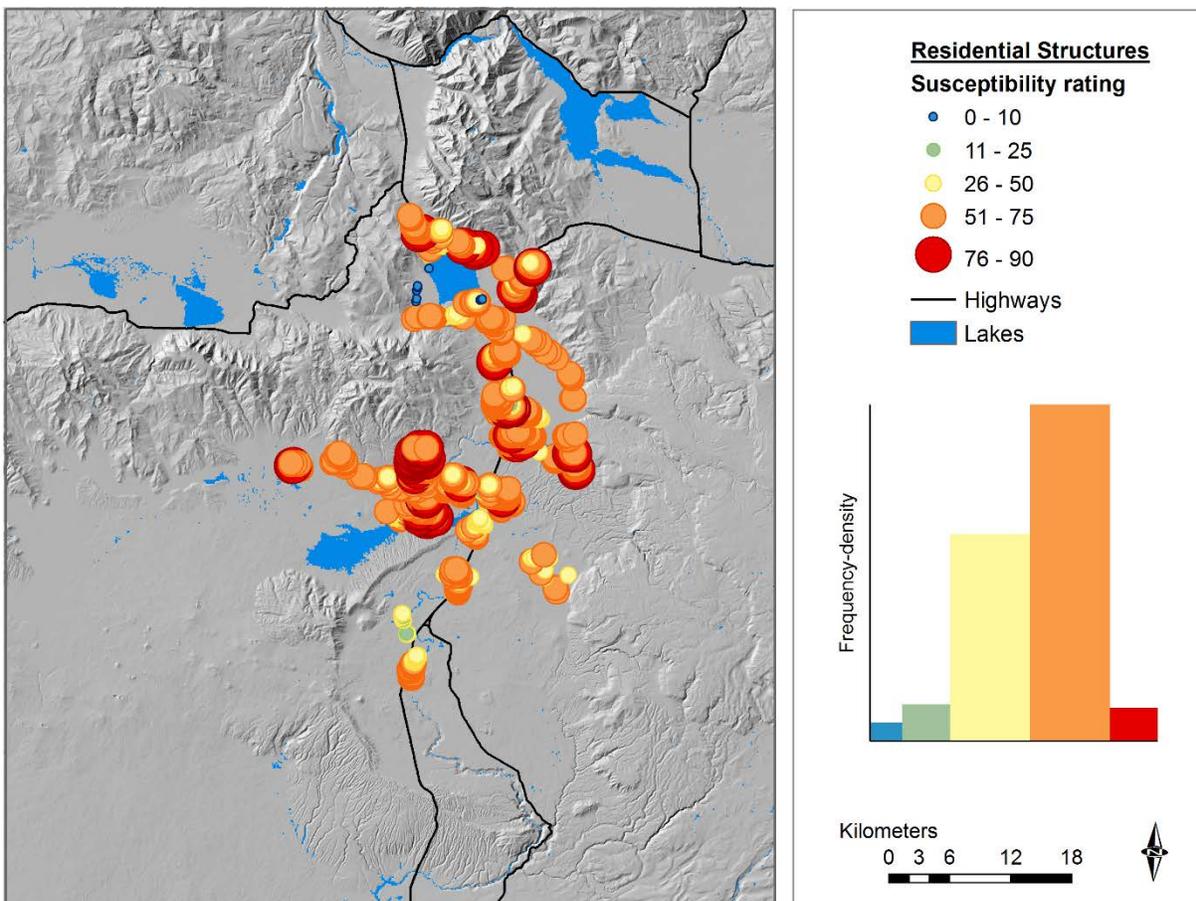


Figure 3. Location of susceptibility rating of 4,007 residential structures within the IPSFC project area.

2.5 Response functions

A response function describes susceptibility as the net change in value (*NVC*) of the HVRA should it experience a fire of a given intensity (Calkin et al. 2010; Scott et al. 2013). Response functions can accommodate both positive and negative value change. A response function value of -100 indicates the greatest possible loss of value, whereas +100 would indicate the greatest possible increase in value, or benefit. This paper focuses on wildfire risk to residential structures, which do not benefit from wildfire of any intensity.

Rather than apply a single response function to all structures, as is typical when using a more generalized characterization of residentially developed areas, we generated a dynamic response function that assigns each structure a unique response function based upon its unique susceptibility score. To do so we designed two response functions—one that would apply to the least-susceptible structure in the dataset and one for the most susceptible (Table 3). The dynamic response function value for each FIL is scaled linearly between the value for the structure with the lowest susceptibility score (0) and the highest (90). For example, a structure with a susceptibility score of 55—very near the center of the distribution—would have an effective response function value 61% of the way (55/90) between the values for the lowest and highest scores.

Table 3. Dynamic response function for damage to residential structures as a function of fire intensity (flame length) and structure susceptibility rating.

Structure Susceptibility Score	Fire Intensity Level (flame-length class)					
	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6
Lowest (0)	0	0	-10	-20	-40	-60
Highest (90)	-80	-90	-100	-100	-100	-100
Example (55)	-49	-55	-65	-69	-77	-84

The response function values in Table 3 can be taken to represent the equivalent chance of complete loss of structure value. Residential structures typically suffer complete loss of value if it suffers any loss at all (Cohen and Butler 1996), so it may be more convenient to think of *NVC* as the chance of the residential structure burning. For example, a response function value of -80 means the equivalent of 80 percent chance of 100% loss. Such a result could also come about from a 100 percent chance of 80% loss of value, or any number of other combinations. We made the calculations of *cNVC* by sampling the six *FLP_i* rasters produced by FSim at each structure location. That information, along with the susceptibility rating for the structure, enables calculation of *cNVC* for each structure. Because the response function value represents the equivalent chance of 100% loss, *cNVC* has the same interpretation; it is simply the weighted mean of the response function values, with *FLP_i* providing the weighting factors. We term this probability-weighted metric the equivalent number of structures affected.

3 Analysis Methods and Results

3.1 Wildfire hazard

We used the FSim large-fire simulator (Finney et al. 2011) to estimate annual burn probability (*BP*) and conditional flame-length probability (*FLP_i*) across the project area at a cell size of 120 m. FSim is a comprehensive wildfire occurrence, growth and suppression simulation system that integrates models of fire weather, occurrence, growth (Finney 1998, 2002) and containment in order to simulate wildfire ignition and growth for thousands of fire seasons. We used FSim to simulate 10,000 fire seasons. The results of these simulations are used to estimate, in raster format, the *BP* and *FLP_i* across the landscape. FSim *BP* is the annual probability of burning; it is estimated by dividing the number of simulated fire seasons that burned each pixel by the total number of simulated fire seasons. *FLP_i* is the conditional probability of wildfire burning in the *i*th flame-length category, given that a wildfire occurs at all (Table 4). At a given pixel, *FLP_i* values across the range of flame-length categories necessarily sum to one. FSim results have been used for spatial risk analyses in a number of contexts (Calkin et al. 2010, Scott et al. 2012a, 2012b; Thompson et al. 2011, 2013a, 2013b).

Table 4. Flame length ranges associated with the six fire intensity levels (FILs).

Fire Intensity Level (Flame-length class)	Flame-length range (ft)
FIL1	0-2
FIL2	2-4
FIL3	4-6
FIL4	6-8
FIL5	8-12
FIL6	12+

In addition to the *BP* and *FLP_i* raster format results, FSim generates polygons, in ESRI Shapefile format, representing the final perimeter of each simulated wildfire. An attribute table specifying certain characteristics of each simulated wildfire—its start location and date, duration, final size, and other characteristics—is included with the shapefile. However, the fire intensity (flame-length class) that occurred at each pixel during each individual wildfire is not recorded. The only fire intensity information available from FSim is the *FLP* grids and the resulting conditional flame length (*CFL*) grid produced from them. *CFL* does not represent an individual fire, but instead integrates the results of all fires that burned a pixel. Fires occurring during the same fire season can be identified through attributes assigned to each fire in the shapefile, so that the cumulative area burned during an entire fire season can be output as well.

FSim requires a number of spatial and tabular inputs. The spatial inputs include a landscape file (LCP), a raster representation of fuel, vegetation and topography across the fire simulation area. We used LANDFIRE version 1.2 as the source for the LCP (Ryan and Opperman 2013). For historical fire occurrence inputs we used the Short (2013) Fire Occurrence Database (FOD), first edition, which covers the 20-year period 1992-2011. Later editions of the FOD were not available at the time of the analysis. We used a large-fire size threshold of 100 ha.

FSim's *BP* and *FLP* results for a given pixel are sensitive to the fuel conditions at each pixel. To mitigate fine-scale spatial inaccuracies in our source data (fuelscape, fire modeling results, and structure locations), we smoothed the *BP* and *FLP* results using a two-step process. First, we used the Focal

Statistics tool in ESRI’s ArcGIS to calculate the mean *BP* and *FLP*, of burnable pixels only, within a 3-pixel by 3-pixel moving window. This step leaves pixels identified as nonburnable in the 120-m resolution fuelscape with a *BP* of 0. This is a potential problem because, especially when resampling from 30-m (native Landfire) resolution data, a residential structure could be located on a 120-m pixel mapped as nonburnable when in fact it is surrounded by fuel. Thus, in a second step, we calculated the mean *BP* and *FLP*, this time including zero values for nonburnable pixels, in a 5-pixel x 5-pixel moving window. This step “backfills” nonburnable pixels within 240 m of a burnable pixel with low but nonzero values based on the surrounding pixels, creating a gradual transition from a non-zero probability along the edge of a nonburnable feature (such as a rock outcropping, waterbody, or town) to a zero probability in the center. This method is in contrast to previous community wildfire risk analyses, where population location was distributed within a given neighborhood to handle the spatial uncertainty associated with both fire behavior results and population/structure locations (Haas et al. 2013).

