

APPENDIX TKTK: FIRE BEHAVIOR TECHNICAL REFERENCE

FIRE BEHAVIOR POTENTIAL ANALYSIS METHODOLOGY

Purpose

The purpose of this appendix is to describe the methodology used to evaluate the threat represented by physical hazards, such as fuels, weather and topography, to values-at-risk in the study area by modeling their effects on fire behavior potential.

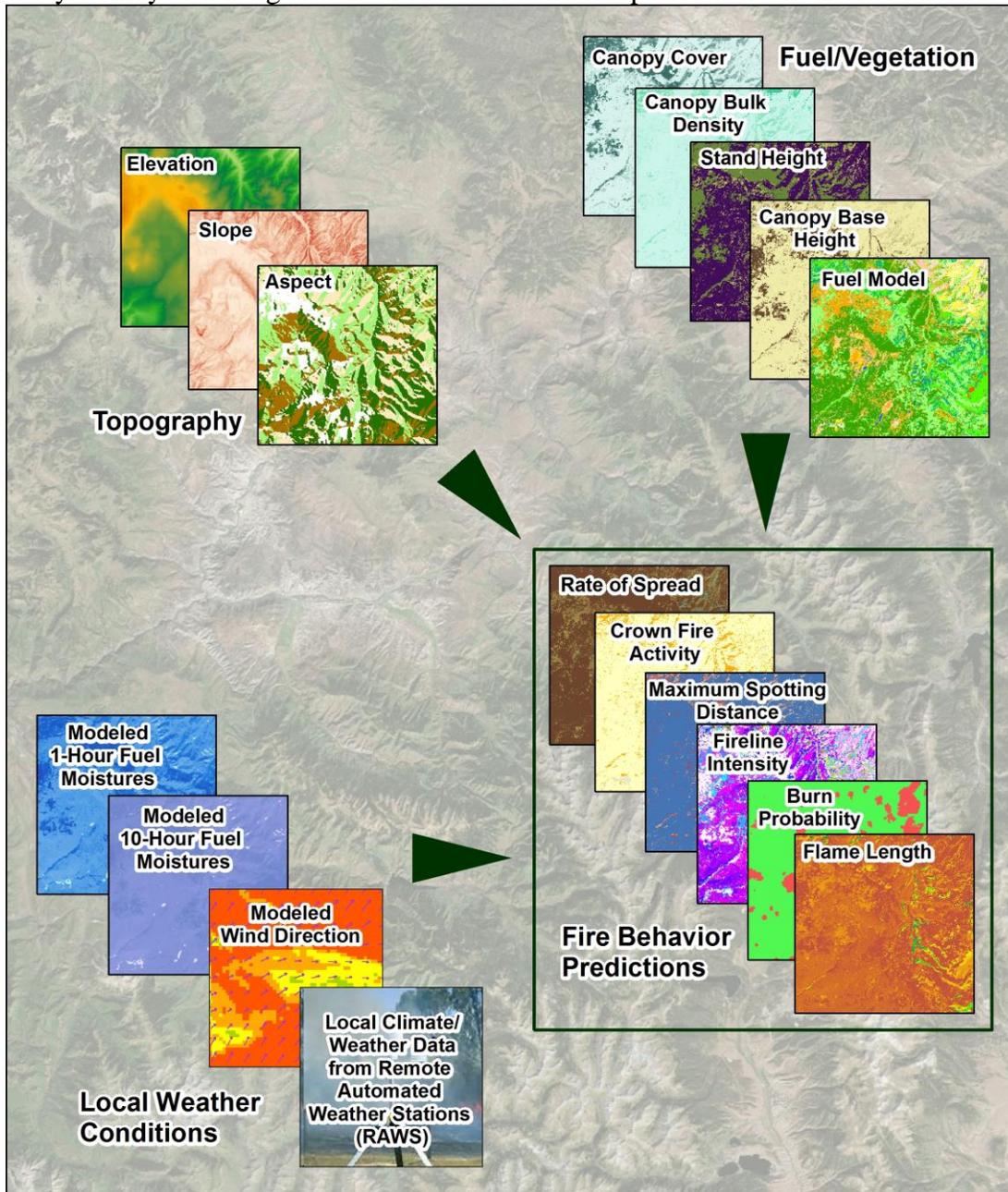


Figure 1 Fire Behavior Flow Chart. Note: This graphic shows input and output data sets that are not required for every analysis run and not all layers shown are used in all cases.

The fire behavior potential analysis graphically reports the following for the analysis area based on a set of inputs significant to fire behavior: rate of spread, flame length, and crown fire potential. The model inputs include aspect, slope, elevation, canopy cover, fuel type, canopy bulk density, canopy base height, stand height, and climate data. The model outputs are calculated using FlamMap, which combines surface fire predictions with the potential for crown fire development.¹

Modeling Limitations and Discussion

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 30-meter x 30-meter cell. These calculations may be conservative (under-predict) compared to observed fire behavior.

Weather conditions are extremely variable and all possible combinations cannot be accounted for. These outputs are best used for preplanning and not as a stand-alone product for tactical planning. Whenever possible, fire behavior calculations should be done with actual weather observations during the fire. The most current Energy Release Component (ERC) values should also be calculated and distributed during the fire season to be used as a guideline for fire behavior potential.

The FlamMap draws heavily on calculations from the BEHAVE fire behavior prediction and fuel modeling system (see below).² BEHAVE is a nationally-recognized set of calculations used to estimate a surface fire's intensity and rate of spread given topographical, fuel, and weather information.

The BEHAVE modeling system has been used for a variety of applications, including predictions of current fires, prescribed fire planning, fuel hazard assessment, initial attack dispatch and fire-prevention planning and training. Predictions of wildland surface fire behavior in BEHAVE are made for a single point in time and space, given user-defined fuels, weather, and topography. Requested values depend on the modeling choices made by the user.

Assumptions of BEHAVE:

- Fire is predicted at the flaming front. (Fire behavior is not modeled for the time after the flaming front of the fire has passed.)
- Fire is free burning (uncontrolled by suppression efforts).
- Behavior is heavily weighted toward the fine fuels (grasses and small-diameter wood).
- Fuels are continuous and uniform.
- Fires are considered to be surface fires. (Crown fire activity is modeled separately.)

