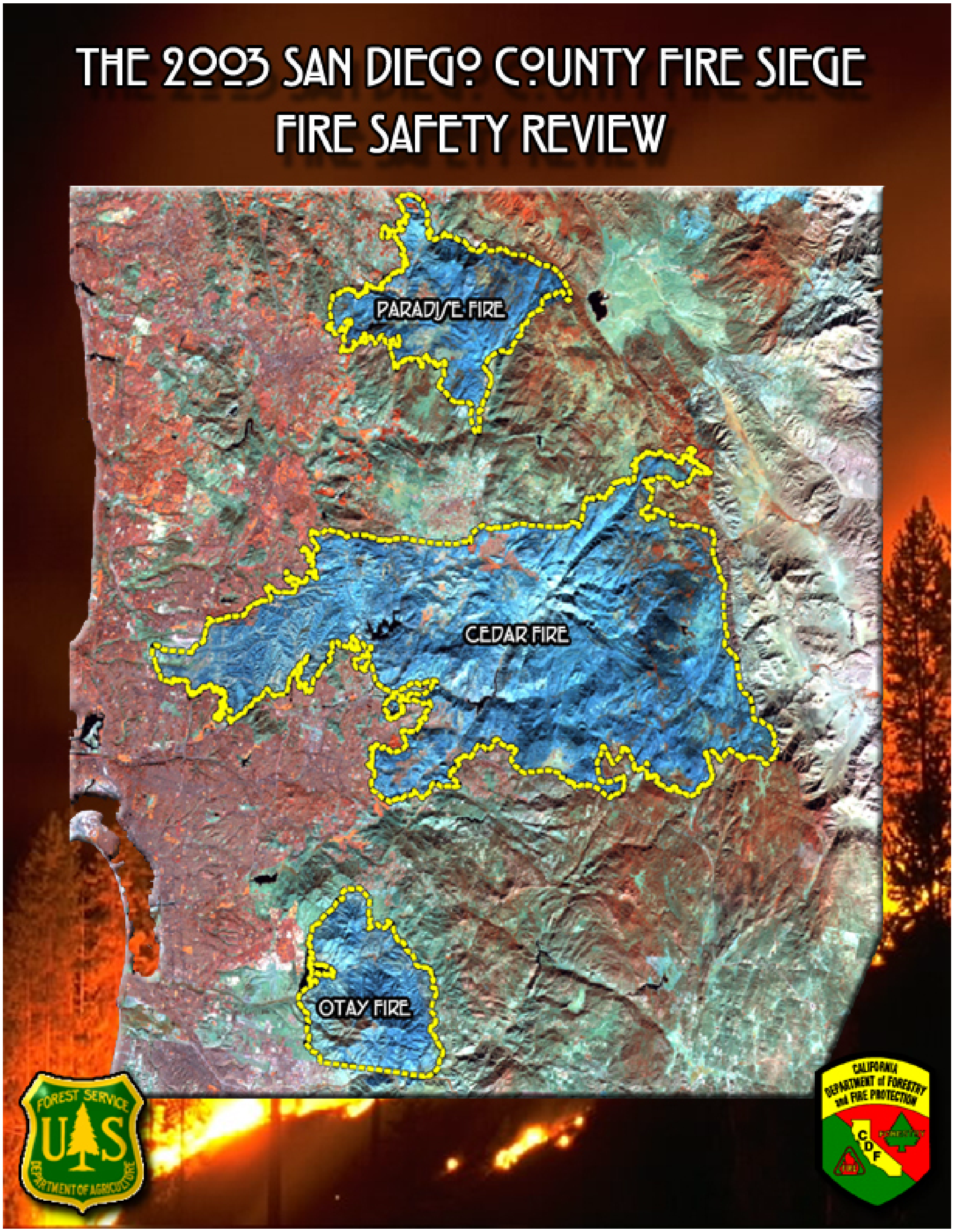
Appendix B: Fire Behavior



Introduction

The fires that took place in San Diego County resulted from a rare combination of meteorological and environmental factors that aligned during the week of October 25, 2003. Extreme drought, multiple large fires burning region wide, wildland urban interface, and extreme fire behavior combined to create the conditions which lead to the 2003 Southern California Fire Siege. The focus of this Appendix is the fires that burned, destroyed, and killed within San Diego County. When the fires were finally suppressed, there were 3241 structures[1] destroyed, 16 people killed, and 43,230,826 dollars spent for suppression.

This Appendix will examine the factors influenced fire behavior throughout San Diego County during the week of October 25, 2003. All three large fires in San Diego County will be examined. There is a concentration on the Cedar Fire due to the extreme rates of spread, loss of life, and structure damage.

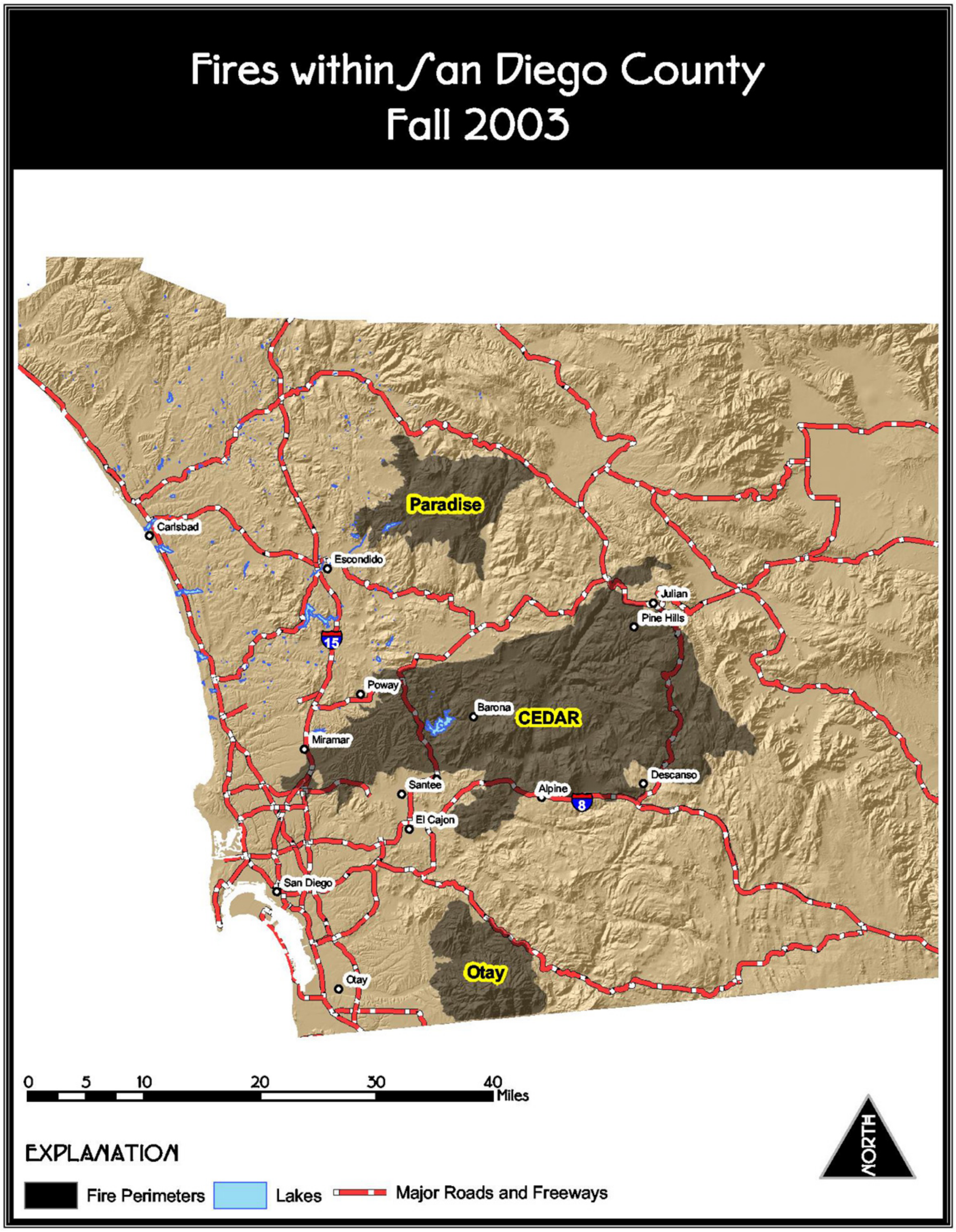
The Fires by Size

The County of San Diego is 2,712,176 acres in size. The perimeters of the three major fires cover 376,237 acres or over 13 percent of the total land mass. The Cedar fire, the largest of the three, was 273,246 acres, the Paradise Fire was 56,700 acres, and the Otay Fire was 46,291 acres. Please see Map One, Fires within San Diego County.

The Big Three

The three major influences on fire behavior are fuel, weather, and topography. Additional factors such as building design, lack of clearances, and lack of egress also contributed to the final size of the fires in San Diego County.

[1] This figure represents all structures including primary residences, commercial structures, and outbuilding.



Map 1: The Fires of San Diego-Fall 2003. The Roblar 2 Fire also burned during October but was contained prior to the siege of fires that began October 25th.

Fuel Conditions

Fuels were critically dry at the time of the San Diego Fires. 2003 followed several years at below normal rainfall. Live fuel moistures[2] reach minimum levels in late fall. The live fuel moisture measured at Descanso Fire Station for chamise was 55 percent for new growth and 49 percent for old growth. When the east winds surfaced, relative humidity plummeted to four percent at the Descanso remote automated weather station (RAWS). This resulted in fine dead fuel moisture of 4 percent.

Fuels in the fire areas were dominated by Southern California mixed chaparral. Both hard and chaparral types were represented. Hard chaparral includes species such as manzanita, red shank, and chamise. These species produce very high intensities with flame lengths normally over 20 feet. Soft chaparral is generally composed of California Coastal Sage Scrub consisting of sage brush and buckwheat. These fuel types produce very high rates of spread. A summation of acres by the vegetation types within each fire are shown in Tables 1-3. The tables included all of the acreage within the fire perimeters. There are large areas within the fires perimeter that were not consumed. Please see Map 2-Vegetation Type by Fire. Data were provided by the California Department of Forestry and Fire Protection Fire Resource Assessment Program (FRAP).

Table 1: Sum of Acres by Vegetation Type for the Cedar Fire. These figures represent the total vegetation type within the final fire perimeter. Some areas within the perimeter did not burn.

SPECIES	ACRES
AGRICULTURE-CROPS	3482
ANNUAL GRASS	14171
BARREN	460
CHAMISE-REDSHANK CHAPARRAL	24080
CLOSED CONE PINE-CYPRESS	90
COASTAL OAK WOODLAND	15498
COASTAL SCRUB	44733
DESERT SCRUB	30
DESERT WASH	8
EUCALYPTUS	455
FRESHWATER EMERGENT WETLAND	720
JEFFREY PINE	2422
MIXED CHAPARRAL	124418
MONTANE CHAPARRAL	1775
MONTANE HARDWOOD	6199
MONTANE HARDWOODS CONIFER	14894
PERENNIAL GRASS	3137
SAGEBRUSH	129
SIERRAN MIXED CONIFER	472

[2] Live fuel moisture (FM) content is the quantity of water in a fuel particle expressed as a percent of the oven dry weight of the fuel particle. FM is computed by dividing the weight of the "water" in the fuel - by the oven dry weight of the fuel and then multiplying by 100 to get the percent of moisture in a fuel.

URBAN	14534
VALLEY FOOTHILL RIPARIAN	1166
WATER	2413
WET MEADOW	537

Table 2: Sum of Acres by Vegetation Type for the Paradise Fire. These figures represent the total vegetation type within the final fire perimeter. Some areas within the perimeter did not burn.

SPECIES	ACRES
AGRICULTURE-CROPS	3530
ANNUAL GRASS	4433
CHAMISE-REDSHANK CHAPARRAL	3882
COASTAL OAK WOODLAND	10581
COASTAL SCRUB	7431
DESERT WASH	12
EUCALYPTUS	25
MIXED CHAPARRAL	25093
MONTANE HARDWOOD	10
MONTANE HARDWOODS CONIFER	237
PERENNIAL GRASS	53
SAGEBRUSH	18
URBAN	1036
VALLEY FOOTHILL RIPARIAN	90
WATER	240
WET MEADOW	22

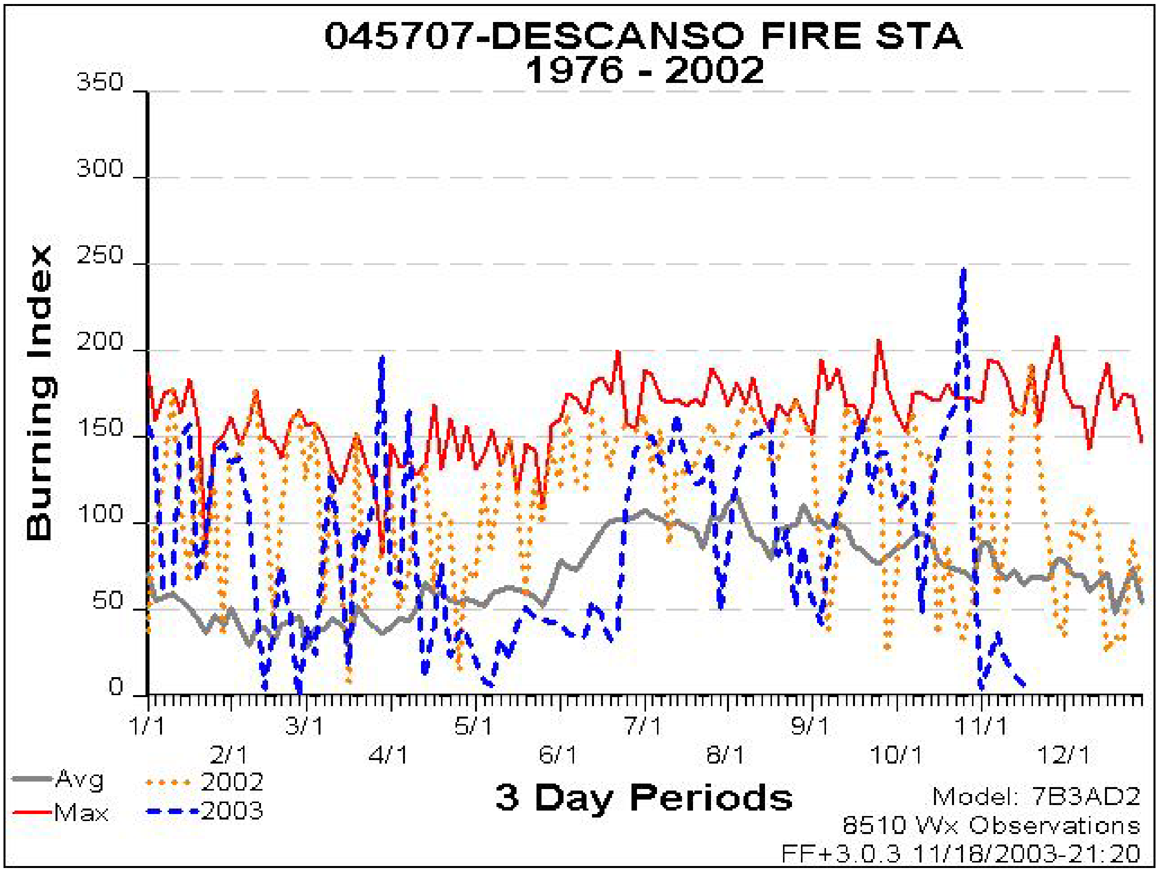
Table 3: Sum of Acres by Vegetation Type for the Otay Fire. These figures represent the total vegetation type within the final fire perimeter. Some areas within the perimeter did not burn.

SPECIES	ACRES
AGRICULTURE-CROPS	526
ANNUAL GRASS	1134
CHAMISE-REDSHANK CHAPARRAL	1439
CLOSED CONE PINE-CYPRESS	4985
COASTAL OAK WOODLAND	239
COASTAL SCRUB	26367
EUCALYPTUS	134
FRESHWATER EMERGENT WETLAND	28
MIXED CHAPARRAL	9102
PERENNIAL GRASS	267
URBAN	267
VALLEY FOOTHILL RIPARIAN	153
WATER	87

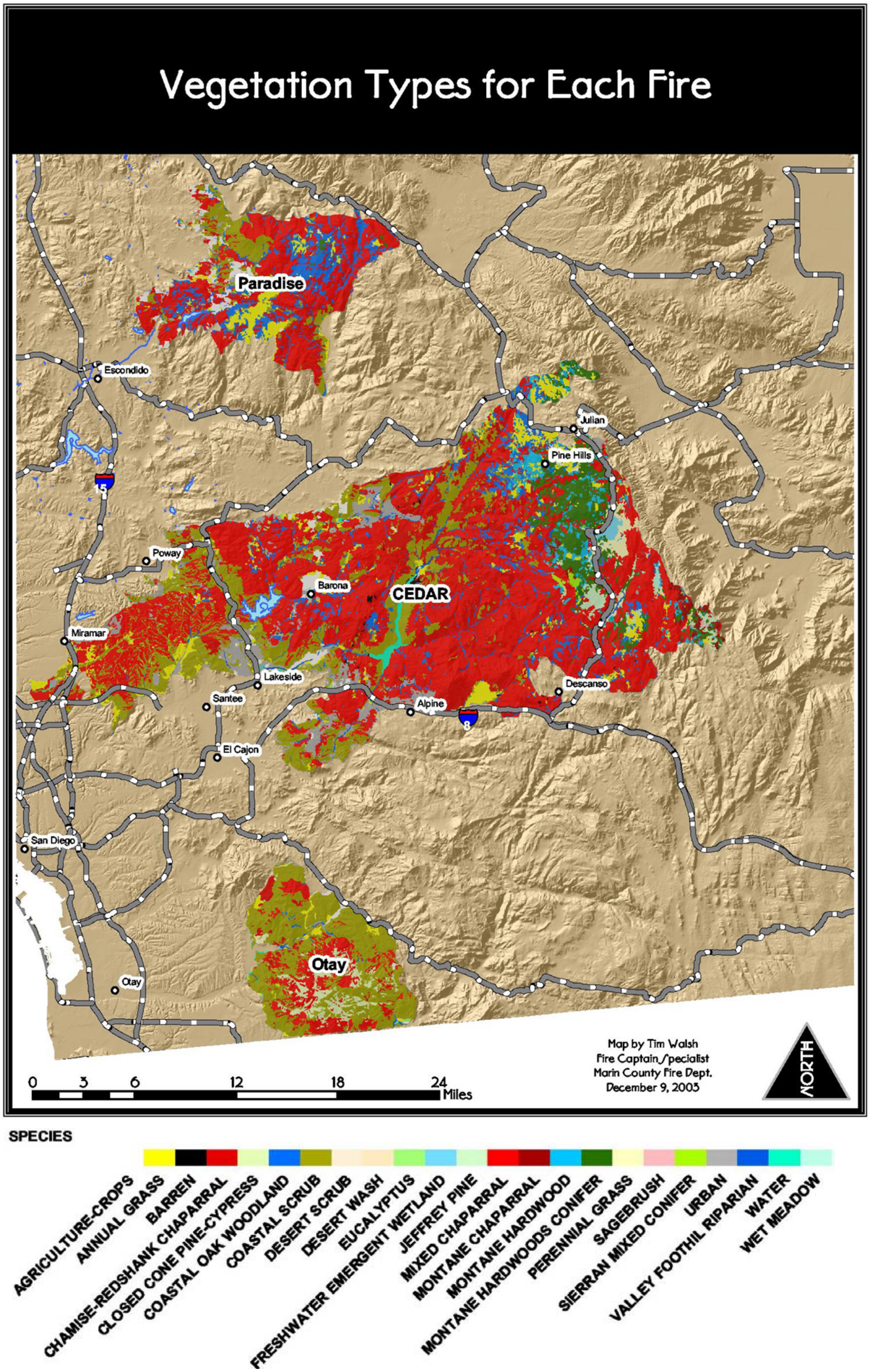
National Fire Danger Rating System Indices

Indicators of the fire danger at the time of the fires were National Fire Danger Rating System (NFDRS) indices such as Burning Index, Energy Release Component, and 1000 Hour Fuel Moisture levels. The NFDRS Indices were at record high levels when the San Diego fires started. The Burning Index (BI) is an NFDRS index relating to the flame length at the head of the fire. BI is an estimate of the potential difficulty of fire control as a function of how fast and how hot a fire could burn. It has been scaled so that the BI value divided by 10 predicts the flame length at the head of a fire. For example, a BI of 75 would predict a flame length of 7.5 feet. During the week of fires, the BI for the Descanso Fire Weather Station was 250 setting a new historical maximum reading for the station. Please see Figure One.

Figure 1: The Burning Index Chart for the Descanso Fire Weather Station



Map 2: Vegetation Types for Each Fire



The Energy Release Component (ERC) is an NFDRS index related to how hot a fire can burn. It is directly related to the 24-hour, potential worst case, total available energy (BTUs) per unit area (in square feet) within the flaming front at the head of a fire.

