Reprinted from
FIRE TECHNOLOGY
4(2):126-141, illus.
May 1968

Fire Weather and Fire Behavior in the 1966 Loop Fire

C. M. COUNTRYMAN, M. A. FOSBERG, and
R. C. ROTHERMEL
Forest Service, U.S. Department of Agriculture
M. J. SCHROEDER
U.S. Weather Bureau

Southern California regularly experiences a wind condition known as the Santa Ana winds. This paper describes the phenomenon and the effects it had on fire behavior during the 1966 Loop Fire in the Angeles National Forest, which claimed the lives of 12 fire fighters.

"TEN Trapped, Killed in Fire." This headline appeared in many newspapers in southern California on November 1, 1966. In a small canyon near the boundary of the Angeles National Forest, California, a roaring forest fire overran a highly skilled U.S. Forest Service fire crew. Ten fire fighters were burned to death and 12 others injured. Two of the injured later died from their burns. The fire was called the Loop Fire.

It is Forest Service policy to assign immediately a team of men skilled in fire control to analyze such disasters. The purpose of the investigation was to determine the causes and circumstances relating to the tragedy and to recommend ways to prevent similar accidents in the future.[1]

Fire behavior usually plays a major role in wildland fire accidents. Thus fire behavior and the weather that influences it receive particular attention in fire-accident analyses. This paper summarizes the fire behavior and weather analyses made for the team that investigated the Loop Fire.

This description of fire behavior, fire weather, and conditions leading to the Loop Fire disaster may provide lessons to those responsible for the fire protection of dwellings, buildings, and other developed sites. This unfortunate accident emphasizes the need for personnel trained in evaluating probable fire behavior in critical weather, fuel, and topographic situations.

FIRE WEATHER CONDITIONS BEFORE THE LOOP FIRE

The fall fire season in southern California followed a period of subnormal precipitation. From March through September, the coastal area had only 20 per cent of normal precipitation. Precipitation at Pacoima Dam, in the vicinity of the fire, for March through October was only 1.44 in., about half falling after May 9.

During early fall, strong winds — known locally as the Santa Ana — blew quite often, particularly in the late parts of September and October. The recorded number of days with significant offshore pressure gradient was above average for both months. The average for 10 years (1957–1966) is 4.6 such days for September and 10.7 such days for October. In 1966, there were 8.3 days in September and 16.4 days in October.

The period of the Santa Ana, leading up to the time of the Loop Fire, began on October 28 when air pressure began building up in the Great Basin. The flow aloft was then predominantly east-west, with the belt of westerlies far north over northern United States and southern Canada. Pressure continued to build in the Great Basin the following day while a polar air mass drifted southward from Canada east of the Rockies.

A vigorous storm then swept eastward along the Canadian border accompanied by a strong short-wave trough aloft. By October 30 the flow aloft was changing from zonal to meridional as the trough deepened over central United States and the ridge built up along the West Coast. Following the surface low, a Pacific air mass moved into the Great Basin and another polar air mass began drifting south from Canada. The pressure remained high in the Great Basin. The air mass there was either the Pacific type or a combination of the Pacific and polar types.[2] The meridional flow pattern aloft was not conducive to eastward movement of the surface pressure systems.

After pressure built up in the Great Basin, it changed little as the offshore pressure gradient across southern California increased. The increase in low-level pressure gradient was caused by a deepening of the trough along the coast, but the reason for this deepening is not definitely known. A possible explanation is that cold air plunging southward into the Southwest Plains and New Mexico may have caused a northward movement of the thermal trough from Mexico along the California coast.

The offshore sea level pressure gradient between Tonopah, Nevada, and Los Angeles is a good indication of the strength of the general offshore wind flow. These gradients at 1:00 P.M. PST (Pacific Standard Time) for the days of this Santa Ana period are shown in Table 1. The gradient was steepest on November 1, the day of the Loop Fire. A 3-mb (millibar) gradient is the criterion for offshore flow.

