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MEMORANDUM

To:	M. Michael Naim
From:	Michael Huff, Principal
Subject:	FlamMap Fire Behavior Modeling, West Hills Crest Project
Date:	October 7, 2015
cc:	Jim Hunt, Hunt Research Corp.
	Scott Eckardt, Dudek
Attachment(s):	1. Map: Flame Length – Summer Fire, Existing Condition
	2. Map: Flame Length – Fall Fire, Existing Condition
	3. Map: Flame Length – Summer Fire, Post-Development Condition
	4. Map: Flame Length – Fall Fire, Post-Development Condition

In support of this project, Dudek utilized the FlamMap fire behavior modeling software package to analyze two different fire scenarios each for the existing condition and post-development condition on the West Hills Crest Project (project) site. The FlamMap software package is a publicly available resource available through the Fire, Fuel, and Smoke Science Program of the United States Department of Agriculture, Forest Service[1]. FlamMap is a geographic information systems (GIS)-based software package that models potential fire behavior for constant environmental conditions (weather and fuel moisture) and generates map files of potential fire behavior characteristics (e.g., spread rate, flame length, crown fire activity). FlamMap outputs represent fire behavior calculated for each pixel within the analysis area independently and does not calculate fire spread across a landscape. The software requires a minimum of five input variables, including elevation, slope, aspect, fuel model, and canopy cover. Wind and weather data are also critical components to FlamMap modeling efforts. The following sections present a background on fire behavior modeling and present the methods and data sources used in performing the FlamMap fire behavior modeling analysis for the project site.

FLAMMAP FIRE BEHAVIOR MODELING

Predicting wildland fire behavior is not an exact science due to the many variables that must be considered. As such, the movement of a fire will likely never be fully predictable, especially considering the variations in weather and the limits of weather forecasting and the weather that is often "created" by firestorms. Nevertheless, practiced and experienced judgment, coupled with a

[1] http://firelab.org/project/flammap

validated fire behavior modeling system, results in useful and accurate fire information[2]. To be used effectively, the basic assumptions and limitations of fire behavior modeling applications must be understood.

- First, it must be realized that the fire model describes fire behavior only in the flaming front. The primary driving force in the predictive calculations is the dead fuels less than 0.25 inches in diameter. These are the fine fuels that carry fire. Fuels greater than 1 inch have little effect, while fuels greater than 3 inches have no effect on fire behavior.
- Second, the model bases calculations and descriptions on a wildfire spreading through surface fuels that are within 6 feet of the ground and contiguous to the ground. Surface fuels are often classified as grass, brush, litter, or slash.
- Third, the software assumes that weather and topography are uniform. However, because wildfires almost always burn under non-uniform conditions, creating their own weather, length of projection period and choice of fuel model must be carefully considered to obtain useful predictions.
- Fourth, fire behavior computer modeling systems are not intended for determining sufficient fuel modification zone/defensible space widths. However, it does provide the average length of the flames, which is a key element for determining defensible space distances for minimizing structure ignition.

Although FlamMap has limitations, it can still provide valuable fire behavior predictions, which can be used as a tool in the decision-making process. In order to make reliable estimates of fire behavior, one must understand the relationship of fuels to the fire environment and be able to recognize the variations in these fuels. Natural fuels are made up of the various components of vegetation, both live and dead, that occur in a particular landscape. The type and quantity will depend upon soil, climate, geographic features, and fire history. The major fuel groups of grass, shrub, trees, and slash are defined by their constituent types and quantities of litter and duff layers, dead woody material, grasses and forbs, shrubs, regeneration, and trees. Fire behavior can be predicted largely by analyzing the characteristics of these fuels. Fire behavior is affected by seven principal fuel characteristics: fuel loading, size and shape, compactness, horizontal continuity, vertical arrangement, moisture content, and chemical properties.

The seven fuel characteristics help define the 13 standard fire behavior fuel models[3] and the more recent custom fuel models developed for Southern California[4]. According to the model

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[2] Rothermel, Richard C. 1983. How to Predict the Spread and Intensity of Forest and Range Fires. USDA Forest Service Gen. Tech. Report INT-143. Intermountain Forest and Range Experiment, Ogden, Utah. http://www.treesearch.fs.fed.us/pubs/24635

classifications, fuel models used for fire behavior modeling (BehavePlus, FlamMap, FARSITE) have been classified into four groups, based upon fuel loading (tons/acre), fuel height, and surface-to-volume ratio. Observation of the fuels in the field (on site) determines which fuel models should be applied in modeling efforts. The following describes the distribution of fuel models among general vegetation types for the standard 13 fuel models and the custom Southern California fuel models:

- Grasses – Fuel Models 1 through 3
- Brush – Fuel Models 4 through 7, SCAL 14 through 18
- Timber – Fuel Models 8 through 10
- Logging slash – Fuel Models 11 through 13.

