Appendix A

Wildfire Hazard Analysis Methodology

Purpose

The purpose of this appendix is to describe the methodology used to estimate the physical hazard fuels weather and topography represent to values-at-risk in the study area by modeling their effects on fire behavior potential.

Model Description

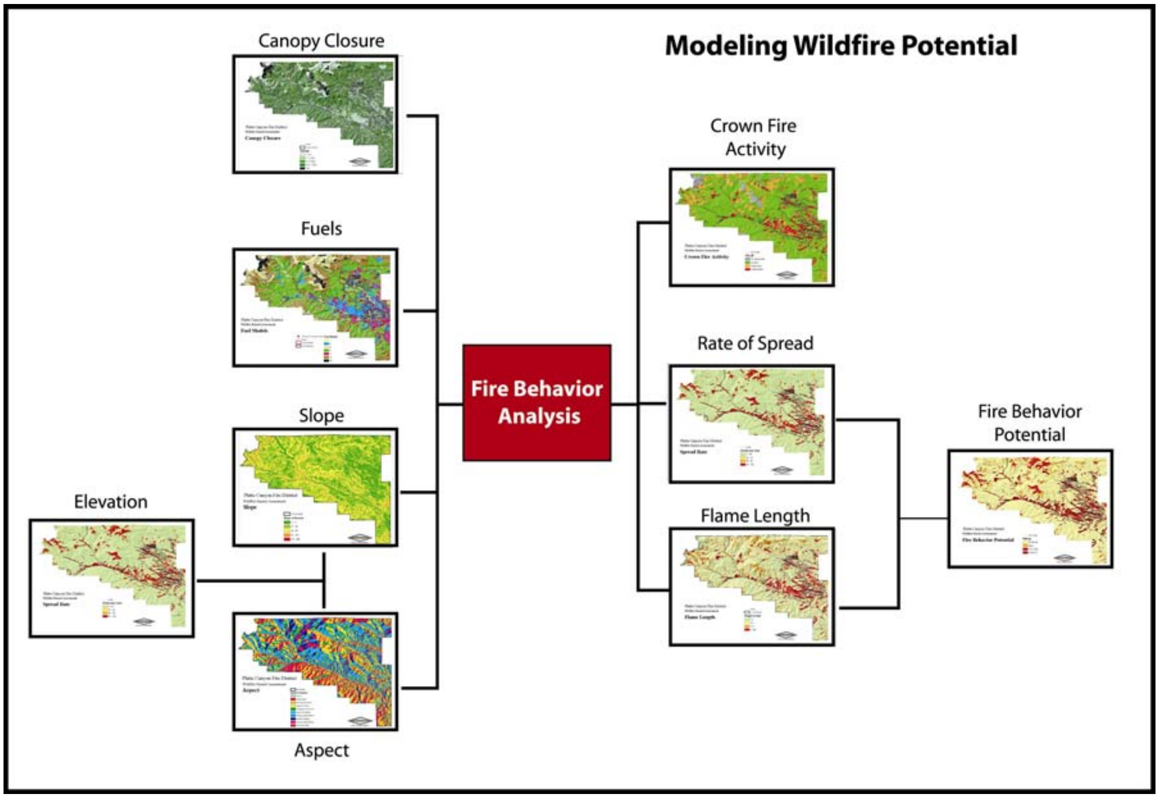

Figure 1: Model Description

The Wildfire Hazard classification represents a relative ranking of locations based upon expected surface fire intensity. The model inputs for surface fire behavior include aspect, slope, elevation, canopy cover and fuel type. The hazard level is determined using **FlamMap** which models wildfire behavior potential. Calculations are based on the USDA Forest Service's fire behavior model **BEHAVE**. **BEHAVE** is a nationally recognized set of calculations to estimate a fire's intensity and rate of spread given certain conditions of topography, fuels and weather.

FlamMap

RedZone Software uses **FlamMap** developed by Systems for Environmental Management (Missoula, Montana) and the Fire Sciences Laboratory of the Rocky Mountain Research Station (USDA Forest Service, Missoula, Montana) to evaluate the potential fire conditions in the study area. The Golden Gate Fire Protection District study area encompasses approximately 31,000 acres (49 square miles), which are broken down into 10 meter (m) grids. Using **FlamMap**'s spatial analysis capabilities, each 10 meter square (sq) grid is queried for its elevation, slope, aspect and fuel type. These values are input into **FlamMap,** along with reference weather information. The outputs of **FlamMap** include the estimated Rate of Spread (ROS), Flame Length (FL) (from **BEHAVE**) and Crown Fire Activity for a fire in that 10m sq grid. The model computes these values for each grid cell in the study area.

BEHAVE Modeling

- The **BEHAVE** modeling system has been used for a variety of applications including prediction of an ongoing fire, prescribed fire planning, fuel hazard assessment, initial attack dispatch and fire prevention planning and training. Predictions of wildland fire behavior are made for a single point in time and space given simple user-defined fuels, weather and topography.

Assumptions of **BEHAVE**

- Fire is predicted at the flaming front
- Fire is free burning
- Behavior is heavily weighted towards the fine fuels
- Continuous and uniform fuels
- Surface fires

Fire Behavior Inputs

Fire behavior is dependant upon aspect, slope, elevation, canopy cover and fuel type. The following pages contain an explanation of each.

