Guidance Document for the Cumulative Impacts Assessment of Wildfire Risk and Hazard

Recommendations submitted to CAL FIRE May 2019

The purpose of this document is to outline recommended procedures to assess the Cumulative Impacts Resource Subject “Wildfire Risk and Hazard” in Timber Harvest Plan documentation, per the California Forest Practice Rules. These procedures shall promote standardized approaches of assessment and encourage consistency across RPF training and knowledge.

These recommendations emerged from (1) a review of the best available science on wildfire hazard and risk assessment from both peer-reviewed and grey literature and (2) insight gleaned from interviews and surveys of Registered Professional Foresters and additional scientists and practitioners in the field of fire science and management. This approach ensures methods which are both scientifically rigorous and technically and logistically feasible, in that each:

- Is able to assess wildfire hazard and/or risk in a meaningful way, consistent with the chosen definitions for these terms
- Is cost-efficient for RPFs, including monetary value, time, and required computing power
- Employs software, tools, and data which are open-access and agency-supported (e.g. FRAP, LANDFIRE)

Introduction to Wildfire Risk and Hazard

While the definitions of wildfire hazard and risk vary substantially throughout literature concerning the assessment and treatment of wildfire, the following CAL FIRE definitions shall be used in assessing this Resource Subject:

Wildfire Hazard: “a measure of the likelihood of an area burning and how it burns”[1]
Wildfire Risk: “threat from wildland fire to Wildland-Urban Interface areas of California”[2], with a focus on risk to “people, property, and infrastructure”[3].

That is, the assessment of Wildfire Hazard concerns the dynamics of fire behavior, while Wildfire Risk is an extension of the assessment into the human dimensions of a landscape.

[1] CAL FIRE. *Fire Hazard Severity Zone Development*. Available at: http://www.fire.ca.gov/fire_prevention/fire_prevention_wildland_zones_development. (Accessed: 21 March 2019)
[2] CAL FIRE. *Characterizing the Fire Threat to Wildland-Urban Interface Areas in California*. Fire Resource and Assessment Program (FRAP). Available at: http://frap.fire.ca.gov/projects/wui/525_CA_wui_analysis.pdf. (Accessed: 25 November 2018).
[3] CAL FIRE. *The Wildland Urban Interface (WUI): Assessing related risks to people, property and infrastructure in California*. 2012. Fire Resource and Assessment Program (FRAP). Available at: http://frap.fire.ca.gov/projects/wui/index. (Accessed: 25 November 2018).

Assessment Parameters

1. Resource Area as a Watershed

The Cumulative Impacts Assessment within Timber Harvest Plans (THP) requires each resource subject be investigated across a resource area, as determined and described by the RPF. The resource area may vary for each resource subject to best capture potential cumulative effects of the timber harvest action(s) from the proposed timber harvest plan.

The recommended resource area for the Wildfire Risk and Hazard resource subject is the Planning Watershed level, specifically the **California Planning Watershed Unit**. Should the proposed timber harvest plot cross the bounds of multiple delineated Planning Watersheds, each should be assessed for potential cumulative impacts.

Planning watersheds are a California-specific measure, summarizing drainage regions, that range from 3,000 to 10,000 acres. A summary of all THPs passed between 2006 and 2016 shows that the average size of a harvest project is 416 acres. A summary of all recorded California wildfires since 1878--from CAL FIRE datasets--finds that the average size of a wildfire is 722.8 acres. Thus, utilizing the smaller Planning Watershed Unit, compared to other watershed delineations, will best capture the scale of both timber harvest actions and wildfire extent. Moreover, the California Planning Watershed unit is already required to be identified for every THP as part of the description of past and reasonably foreseeable future projects. A review of recent THPs has shown that many RPFs already use this metric to assess other resource subjects.

Importantly, the watershed unit represents characteristics of the landscape (topography, vegetation type, climate, and weather) that impact how a wildfire burns. Topography, along with weather and vegetation, have been shown to be the major drivers of wildfire severity and burn patterns.[4,5] Topography and vegetation both influence the pattern of burning and provide corridors for fire continuance and natural fuel breaks.[6] Fire is a naturally occurring disturbance across most of northern California, so using a landscape-relevant metric for assessment will incorporate those factors that have guided wildfire presence throughout time.

2. Timeline of assessment :

We recommend that Wildfire Risk and Hazard be assessed **pre-harvest, at 5 years post-harvest, and at 30 years post-harvest**. Wildfire Risk and Hazard should also be assessed at 5 years and 30 years after the proposed timber harvest action as if the action did not occur and

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[4] Dillon, G. K. *et al.* Both topography and climate affected forest and woodland burn severity in two regions of the western US, 1984 to 2006. *Ecosphere* **2**, art130 (2011).

[5] Thompson, J. R. & Spies, T. A. Vegetation and weather explain variation in crown damage within a large mixed-severity wildfire. *For. Ecol. Manag.* **258**, 1684–1694 (2009).