The ERC can serve as a good characterization of the fire season as it tracks seasonal fire danger trends. The ERC is a function of the fuel model and live and dead fuel moistures. Fuel loading, woody fuel moistures, and larger fuel moistures all have an influence on the ERC, while the lighter fuels have less influence and wind speed has none. ERC has low variability, and is the best fire danger component for indicating the effects of intermediate to long-term drying on fire behavior (if it is a significant factor) although it is not intended for use as a drought index. The Energy Release Component for the Descanso Fire Weather Station was over 120 also setting a new historical maximum reading. Please see Figure 3.

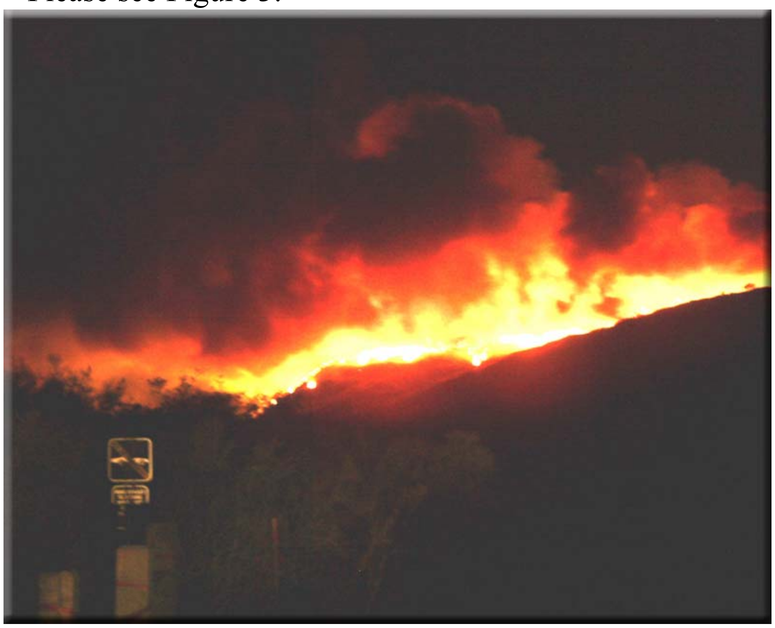


Figure 2: The Cedar Fire burning at 23:28 hours on October 25. With the ERC's at their critically low levels, nighttime fire activity is intensified as the east winds surface. Photo by CDF Division Chief Randy Lyle.

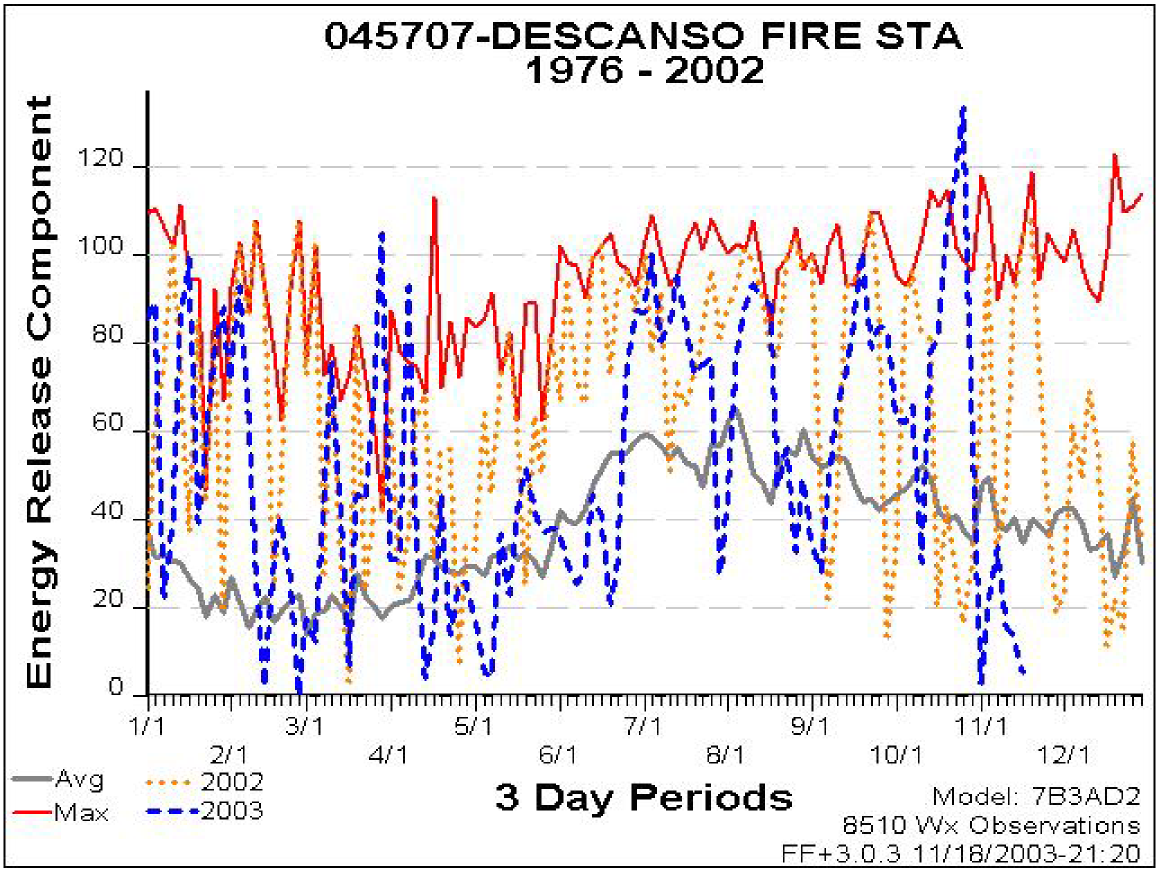


Figure 3: Energy Release Component for the Descanso Fire Weather Station

The last index is the 1000-Hour dead fuel moisture level. 1000-Hour dead fuel moisture levels are computed from a 7-day average boundary condition composed of day length, hours of rain, and daily temperature/humidity ranges. Fuel sizes range from 3 to 8 inches in diameter. The 1000-Hour dead fuel moisture was at eight percent hovering at the historical low level. Please see Figure 4.

To fully appreciate how these indices affect fire behavior, please see Figure 6. Figure 6 depicts a before and after photograph taken of a ridge above the San Diego River Drainage. In the before photo, infrared photography shows heavy vegetation below a home. In the after photo, there is 100 percent consumption of the fuel resulting in a barren hillside. The arrow spatially ties the same location from both photos.

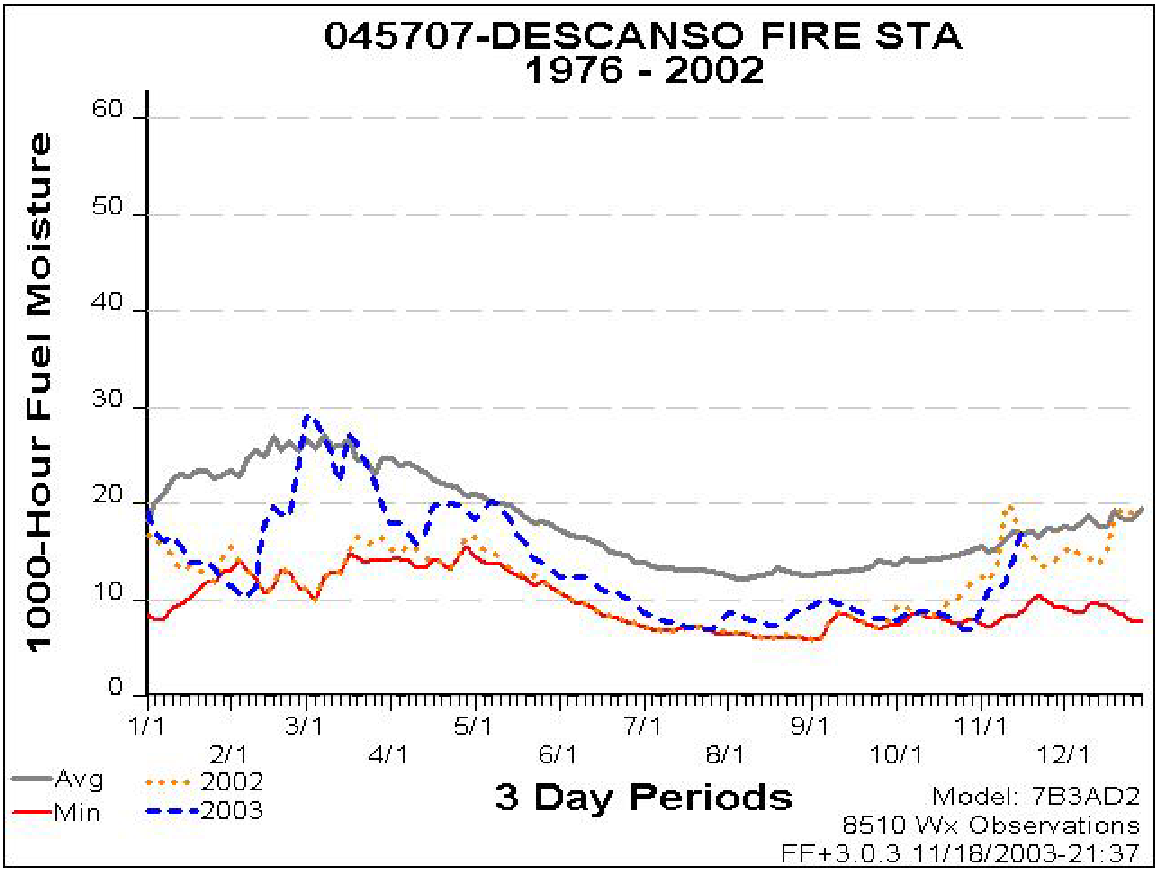


Figure 4: 1000-Hour Dead Fuel Moisture for the Descanso Fire Weather Station

Figure 5: Nighttime burning conditions at the Cedar Fire where a result of fuels at critically low fuel moistures combined with a wind event as shown in the picture above. The fire is burning in relatively short fuel (1-2 foot brush) but still producing 4-6 foot flames. Spot fires were continuously starting new fires in front of the main fire resulting in extreme rates of spread.

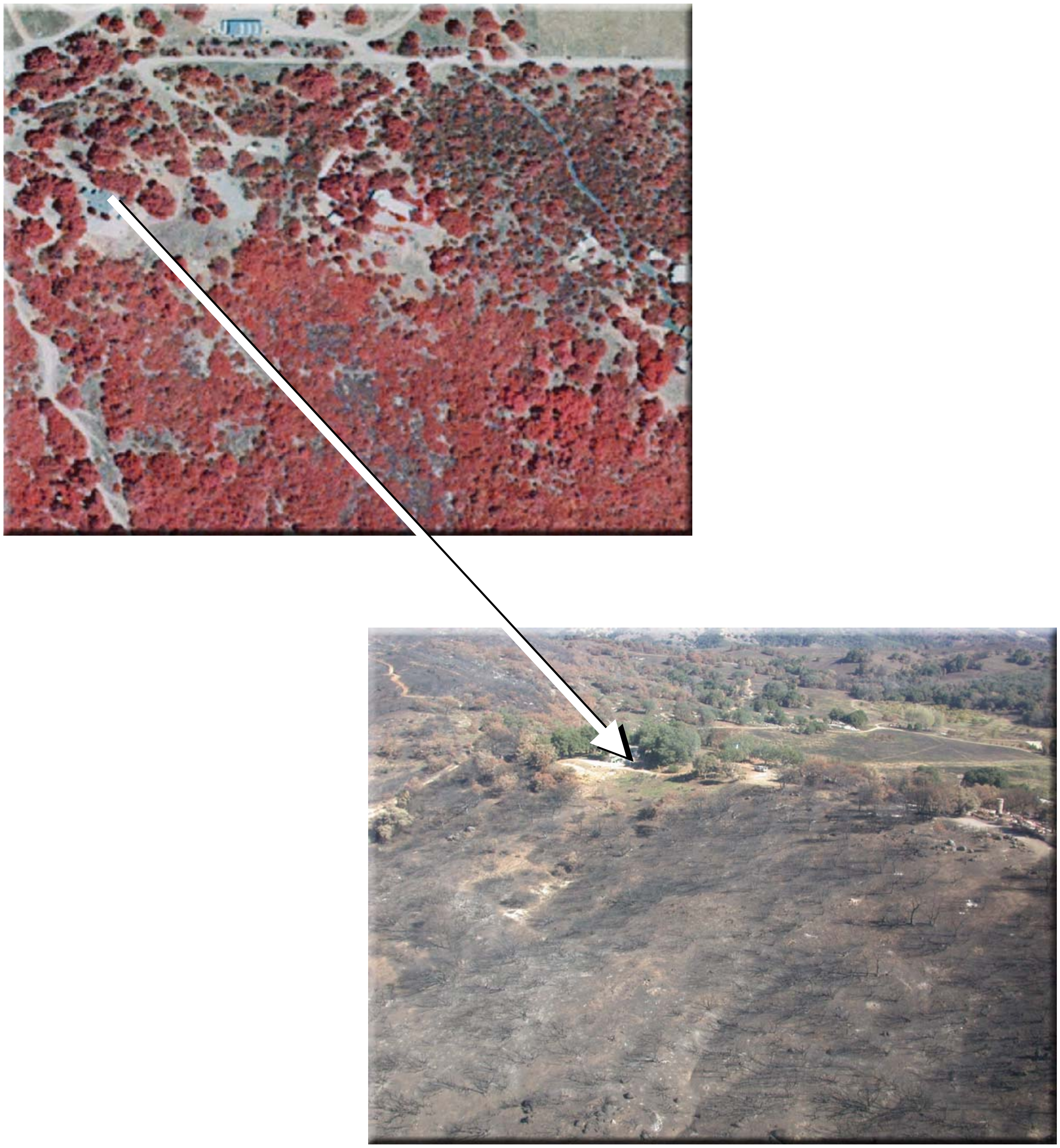


Figure 6: The above image is a 1-meter infrared photo of a house above the San Diego River. The lower photograph is the same slope after the fire showing almost complete consumption of the vegetation. The arrow ties the same location in each photo together. The top of both photos is east-northeast.

Fire History

Historical fire locations, their burn patterns, and how often they occur must be evaluated to understand fuels and their relationship to the San Diego County fires. Within San Diego County, fire is a natural and often beneficial part of the ecosystem. Fire removes biomass that accumulates over time. It recycles nutrients, eliminates some pests and disease, and provides better habitats for some species.

To quote experts from the County, "Fires in the forest and brush lands of San Diego County have been a recurring part of the ecosystem for thousands of years. Early inhabitants used fire in hunting, for enhancing plants yields, and for insect control, as well as for cooking and warmth…Frequent fires set by early residents or lightning provided a natural mosaic of different ages of brush. The mosaic landscape tended to limit the size of fires because young brush is generally less dense and less likely to burn."[3]

San Diego County burns frequently and with large acreage amounts. To prove this point, fires from 1910 to 2002 have been mapped. Acreage calculations were performed and summed indicating 2,339,216 acres have burned over 92 years. This equates to 25,426 acres on average per year. Please see Map 3-Fire History by Year.

Historical Fires

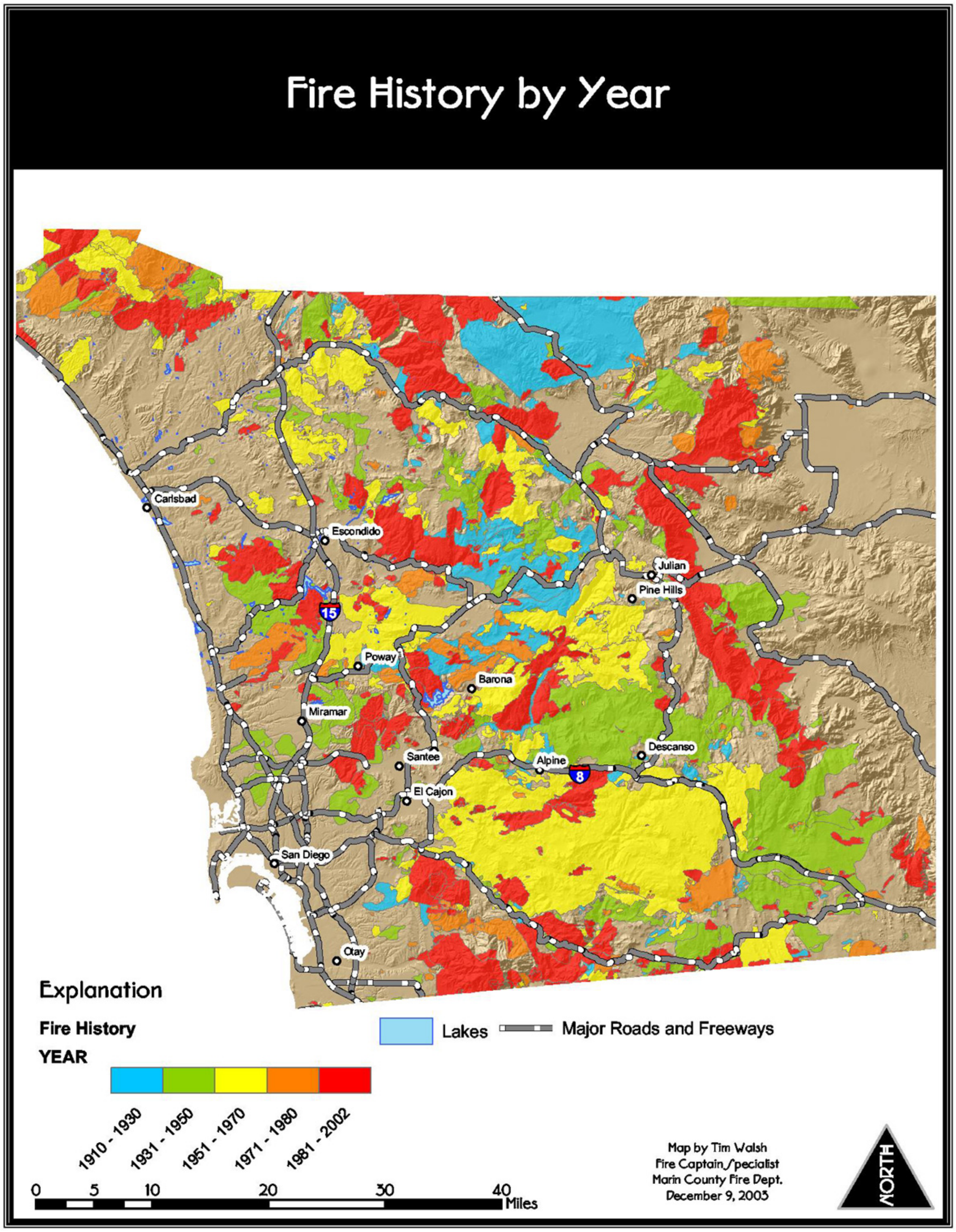
Table 4 lists notable fires that have burned in San Diego County. Please see Map 4.

Table 4: Historical Fires with Statistics

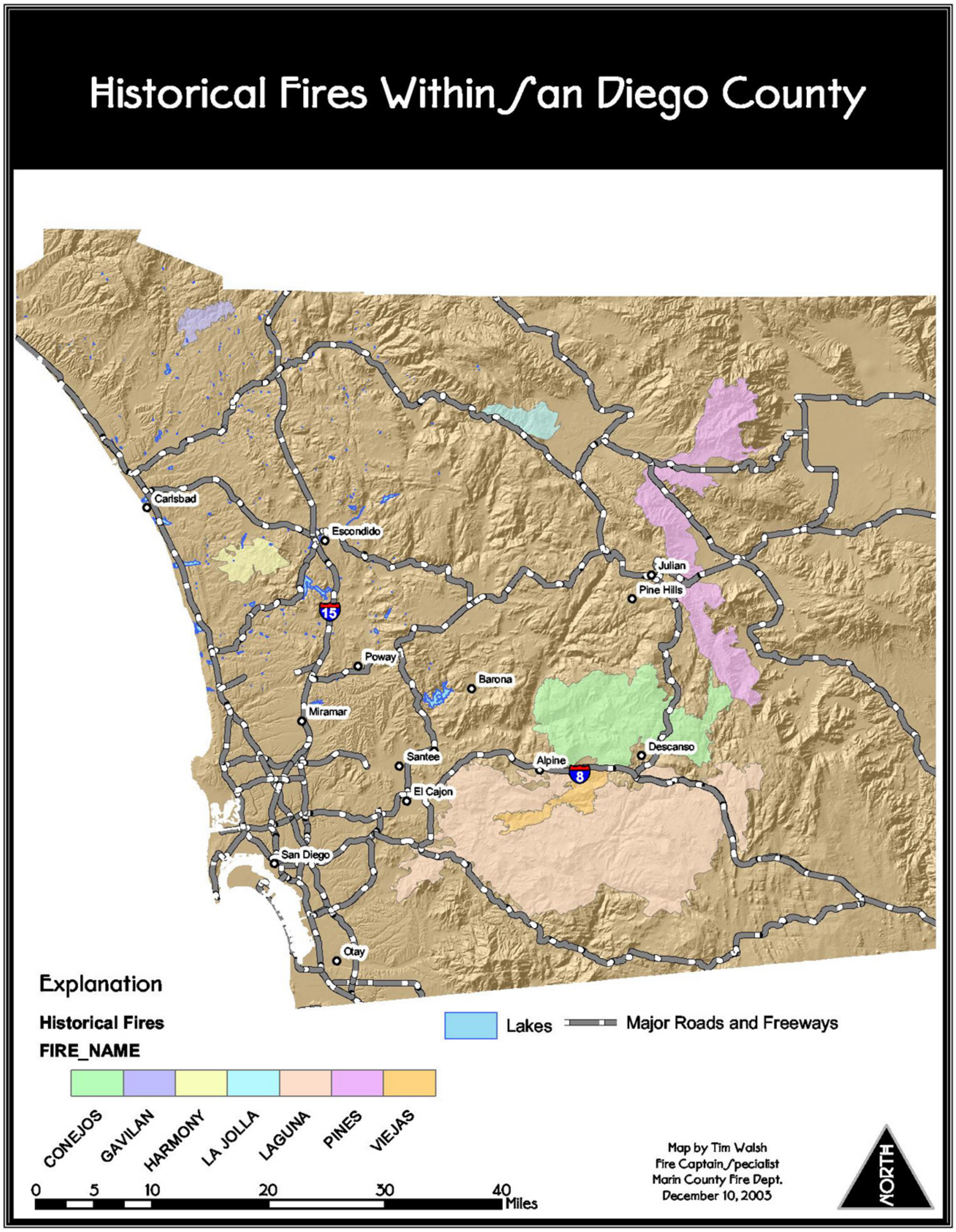
Fire Name	Date	Acres Burned[4]	Structures Lost	Structures Damaged	Deaths
Conejos	July 1950	62,848	Not Available	Not Available	0
Laguna	October 1970	174,162	382	Not Available	5
Harmony	October 1996	9,359	122	142	1
La Jolla	September 1999	7,845	2	2	1
Viejas	January 2001	10,438	23	6	0
Gavilan	February 2002	5,663	43	13	0
Pines	July 2002	61,691	45	121	0

[3] County of San Diego. August-2003 San Diego County Wildland Fire Task Force "Mitigations Strategies for Reducing Wildland Fire Risks" Findings and Recommendations-Report to the Board of Supervisors

[4] This table was also within the Footnote 2 document. Acreage has been recalculated to be more accurate than what was reported. Other fires are of historic significance but were not included in the County's table. One such notable fire was the Inaja Fire-November 25, 1956 that burned 43,611 acres and killed 11 firefighters.