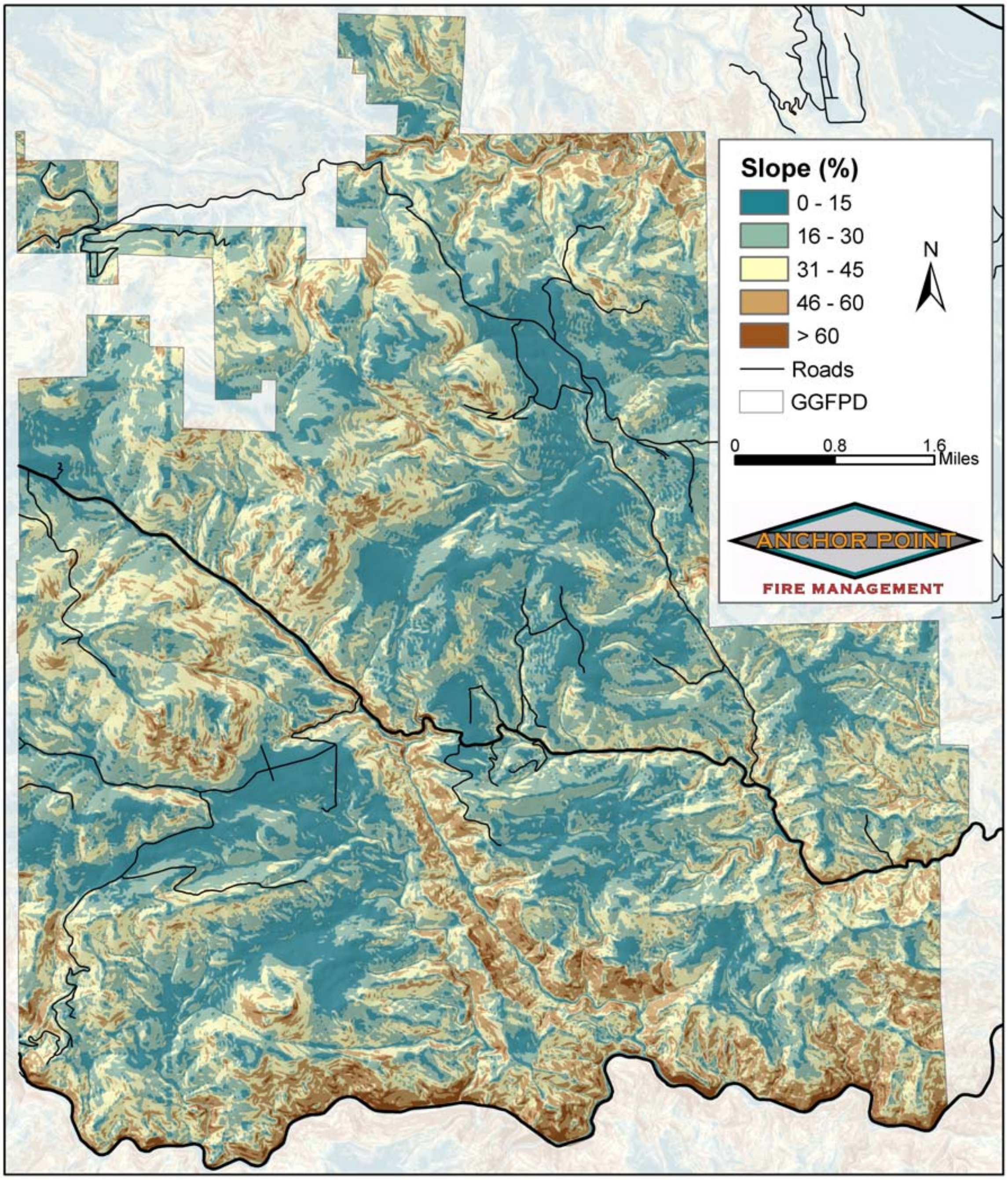

Figure 2: Slope

Slopes are shown here as percent (rise/run x100). Steeper slopes intensify fire behavior and thus will contribute to a high wildfire hazard rating. Rates of spread for a slope of 30% are typically double those of flat terrain when all other influences are equal.

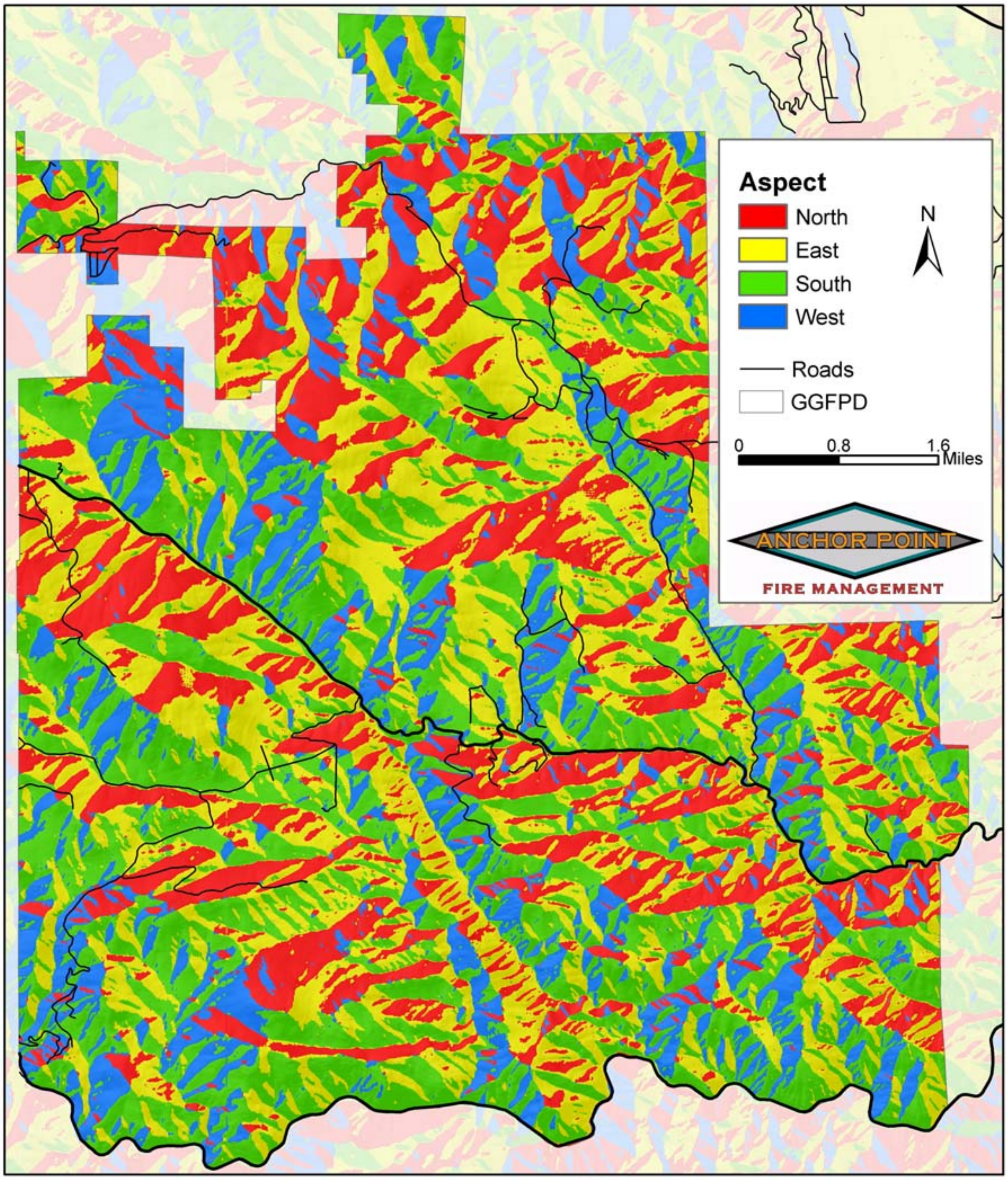

Figure 3: Aspect

Aspects are shown as degrees from North ranging from 0 to 360 according to their orientation. Aspects are influential in the type and quantity of vegetative fuels. Fuels on south facing slopes tend to be drier and more lightly loaded than fuels on north facing slopes when all other influences are equal. Aspect also has an influence on species dominance.