EXPECTED SANTA ANA FLOW

Local scale features of the Santa Ana have been well documented.[3-5] Extremely dangerous fire weather can be produced by surfacing of the strong northeasterly flow, by terrain-produced eddies ranging from a few feet to 25 or 30 miles in diameter, and by dry — sometimes hot — air.

The generally expected flow at ground level and slightly above in, and immediately north of, the San Fernando Valley during a Santa Ana (see

Figure 1) is from the northeast. Small changes in direction in the lower levels are produced by channeling of the flow within the canyons. A uniformly northeast flow moves over the northern part of the valley, shifting to northerly or even north-northwest over the southern portion. At the extreme east end of the valley, northwest flow is common because of the low level gap to the Los Angeles area.

At the western end of the valley, the flow often shifts to east-northeast or east as the Santa Ana is channeled through a gap to the coastal lowlands to the west. Several small-scale features of the Santa Ana are often observed in this area. One feature is the flow in the region south of Van Nuys that sometimes impinges on the Santa Monica Mountains and is deflected both east and west rather than moving over the mountains. When this happens, eddies 5 to 10 miles across are established in the flow. Another feature of the Santa Ana, during the decaying stages, is the marine flow streaming around the Santa Monica Mountains. The marine flow usually brings relief in the form of high humidities, but sometimes brings the hazard of eddies and sharp wind shifts. A third feature — quite local in nature — is observed at the mouth of nearly every canyon and ravine. As the strongly channeled air flows out of the canyons, much like a jet, air is entrained and small eddies are produced. These 1-mile-or-less eddies are the rule rather than the exception, and such phenomena have long been understood.

TABLE 1. *Los Angeles, California minus Tonopah, Nevada Sea Level Pressure Differences. A 3 mb (millibar) Difference is the Criterion for an Offshore Flow*

Date	*Pressure differences (mb)*
October 28	− 3.1
29	− 7.9
30	− 8.0
31	− 8.8
November 1	− 12.5
2	− 5.8
3	− 1.2

Wind speeds generally reach their peak at the ridgetops and decrease as elevation decreases. If wave motion surfaces along the lee slopes of the ridges, then the strongest winds are observed on the lee slopes, particularly those slopes perpendicular to the general direction of the Santa Ana flow. Within the canyons, two flow patterns exist: for canyons whose long axis lies along the direction of mean flow, strong channeling produces high wind speeds; for canyons perpendicular to the mean flow, winds are light and highly variable. For other canyons features of both patterns may be experienced to a greater or lesser degree, depending on canyon orientation.

The thermal structure of the lower layers in Santa Ana is weakly stable, so that the lapse rate of temperature is only slightly less than adiabatic. Surface heating does not significantly alter the thermal structure because thermal elements are sheared off by strong winds, and the lower layers are

Figure 1. Area of southern California subject to Santa Ana winds.

well mixed. The temperature structure provides a clue as to whether or not this air is involved in Santa Ana flow.

FIRE WEATHER ON NOVEMBER 1

Structure of the Santa Ana on November 1, 1966 in the vicinity of the San Fernando Valley was determined by detailed numerical analysis of data from 29 stations in the vicinity. Data collected were wind direction, wind speed, and temperature. Humidity data were not used, first, because of the lack of sufficient reporting stations; and second, because of the rather homogeneous values observed both within the Santa Ana air and in the air outside the Santa Ana flow — particularly the pseudo sea breeze, which is returning Santa Ana air. The data collected were by no means complete because all stations did not report all items, nor were all stations able to provide observations at all analysis times.

Sources of the data were: U.S. Weather Bureau, U.S. Federal Aviation Agency aviation weather network, fire danger rating stations of both the U.S. Forest Service and Los Angeles County Fire Department, Rocketdyne Corporation, Los Angeles County Air Pollution Control District wind network, and *Los Angeles Times* weather page reports of maximum and minimum temperatures.

Temperature data were analyzed by first reducing them adiabatically to sea level, as follows:

$$\theta = T + Z\Gamma$$

in which θ = sea level potential temperature, T = observed temperatures, Z = elevation of station, and Γ = dry adiabatic lapse rate. This equation allows a delineation to be made between air masses without resorting to an analysis of the three-dimensional structure (because sufficient upper-air observations for such an analysis do not exist).