FSim simulated a total of 80,924 individual wildfires over 10,000 iterations. However, for the current-condition simulation, only 23,520 of those wildfires reached the 100-ha large-fire size threshold, for a mean of 2.35 large-fire occurrences per year within the 2.2-million ha fire modeling landscape. The simulated large fires burned a total of 78.6 million ha, for a mean of 7,860 ha per year, and a mean large-fire size of 3,340 ha per large-fire occurrence. The simulated mean annual *BP* was 0.00357, very near the historical mean of 0.00396.

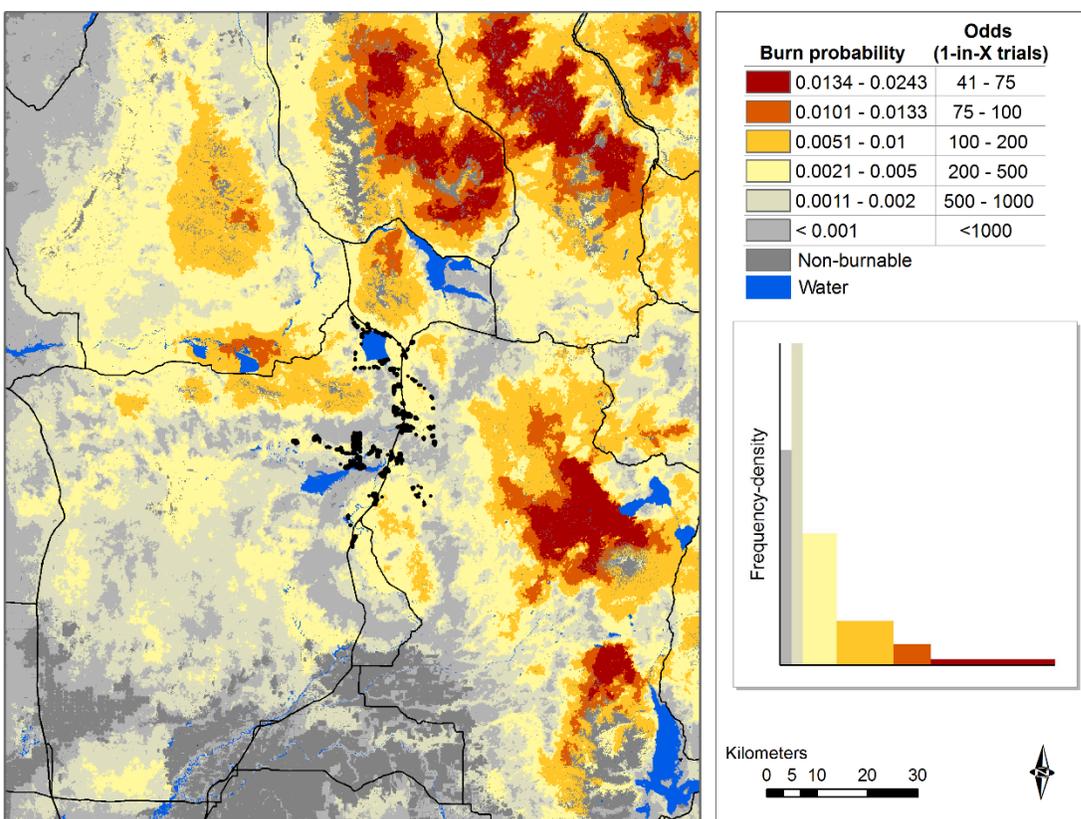


Figure 4. Current-condition burn probability.

Residential structures in the IPSFC are located in a relatively low-probability portion of the landscape, with much higher likelihoods to the east and north (Figure 4). Fire intensity is highly variable throughout

the portion of the landscape where the residential structures are located. Flame lengths tend toward the lower flame length classes (≤ 6 feet) with less likelihood of flame lengths greater than 6 feet (Figure 5).

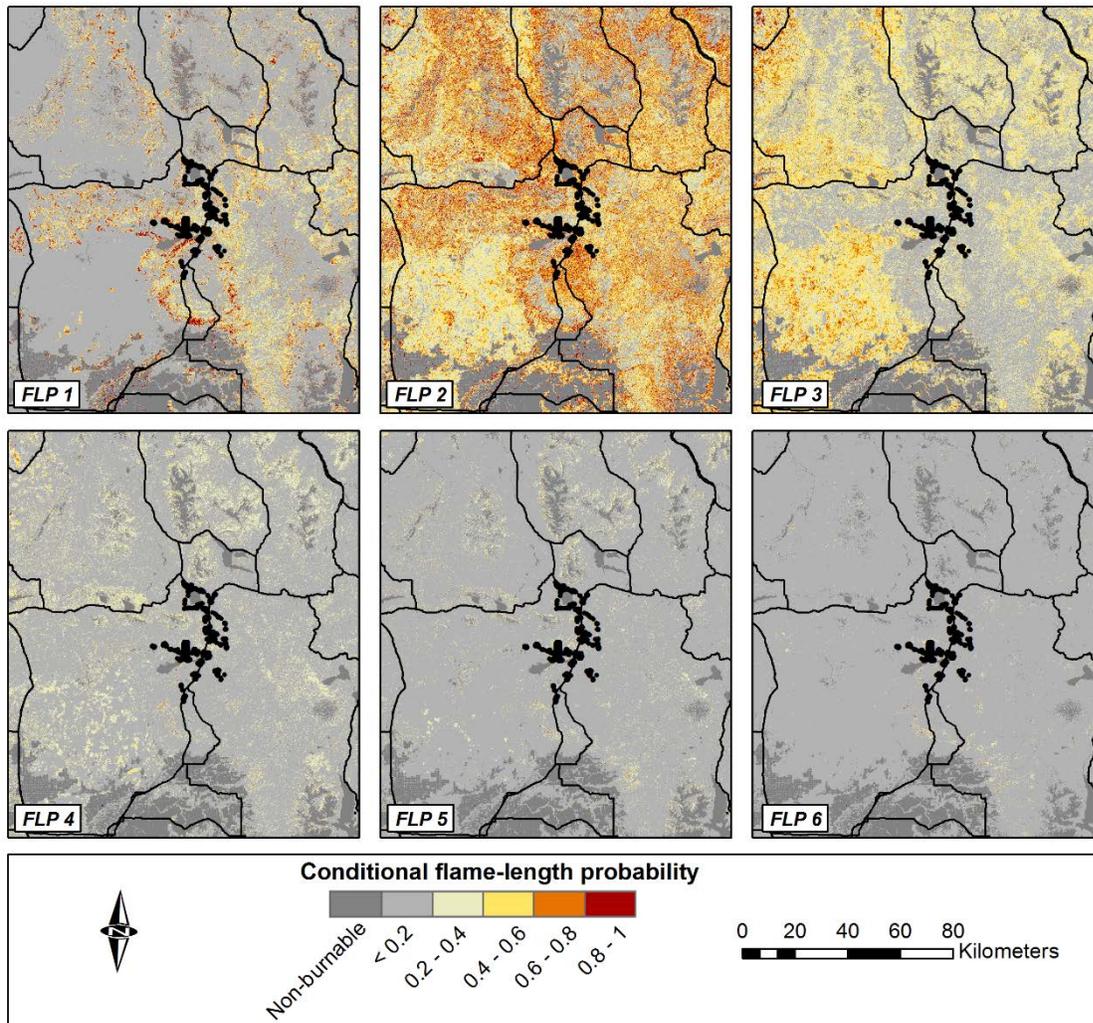


Figure 5. Current-condition six-panel FLP map.

3.2 Risk to residential structures

We used the smoothed *BP* and *FLP* raster outputs (see section 3.1) along with the response functions (Table 3, Section 2.5) to calculate *cNVC* and *eNVC* for every residential structure, using the equations in Section 1.3.

Conditional *NVC* varied widely across the study area (Figure 6) due to variability in structure susceptibility and fire intensity. Structure susceptibility is not an inherently spatial characteristic, so *cNVC* can vary widely even between adjacent structures exposed to similar flame lengths. The *BP* at a structure is not included in this *cNVC* result; *BP* is only a factor in *eNVC*. Figure 7 displays *eNVC* results on a scatterplot combining *cNVC* (consequence) with *BP* (likelihood), where each point represents an individual structure. The curving reference lines represent equal *eNVC* values corresponding to the 33rd, 67th, and 95th percentiles, and provide a useful classification of the most at-risk structures. In the upper right corner of Figure 7 you see the 5% most at-risk structures above the 95th percentile line, followed by the top third (above the 67th percentile line) and the top two-thirds (above the 33rd percentile line). Ideal

risk mitigation would shift the whole plot down and left—from the highest likelihood/highest consequence to the lowest likelihood/lowest consequence.

We then used the simulated fire perimeters to calculate the number of structures exposed to and affected by each simulated wildfire during a season. To do that, we merged the simulated fires that occurred during an iteration (one iteration represents a whole fire season) into a single multi-part polygon and then tallied, within each multi-part polygon, the number of structures. This tally represents the number of structures exposed to a wildfire during each simulated wildfire season. We also summed the *cNVC* values for each structure within each perimeter and divided by 100, which represents the number of structures affected. These exposure and effects values associated with each perimeter permit the firehed analysis presented in section 3.2.1 and the extreme value analysis in section 3.2.2.

