Potential Fire Behavior in the Lassen Foothills, East Tehama County, California

Deer Creek © R. Reiner

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Introduction

The objective of this effort is to produce information to guide fire management in the Lassen Foothills of eastern Tehama County. The study area (Figure 1) is essentially the same as that of the 2008 Tehama East Fire Plan[1] (TEFP) which uses 2005 CDF fuel rank mapping as its basis for fire behavior and risk. Fuel rank is a classified measure of fire behavior for specified topography, fuels, and weather. To avoid duplication, I focused on several other measures of potential fire behavior. The reader is advised to see the TEFP for information about local suppression resources and assets at risk.

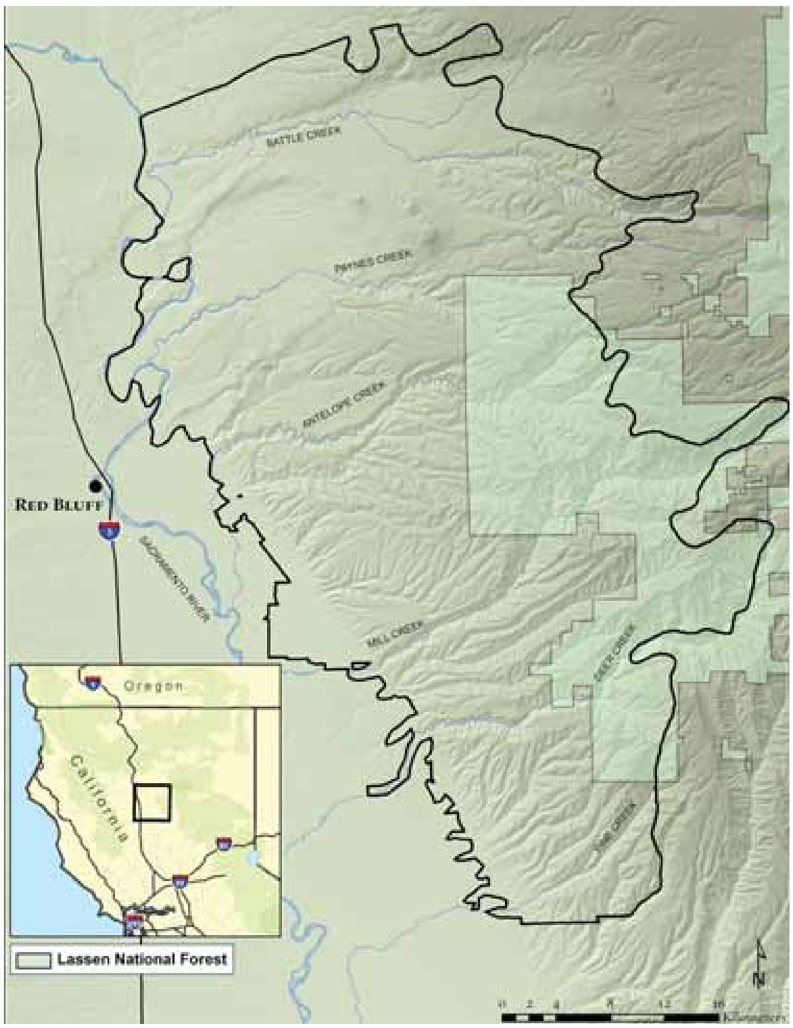

Figure 1. The study area contains approximately 400,000 acres within the Lassen Foothills.

[1] http://www.tehamacountyrcd.org/ixtefp.htm

Fire Behavior Modeling

FlamMap[2] is a spatial fire behavior model that produces estimates of potential fire behavior for given topography, fuels, and weather data. It is very similar to FARSITE[3] which models fire spread and behavior over a period of time during which weather conditions are allowed to vary. I utilized FlamMap exclusively to produce spatial estimates of potential rate of spread, flamelength, and crown fire activity for three wind scenarios described below. In addition, I used FlamMap to produce spatial estimates of burn probability, arrival time, and flow path for two of those wind scenarios.

Fuel Moistures and Wind Scenarios

FlamMap requires a table of initial fuel moistures for each fuel model (Table 1) from which it creates a spatial map of fuel moistures based on topography, canopy shading, and the specified weather stream (Table 2). I used FireFamily Plus[4] to determine average fuel moisture values recorded at the Cohasset RAWS[5] (remote automated weather station) under 90th percentile weather conditions (as delineated by the burning index) during the period 01 June-15 October between 1995 and 2008. This RAWS is located at 1,733 feet in chaparral, roughly 2 km outside the southern edge of the study area. Values in Table 1 also reflect some variation in 100-hr fuel moistures based on a study from northeast Oregon[6] and are further adjusted internally by FlamMap to reflect local conditions as described above. Early June 90th percentile live herbaceous fuel moistures are generally around 40% but drop to less than 5% (mean 2.58%) by early July as the grasses cure. I used a value of 5% as a slightly less extreme compromise. The five most widespread fuels[7], which cover almost 80% of the study area, are GS2 (moderate load, dry climate grass-shrub; 30.2% of the study area), GR2 (low load, dry climate grass; 29.0%), GR1 (short, sparse dry climate grass; 7.7%), SH5 (high load, dry climate shrub; 6.4%), and GS1 (low load, dry climate grass-shrub; 6.2%).

Fuel Model	1-hr (%)	10-hr (%)	100-hr (%)	Live Herb. (%)	Live Woody (%)	% of Area
Grass						
GR1	3	4	6	5	59	7.7
GR2	3	4	5	5	59	29.0
Grass-shrub						
GS1	3	4	5	5	59	6.2
GS2	3	4	5	5	59	30.2

[2] http://www.firemodels.org/content/view/14/28/
[3] http://www.firemodels.org/content/view/112/143/
[4] http://www.firemodels.org/content/view/15/29/
[5] http://www.raws.dri.edu/cgi-bin/rawMAIN.pl?caCCOH
[6] Ager, A., A. McMahan, J. Barrett, and C. McHugh. 2007. A simulation study of thinning and fuel treatments on wildland-urban interface in eastern Oregon, USA. Landscape Planning and Management 80: 292-300.
[7] Scott, J. and R. Burgan. 2005. Standard fire behavior fuel models: A comprehensive set for use with Rothermel's Surface Fire Spread Model. USDA Forest Service General Technical Report RMRS-GTR-153.

Shrub						
SH1	3	4	5	5	59	5.4
SH2	3	4	5	5	59	2.5
SH5	3	4	5	5	59	6.4
Timber-understory						
TU1	3	4	5	5	59	1.2
TU5	3	4	5	5	59	2.6
Timber litter						
TL1	3	4	5	5	59	0.001
TL2	3	4	6	5	59	0.1
TL3	3	4	5	5	59	0.9
TL6	3	4	6	5	59	1.2
TL7	3	4	5	5	59	0.2
TL8	3	4	5	5	59	0.1
TL9	3	4	6	5	59	0.6

Table 1. Fuel models within the study area and their initial fuel moistures.

I used weather recorded just before the Gun II Fire (29 September-06 October, 1999) at the Cohasset RAWS to pre-condition initial fuel moistures with FlamMap. I chose the Cohasset RAWS because it sits in similar fuels near the middle of the elevation band over which the fire burned (mean 1,561 ft, range of roughly 1,000-4,000 ft). These values (Table 2) are similar to the mean 90th percentile conditions (low temperature = 77°F, high temperature = 99°F, low RH = 36%, and high RH = 86%) although relative humidity was exceptionally low.

Mo.	Day	Precip	Time of high temp.	Time of low temp.	Low temp.	High temp.	High RH	Low RH
9	25	0 in.	0500	1500	75°F	96°F	31%	8%
9	26	0 in.	0500	1600	70°F	91°F	23%	8%

Table 2. Weather stream used to pre-condition initial fuel moistures.

FlamMap also requires a wind file to pre-condition initial fuel moistures, although only the cloud cover values from the file are actually used (0% for every day of this fire). For conditions during the fire behavior simulations I used a sustained 20-ft wind speed of 12 mph coming from 260° which is similar to Cohasset RAWS values on the first day of the Gun II Fire. Wind direction is highly variable so I chose to use the direction at the hottest part of the day. Wind speed is likewise highly variable so I chose to use the maximum wind speed at that same time. To capture some of this variability I used WindNinja[8] to model the effect of topography on instantaneous wind flow (Figures 2-5). (Wind direction resolution is lowered in the figures for visual clarity.) WindNinja produces spatial wind direction and velocity outputs based on the given prevailing winds (scenario one-12 mph from 260°) that FlamMap can then use for its fire behavior simulations.

[8] http://www.firemodels.org/content/view/132/169/

These relatively high wind speeds, plus the use of very low fuel moistures as described above, mean that all subsequent results can be considered near-worst case scenarios. These conditions are useful for analyzing the potential for a fire to move from low elevation grass and shrubs up into higher elevations to the east. Because the Lassen Foothills are prone to unpredictable wind direction reversals as well as seasonal foehn winds, I also ran simulations with WindNinja-derived winds from the east-northeast (scenario two- 12 mph from 80°) to simulate fire moving from the timber down into the lower elevations (Figure 4). Finally, according to CDF/USFS data[9], the Gun II Fire spread downhill with northeast winds from 10-50 mph. To consider this extreme case, I include rate of spread, flamelength, and crown fire activity predictions with WindNinja-derived winds from 45° at 50 mph (scenario three). Foliar moisture content was held constant at 100%.

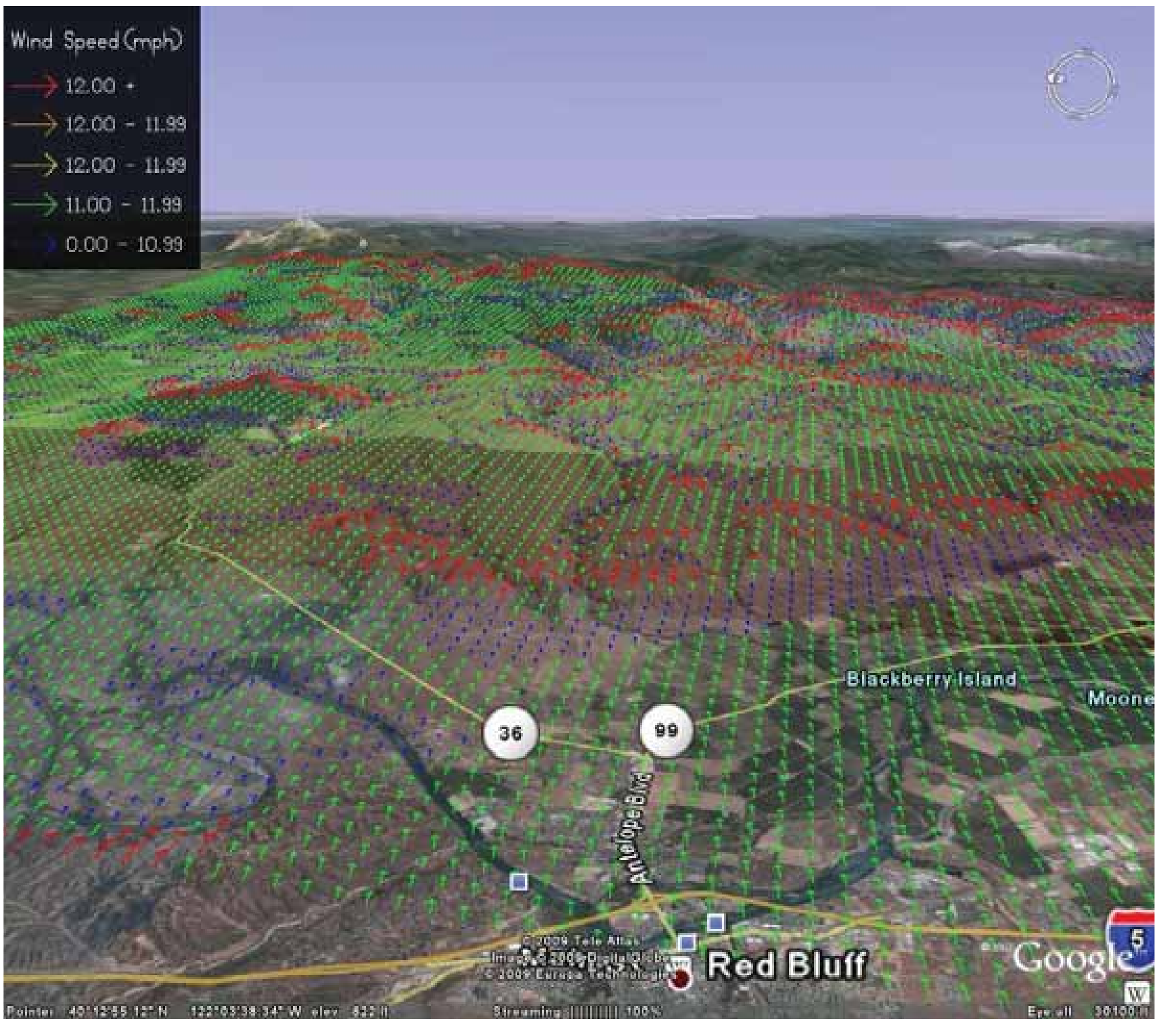

Figure 2. Google Earth view of WindNinja-derived wind speed and direction with initial winds at 12 mph from 260° (looking east into study area from Red Bluff).