Wind data were analyzed by determining the east-west component (u) and the north-south component (v) and interpolating these wind components to a series of grid points. From these the wind speed was computed at each grid point as follows:

$$V = (u^2 + v^2)^{1/2}$$

The grid system (Figure 1) set up for this analysis consisted of 35 points (five north-south and seven east-west) spaced 5 miles apart. The wind data were then analyzed to obtain certain hydrodynamical properties of the flow. The magnitude of the wind along with unit vectors completely describes the velocity field. This method of describing the velocity field was chosen over a stream function method because of the difficulty of formulating boundary conditions for the stream function computation.

Next, the vertical component of the vorticity of the flow was computed from wind data:

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

The vorticity (ζ) suggests two important features of the flow: (a) the rotation of the flow; and (b) the relationship between the vorticity advection and vertical motion. Admittedly the relationship is a gross simplification. We are concerned, however, only with the sign of the vertical motion. Upward motion can be expected downstream from a negative vorticity maximum and downward motion can be expected downstream from a positive vorticity maximum.

The kinetic energy was evaluated by computing the area integral of the kinetic energy as follows:

$$\{E_k\} = \frac{1}{2} \int_0^{25} \int_0^{35} (u^2 + v^2)\, dx\, dy$$

The kinetic energy may be interpreted as applying to the surface boundary layer — a depth of about 50 ft. In general, the integral indicates the strength of the Santa Ana.

Analyses of this case were done at 3-hour intervals from 7:00 A.M. to 7:00 P.M., November 1, 1966.

The Santa Ana flow at 4:00 A.M. was primarily aloft, with only the higher elevations affected. Between 4:00 A.M. and 7:00 A.M., it surfaced in the San Fernando Valley and in the fire area itself and persisted throughout the day. The vertical motion in the Santa Ana flow, as indicated by the vorticity advection, confirmed the presence of waves in the area. The fire area was in a region of downward motion early in the forenoon when the wind surfaced on the lee slope.

During the late afternoon on November 1 the thermal structure (Figure 2) showed continued Santa Ana surfacing (although the lee slope was in a wind shadow). By 1:00 P.M. (PST), the sea breeze had begun to penetrate weakly into the wind shadow of the Santa Monica Mountains, but had no influence on the weather at the fire area. The wind field at 4:00 P.M. (Figure 3) was typical of a slackening Santa Ana — typical speed in the vicinity of the fire was only about 15 mph. The vorticity field at 4:00 P.M. (Figure 4) still indicated a wave pattern, with the crest of the wave just upstream from the fire area.

The kinetic energy integral (Figure 5) showed a gradual weakening of the intensity of the Santa Ana throughout the day until 4:00 P.M., when it began to drop abruptly. Two interpretations of this drop may be made — one is that the Santa Ana stopped blowing, and the other is that the waves were no longer surfacing. The vorticity advection continued to show a wave flow. Therefore, presumably the Santa Ana was no longer surfacing. The velocity field became less organized and weaker, but the fire area still was experiencing a northeasterly flow.

A study of winds from San Nicholas Island, Rocketdyne, Sandberg, and Edwards Air Force Base on the Mojave Desert (Figure 6) showed generally northeast winds in the lower levels, with some horizontal waves aloft. Always observed in Santa Ana winds, these horizontal waves more or less define the general features of the surface flow. The wind cross section on November 1 was consistent with the northeasterly flow above the fire area and showed no processes that would produce wind shifts, abrupt changes in speed, or large eddies.