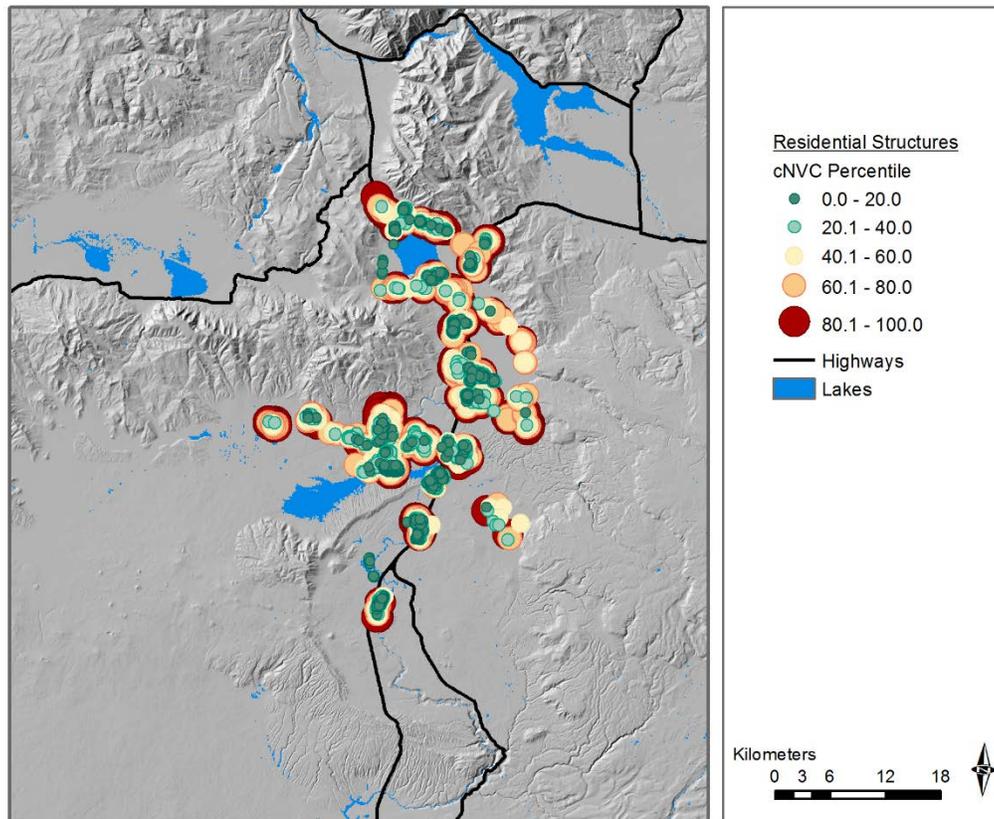


Figure 6. Conditional net value change (*cNVC*) for residential structures in the IPSFC.

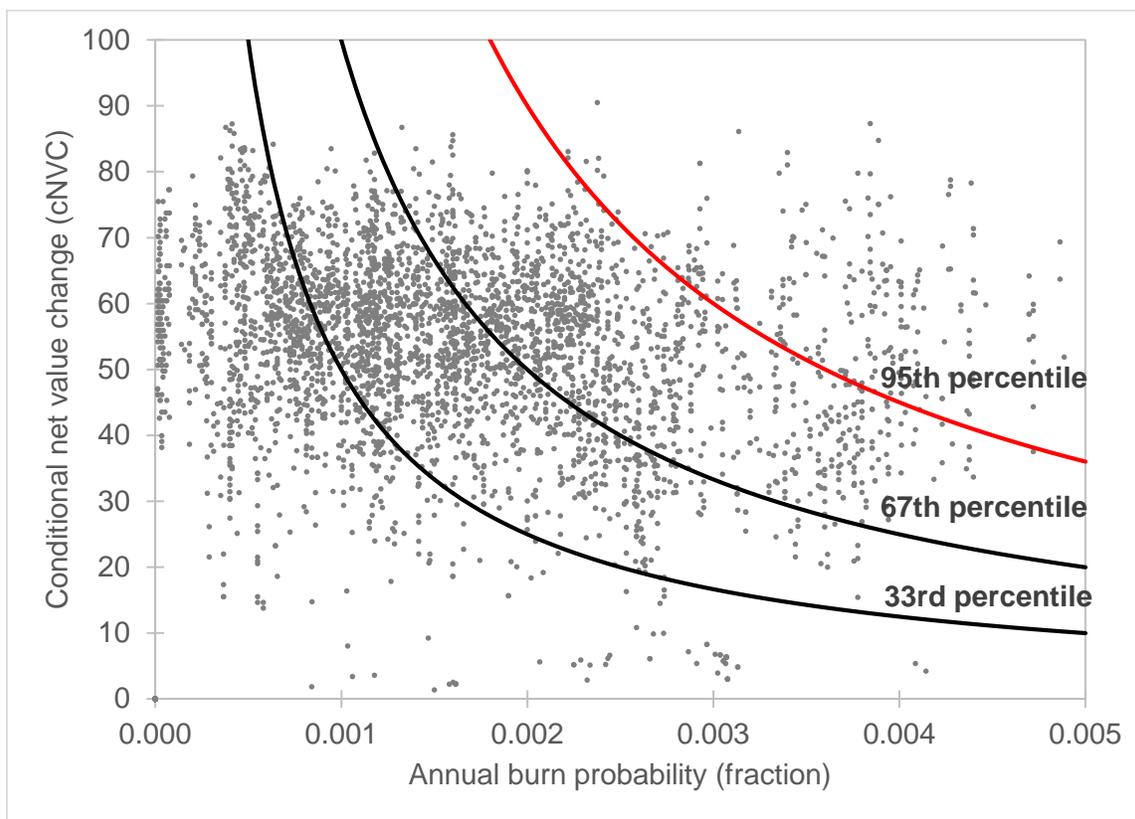


Figure 7. Scatterplot of burn probability versus conditional net value change at each of 4007 residential structures in the IPSFC project area. Reference lines indicate percentile values of expected net value change.

3.2.1 Fireshed analysis

We delineated the biophysical fireshed by first plotting the ignition locations of all simulated fires that exposed at least one structure. We then found the convex hull that bounds those selected ignition points, and then buffered that convex hull by an arbitrary 5 km to account for uncertainty about the outer limit (Figure 8). Although simulated fires started throughout the study area, and also throughout the fireshed, it is apparent that the majority of wildfires that exposed structures originated relatively near those structures (Figure 8). To quantify that observation, we divided the fireshed into zones based on the distance from any structure, and summarized the propensity of the different zones to produce fires that expose and effect residential structures.

Although fires can reach at least one structure from anywhere within the fireshed, the data summary confirms that fires starting relatively close to the structures tend to expose a greater number at one time (Table 5). For example, 93% of the total structures exposed and affected annually are by ignitions within 7 km of a structure. Within the fireshed, the proportion of ignitions that reach at least one structure is greatest (81.4%) within the first 1-km zone, followed by 42.2% in the 1-3 km zone, 15.9% in the 3-5 km zone, and 6.7% in the 5-7 km zone. For all zones greater than 7 km from any structure, the fraction of large-fire ignitions that reached any structure was 5% or less. All ignitions capable of reaching a structure originated within 25 km of a structure. The total expected number of structures exposed annually is 6.20 and the value change (*eNVC*) to those structures is 3.18 (Table 5). In this study, effects analysis results mirrored exposure results, with the cumulative proportions of structures exposed versus structures affected matching almost exactly.

To illustrate the propensity for fires to damage structures, we normalized the annual exposure and effects to structures to a unit area (1000 ha), by distance zone. This normalization is required because the area varies among the distance zones (Table 5). Figure 9 compares two risk-source maps, again highlighting both the related outcomes of exposure and effects analysis in this example and the likelihood of ignitions nearest structures to cause damage. Generally, the propensity for a wildfire to expose or affect structures is greatest very near the structures and decreases significantly further out.

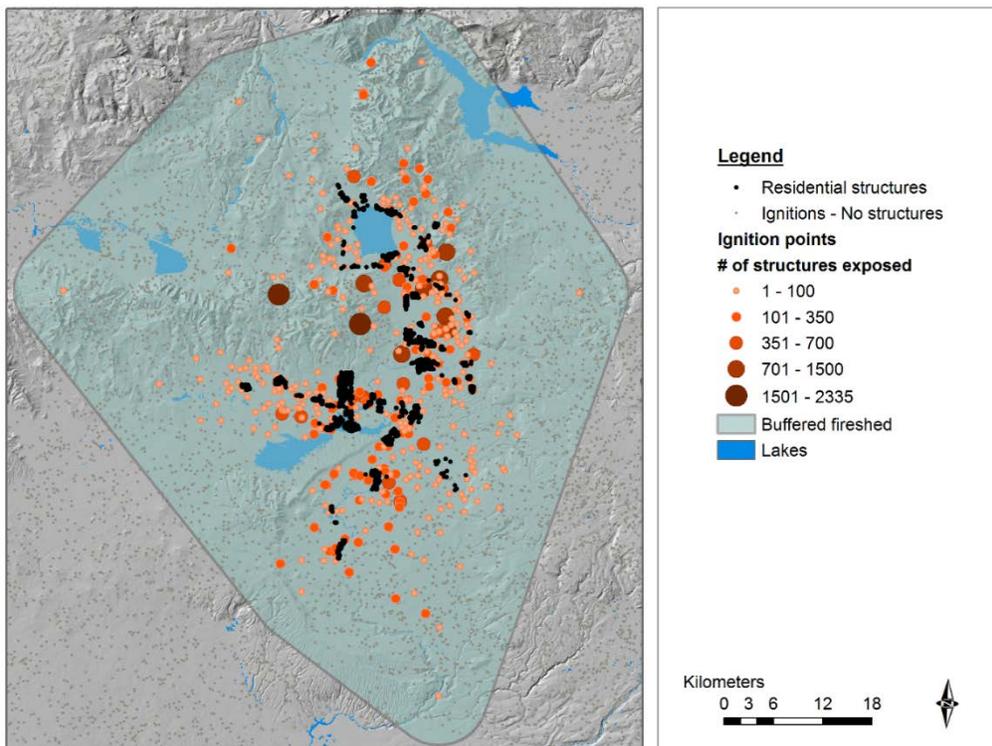


Figure 8. Start locations of simulated fires in the IPSFC project area symbolized according to the number of structures affected by the fire.

Table 5. Summary of risk-source to residential structures within the IPSFC fireshed based on distance from a structure. Distance zone width increases beyond 7 km because of the relatively small number of fires that reach a structure from beyond that distance.