[6] Thompson, J. R. & Spies, T. A. Vegetation and weather explain variation in crown damage within a large mixed-severity wildfire. *For. Ecol. Manag.* **258**, 1684–1694 (2009

the forest continued to grow undisturbed. While a typical THP represents only 5 years of activity, modeling at these time steps will importantly support the assessment of potential impacts of timber harvest actions into the future, per legal requirements to consider "cumulative" impacts of Projects. Note that since the assessment is completed over the planning watershed area, some parts of the forest will continue to grow undisturbed, while others will experience regrowth following harvest. Resulting stand structures will importantly inform wildfire hazard assessments, as described later in this document.

3. Metric of Assessment (crown fire conversion)

Metrics of wildfire hazard provide a system of measurement for the intensity at which a fire burns. Quantitatively, fire intensity can be represented by flame length, fire line intensity (heat expelled at the head of a fire), and rate of fire spread. The chosen metric of assessment for this report is **flame length**.

Flame length is a common metric used to measure wildfire hazard as it clearly correlates with the likelihood of a canopy fire igniting and propagating.[7] Canopy fires are considered the most dangerous since they are difficult to put out, can be more intense, and can travel quickly with exposure to high winds.[8] A number of wildfire behavior modelling programs have flame length as an output. CAL FIRE uses flame length in their model that calculates fire hazard severity zones.[9] Similarly, the Fire Program Analysis (FPA) system created a tool, the large Fire Simulation system (FSIM), which measures fire intensity level by flame length classes.[10]

Overview of Factors Dictating Wildfire Hazard

The behavior of wildfire across a landscape is influenced by many spatial and temporal conditions such as topographic landscape characteristics (e.g. slope, aspect), climate, weather (e.g. wind, temperature, humidity), forest type (e.g. mixed conifer, redwood), and previous disturbance regimes (e.g. historic timber harvesting and wildfire events), each of which should be considered in evaluating the potential impacts to wildfire hazard in a landscape. Critically, an evaluation of the specific forest practices on a given timber plot should be a focus for assessing potential cumulative impacts to wildfire hazard. These forest practices may include (as represented in **Figure 1**):

(a) **harvest actions**, such as yarding method,
(b) **maintenance actions**, such as precommercial thinning or pruning,
(c) **surface fuels treatments**, such as prescribed burns or mastication,
(d) **restocking approaches**, and

[7] US Forest Service. Predicting Behavior and Size of Crown Fires in the Northern Rocky Mountains. https://www.fs.fed.us/rm/pubs_int/int_rp438.pdf

[8] David Graetz, John Sessions, and Steven Garman. *Understanding stand-level optimization to reduce crown fire hazard*. 2007. https://www.sciencedirect.com/science/article/pii/S0169204606002271

[9] CAL FIRE. Fact Sheet: Fire Hazard Severity Zone Model - A Non-technical Primer. http://www.fire.ca.gov/fire_prevention/downloads/FHSZ_model_primer.pdf

[10] US Forest Service. Wildland Fire Potential: A Tool for Assesing Wildfire Risk and Fuels Management Needs. https://www.fs.fed.us/rm/pubs/rmrs_p073/rmrs_p073_060_076.pdf

(e) **the inclusion of fuel breaks or road access**.

Taken individually or together, these forest practices can influence fire behavior through the modification of **forest structure**, including changes to species composition, fuel structures, fuel moisture, and surface winds. Special attention should be paid to the following characteristics in assessing the potential cumulative impacts of timber harvest actions:

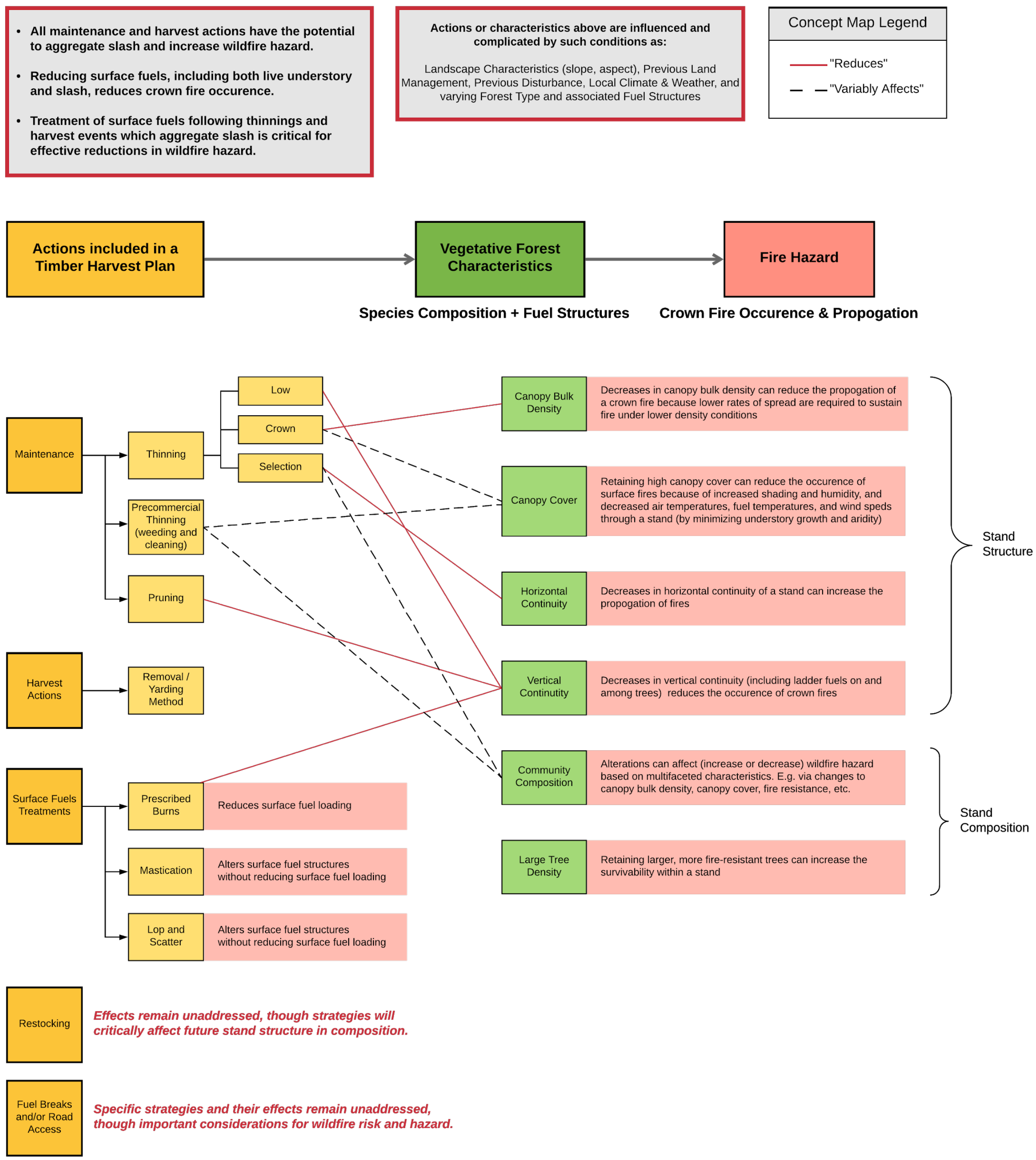
Key Structural (Vegetative) Forest Characteristics which Influence Wildfire Hazard:

- Canopy bulk density
- Canopy cover
- Horizontal continuity
- Vertical continuity
- Community composition
- Large tree density

Key Management Strategies to Reduce Hazard and/or Promote Fire Resistant Forests:

- Reduce surface fuels: reduces crown fire occurrence
- Reduce ladder fuels (increase height to live crown, canopy base height): reduces crown fire occurrence
- Reduce canopy bulk density: minimizes spread of crown fire
- Reduce the continuity of the forest canopy: minimizes spread of a crown fire
- Retain fire resistant species and larger trees: increases survivability of trees

Figure 1. The following concept map was designed to summarize the effect of timber actions on important structural (vegetative) forest characteristics as they relate to wildfire hazard.



The following table was designed to summarize general trends concerning forest management actions, forest characteristics, and wildfire hazard. There are associated studies and literature that should be referenced for further information.

Table 1. Summary of hypothesis and inferred timber harvest implications associating fuel treatment types, weather, and topographic characteristics with wildfire hazard. Full citations for these resources can be found in Appendix A.

Component	***Hypothesis***	***Literature Reviewed***	***Inferred Timber Harvest Implication***
Fuel Treatment Types	1a. Fuel treatments, including prescribed burning and thinning, reduce forest density, raise crown base height, and can lower crown bulk density	Fulé, P. Z., Waltz, A. E. M., Covington, W. W. & Heinlein, T. A.	Reducing density, raising crown base height, and reducing crown bulk density are linked with decreased wildfire hazard.
	1b. Mechanical thinning (including crown thinning, thinning from below, mastication) reduces fire hazard	*Ponderosa pine forest in Arizona* - Fulé, P. Z., Waltz, A. E. M., Covington, W. W. & Heinlein, T. A. *California mixed-conifer* - Stephens, S. L. & Moghaddas, J. J., Stephens, S. L., Collins, B. M. & Roller, G. *Ponderosa pine forests in CA, AZ, MO, WA* - Pollet, J. & Omi, P. N. *Conifer forest in Greece* - Zagas, T., Raptis, D., Zagas, D. & Karamanolis, D.	Activities that reduce the density of a forest will reduce wildfire hazard.
	1c. Prescribed burning is more effective at reducing fine and coarse woody fuel loads up to 7 years after treatment.	Stephens, S. L., Collins, B. M. & Roller, G.	Prescribed burn treatments reduce wildfire hazard, but treatments should be regularly scheduled to maintain this reduction
	1d. Even aged thinning (removing small size classes first) is more effective at reducing hazard than uneven aged thinning.	Huggett, R. J., Abt, K. L. & Shepperd, W..	Removing smaller size classes (uneven aged thinning) is more effective at reducing wildfire hazard than even aged thinning.
	1e. Average and maximum fire area burned decreases proportionally to increased treatment area (thinning, underburning, and mechanical treatment)	Ager, A., Vaillant, N. & Finney, M.	Increased area of fuel treatments reduce the area burned in a landscape.
Species composition	2a. Restocking can lead to loss of diversity, leading to increased wildfire hazard	Nolet P., *et al*.	
Management (Suppression) Activities	3a. Most forests in California have undergone change resulting in altered fire regime.	Steel, Z. L., Koontz, M. J. & Safford, H. D.	Altered fire regimes introduces uncertainty about fire severity