[9] Personal communication, 25 March 2009. Chuck Schoendienst (CDF Division Chief, Red Bluff, CA).

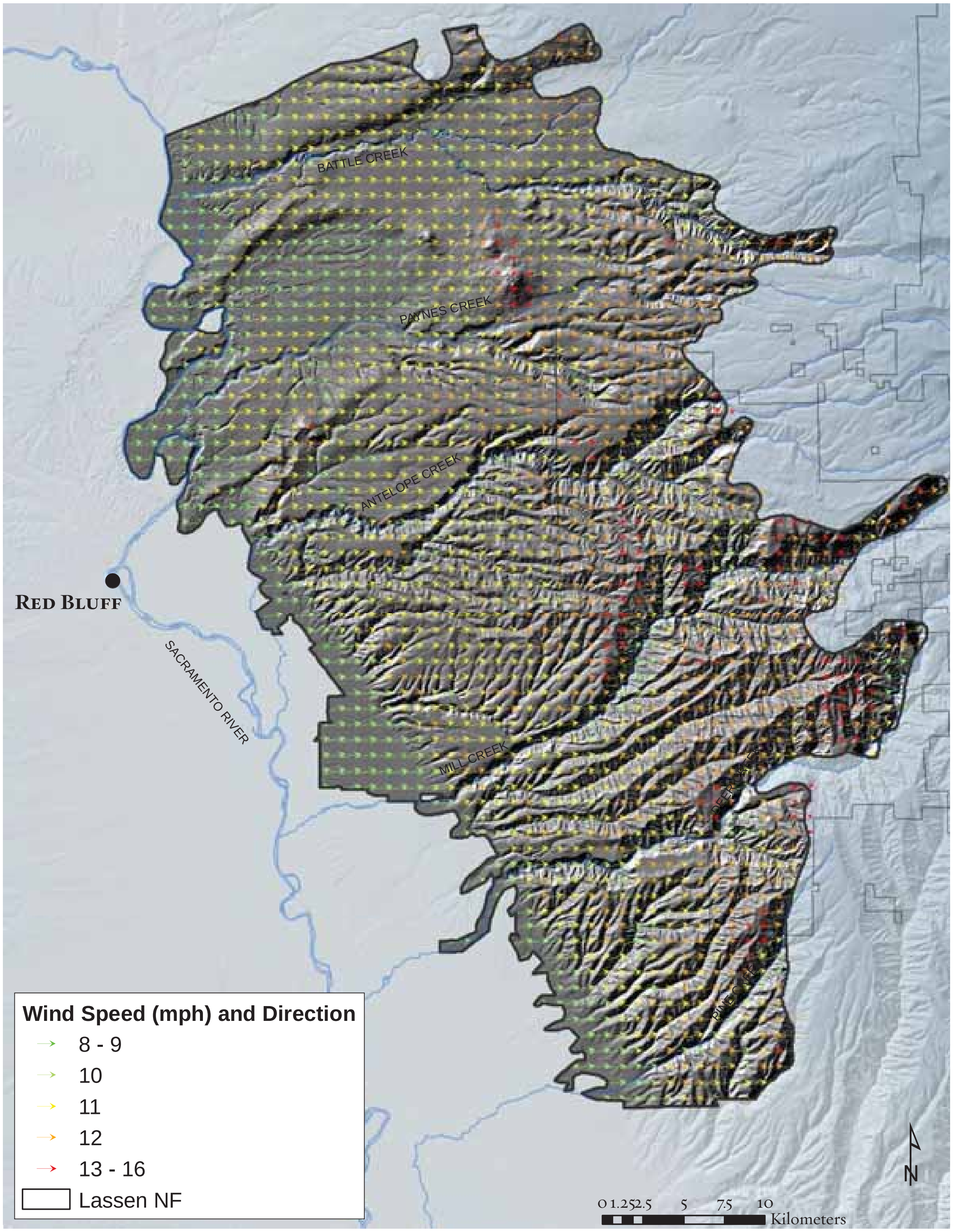

Figure 3. WindNinja-derived wind speed and direction with prevailing winds at 12 mph from 260° (scenario one).

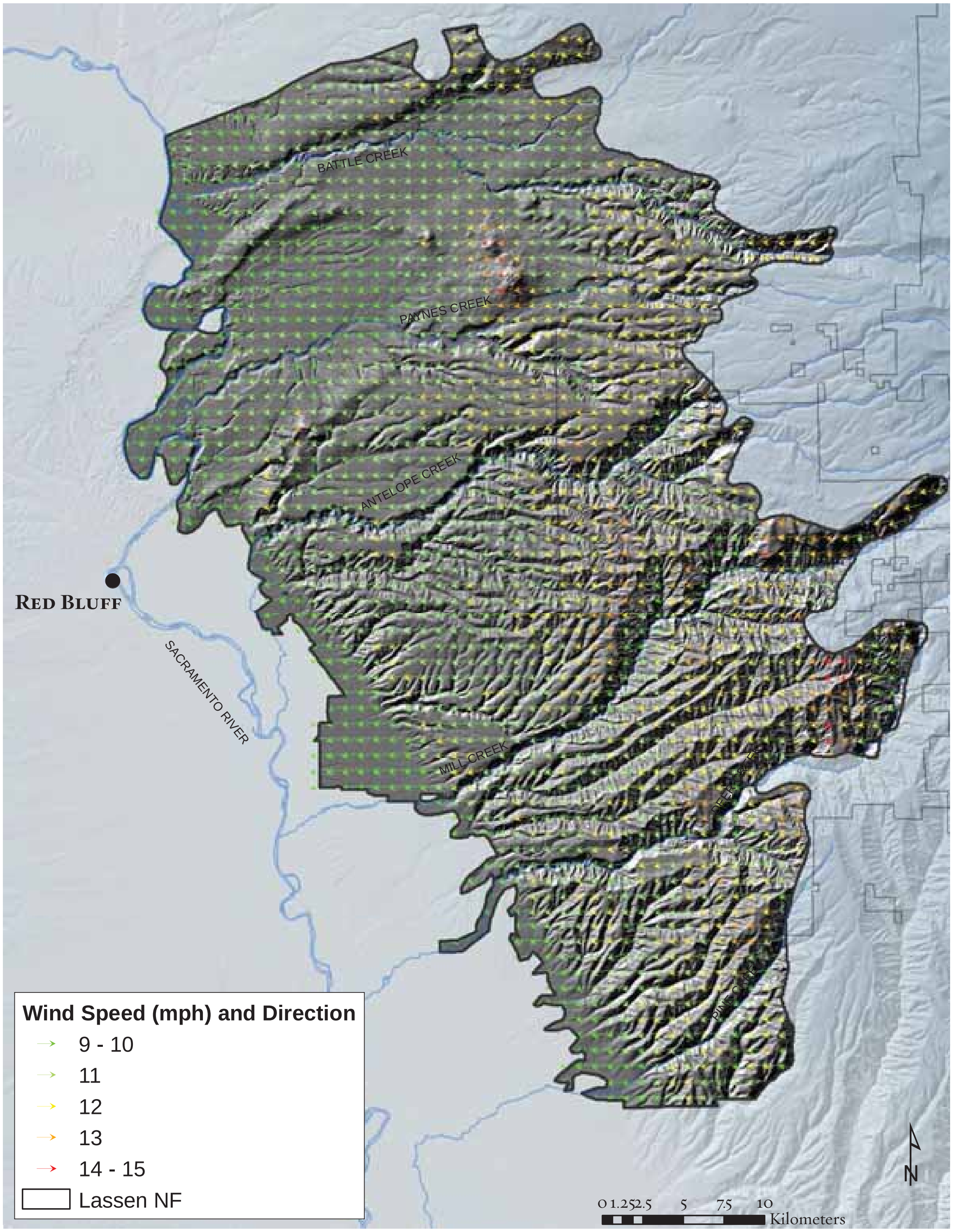

Figure 4. WindNinja-derived wind speed and direction with prevailing winds at 12 mph from 80° (scenario two).

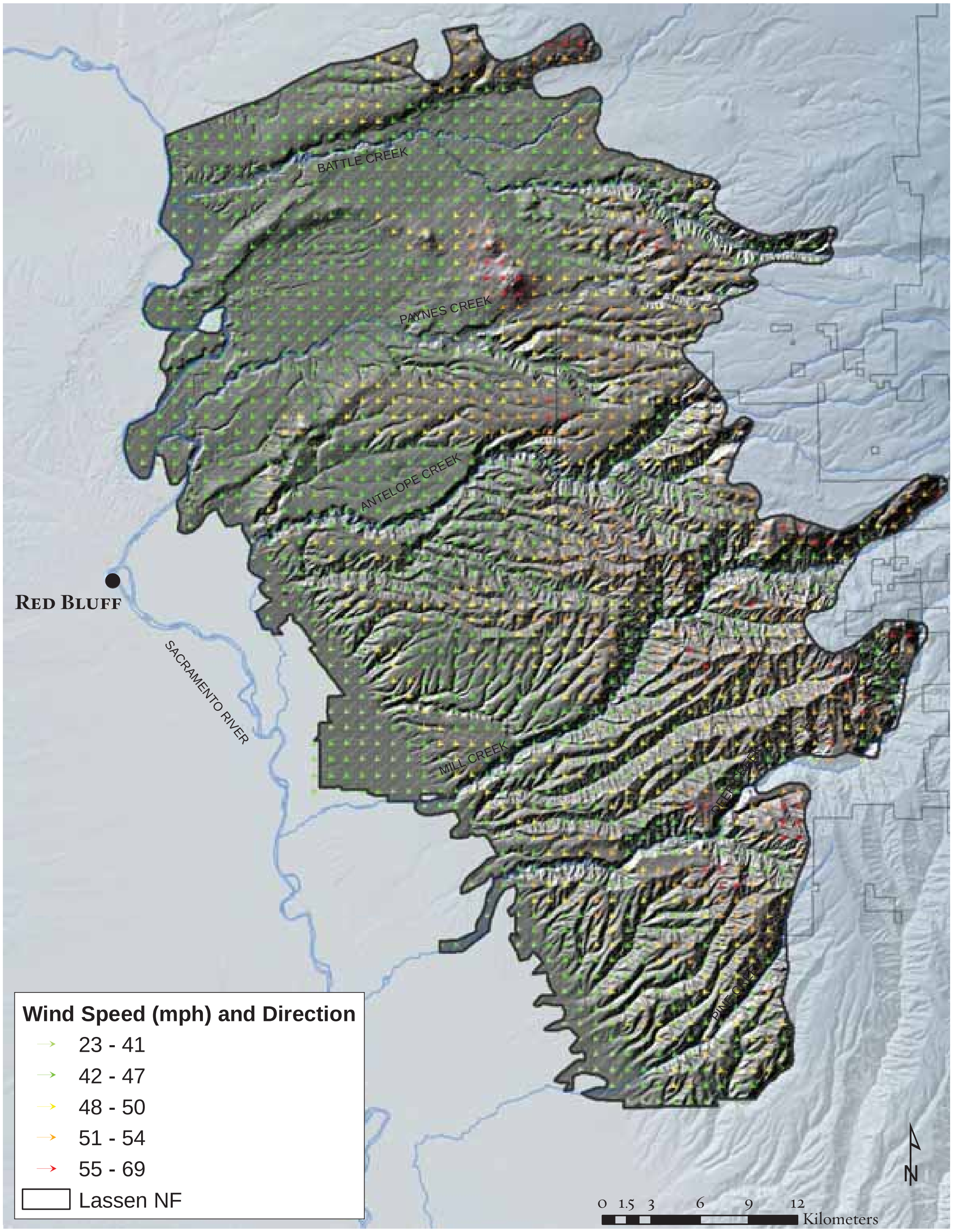

Figure 5. WindNinja-derived wind speed and direction with prevailing winds at 50 mph from 45° (scenario two). Note the new windspeed scale.

In addition to weather data, FlamMap requires spatial descriptions of elevation, aspect, and slope. These were derived from a standard 30-m DEM.