Distance from structure to ignition (km)	Distance-zone area (ha x 1000)	Fraction of large fires reaching at least one structure	Expected annual structures exposed	Proportion exposed (%)	Expected annual structures affected	eNVC proportion (%)
0-1	32	81.4	2.15	34.7	1.13	35.5
1-3	52	42.2	2.20	35.5	1.11	34.9
3-5	39	15.9	1.00	16.1	0.51	16.2
5-7	37	6.69	0.42	6.72	0.21	6.50
7-10	56	5.06	0.35	5.70	0.18	5.64
10-15	93	1.13	0.07	1.19	0.04	1.22
15+	73	0.36	0.005	0.08	0.002	0.08
TOTAL	381		6.20		3.18	

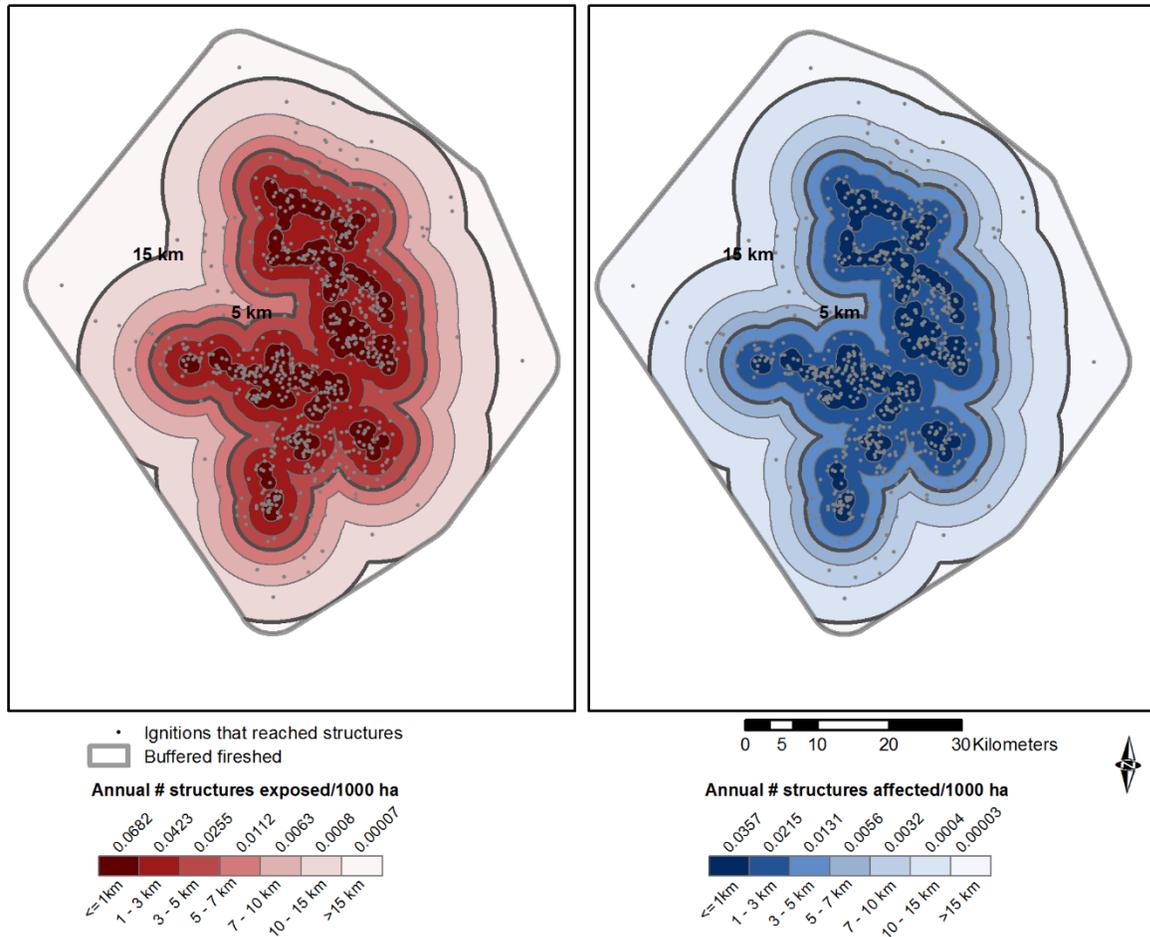


Figure 9. Annual number of structures exposed and affected by wildfire per 1000 ha by fires originating various distances from a structure.

3.2.2 Exceedance probability

We generated exceedance probability curves representing the annual probability that a wildfire will exceed a given number of structures exposed or equivalent structures affected. The EP curves are plotted from these results (Figure 10). As must be the case, number of structures exposed is greater than or equal to the equivalent number of structures affected for any level of exceedance probability. The maximum exceedance-probability value for both curves is 5.4 percent, meaning that the annual probability of exposing at least one structure to a large wildfire is 5.4 percent. There is a 1 percent chance annually of exposing at least 125 structures to a large wildfire, which represents a 100-year event in terms of structures exposed. Given the response functions, susceptibility of the structures, and intensity where the structures occur, there is a 1 percent chance annually of causing the equivalent loss of 59 structures.

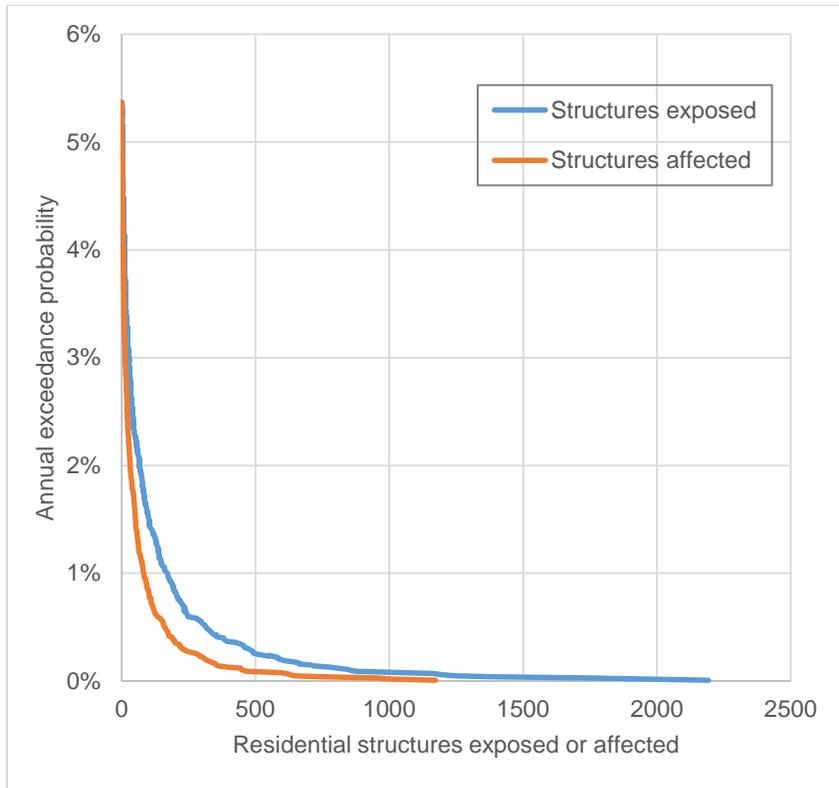


Figure 10. Exceedance probability curves for structures exposed and structures affected for the current-condition landscape.

4 Future hazard, exposure and effects

We used the baseline current-condition simulation to perform simulations for the three alternative fuelscapes described in section 2.1.2 above. These follow-on simulations used the exact same fire start locations and daily ERC streams (i.e., weather scenarios) as the current-condition simulation so that differences among them can be attributed to the fuelscapes rather than to stochasticity. The No-action fuelscape experienced 30% more large-fires than the current condition (Table 6), and those grew considerably larger (86%) than on the current condition landscape, resulting in much greater annual area burned (143%). Compared to the No-action scenario, the NEAR scenario reduced the annual number of large fires only 0.3%, from 3.063 fires/yr to 3.053 fires/yr. Mean large-fire size was reduced from 6,228 ha to 6,134 ha, a reduction of 1.5%. The overall annual area burned was reduced by 1.8% from 19,077 ha/yr to 18,727 ha/yr, representing an avoided “loss” of 350 ha/yr to wildfire. The REMOTE scenario results were similar to the NEAR scenario in terms of the number, annual area burned, and mean fire size of large fires.

Table 6. Summary of landscape-scale effects on simulated fire occurrence.

	Number of large fires per year (fires/yr)	Annual large-fire area burned (ha/yr)	Mean large-fire size (ha/fire)
Current condition	2.352	7,859	3,341
No-action 2055	3.063	19,077	6,228
NEAR 2055	3.053	18,727	6,134
REMOTE 2055	3.055	18,731	6,131

The treatment scenarios are primarily designed to mitigate wildfire threat to structures, so it is appropriate to summarize hazard where the structures exist (Table 7). The mean burn probability increased from 0.0016 (1-in-625) under the current condition to 0.0091 (1-in-110) under the No-Action scenario at the structure locations and from 0.0021 (1-in-476) to 0.0103 (1-in-97) within 500 m of structures. Mean conditional flame length increase by 2.9% at the structure locations and 5.1% within 500 m of structures. The NEAR scenario resulted in a mean burn probability of 0.0069 (1-in-145) at the location of the structures and 0.0078 (1-in-128) within 500 m of the structures—a reduction in mean burn probability from the No-action scenario. The REMOTE 2055 scenario had less of an effect on reducing burn probability than the NEAR scenario, with a mean burn probability at structure locations of 0.0082 (1-in-122) and 0.0093 (1-in-108) within 500 m of structures. Mean conditional flame length decreased by 11.1% at structure locations and 9.8% within 500 m of structures in the NEAR scenario compared to No-action. The REMOTE scenario resulted in decreases in mean conditional flame length of only 2.8% at the structure locations and 2.4% within 500 m compared to No-action.

Table 7. Summary of local-scale effects of the current condition and three future fuelscapes on wildfire hazard.