	3b. The greatest increase in fire severity in recent fires is seen in the Sierra Nevada. 3c. Overstocked mixed-conifer forests have high flame length values	Steel, Z. L., Koontz, M. J. & Safford, H. D. Ager, A., Vaillant, N. & Finney, M.	Sierra Nevada forests are most at risk for high severity fires in California Overstocked mixed-conifer forests have high flame length values, leading to increase fire severity
Topographic	4a. Wildfire hazard increases with increasing slope angle 4b. Higher wildfire hazard associated with higher elevation mixed-conifer forests	Aspen, pinyon-juniper, mixed-conifer forest in CO - *Romme, W. H., Barry, P. J., Hanna, D. D., Floyd, M. L. & White, S.* Oregon - Calkin, *et al.* 2010	
Weather	5a. Average daily temperature is the most important predictor in conifer damage during wildfire.	Thompson and Spies, 2009	

Methods of Assessment

Wildfire Hazard Assessment

The following **decision tree** outlines recommended methods of assessment for wildfire hazard, driven by data availability (**Figure 2**). The first methodology for assessing wildfire hazard provides a format for the qualitative assessment of wildfire hazard, offering a framework that can inform RPF understanding of how timber harvest actions can influence wildfire hazard in lieu of credible or complete spatial data. The next method requires the most intensive data: stand specific information about species and specific trees on the plot. The final method utilizes more widely available data, including environmental and stand characteristic data, on the broad scale.

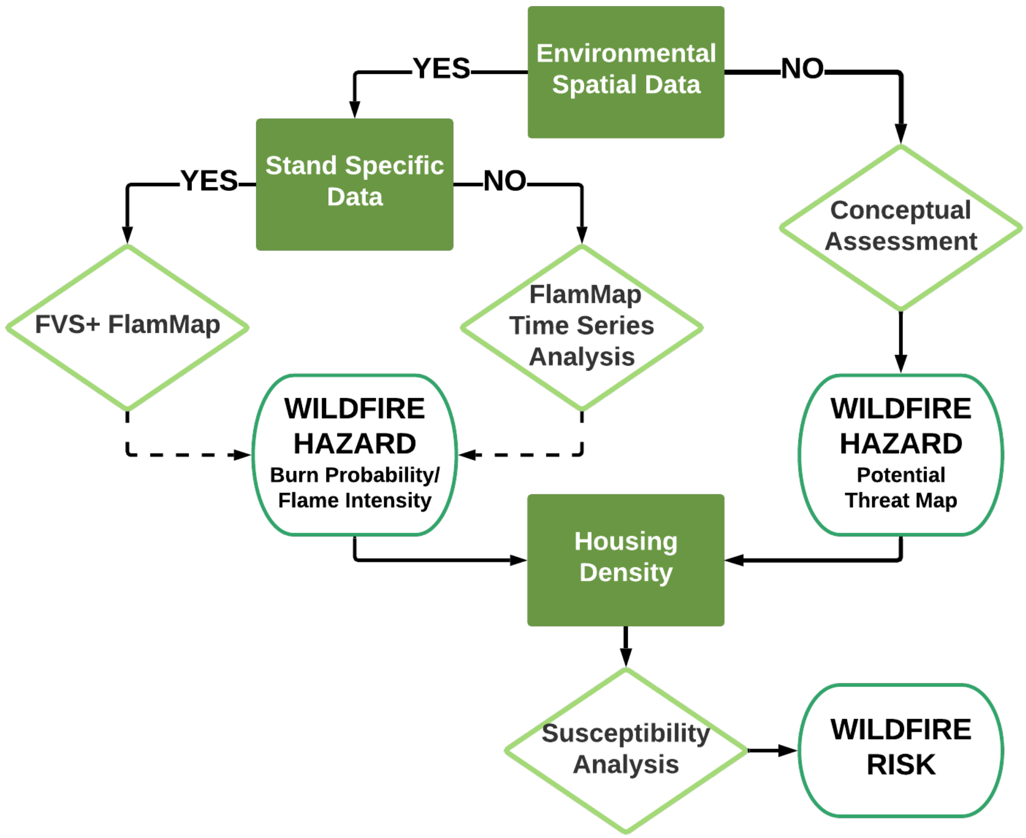


Figure 2. Decision tree summarizing methods proposed for wildfire hazard and risk assessment.

a. Qualitative Assessment

If neither stand-specific data or landscape spatial data are sufficiently credible or available, an evaluation of proposed harvest actions, topographic features, and climate/weather conditions should be used to assess expected changes in wildfire hazard following a harvest. This method draws upon the aforementioned table which summarizes a number of these factors and their relationship to wildfire behavior and timber harvesting to increase practitioner knowledge (**Table 1**), and is constituted by the completion of two checklists which can identify actions within the proposed timber harvest that are expected to alter wildfire hazard (**Tables 2 & 3**).