Classification	North	East	South	West
Range	315-45	45-135	135-225	225-315

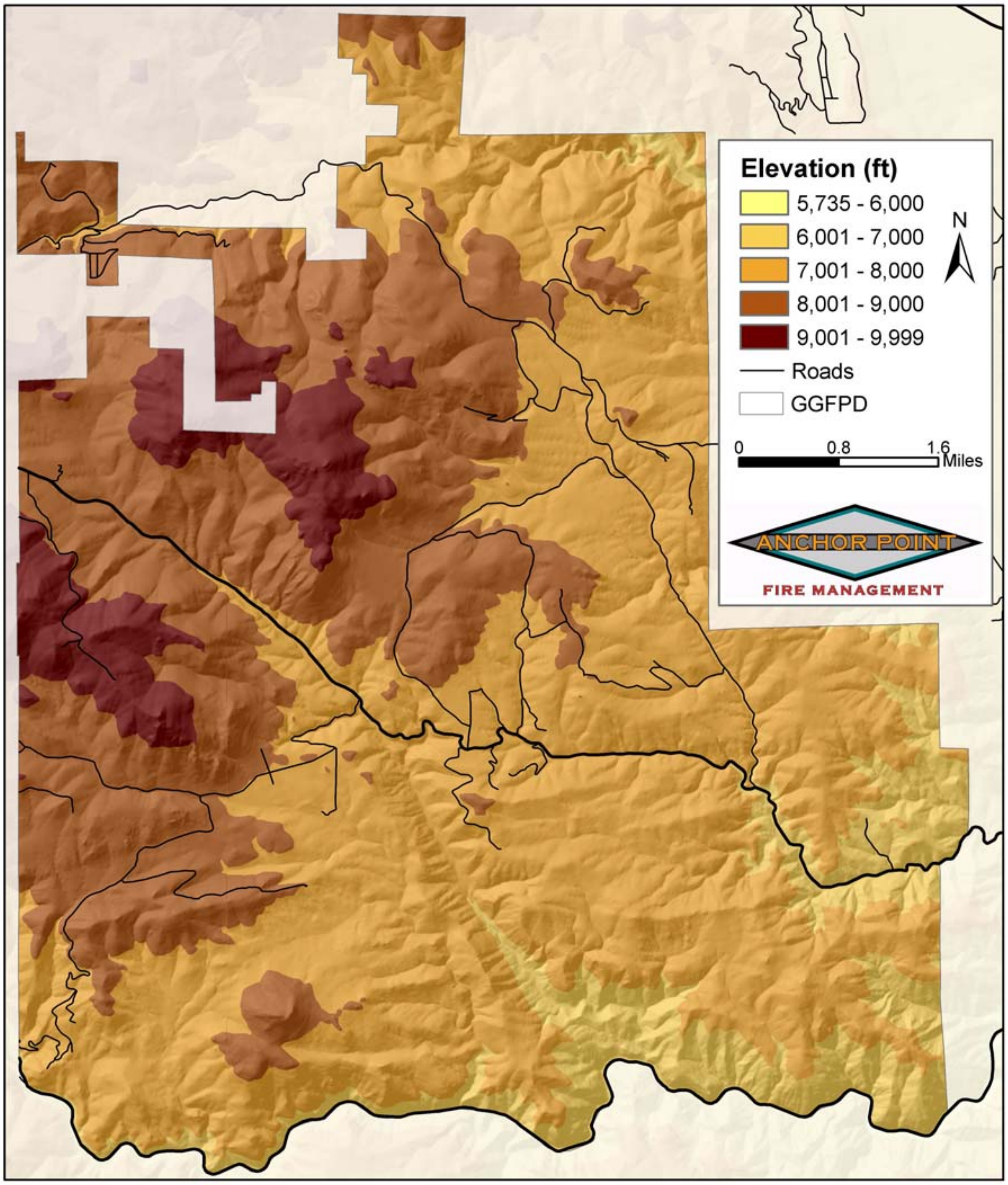

Figure 4: Elevations

Elevations within Golden Gate FPD vary from 5,700' to almost 10,000'. As elevation increases, fuel loading and available oxygen for combustion change. Above tree line, fuels become sparse and the natural burn interval is measured in centuries.

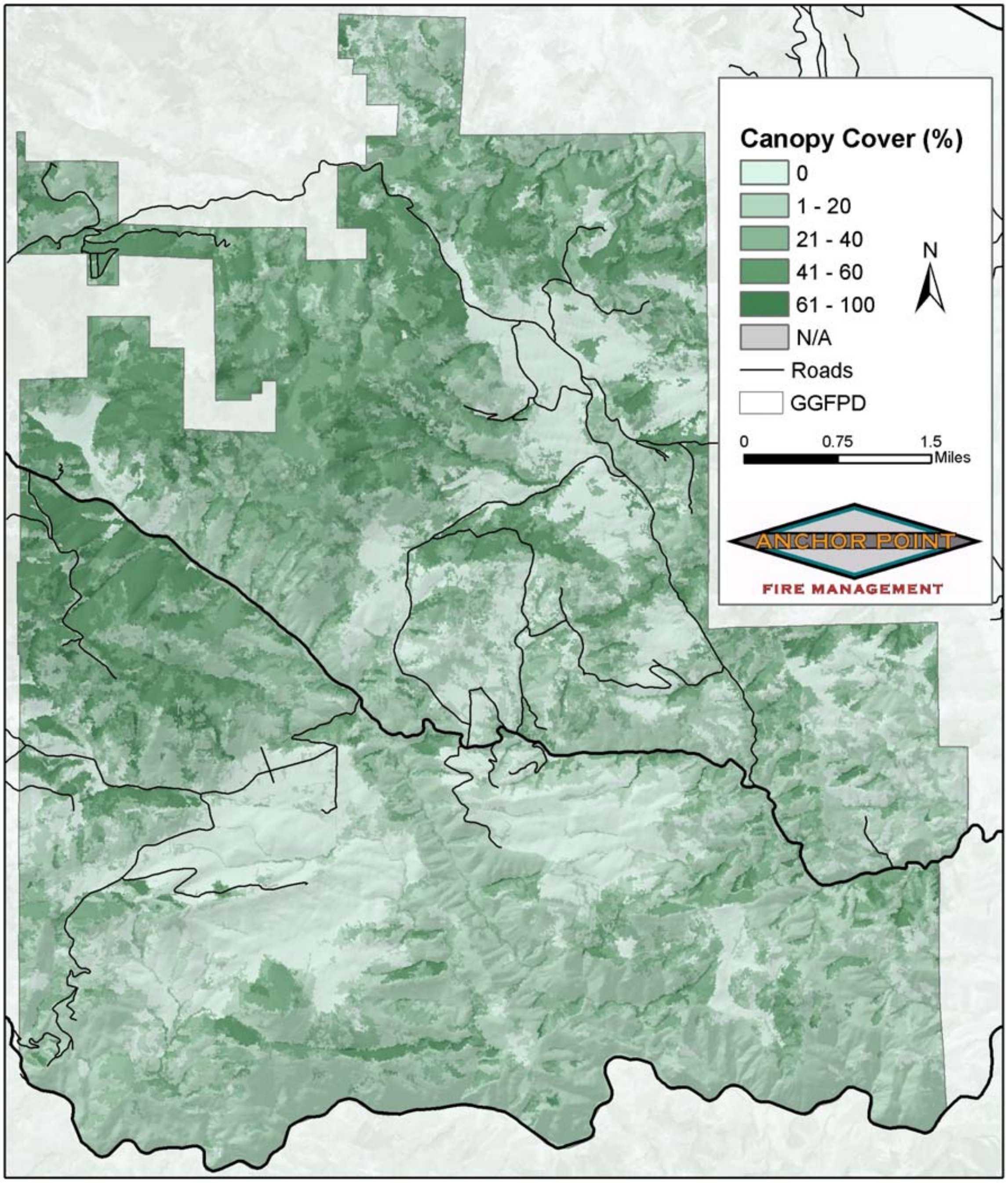

Figure 5: Canopy Cover

Canopy cover is the horizontal percentage of the ground surface that is covered by tree crowns. Canopy cover is measured as the horizontal fraction of the ground that is covered directly overhead by tree canopy. Coverage units are in four categories. 1=1-20%. 2=21-50%. 3=51-80%. 4= 81-100%. Coverage has a direct effect on the type and amount of surface fuels available for burning through shading. Canopy cover is also a measure of the horizontal continuity of aerial fuels. Heavier canopy cover allows for an easier transmission of fire from crown to crown.

Fuel Models And Fire Behavior

Fuel models are a set of numbers that describe the fuel in terms that a fire spread model can use. There are seven characteristics that are used to categorize fuel models.

- Fuel Loading
- Size and Shape
- Compactness
- Horizontal Continuity
- Vertical Arrangement
- Moisture Content
- Chemical Content

The study area is represented primarily by five fuel models (FM): FM 1, 2, 8, 9 and 10 (Anderson, 1982). Other fuel models exist, but not in enough quantity to significantly influence fire behavior in the Wildland-Urban Interface. Each of the major fuel types present are described below with a table showing a range of fire behavior based on the **BEHAVE** system. Figure 6 displays the fuel types graphically for Golden Gate FPD.

The **BEHAVE** Fire Behavior Prediction and Fuel Modeling System was utilized to help determine the wildfire hazard for this study. It has been used for a variety of applications including prediction of an ongoing fire, prescribed fire planning, fuel hazard assessment, initial attack dispatch, fire prevention planning and training. Predictions of wildland fire behavior are made for a single point in time and space given simple user-defined fuels, weather, and topography. Requested values depend on the modeling choices made by the user. For example, fuel model, fuel moisture, wind speed and direction, terrain and slope are used to calculate rate of spread, flame length and intensity.