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² Patricia L. Andrews, producer and designer, Collin D. Bevins, programmer and designer, The Joint Fire Sciences Program of the Rocky Mountain Research Station (USDA Forest Service, Missoula, Montana) and Systems for Environmental Management (Missoula, Montana).

BEHAVE makes calculations at a single point. In order to make calculations for an entire landscape (important for preplanning the effects of a wildfire at the community, district, or county scale), fire behavior is modeled using FlamMap, which models surface fire predictions and the potential for crown fire development.³

Assumptions of FlamMap:

- Each calculation in a given area is independent of calculations in any other area. Fire is not modeled dynamically across the landscape but statically as a series of individual calculations.
- Weather inputs such as wind and fuel moistures do not change over time.
- Fire behavior modeling calculations are performed in a series of uniform squares (or “pixels”) across the landscape. These pixels determine the level of detail and nothing smaller than a pixel (30 meters x 30 meters in this case) is included in the modeling.

Crown fire activity, rate of spread, flame length, and fireline intensity are derived from the fire behavior predictions. A limitation of FlamMap is that crown fire is not calculated for shrub models. The best method for determining the probability of crown fire in shrubs is to look at the flame length outputs and assume that if the flame length is greater than half the height of the plant, it will likely torch and/or crown. The following maps graphically display the outputs of FlamMap for both moderate and high weather conditions.

The outputs of the fire behavior analysis can be used in conjunction with Community Wildfire Hazard Ratings (WHR) treatment recommendations, which are useful for prioritizing mitigation actions. The map below shows the recommendations overlaid on the fireline intensity. This allows for a general evaluation of the effects of the predicted fire behavior in areas of high hazard. However, remember that the minimum mapping unit used for fire behavior modeling is one acre; therefore, fine-scale fire behavior and effects are not considered in the model.

FlamMap

Anchor Point used FlamMap to evaluate the potential fire conditions in the fire behavior study area. The study area, including the 1mi buffer comprising the WUI boundary, encompasses 127,878 acres (~200 square miles).

The study area is broken down into grid cells 30 meters x 30 meters, for each of which fire behavior is predicted based on input fuel, weather, and topographic information. For the FlamMap run, data from the Land Fire v 1.20 were used for surface fuels, aspect, slope, elevation, canopy closure, canopy base height (CBH), and canopy bulk density (CBD).⁴ Modifications to the standard input data were made to reflect the extensive mitigation work that has been done in the area. A new, custom fuel model was also used to address changes due to Mountain Pine Beetle activity.

³ Van Wagner, C.E. 1977. “Conditions for the start and spread of a crown fire.” *Canadian Journal of Forest Research*. 7: 23-24.

⁴ www.landfire.gov

The final set of input data for the FlamMap model consists of reference weather and fuel moisture information summarized from a Remote Automated Weather Station (RAWS) site. See the section below for details on RAWS information.

REFERENCE WEATHER USED IN THE FIRE BEHAVIOR POTENTIAL EVALUATION

As stated above, climate and fuel moisture inputs for FlamMap were created by using data collected from a RAWS. The Harbison Meadow RAWS was used to capture the climate for the project area because of its location and elevation.

Latitude (dd.ddddd)	40.27056° N
Longitude (dd.ddddd)	105.8383° W
Elevation (feet)	8640

Table C1. Harbison Meadow RAWS (050402) information.

Weather observations for a 21-year period (1993-2013) were used. The moderate condition class (16th to 89th percentile, sorted by ERC) was calculated for each variable (1-hour, 10-hour, and 100-hour fuel moisture and 20-foot wind speed) using Fire Family Plus. This weather condition class most closely represents an average fire season day.

A second set of weather conditions was calculated to capture a high fire day (in terms of fuel moistures and wind speed). Values in the data set that were in the 90th percentile or greater class (sorted by ERC) were used to calculate the high condition class.

Preconditioning of fuel moistures was calculated for both weather scenarios. The models calculate separate dead fuel moistures for each landscape cell based on the topography (slope, aspect and elevation) and shading from forest canopy and clouds, as well as the recorded weather (precipitation, high and low temperatures, and high and low relative humidity values) for the previous three days. The dead fuel moistures that have been calculated by the start date and time of the analysis are used to determine the outputs in fire behavior models.

The following values, derived from Fire Family Plus, were used as climate/fuel moisture inputs in FlamMap:

Moderate Weather Conditions		High Weather Conditions	
Variable	Value	Variable	Value
20-foot wind speed upslope	17 mph*	20-foot wind speed upslope	30 mph*
Herbaceous fuel moisture	101%	Herbaceous fuel moisture	42%
Woody fuel moisture	122%	Woody fuel moisture	91%
1-hr fuel moisture	6%	1-hr fuel moisture	4%
10-hr fuel moisture	10%	10-hr fuel moisture	6%
100-hr fuel moisture	14%	100-hr fuel moisture	12%

Table C2. Input wind and fuel moisture parameters used for fire behavior models.

* Winds blowing uphill.

Wind Speeds Adjusted

Wind speeds from a RAWS are 10-minute average sustained wind speed values⁵. During this 10-minute period, it is likely that winds of higher speeds were encountered. These faster winds could have been enough to transition fire from surface to crowning. Because of this, a table produced by the National Oceanic and Atmospheric Administration was used to adjust wind speeds from 10-minute averages to the Average Probable Momentary Gust. These adjusted wind speed values were used to run the fire behavior models.

Upslope Winds

Upslope winds were used instead of directional winds because aligning slope and wind will give the worst-case results. Directional winds would favor one aspect over another and would show lower fire behavior on the leeward aspects. This is only the case under the given wind direction and would not account for other possible wind directions. Upslope winds reflect a generic worst-case scenario and are therefore better for pre-planning uses.