I chose the Gun II Fire conditions because this is a typical “problem fire” for the area. A problem fire is a recent, local severe fire that would escape initial attack (or expectations of such a fire). For the purpose of a FlamMap simulation it is defined by potential fire size, length of burn period, 20-ft wind speed (constant), wind direction (constant), initial fuel moistures, weather for fuel moisture pre-conditioning (variable), and finally, possible ignition sources and locations. The Gun II Fire burned almost entirely within the study area in 1999. This was an extreme fire characterized by high winds, low humidity, and high spread rates. It is a good representative problem fire for the area because its behavior is typical of late summer-early fall fires: spread was wind-driven in the Mill Creek canyon and burned primarily in cured grass and chaparral. The Gun II Fire burned roughly 59,000 ac in its first six days before it was stopped by rain at 60,390 ac.

The most critical, yet poorly quantified input data describe fuels conditions. FlamMap requires the following input rasters: fuel model, canopy cover, crown base height, canopy bulk density, and stand height. Because so much of this study area is located off U.S. Forest Service lands, the best available data source is the LANDFIRE project[10]. Although this is a tremendous resource, there are some issues with the LANDFIRE fuels data. Typically one calibrates FlamMap by comparing its predictions of a historic problem fire’s behavior to that fire’s known real-world behavior. Although LANDFIRE datasets are periodically updated to reflect the most current conditions (I downloaded the input data in early March 2009), the underlying base data are in many cases nearly a decade old. The Gun II Fire was recent when the data were assembled for this particular area which therefore reflects reduced potential fire behavior within burn perimeters as would be expected. This makes calibration difficult because predictions reflect post-fire conditions rather than conditions existing at the time of the fire. Unfortunately the other large fires in the area occurred before the advent of widespread GIS mapping. Secondly, the study area contains the transition from Central Valley grasslands to foothill oak woodlands and chaparral (and barely reaches the lower montane mixed conifer zone). One of LANDFIRE’s mapping zone boundaries runs along this transition. Due to LANDFIRE’s modeling methodology, there are substantial differences in mapped fuels, canopy cover, and other variables along the border which do not reflect reality. This affects FlamMap’s fire behavior modeling and is particularly obvious in the potential flamelength map.

Figures 6 and 7 describe the study area’s wildland-urban interface and ownership patterns.

LANDFIRE

Figures 8 and 9 depict the LANDFIRE products I used as FlamMap inputs. Although only the fuel models and canopy cover as shown, I also used LANDFIRE crown base height, canopy bulk density, and stand height.

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[10] http://www.landfire.gov

Wildland-Urban Interface. The study area is very sparsely populated although there is some development at the boundaries. There are several small communities as well as widely scattered structures throughout the interior.

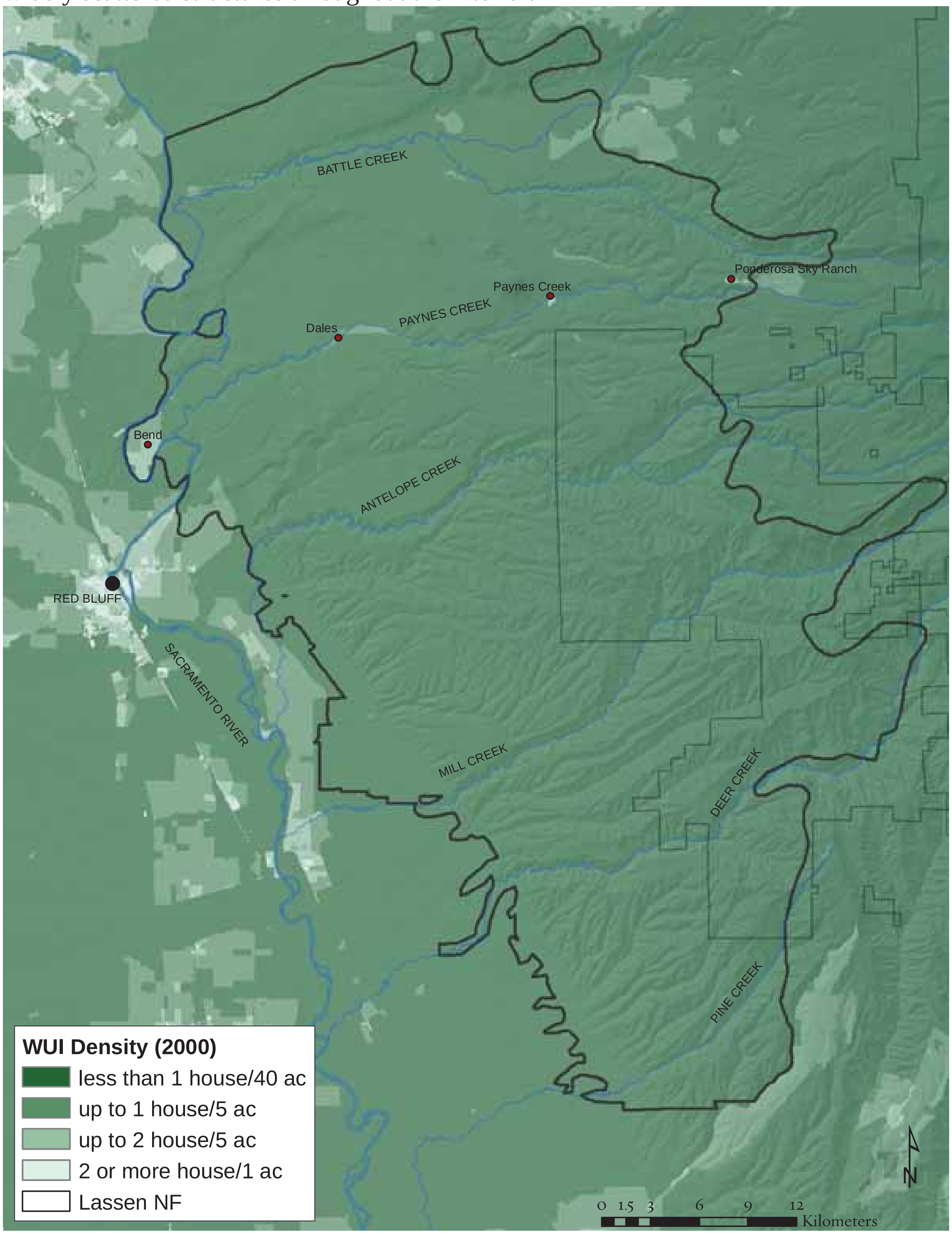

Figure 6. Wildland-urban interface density in 2000.

Ownership. The study area is a mix of public and private lands including the Lassen National Forest and Ishi Wilderness Area, TNC's Dye Creek Reserve, BLM land, DFG land, and private ranches.

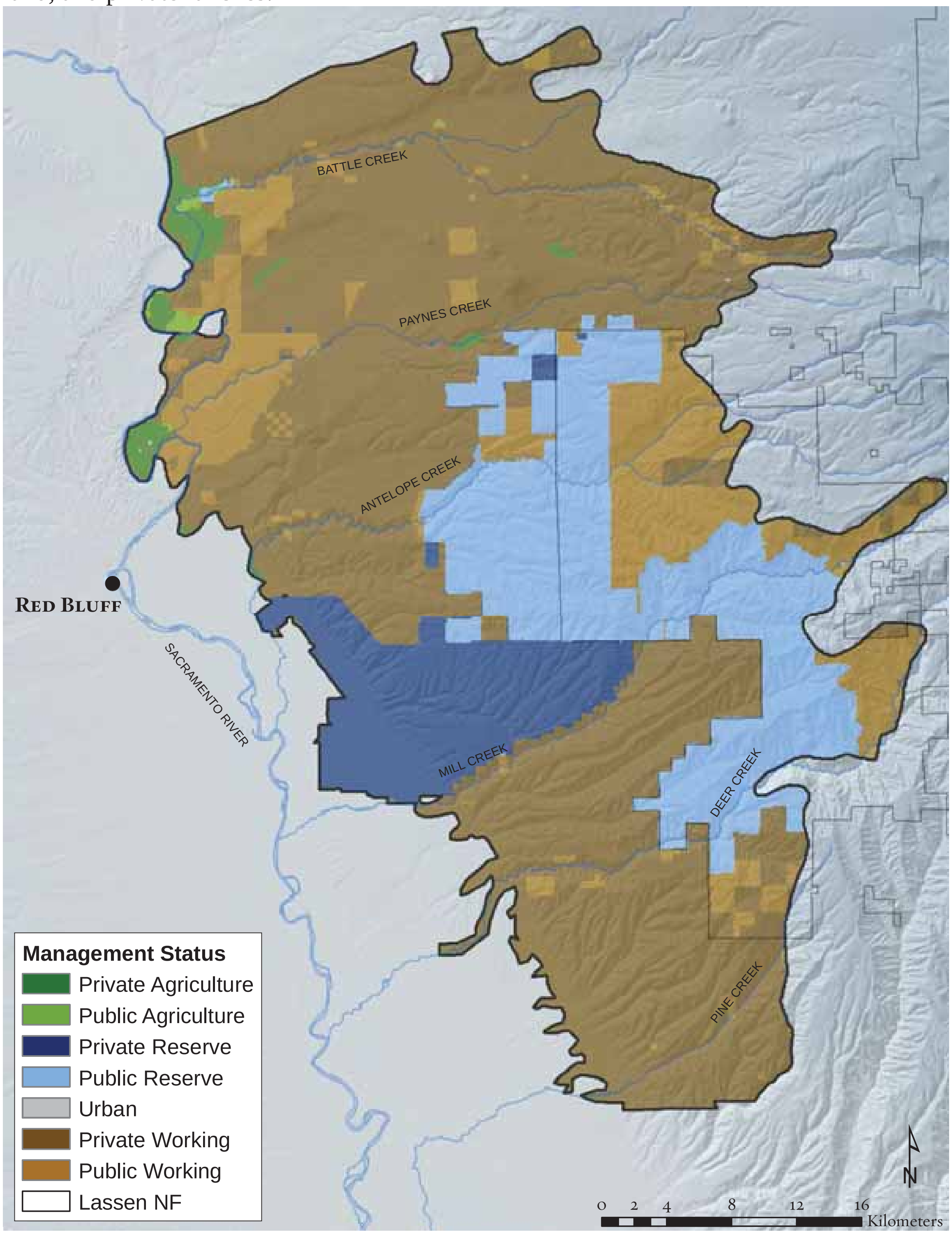

Figure 7. Much of the study area is privately-owned cattle ranches.

Fuels. LANDFIRE produced fuel model data that are periodically updated to reflect current conditions. The low- and mid-elevations of the study area are classified as grass and shrub fuels while timber models only occur in the far east at the highest elevations. One of the LANDFIRE map zone boundaries runs though the study area.

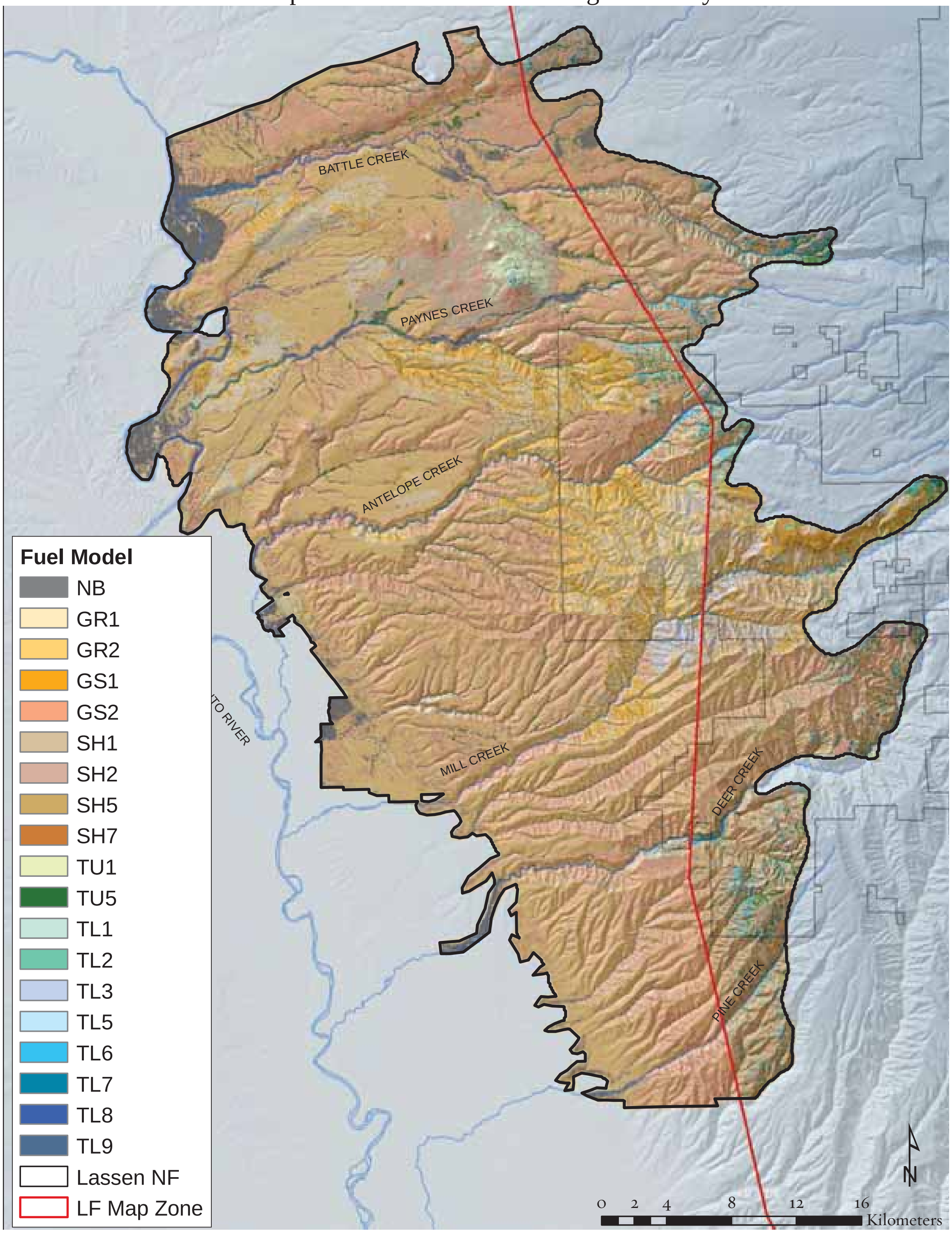

Figure 8. LANDFIRE fuel models and map zone boundary ("NB" = Non-burnable, "GR" = grass, "GS" = grass-shrub, "TU" = timber-understory, and "TL" = timber litter).