One other process was examined. In gravity waves, momentum is transferred downward and energy upward. If momentum is transferred downward, the wind speed must increase as elevation increases, such as the

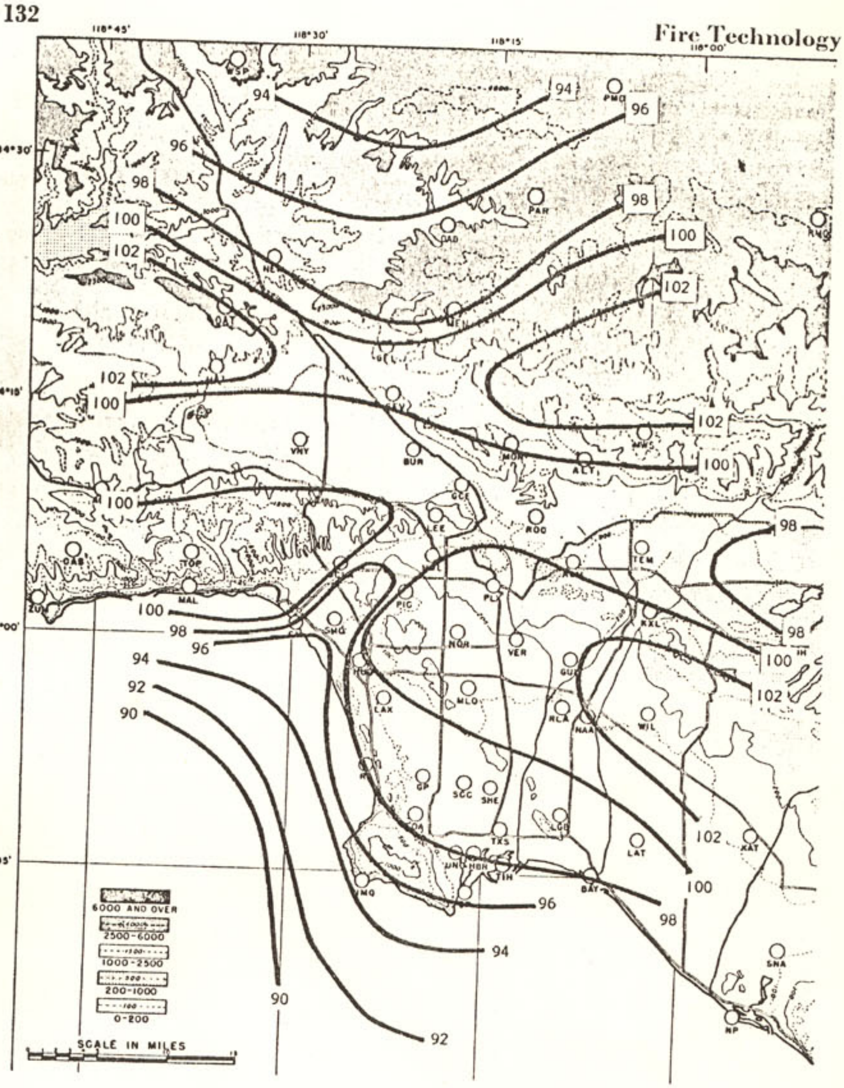

Figure 2. Thermal structure during late afternoon on November 1.

case of the Rocketdyne wind profile on October 31 (Figure 7). However, on November 1, the Rocketdyne wind profile showed no such increase in speed with elevation. Thus, in the afternoon of November 1, there was probably no descent of stronger winds from aloft.

On the basis of reports of personnel at the fire and of weather observations in the surrounding area, the weather in the fire area may be described as follows:

Throughout the day air flowed generally from the northeast quadrant. Wind speeds remained quite high until about noon. Rocketdyne, for ex-