Map 3: Fire History by Year

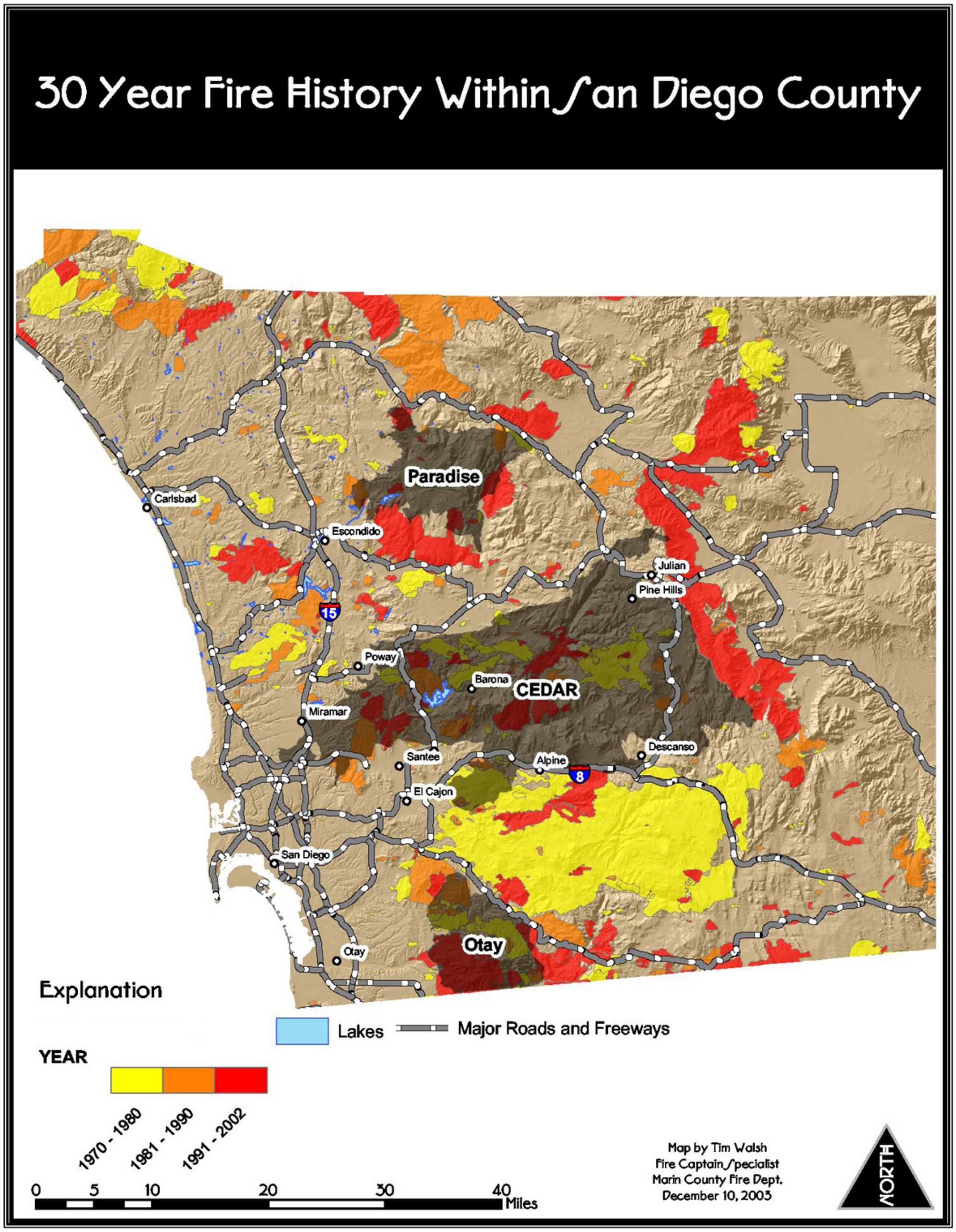


Map 4: Historical Fires within San Diego County. These fires are classified as historical due to the structure loss, size, or fatalities.

Recent Fire History

Fires in chaparral often consume most of the standing live and dead fuels. In the absence of fires fuels accumulate. Decay is slow in the dry Mediterranean climate. Many brush species have very high dead fuel loads that increase over time. It is generally accepted in the wildland fire science community that chaparral fuel types reach their critical levels after 30 years. Much of the area within the perimeter of the Cedar Fire had not burned in 30 years or more. Many of the areas within the fire perimeters do not have recent (30 year) fire history. Please see Map 5 that depicts areas that have, and more importantly, haven't burned since 1970.

Figure 7: Firebrands lofted ahead of the main fire front caused numerous spot fires during the early morning hours of October 26 on the Cedar Fire. These spot fires continued to grow pulling the main fire with them increasing the rates of spread.



Map 5: Fires since 1970 within San Diego County. Large areas within the Cedar Fire have not burned since 1970. Past fires may have helped control the Paradise, Cedar, and Otay Fires. The Fires mapped in red have much younger and sparser fuels allowing fires to be suppressed and sometimes self extinguish.

Topography

Topography is the lay of the land. Topography plays a major role in how a fire burns and how quickly suppression forces may be deployed to take action on a fire. The topography played a major role as it relates to access to the fires. On the Cedar Fire firefighters could not see the initial fire because their view was blocked by the steep terrain. Topography prevented firefighting apparatus from quickly deploying across the San Diego River Canyon.

Slope

Slope is defined as change in elevation compared to horizontal distance. For wildland fire behavior calculations, it is figured in percent slope, not degrees. For clarification, when the slope angle equals 45 degrees, the rise is equal to the run. Expressed as a percentage, the slope of this angle is 100 percent. Slopes over 45 degrees exceed 100 percent.

Figure 8: Flames bend upslope often preheating fuels above them forced by rising superheated air as seen on the Cedar Fire.

Wildland fire behavior analysts often must decide which factor has greater influence on a fire: slope or wind. During the period of greatest fire spread on October 25-26th, wind was dominant. Slope still is a major influence, especially in how wide the fire becomes. Table 5 shows how dramatically a fire's rate of spread increases with a corresponding increase in slope.

Table 5: Slope as it relates of a fires rate of spread for Fuel Model 4-Tall Chaparral.

Slope	Rate of Fire Spread in Feet per Hour
Flat	429
20 Percent	910.8
40 Percent	2349.6
60 Percent	4745.4

The slopes within the San Diego fire perimeters range from flat ground to almost vertical cliffs. The mean slope for all of the fires is less than 35 percent. The steepest mean slopes were found on the Otay Fire. Please see Table 6 slope statistics.

Table 6: Slope statistics for the area within the fire perimeters.

Fire	Minimum Slope	Maximum Slope	Mean Slope
Paradise	Flat	163 %	25 %
Cedar	Flat	248%	26 %
Otay	Flat	128%	33 %

Topographical variation includes canyons, saddles, or chimneys, all of which funnel air currents and flames. As seen in the many maps throughout this document, San Diego County is anything but flat. Rates of fire spread were increased many times due to these topographic influences.

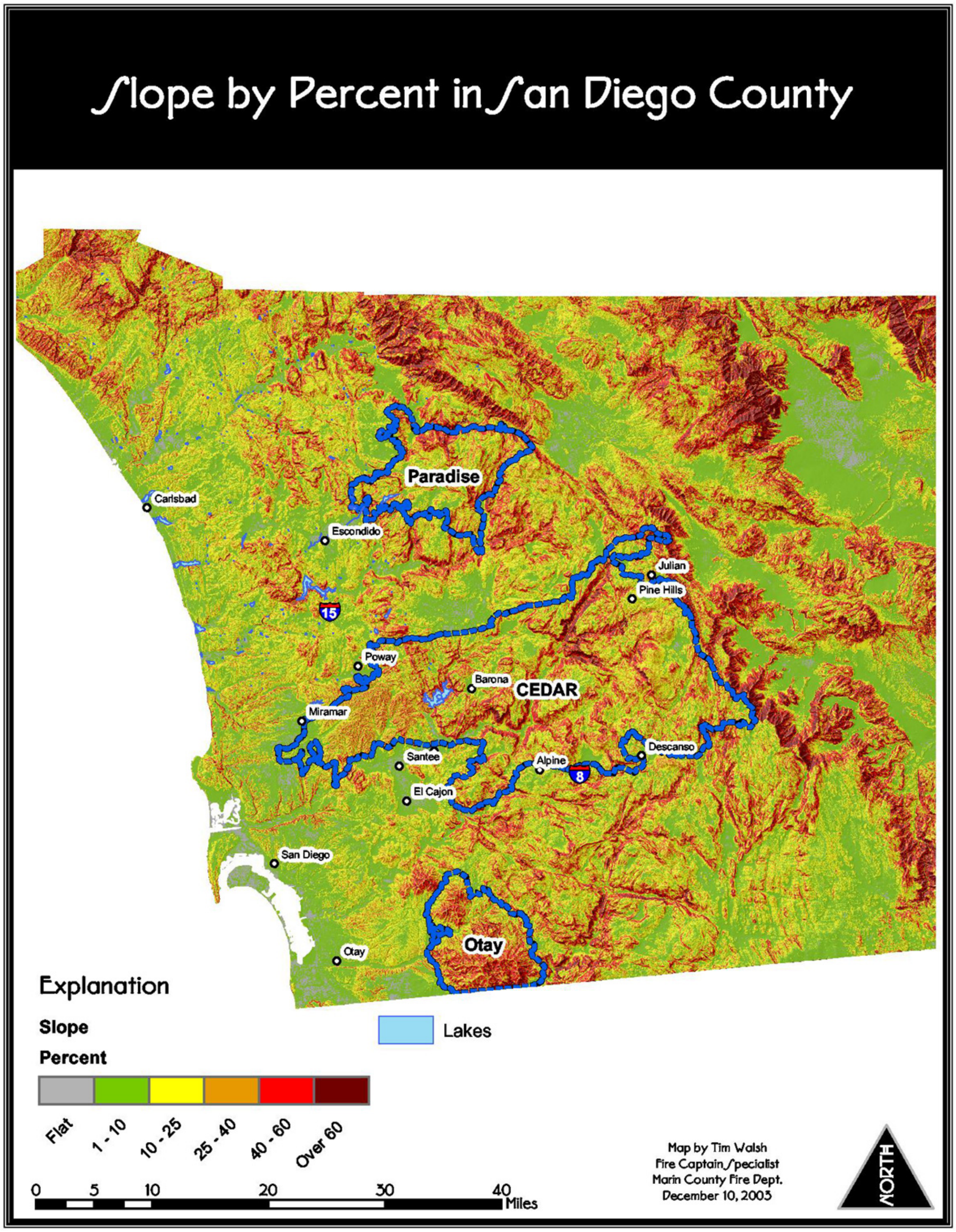
Figure 9: Fire activity increasing in this topographic saddle-Cedar Fire

Aspect

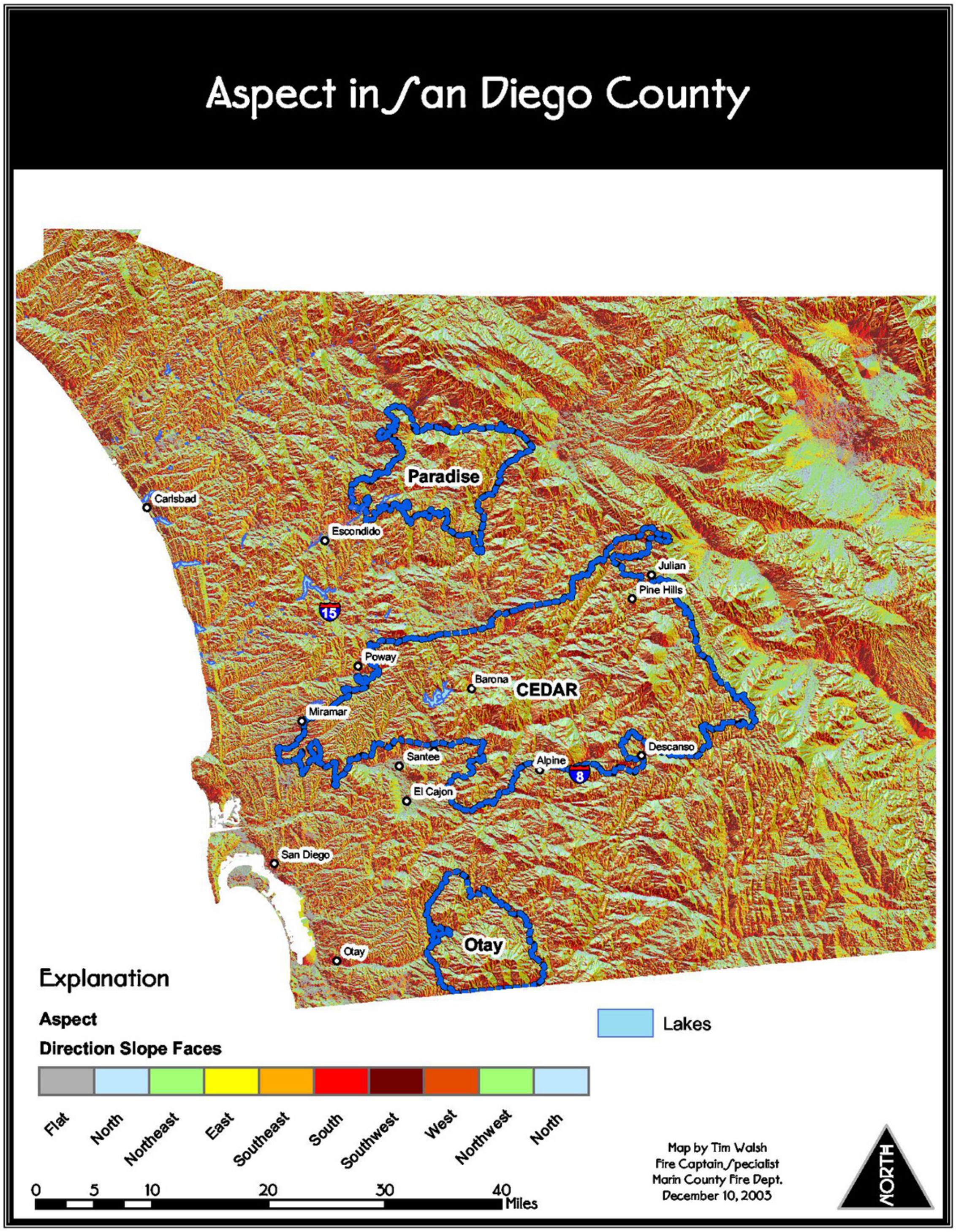
Aspect is the direction the slope faces. Aspect, along with soil type, elevation and other factors determines the vegetation type and plays a major role with fuel moisture. Northern slopes dry more slowly because they receive less solar radiation. This results in higher fuel moistures and heavier fuel loading. In higher elevations, the north slopes will support conifer fuel types even in an environment that borders the desert. In lower elevations, the northern aspect will support the heaviest fuel loading as well but the vegetation is frequently hard chaparral.

The southern aspects are just the opposite. They dry quickly, have the highest daytime temperatures, lowest relative humidity, and have the lowest fuel moistures. Vegetation corresponds to these environmental conditions. Light flashy fuels such as grass, buckwheat, and small sage brush commonly grow on these slopes. These aspects will support high rates of spread with little wind or slope and extremes rates of spread with a moderate wind.

Transitional aspects have characteristics of both north and south slopes For example; an east slope is exposed to the solar radiation first thing in the morning. It will warm quickly, but also cool earlier in the afternoon. The northeast will cool more quickly than the southeast slope. Please see Map 7 Aspects in San Diego County.



Map 6: Slope by Percent in San Diego County



Map 7: Aspect in San Diego. The slopes are shaded thematically by the amount of solar radiation they receive. The warmest colors are the southerly aspects; the cooler colors are the northerly aspects. Colors found in between are transitional aspects.

San Diego River Drainage

One of the dominant topographic features in the county is the San Diego River drainage. On the Cedar Fire, this drainage channeled wind flow and hindered suppression efforts. The river runs from the southwest to the northeast for over 20 miles. As this long topographic feature funnels wind, it increases velocity where it narrows. The San Diego River geographically isolated the Cedar Fire. Fire suppression crews responded to the dispatched location on the east side of the river. After trying to locate the fire, the east winds surfaced. Crews had to be repositioned to the west side of the river with extended travel times due to the long travel routes across the drainage.

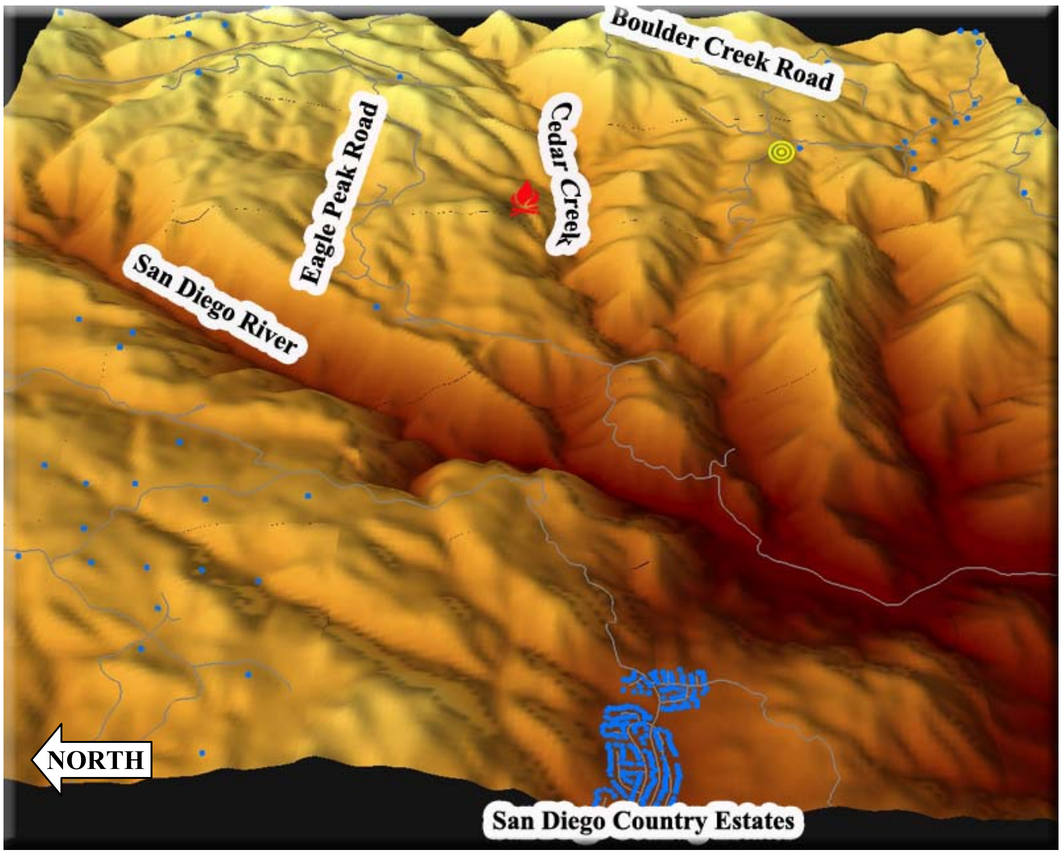


Figure 8: The San Diego River Drainage transects the lower center of the image. The origin of the fire is located between Cedar Creek and Eagle Peak Road seen on the image above as the red campfire. Initial attack fire suppression equipment staged on Boulder Creek Road marked with the yellow target. The blue dots represent addressable home locations.