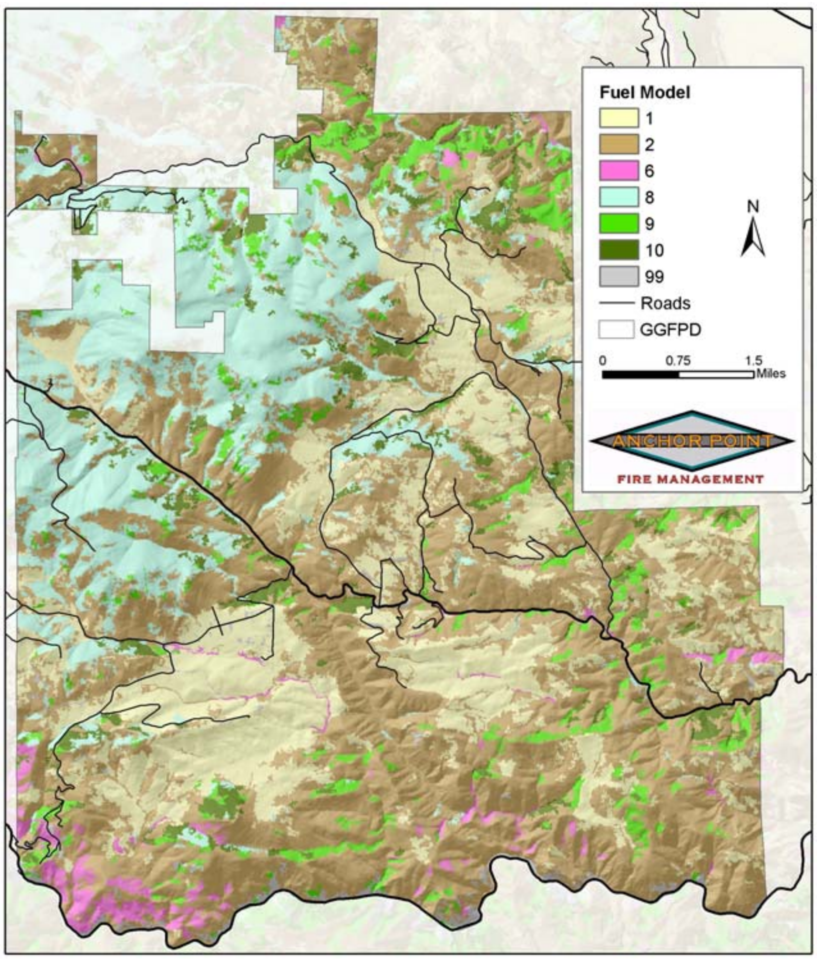

Figure 6: Golden Gate FPD Fuel Models

FUEL MODEL 1[1]

Figure 7: Short Grasses

Characteristics
Grasslands and savanna are represented along with stubble, grass-tundra and grass-shrub combinations.

Common Types/Species
Annual and perennial grasses are included in this fuel model.

Fire Behavior
Fire spread is governed by the fine, very porous and continuous herbaceous fuels that have cured or are nearly cured. Fires in this fuel model are surface fires that move rapidly through the cured grass and associated material. Very little shrub or timber is present, generally less than one-third of the area.

Rate of spread in chains/hour (1 chain=66 ft)

		Mid-flame Wind Speed					
Fine Dead Fuel moisture %		2.0	4.0	6.0	8.0	10.0	12.0
	2.0	28.8	92.9	203.6	362.4	570.1	665.6
	4.0	22.0	71.1	155.7	277.0	345.1	345.1
	6.0	19.4	62.4	136.8	243.4	270.1	270.1
	8.0	16.7	53.9	118.1	198.7	198.7	198.7
	10.0	11.0	35.6	64.8	64.8	64.8	64.8

10 hr fuel=5%, 100 hr fuel=6%, herbaceous fuel moisture=100%, slope=10%

[1] Hal Anderson, "Aids to Determining Fuel Models for Estimating Fire Behavior" (Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station 22 p. [NFES 1574], 1982).

Flame Length in Feet

		Mid-flame Wind Speed					
		2.0	4.0	6.0	8.0	10.0	12.0
Fine Dead Fuel moisture %	2.0	3.0	5.1	7.3	9.6	11.8	12.7
	4.0	2.4	4.1	5.9	7.8	8.6	8.6
	6.0	2.2	3.8	5.5	7.1	7.5	7.5
	8.0	2.0	3.4	4.9	6.3	6.3	6.3
	10.0	1.4	2.4	3.2	3.2	3.2	3.2

FUEL MODEL 2[2]

Figure 8: Timber with Grass Understory

Characteristics

This type consists of open grown pine stands. Trees are widely spaced with few understory shrubs or regeneration. Ground cover consists of mountain grasses/and or needles and small woody litter. This model occurs in open-grown and mature ponderosa pine stands in the Foothill to Montane zones. Open shrub lands and pine stands or scrub oak stands that cover one-third to two-thirds of the area may generally fit this model; such stands may include clumps of fuels that generate higher intensities and that may produce firebrands. Scattered sage within grasslands and some pinyon-juniper may be in this model.

Common Species/Species

The dominant tree species is ponderosa pine. This type may include some scattered Douglas-fir. Other tree and shrub species include common and Rocky Mountain juniper, buckbrush, sage, bitter brush, and mountain mahogany. Mountain grasses are included in this model.

Fire Behavior

Fire spread is primarily through the fine herbaceous fuels, either curing or dead. These are surface fires where the herbaceous material, in addition to litter and dead-down stem wood from the open shrub or timber overstory, contribute to the fire intensity.

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[2] Hal Anderson, "Aids to Determining Fuel Models for Estimating Fire Behavior" (Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station 22 p. [NFES 1574], 1982).

Rate of spread in chains/hour (1 chain=66 ft)

	Mid-flame Wind Speed					
Fine Dead Fuel moisture %	2.0	4.0	6.0	8.0	10.0	12.0
2.0	12.4	34.2	67.5	111.6	166.0	230.2
4.0	10.2	28.0	55.3	91.4	135.9	188.5
6.0	9.0	24.9	49.1	81.2	120.8	167.6
8.0	8.3	22.9	45.3	74.9	111.3	154.4
12.0	7.4	20.5	40.5	67.0	99.7	138.3

10 hr fuel=5%, 100 hr fuel=6%, herbaceous fuel moisture=100%, slope=10%

Flame Length in Feet

	Mid-flame Wind Speed					
Fine Dead Fuel moisture %	2.0	4.0	6.0	8.0	10.0	12.0
2.0	4.3	6.9	9.4	11.8	14.2	16.5
4.0	3.7	5.8	8.0	10.1	12.1	14.0
6.0	3.4	5.4	7.3	9.2	11.1	12.9
8.0	3.2	5.1	6.9	8.7	10.5	12.2
10.0	2.9	4.7	6.4	8.1	9.7	11.2

FUEL MODEL 8[3]

Figure 9: Timber Litter, Light Fuel Load

Characteristics
Closed canopy stands of short-needle conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly needles, leaves, and occasionally twigs because little undergrowth is present in the stand. Amounts of needle and woody litter are also low. This fuel model occurs at higher elevations in the Montane zone.

Common Types/Species
Representative conifer types are white pine, lodgepole pine, spruce, fir, and larch but ponderosa pine can also be included. Closed stand of birch-aspen with leaf litter compacted and western hemlock stands are also representative. There are little or no understory plants.

Fire Behavior
Fires in this fuel model are slow burning, low intensity fires burning in surface fuels. Fuels are mainly needles and woody litter. Heavier fuel loadings can cause flare-ups. Heavier fuel loads have the potential to develop crown fires in extreme burning conditions.

Rate of spread in chains/hour (1 chain=66 ft)

		Mid-flame Wind Speed					
Fine Dead Fuel moisture %		2.0	4.0	6.0	8.0	10.0	12.0
	2.0	1.1	2.3	3.9	5.7	7.8	10.1
	4.0	0.9	1.9	3.2	4.7	6.4	6.9
	6.0	0.7	1.6	2.6	3.9	4.9	4.9
	8.0	0.6	1.4	2.3	3.4	3.8	3.8
	10.0	0.6	1.2	2.0	3.0	3.1	3.1
	12.0	0.5	1.1	1.8	2.7	2.7	2.7

10 hr fuel=5%, 100 hr fuel=6%, herbaceous fuel moisture=100%, slope=10%

[3] Hal Anderson, "Aids to Determining Fuel Models for Estimating Fire Behavior" (Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station 22 p. [NFES 1574], 1982).

Flame Length in Feet

		Mid-flame Wind Speed					
Fine Dead Fuel moisture %		2.0	4.0	6.0	8.0	10.0	12.0
	2.0	0.9	1.3	1.7	2.0	2.3	2.6
	4.0	0.8	1.1	1.4	1.7	2.0	2.0
	6.0	0.7	1.0	1.2	1.5	1.7	1.7
	8.0	0.6	0.9	1.1	1.3	1.4	1.4
	10.0	0.6	0.8	1.0	1.2	1.3	1.3
	12.0	0.6	0.8	1.0	1.2	1.3	1.3

FUEL MODEL 9[4]

Figure 10: Timber Litter (note heavier surface fuels and understory plants).