In addition, the aforementioned fuel characteristics were utilized in the recent development of 40 new fire behavior fuel models[5] developed for use in the BehavePlus, FlamMap, and FARSITE modeling systems. These new models attempt to improve the accuracy of the 13 standard fuel models outside of severe fire season conditions, and to allow for the simulation of fuel treatment prescriptions. The following describes the distribution of fuel models among general vegetation types for the 40 new fuel models:

- Non-burnable – Models NB1, NB2, NB3, NB8, NB9
- Grass – Models GR1 through GR9
- Grass shrub – Models GS1 through GS4
- Shrub – Models SH1 through SH9
- Timber understory – Models TU1 through TU5
- Timber litter – Models TL1 through TL9
- Slash blowdown – Models SB1 through SB4.

Table 1 provides a description of 9 fuel models (including one non-burnable model) coded for the site that were subsequently used in the on-site FlamMap analysis for this project.

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[3] Anderson, Hal E. 1982. Aids to Determining Fuel Models for Estimating Fire Behavior. USDA Forest Service Gen. Tech. Report INT-122. Intermountain Forest and Range Experiment Station, Ogden, Utah. http://www.fs.fed.us/rm/pubs_int/int_gtr122.pdf

[4] Weise, D.R. and J. Regelbrugge. 1997. Recent chaparral fuel modeling efforts. Prescribed Fire and Effects Research Unit, Riverside Fire Laboratory, Pacific Southwest Research Station. 5p.

[5] Scott, Joe H. and Robert E. Burgan. 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, Colorado: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.

Table 1
On-Site Fuel Model Characteristics

Fuel Model	Description	Land Cover Classification	Canopy Cover Value
0	Non-burnable	Barren or Sparsely Vegetated	0
2	Timber with Grass and Understory	Coast Live Oak Woodland/Purple Sage – California Sagebrush; California Walnut Groves/California Sagebrush; Native/Non-Native Grasses/Forbs + Sawtooth Goldenbush Scrub; Sawtooth Goldenbush Scrub; Individual California Black Walnut Trees with Grass/Scrub Understory	0 (scrub); 2 (woodland); 3 (individual tree overstory)
GR1	Short, Sparse Dry Climate Grass	Fuel Reduction Area (disced)	0
GR2	Low Load, Dry Climate Grass	California Walnut Groves/Annual Grass-Herb	2
GR4	Moderate Load, Dry Climate Grass	Native and Non-Native Grasses and Forbs; Individual Valley Oak, California Black Walnut, and Coast Live Oak Trees with Grass Understory	0 (grass); 3 (individual tree overstory)
SCAL 18	Coastal Sage Scrub	California Sagebrush – California Buckwheat - Black Sage Scrub; California Sagebrush – California Buckwheat Scrub; Narrowleaf Stillingia; California Sagebrush Scrub; California Buckwheat Scrub; Individual California Black Walnut and Coast Live Oak Trees with Scrub Understory	0 (scrub); 3 (individual tree overstory)
SH2	Moderate Load Dry Climate Shrub	Coyote Brush – California Sagebrush Scrub; Coastal Goldenbush Scrub; California Encelia Scrub; Individual California Black Walnut Trees with Shrub Understory	0 (shrub); 3 (individual tree overstory)
SH5	High Load, Dry Climate Shrub	Purple Sage Scrub; Bush Mallow – Laurel Sumac Scrub; Laurel Sumac – California Sagebrush Scrub; Laurel Sumac Scrub; Purple Sage – California Sagebrush Scrub; Laurel Sumac Scrub; Bush Mallow – Purple Sage Scrub; Bush Mallow – Black Sage Scrub; Individual California Black Walnut and Coast Live Oak Trees with Shrub Understory	0 (shrub); 3 (individual tree overstory)
TL6	Moderate Load Broadleaf Litter	Coast Live Oak – California Walnut Woodland; Coast Live Oak Woodland	2 (oak/walnut woodland), 3 (oak woodland)

FlamMap Analysis

FlamMap software was utilized to graphically depict potential fire behavior for the project site. FlamMap utilizes the same fire spread equations built into the BehavePlus software package, but allows for a geographical presentation of fire behavior outputs as it applies the calculations to each pixel in the associated GIS landscape[6]. Both summer weather conditions (on-shore flow) and more extreme fall weather conditions (off-shore, Santa Ana conditions) were modeled for both the existing site condition and the proposed post-development site condition.

FlamMap software requires a minimum of five (5) separate input files that represent field conditions in the analysis area, including elevation, slope, aspect, fuel model, and canopy cover. Each of these files was created as a raster GIS file using ArcGIS 10.3.1 software, exported as an ASCII grid file, then utilized in creating a FARSITE Landscape file that served as the base for the FlamMap runs. The resolution of each grid file and associated ASCII file that was used in the models described herein is 3 meters, based on available digital terrain data (described below). In addition to the Landscape file, wind and weather data are incorporated into the model inputs. The output fire behavior variable chosen for each of the modeling runs was flame length, measured in feet.