Crews could not find access into the fire due to the lack of visibility from topography, vegetation, and darkness. As the winds surfaced from the east or the top of Figure 8, they were funneled through Cedar Creek until they reached the San Diego River where they turned to the south.

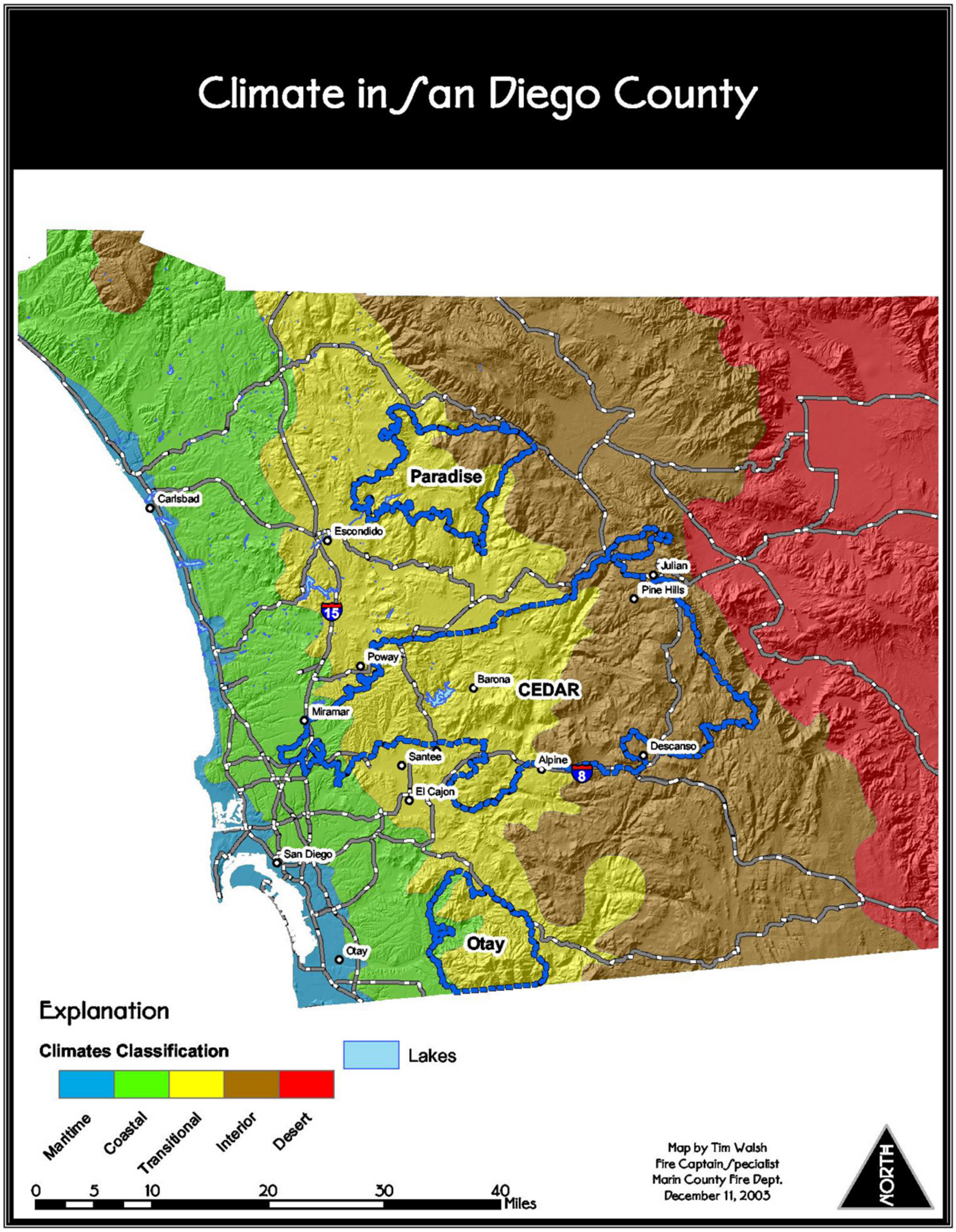
Figure 9: Looking north into San Diego River drainage.

Weather

The weather factor that most influenced the fire behavior was the Santa Ana winds. Santa Ana winds form when a high pressure sets up over the Great Basin. Cool air masses from either Canada or the Northern Pacific move into the Great Basin and stagnate in this intermountain area. The dry east-northeast winds, warmed adiabatically as air flows from higher to lower elevation, travel at high rates of speed. This wind caused temperatures to be unseasonably warm and relative humidity to be critically low. For the incredible rates of spread to occur throughout San Diego County, all of these critical weather conditions surfaced simultaneously.

Climate

The climate of San Diego County makes it very unique. Very few places exist where a coastal environment is in as close proximity to a desert as in San Diego County. The moist coast transitions to a barren desert in the short span of 44 miles. This climate is very conductive to large wildland fires. The marine influence supplies copious moisture for plants to grow rapidly in the form of fog and moist air. The desert influence dries vegetation, especially under east wind conditions. The five classifications of climate within the county are Maritime, Coastal, Transitional, Interior, and Desert. All three fires primarily burned in the Transitional and Interior Climate areas. The Cedar and Otay fires both burned into the coastal area prior to being suppressed. Please see Map 8 Climate in San Diego County.



Map 8: Climate in San Diego County Map. Fire perimeters are represented in dark blue.

The Wind Event

The weather pattern that set up during October 25-29 can best be understood by observing the satellite photos.

Figure 10: October 25, 2003-The fires in San Bernardino and Venture County can be readily seen with the Santa Ana winds pushing the smoke off shore. There are no large fires in San Diego County.

Figure 11: October 26, 2003-The Santa Ana wind is in full force with the Paradise, Cedar, and Otay fires in San Diego visible. The long elliptical burn pattern of the Cedar Fire is a strong indicator of the high east winds that were blowing. The bright red used in the images represents the hottest portions of the fire.

Figure 12: October 27, 2003-Although strong east winds are still aloft or in the upper atmosphere, the surface winds have subsided. The hottest area of fire spread is now on the eastern edge of the Cedar Fire being driven by heavier fuel and slope.

Figure 13: October 28, 2003-As the high pressure system over the Great Basin moves out of the area, the smoke is changing from an east flow to the more prevalent marine influence. The fires western edges are much cooler as seen by the dark red color.

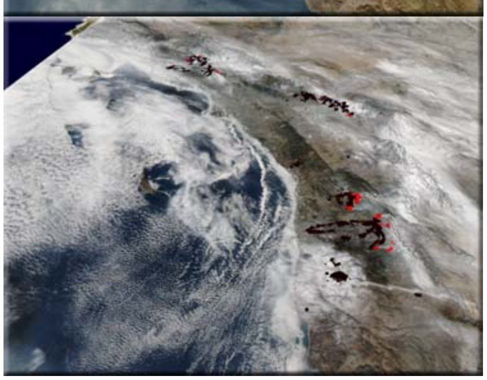


Figure 14: October 29, 2003-The marine influence is now well established. Large layers of moisture can be seen throughout Southern California. West winds are clocked at 15-16 miles per hour (mph) on the Cedar Fire with gusts to 30 mph.

Specific Weather Data

Remote automated weather stations (RAWS) are strategically placed throughout the nation to measure, record, and transmit via satellite fire weather readings. Although the entire period of the 2003 fire siege is important, RAWS data for October 25 and 26 during the major westward fire spread will be the emphasis. RAWS data will be examined for the area of the Cedar Fire but it is also representative of how hot, dry, and windy is was throughout San Diego County.

The Descanso and Goose Valley RAWS stations were used to depict fire weather. The two stations were used to provide weather data at two different elevations. Although the Pine Hills RAWS is closer to the origin of the Cedar fire, the hourly relative humidity readings remain constant at 25 percent indicating that the sensor was malfunctioning. For this reason, the Descanso RAWS is used for the middle elevation readings. In Tables 7 and 8, weather information was queried to show the conditions that persisted during the greatest fire spread. The dates in the tables start with the most recent date, October 26th at midnight to a point prior to the ignitions at 13:30 hours on October 25th which is the bottom entry on the tables.

Figure 15: This photo gives a perspective of how strong the winds were. Spot fires can be seen in the foreground.

The yellow line through the tables represents a void in the data. Voids can be caused by several factors but since both weather stations are missing data during approximately the same period, the satellite transmission link was probably malfunctioning. The red line represents another problematic issue that occurred during the fire. It appears that an hour of data is repeated. Actually, this occurred due to the twice yearly time change for daylight savings time. This resulted in some challenges with data interpretation. For example, while reading the dispatch logs, it was not always clear if the fire or law enforcement dispatch logs reflected the time change.

The weather prior to the Santa Ana winds surfacing encouraged fire spread because of the hot, dry, windy conditions. During the afternoon of October 25th, the temperature was 97 degrees in Goose Valley an 91 degrees in Descanso. During the period of greatest fire growth relative humidity plummeted to the single digits. Winds were sustained at 15-19 miles per hour (mph) and peak wind gust were recorded at 56 mph at Descanso and 41 mph at Goose Valley.

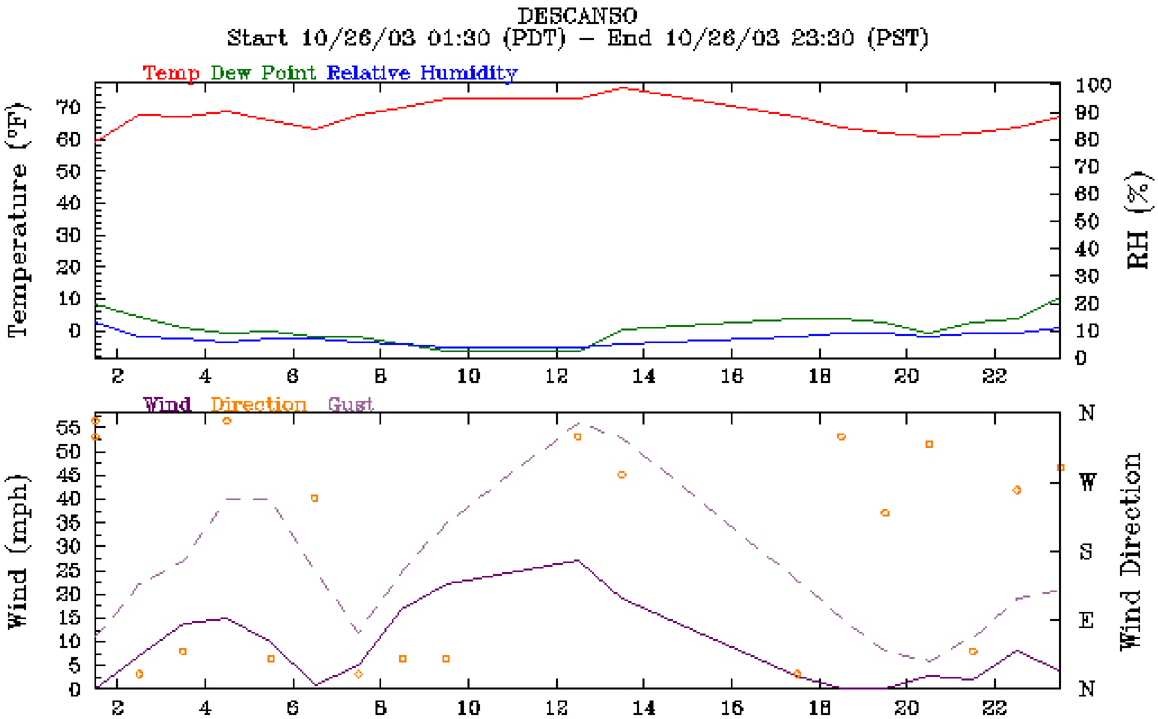


Figure 15: The graphs from the University of Utah-Mesowest Data dramatically shows the weather extremes that occurred from midnight October 25 to midnight October 26 at the Descanso Remote Automated Weather Station.

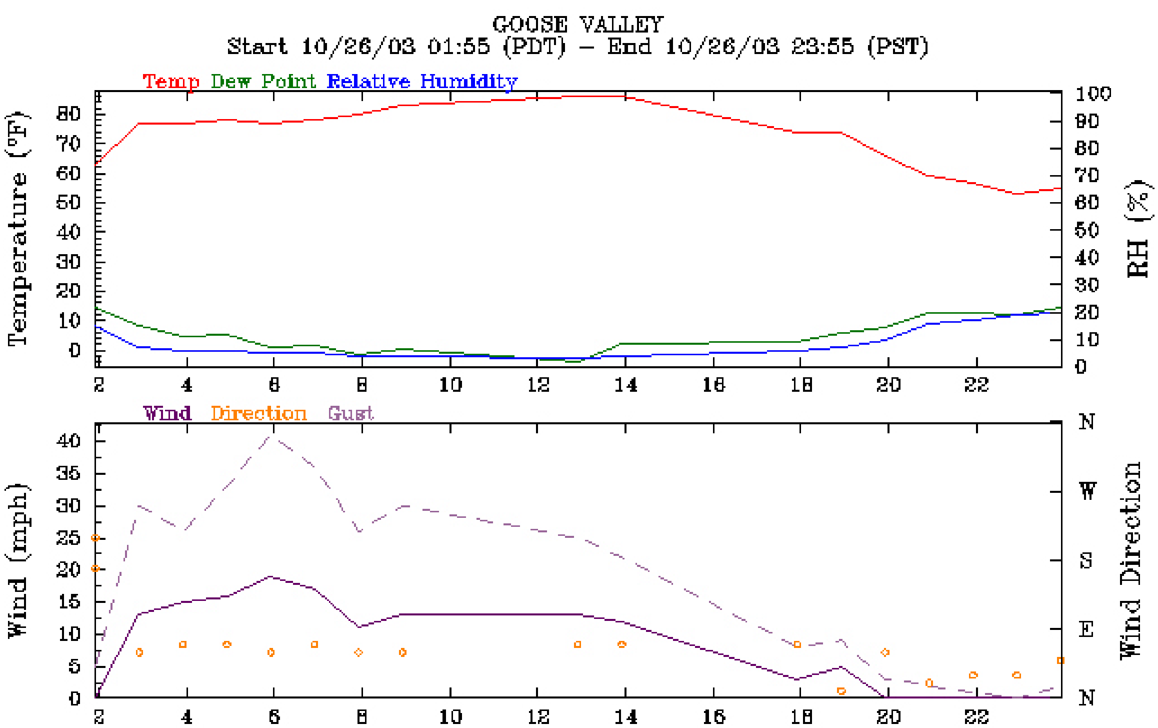


Figure 16: The graphs from the University of Utah-Mesowest Data for midnight October 25 to midnight October 26 at the Goose Valley Remote Automated Weather Station.

Table 7: Hourly air temperature readings from the Descanso RAWS-3481 feet elevation

Time(PST)	Temperature ° F	Relative Humidity %	Wind Speed mph	Wind Gust mph	Wind Direction	Solar Radiation W/m*m	Fuel Temperature ° F
23:30	67.0	11	4	21	WNW	0.0	61.0
22:30	64.0	9	8	19	W	0.0	61.0
21:30	62.0	9	2	11	NE	0.0	58.0
20:30	61.0	8	3	6	NW	0.0	56.0
19:30	62.0	9	0	8	SW	0.0	55.0
18:30	64.0	9	0	15	NNW	0.0	60.0
17:30	67.0	8	3	23	NNE	3.0	64.0
13:30	76.0	5	19	53	W	894.0	84.0
12:30	73.0	4	27	56	NNW	979.0	81.0
9:30	73.0	4	22	35	NE	686.0	76.0
8:30	70.0	5	17	25	NE	499.0	70.0
7:30	68.0	6	5	12	NNE	274.0	65.0
6:30	63.0	7	1	25	WSW	6.0	57.0
5:30	66.0	7	10	40	NE	0.0	61.0
4:30	69.0	6	15	40	N	0.0	65.0
3:30	67.0	7	14	27	NE	0.0	65.0
2:30	68.0	8	7	22	NNE	0.0	65.0
1:30	59.0	13	0	11	NNW	0.0	51.0
1:30	66.0	9	4	16	N	0.0	61.0
23:30	68.0	9	12	15	NE	0.0	66.0
22:30	67.0	9	8	14	N	0.0	65.0
21:30	59.0	15	3	10	NE	0.0	52.0
20:30	64.0	12	1	11	NE	0.0	59.0
19:30	66.0	11	1	7	S	0.0	61.0
18:30	74.0	9	0	13	ENE	5.0	69.0
17:30	84.0	7	3	15	N	221.0	85.0
16:30	87.0	6	5	15	NE	472.0	93.0
15:30	89.0	5	5	16	NNE	720.0	100.0
14:30	90.0	4	7	16	NNE	894.0	103.0
13:30	91.0	3	7	15	N	991.0	102.0

Table 8: Hourly Readings from the Goose Valley RAWS-Elevation 1529 feet

Time(PST)	Temperature ° F	Relative Humidity %	Wind Speed mph	Wind Gust mph	Wind Direction	Solar Radiation W/m*m	Fuel Temperature ° F
23:55	55.0	20	0	2	NE	0.0	47.0
22:55	53.0	19	0	0		0.0	47.0
21:55	57.0	17	0			0.0	49.0
20:55	59.0	16	0	2	NNE	0.0	49.0
19:55	66.0	10	0	3	ENE	0.0	59.0
18:55	74.0	7	5	9	N	0.0	70.0
17:55	74.0	6	3	8	ENE	0.0	70.0
13:55	86.0	4	12	22	ENE	652.0	95.0
12:55	86.0	3	13	25	ENE	806.0	97.0
8:55	83.0	4	13	30	ENE	630.0	89.0
7:55	80.0	4	11	26	ENE	324.0	78.0
6:55	78.0	5	17	36	ENE	77.0	77.0
5:55	77.0	5	19	41	ENE	4.0	77.0
4:55	78.0	6	16	33	ENE	0.0	76.0
3:55	77.0	6	15	26	ENE	0.0	75.0
2:55	77.0	7	13	30	ENE	0.0	74.0
1:55	63.0	15	0	5	SSW	0.0	57.0
1:55	63.0	16	0	0		0.0	55.0
23:55	62.0	15	0	3	NNW	0.0	53.0
22:55	67.0	12	0	0		0.0	57.0
21:55	73.0	9	3	7	NNW	0.0	68.0
20:55	69.0	13	3	7	NE	0.0	63.0
19:55	72.0	11	3	6	NE	0.0	66.0
18:55	73.0	16	3	6	NE	0.0	69.0
17:55	79.0	34	0	0		6.0	72.0
16:55	89.0	23	4	7	WSW	167.0	89.0
15:55	95.0	9	6	11	WSW	425.0	101.0
14:55	97.0	6	7	12	W	625.0	105.0
13:55	95.0	7	7	12	WSW	791.0	106.0

Drought Conditions

Keetch-Byram Drought Index

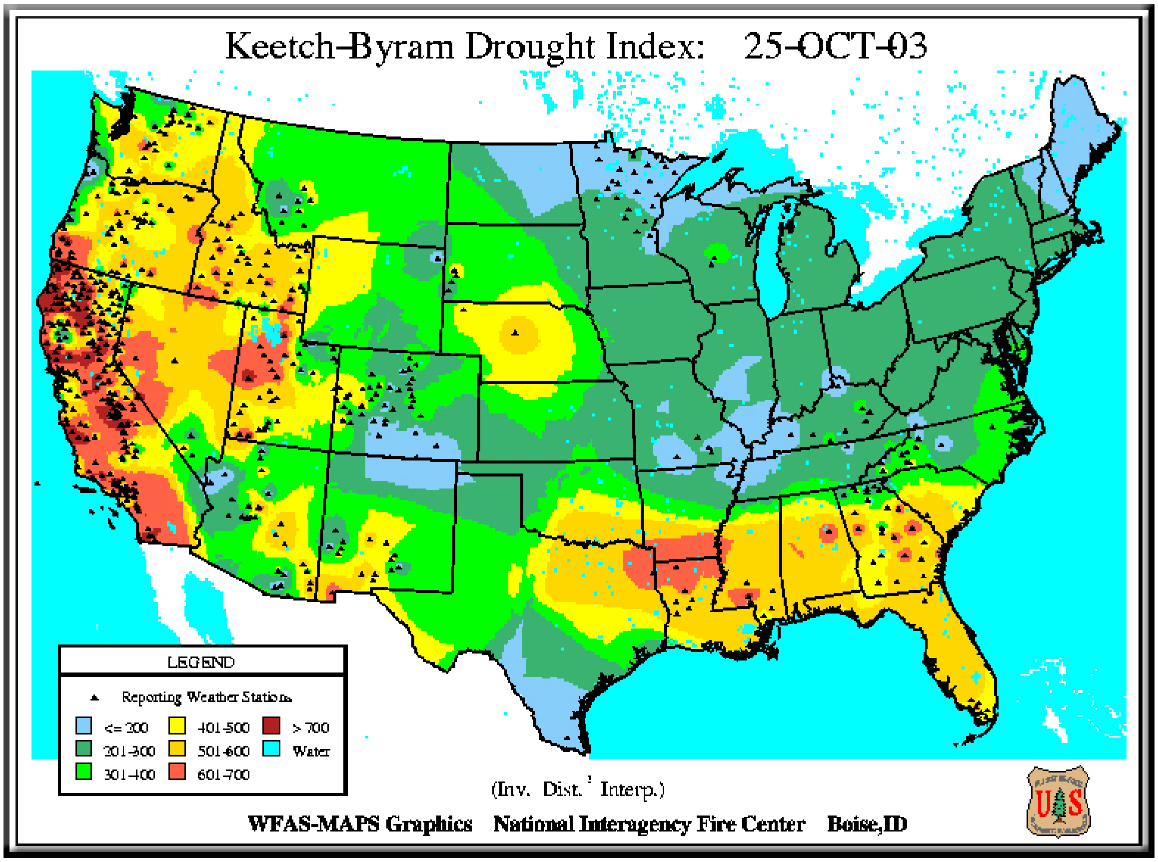


Figure 17: The Keetch-Byram Drought Index for the Unites States for October 25, 2003.