Characteristics
Both long-needle conifer stands and hardwood stands, especially the oak-hickory types, are typical. Concentrations of dead-down woody material will contribute to possible torching out of trees, spotting and crowning.

Common Types/Species
Closed stands of long-needled pine like ponderosa, Jeffrey, and red pines, or southern pine plantations are grouped in this fuel model.

Fire Behavior
Fires in this fuel model run through the surface litter faster than model 8 and have longer flame height. Fall fires in hardwoods are predictable, but high winds will actually cause higher rates of spread than predicted because of spotting caused by rolling and blowing leaves.

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[4] Hal Anderson, "Aids to Determining Fuel Models for Estimating Fire Behavior" (Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station 22 p. [NFES 1574], 1982).

Rate of spread in chains/hour (1 chain=66 ft)

		Mid-flame Wind Speed					
Fine Dead Fuel moisture %		2.0	4.0	6.0	8.0	10.0	12.0
	2.0	4.0	9.8	18.1	28.7	41.5	56.2
	4.0	3.2	7.7	14.3	22.7	32.7	44.4
	6.0	2.6	6.4	11.8	18.8	27.1	36.7
	8.0	2.3	5.5	10.2	16.3	23.5	31.8
	10.0	2.0	5.0	9.2	14.7	21.2	28.7
	12.0	1.9	4.6	8.5	13.5	19.5	26.5

10 hr fuel=5%, 100 hr fuel=6%, herbaceous fuel moisture=100%, slope=10%

Flame Length in Feet

		Mid-flame Wind Speed					
Fine Dead Fuel moisture %		2.0	4.0	6.0	8.0	10.0	12.0
	2.0	2.3	3.5	4.7	5.8	6.8	7.9
	4.0	1.9	2.9	3.9	4.8	5.7	6.6
	6.0	1.7	2.5	3.4	4.2	5.0	5.7
	8.0	1.5	2.3	3.1	3.8	4.5	5.2
	10.0	1.4	2.2	2.9	3.5	4.2	4.8
	12.0	1.4	2.1	2.7	3.4	4.0	4.6

FUEL MODEL 10[5]

Figure 11: Heavy Timber Litter in Mature Lodgepole Stands

Characteristics

This model is represented by dense stands of over-mature ponderosa pine, lodgepole pine, mixed conifer and continuous stands of Douglas-fir. In all stand types, heavy down material is present. There is also a large amount of dead, down woody fuels. Reproduction may be present, acting as ladder fuels. This model includes stands of budworm killed Douglas-fir, closed stands of ponderosa pine with large amounts of ladder and surface fuels. Stands of lodgepole pine with heavy loadings of downed trees. This model can occur from the foothills through the sub-alpine zone.

Common Types/Species

All types of vegetation can occur in this model, but primary species are, Douglas-fir, ponderosa pine, and lodgepole pine.

Fire Behavior

Fire intensities can be moderate to extreme. Fire moves through dead, down woody material. Torching and spotting are more frequent. Crown fires are quite possible.

Rate of spread in chains/hour (1 chain=66 ft)

		Mid-flame Wind Speed					
Fine Dead Fuel moisture %		2.0	4.0	6.0	8.0	10.0	12.0
	2.0	3.8	8.2	13.7	20.1	27.3	35.1
	4.0	3.3	7.2	12.1	17.8	24.1	31.0
	6.0	3.0	6.6	11.0	16.1	21.8	28.0
	8.0	2.8	6.1	10.2	14.9	20.2	26.0
	10.0	2.6	5.7	9.6	14.1	19.1	24.5
	12.0	2.5	5.5	9.2	13.4	18.2	23.4

10 hr fuel 5%, 100= 6%, woody fuel moisture= 100%, slope 10%

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[5] Hal Anderson, "Aids to Determining Fuel Models for Estimating Fire Behavior" (Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station 22 p. [NFES 1574], 1982).

Flame Length in Feet

		Mid-flame Wind Speed					
		2.0	4.0	6.0	8.0	10.0	12.0
Fine Dead Fuel moisture %	2.0	3.8	5.5	7.0	8.3	9.5	10.7
	4.0	3.5	5.0	6.3	7.5	8.6	9.7
	6.0	3.2	4.6	5.8	6.9	7.9	8.9
	8.0	3.0	4.3	5.5	6.5	7.5	8.4
	10.0	2.9	4.1	5.2	6.2	7.2	8.0
	12.0	2.8	4.0	5.1	6.0	6.9	7.8

Reference Weather Used in the Wildfire Hazard Evaluation

The Wildfire Hazard classification represents a relative ranking of locations based upon expected surface fire intensity. The weather inputs for **FlamMap** were created by using weather data collected at Boulder.

Latitude (dd mm ss)	40 ° 01 ' 05 " N
Longitude (dd mm ss)	105 ° 21 ' 38 " W
Elevation (ft.)	6,775

Weather observations from the Boulder Remote Automated Weather Station (RAWS) were averaged for a ten-year period (May to October 1992-2002) to calculate these conditions. The mean for each variable (1 hr, 10 hr, and 100 hr fuel moisture, woody fuel moisture, herbaceous fuel moisture, and wind speed) was calculated. The average of each mean/month was then calculated to represent an average fire season day.

The "extreme conditions" were calculated using ninety-seventh percentile weather data. That is to say, the weather conditions existing on the four most severe fire weather days (sorted by Energy Release Component ERC) in each season for the ten-year period were averaged together. It is reasonable to assume that similar conditions may exist for at least four days of the fire season during an average year. In fact, during extreme years such as 2000 and 2002, such conditions may exist for significantly longer periods. Even these calculations may be conservative compared to observed fire behavior. Drought conditions the last few years have significantly changed the fire behavior in dense forest types such as mixed conifer. The current values underestimate fire behavior especially in the higher elevation fuels, because the extremely low fuel moistures are not represented in the averages. The following values were used in **FlamMap**:

Average Weather Conditions	
Variable	**Value**
20 ft Wind speed up slope	12 mph
Herbaceous fuel moisture	57%
Woody fuel moisture	110%
100 hr fuel moisture	11%
10 hr fuel moisture	9%
1 hr fuel moisture	7%

Extreme Weather Conditions	
Variable	**Value**
20 ft Wind speed up slope	19 mph
Herbaceous fuel moisture	30%
Woody fuel moisture	80%
100 hr fuel moisture	6%
10 hr fuel moisture	4%
1 hr fuel moisture	3%

Fire Behavior Analysis Outputs

From the fire behavior analysis predictions of crown fire activity, rate of spread and flame length are derived. The maps on pages 16-21 graphically display the outputs of FLAMMAP for both average and extreme weather conditions.