***Canopy Cover*.** Canopy cover (CC) was updated by LANDFIRE to reflect 1999-2007 wildfire burn severity where high severity reduced CC to 0% while moderate severity reduced CC by 40% and low severity did not change CC. Satellite imagery dates in map zone 5 (California Central Valley) are 2000-2001 and 1999-2003 in map zone 6 (Sierra Nevada Mountains). Roughly 45% of the study area is non-forested.

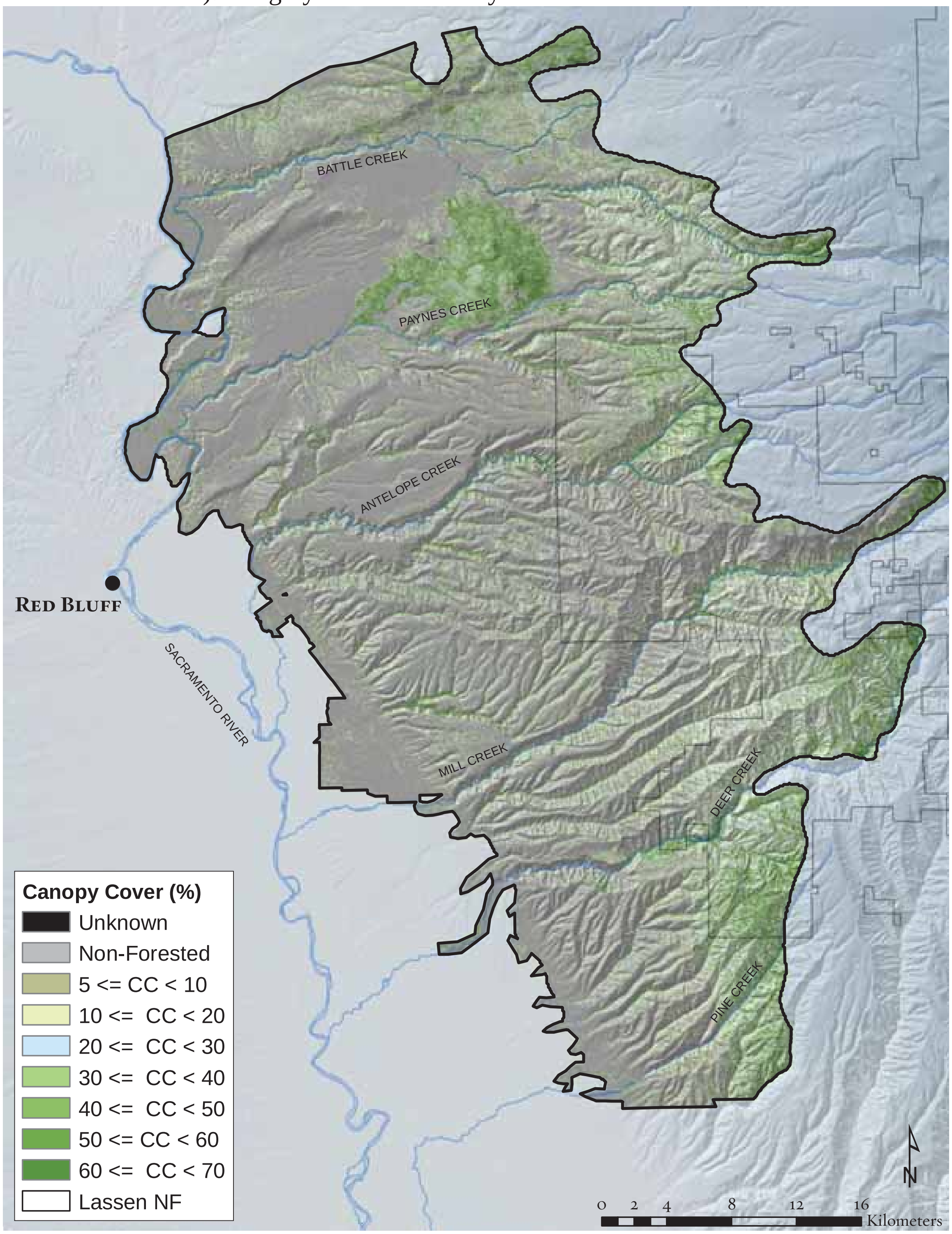

Figure 9. Canopy cover.

Potential Fire Behavior

The following sections describe potential fire behavior in terms of rate of spread, flamelength, and crown fire activity for the three wind scenarios described above.

Rate of Spread

Rate of spread (ROS) is a fundamental fire behavior prediction from which flamelength and crown fire activity are derived (Figures 10 and 11). ROS is strongly influenced by several 1999 fires which are outlined here (Figure 10). Fire spread is predicted to effectively stop within these old burn perimeters, although fuels have since regrown. These rates of spread (scenario one) are relatively low (mean = 10.6 chains/hr or 0.133 miles/hr, maximum = 133 chains/hr) because of the sparse nature of the fuels. For comparison, 24 chains/hr is roughly the speed at which a backpacker can ascend a 100% slope, while a fire in low sage during Santa Ana wind conditions can spread at roughly ten times that speed. Scenario two winds did not significantly change the magnitude or spatial pattern of rate of spread (mean = 10.4 chains/hr, maximum = 154 chains/hr).

Chains/hour	Miles/hour	Percent of Landscape
0 (unburnable)	0.00	4.0
<1	0.01	6.4
<5	0.06	50.0
<10	0.13	8.4
<20	0.25	8.0
<40	0.50	21.1
<80	1.00	0.5
>80	>1.00	1.6

Table 3. Scenario one rates of spread.

Chains/hour	Miles/hour	Percent of Landscape
0 (unburnable)	0.00	4.0
<1	0.01	6.4
<5	0.06	50.1
<10	0.13	9.0
<20	0.25	8.2
<40	0.50	20.2
<80	1.00	0.5
>80	>1.00	1.6

Table 4. Scenario two rates of spread.

Under scenario three, however, rate of spread increased dramatically, as expected. Mean rate of spread jumped to 68 chains/hr and the maximum was 767 chains/hr. The maximum values only occurred in a few pixels and should not be considered representative.

Chains/hour	Miles/hour	Percent of Landscape
0 (unburnable)	0.00	4.0
<1	0.01	0.0
<5	0.06	50.2
<10	0.13	1.1
<20	0.25	1.2
<40	0.50	0.9
<80	1.00	8.1
>80	>1.00	34.4

Table 5. Scenario three rates of spread.

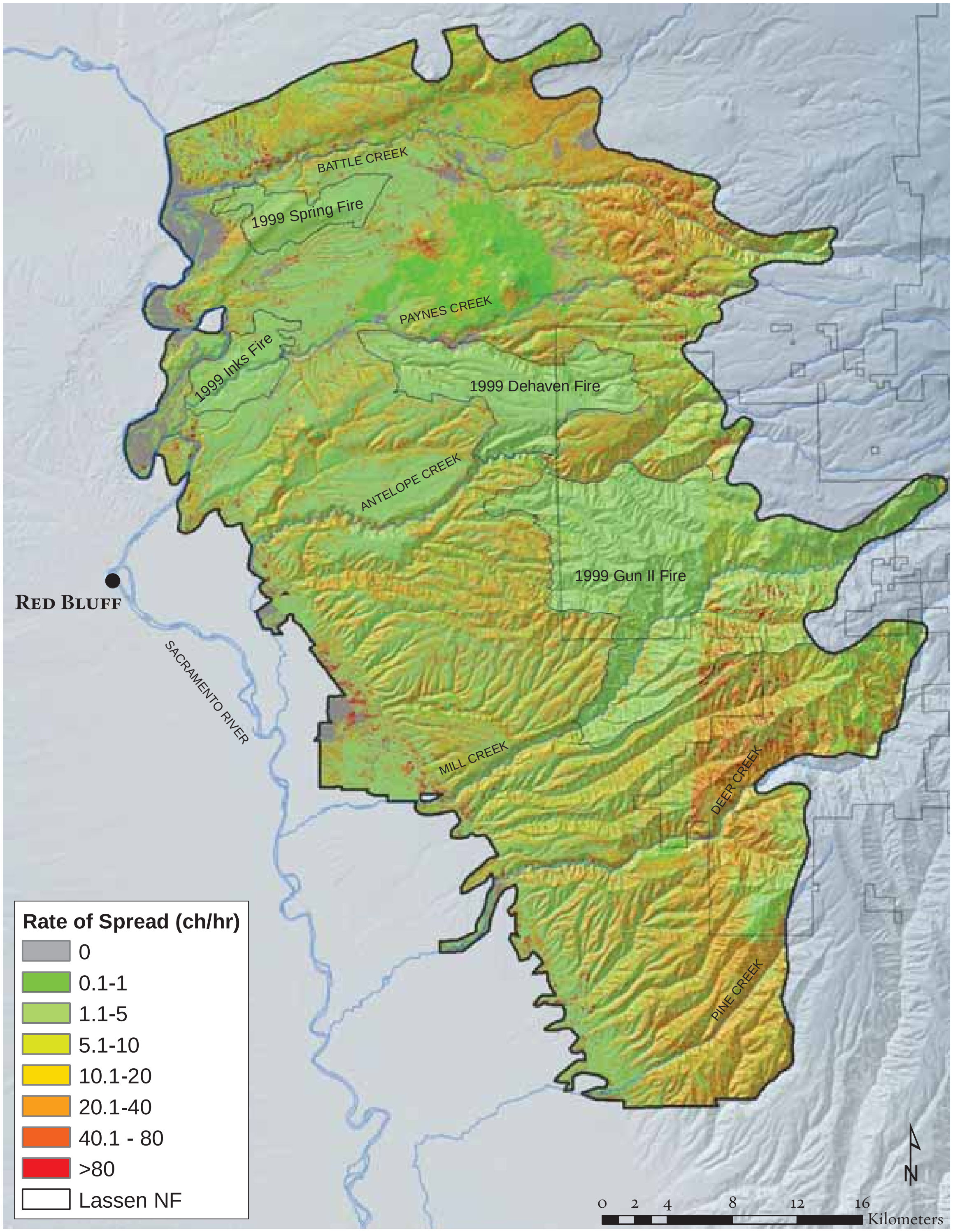

Figure 10. Potential rate of spread (scenarios one and two). The perimeters of four 1999 fires are outlined to show how they influence rate of spread.