The Keetch-Byram Drought Index (KBDI) is a numerical index representing the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in deep duff or upper soil layers. Drought index measures the tendency of organic soil material to burn. As depicted in Figure 18, KBDI for San Diego County was over the 600 level with some areas over the 700 level. There are many eucalyptus trees within the Cedar fire perimeter. The soil under the mature stands of trees is composed of very deep layers of organic material or duff. The duff is made of bark that peels from the trees as well as dead leaves. The KBDI indicates that this material was very dry.

Other Signs of Drought:

Figures 19-21 are maps that indicate how dry Southern California and specifically San Diego County was during the fire siege. Images were provided by Heath Hockenberry of the National Interagency Fire Center and produced by the Western Regional Climate Center.

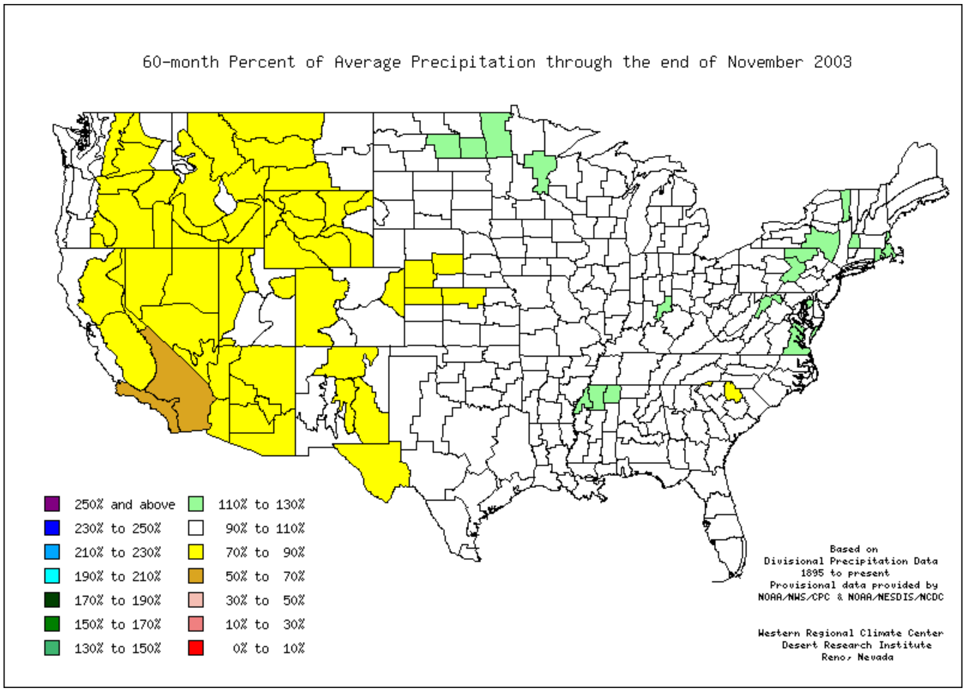


Figure 19: This map shows the percent of average precipitation over the past 5 years by climate division ending at the end of November 2003. It illustrates over the past 5 years that all of southern California has only received 50 to 75% of its normal rainfall.

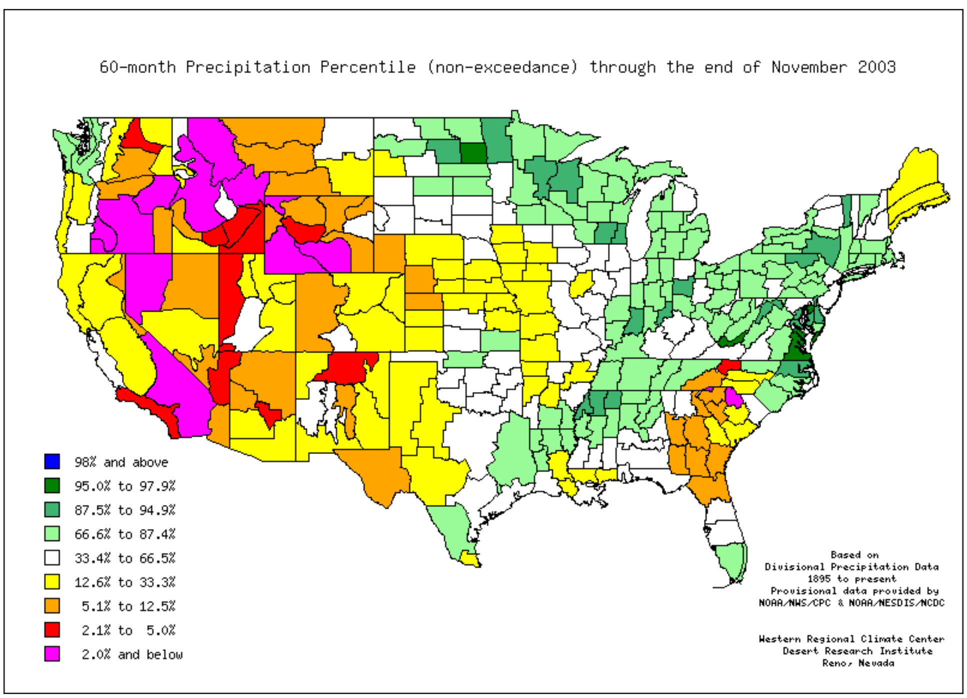


Figure 18: This map was created using the Climate Division data that has been kept dating back to 1895. San Diego County has experienced a five year period that ranks in the bottom 5th percentile of rainfall.

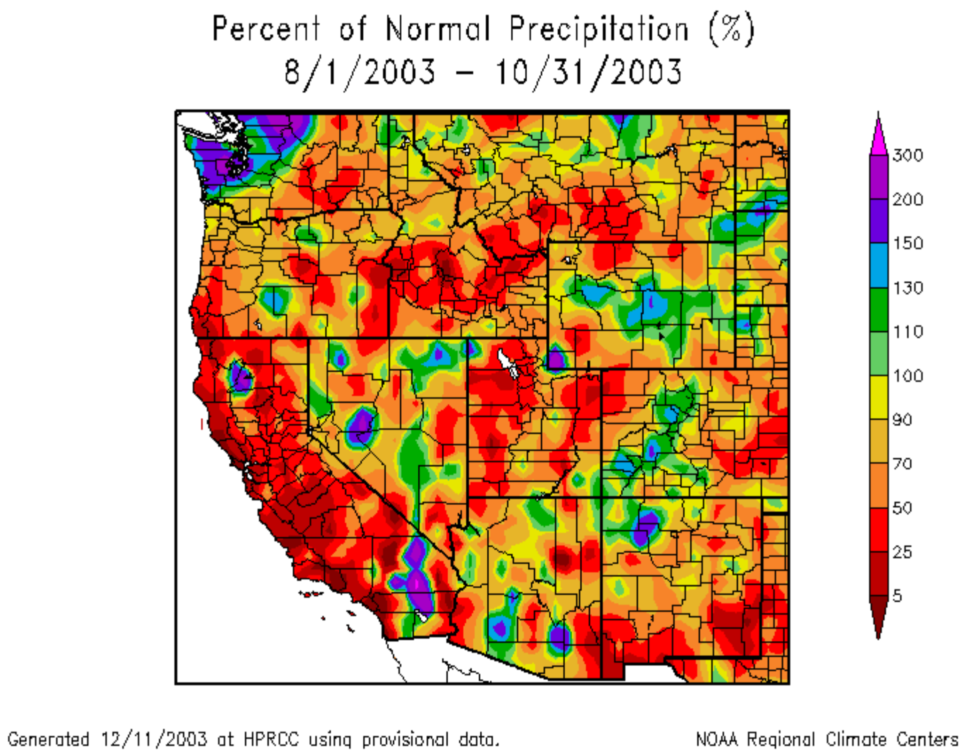


Figure 20: This diagram displays the percent of normal precipitation during the 3 months leading up to the southern California fire event. It shows shorter term dryness from August 2003 right through the end of October. Even though it is the dry season anyway in southern California, this map at least shows that there were no significant summer storm systems that brought rains that raised the average to normal or above.

Five Year Rainfall Totals

Other data that supports the critical level the fuels were under due to long term drought is displayed in the rainfall tables for areas throughout the Cedar Fire. Please see Table 9 and Charts 1-5.

Table 9 Average rainfall amounts compared to average for the last 5 years. Data provided by the Western Regional Climate Center.

Weather Station Name	Total Average Rainfall for all Years	Last 5 Year Average
Cuyamaca	33.54 inches	18.40 inches
Palomar	28.11 inches	19.63 inches
Alpine	16.48 inches	10.53 inches
El Cajon	12.11 inches	6.80 inches
San Diego Airport	10.21 inches	6.69 inches

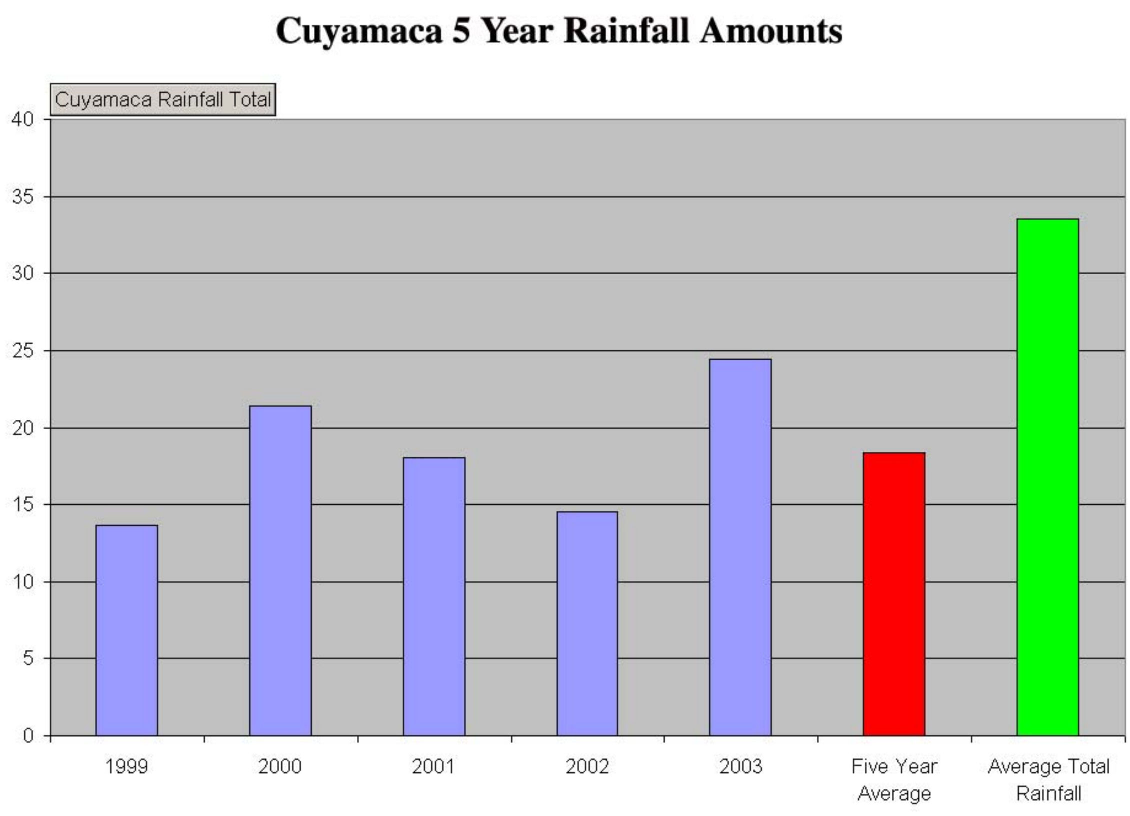


Chart 1: Cuyumaca Weather Station 5 Year Rainfall Average (Red Bar) compared to the Total Average Rainfall (Green Bar). The vertical axis represents inches of rainfall.

Palomar 5 Year Rainfall Amounts

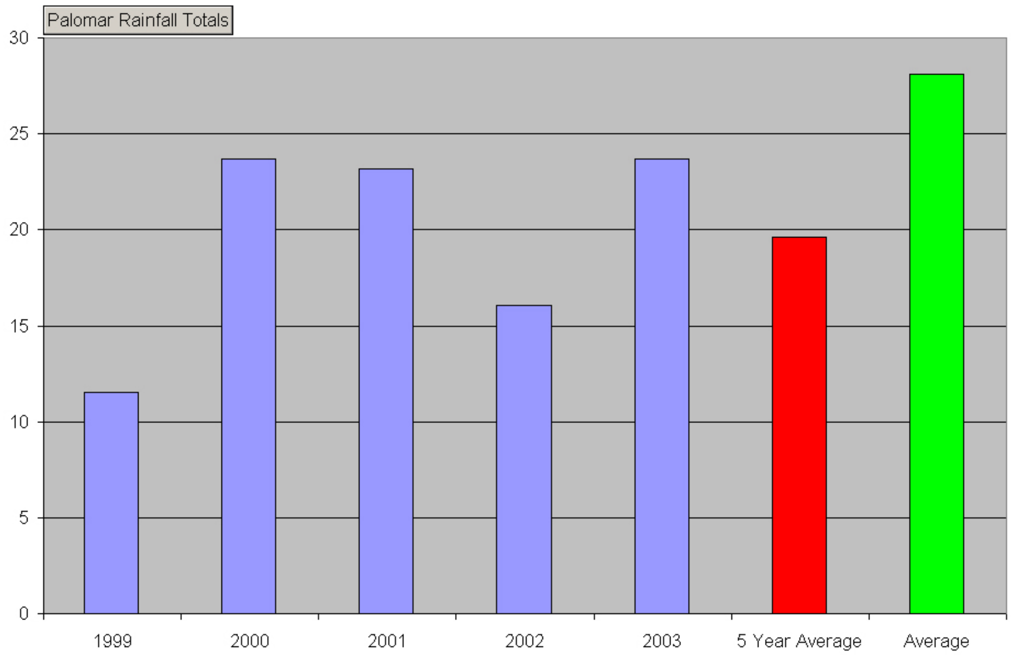


Chart 2: Palomar Weather Station 5 Year Rainfall Average (Red Bar) compared to the Total Average Rainfall (Green Bar). The vertical axis represents inches of rainfall.

Alpine 5 Year Rainfall Amounts

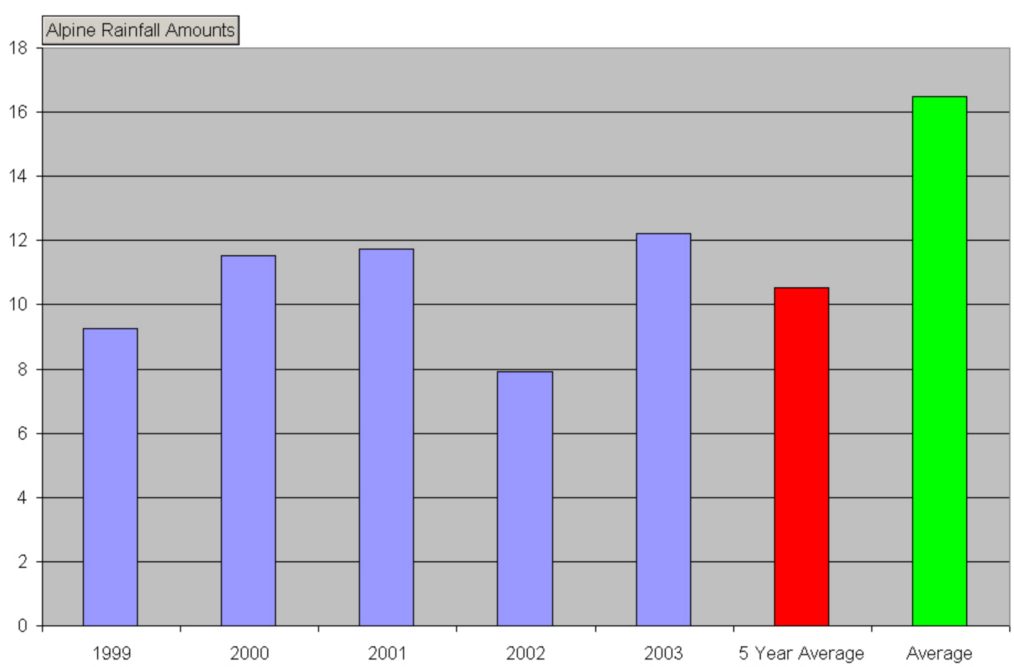


Chart 3: Alpine Weather Station 5 Year Rainfall Average (Red Bar) compared to the Total Average Rainfall (Green Bar). The vertical axis represents inches of rainfall.

El Cajon 5 Year Rainfall Amounts

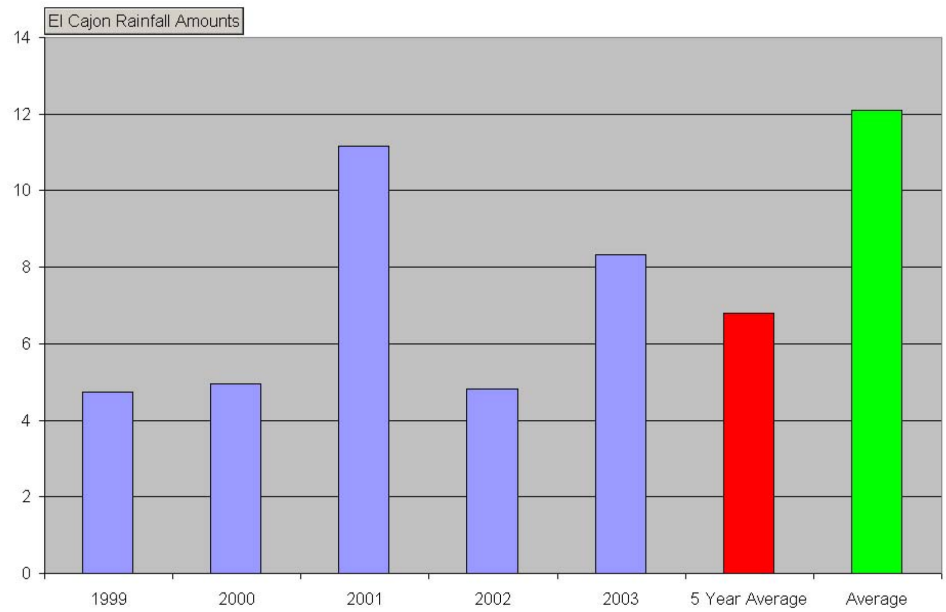


Chart 4: El Cajon Weather Station 5 Year Rainfall Average (Red Bar) compared to the Total Average Rainfall (Green Bar). The vertical axis represents inches of rainfall.

San Diego Airport 5 Year Rainfall Amounts

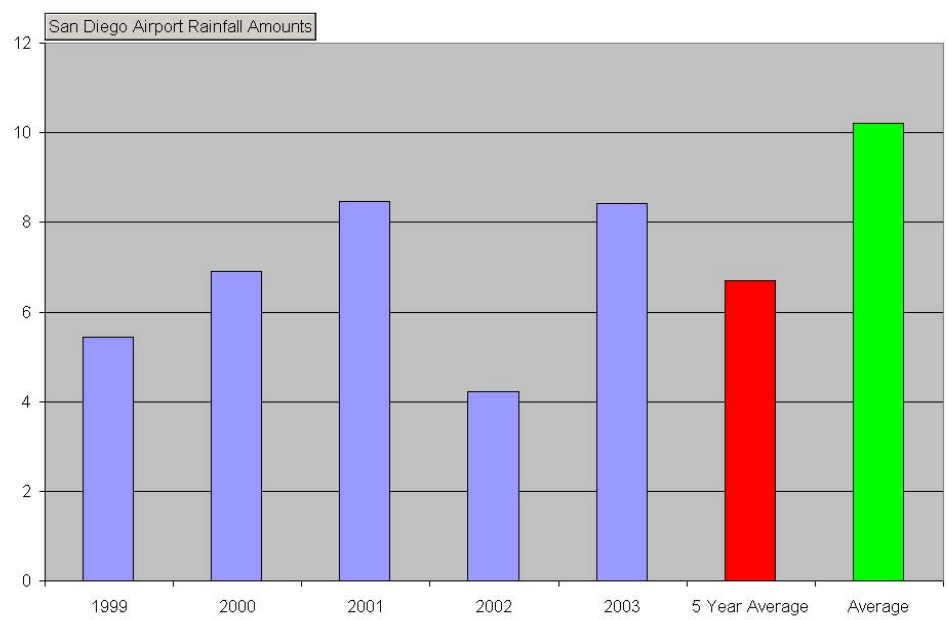


Chart 5: San Diego Weather Station 5 Year Rainfall Average (Red Bar) compared to the Total Average Rainfall (Green Bar). The vertical axis represents inches of rainfall.