	Mean burn probability		Mean conditional flame length	
	At each structure location	Within 500 m of any structure	At each structure location	Within 500 m of any structure
Current condition	0.0016	0.0021	3.5	3.9
No-action 2055	0.0091	0.0103	3.6	4.1
NEAR 2055	0.0069	0.0078	3.2	3.7
REMOTE 2055	0.0082	0.0093	3.5	4.0

The mean number of structures exposed to wildfire per year increased from 6.2 to 36.6 between the current condition and No-action fuelscapes (Table 8). The mean number of structures affected per year by wildfire, meaning they were exposed to fire intensity levels for which they are susceptible (see Table 3), increased from 3.18 to 19.8. Compared to the No-action scenario, the NEAR scenario reduced the annual number of structures exposed by 24.3%, from 36.6 per year to 27.7 per year. The mean number of structures affected was reduced from 19.8 to 14.5, a reduction of 26.8%. The REMOTE scenario was less effective, reducing the number of structures exposed by 8.5% and the number of structures affected by 9.6%.

Table 8. Mean number of structures exposed and affected for the current condition and three future fuelscapes.

	Structures exposed per year	Structures affected per year
Current condition	6.20	3.18
No-action 2055	36.6	19.8
NEAR 2055	27.7	14.5
REMOTE 2055	33.5	17.9

5 Summary and Discussion

This report presents results of a comprehensive assessment of wildfire risk to residential structures in the communities of Island Park, ID. The assessment builds off previous work done by Hollingsworth and Parsons (2013) and includes a comparison of alternative risk mitigation strategies on future residential wildfire-resilience. The fundamental components of wildfire risk to residential structures are the likelihood of structure exposure, the fire intensity to which the structures are exposed should a wildfire occur, and the susceptibility of the structures to damage from wildfire. Likelihood of exposure and fire intensity were estimated through the use of wildfire simulation modeling and geospatial data representing the location of each of 4,007 residential structures in the Island Park area. The susceptibility of these structures to damage from wildfire was estimated by developing dynamic response functions based on each structure's "hazard" rating determined through application of RedZone™ software. We quantified a range of risk-based metrics that can provide complementary pieces of information on structure exposure and potential loss.

Historical wildfire data from the 20-year period 1992-2011 were used to calibrate our wildfire simulations such that our current-condition simulated wildfires are characteristic of the location, frequency, and size of actual wildfires. The simulated mean *BP* in the modeling area was 0.00357 (1-in-280), very near the previous 20-year mean of 0.00396 (1-in-253). FSim simulated 23,520 wildfires, 100 ha or greater in size, over 10,000 simulations for a mean of 2.35 large-fire occurrences per year within the 2.2 million ha fire modeling landscape. However, the residential structures are located in a relatively low-probability portion of the landscape, with much higher likelihoods to the east and north (Figure 4). This is not surprising given that larger fires lead to higher burn probabilities (more pixels have the opportunity to burn), and the majority of the residential structures are located in the lodgepole pine or grass/shrub vegetation types of the caldera with light fuels and little topographic relief resulting in lower flame lengths, rates of spread and effective suppression under all but the most extreme weather events.

Under the current condition, *cNVC* varied widely due to variability in structure susceptibility and predicted fire intensity at the structure locations (Figure 6). The *cNVC* metric does not include the probability of burning, rather it measures the potential change, conditional on a fire occurring at the

location of the structure. Thus, risk mitigation measures aimed at reducing the potential fire intensity at the location of the structure and/or the susceptibility of the structure to damage from fire will lower *cNVC* regardless of its probability of exposure. Breaking these wildfire risk assessment results down into the component parts of the wildfire risk triangle (Scott et al. 2013)—likelihood, intensity, and susceptibility—informs homeowners, planners and land management agencies about which types of mitigation activities are most appropriate and who can most readily implement those types of activities (Calkin et al. 2014). For example, alteration of landscape *BP* values (likelihood) may require large landscape-scale treatments falling under the purview of land management agencies, however implementation of these treatments is often constrained for a variety of reasons (Collins et al. 2010; North et al. 2015). Reducing structure susceptibility and conducting fuel reduction (reducing intensity) in the vicinity of structures, on the other hand, is the responsibility of individual homeowners.

Under the current condition, there is a 5.4 percent chance of exposing at least one structure to a large wildfire in any given fire season. There is a 1 percent chance annually of exposing at least 125 structures to a large wildfire, which represents the “100-year event” in terms of structures exposed. However, the propensity for a wildfire to expose structures varies based on ignition location—fires starting relatively close to the structures tend to expose a greater number at one time. This may seem like a common sense conclusion, however, “fuel treatments” are often placed in areas remote from the things they are intended to protect (Schoennagel et al. 2009). Within the residential structure fireshed (Figure 8), 81.4% of the ignitions within 1 km of the structures reached at least one structure. The number of ignitions reaching at least one structure drops by nearly half (42.2%) when the ignition location is between 1 and 3 km from the structures.

Given the propensity for a wildfire to expose structures under the current condition was greatest when those fires were very near the structures and decreased significantly further out, we compared three alternative management scenarios using the same ignition locations and weather scenarios of the current condition: no-action, application of fuel treatments on NFS land within 1-2 km of the residential structures, and application of fuel treatments on NFS land 2-5 km from the residential structures.

The No-action scenario represented a more hazardous fuelscape and resulted in more and larger fires than under the current condition fuelscape (Table 6). The mean burn probability increased at the structure locations from 0.0016 (1-in-625) under the current condition to 0.0091 (1-in-110) under the No-Action scenario. Mean conditional flame length remained similar raising from only 3.5 to 3.6 feet. The increase in burn probability resulted in significantly higher structure exposure, from a mean of 6.2 structures per year under the current condition to 36.6 per year under the No-action scenario. Of those exposed, the mean number of structures affected increased from 3.18 per year to 19.8 per year.

Both the NEAR and REMOTE treatment scenarios reduced the number of structures exposed and effected by wildfire compared to the No-action scenario. Placing treatments closer to the communities resulted in a greater reduction of mean annual structures exposed (from 36.6 to 27.7) vs. placing treatments further from the communities (36.6 to 33.5). The proportion of structures affected mirrored that of the structures exposed; reducing the mean number of structures affected from 19.8 under the No-action scenario to 14.5 and 17.9 under the NEAR and REMOTE scenarios, respectively. These results suggest that risk-mitigation measures that focus on reducing fuels near residential structures and decreasing the susceptibility of those structures to wildfire may yield greater overall risk reduction than strategies attempting to limit the transmission of wildfire to residential areas from more remote areas.

6 References

- Ager, A. A., Day, M. A., McHugh, C. W., Short, K., Gilbertson-Day, J., Finney, M. A., & Calkin, D. E. 2014. Wildfire exposure and fuel management on western US national forests. *Journal of Environmental Management* 145, 54-70.
- Calkin, D. E., J. D. Cohen, M. A. Finney, and M. P. Thompson. 2014. How risk management can prevent future wildfire disasters in the wildland-urban interface, *Proceedings of the National Academy of Sciences*. 111(2), 746-751.
- Calkin, David E.; Ager, Alan A.; Gilbertson-Day, Julie, eds. 2010. Wildfire risk and hazard: procedures for the first approximation. Gen. Tech. Rep. RMRS-GTR-235. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.
- Cohen, J. D., & Butler, B. W. 1996. Modeling potential structure ignitions from flame radiation exposure with implications for wildland/urban interface fire management. In *Thirteenth Fire and Forest Meteorology Conference*, Lorne, Australia.
- Collins, B. M., Stephens, S. L., Moghaddas, J. J., & Battles, J. 2010. Challenges and approaches in planning fuel treatments across fire-excluded forested landscapes. *Journal of Forestry*, 108(1), 24-31.
- Fairbrother, A.; & Turnley, J. G. 2005. Predicting risks of uncharacteristic wildfires: application of the risk assessment process. *Forest Ecology and Management*. 211(1): 28-35.
- Finney, Mark A. 1998 (Revised 2004). FARSITE: Fire Area Simulator—model development and evaluation. Res. Pap. RMRS-RP-4, Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.
- Finney, M. A. 2002. Fire growth using minimum travel time methods. *Canadian Journal of Forest Research*, 32(8), 1420-1424.
- Finney, M. A. 2005. The challenge of quantitative risk analysis for wildland fire. *Forest Ecology and Management*, 211(1), 97-108.
- Finney, M. A.; McHugh, C. W.; Grenfell, I. C.; Riley, K. L.; Short, K. C. 2011. A simulation of probabilistic wildfire risk components for the continental United States. *Stochastic Environmental Research and Risk Assessment*. 25: 973-1000.
- Gibbons, P., van Bommel, L., Gill, A.M., Cary, G.J., Driscoll, D.A., Bradstock, R.A., Knight, E., Moritz, M.A., Stephens, S.L., Lindenmayer, D.B., 2012. Land management practices associated with house loss in wildfires. *PloS One* 7 (1), e29212.
- Haas, J. R., Calkin, D. E., & Thompson, M. P. 2013. A national approach for integrating wildfire simulation modeling into Wildland Urban Interface risk assessments within the United States. *Landscape and Urban Planning*, 119, 44-53.
- Haas, J. R., D. E. Calkin, and M. P. Thompson 2015. Wildfire risk transmission in the Colorado Front Range, USA, *Risk Analysis*, 35(2), 226-240.