Table 2. Checklist to guide a qualitative assessment of potential cumulative impacts of a proposed timber harvest project on wildfire hazard. This table is focused on changes to forest structure and species composition. The changes at the three suggested time frames should be described as increasing/decreasing or via a description of the changes. These may then be compared to Table 1.

Category	Condition	Immediately Post-Harvest	5 Years	30 Years

Stand Structure	Canopy Bulk Density (crown fuels)			
	Canopy Cover			
	Horizontal Continuity (stand density)			
	Vertical Continuity (ladder fuels)			
Stand Composition	Community Composition			
	Large Tree Density			
Surface Fuels	Surface fuel loading			
	Surface fuel structure			

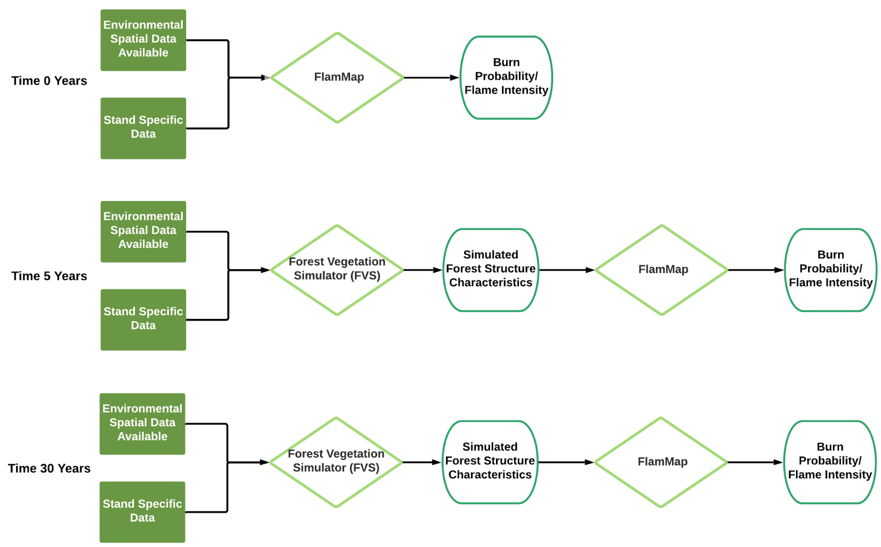
Table 3. Checklist to guide a qualitative assessment of potential cumulative impacts of a proposed timber harvest project on wildfire hazard. This table outlines landscape-level characteristics that affect wildfire behavior regardless of overlying vegetation changes and actions that have clear impacts on wildfire behavior.

Category	Condition	High Hazard, or will Increase Hazard	Low Hazard, or will Reduce Hazard
Topographic	Slope		
	Aspect		
	Elevation		
Climate	Regional Climate		
	Microclimate of THP Site		
Prior Land Management	Fire Suppression		
	Overstocking		

	Timber Harvest		
Defenses	Fire breaks		
	Road access		

b. FVS and FlamMap

In the case where stand specific data is available, the software tools FVS and FlamMap can be paired to (1) simulate forest growth and regrowth after the proposed timber harvest action using FVS and (2) compare these forest structure differences to assess potential changes to wildfire hazard using FlamMap.



The U.S. Forest Service's Forest Vegetation Simulator (FVS) combines a number of vegetation growth models to understand forest regrowth following a disturbance, including harvest actions.[11] FVS allows the user to simulate future forest structures by generating spatial data for the forest based on predicted growth. By simulating forest growth 5 years and 30 years in the future, and by simulating the forest condition immediately following harvest, 5 years after harvest, and 30 years after harvest, FVS provides the opportunity to assess potential adverse effects on wildfire hazard.

The FVS generated spatial outputs of canopy cover, canopy height, crown base height, and crown bulk density may then be used in FlamMap 5.0, a fire behavior modelling software developed by the Fire, Fuel, Smoke Science Program through the U.S. Forest Service.[12] FlamMap requires eight spatial layers that convey environmental characteristics crucial to

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[11] U.S. Forest Service, "Forest Vegetation Simulator (FVS)," https://www.fs.fed.us/fvs/software/index.shtml

[12] Fire, Fuel, Smoke Science Program, "FlamMap," https://www.firelab.org/project/flammap

wildfire hazard determinations (**Table 1**). Via this method, the input layers would be sourced from the FVS output file. This method for using FVS output data in FlamMap was developed by the U.S. Forest Service to examine the effects of fuel treatments on wildfire behavior, and may be used to examine timber harvest actions as well.[13] Basic FlamMap should be used to model flame length. For each timestep, the spatial output files should be clipped to (a) the proposed timber harvest area alone, and then (b) to the surrounding Planning Watershed(s), removing the timber harvest area. This will allow for a comparison of changes in wildfire hazard (a) within the timber harvest area over time, and (b) beyond the timber harvest plan that may result from the harvest action.