Other Factors that Relate to Spread and Intensity

Structures in the Path of the Fire

Over 30 years ago, Fire Scientist Clive M. Countryman[5] noted how man has changed the vegetation. "… In addition, the exclusion of periodic fire through fire protection may change the amount and characteristics of the fuel. Man also changes the fuel-and distribution. This complicates the fire control problem in the process-by building homes in the wildlands and living surrounded by flammable fuel. This practice has become so prevalent that the wildland fuel-building mixture is now often considered a separate fuel type." This was an early description of what today is referred to the wildland urban interface or intermix. Structures as they relate to fire spread will be covered in a separate chapter.

Once a structure or any other inorganic material becomes ignited, they become another fuel type. Once several homes on Cedar and Paradise Fires were ignited, they threatened improvements and wildlands alike. Houses burn with extreme intensity and additional burning material is lofted into the convection column. Once burning material such as shingles, lawn furniture, or other structural components become part of the convective column, they can travel several thousand feet causing spot fires or land on other homes causing additional damage. Homes can also become exposures from radiant heat from neighboring burning structures. The Cedar and Paradise fires, like other wildland interface conflagrations, experienced house to house ignition. Once one home was ignited, adjacent buildings were often damaged or destroyed.

Figure 21: A home burning during the Cedar Fire.

There were a number of homes in the fire area with wood shake or shingle roofs. These homes were a great risk and once ignited, produced burning embers that were lofted into the convective column. For example, in Scripps Ranch, approximately 201 of the 340 structures destroyed had wood roofs[6]. The influence of roofing material was most dramatic within the city of San Diego. Of the approximately 2230 homes destroyed countywide, 77 were classified with a wood roof. This may be due to a roofing ordinance

[5] Countryman, Clive M. 1972. "The Wildland Fire Environment Concept"
[6] Data provided by the City of San Diego.

passed in 1996 requiring Class A roofs. Unfortunately, the requirement does not prevent wood from being used as a primary siding material. Of the approximately 2230 destroyed homes, almost 800 had wood listed as the primary siding material[7].

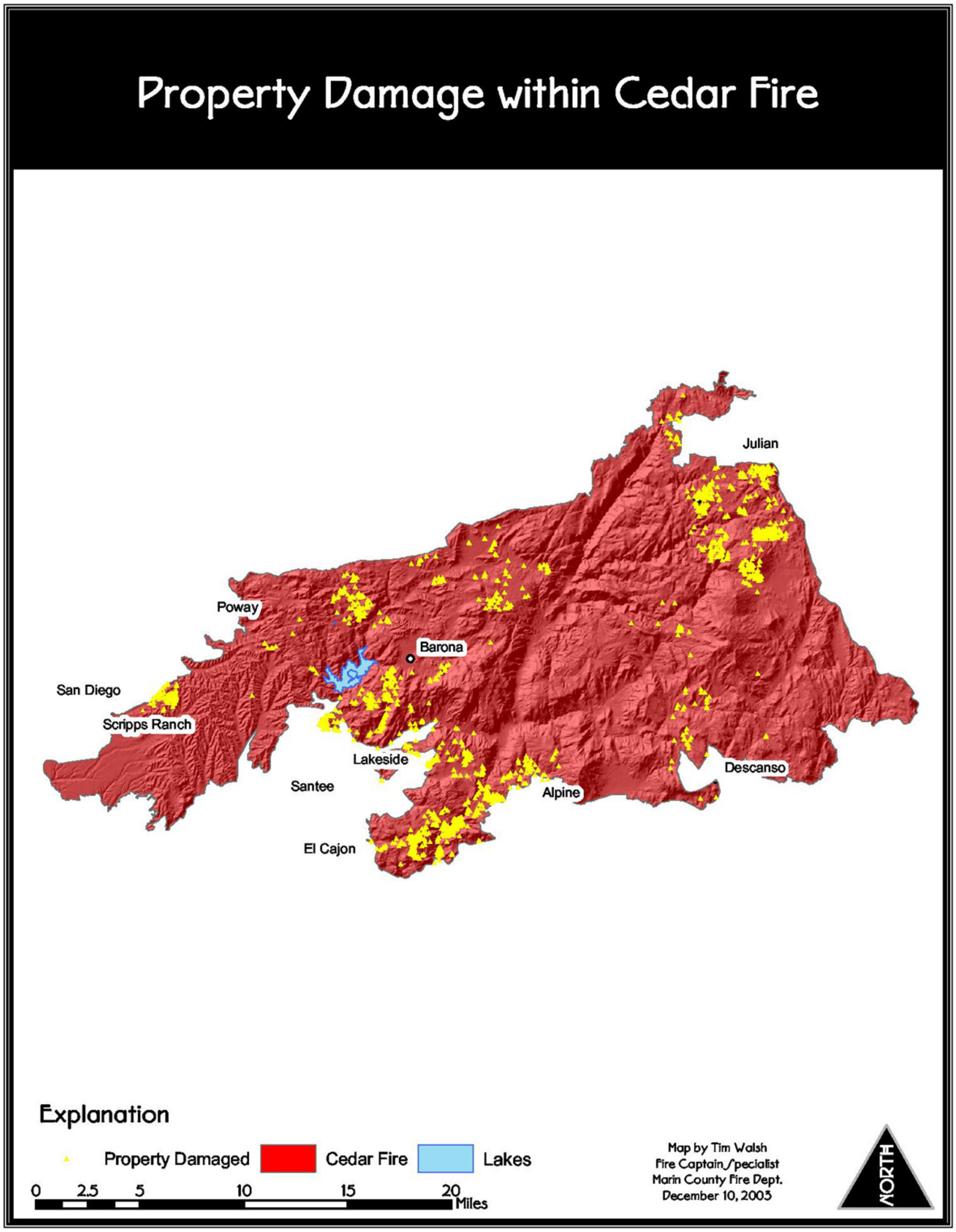
Table 10: Number of Structures Damaged or Destroyed in the San Diego Fires

Fire Name	Residences Lost	Commercial Building Lost	Other Buildings Lost
Cedar	2232	22	566
Paradise	221	2	192
Otay	1	0	5

One question posed by many concerned citizens is why this fire destroyed so many homes compared to the 1970 Laguna Fire. One obvious answer is the fire occurred in a more populated area. Another reason is the amount of development since the Laguna Fire occurred.

The County's parcel data was used to find improved[8] parcels within the Cedar Fire perimeter. A query was written to obtain the year each home or other building was constructed. Within the parcel data, there is an attribute field named "effective year". After consulting with the County's GIS staff, the field is believed to represent the year each house was built. From these parcels, another query was written to find homes built prior to and after 1970. Of the 12,149 improved parcels with an effective year, 2,432 were built prior to 1970. Eighty percent or 9,717 structure were built after 1970.

[7] Data provided by the County of San Diego.
[8] Within the parcel database, a field delineated as "ASR_IMPR" was interpolated as the value of improvements found on each parcel.



Map 9: Distribution of Damaged Property found on the Cedar Fire.

Open Space

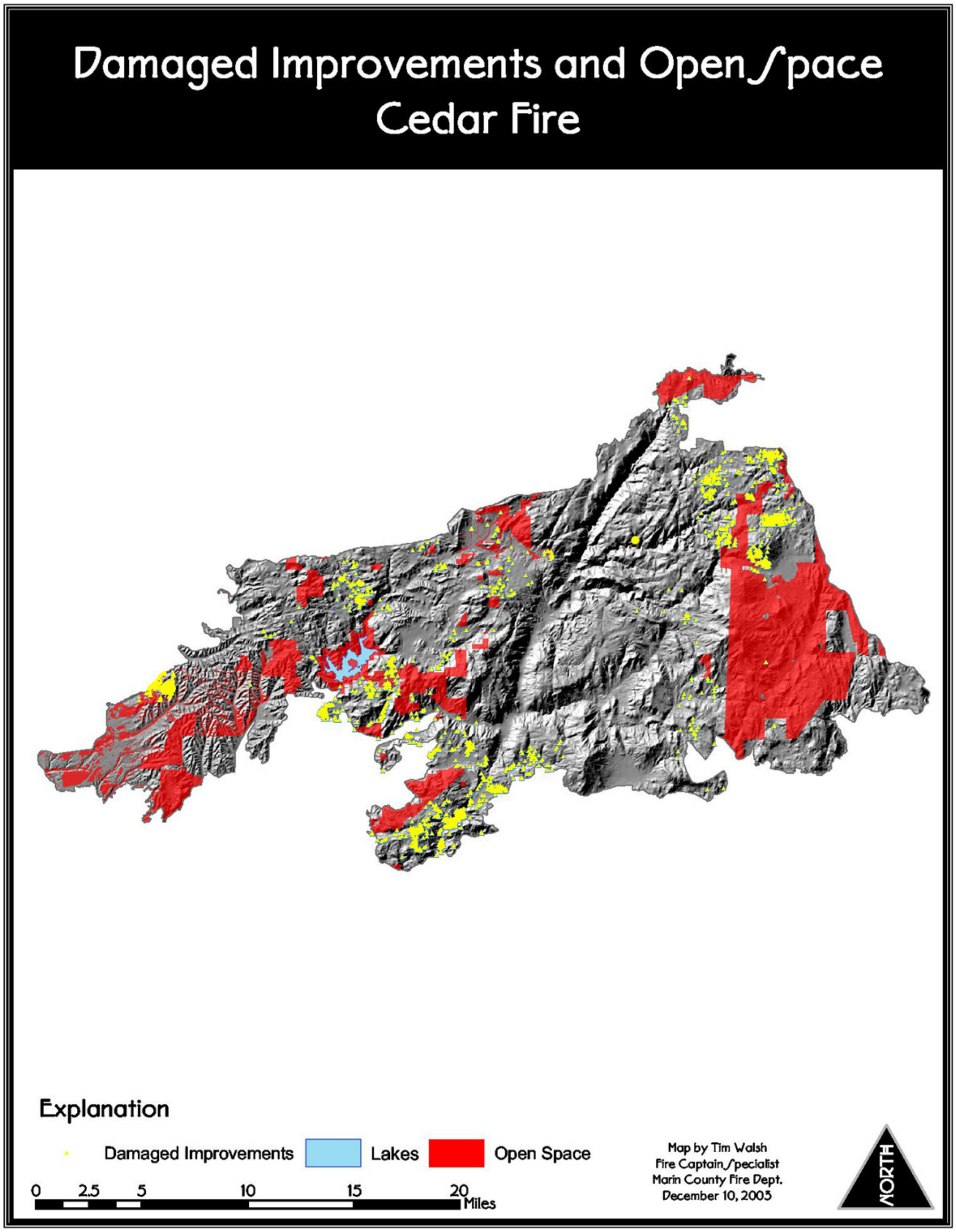
Throughout the Safety Review Team's interviews, many common concerns were voiced. One such concern was that open space areas or corridors may have contributed to the structure loss figures. Open space is not easily classified or defined. Is it public lands or land set aside in a natural setting? The San Diego Association of Governments (SANDAG) has created a database from the County's land use records. Within the database, there is an "open space" land use classification. The open space lands were buffered to show areas that are within 500, 1000, and 1500 feet from publicly owned land.

Using the BEHAVE fire model calculations were performed to determine how far a spot fire could be lofted in front of the main fire. A spotting distance of one half of a mile or 2,640 feet was determined using very conservative figures. It would be safe to assume that structures within 1,500 feet from open space were at risk if fuel reduction, modification, or a past fire has not altered the fuel loading. Table 10 shows how much property damage occurred within the analyzed buffer distance from open space. Please see Map 10 for Property Damage and Open Space Lands. Please see Map 11 for Property Damage and Open Space Lands in Scripps Ranch.

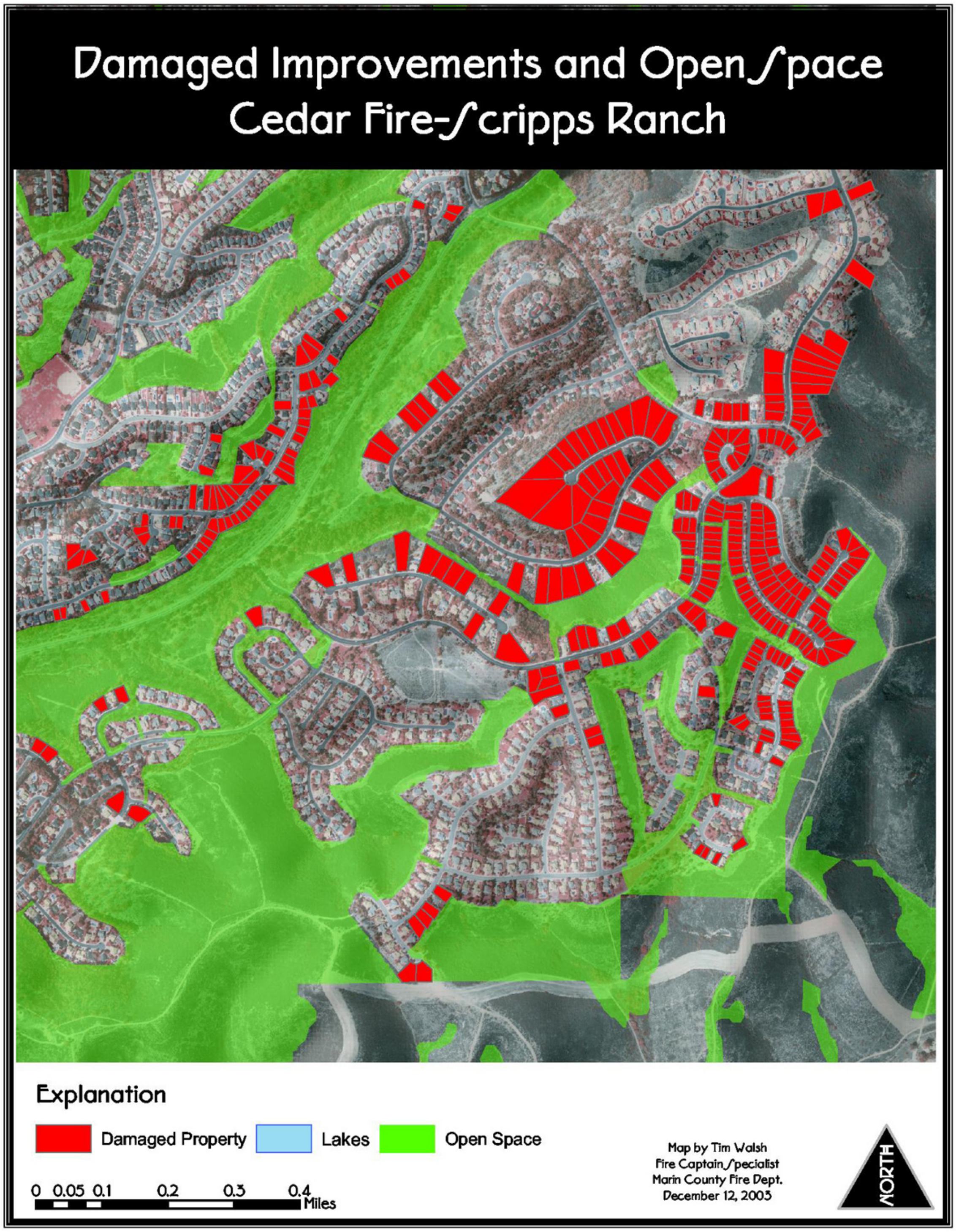
Figure 22: Homes burning next of open space corridors, with eucalyptus surrounding the neighborhood on both ridgelines and valley bottoms.

Table 11: Property Damage in Proximity to Open Space Lands

Distance from Open Space	Number of Properties Damaged
500 feet	430
1000 feet	202
1500 feet	153



Map 10: Damaged Improvements and Open Space within the Cedar Fire



Map 11: Damaged Improvements with Open Space within Scripps Ranch

Eucalyptus

The major fuel types that lead to the extreme rates of spread and intensity were Southern California mixed chaparral and coastal sage shrub. Eucalyptus trees did not appear to burn through their canopies and comments were made that they were not a problem from a fire behavior perspective. Hopefully this is not a widely held belief and their removal needs to be continuously addressed through fuel management projects. Although the canopies did not burn, the greatest challenges posed by eucalyptus are twofold.

Figure 23: A hot burning chaparral fire will transition into the Eucalyptus grove seen in the foreground. As the fire moves into this vegetation type, it will quickly produce ember showers due to the loosely stacked duff layer found under the trees. The street signs indicate this photo is in Scripps Ranch.

First, the duff layer under the trees is very deep. This duff layer builds quickly as leaves continuously fall. The vertical arrangement of the organic material creates a layer of very loosely stacked material that is very flammable due to oils contained within the leaves. This material reacts quickly to changes in the weather. As temperatures rise and the air dries, the duff layer reacts accordingly resulting in a perfect layer of kindling. Once ignited, wind can loft the aerodynamic leaves great distances, often landing on homes or igniting spot fires.

The second problematic concern is the shredded and aerially suspended bark that clings to the trunks. Fire climbs the shredded bark and travels up the tree. With a gust of wind, the burning shredded bark breaks away from the trunk and travels great distance. Areas such as Eucalyptus Hills and Scripps Ranch were subjected to the detrimental effects of this species.

Actual vs. Modeled Fire Behavior

Actual Fire Behavior

Fire behavior is a very complex subject but can be simply defined as how fast and how hot fires burn. Using this simple definition, we can observe some of the characteristics that define fire behavior using different means. During an event of this magnitude, personnel were not available to document the fires rates of spread or intensities. It would be safe to say most emergency responders were not aware of how fast and far the fire was moving due to spot fires ahead of the main fire front, lack of resources, and darkness.

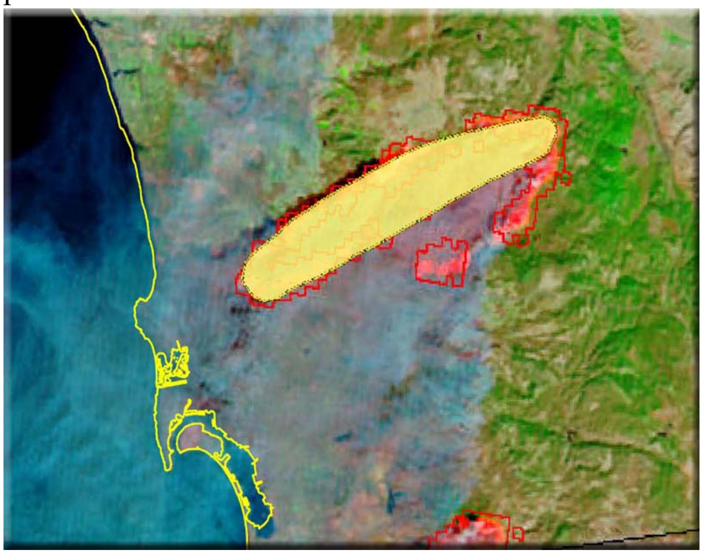


Figure 24: The MODIS image was georeferenced to a known geographic projection. This procedure allowed for calculations to be performed determining size and shape of the drawn ellipse.

Using imagery collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra Satellite from October 26th, some basic assumptions can be made. The image was georeferenced in a Geographic Information System. An ellipse was drawn over the area of image where the fire spread the fastest. Using the fire shapes associated with effective wind speeds found in the ***Fire Behavior Field Reference Guide****,* the Cedar fire burned with an effective wind speed of over 15 miles an hour. The size of the ellipse is approximately 76,200 acres and measures 5 miles wide by 29 miles long. The fire made this 29 mile run from approximately midnight of October 25th until 10:00 hours October 26th. This would equate to the fire spreading 2.9 miles and burning 7620 acres every hour.

To determine spread distance over time, the communication logs from CDF, San Diego County Sheriffs (SDSO), and USFS were read. Points were placed on a map where a time and a place were mentioned in the logs. Unfortunately, there are only a few detailed entries in the dispatch logs that tie a place and time together. Once the fire burned further to the west, there are less radio communications that provide a temporal and spatial connection.

The city of San Diego collected times from interviewing firefighters for various locations. Map points were provided by the City with this information. This data was combined with the radio log points to determine rates of spread.

The fire moved very slowly from 17:38 hours, the time of dispatch, until approximately 23:00 hours. It was described by the Operations Section Chief, located at the east end of the San Diego County Estates as approximately five acres backing down slope and the Initial Attack Incident Commander as 20-25 acres. The reason for the difference in acres is most likely attributed to visibility and perspective. Two factors alter what each person could see. First, daylight, or the lack thereof, make it very difficult to approximate acreage. Secondly, the topography itself will block areas that may be visible from a different prospective.

The following comments were pulled from various dispatch logs that document time, weather, and fire behavior as the fire transitions from a backing fire to a very fast high intensity brush fire with long range spotting. Over 790 pages of dispatch logs were read. Passages that were taken out of the logs are within quotation marks with all of the lingo and slang copied verbatim.