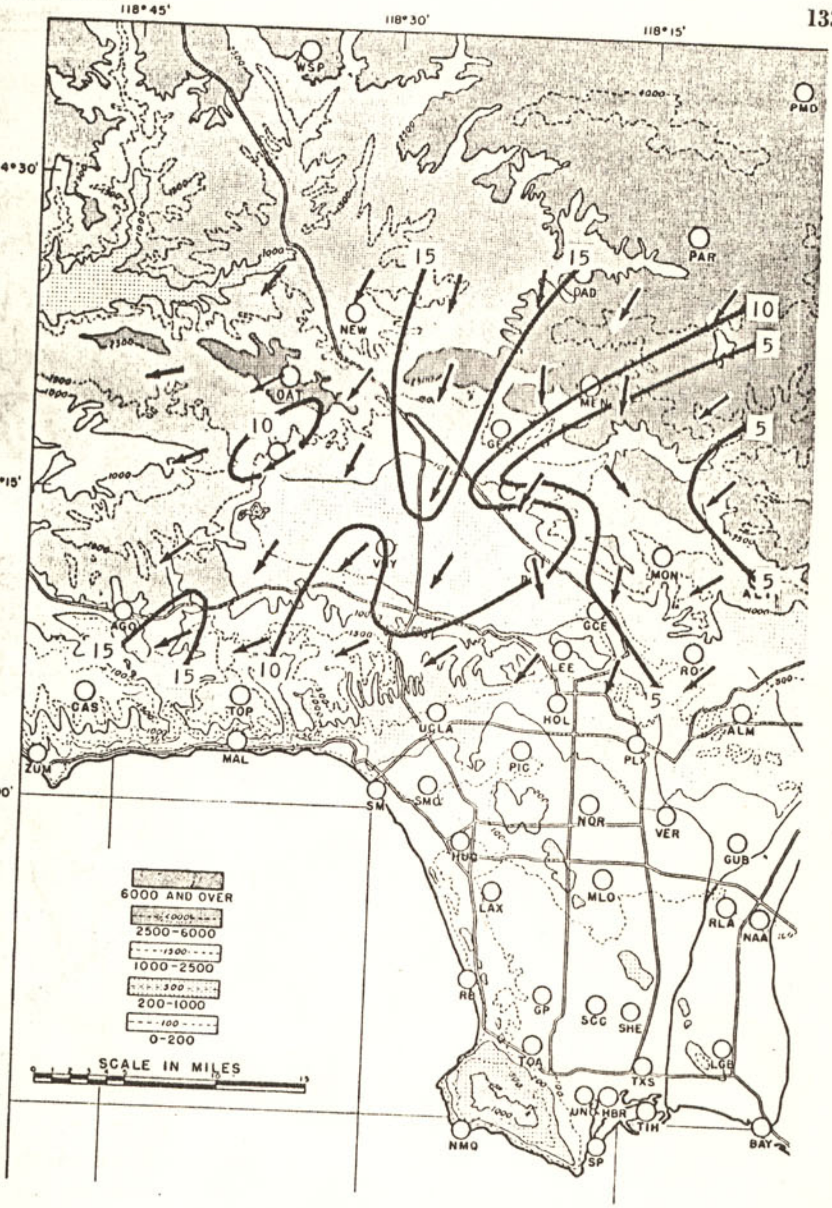

Figure 3. Wind field during late afternoon on November 1.

ample, had winds of 24 to 28 mph at 4:00 A.M., and anywhere from 13 to 36 mph at least until 1:00 P.M. At Van Norman Reservoir, wind speed was 24 knots (27.6 mph) with gusts to 30 knots (34.5 mph) at 7:00 A.M., and 15 knots (17.3 mph) with gusts to 20 knots (23 mph) at 10:00 A.M.