Dead Fuel Moisture

Dead fuel moisture responds solely to ambient environmental conditions and is critical in determining fire potential. Dead fuel moistures are classed by timelag. A fuel's timelag is proportional to its diameter and is loosely defined as the time it takes a fuel particle to reach two-thirds of the way to equilibrium with its local environment. Dead fuels in the National Fire Danger Rating System (NFDRS) fall into four classes: 1-hour, 10-hour, 100-hour, and 1,000-hour.⁶

Live Fuel Moisture

Live fuel moisture is the amount of water in a fuel, expressed as a percent of the oven-dry weight of that fuel. Fuel moisture between 300 percent and 30 percent is considered live. Anything below 30 percent is considered dead fuel. Fuel moistures can exceed 100 percent because the living cells can expand beyond their normal size to hold more water when available.

⁵ <http://graphical.weather.gov/definitions/defineWind20ft.html>

⁶ U.S. National Fire Danger Rating System Overview: INT-GTR-367 - FIRES: Fire Information Retrieval and Evaluation System - a Program for Fire Danger Rating Analysis.

FUEL MODELS AND FIRE BEHAVIOR

In the context of fire behavior modeling, “fuel models” are a set of numbers that describe fuels in terms that the fire behavior modeling equations can use directly. There are seven characteristics used to categorize fuel models:

- Fuel loading
- Size and shape
- Compactness
- Horizontal continuity
- Vertical arrangement
- Moisture content
- Chemical content

Each of the major fuel types present in the study area is described below. Unless otherwise noted, fuel model descriptions are taken from Scott and Burgan’s *Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel’s Surface Fire Spread Model*, a national standard guide to fuel modeling.⁷

In *Standard Fire Behavior Fuel Models*, Scott and Burgan describe 40 fuel models in the following six groups: non-burnable (NB), grass (GR), grass/shrub (GS), shrub (SH), timber understory (TU) and timber litter (TL). The study area is represented primarily by the following fuel models (FM):

Grass Fuel Models	Shrub Fuel Models	Timber Fuel Models	Non-Burnable
FM121 (GS1)	FM141 (SH1)	FM40 (Custom MPB Model)	None > 5%*
FM122 (GS2)		FM161 (TU1)	
		FM165 (TU5)	
		FM183 (TL3)	

Table C1. Fuel models found in the study area.

* Some fuel models may exist but not in quantities (less than 5 percent on the landscape) sufficient to significantly influence fire behavior across the landscape.

⁷ Scott, J.H. and R. Burgan. 2005. *Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel’s Surface Fire Spread Model*, United States Department of Agriculture Forest Service, RMRS-GTR-153.

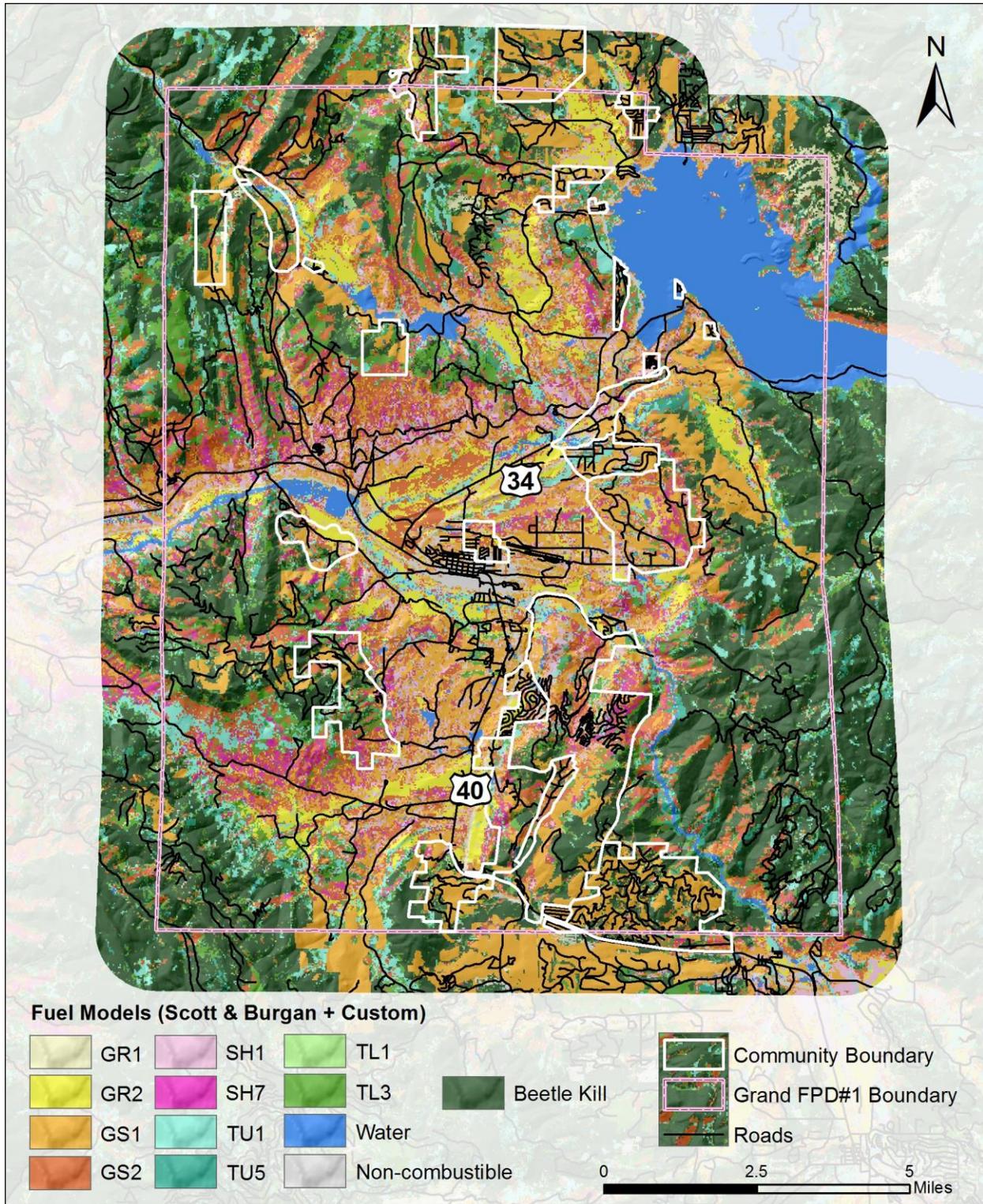


Figure 2. Fuels found in GFPD1 study area.