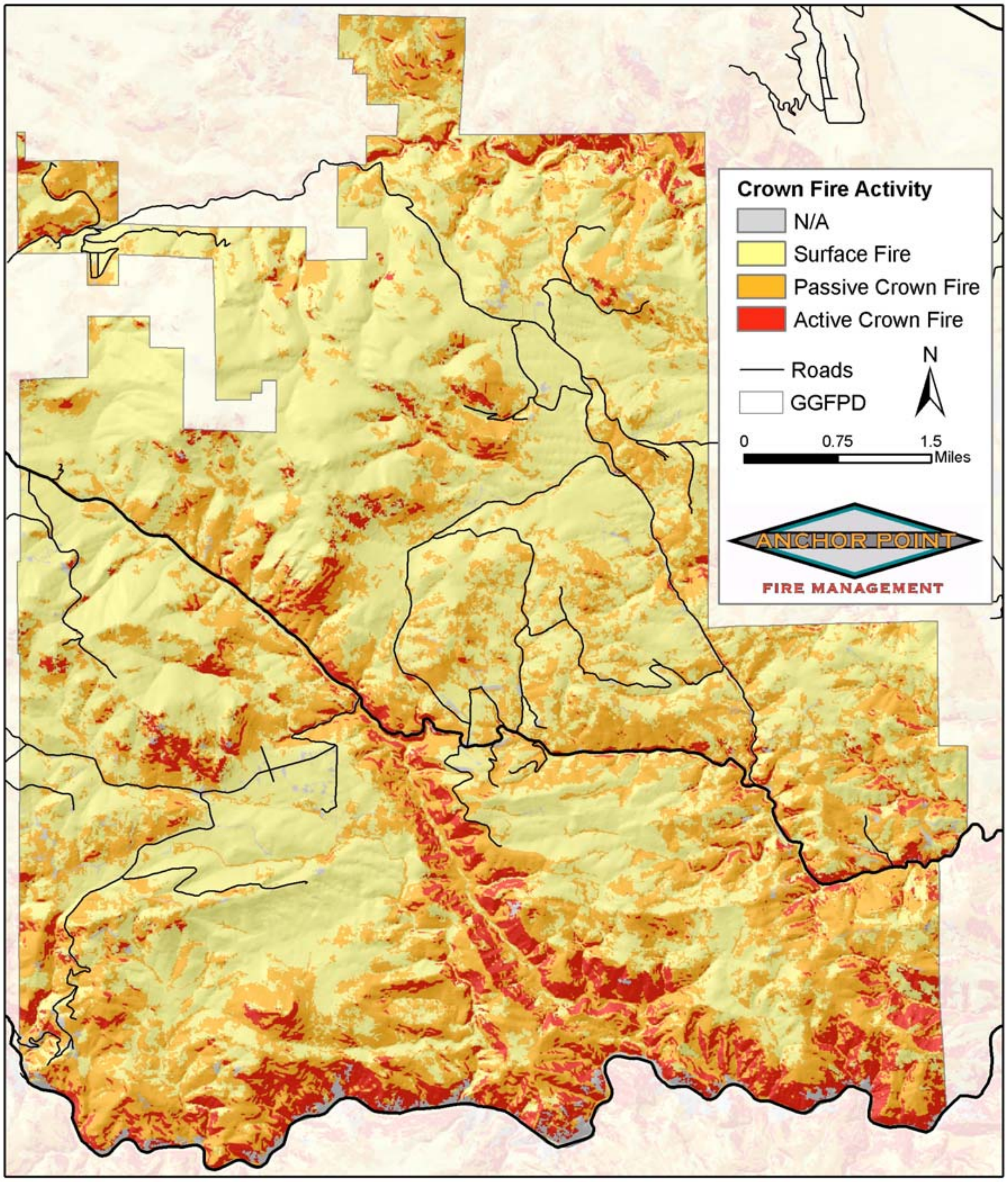

Figure 12: Predictions of Crown Fire Activity (Average Weather Conditions)

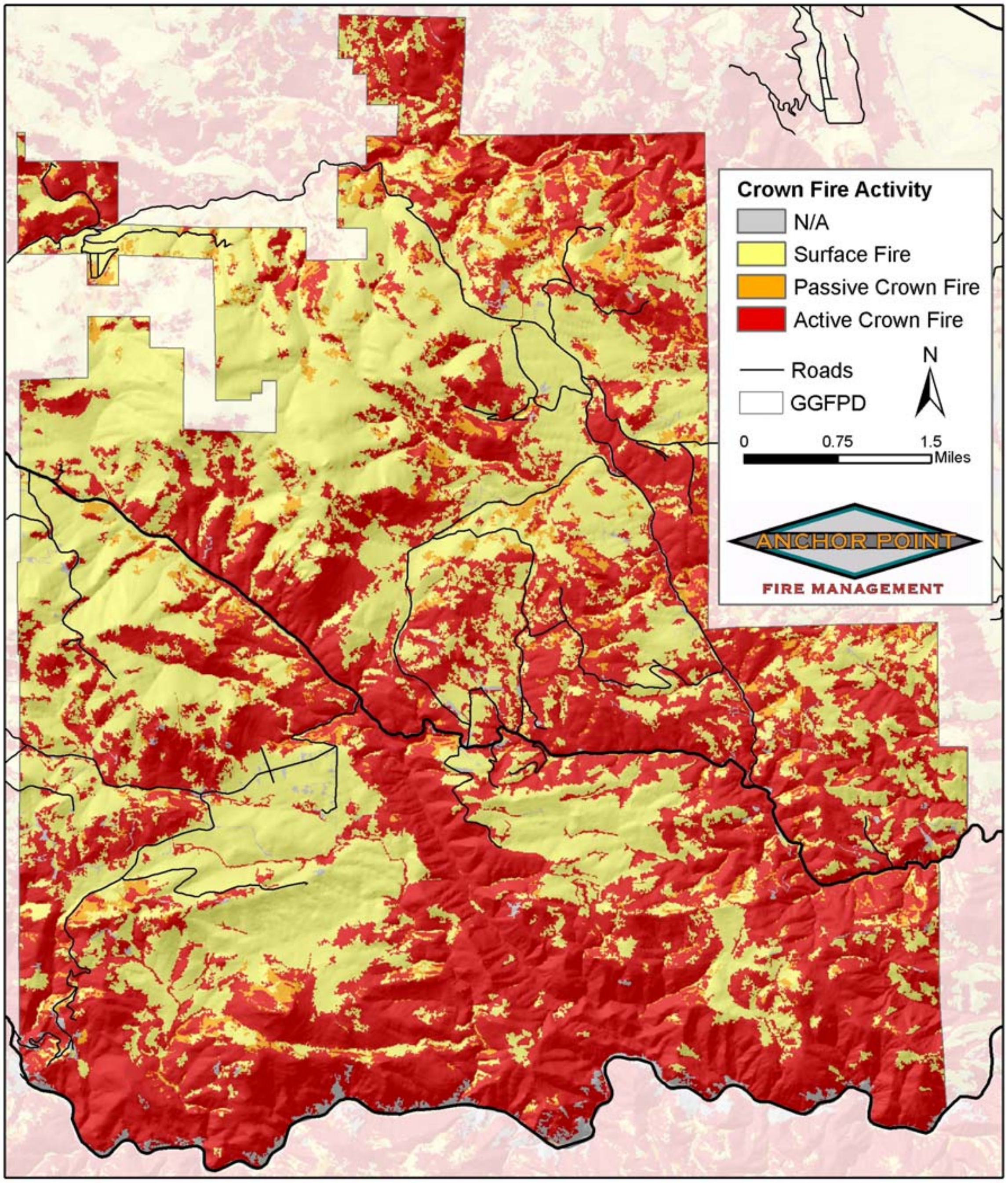

Figure 13: Predictions of Crown Fire Activity (Extreme Weather Conditions)

Crown fire activity values are generated by the FlamMap model and classified into 4 categories based on standard ranges: active, passive, surface and not applicable. In the surface fire category, little or no tree torching will be expected. During passive crown fire activity, isolated torching of trees or groups of trees will be observed and canopy runs will be limited to short distances. During active crown fire activity, sustained runs through the canopy will be observed that may be independent of surface fire activity.