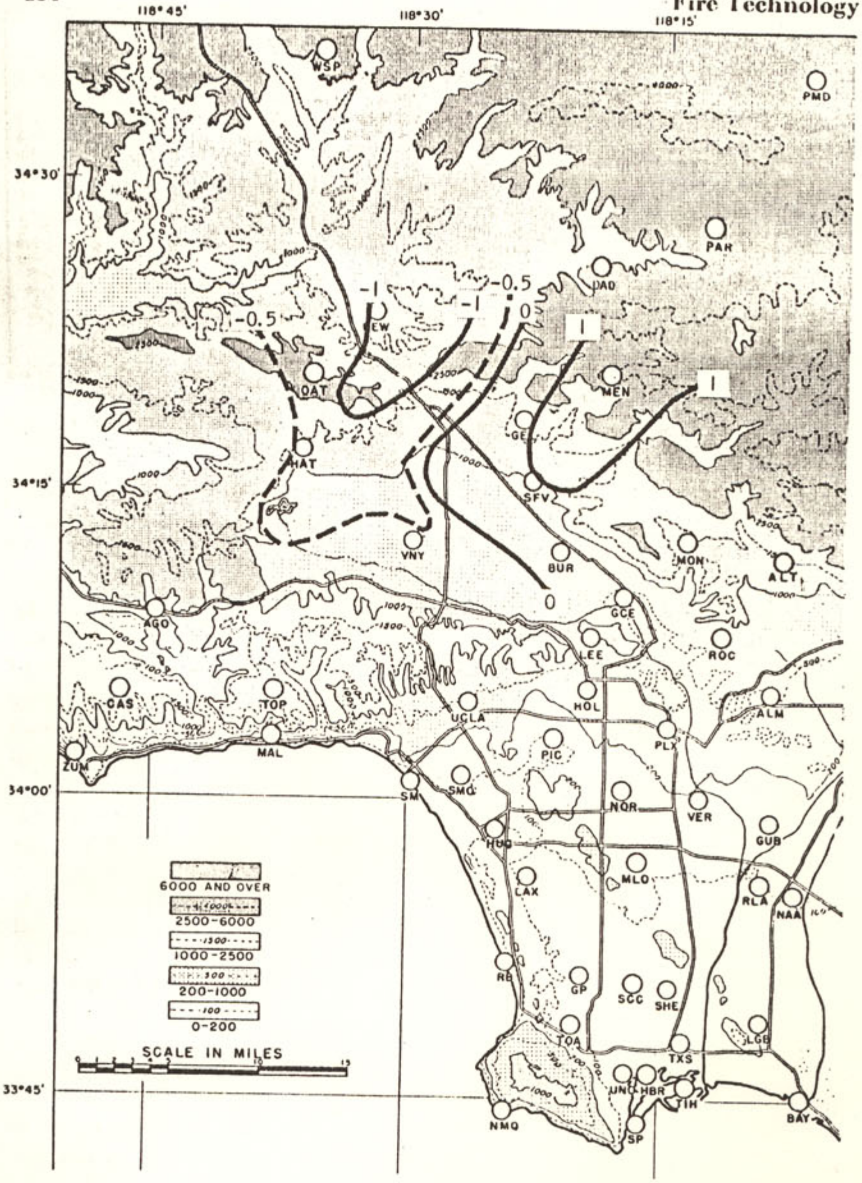

Figure 4. Vorticity field during late afternoon on November 1.

Lookouts in the area reported gusts to 50 mph, and it is not unlikely that gusts of that magnitude or even greater were experienced at higher elevations in the fire area. One observer reported gusts "strong enough to blow a man down if he did not brace himself." The direction of the fire spread,

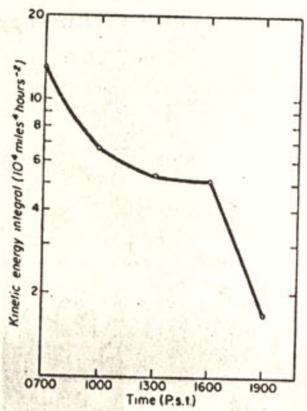

Figure 5. Kinetic energy integral for a 12-hour period on November 1.

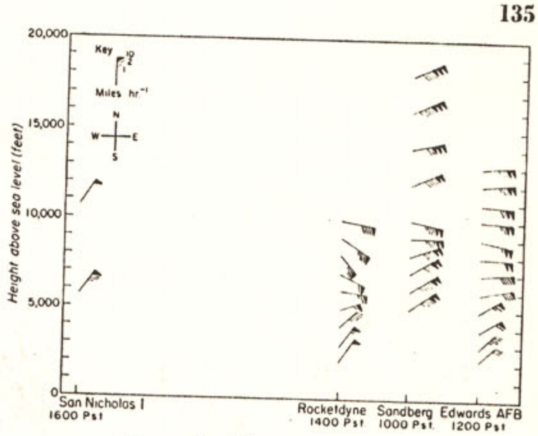

Figure 6. Wind velocity data.

from the point of origin until it ran into an old burned-over area, confirms the northeasterly direction of the wind and also indicates that the Santa Ana wind was surfacing on the south-facing slope.

