APPENDIX A

WILDLAND FIRE SUSCEPTIBILITY ANALYSIS

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(From Wildland Fire Risk Assessment for the Lake Tahoe Region, 10/28/99, Completed For The USDA-Forest Service, Lake Tahoe Basin Management Unit, By Jones and Stokes Associates, Sacramento, California, Fire Program Solutions, Estacada, Oregon, Dr. Mark A. Finney, Missoula, Montana)

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The wildland fire susceptibility analysis integrates the probability of an acre igniting and wildland fire behavior. It combines the data from the FOAs with fire behavior data developed by FlamMap. This analysis calculated a Wildland Fire Susceptibility Index (WFSI) for each 30x30 meter cell in the study area. The analysis also included a factor that would limit the size of a fire, because of containment by suppression resources and/or the presence of non-burnable surfaces, such as water or rock.

Factors Affecting Fire Size

Expected fire size was assessed by determining the relationship between rate of spread and expected fire size when the fire was contained by initial attack resources and when the fire was not contained by initial attack. Limitations on fire size because of the presence of non-burnable surfaces was also evaluated in the susceptibility analysis.

Successful Initial Attack. The size of contained fires was evaluated using the Interagency Initial Attack Assessment (IIAA) program and data provided by the LTBMU, the Eldorado National Forest and the Tahoe National Forest. The IIAA program contains fire program initial attack options, used to determine initial attack efficiency by fuel models. All assumptions used for resource staffing and dispatch philosophies were defined in the IIAA data files for the Eldorado and Tahoe National Forests and LTBMU for program option (M30), the Most Efficient Level minus 30%. Staffing under this fire program option was selected because it best represented current fire suppression resource staffing and a level of staffing that is most likely in the near future.

The fire size upon containment is estimated by the IIAA using the double ellipse area model developed by Fons (1946) as documented by Anderson (1983). The model calculates fire size (Area) as:

$$\text{Area} = K * D^2 \quad \text{Equation 1}$$

where K is a constant dependent solely on mid-flame wind speed and D is the distance the fire has traveled from its point of origin (D = rate of spread times containment time). Mid-flame windspeed was set at 7.6 mph since this is the value used in the IIAA (Booher, personal communication).

The LTBMU, Eldorado and Tahoe National Forest IIAA mdb data for all Fire Management Zones (FMZ) were used to determine the relationship between containment time and rate-of-spread (Figure 8).

Equation 2 ($r^2 = 0.80$) describes the relationship between containment time and rate of spread (ROS) in Figure 2.

Containment Time (CT) = 4.826 * Rate-of-Spread (ROS) Equation 2

The main variation comes from the variation in containment time at the various representative fire locations.

Inserting the containment cime versus rate-of-spread (ROS) relationship (Equation 2) into Fon's formula with a 7.6 mph midflame windspeed produces the following relationship:

Contained Fire Size (CFS) = 0.0002544333 * ROS^4 Equation 3

Equation 3 was used to estimate fire size for fires spreading at rates of spread from 1 to 24 ch/hr. These rates of spread were selected based on the IIAA data files which showed that fires escape initial attack at approximately the following rates-of-spread: LTBMU - 24 ch/hr; Eldorado - 37 ch/hr; Tahoe - 40 ch/hr.

Escaped Fires. For escaped fires (fires not contained by initial attack resources), the expected fire size is estimated by the IIAA and empirical data from large fires in the Central Sierra and Southern Cascades. Four fires were selected that burned in fuel types similar to those in the study area and are well documented. To examine the relationship between the net rate-of-spread of a fire during its major growth period and the fire's final size, data were evaluated from the Cleveland and Pelican fires on the Eldrorado National Forest. During the initial burning periods for the Cleveland fire, a 41 chains/hour (ch/hr) ROS resulted in 5400 acres burned in the first burning period. During the initial burning periods for the Pelican fire, ROS was 48 ch/hr and the fire was 6,300 acres. The Paulina Fire on the Deschutes National Forest spread to a final fire size of 23,000 acres under a net spread rate of 54 ch/hr and the Lone Pine fire on the Winema National Forest spread to a final fire size of 30,000 acres under a net spread rate of 60 ch/hr.