FUEL GROUP DESCRIPTIONS AND COMPARISONS

Grass Fuel (GR) Type Models

The primary carrier of fire in the GR fuel models is grass. Grass fuels can vary from heavily grazed grass stubble or sparse natural grass to dense grass more than six feet tall. Fire behavior varies from moderate spread rate and low flame length in the sparse grass to extreme spread rate and flame length in the tall grass models.

All GR fuel models are dynamic, meaning that their live herbaceous fuel load shifts from live to dead as a function of live herbaceous moisture content. The effect of live herbaceous moisture content on spread rate and intensity is strong.

Grass-Shrub (GS) Fuel Type Models

The primary carrier of fire in the GS fuel models is grass and shrubs combined; both components are important in determining fire behavior.

All GS fuel models are dynamic, meaning that their live herbaceous fuel load shifts from live to dead as a function of live herbaceous moisture content. The effect of live herbaceous moisture content on spread rate and intensity is strong and depends on the relative amount of grass and shrub load in the fuel model.

Shrub (SH) Fuel Type Models

The primary carrier of fire in the SH fuel models is live and dead shrub twigs and foliage in combination with dead and down shrub litter. A small amount of herbaceous fuel may be present, especially in SH1 and SH9, which are dynamic models (their live herbaceous fuel load shifts from live to dead as a function of live herbaceous moisture content). The effect of live herbaceous moisture content on spread rate and flame length can be strong in those dynamic SH models.

Timber-Understory (TU) Fuel Type Models

The primary carrier of fire in the TU fuel models is forest litter in combination with herbaceous or shrub fuels. TU1 and TU3 contain live herbaceous load and are dynamic, meaning that their live herbaceous fuel load is allocated between live and dead as a function of live herbaceous moisture content. The effect of live herbaceous moisture content on spread rate and intensity is strong and depends on the relative amount of grass and shrub load in the fuel model.

Timber Litter (TL) Fuel Type Models

The primary carrier of fire in the TL fuel models is dead and down woody fuel. Live fuel, if present, has little effect on fire behavior.

FIRE BEHAVIOR OUTPUTS

Rate of Spread

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

**Rate of spread in chains/hour
(1 chain=66') (80 chains/hr = 1 MPH)**

Note: A high rate of spread is not necessarily severe. Fire will move very quickly across grass fields but will not burn very hot and does not cause any major damage to the soil.

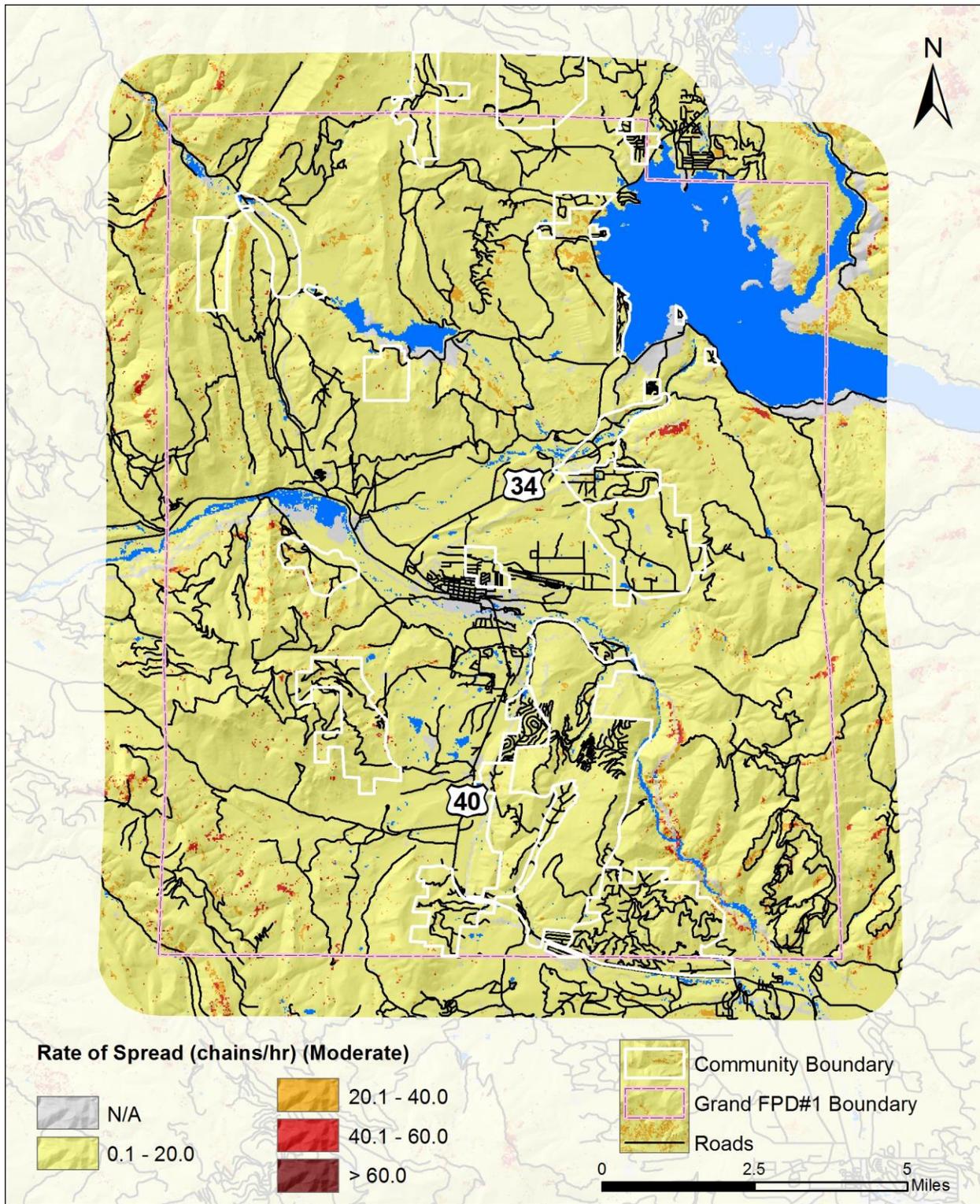


Figure 5. Predicted rate of spread under moderate weather conditions.