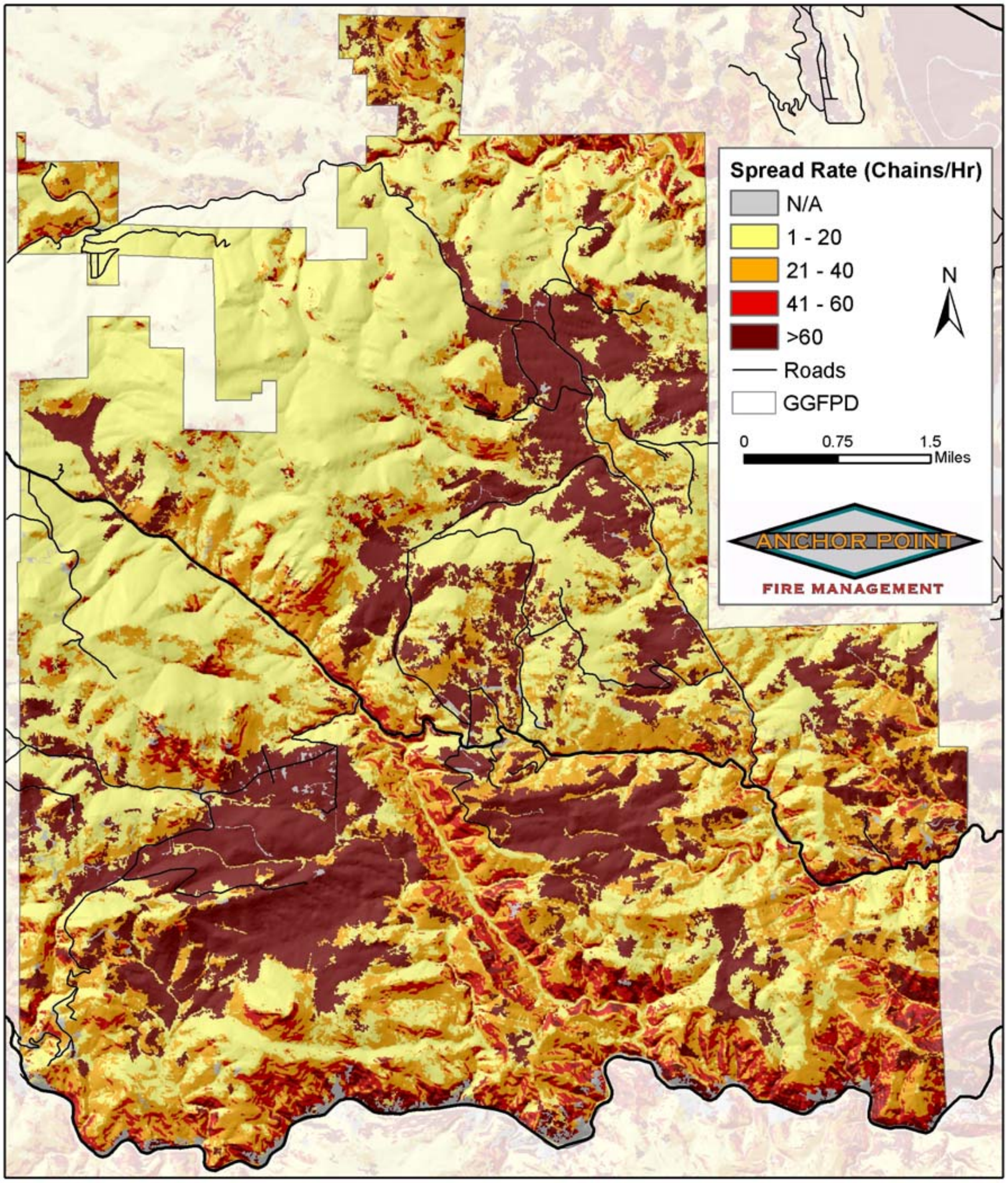

Figure 14: Spread Rate Predictions (Average Weather Conditions)

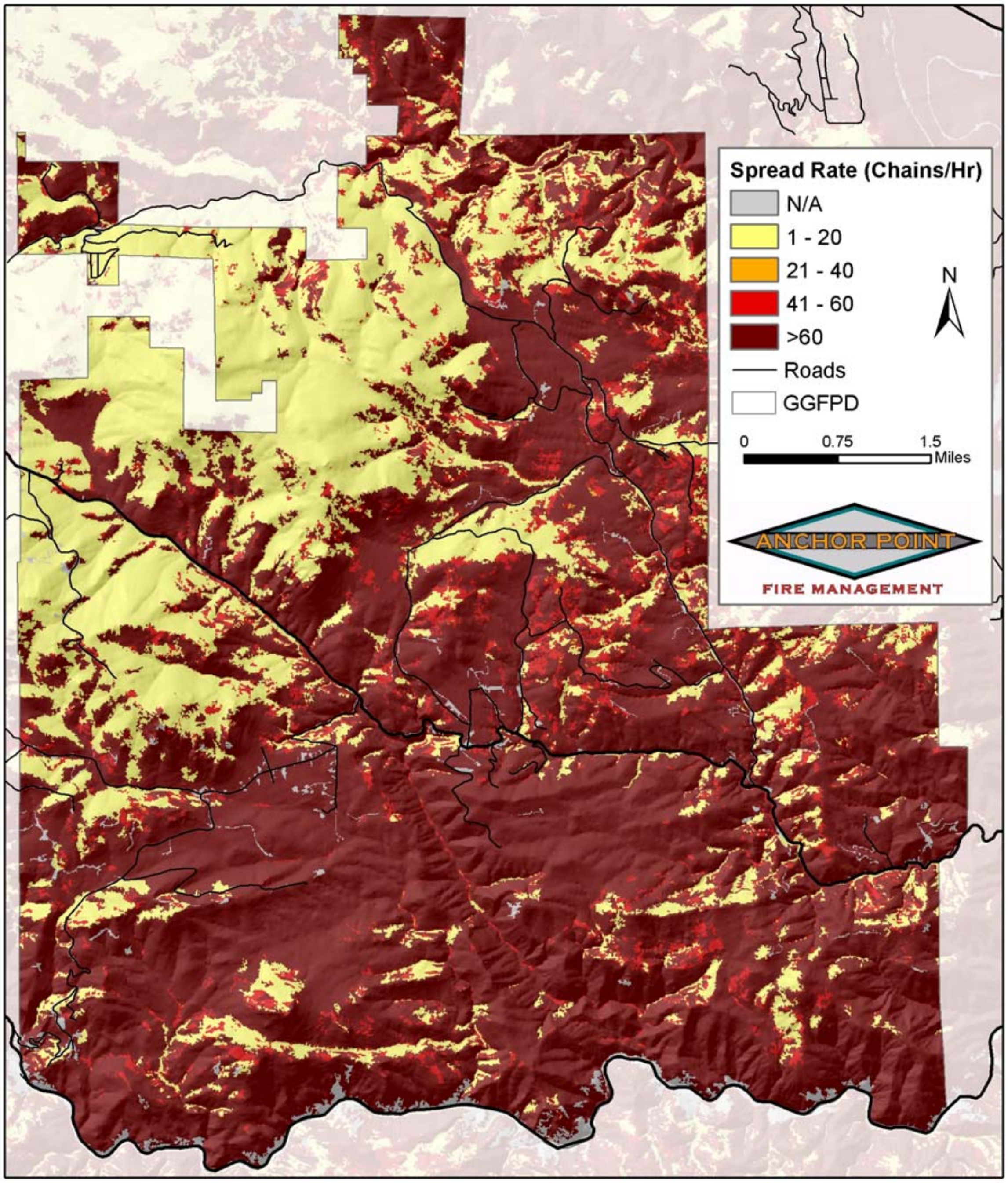

Figure 15: Spread Rate Predictions (Extreme Weather Conditions)

Spread rate values are generated by the FlamMap model and classified into four categories based on standard ranges: 0-20 CPH (chains/hour), 20.1-40 CPH, 40.1-60 CPH, and greater than 60 CPH. A chain is a logging measurement that is equal to 66 feet. One mile equals 80 chains. 1 CPH equals 1 foot/minute.