Statistical Tests for Wildfire Hazard
The spatial output files prepared in FlamMap should be assessed to determine significant changes to Wildfire Hazard using statistical tests. For this method, each FlamMap output of flame length was converted into a data table, which was organized into counts of the number of data cells in each spatial area that fell into each of the Forest Service's Wildfire Hazard categories of flame length, which range from very low (0-1 feet) to extreme (>25 feet).[14] Paired two-sided T-tests with 95% confidence intervals should be performed to determine significant changes to the number of cells falling into a specific Wildfire Hazard category. For example, one T-test may be performed to determine significant changes to the number of cells categorized as "high" Wildfire Hazard and the number of cells categorized as "very high" Wildfire Hazard in the watershed. If significant changes are detected, one-sided T-tests should be performed to determine if the change to Wildfire Hazard categories are shifts in which more cells moved to a higher or lower hazard category. Each test should be performed on the THP area as well as the surrounding watershed area, to allow for some analysis of whether the changes to Wildfire Hazard can be best linked to the timber harvest action, or to other environmental changes in the area.

This statistical testing can be easily performed in the free, open-source software R Studio. An example R Studio script for processing FlamMap output files is available at: https://github.com/cmswalec/citeplan. FlamMap outputs can be saved in a variety of formats including *.adf files, which can be read into R Studio as raster data using the rgdal package. As raster data, these FlamMap outputs can be converted to data frames, which allow for plotting and statistical analysis using the ggplot and gstat packages, respectively. The sample script provided generates a series of histogram plots and a table of T-Test outputs.

Table 4. Spatial layer inputs for FlamMap. Required environmental layer inputs to run FlamMap modelling software.

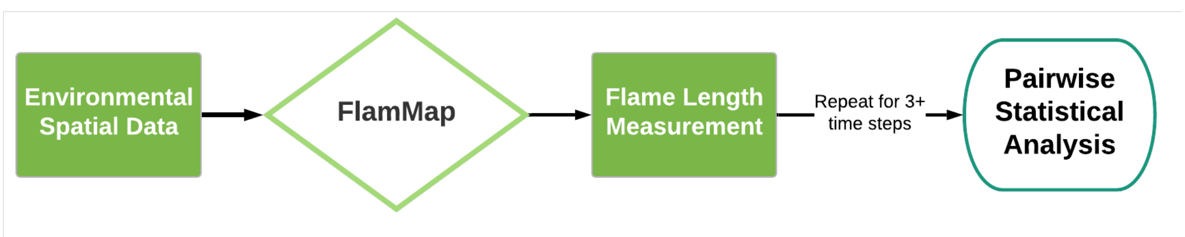
Environmental Layer	***Units***

[13] U.S. Forest Service, "Designing fuel treatment alternatives," https://www.fs.fed.us/wwetac/tools/arcfuels/help/Content/03Fuel%20Treatment%20Scenarios/06c-Alts.htm
[14] https://www.fs.fed.us/rm/pubs/rmrs_gtr153.pdf

Elevation	Meters
Slope	Grade (%)
Aspect	Degrees
Fuel Model	Anderson 13
Canopy Cover	Percent
Crown base height	Meters
Canopy bulk density	kg/m^3
Crown base height	Meters

c. FlamMap Times Series

In lieu of modelling forest regrowth following a timber harvest action, a time series analysis of a prior harvest action either on the same plot or a similar plot may be used to assess wildfire hazard. FlamMap is used to model flame length, a metric for wildfire hazard measurement, during at least three time steps, including a baseline measurement, and the time step measurements are compared using a series of statistical analyses. Significant changes in wildfire hazard, as measured by flame length, are then considered in the Wildfire Risk and Hazard section of the Timber Harvest Plan.



If stand specific data are not available, a time series method using FlamMap 5.0 and publicly available spatial data may be completed. Ideally, this method is applied on the same landscape as the proposed timber harvest plan, but if historic timber harvest or spatial data are unavailable, a harvest plan utilizing the same harvest methods in a similar and nearby landscape may be used.

All necessary data inputs for FlamMap can be sourced from LANDFIRE.[15] Currently, spatial data are available for the following years: 2001, 2008, 2010, 2012, 2014. Running FlamMap

[15] LANDFIRE, https://landfire.gov/

Basic for each of these years will create a timeseries of a given fire behavior metric, in this case, flame length.

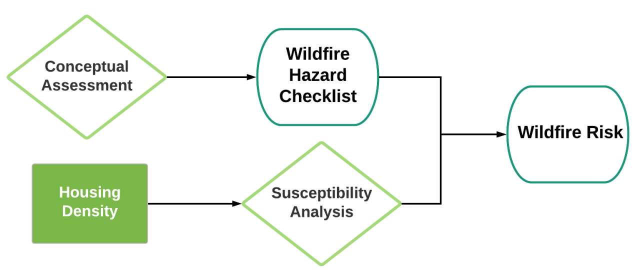
A comparison of flame length [average across the THP, proportion of flame length bins in each of the following hazard categories, the proportion of cells that shift to increased flame length] in the same plot over time can reveal how the forest changes following a harvest activity with respect to wildfire behavior. The outputs of this method should be assessed by the same *Statistical Tests for Wildfire Hazard* as described under "b. FVS and FlamMap."