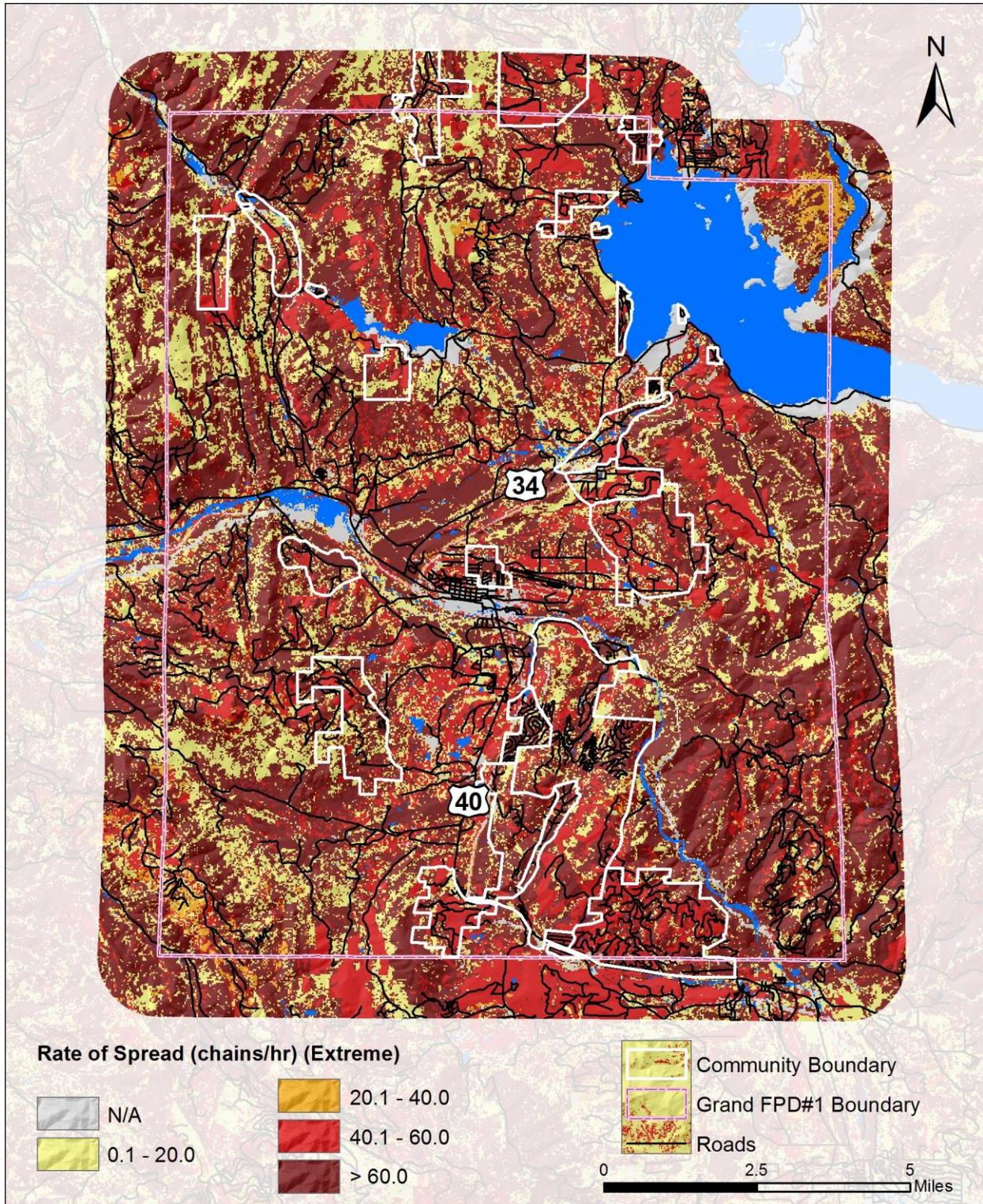


Figure 6. Predicted rate of spread under high weather conditions.

Flame Length

Flame length values are generated by the FlamMap model and classified into four categories based on standard ranges: 0.1-4.0 feet; 4.1-8.0 feet; 8.1-11.0 feet; and greater than 11.0 feet.

The legend boxes display flame length in ranges that are meaningful to firefighters. The flame lengths are a direct measure of how intense the fire is burning. Flame lengths of four feet and less are deemed low enough intensity to be suitable for direct attack by hand crews and therefore represent the best chances of direct extinguishment and control. Flame lengths of less than eight feet are suitable for direct attack by equipment such as bulldozers and tractor plows. Flame lengths of eight to 11 feet are usually attacked by indirect methods and aircraft. In conditions where flame lengths exceed 11 feet, the most effective tactics are fuel consumption ahead of the fire by burnouts or mechanical methods (see Figure 7)