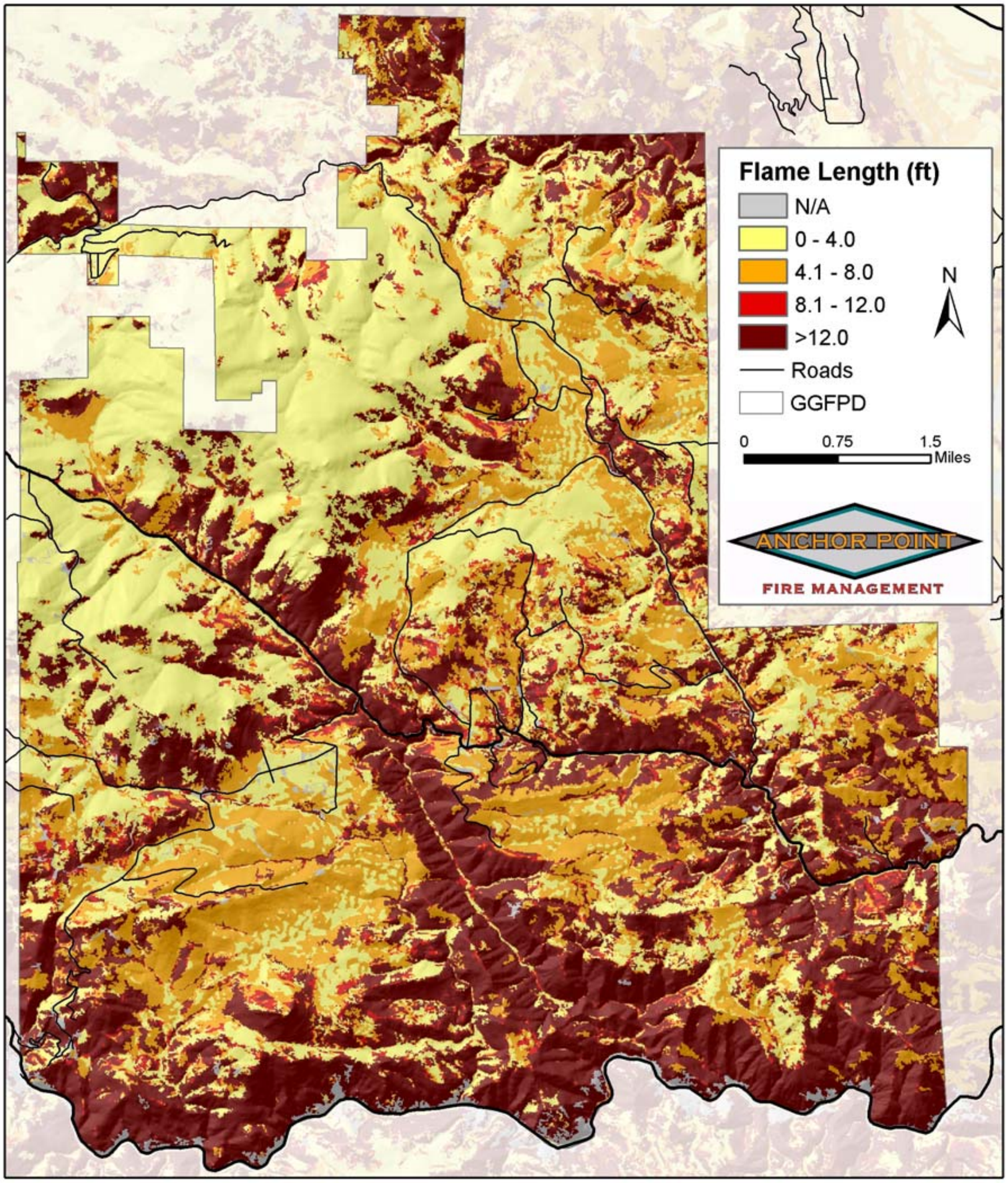

Figure 16: Flame Length Predictions (Average Weather Conditions)

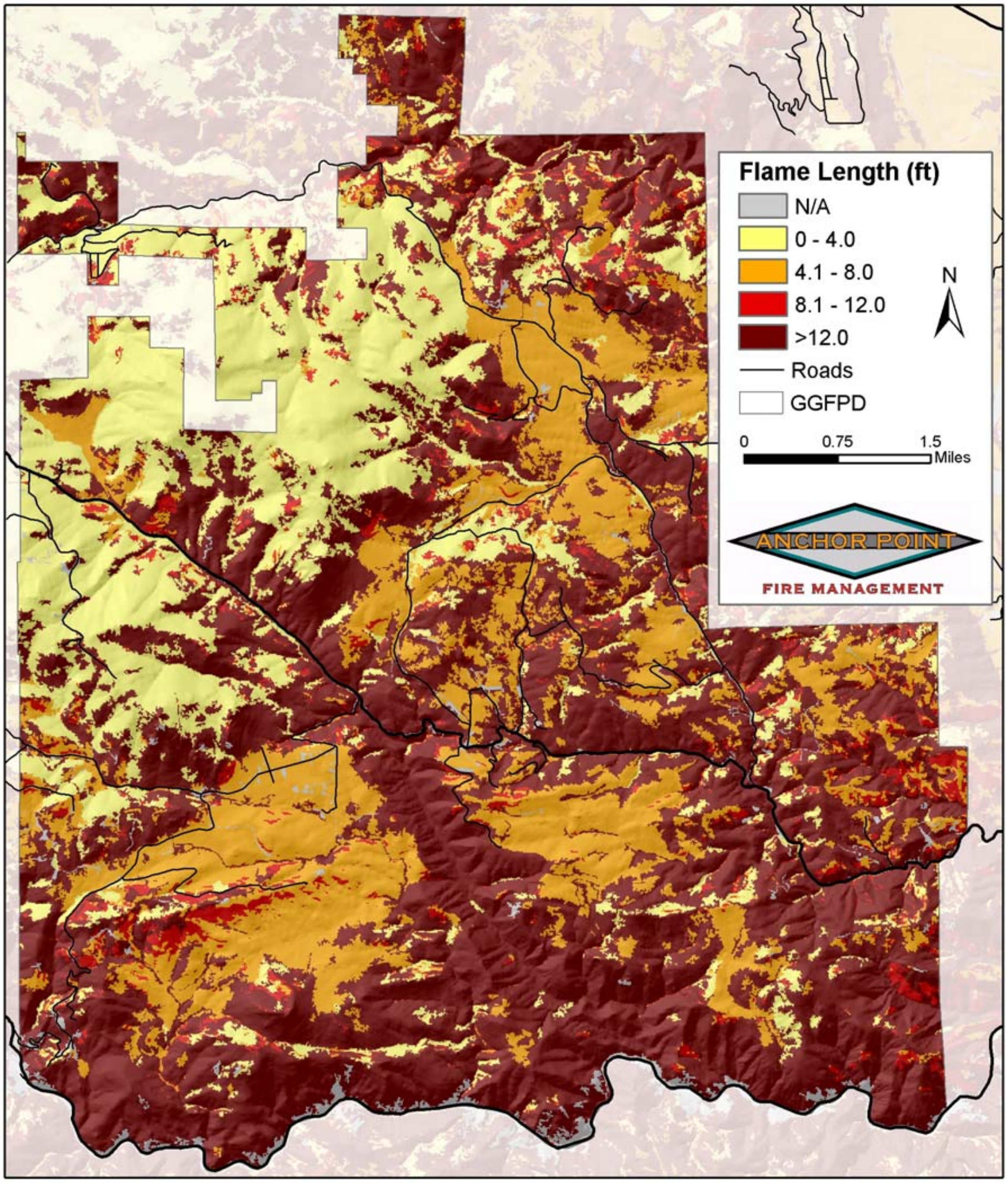

Figure 17: Flame Length Predictions (Extreme Weather Conditions)

Flame length values are generated by the FlamMap model and classified in the four categories based on standard ranges: 0-4 feet, 4.1-8 feet, 8.1-12 feet and 12.1-60 feet. Flame lengths of 4 feet and less are acceptable for direct attack by hand crews. Flame lengths of 8 feet and less are suitable for direct attack by machinery. With flame lengths of greater than 8 feet, indirect and aerial attack are the preferred methods.

Fire Behavior Interpretation and Limitations

This evaluation is a prediction of likely fire behavior given a standardized set of conditions and a single point source ignition at every point. It does not consider cumulative impacts of increased fire intensity over time and space. The model does not calculate the probability that a wildfire will occur. It assumes an ignition occurrence for every cell (a 10 x 10 meter area).

Weather conditions are extremely variable and not all combinations are accounted for. These outputs are best used for pre-planning and not as a stand-alone product for tactical planning. It is recommended that whenever possible, fire behavior calculations be done with actual weather observations during the fire. It is also recommended that the most current ERC values be calculated and distributed during the fire season to be used as a guideline for fire behavior potential.