- Hollingsworth, LaWen; Parsons, Russell. 2013. Wildfire Risk to Structures: Island Park Sustainable Fire Community. Unpublished report. USDA Forest Service. On file at: Island Park Ranger District Office, Island Park, ID. 41 p.
- Kuhlmann, C. A., D. L. Martell, R. J. Wets, and D. L. Woodruff 2015. Generating Stochastic Ellipsoidal Forest and Wildland Fire Scar Scenarios for Strategic Forest Management Planning under Uncertainty, *Forest Science*, 61(3), 494-508.
- Miller, C., & Ager, A. A. 2013. A review of recent advances in risk analysis for wildfire management. *International journal of wildland fire*, 22(1), 1-14.
- North, M., Brough, A., Long, J., Collins, B., Bowden, P., Yasuda, D., Miller, J. and Sugihara, N. 2015. Constraints on mechanized treatment significantly limit mechanical fuels reduction extent in the Sierra Nevada. *Journal of Forestry*, 113(1), pp.40-48.
- Reeves, M. C.; Ryan, K. C.; Rollins, M. G.; Thompson, T. G. 2009. Spatial fuel data products of the LANDFIRE Project. *International Journal of Wildland Fire*, 18(3), 250-267.
- Rollins, M. G. 2009. LANDFIRE: a nationally consistent vegetation, wildland fire, and fuel assessment. *International Journal of Wildland Fire*, 18(3), 235-249.
- Ryan, K. C., & T. S. Opperman 2013. LANDFIRE- A national vegetation/fuels data base for use in fuels treatment, restoration, and suppression planning, *Forest Ecology and Management*, 294, 208-216.
- Schantz, R.; Lowell, T.; Helmbrecht, D. 2016. Island Park Sustainable Fire Community Project: Silvicultural options for lodgepole pine and Douglas-fir stand management. Unpublished report. USDA Forest Service. On file at: Island Park Ranger District Office, Island Park, ID. 32 p.
- Schoennagel, T., Nelson, C.R., Theobald, D.M., Carnwath, G.C. and Chapman, T.B., 2009. Implementation of National Fire Plan treatments near the wildland–urban interface in the western United States. *Proceedings of the National Academy of Sciences*, 106(26), pp.10706-10711.
- Scott, J. H. 2006. An analytical framework for quantifying wildland fire risk and fuel treatment benefit. In: Andrews, P.L., Butler, B.W. (Comps.), *Fuels management—how to measure success: conference proceedings; March 28–30; Portland, OR*. Proc. RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 169–184.
- Scott, J. H., & Burgan, R. E. 2005. Standard fire behavior fuel models: A comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.
- Scott, J. H.; Thompson, M. P.; Calkin, D. E.; Marcille, K. 2012a. Probabilistic assessment of wildfire hazard and municipal watershed exposure. *Natural Hazards*. 64(1): 707- 28.
- Scott, J. H., Helmbrecht, D., Parks, S., & Miller, C. 2012b. Quantifying the threat of unsuppressed wildfires reaching the adjacent wildland-urban interface on the Bridger-Teton National Forest, Wyoming, USA. *Fire Ecology*, 8(2), 125–142.
- Scott, J. H., M. P. Thompson, and D. E. Calkin 2013. A wildfire risk assessment framework for land and resource management, Gen. Tech. Rep. RMRS-GTR-315. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p.

- Scott, J. H., Thompson, M. P., & Gilbertson-Day, J. W. 2016. Examining alternative fuel management strategies and the relative contribution of National Forest System land to wildfire risk to adjacent homes—A pilot assessment on the Sierra National Forest, California, USA. *Forest Ecology and Management*, 362, 29-37.
- Short, Karen C. 2013. Spatial wildfire occurrence data for the United States, 1992-2011 [FPA_FOD_20130422]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. <http://dx.doi.org/10.2737/RDS-2013-0009>.
- Thompson, M. P.; Calkin, D. E. 2011. Uncertainty and risk in wildland fire management: a review. *Journal of Environmental Management*. 92(8): 1895-1909.
- Thompson, M. P., Scott, J., Kaiden, J. D., & Gilbertson-Day, J.W. 2013a. A polygon-based modeling approach to assess exposure of resources and assets to wildfire. *Natural Hazards*, 67(2), 627–644.
- Thompson, M. P.; Scott, J. H.; Helmbrecht, D.; Calkin, D. E. 2013b. Integrated wildfire risk assessment: framework development and application on the Lewis and Clark National Forest in Montana, USA. *Integrated Environmental Assessment and Management*. 9(2): 329-342.
- Thompson, M. P., J. W. Gilbertson-Day, and J. H. Scott. 2015. Integrating Pixel- and Polygon-Based Approaches to Wildfire Risk Assessment: Application to a High-Value Watershed on the Pike and San Isabel National Forests, Colorado, USA, *Environmental Modeling & Assessment*, 1-15.

Appendix A: Field Report

Task 2: Summary of field visit (fire/fuels)

Work Order: U90JFB

Don Helmbrecht

June 25, 2014

Background:

The purpose of the field visit was to gain familiarity with the vegetation, fuels, and general landscape context of the Island Park Sustainable Fire Community (IPSFC) project area, and to validate the geospatial data to be used for fire behavior modeling.

In our initial review of the geospatial data provided by the Fire Modeling Institute (FMI) (Task 1), we determined that the hybridization of the LANDFIRE and RSAC data – conducted by FMI to modify canopy bulk density – did not provide an advantage over the off-the-shelf LANDFIRE data for the purposes of this assessment. We further concluded that the limited-extent and methods used in the hybridization process may create new issues in modeling burn probability (see Task 1 summary).

After discussing the findings of task 1, and in consideration of the project budget and timeline, the TEAMS and Pyrologix LLC wildland fire analysts, State and Private Forestry National Fire Plan Coordinator, and Ashton/Island Park District Ranger decided that for the assessments under work order U90JFB we would use LANDFIRE 2010 data with minor review and updates.

Basic fire behavior modeling and a field visit were conducted to validate the LANDFIRE vegetation and fuels data. This document summarizes our findings, lists the modifications to be made, and completes the fire and fuels portion of task 2 (the project silviculturist will still be conducting a site visit and data review).

LANDFIRE Vegetation & Surface Fuel Data Review:

Sagebrush

The IPSFC modeling landscape intersects three LANDFIRE map zones (18, 19, and 21). The surface fuel mapping rules for existing vegetation type (EVT) 3220 (*Artemisia tridentata* ssp. *vaseyana* Shrubland Alliance) differ between zones. A significant amount of this EVT is mapped within zone 18 – immediately adjacent to and protruding into the southwest portion of the IPSFC project area (Figure 1). The zone 18 rules assign fuel model SH7 to this EVT when canopy cover exceeds 19 percent. We were not able to validate this fuel model assignment within the IPSFC modeling extent, and based on field observation (figure 2) and comparison of expected vs. predicted fire behavior (figure 3) recommend using the mapping rules from map zone 21, which assign fuel model GS2. As pointed out in the FMI report, fuel model SH7 would likely over predict rate of spread and flame lengths.

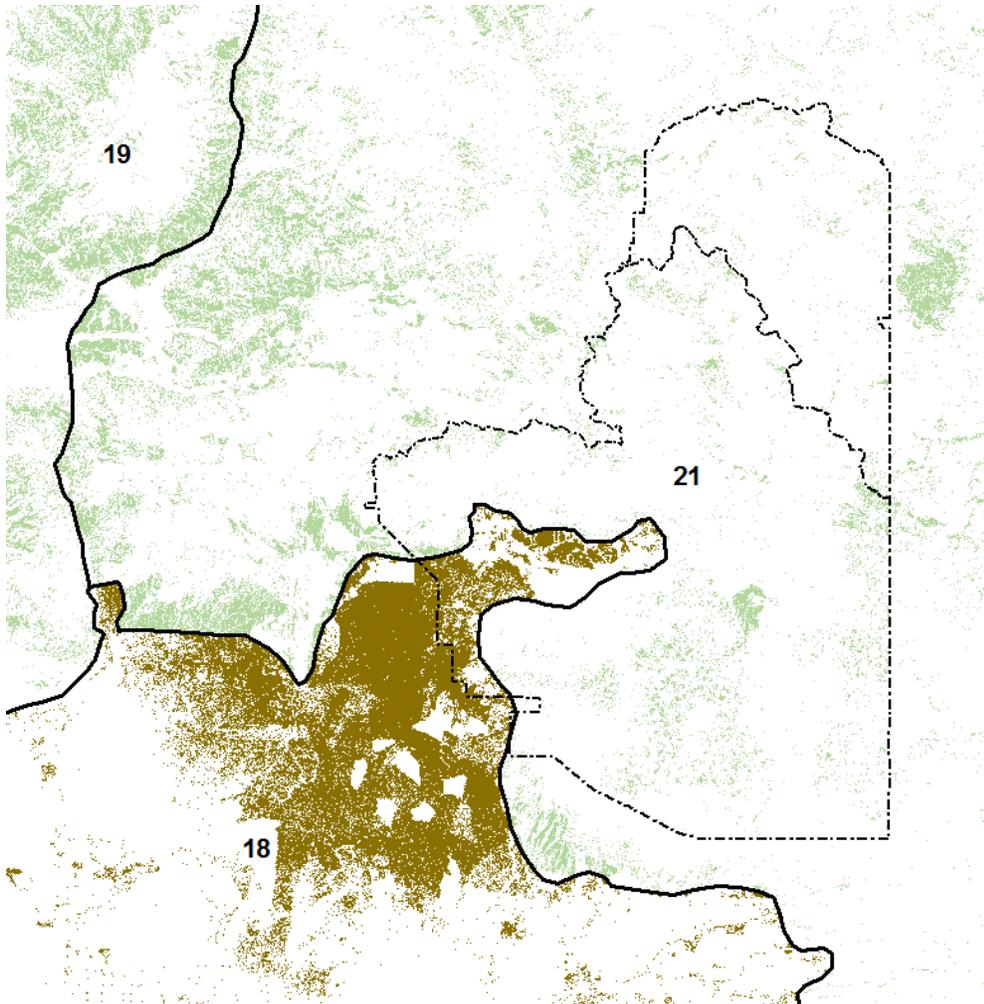


Figure 1: Existing vegetation type (EVT) 3220 (*Artemisia tridentata* ssp. *vaseyana* Shrubland Alliance) fuel rule discrepancy. Areas of the EVT that exceed 19 percent canopy cover in zone 18 (shown in brown) are mapped to fuel model SH7. These areas (shown in light green) are mapped to GS2 in zones 19 and 21. LANDFIRE map zones are indicated by solid black lines and labels. Project boundary is indicated by the dashed outline.