October 25, 2003:

To set the stage the afternoon Fire Weather Forecast was read at 17:14 hours.
"All stations, Cleveland, the Southern California fire weather forecast for Saturday, October 25th. With the pacific high pressure moving into the west coast, locally strong and gusty northeast winds will move over the area today and Sunday and decreasing Monday afternoon, with warmer than normal temperatures and low humidity.

Break.

For the Southern California Mountains for tonight, clear, 15 to 30 percent maximum humidity, ridge top winds north to northeast 20 to 35 miles with higher gusts along with local northwest to northeast 20 to 35 miles with higher gusts. For Sunday and Monday sunny, mid eighties to mid nineties, eight to 15 percent minimum humidity is forecasted. Ridge top winds northeast to east 20 to 35 miles with higher gusts along with local north to east, 20 to 35 miles with higher gusts. Fire activity level one, fire danger adjective very high to extreme.

Break.

Cleveland continuing. The BI staffing and activity levels for area 630. Actual BI160 predicts, BI218 staffing level five adjective extreme. Area 640 actual BI180 predicted, BI206 staffing level five adjective extreme. Area 675 and 680, no actual or predicted BI's available. Both staffing level five, adjective extreme. Area 685 actual BI209 predicted, BI232. Staffing level five adjective extreme. Forest average actual BI188 predicted, BI219 staffing level five adjective extreme. Activity level for all areas five. This completes the afternoon fire weather forecast, BI staffing and activity levels at 17:14"

The fire is first noted in the log of the Cleveland National Forest at 17:38 hours. "Possible vegetation fire, Cedar Creek Falls. Possible vegetation fire on scene. It's incident 30563056, Cedar Creek Falls. Will Battalion 33, Descanso Crew Five, Engine

34, Engine 32, Engine 33, Engine 48, Engine 45, water tender three; respond to a report of vegetation fire, Cedar Creek Falls. Cleveland at 17:38."

At approximately 21:46 hours, dispatch receives a report from a lookout, "Winds are variable north, northeast, east at nine to 26 miles per hour. The temperature is at 68. Relative humidity is at 11 percent. The dew point at 11. And also the fire just made a run to the top of the ridge. It probably can be seen from just about anywhere in the south."

At approximately 22:20 hours, "Wind conditions update. Out of north, northeast and east at 18 to 27, gusty to 37 miles per hour."

At 22:50 hours CNF Battalion 33 reports, "The fire has crossed Eagle Peak Road." This is the last line of defense prior to the fire becoming established into the San Diego River Drainage. The fire has moved 1.6 miles (128 chains) to the west-southwest.

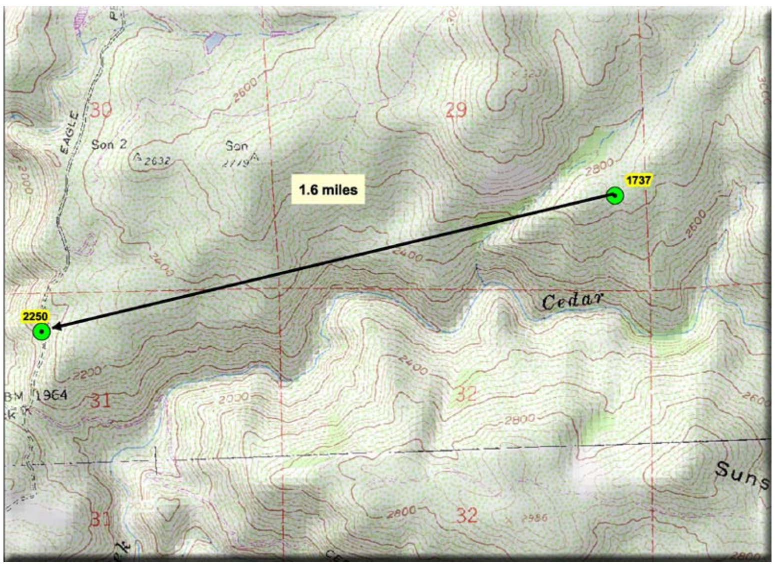


Figure 25: The fire has spread 1.6 miles to the west-southwest and crossed Eagle Peak Road at 22:50 hours. East winds were funneled through the Cedar Creek drainage.

The CDF Battalion Chief described the fire at 23:18 hours from the east end of the San Diego Country Estates, "Well let me tell ya, I'm watchin' what I think are probably 75-foot flames right now just rollin' and we had probably about a 60 or 80 acre air (aerial) ignition goin' about five minutes ago. And I've got now, they're probably well over 100 acres, or 100-foot flames now." This is the first reference of extreme fire behavior.

At 00:09 hours, CNF Division 4 states, "Fire activity has increased and long range spotting and it has crossed the San Diego River. This would approximately equate to another eight tenths of a mile (64 chains) of forward spread.

Many of the entries in the dispatch logs do not have a time stamp. Sometimes, the only indication of time is when the cassette tape recording the conversations is changed. Just prior to the tape ending at 00:27 hours, a report from the Structure Branch Director from the west side of the San Diego River, "I got a spot fire now. It's less than a half mile away. So her speed to these structures is increasing." CNF Battalion 33 adds, "We've got a pretty good fire activity now and it's not lying down as much as before."

Prior to 01:13 the Structure Branch Director states, "This thing is progressing around the Ramona Oaks area quite rapidly. It's starting to head from Barona, excuse me, Baron Mesa, which I'm moving some resources in there now."

At 01:16 CNF Dispatch receives a report of a Sheriff Officer trapped in a burning building on Matlin Road. The fire traveled west another 2 miles (160 chains) from the river bottom to Matlin Road in approximately 1 hour.

Prior to 01:30 hours, an unknown voice, but mostly likely a lookout reports to CNF Dispatch, "Winds still out of the northeast to east, northeast at, but they're up 25 to 40 miles per hours with 53 miles per hour. Temperature is at 66. Humidity is at 11 percent. Dew point is at nine degrees."

At 01:45 hours, the sheriff's dispatch log states the fire has jumped Rancho Barona Road. This would equate to over 1 mile (80 chains) of fire spread to the west-southwest.

At 02:25 hours, the CNF dispatch log states that an elderly couple is trapped on Albania St. This would equate to 1.3 miles (104 chains) of spread, but mostly to the north indicating that the fire is getting wider in size.

After the fire burned through the San Diego Country Estates, it headed in a southwesterly direction. Prior to 03:02 hours, CDF initial attack dispatcher states, "No, and our other fire is about 6,000 acres plus and may be heading towards 67." This is most likely a gross understatement of acreage based on rates of spread.

At 03:09 hours, there is a report from the sheriff's office of four persons trapped on Wildcat Canyon Road. This would equal a fire spread of 4.5 miles (360 chains) in 44 minutes. Between the hours of 03:00 and 07:00, sustained winds are between 13-14 mph with gust up to 40 mph recorded at the Goose Valley RAWS. It is believed that a majority of the civilian fatalities occurred during this time period.[9]

[9] The exact time of death has not been determined at the time of this writing.

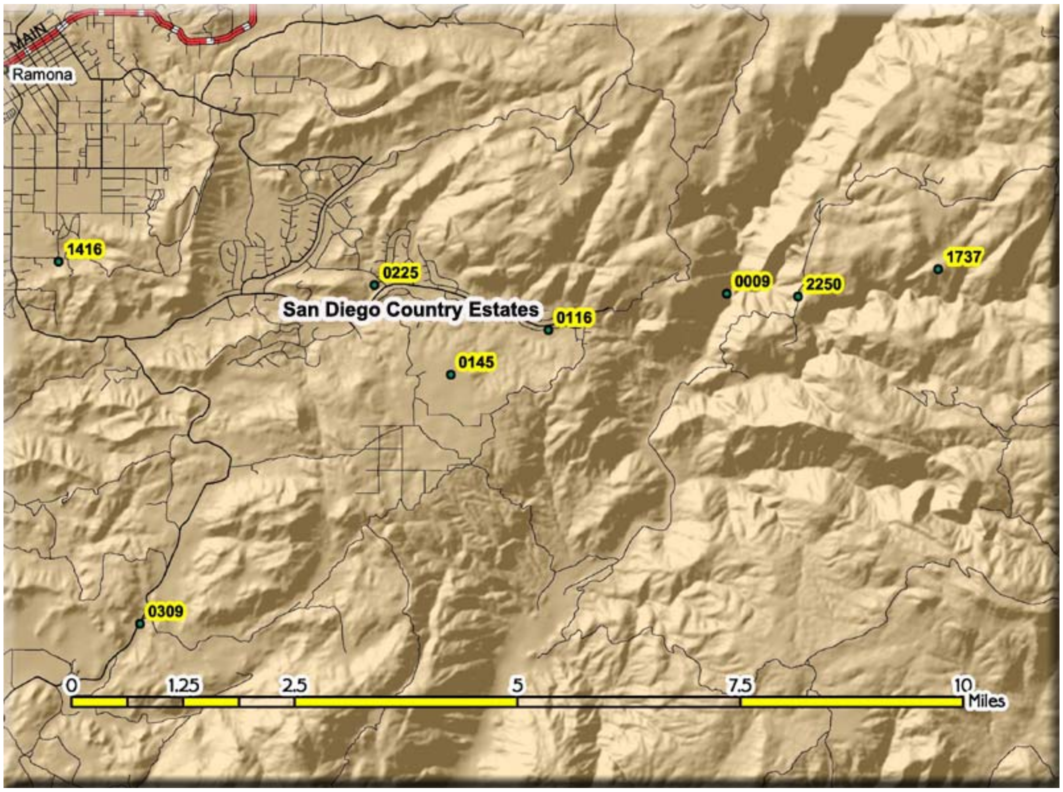


Figure 26: The yellow text represents the times where the fire spread according to the dispatch logs.

At 05:25 hours, there is a report to the CDF dispatch that the fire is in the backyard of a house on Old Barona Road. This would equate to another 2.8 miles (224 chains) of fire spread.

The following time frames are based on map points provided by the City of San Diego. The fire spread to the west 3.7 miles reaching Highway 67 although the exact time is unclear. The fire reached Scripps Ranch at approximately 08:30. It continued to spread to the west reaching Highway 15 at approximately 10:00 hours. The fire then began to spread to the east reaching Terra Santee by 13:00.

The CNF dispatch log states the units are trapped on Mussey Grade at 14:04 hours. At 14:16 hours, a house is burning on Gem Lane which is just south of Ramona. At 14:32, there is a "½ mile fire heading towards Harrison Canyon". By 14:50 it is "hitting Alpine heavy".

The first sign of the Santa Ana winds diminishing was during the late afternoon on October 27th. At 20:00 hours the Julian RAWS recorded winds with a westerly component blowing from the south-southwest at 1-2 mph. At the Descanso RAWS, the wind blew from the west-southwest at 18:30 hours at 0 mph with a gust of 7 mph.

October 28th was a day of transitional winds. Winds were out of the west at 4-8 mph with gust recorded at 10-12 mph from the Descanso RAWS. This allowed the very dry fuels to dominate fire behavior. Throughout the day, the fire continued to burn to the east. Fuel loading became heavier with a rise in elevation with conifers becoming more prevalent.

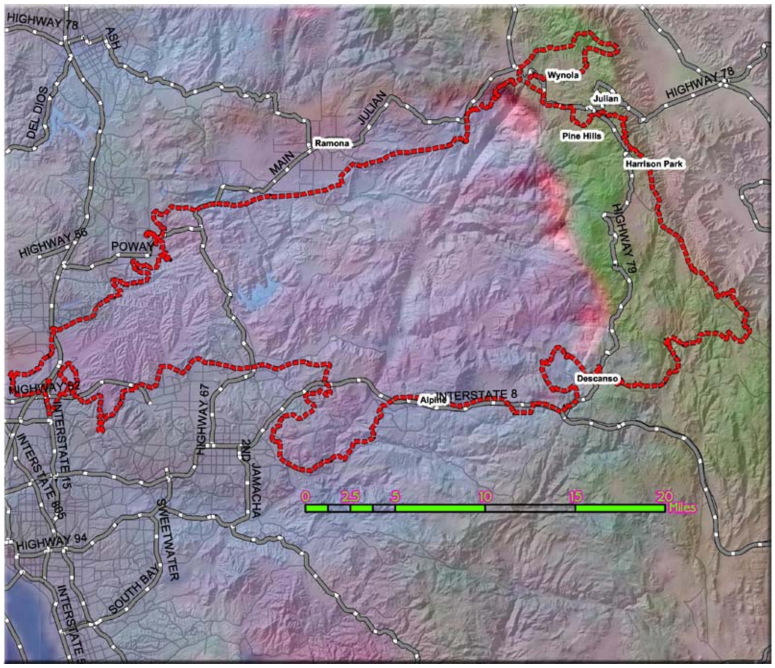


Figure 27: This satellite image draped over a topographic hillshade shows the highest concentration of heat in pink during the early morning of the October 28th. The satellite image was part of a data package located on San Diego State University's GIS website. An exact time of the image was not provided, only the date of October 28th.

Within the conifer fuel type were groves of bug killed pines that burned with very high intensities that also lofted several embers to the east. With a wind behind it, the fire was in direct alignment to burn North and Middle Peaks making upslope runs and spotting ahead of itself during the early morning hours. Prior to 09:00[10] hours, the fire is backing down the eastern slopes of North, Middle and Cuyamaca Peaks.

By sundown, the fire burned with high intensities into the community of Cuyamaca destroying structures. By 20:39 hours, the fire was threatening and destroying structures in the Harrison Park area temporarily trapping a structure protection group. By 21:00 hours, the fire had crossed the Sunrise Highway and was heading towards the La Cima Conservation Camp.

The fire continued to move in an easterly direction to the north and south. By 03:17 on October 29th the fire is spotting into the community of Kentwood in the Pines located to the southeast of Julian. As the fire spread east of Kentwood, it ran out of fuel burning into the 2002 Pines Fire.

As the day progressed, a strong westerly wind flowed over and through the San Diego River Drainage. The winds funneled up the river and caused the fire to spread into the community of Wynola. Winds were clocked at 9-17 mph with gust at 16-30 mph between 06:10-and 12:10 hours at the Julian RAWS. The fire spread to the northeast destroying more structures and killing a firefighter. By 16:10 hours, the humidity

[10] Temporal and spatial fire location relationships extracted from Division Chief Randy Lyle's narrative.

increased to 50 percent, by 18:10 to 80 percent, and by 21:10 hours, it reached total saturation of 100 percent. The air remained saturated with measurable rain falling by 6:10 hours on November 1st at the Julian RAWS.

Photos of Actual Fire Behavior

Another way to document fire behavior is from photographs. Unfortunately, the hundreds of photographs found on the internet do not provide a time and a place. With this limitation aside, there is still valuable information that can be extracted from these photographs.

Figure 28: The fire is burning with a wide flame front. This photo gives a good representation of fire behavior in the coastal sage scrub.

Figure 29: Flame lengths estimated at approximately 20 feet compared to a 40 foot telephone pole

Figure 30: This image gives a perspective to spotting distance as the fire jumps a four land road. Although in the foreground of the photo it appears to be a 6 lane road, the turn lanes most likely diminish.

Another awesome display of the fire's intensity is where it jumped Highway 15 which varies from 10-12 lanes measuring over 300 feet wide.

Figure 31: Flame front burning in chaparral threatening a neighborhood. The winds are blowing from the left to the right of the image. Note the fuel break in the upper left-hand side of the photo and how it breaks up the continuous front of fire

Figure 32: One of the best indications of extreme fire behavior is fire whirl development seen in this image. Note the size of the vegetation in the foreground.

Fire Models

FARSITE

Measuring fire behavior accurately is difficult! For accurate measurements, sensors need to be placed to measure outputs such as temperatures, flame lengths, and rates of spread. Not knowing where fires will burn makes it difficult if not impossible to place fire behavior sensors prior to their occurrence. Outside of photographs, fire behavior outputs such as flame lengths, rates of spread, and intensities are difficult to measure and observe. Another method to estimate fire behavior is to utilize models. Fire behavior models allow users to recreate or re-burn a fire to observe flame lengths, rates of spread, and intensity.

There are several limitations to any model due to the variability in reality such as wind, temperature, and topography. For example, winds change continuously but when modeling fires, they only change hourly[11]. A fire can cast thousands of embers but due to limitations of data processing and computer speeds, this also needs to be limited. Two models were used to recreate the fire behavior experience at the Cedar Fire.

The first model is FARSITE. FARSITE *(**F**ire **Ar**ea **Si**mula**t**or)* is a model for spatially and temporally simulating the spread and behavior of fires under conditions of heterogeneous terrain, fuels, and weather. This allows fires to burn across a simulated landscape providing outputs for a simulated fire. FARSITE requires the support of a Geographic Information System (GIS) to generate, manage, and provide spatial data

[11] Any length of time can be utilized but 1 hour intervals were used. The FARSITE program is very demanding computationally! The model took over 36 hours of processing to complete.

themes containing fuels vegetation, and topography. Five raster data themes are required to run FARSITE; elevation, slope, aspect, fuels, and canopy cover.

The elevation data was derived from United State Geological Survey (USGS) 30-meter digital elevation models (DEM). Slope and aspect themes were created from the USGS DEM. The vegetation theme was downloaded from the CDF Fire Resource Assessment Program's website. Canopy covers were derived from this spatial theme. Although the modeled shape for the Cedar Fire was very close to the actual fire, the rates of spread were not nearly as fast as reality. For the modeled rates of spread, another model call FlamMap was used.

Flame Lengths

The modeled flame lengths and intensity suggest why the Cedar Fire was difficult to suppress. Table 12 gives a basic understanding of flame lengths and fire line intensities as they relate to fire suppression. As seen in Map 12, a vast amount of the area within the Cedar Fire was beyond the capabilities of fire suppression forces.

Fire line Intensity

Fire line intensity is a fire behavior measure for describing the energy output of a flaming front and correlates directly with how difficult a fire is to control. An intensity of 50 BTU[12] per foot per second (50BTU/ft/sec) is the range desired for most prescribed burns. After a fire reaches 500 BTU/ft/sec, it is beyond the control of fire suppression. Once it reaches 1000 BTU/ft/sec, a major fire will occur with numerous spot fires, multi-tree torching and fire whirl development.

The theoretical limit for fire line intensity has been calculated at about 30,000 BTU/ft/sec. When fires reach this level of intensity, they are only stopped by an extensive change in the fire environment such as a fuel modification or experiencing a weather change. The modeled Cedar Fire projected intensities of over 26,000 BTU/ft/sec. As the actual fire burned to the west, it eventually ran out of wildland fuel as it spread into the developed areas of San Diego City. This theory is based on the fact that wind speeds were still high during the early afternoon of October 26th, well after the fire stopped spreading to the west. Northeast winds were recorded at 20 mph sustained with gusts to 25 mph at 12:55 hours at Miramar Naval Air Station. Winds were strong enough to continue the western spread if the fuels were conducive to burn. Please see Map 13 for modeled fire line intensities using FARSITE.

[12] British Thermal Unit: the amount of heat needed to heat one pound of water one degree Fahrenheit.

Table 12: Fire Suppression Interpretation compared to Fire Behavior[13]

Flame Lengths	Fire line Intensity	Interpretations
< 4 Feet	< 100 BTU/Foot/ Second	Fires can generally be attacked at the head or flanks by persons using hand tools Hand lines should hold the fire.
4-8 Feet	100-500 BTU/Foot/ Second	Fires are too intense for direct attack on the head using hand tools. Hand line cannot be relied on to hold fire. Equipment such as dozers, engines, and airdrop may be effective.
8-11 Feet	500-1,000 BTU/Foot/ Second	Fires may present serious control problems, torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.
> 11 Feet	>1000 BTU/Foot/ Second	Crowning, spotting, and major fire runs are probable. Control efforts at head of fire are ineffective.

FlamMap

Rates of Spread

The Cedar Fire burned from east to west with very fast rates of spread. To show how quickly fires can burn across the landscape, another fire modeling program was used. The program is called FlamMap. The FlamMap program creates raster maps of potential fire behavior characteristics over an entire landscape. These raster maps can be viewed in FlamMap or exported for use in a GIS.

It differs from FARSITE as there is no temporal component in FlamMap. It uses spatial information on topography and fuels to calculate fire behavior characteristics at one instant. It incorporates the following fire behavior models;

- Rothermel's 1972 surface fire model,
- Van Wagner's 1977 crown fire initiation model,
- Rothermel's 1991 crown fire spread model,
- Nelson's 2000 dead fuel moisture model.

However FlamMap will not simulate temporal variations in fire behavior caused by weather and diurnal fluctuations. Nor will it display spatial variations caused by backing

[13] Based on :Roussopoulos, Peter J.; Johnson, Von J. Help in making fuel management decision. Research paper NC-1 12. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 1975. 16 p.

or flanking fire behavior. These limitations need to be considered when viewing FlamMap output in an absolute rather than relative sense.

Two windspeeds were used to compare the potential rates of spread through the area where the Cedar Fire burned. The first model indicates rates of spread with a 10 mph wind. The outputs are colored showing rates of spread expressed in feet per minutes. The outputs range from no spread to 308 feet per minute. Please see Map 14. The second model indicates potential rates of spread with a 20 mph wind. Under a 20 mph wind, a majority of the landscape supports rates of spread at over 60 feet per minute. Another way to express how fast the modeled fire is burning is at 60 feet per minute, the fire is burning one foot of every second. Please see Map 15.