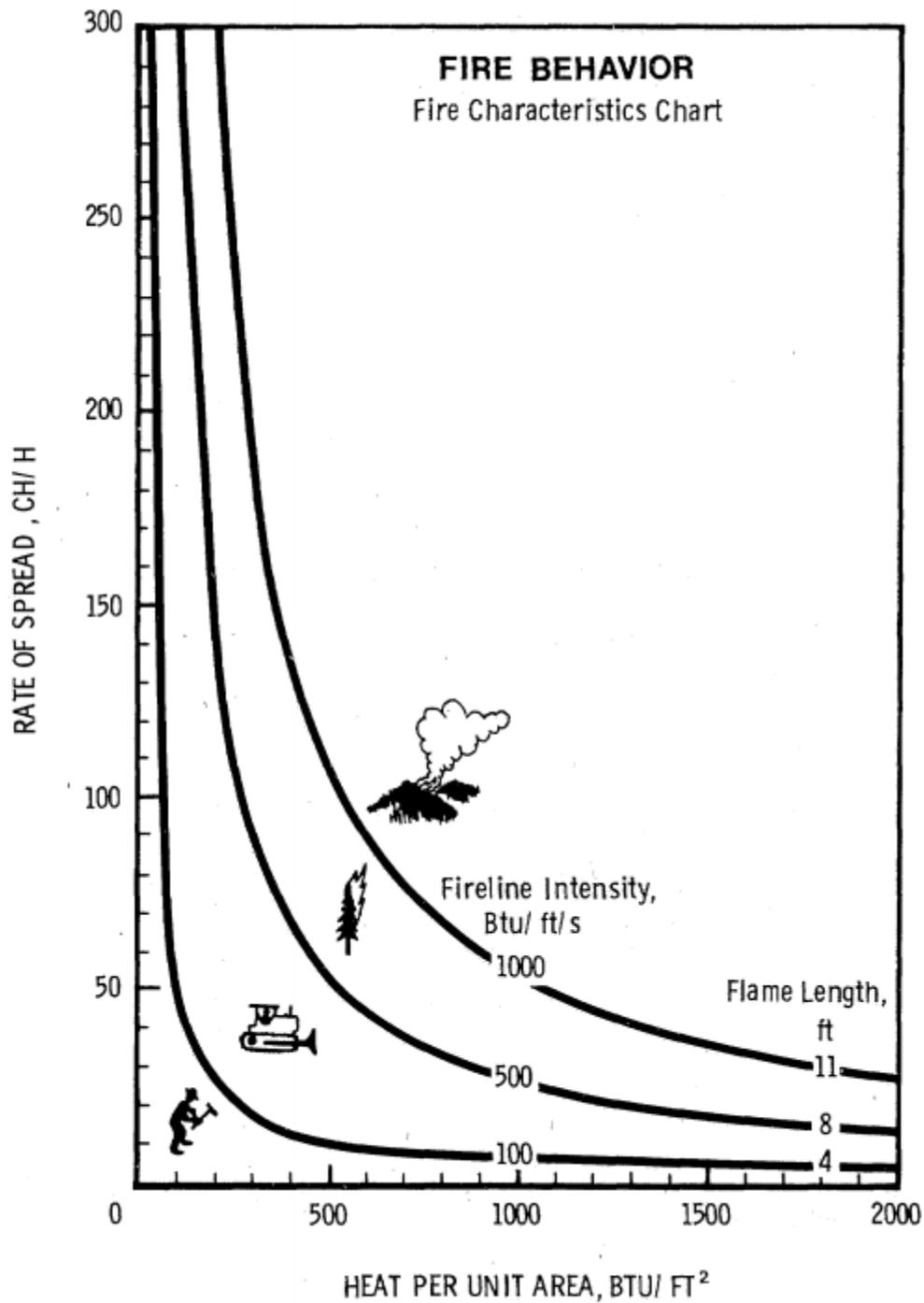


Figure 7 Graph of fire behavior vs. suppression strategies

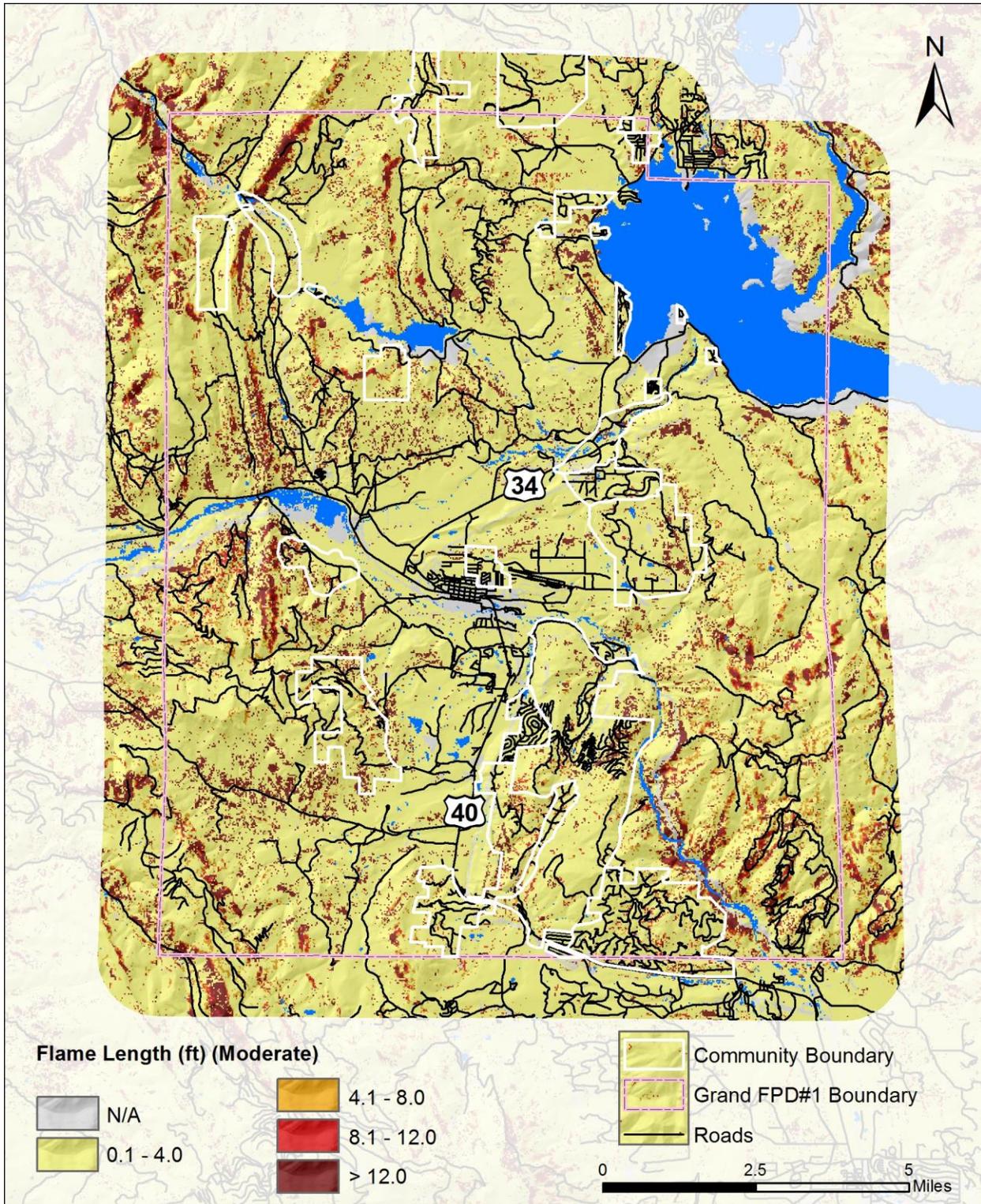


Figure 8. Predicted flame lengths under moderate weather conditions.