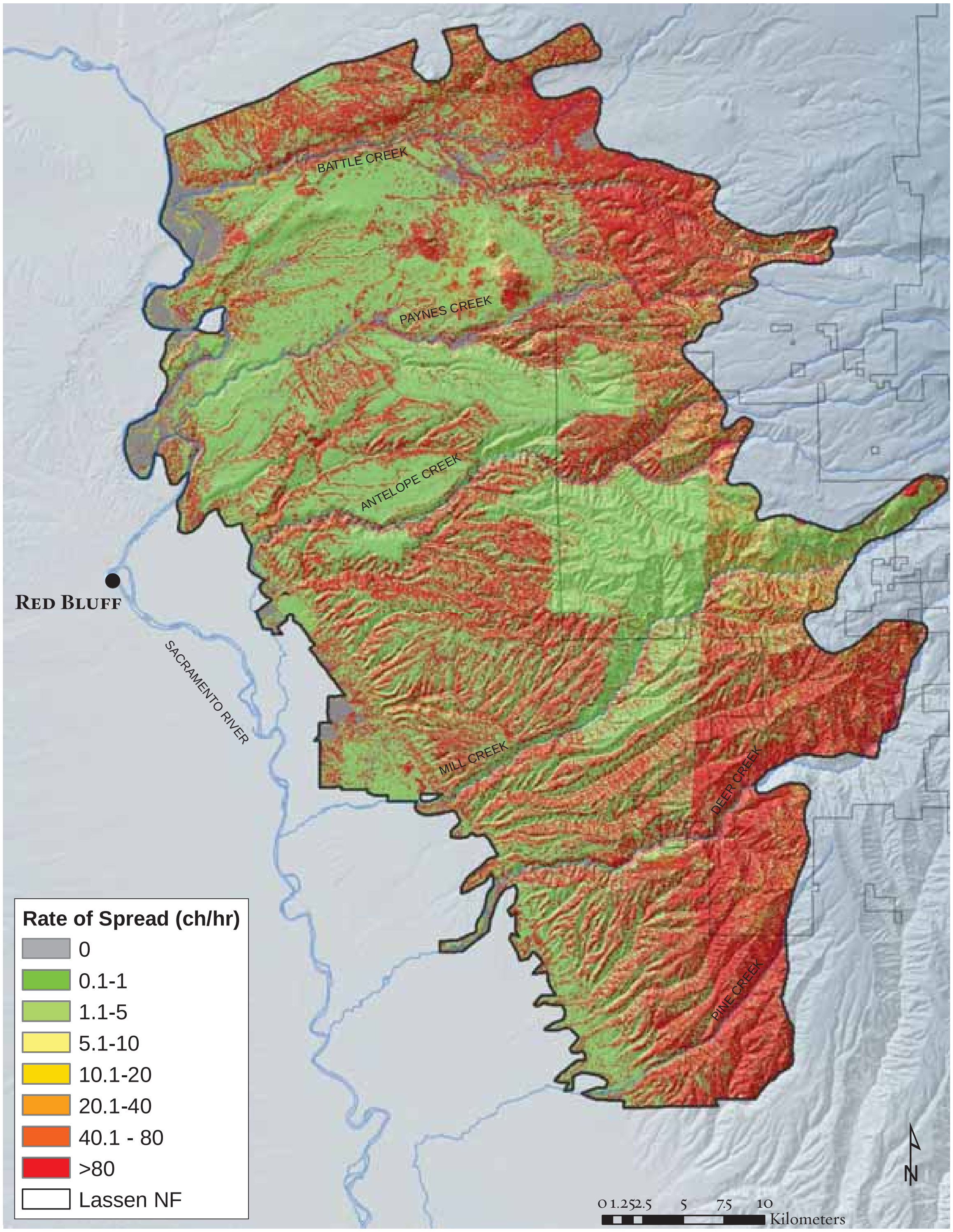

Figure 11. Potential rate of spread (scenario three).

Flamelength

The map zone boundary is particularly obvious in the potential flamelength maps (Figures 12-14). Potential flamelength categories follow the “hauling chart”: flames of up to 4 ft can be suppressed by handcrews; up to 8 requires mechanized resources such as engines, dozers, and aircraft; at greater than 8 feet direct attack is likely to be ineffective due to spotting; and above 11 feet direct attack is not feasible. With winds from 260° mean flamelength was 3.9 ft (maximum of 109.8 ft).

Flamelength (ft)	Percent of Landscape
0 (unburnable)	4.0
<4	65.6
<8	19.6
<11	1.8
<20	3.4
>20	5.5

Table 6. Scenario one flamelengths.

Flamelengths are dramatically reduced under scenario two wind conditions (Figure 13). Mean flamelength was 1.2 ft (maximum of 30.9 ft). This reduction is likely due to topography as the winds force the fire to spread downhill. The fire is pushed downhill through the timber on the east, whereas in scenario one it hits the timber with the advantage of both slope and wind.

Flamelength (ft)	Percent of Landscape
0 (unburnable)	4.0
<4	87.5
<8	6.7
<11	1.4
<20	0.3
>20	0.01

Table 7. Scenario two flamelengths.

When winds are from 45° at 50 mph (scenario three), mean flamelength is 21.6 ft (maximum = 561.6 ft) (Figure 14). The maximum values only occurred in a few pixels and should not be considered representative. The extremely high wind speed overrides topographic influence.

Flamelength (ft)	Percent of Landscape
0 (unburnable)	4.0
<4	51.2
<8	1.2
<11	11.4
<20	10.1
>20	22.1

Table 8. Scenario three flamelengths.

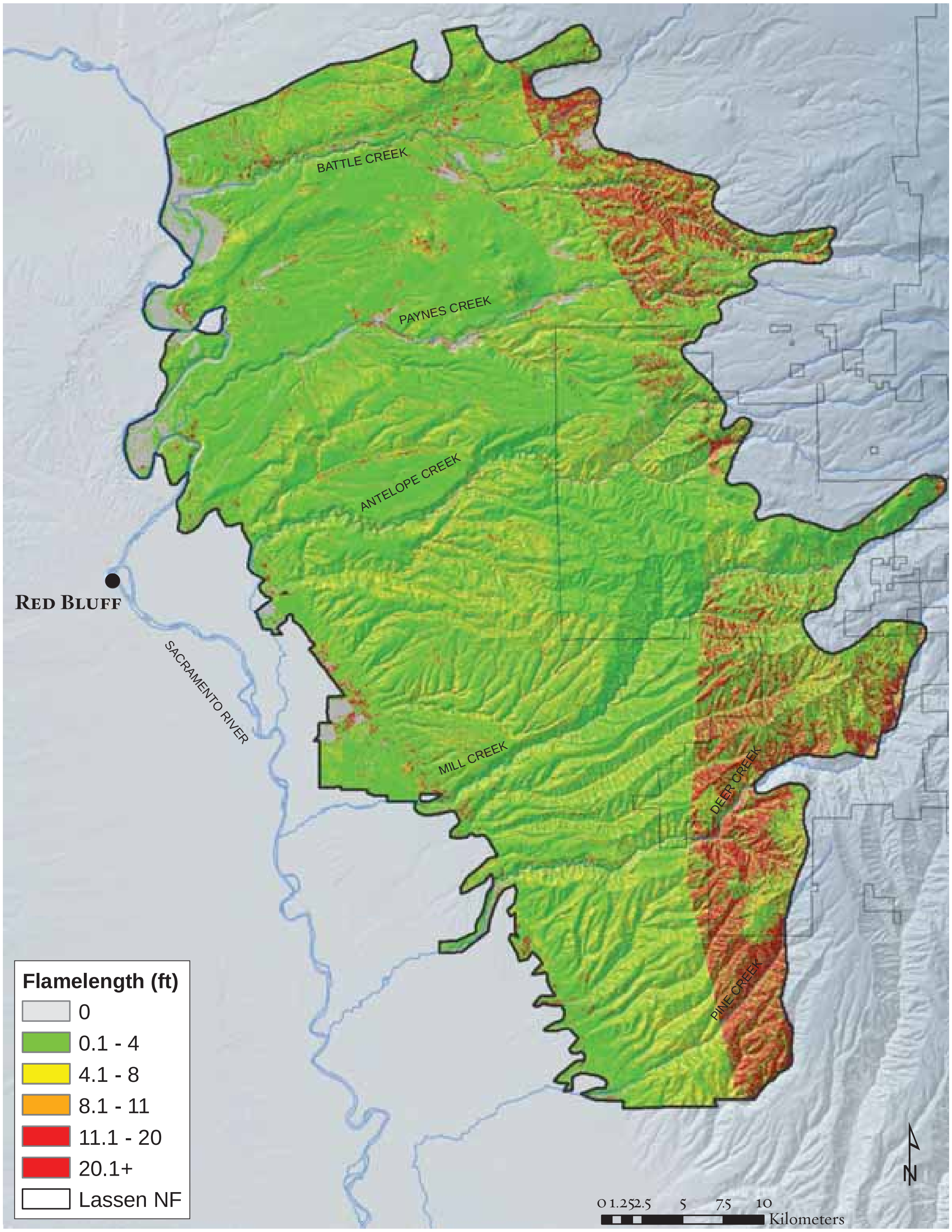

Figure 12. Potential flamelengths with winds from 260° (scenario one).

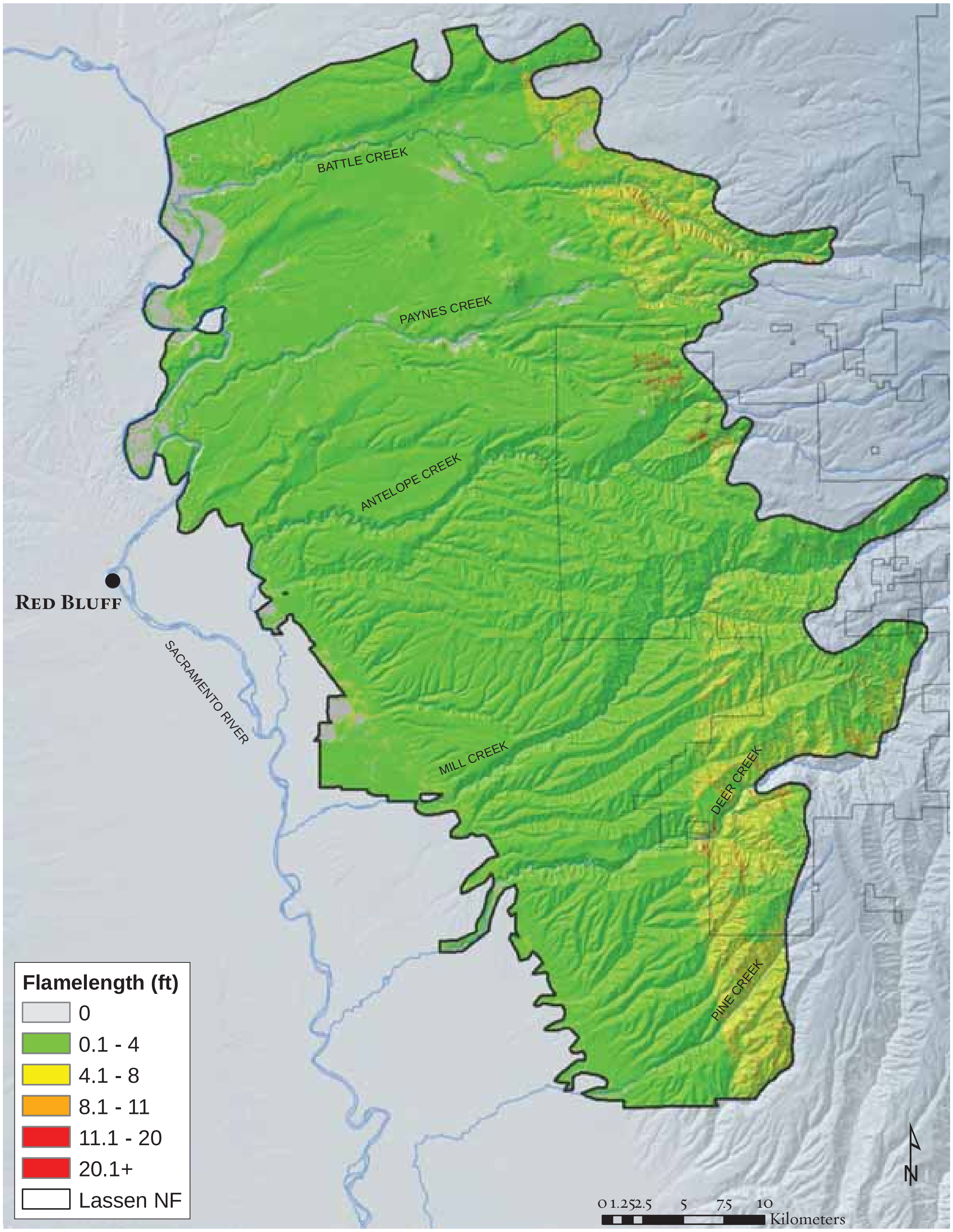

Figure 13. Potential flamelengths with winds from 80° (scenario two).