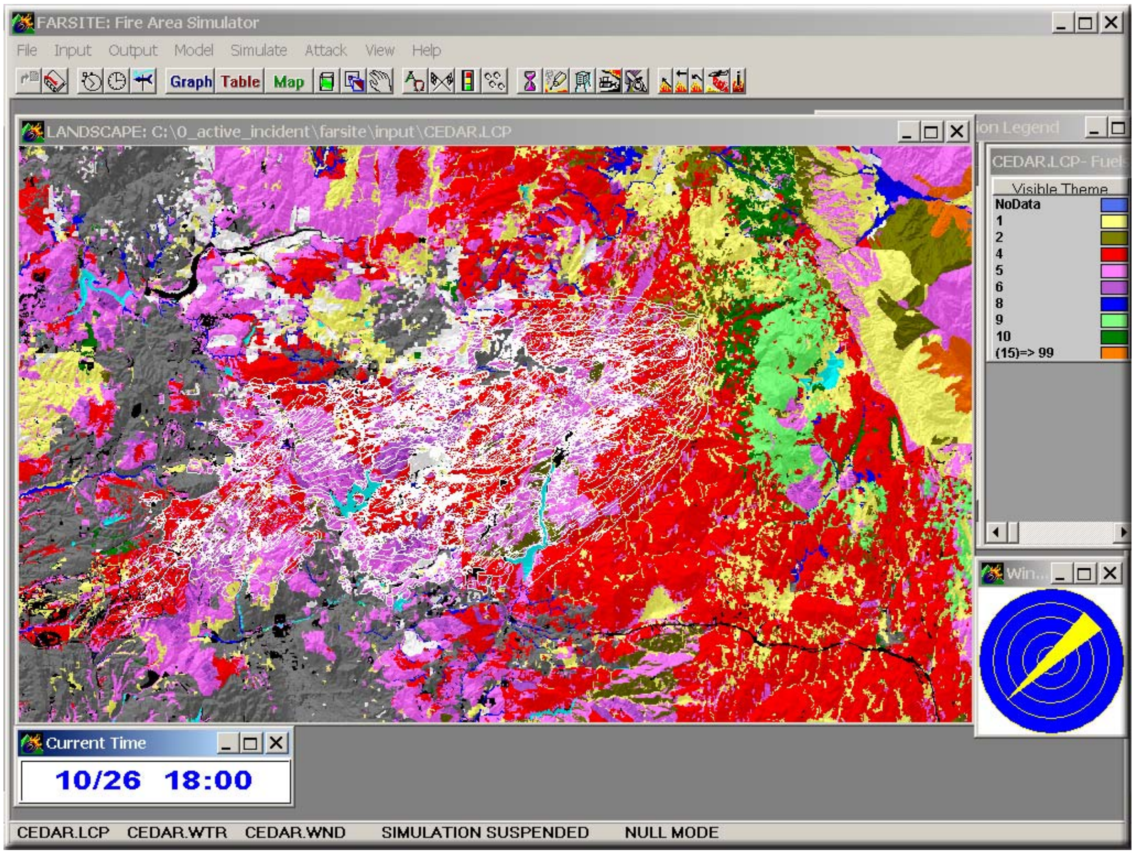


Figure 33: A screenshot of the FARSITE modeling program. The different colors represent changes in fuel models.

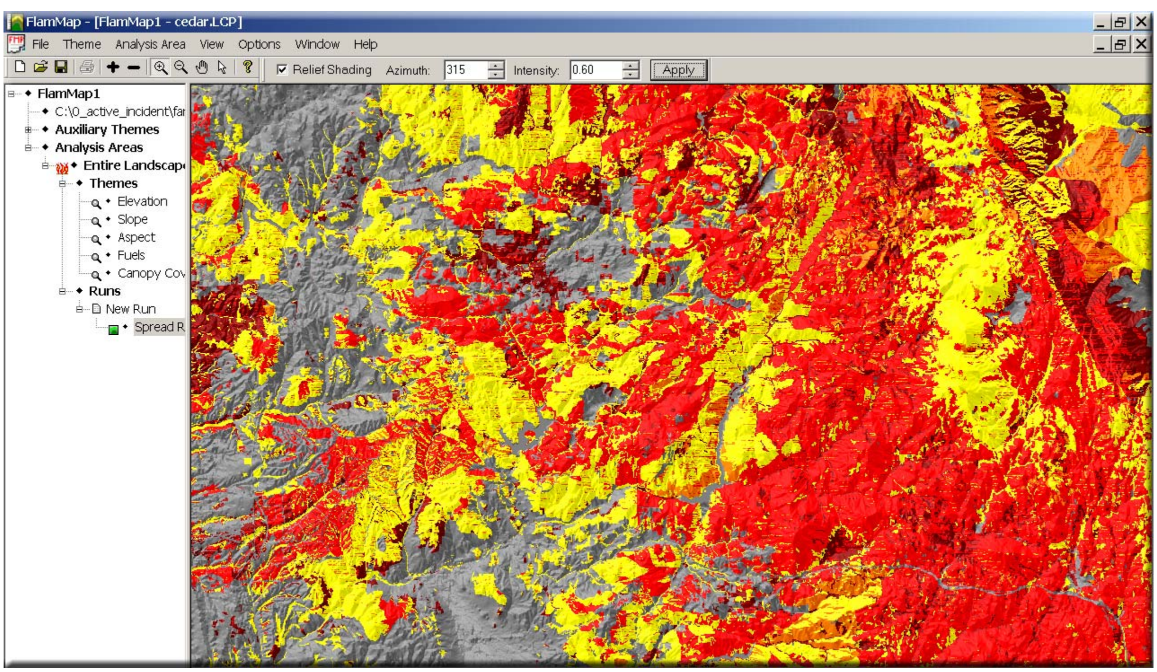
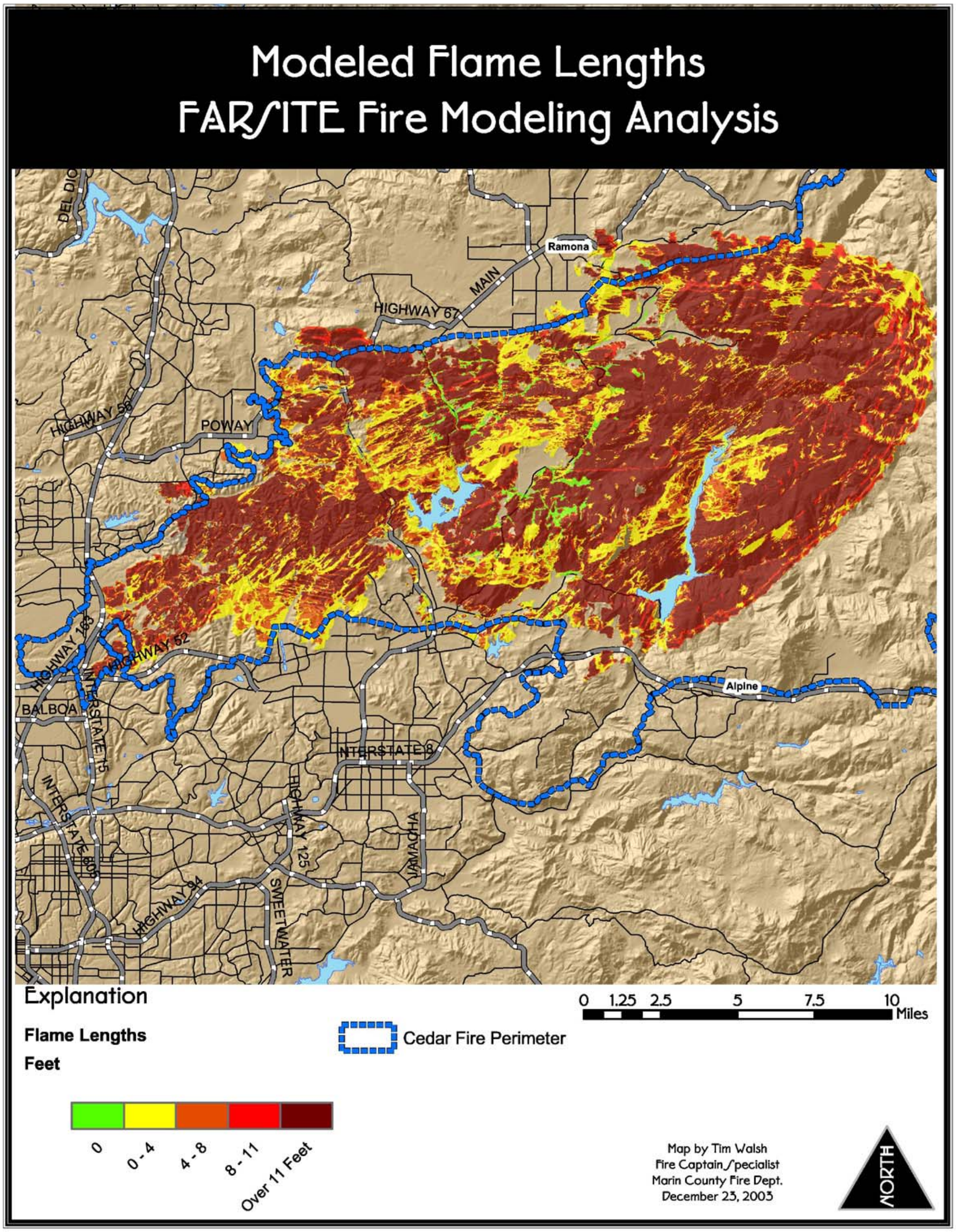
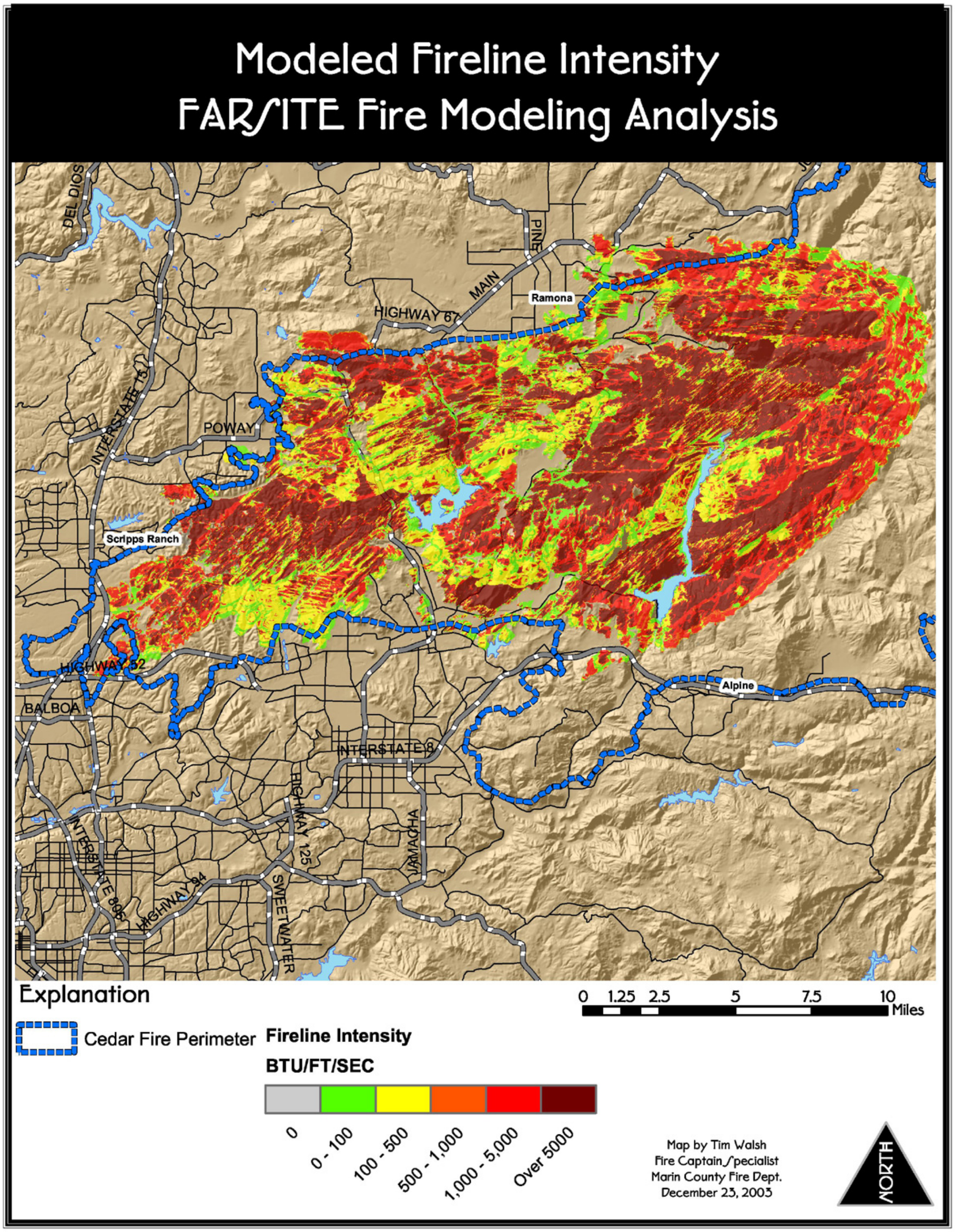


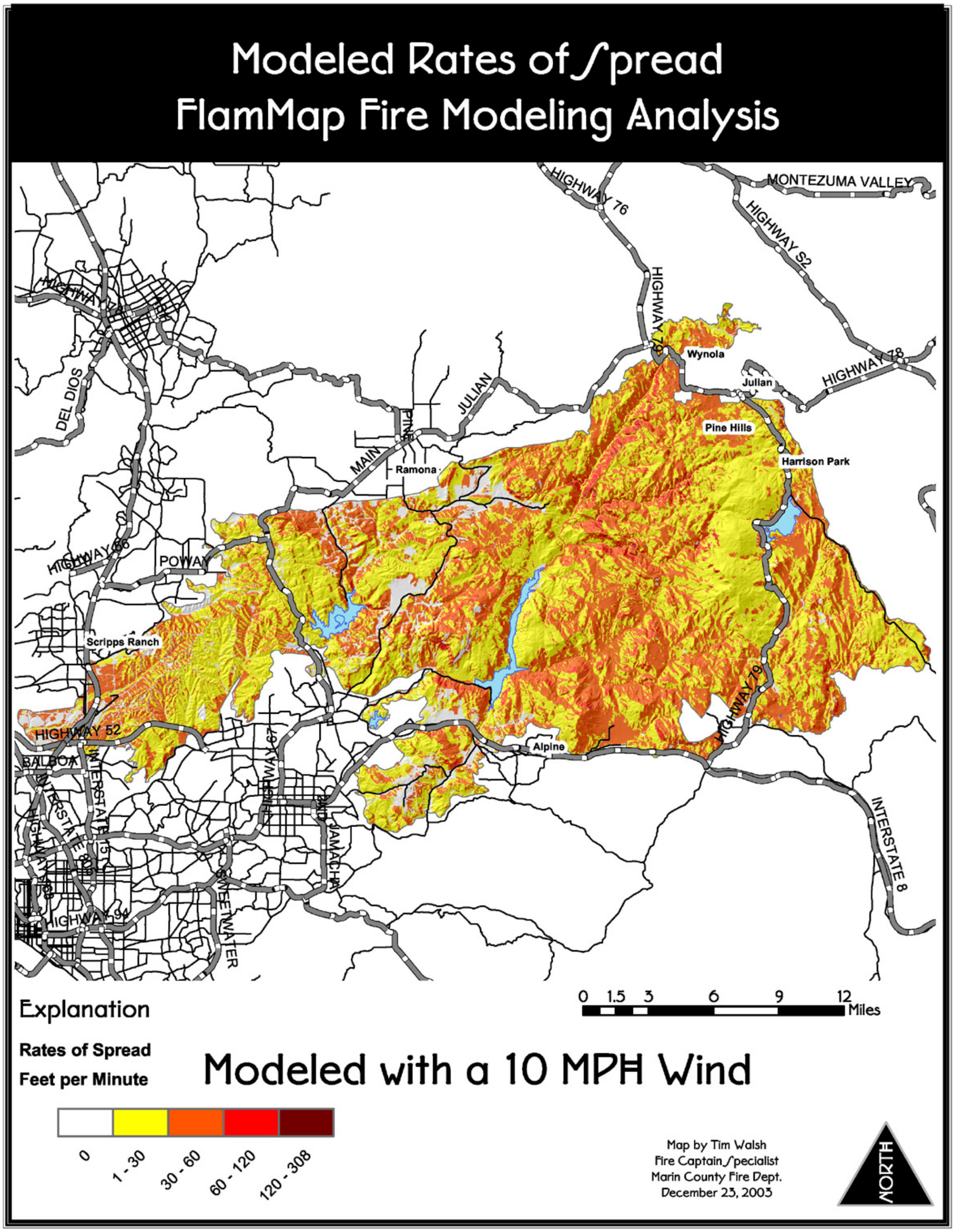
Figure 34: A screenshot of the FlamMap modeling program. The different colors represent rates of spread express in feet per minute.



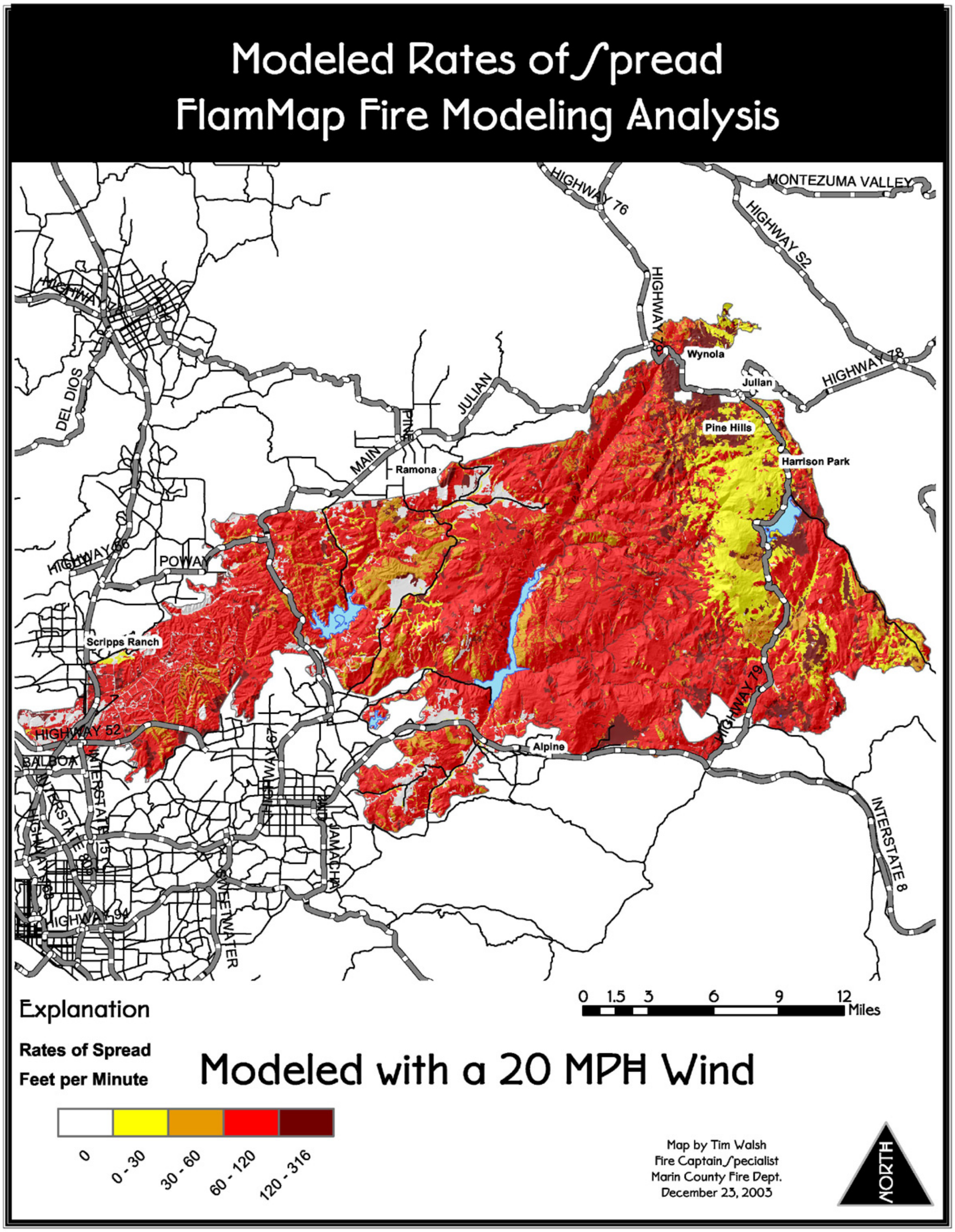
Map 12: Flame length outputs from the FARSITE fire modeling program. As documented in Table 12, flame lengths over 8 feet present serious control problem problems.



Map 13: Model Fire line Intensity using the FARSITE modeling program. Notice how much of the area is over 5000 BTU/ft/sec.



Map 14: FlamMap outputs modeling Rates of Spread with a 10 mph wind.



Map 15: FlamMap outputs modeling Rates of Spread with a 20 mph wind.

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Timothy P. Walsh
Fire Behavior Analyst
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