A curve fit using the LTBMU, the Eldorado National Forest and the Tahoe National Forest IIAA data as well as the Pelican, Cleveland, Paulina and Lone Pine Fire data (Figure 9) resulted in the following relationship for escaped fires. These are fires spreading at a rate greater than 24 chains per hour.

$$FFS = (0.000000279)*ROS^{6.222} + (31.02)*ROS^{-3.527} \quad \text{Equation 4}$$

Figure 8

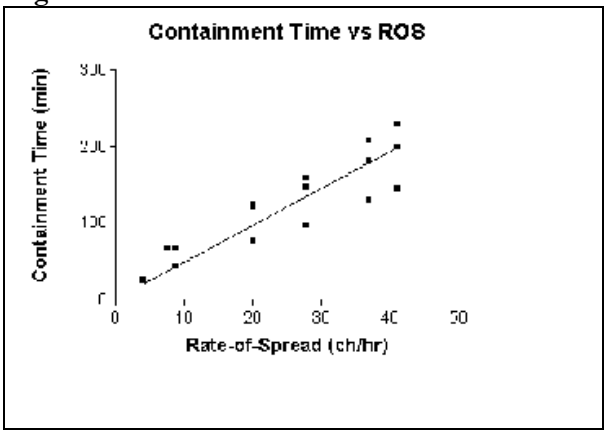
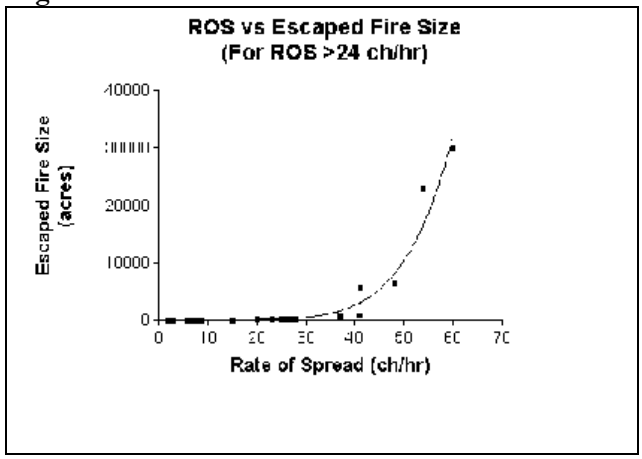


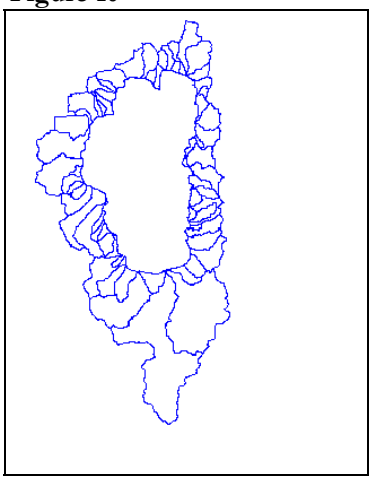
Figure 9



Drainage Orientation, Wind Direction, Presence of Barren and Water Surfaces As It Relates to Maximum Fire Size

The maximum size of escaped wildfires in the LTBMU would also be affected by the presence of barren areas along the crest of the mountains and the water in Lake Tahoe, and the orientation of sub-watersheds (Figure 10).

Figure 10



Drainage Orientation and Wind Direction.

Wind direction and speeds between June 1 and November 15 at Meyers Weather Station are shown in Table 13. The predominant (88%of the time) wind direction is from the north, northwest, west, southwest, or south. Most drainages in the LTBMU are oriented in a west/southwest to east/northeast direction. Winds from the southwest, south, and southeast occur 54th% of the time and are the strongest. This orientation of drainages will "funnel" fires within drainages which will tend to limit for spread to one for several sub-watersheds.