Results from such a historical analysis can be used to inform potential cumulative impacts from the current, proposed timber harvest.

Wildfire Risk Assessment

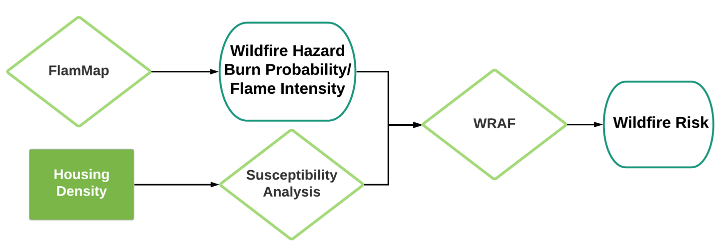
Wildfire Risk Assessment can be carried out in one of two ways depending on the availability of spatial data: (1) ***The qualitative method:*** *In the case where spatial data is not available, the Wildfire Hazard checklist can be paired susceptibility analysis to conceptually evaluate Wildfire Risk; (2)* ***The quantitative spatial data method:*** *In the case that spatial data is available, the FlamMap burn probability and flame length matrix output can be paired with susceptibility analysis to compute Wildfire Risk using the Wildfire Risk Assessment Framework (WRAF) model.*

The qualitative method



(1)

The quantitative spatial data method



(2)

From the literature review, it was determined that Wildfire Risk is a scalable function of Wildfire Hazard and can be effectively utilized to evaluate alternate mitigation measures. As stated in the introduction, the CAL FIRE definition for Wildfire Risk is the, "threat from wildland fire to Wildland-Urban Interface areas of California", with a focus on risk to, "people, property, and infrastructure". Therefore, Wildfire Risk the product of the metric of susceptibility and probable quantity and/or value of "people, property, and infrastructure"[16] damaged applied to Wildfire Hazard assessment.

The Wildfire Risk metric should be assessed based on the susceptibility of people and structures within the wildland urban interface. Regional housing density was selected as a proxy to simplify the estimation of susceptible people and structures. Susceptibility can be calculated as the product of housing density within the planning area and some fraction of homes found within the wildland urban interface under moderate to high wildfire threat. The fraction of homes under moderate to high wildfire threat can be determined on a community basis using the FRAP *Characterizing the Fire Threat to Wildland–Urban Interface Areas in California*.[17]

The qualitative method for assessing Wildfire Risk (without spatial data) is simply the reported combination of (a) the Wildfire Hazard checklist evaluation along with (b) the susceptibility findings of the fraction of homes under threat within the timber harvest planning area.

The quantitative spatial data method for Wildfire Risk assessment is a combination of the US Forest Service's *Wildfire Risk Assessment Framework for Land and Resource Management Framework* (WRAF)[18] and the susceptibility assessment. WRAF uses burn probability as a Wildfire Hazard metric and an ascribed net value change (NVC) related to the fire intensity level applied to structures within the planning area to determine the expected net value change (E(NVC)) (*eq. 1*).

$$Risk\ or\ E(NVC) = S \sum_{j}^{n} \sum_{i}^{6} \left(BP_i * NVC_{ij} \right) \qquad \text{[Eq. 1]}$$

- i - fire intensity class
- j - spatial unit
- E(NVC) - expected NVC
- S - susceptibility of structures to wildfire in the Wildland urban interface
- BP_i - burn probability per spatial unit

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16 CAL FIRE. *The Wildland Urban Interface (WUI): Assessing related risks to people, property and infrastructure in California*. 2012. Fire Resource and Assessment Program (FRAP). Available at: http://frap.fire.ca.gov/projects/wui/index. (Accessed: 25 November 2018).

17 CAL FIRE. *Characterizing the Fire Threat to Wildland–Urban Interface Areas in California*. 2003. Forest and Range Assessment of the Fire Resource and Assessment Program (FRAP). Available at: http://frap.fire.ca.gov/projects/wui/index. (Accessed: 25 November 2018).

18 Scott J, Thompson M, and Calkin D. *A Wildfire Risk Assessment Framework for Land and Resource Management*. October 2013. United States Department of Agriculture/Forest Service. General Technical Report RMRS-GTR-315. Available at: https://www.fs.fed.us/rm/pubs/rmrs_gtr315.pdf. (Accessed: 21 March 2019).

- NVC_{ij} - net value change relating to flame length intensity

The resulting expected net value change [E(NVC)] is a product of burn probabilities and NVC summed over all spatial cells (*eq. 2*) and the susceptibility of structures within the THP planning area. Burn probability is a function of fire intensity level (*fig. 1*). The fire intensity level is based on a flame length assessment (*tbl. 5*). Flame length assessment also relates the percent net value change to structures expected for each fire intensity level (tbl. 5). All components of this equation except percent NVC are derived from the Flame Length Probability Matrix (FLP) file created with the Minimum Travel Time Flammap 5.0 module.

$$\begin{aligned}(BPa * NVCa) = {} & (-50 * 0.005) + (-60 * 0.004) + (-70 * 0.003) \\ & + (-80 * 0.002) + (-90 * 0.001) + (-100 * 0.0005) \qquad \text{[Eq. 2]}\end{aligned}$$