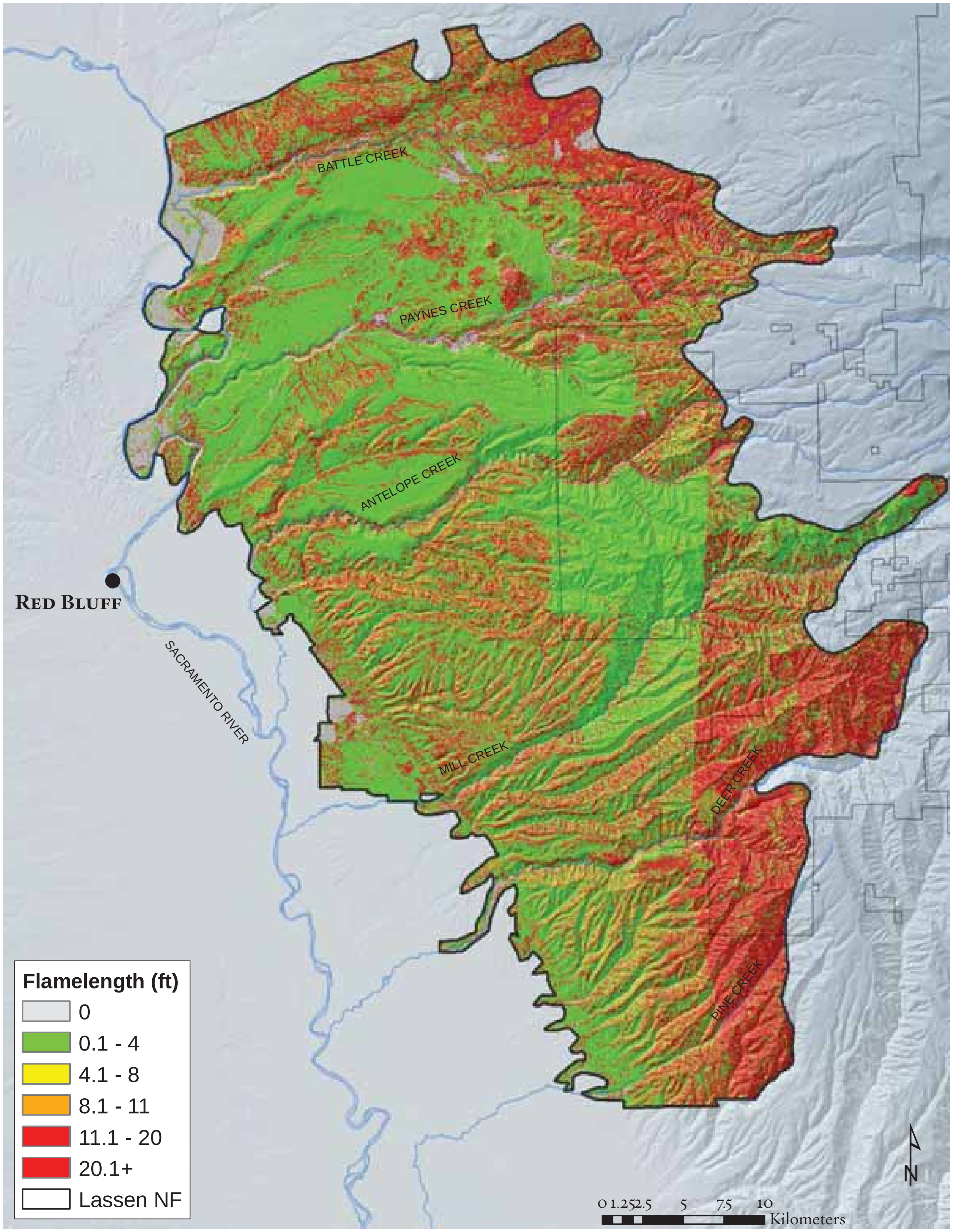

Figure 14. Potential flamelengths with 50 mph winds from 45° (scenario three).

Crown Fire Activity

FlamMap predicts that roughly two-thirds of the study area would burn as a surface fire under scenario one winds (Figures 15). The situation is very similar with scenario two winds. This relative lack of high intensity fire is not unexpected because so much of the area is grassland or shrubland. The small area of potential crown fire is in a timber stand at the upper elevations of Antelope Creek.

Crown Fire Activity	Percent of Landscape
Unburnable	4.0%
Surface Fire	67.8%
Torching	27.9%
Crowning	0.4%

Table 9. Scenario one crown fire activity.

Crown Fire Activity	Percent of Landscape
Unburnable	4.0%
Surface Fire	68.0%
Torching	27.7%
Crowning	0.3%

Table 10. Scenario two crown fire activity.

However, when wind speed is increased in scenario three, more than 10% of the landscape is predicted to burn as crown fire (Figure 16). Timber along the drainages burns with much more intensity. Unfortunately the mapping zone boundary plays a role here as well.

Crown Fire Activity	Percent of Landscape
Unburnable	4.0%
Surface Fire	64.5%
Torching	19.3%
Crowning	12.2%

Table 11. Scenario three crown fire activity.

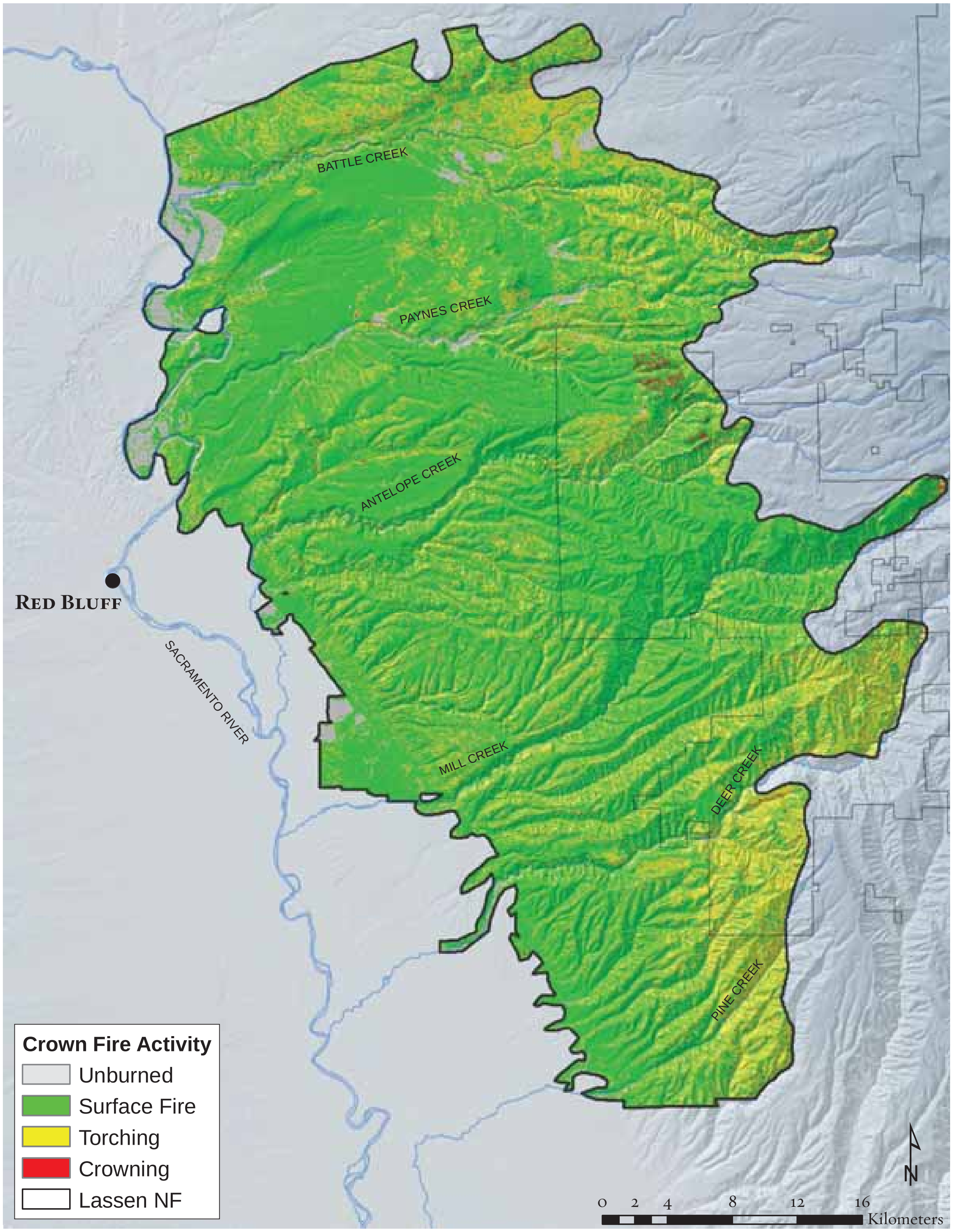

Figure 15. Potential crown fire activity (scenarios one and two).

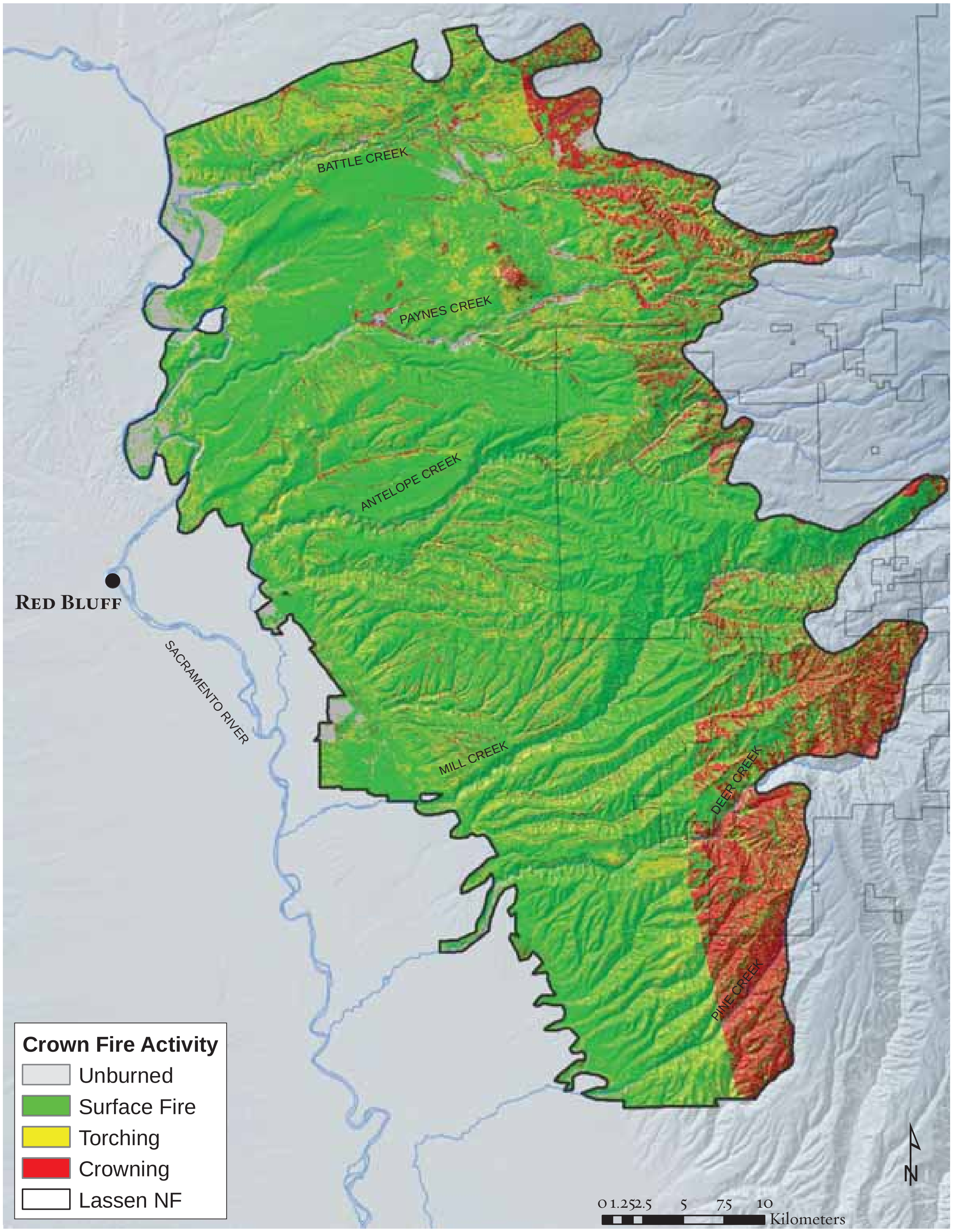

Figure 16. Potential crown fire activity (scenario three).

Other Fire Behavior

In addition to basic fire behavior outputs, FlamMap can also produce burn probability estimates, mean arrival time predictions, and minimum-time travel routes. These results were simulated using a larger study area to minimize boundary issues and later clipped to the study area.