Table 13 - Wind Speed and Direction at Meyer Weather Station

	No.	% of	90th %ile	20' Wind Speed (mph)		
				Mod	High	Ext
N	895	27%	10	8	12	14
NE	173	5%	10	8	11	14
E	59	2%	10	7	13	15
SE	149	4%	14	9	14	26
S	668	20%	15	11	16	17
SW	680	20%	15	10	16	20
W	291	9%	11	8	12	15
NW	411	12%	10	8	11	14

Presence of Barren and Water Surfaces. The number of burnable acres in each sub-watershed in the LTBMU was calculated by subtracting acres of barren areas and water from the total acres in each sub-watershed (Table 14). The average size of a sub-watershed is 3,211 acres; however, the average size in terms of burnable acres is 2,779 acres and the median size is 1,368 acres. On the west side of the LTBMU, the drainages are bounded on the west by large rocky areas and on the east by Lake Tahoe. On the east side of the LTBMU, a similar situation exists with Lake Tahoe on the west and higher terrain to the east with vegetation becoming more sparse are the higher elevations. Fires burning under the strongest winds (from the southwest, south, or southeast) have the greatest opportunity to become larger in the area south and the area north of Lake Tahoe. In these areas, the topography lines up better with the wind direction and these areas contain more area with continuous fuel profiles.

Table 14 Total and Burnable Acres By Sub-Watershed			
Drainage	Total Acres	Non-Burnable Acres	Burnable Acres
UPPER TRUCKEE RIVER	36223	5583	30640
TROUT CREEK	26432	2365	24067
WARD CREEK	8179	527	7652
BLACKWOOD CREEK	7423	657	6766
TAYLOR CREEK	11789	5581	6208
GENERAL CREEK	5777	352	5425
MEEKS	5608	929	4679
TRUCKEE RIVER	4371	133	4238
INCLINE CREEK	4296	227	4069
EDGEWOOD CREEK	4276	271	4005
BURTON CREEK	3665	45	3620
TAHOE VISTA	3476	266	3210
GLENBROOK CREEK	3232	115	3117
BURKE CREEK	3180	124	3056
THIRD CREEK	3863	842	3021
MKINNEY CREEK	3134	134	3000
SLAUGHTER HOUSE	3144	147	2997
GRIFF CREEK	2910	113	2797
MARLETTE CREEK	3167	417	2750
EAGLE CREEK	5640	2917	2723
SECRET HARBOR CREEK	2726	71	2655
CARNELIAN CANYON	2664	159	2505
MCFAUL CREEK	2523	28	2495
TALLAC CREEK	2932	570	2362
CAMP RICHARDSON	2652	640	2012
NORTH ZEPHPR CREEK	1676	9	1667
BIJOU PARK	1974	324	1650
LINCOLN CREEK	1648	2	1646
BIJOU CREEK	1807	227	1580
RUBICON CREEK	1827	290	1537
WATSON	1492	11	1481
LOGAN HOUSE CREEK	1380		1380
MADDEN CREEK	1462	107	1355
SAND HARBOR	1376	51	1325
WOOD CREEK	1514	235	1279
NORTH LOGAN HOUSE CREEK	1307	30	1277
MILL CREEK	1408	132	1276
CASCADE CREEK	3020	1793	1227
CEDAR FLATS	1167	59	1108
DOLLAR CREEK	1166	92	1074
TUNNEL CREEK	1096	49	1047
SECOND CREEK	1183	171	1012
QUAIL LAKE CREEK	1049	38	1011
FIRST CREEK	1117	116	1001
CAVE ROCK	1010	38	972

Table 14 Total and Burnable Acres By Sub-Watershed			
Drainage	Total Acres	Non-Burnable Acres	Burnable Acres
ZEPHYR CREEK	938	19	919
BLISS STATE PARK	930	49	881
DEADMAN POINT	870	0	870
EAST STATELINE POINT	875	77	798
SIERRA CREEK	763	29	734
TAHOE STATE PARK	782	74	708
PARADISE FLAT	709	40	669
LONELY GULCH CREEK	692	27	665
BARTON CREEK	716	53	663
HOMEWOOD CREEK	645	12	633
CARNELIAN BAY CREEK	641	13	628
KINGS BEACH	726	103	623
BONPLAND	565		565
EAGLE ROCK	521	9	512
SKYLAND	503	12	491
BURNT CEDAR CREEK	579	107	473
BLISS CREEK	398	3	395
LAKE FOREST CREEK	448	77	371
SOUTH ZEPHYR CREEK	263	4	259
TOTAL ACRES	205525	27693	177832