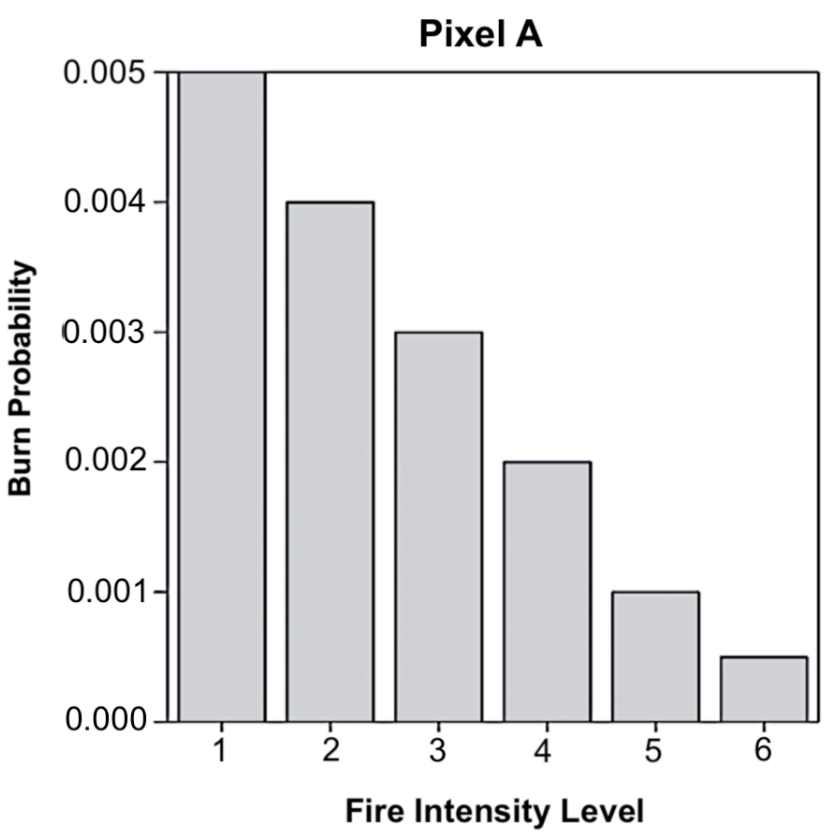

Figure 3. Sample pixel (A) bar graph of burn probability as a function of fire intensity level. Fire intensity level is determined by flame length range (tbl. 5) and can be used to calculate the NVC (eq. 2) of each spatial cell and

summed to find the total E(NVC) (eq. 1) over the entire THP planning area.[19]

Table 5. Fire intensity levels based on flame length ranges by feet. The negative percentage is associated with critical damage infrastructure suffers and is dependent on the fire intensity level.[18]

Fire Intensity Level	*1*	*2*	*3*	*4*	*5*	*6*
Flame Length Range (feet)	0 - 2	2 - 4	4 –6	6 - 8	8 - 12	12+
Percent Net Value Change of Structures	-50	-60	-70	-80	-90	-100

This quantitative spatial data method for Wildfire Risk assessment is the highly recommended practice and most suited to then aid an evaluation of mitigation strategies when aligned with a vegetation simulator in the Wildfire Hazard assessment.

Appendix A.

Agee, J. K. & Skinner, C. N. Basic principles of forest fuel reduction treatments. *Forest Ecology and Management* **211**, 83–96 (2005).

Ager, A., Vaillant, N. & Finney, M. A comparison of landscape fuel treatment strategies to mitigate wildland fire risk in the urban interface and preserve old forest structure. *Forest Ecology and Management* **259**, 1556–1570 (2010).

Calkin, D. E., Ager, A. A. & Gilbertson-Day, J. *Wildfire risk and hazard: procedures for the first approximation*. (U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 2010). doi:10.2737/RMRS-GTR-235

[19] Scott, Joe H., Matthew P. Thompson, and David E. Calkin. 2013. A Wildfire Risk Assessment Framework for Land and Resource Management. RMRS-GTR-315. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Fulé, P. Z., Waltz, A. E. M., Covington, W. W. & Heinlein, T. A. Measuring Forest Restoration Effectiveness in Reducing Hazardous Fuels.

Huggett, R. J., Abt, K. L. & Shepperd, W. Efficacy of mechanical fuel treatments for reducing wildfire hazard. *Forest Policy and Economics* **10**, 408–414 (2008).

Nolet, P., Kneeshaw, D., Messier, C. & Béland, M. Comparing the effects of even- and uneven-aged silviculture on ecological diversity and processes: A review. *Ecology and Evolution* **8**, 1217–1226 (2018).

Pollet, J. & Omi, P. N. EFFECT OF THINNING AND PRESCRIBED BURNING ON WILDFIRE SEVERITY IN PONDEROSA PINE FORESTS. *The Joint Fire Science Conference and Workshop*

Romme, W. H., Barry, P. J., Hanna, D. D., Floyd, M. L. & White, S. A Wildfire Hazard Assessment and Map for La Plata County, Colorado, USA. *Fire Ecology* **2**, 7–30 (2006).

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