Burn Probability

To estimate burn probability, I simulated 5,000 randomly distributed ignitions that were allowed to spread for 48 hours under wind scenarios one and two (Figures 17 and 18). This effectively isolates the effect of topography and fuels (which be modified, unlike weather or topography) on fire spread. These parameters were chosen to maximize the area reached by a fire at least once to ensure robust sampling. Probability is based on the percentage of fires that will reach a node at least once during the period of simulation. The study area is covered by roughly 700 nodes when spatial resolution is set to 100 m. Calculations at this resolution require more than 20 hours of processing time on a 3.2 GHz dual-processor machine with 4 Gb of RAM. Higher resolutions result in exponentially longer processing times. High probabilities are the result of large fires that are capable of burning proportionally more of the landscape. Large fires in turn depend on high rates of spread. Burn probability is not a prediction of future fire occurrence or likelihood. The areas with the highest burn probabilities are in the mid-elevation portions of the study area, although the results are confounded by the map zone boundary. The mean burn probability under scenario one is 2.1% (maximum 8.4%). The only potential fire shadow is a small area to the lee-ward of the butte to the north of Paynes Creek. It appears that under scenario one winds this topographic feature shields the area immediately behind it from fire. A similar area appears in scenario two, leading me to believe it is not truly a fire shadow.

Burn Probability (%)	Percent of Landscape
0	2.0
<1.0	37.6
<2.0	25.2
<3.0	12.9
<4.0	4.9
<5.0	3.6
<6.0	5.7
<7.0	4.8
<8.0	3.0
<9.0	0.5

Table 12. Scenario one burn probability.

The mean and maximum burn probabilities for scenario two winds- 2.4% and 7.5% respectively- are very similar to scenario one results. The 1999 fires appear to produce fire shadows by significantly reduce burn probabilities to their lee-ward (west-southwest).

Burn Probability (%)	Percent of Landscape
0	1.9
<1.0	30.7
<2.0	17.7
<3.0	17.4
<4.0	8.8
<5.0	10.1
<6.0	5.9
<7.0	5.7
<8.0	1.8
<9.0	0.0

Table 13. Scenario two burn probability.

Arrival Time and Minimum-Time Travel Routes

Arrival time calculations require simulating a single large fire under problem fire conditions. In this case I used long ignition strips along the wind-ward west and east edges oriented perpendicular to scenarios one and two winds to simulate the effect of wind-driven fire spreading into the study area from the grasslands below or down from the timber above (Figures 21 and 22). This allows arrival time to be determined for the entire landscape, rather than the much smaller area possible with discrete ignition sources. The resulting maps show the effect of topography and fuels under constant weather conditions on the time required for fire to reach various points on the landscape. A fire burning in scenario one conditions was predicted to reach roughly 6% of the study area within 12 hours and 25% of the study area within 36 hours (Figure 19). Within 144 hours (6 days) a fire could burn over 70% of the study area.

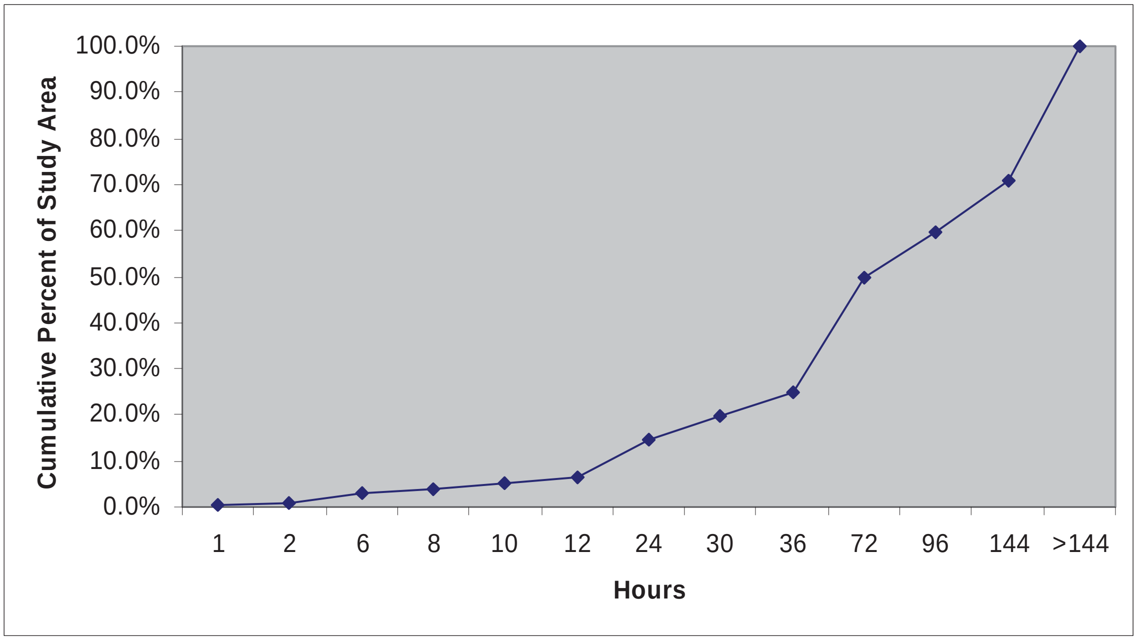

Figure 19. Cumulative percent of the study area reached by arrival time (scenario one).

Scenario two winds produce similar results. A fire burning in these conditions was predicted to reach roughly 7% of the study area within 12 hours and about 20% of the study area within 36 hours (Figure 19). Within 144 hours (6 days) a fire could burn over 80% of the study area.

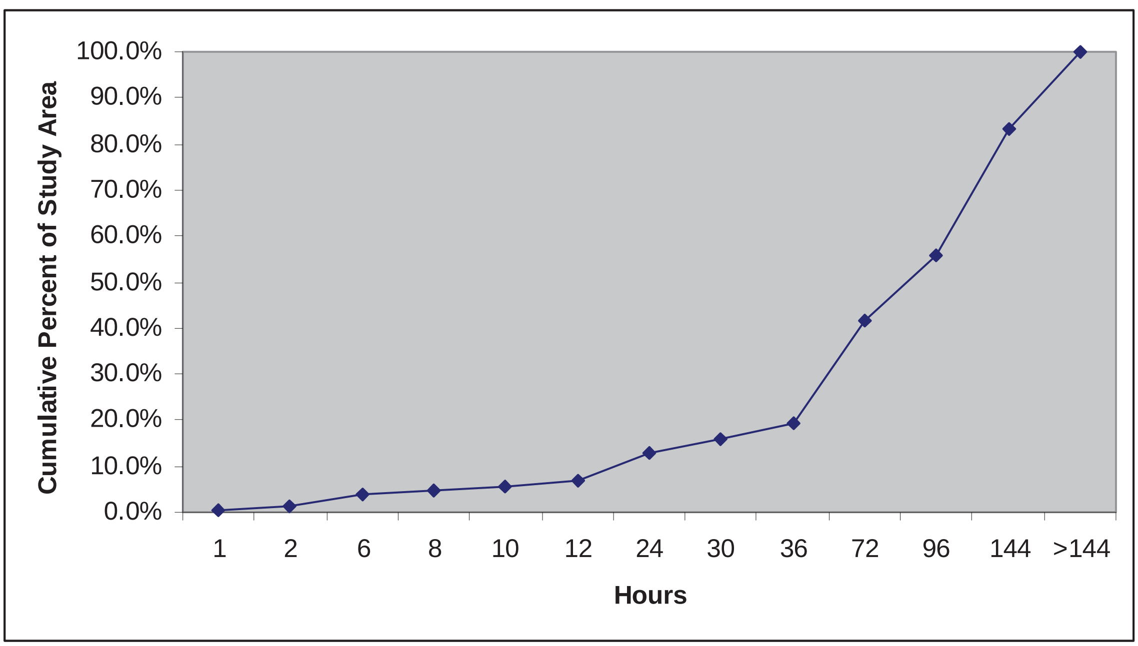

Figure 20. Cumulative percent of the study area reached by arrival time (scenario two).

I overlaid minimum-time travel routes on the arrival time maps (Figures 21 and 22). These are FlamMap's projections of the most likely routes that fires will follow across a landscape for a given wind direction. These minimum-time travel routes (or flow paths) show that fires generally spread along major watersheds but not in every case.

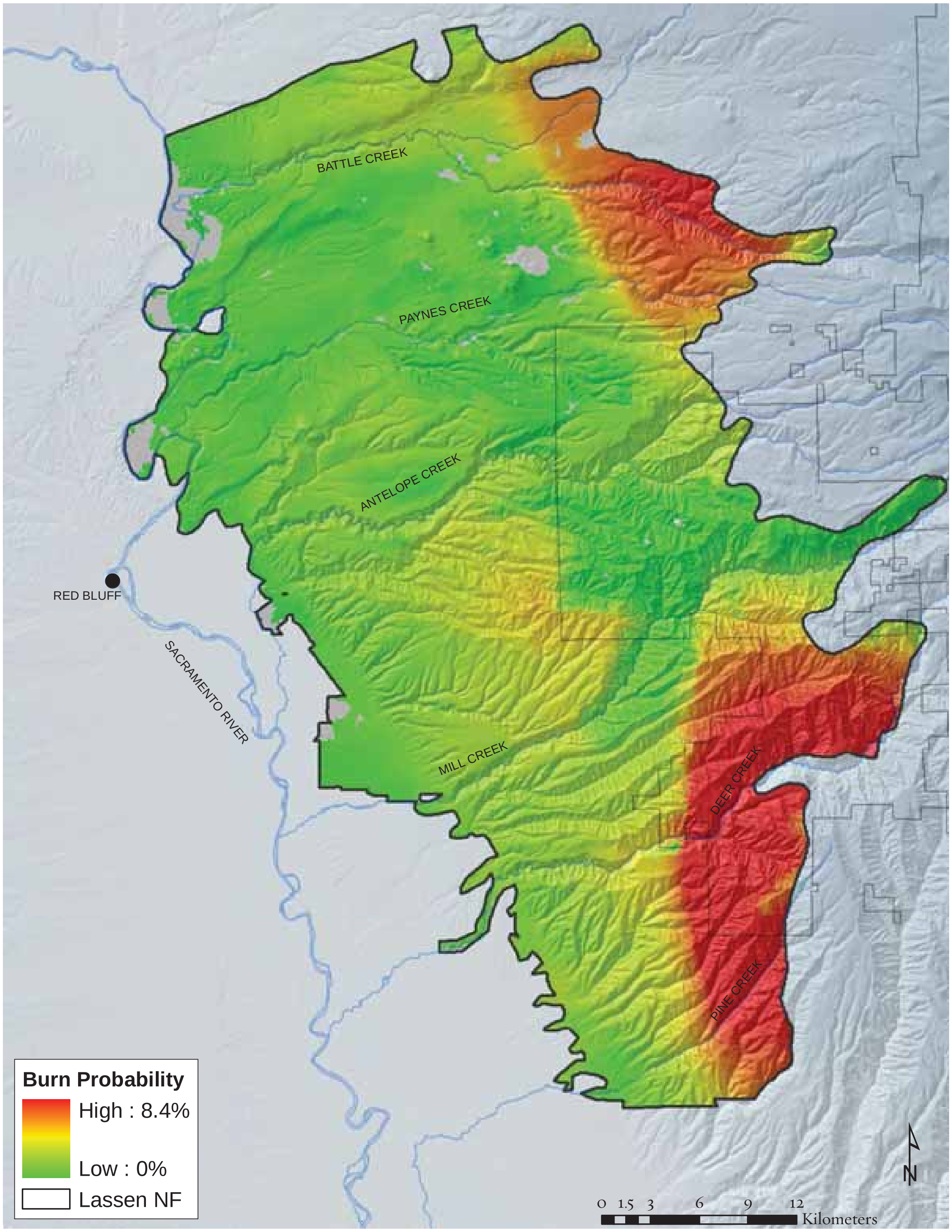

Figure 17. Burn probability (scenario one).