Maximum Fire Size Assumption

Historic data on fire size and watershed variables were used to develop an assumption about the maximum fire size in the study area. No fires greater than 10,000 have occurred in the study area, although several have occurred in other areas of the Eldorado and Tahoe National Forests. From 1908 to 1939 and 1973 to 1996, one fire greater than 1,000 acres occurred in the LTBMU and a total of six occurred in the entire study area (Table 4 and 5). Thus, fires greater than 1,000 acres are a rare occurrence. Additionally, considering the orientation of the drainage in each watershed, the number of acres of burnable vegetation in each watershed, and the current fuels profiles, a maximum fire size of 3,000 acres was used in this analysis for wildland fire susceptibility.

Estimates of Fire Sizes Based on Rates of Spread.

Using equation 3 for contained fires, equation 4 for escaped fires, and a maximum final fire size of 3,000 acres, the final fire size used based on rate-of-spread is summarized in Table 15. As mentioned earlier, the rate of spread were a wildland fires escapes initial attack is about 24 chains/hr in the LTBMU.

Table 15 - Summary of Final Fire Size Based on Rate-of-Spread			
Rate of Spread (ch/hr)	Final Fire Sized Used	Final Fire Size (Acres) Contained Fires - Equation 3	Final Fire Size (Acres) Escaped Fires - Equation 4
5	0.16	0.16	Equation 3 does not fit well here as
10	2.50	2.50	
15	12.9	12.9	
20	40.7	40.7	
24	84.0	84.0	
25	170	1573	170
30	463	2265	463
35	1160	3083	1160
40	2623	4027	2623
45	3000	5096	5425
50	3000	6296	10420
55	3000	7614	---
56+	3000	---	---

CALCULATION OF THE WILDLAND FIRE SUSCEPTIBILITY INDEX

The WFSI is calculated with a spreadsheet of which an example portion is shown in Table 16. Appendix F contains the printouts of spreadsheets used to calculate the WFSI for the study.

Table 16 - Example of Calculation of Wildland Fire Susceptibility Index For A Two Specific Fire Occurrence Areas (FOA 1 and FOA 2)			
Calculation Is For The Moderate Weather Class The Probability of a Fire in The Weather Category is 0.71 For the Example			
Row		FOA 1	FOA 2
1	Total FOA Acres (Excluding water)--->	541,578	56,746
1a	Total Non-Burnable Acres--->	86,304	7,647
1b	Total Burnable Acres--->	455,274	49,099
2	Total Fires in FOA (1970-1998)-->	1,293	497
3	Number of Years for Data-->	27	27
4	Total Fires/Yr in FOA-->	47.89	18.41
5	Total FOA Rate (Fires/1000ac/Yr)-->	0.0884	0.3244
6	No of Fires/Yr in Wx Class in FOA-->	34.00	13.07
7	Rate-of-Spread = 5 Ch/Hr	0.000012	0.000042
8	Rate-of-Spread = 25Ch/Hr	0.010395	0.037048
9	Rate-of-Spread = 45Ch/Hr	0.224048	0.798545

Row 1. This is the total number of acres within the FOA not cover by water.

Row 1a. This is the total number of non-burnable acres within the FOA.

Row 1b. This is the total number of burnable acres within the FOA (Row 1 - Row 1a).

Row 2. This is the total number of fires for the time period noted within the FOA.

Row 3. This is the number of years in the time period.

Row 4. This is the Annual Number of Fires within the FOA and is calculated by dividing by Row 2 by Row 3:

Row 4 = Row 2 / Row 3 Equation 5

Row 5. This is the fire occurrence rate in the FOA expressed in fires per 1000 acres per year. It is calculated as follows:

Row 5 = (Row 4 * 1000) / Row 1 Equation 6

Row 6. This is the number of fires per year in the weather class. For this example, the moderate weather class is being used which has a frequency of occurrence of 0.75 but only 71% of the wildland fires historically occur in this weather class. Hence, this row is the product of Row 6 and 0.71:

Row 6 = Row 6 * 0.71 Equation 7

Overview of Rows 7-9. These rows provide the WFSI for each FOA and for a rate-of-spread from FlamMap output.