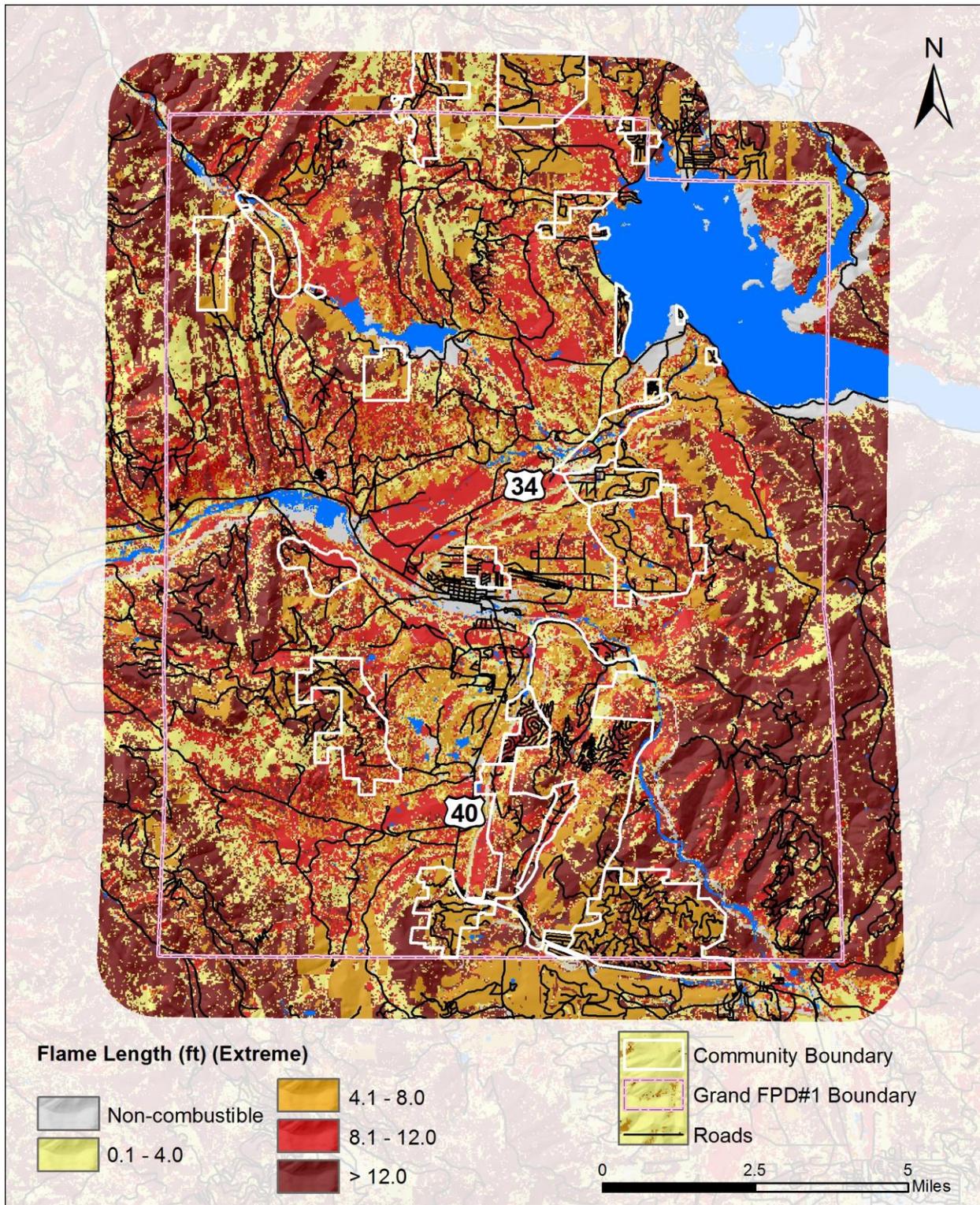


Figure 9. Predicted flame lengths under extreme weather conditions.

Crown Fire

Crown fire activity values are generated by the FlamMap model and classified into four categories based on standard descriptions: active; torching; surface; and non-combustible. 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 (though these types canopy fire are not modeled)