The following paragraphs provide descriptions of the input and output variables used in processing the FlamMap models. In addition, data sources are cited and any assumptions made during the modeling process are described.

Elevation

Elevation data were derived from a 3 meter resolution Interferometric Synthetic Aperture Radar (IfSAR) measurement for coastal Southern California, acquired from the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center and projected in the NAD 1983, California State Plane, Zone 5 coordinate system, with units in feet. Elevation values on the property range from approximately 975 to 1,350 feet above mean sea level (AMSL). This data were utilized to create an elevation grid file, using units of feet above mean sea level. The elevation data are a required input file for FlamMap runs and are necessary for adiabatic adjustment of temperature and humidity and for conversion of fire spread between horizontal and slope distances.

Slope

Using ArcGIS Spatial Analyst tools, a slope grid file was generated from the elevation grid file described above. Slope measurements utilized values in percent of inclination from horizontal. Slope values in the analysis area range from 0–115%. The slope input file is necessary for computing slope effects on fire spread and solar radiance.

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[6] Finney, M.A. 1998. FARSITE: Fire Area Simulator—model development and evaluation. Res. Pap. RMRS-RP-4, Ogden, Utah: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.

Aspect

Using ArcGIS Spatial Analyst tools, an aspect grid file was generated from the elevation grid file described above. The aspect values utilized were azimuth degrees. Aspect values are important in determining the solar exposure of grid cells.

Fuel Model

Vegetation coverage data in the form of a GIS shapefile[7] were used in this analysis to create a fuel model file for existing conditions, which was derived from vegetative cover data mapped for the project site. Vegetation mapping data was utilized to classify vegetation cover type with an appropriate fuel model. Fuel model assignments for existing vegetation are presented in Table 1.

To analyze post-development fire behavior, a separate fuel model shapefile was created using the existing vegetation coverage and reclassifying fuels based on location within the proposed development. All fuels within areas proposed for conversion to non-fuel types (e.g., roads, driveways, structures) were reclassified as Fuel Model “0” to represent developed, non-combustible land uses. Post-development fuel model classification for non-developed areas within the project site were classified as follows:

- Fuel Modification Zone A: Fuel Model 8
- Fuel Modification Zone B: Fuel Model GR1
- Fuel Modification Zone C and Roadside Fuel Modification Zones: Fuel Model TU1
- Irrigated Landscape Areas: Fuel Model 8

Table 2 provides a description of 9 fuel models (including one non-burnable model) coded for the post-development site condition (including developed and non-developed areas) that were subsequently used in the on-site, post-development FlamMap analysis for this project.

Table 2
On-Site Fuel Model Characteristics for Post-Development Condition

Fuel Model	Description	Land Cover Classification	Canopy Cover Value
0	Non-burnable	Developed, Paved Areas, Buildings	0
1	Short Grass	Annual Grassland, Annual Grassland/Rock Outcrop, Disturbed	0

[7] Envicom 2015

Fuel Model	Description	Land Cover Classification	Canopy Cover Value
8	Closed Timber Litter	Coast Live Oak/Riparian Woodland, Wetlands. Fuel Modification Zone A, Irrigated Landscape Areas	3 (Woodland), 0 (FMZ A, Irrigated Landscape Areas)
SCAL18	Sage/Buckwheat	Mixed Scrub, Disturbed Mixed Scrub	0
GR1	Short, Sparse Dry Climate Grass	Agriculture, Fuel Modification Zone B	0
SH3	Moderate Load, Humid Climate Shrub	Restored Riparian Scrub, Wetlands with Mulefat Scrub,	0
SH5	High Load, Dry Climate Shrub	Chaparral	0
TU1	Low Load Dry Climate Timber-Grass-Shrub	Fuel Modification Zone C, Roadside Fuel Modification Zones	0

Once fuel model values were assigned to vegetation or land cover types, the vector-based vegetation data files (existing and proposed) were converted to grid files for inclusion in FlamMap modeling.

Canopy Cover

Canopy Cover is a required raster file for FlamMap operations. It is necessary for computing shading and wind reduction factors for all fuel models. Canopy cover is measured as the horizontal fraction of the ground that is covered directly overhead by tree canopy. Crown closure refers to the ecological condition of relative tree crown density. Stands can be said to be “closed” to recruitment of canopy trees but still only have 40% or 50% canopy cover. Coverage units can be categories (0–4) or percentage values (0–100).

For the purposes of the FlamMap analysis, Dudek utilized vegetation type classifications to determine canopy cover assignments. Canopy cover assignments are presented in Tables 1 and 2, by fuel model.