Figure 2: Photo of area mapped incorrectly as fuel model SH7.

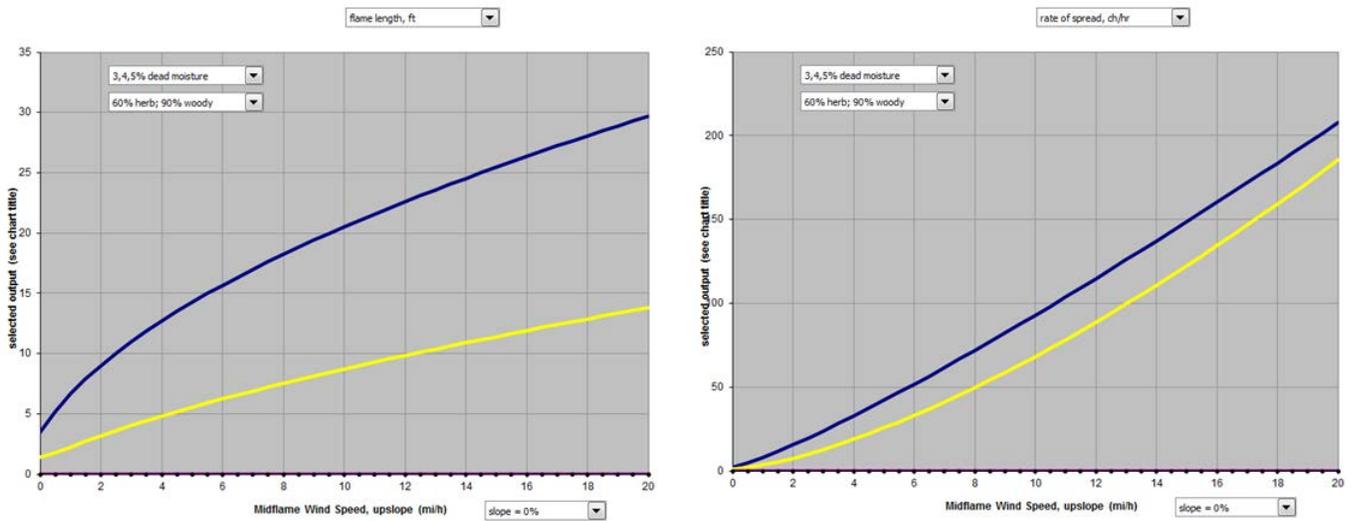


Figure 3: Modeled flame length (left graph) and rate of spread (right graph) for fuel models SH7 (blue lines) and GS2 (yellow lines). Live fuels are assumed two-thirds cured.

Lodgepole pine

Existing vegetation type 3050 (Rocky Mountain lodgepole pine forest) is mapped extensively throughout the fire modeling landscape in map zone 21. Within mature forest (i.e., > 5 m canopy height) of this EVT, mapping rules assign TU5 where canopy cover is less than 40 percent and TL3 where canopy cover is 40 percent or greater. We were unable to validate the TU5 fuel model in our field visit regardless of canopy cover. The surface fuel in lodgepole pine was fairly consistent in the areas we visited – primarily low to moderate needle litter with varying amounts of an herbaceous and shrub component (figure 4).



Figure 4: Typical surface fuel in existing vegetation type 3050 (Rocky Mountain lodgepole pine). The top photo is from the Island Park section of the project area and was mapped as fuel model TL3. The bottom photo is from the Hebgen Lake section of the project area near West Yellowstone and was mapped as fuel model TU5.

We recommend using fuel model TU1 in the Rocky Mountain lodgepole pine EVT for the full range of canopy cover. Although a timber litter model may be the most appropriate fit where the herbaceous and

shrub component is less prominent (e.g., bottom photo, figure 4), these sites appear to be the exception rather than the rule. We did not observe a consistent variable of vegetation structure with which to map these two conditions independently (e.g., canopy cover breakpoint) – differences are likely due to topographic conditions. Using a dynamic fuel model such as TU1 will better enable us to capture the variability in fire behavior due to seasonal changes in live herbaceous moisture content. For example, when the herbaceous fuel is completely cured, fuel model TU1 will produce flame lengths and rate of spread higher than TL3 but when the herbaceous component is fully green the opposite is true (figure 5).

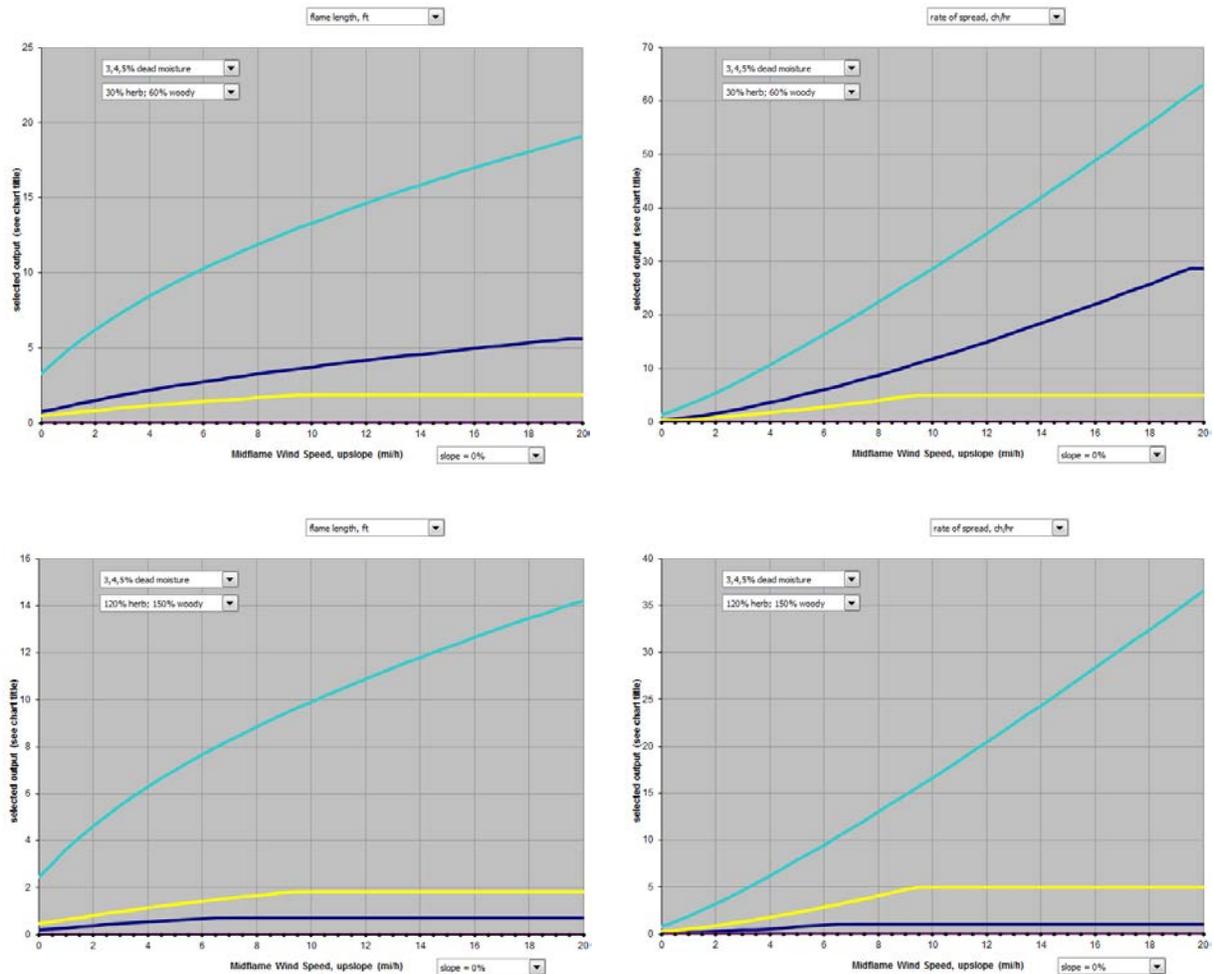


Figure 5: Modeled flame length (left graphs) and rate of spread (right graphs) for fuel models TU1 (dark blue lines), TL3 (yellow lines), and TU5 (light blue lines). Top graphs show fire behavior with the live herbaceous component fully cured. Bottom graphs show fire behavior with the live herbaceous component fully green. TU5 over predicts surface fire behavior in the lodgepole pine forest type.

Douglas-fir

The primary Douglas-fir EVT – 3235 (xeric montane Douglas-fir Forest) and 3166 (middle Rocky Mountain montane Douglas-fir forest and woodland) – are found on the lower and mid-elevation slopes of the project area. These EVT use the same fuel mapping rules; within mature forest (i.e., > 5 m canopy height) TL4 is assigned where canopy cover is less than 40 percent and TU5 is assigned where canopy cover is 40 percent or greater. We were unable to validate the TL4 or TU5 fuel model assignments. The Douglas-fir sites that we visited were composed of a moderate litter load with an herbaceous and shrub component (figure 6).



Figure 6: Typical surface fuel observed in existing vegetation types (EVT) 3235 (xeric montane Douglas-fir Forest) and 3166 (middle Rocky Mountain montane Douglas-fir forest and woodland). Both photos were taken in an area mapped as EVT 3235. The top photo is from the Yale Creek area and mapped as a heterogeneous mix of fuel models TL4 and TU5. The bottom photo is from Keg Creek and mapped as fuel model TU5.

As with lodgepole pine, we did not observe a major difference in surface fuel with changes in overstory canopy cover. Differences in the amount of herbaceous and shrub components are likely more driven by

topo-edaphic conditions. Based on our observations and comparison of expected vs. predicted fire behavior we suggest using fuel model TU1 in the Douglas-fir EVT for the full range of canopy cover. TU1 and TL4 predict very similar fire behavior under typical fire weather conditions (figure 7) but TU1 will provide variability with differences in live herbaceous moisture content.