The WFSI is calculated as follows:

WFSI = (Expected Acres Burned In The FOA) / (Total Burnable Acres in the FOA) Equation 8

The rate-of-spread allows for estimation from Equation 3, Equation 4 or the maximum fire size of the estimation of the final fire size (FFS) for a single ignition that occurs within the cell (Table 15). This FFS is based on the **assumption** that the wildland fire is burning uniformly and continuously in a fuels and topographic situation as is described in the cell. Since there are no contagion effects considered, the calculated value for the WFSI is best viewed as an index that ordinates Wildland Fire Susceptibility based on the probability of wildland fire ignition (FOA) and fire spread potential (FlamMap). If the expected acres burning could be precisely determined, then the WFSI could be viewed as the "probability of an acre burning." For rates-of-spread less than 24 chains per hours, it is a close approximation of the "probability of an acre burning" as the resultant fire size is small.

The "Expected Acres Burned In The FOA" is calculated as follows:

Expected Ac. Burned In The FOA =
FFS * Number of Fires/Year in FOA in Weather Class Equation 9

Row 7. This row provides the WFSI for each FOA and for a rate-of-spread from FlamMap of 5 chains per hour. Since this rate-of-spread is between 1 and 24 chains per hour, Equation 3 (contained fire) is used to estimate the FFS. For FOA 1, this calculation is as follows:

WFSI (FOA 1 & ROS=5 ch/hr) =
(FFS * Number of Fires/Year in FOA in Weather Class) / (Burnable Acres in the FOA)
Equation 10

= (0.16 acres * 34.00 fires/yr) / (455,274 acres in FOA)

= 0.000012 .

Row 8. This row provides the WFSI for each FOA and for a rate-of-spread from FlamMap of 25 chains per hour. This rate-of-spread is greater than 24 chains per hour; therefore, Equation 4 (escaped fire) is used to estimate the FFS up to a maximum FFS of 3,000 acres. For FOA 1, this calculation is as follows:

WFSI (FOA1& ROS=25 ch/hr) =
(FFS * Number of Fires/Year in FOA in Weather Class) / (Burnable Acres in the FOA)

Equation 10

= (139.18 acres * 34.00 fires/yr) / (455,274 acres in FOA)

= 0.010395 .

Row 9. This row provides the WFSI for each FOA and for a rate-of-spread from FlamMap of 45 chains per hour. This rate-of-spread is greater than 24 chains per hour and hence Equation 4 (escaped fire) is used to estimate the final fire size (FFS) up to a maximum FFS of 3,000 acres. Using Equation 4, the FFS would be 5,394 acres which is greater than the 3,000 acre maximum FFS assumed. For FOA 1, this calculation is as follows:

WFSI (FOA1& ROS=45 ch/hr) =
(FFS * Number of Fires/Year in FOA in Weather Class) / (Burnable Acres in the FOA)

Equation 10

= (3,000 acres * 34.00 fires/yr) / (455,274 acres in FOA)

= 0.224048 .

Summary of WFSI Calculation

The WFSI value is proportional to the FOA rate (Row 6). The rate in FOA 2 is about 4 times that in FOA 1 and the WFSI values in FOA 2 are about 4 times those in FOA 1. This is a result of the use of the standard "expected value" methodology used to calculate the WFSI. Also note that if a dollar or index "value" were assigned to each cell in a Effects Layer, the product of the WFSI and the index value in the Effects Layer would yield an "expected effects index."

Table 17- Summary for Example of Wildland Fire Susceptibility Index

Calculation Is For The Moderate Weather Class The Probability of a Fire in The Weather Category is 0.71 For the Example			
7	Rate-of-Spread = 5 Ch/Hr	0.000012	0.000042
8	Rate-of-Spread = 25Ch/Hr	0.010039	0.037048
9	Rate-of-Spread = 45Ch/Hr	0.224048	0.798545