Weather

In order to utilize weather and fuel moisture variables for the project site, data from the Cheseboro Remote Automated Weather Station (RAWS) was analyzed. Utilization of RAWS data is necessary for fire behavior modeling as it includes data for fuel moisture conditions, and, as of the date of this memorandum, no RAWS are located on the project site. The Cheseboro RAWS is located approximately 3 miles to the west of the West Hills Crest property. The following summarizes the location and available data ranges for the Cheseboro RAWS:

- Latitude: 34.18639
- Longitude: -118.71944
- Elevation: 1,707 feet

- Data years: 1995–2014.

Wind and weather data are a required component to fire behavior modeling efforts. The Cheseboro RAWS data was processed with the FireFamily Plus v. 4.1.0 (FireFamily Plus 2007) software package to determine summer (50th percentile) and fall (97th percentile) weather conditions to be incorporated into the Initial Fuel Moisture file used as an input in FlamMap. Wind direction and wind speed values for the FlamMap runs were manually entered during the data input phase. Table 3 summarizes weather and fuel moisture data inputs used for both summer and fall weather conditions.

Table 3
FlamMap Weather Input Variables

Model Variable	50th Percentile Weather (June 1 – August 31)	97th Percentile Weather (September 1 – November 30)
1 h fuel moisture	5%	2%
10 h fuel moisture	6%	3%
100 h fuel moisture	11%	4%
Live herbaceous moisture	60%	30%
Live woody moisture	92%	59%
20 ft. wind speed (mph)	7 mph	19 mph (max. 39 mph)
Wind direction	uphill	30 degrees
Slope steepness	Variable by location	Variable by location

mph = miles per hour

FlamMap Fuel Model Outputs

One output grid file was generated for each of the FlamMap runs and represents flame length (feet) values in existing and proposed site conditions during summer and peak weather scenarios. Flame length, the length of the flame of a spreading surface fire within the flaming front, is measured from midway in the active flaming combustion zone to the average tip of the flames[8]. It is a somewhat subjective and non-scientific measure of fire behavior, but is extremely important to fireline personnel in evaluating fireline intensity and is worth

[8] Andrews, Patricia L.; Bevins, Collin D.; Seli, Robert C. 2008. BehavePlus fire modeling system, version 4.0: User's Guide Revised. Gen. Tech. Rep. RMRS-GTR-106WWW Revised. Ogden, Utah: Department of Agriculture, Forest Service, Rocky Mountain Research Station. 123p.

considering as an important fire variable[9]. The information in Table 4 presents an interpretation of flame length and its relationship to fireline intensity.

Table 4
Fire Suppression Interpretation

Flame Length (feet)	Fireline Intensity (Btu/ft/s)	Interpretations
Under 4	Under 100	Fires can generally be attacked at the head or flanks by persons using hand tools. Hand line should hold the fire.
4—8	100—500	Fires are too intense for direct attack on the head by persons using hand tools. Hand line cannot be relied on to hold the fire. Equipment such as dozers, pumpers, and retardant aircraft can be effective.
8—11	500—1,000	Fires may present serious control problems—torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.
Over 11	Over 1,000	Crowning, spotting, and major fire runs are probable. Control efforts at head of fire are ineffective.

Source: BehavePlus 5.0.5 Online Documentation, March 16, 2010. BehavePlus Fire Modeling System: Version 4.0 User's Guide (Andrews, Bevins, and Seli 2008)

Maps depicting flame length values for the 50th percentile weather scenario (summer) and the peak (fall) weather scenario for existing conditions are included in Attachments 1 and 2, respectively. Maps depicting flame length values for the 50th percentile weather scenario (summer) and the peak (fall) weather scenario for post-development conditions are included in Attachments 3 and 4, respectively. The fire behavior modeling results vary depending on topography and fuel type. As FlamMap utilizes site-specific digital terrain data (including slope, vegetation, aspect, and elevation data) slight variations in predicted flame length values can be observed based on fluctuations of these attributes across the landscape. As presented, wildfire behavior in each of the fuel types varies depending on weather conditions.

When classifying vegetation types into fuel models, efforts were made to most accurately represent the fuel type observed. However, the scale at which the vegetation mapping was conducted did not allow for small-scale fuel mapping within a larger vegetation type classification. For example, small pockets of tall grass within a larger area classified as scrub were not separated for this analysis. Second, the fuel models selected to represent post-developed conditions were selected based on expected fire behavior in these fuel types, as no available fuel models exist for managed and/or irrigated landscape vegetation.

[9] Rothermel, Richard C. 1983. How to Predict the Spread and Intensity of Forest and Range Fires. USDA Forest Service Gen. Tech. Report INT-143. Intermountain Forest and Range Experiment, Ogden, Utah. http://www.treesearch.fs.fed.us/pubs/24635