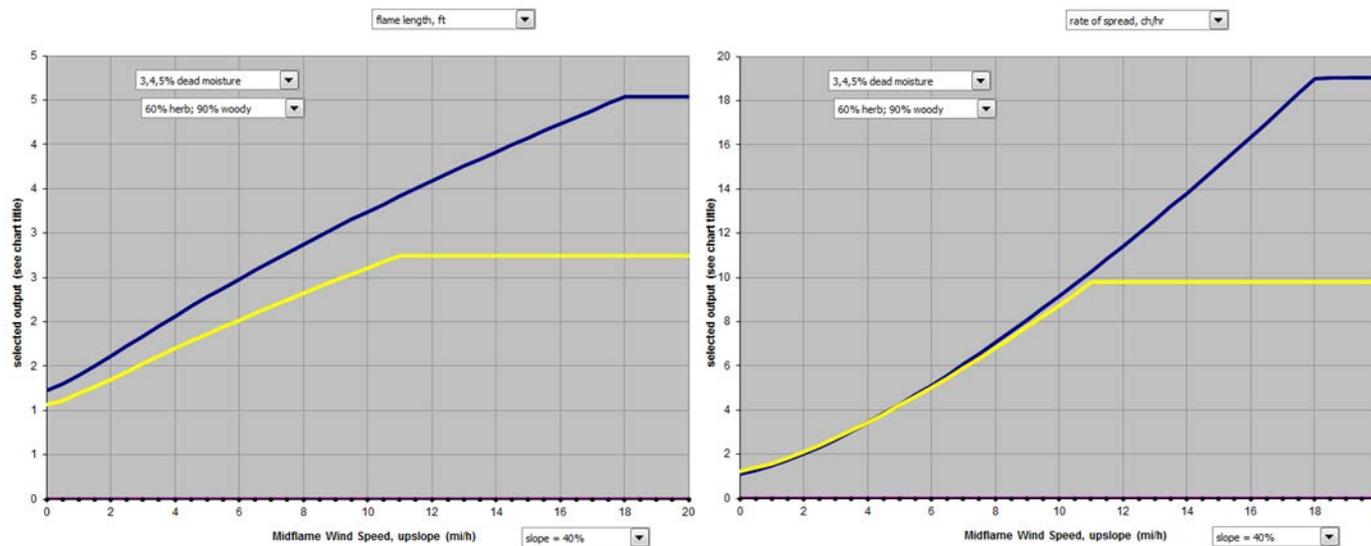


Figure 7: Modeled flame length (left graph) and rate of spread (right graph) for fuel models TU1 (dark blue lines) and TL4 (yellow lines). Live fuels are assumed two-thirds cured.

LANDFIRE Canopy Fuel Data Review:

Canopy Base Height

The LANDFIRE canopy base height values appeared to be high in some areas but reasonable in others based on our field observations. Regardless, when combined with fuel model TU1 these values would under predict the expected conditions required to transition from surface to crown fire. Balancing surface fuel model and canopy base height is always a balancing act in modeling reasonable landscape fire behavior.

LANDFIRE canopy base height assignments in the non-disturbed lodgepole pine forest type range from 0 to 2.5 meters; however 99 percent of the area in this type is assigned a canopy base height of 0.8 meters. In the Douglas-fir forest types, non-disturbed base height assignments range from 0 to 9.7 meters with 39 percent of the area assigned a canopy base height of 0.5 meters and 52 percent assigned a canopy base height of 0.9 meters. We suggest modifying canopy base heights to find the right combination of surface and crown fire behavior for the Island Park landscape (table 1).

Canopy Bulk Density

Canopy bulk density values seem reasonable based on our field observation and preliminary fire behavior modeling. Sixty-eight percent of the non-disturbed lodgepole pine forest type and 62 percent of the non-disturbed Douglas-fir forest types – primarily stands greater than ten meters in height with canopy cover of 30 to 49 percent – are assigned a canopy bulk density of 0.06 or 0.08 kg/m³ (figure 8). Seventeen percent of the Douglas-fir types – stands greater than ten meters in height with canopy cover of 50 to 59 percent – are assigned a canopy bulk density of 0.11 kg/m³ and will be more prone to active crown fire under lower wind conditions (figure 8).

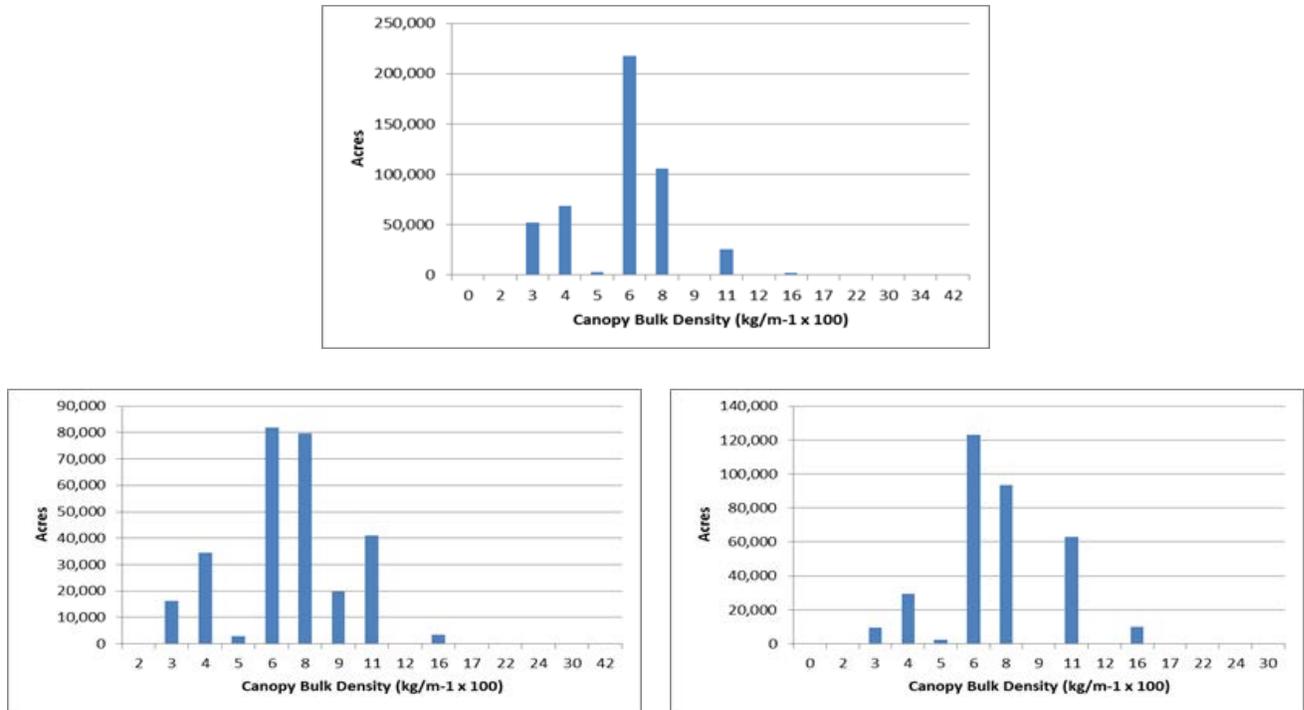


Figure 8: Distribution of canopy bulk density for non-disturbed (1999-2010) Rocky Mountain lodgepole pine forest (top chart), middle Rocky Mountain montane Douglas-fir forest and woodland (bottom-left chart), and xeric montane Douglas-fir forest (bottom-right chart) existing vegetation types.

Using a TU1 fuel model, low dead fuel moisture, and two-thirds cured live herbaceous fuel moisture values, the prominent lodgepole pine and Douglas-fir stand conditions would result in a torching index of 25 to 58 mph and crowning index of 29 to 36 mph on flat ground (table 1) assumingly under predicting crown fire behavior. Setting the canopy base height to 0.4 meters may produce more reasonable results. Values may be adjusted further during FSim calibration.

Table 1: Torching and crowning indices for prominent stand conditions in the Island Park Sustainable Fire Community project area using LANDFIRE data. Modeled in NEXUS using fuel model TU1; 1hr, 10hr, & 100hr dead fuel moisture values of 3,4, & 5 percent; live herbaceous and live woody fuel moisture values of 60 and 90 percent; a foliar moisture content of 100 percent; and flat ground. Reducing base height to 0.4 meters would result in a torching index of 18.4 mph for 35% canopy cover stands and 21.5 mph for 35% canopy cover stands.

Scenario	Canopy Cover (percent)	Canopy Base Height (meters)	Canopy Bulk Density (kg/m ³)	Wind Reduction Factor	Torching Index (mph)	Crowning Index (mph)
Prominent LANDIFRE Structure	35	0.5	0.06	0.14	24.5	35.5
	45	0.5	0.08	0.12	28.6	28.9
	35	0.8	0.06	0.14	43.2	35.5
	45	0.8	0.08	0.12	50.4	28.9
	35	0.9	0.06	0.14	49.5	35.5
	45	0.9	0.08	0.12	57.8	28.9
Suggested Modification	35	0.4	0.06	0.14	18.4	35.5
	45	0.4	0.08	0.12	21.5	28.9

Summary of changes to be made:

Table 2: Summary of changes to surface fuel models. No other changes will be made to the base LANDFIRE fuel model data.

Vegetation Type	Canopy Cover (percent)	Old Fuel Model	New Fuel Model
Sagebrush (zone 18)	20 – 49	SH7	GS2
Lodgepole pine	10 – 39	TU5	TU1
	40 – 100	TL3	TU1
Douglas-fir	10 – 39	TL4	TU1
	40 – 100	TU5	TU1

Table 3: Summary of changes to canopy fuel characteristics. No other changes will be made to the base LANDFIRE canopy fuel data.

Vegetation Type	Old Base Height (meters)	New Base Height (meters)
Lodgepole pine	0.8	0.4
Douglas-fir	0.5	0.4
	0.9	0.4