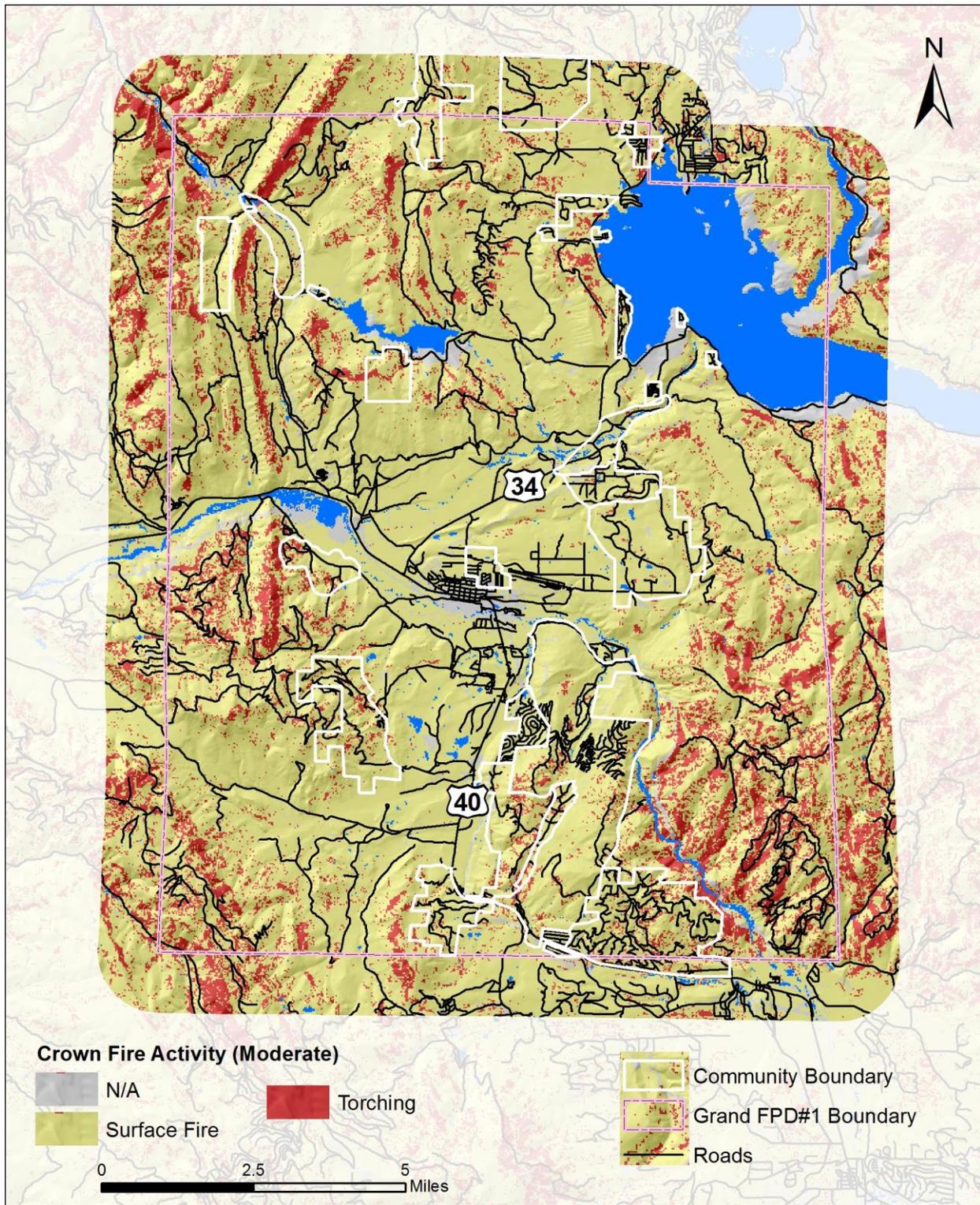


Figure 10. Predicted crown fire activity under moderate weather conditions.

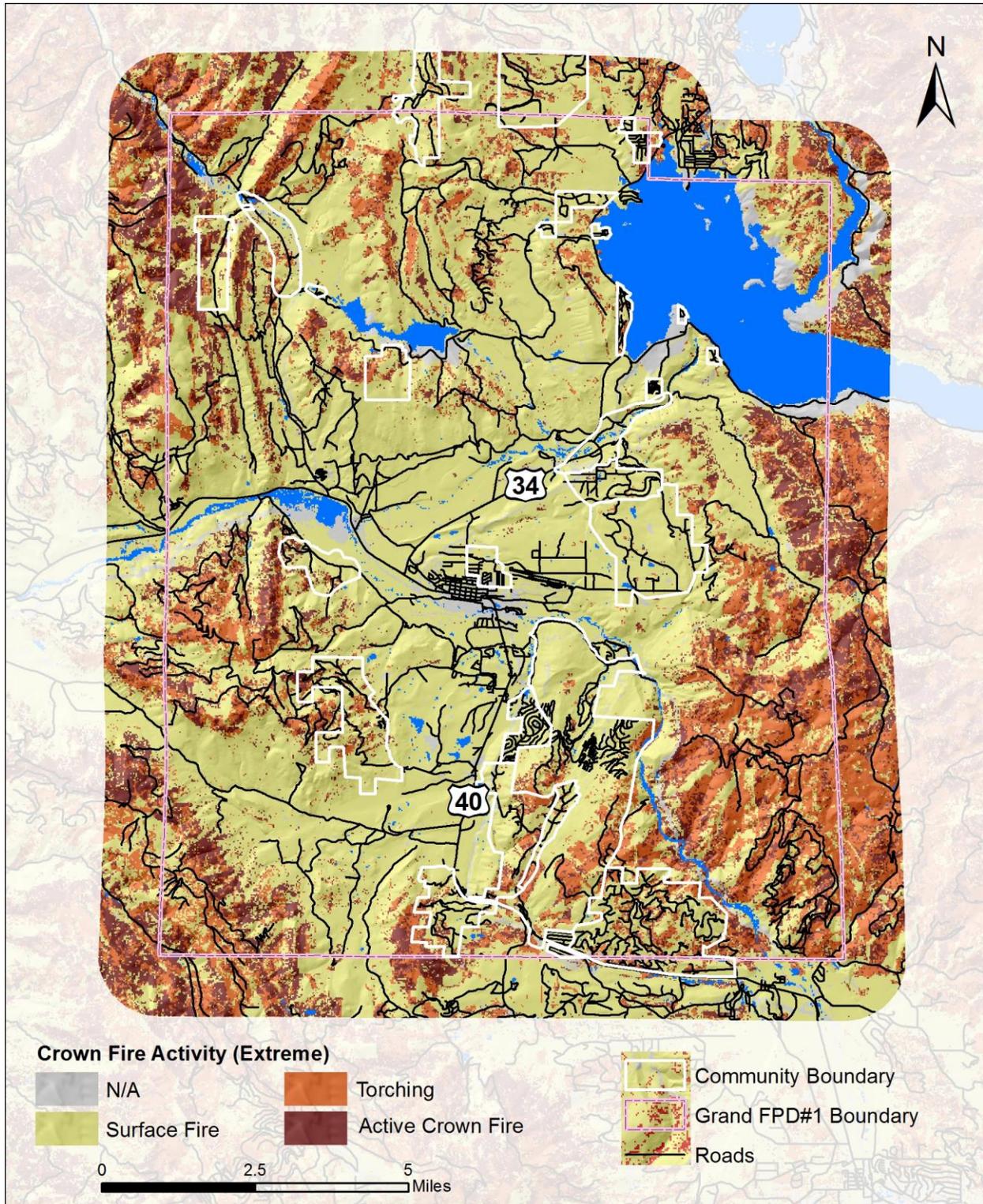


Figure 11. Predicted crown fire activity under extreme weather conditions.