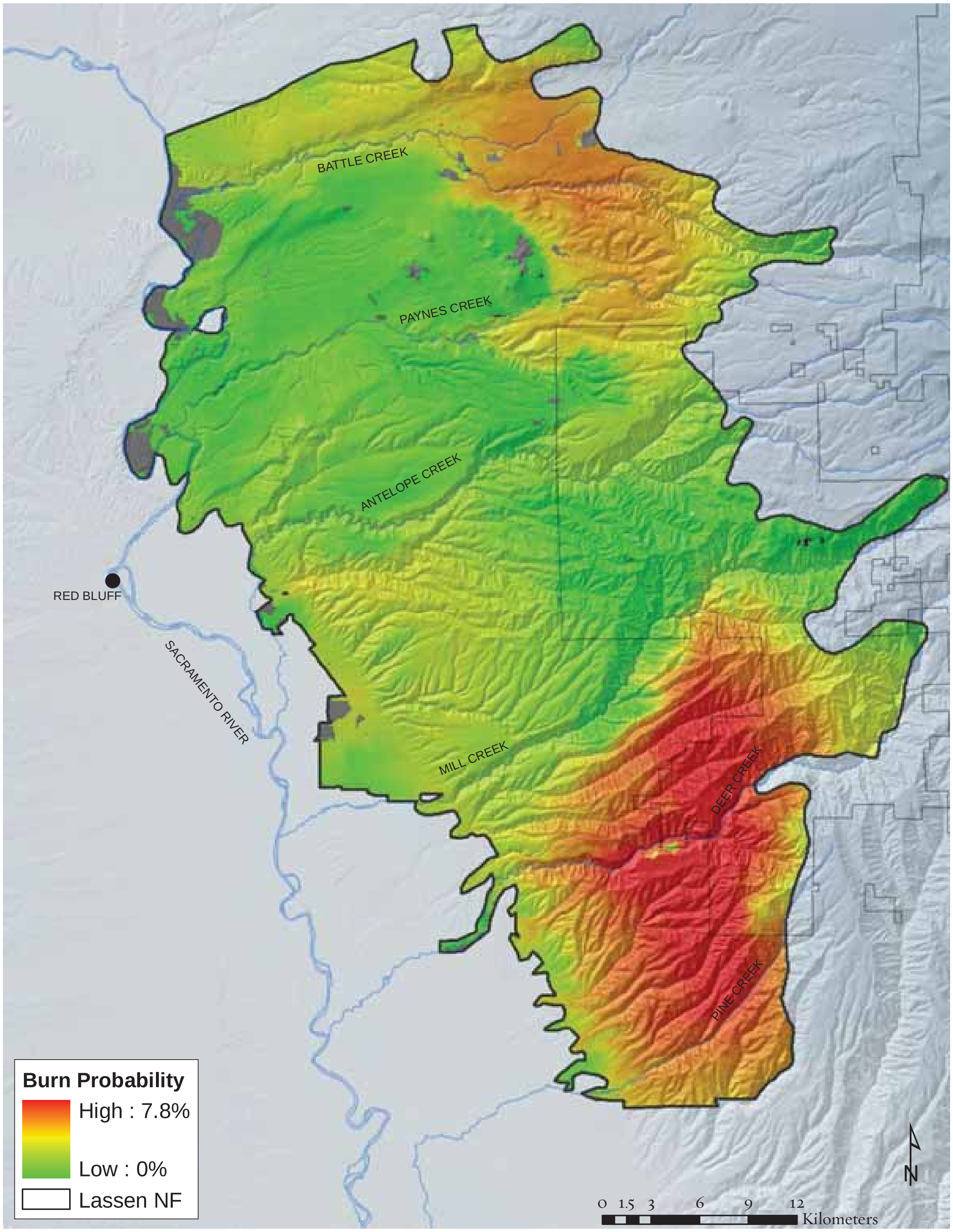

Figure 18. Burn probability (scenario two).

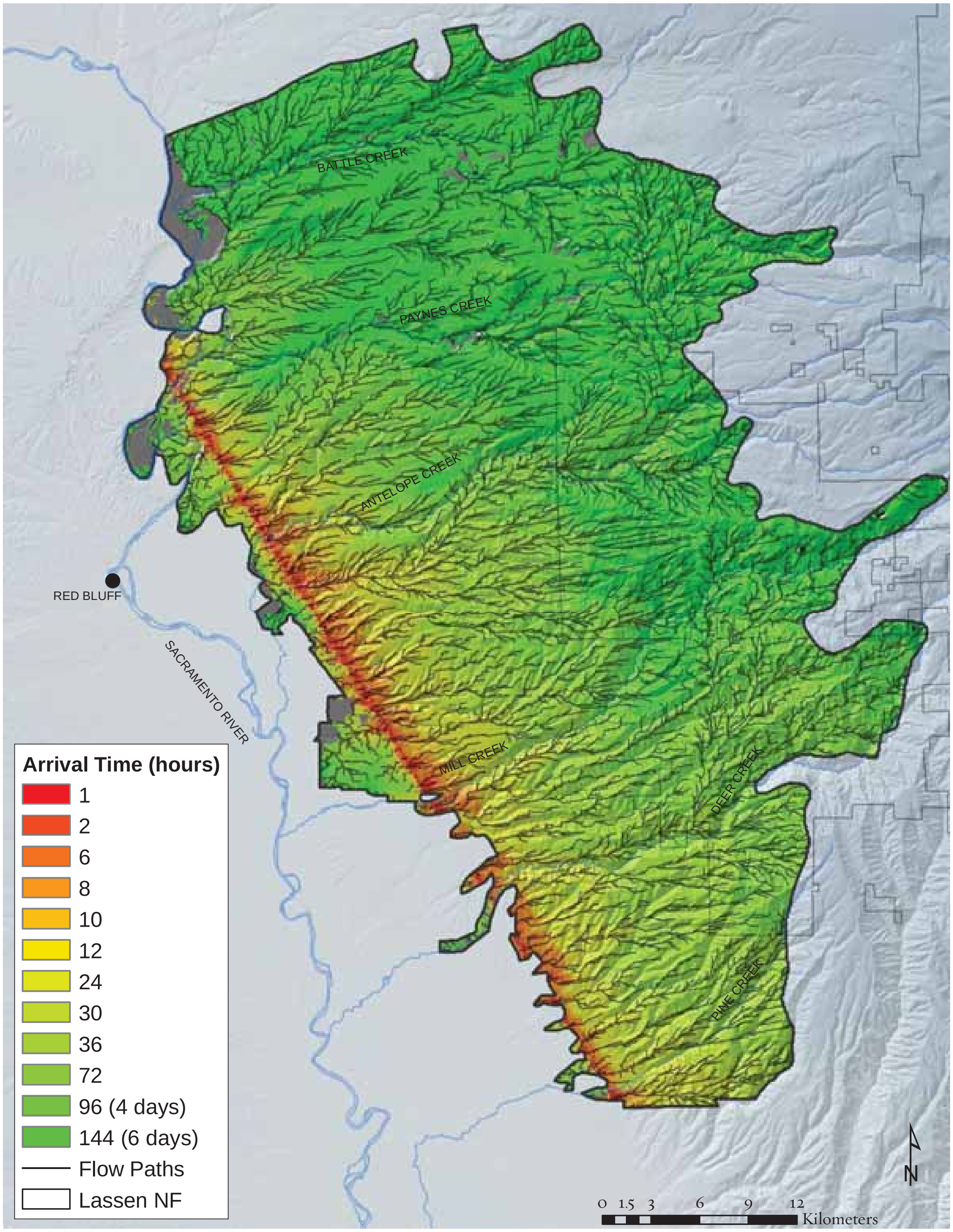

Figure 19. Arrival time and minimum-time travel routes (scenario one).

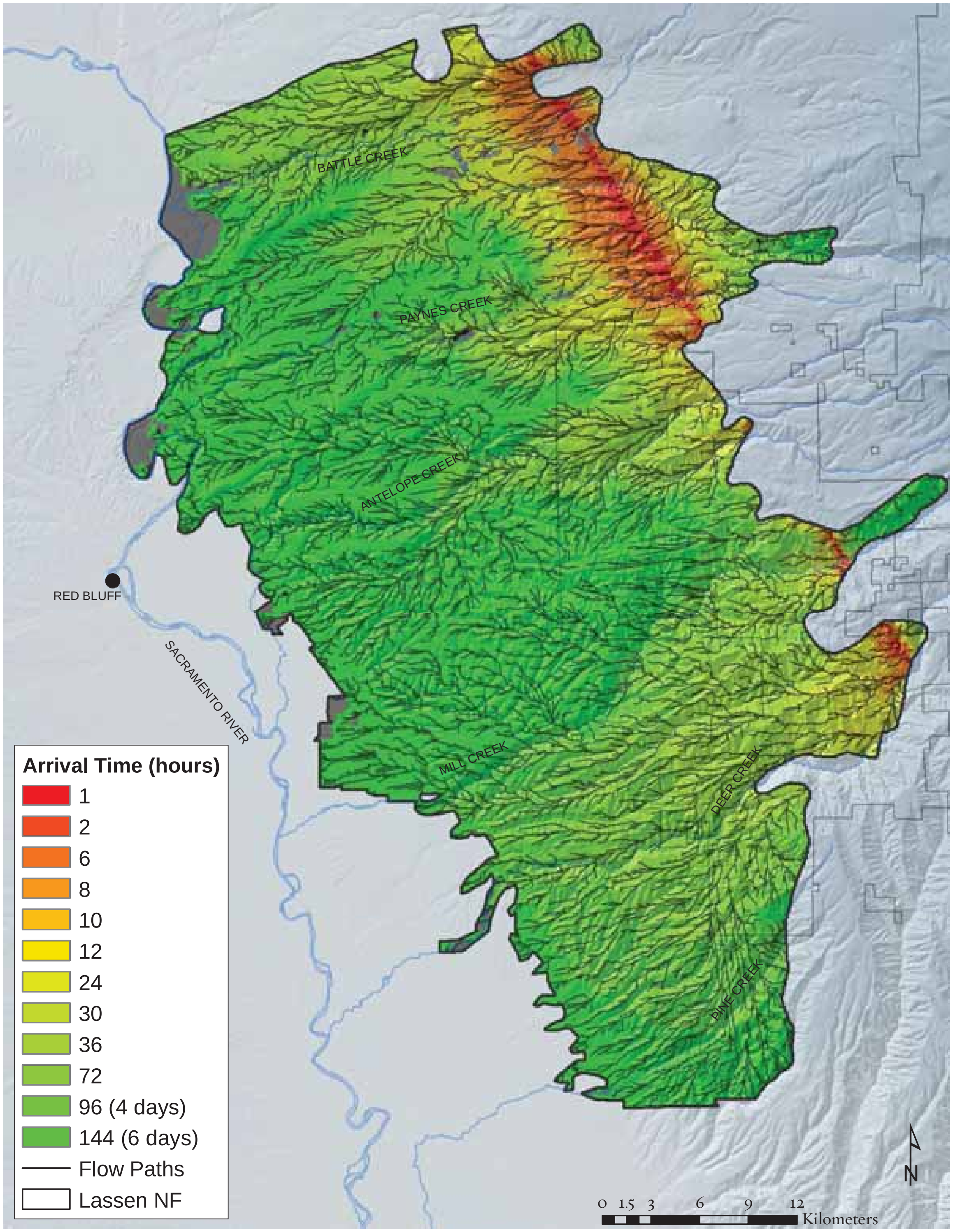

Figure 20. Arrival time and minimum-time travel routes (scenario two).

Conclusions

In conclusion, LANDFIRE fuels data provide a tremendous resource for fire behavior modeling in the absence of high quality local data. Krasnow *et al.* (2009)[11] tested LANDFIRE fuels data against field-collected data in Boulder County, Colorado by comparing FARSITE fire behavior predictions of a known fire. LANDFIRE tended to under-predict rate of spread (and therefore area burned) and crown fire activity. Although they found that LANDFIRE-based FARSITE predictions were less accurate than those that used their field-collected data, they concluded they were still useful.

The mapping zone boundaries are a significant issue. I am unaware of a straightforward solution to this problem that does not involve remapping fuels based on fieldwork or local knowledge at great cost in time and effort. The user must be aware that while this boundary is largely artificial, there is a natural gradient as the vegetation transitions from Central Valley to Southern Cascade foothills, albeit much more subtle and variable. Another significant issue is the dated nature of the fuels data. It is unlikely that the effectiveness of the area's 1999 fires on reducing potential fire behavior has persisted to the extent predicted by FlamMap.

Even under 90th percentile weather conditions the sparse nature of the fuels in this study area keeps potential fire behavior relatively low-intensity. This is not to say that fire is not a problem. As was seen during the Gun II Fire, fire behavior in this area can be very intense. The topography makes access for suppression problematic and the widespread nature of development within the study area makes structure protection difficult. In addition, repeated fires are likely to result in the loss of chaparral from the ecosystem which will convert to non-native invasive annual grasses.

Despite the data issues, I believe these results are useful for planning fire suppression and fuels treatments. The modeling will improve as LANDFIRE continues to update and refine its products.

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[11] Krasnow, K, T. Schoennagel, and T. Veblen. 2009. Forest fuel mapping and evaluation of LANDFIRE fuel maps in Boulder County, Colorado, USA. Forest Ecology and Management 257:1603-1612.