Temperatures at lower elevations rose from the 70's in the early morning hours to the middle 80's by mid-forenoon and to the low 90's by midday. At higher elevations, temperatures were in the 60's in the early morning and in the low 70's by mid-day. Relative humidities were low, as would be expected in a Santa Ana situation. Rocketdyne reported humidities ranging from 9 to 12 per cent from 1:00 A.M. to 1:00 P.M. At Van Norman Reservoir humidities ranged from 14 to 18 per cent during the period from 7:00 A.M. to 1:00 P.M. At Pacoima Dam the readings ranged from 18 to 22 per cent for the same period. However, since the Pacoima Dam readings were recorded on a hygrothermograph, there is a possibility of calibration error.

During the afternoon the wind speeds generally decreased. Aircraft and helicopters were then able to fly. Subjective estimates indicated speeds near the surface of 15 to 20 mph by noon and 10 to 15 mph, sometimes less, during the afternoon. One measurement on the ridge at the east side of the fire showed a northeast wind of 8 mph with gusts to 12 at 2:30 P.M.

There was considerable channeling of the wind by the topography. North and northwest winds were reported in saddles on the north and northwest sides of the fire, respectively. There was also considerable wind turbulence and eddying, particularly when wind speeds picked up temporarily, and particularly on the lower side of the fire. Winds above the terrain varied in speed — a helicopter pilot estimated 10 to 30 mph.

Temperatures at lower elevations were in the 90's and in the 70's or perhaps low 80's at higher elevations during the afternoon. Relative humidities appeared to change only a few per cent from forenoon to afternoon. Fuel stick moisture readings were in the range of 3 to 4 per cent.

Fire load indexes* at 1:00 P.M. on November 1 were quite variable, mostly because wind speed varied. The indexes ran from 26 at Little Tujunga and Eaton Canyons, 35 at Mendenhall, to 93 at Vincent and 100 at Sierra Pelona. Values above 12 are considered "high", above 27, "very high", and above 40 "extreme". Ignition indexes ranged from 71 to 95. Values above 75 are considered as indicating fuel conditions susceptible to spotting.

EVALUATION OF FIRE WEATHER

Meso-scale analyses indicated that the behavior of the atmosphere was typical of that under Santa Ana conditions until 4:00 P.M. The fire area was under the influence of a Santa Ana in its weakening stages. The vertical motion was slightly downward over the fire, but not significantly so. Wind profiles and vertical cross sections of the wind indicate no meso-scale or larger changes in the flow pattern. Wind shifts in the fire area were probably caused by small eddies a few hundreds of feet in diameter from the jet-like flow emerging from canyons, particularly those canyons with a southwest-northeast orientation. Pacoima Canyon has this orientation, and eddies can be anticipated at its mouth during a surfaced Santa Ana. Sometime between 4:00 P.M. and 7:00 P.M., the Santa Ana flow rose from the surface.

A northeasterly wind would tend to be funneled down Pacoima Canyon because of its orientation. In the region of the Dam keeper's residence, the canyon turns clockwise. Witnesses in the area reported that winds were occasionally turbulent and changeable in direction. One witness estimated winds there of 20 to 25 mph. A helicopter pilot stated that as the wind flow increased, he noticed eddies and turbulence. Then as the winds diminished, the flow evened out and the winds appeared to be upslope on the south-facing side of the canyon in this area.

In a reconstruction of the air flow in this area during the afternoon of November 1, the flow is depicted for a peak, rather than a lull, in the variable wind flow (Figure 8). Eddies produced in the mouth of the canyon could have resulted in upslope air movement in the area of the tragedy. And turbulence over the spur ridge, which formed the final fire line in this area, could have further complicated the air flow.

We found no evidence that the general wind flow shifted. The sea breeze penetrated only portions of the immediate coast by late afternoon. After the tragedy, during the time the area to the east burned out, the general wind flow remained northeasterly, according to helicopter personnel making drops on the fire.

In the chute in which the men were burned, and in other similar chutes to the east which burned later, convection alone could have accounted for rapid movement of the fire up the slope. However, the eddy motion en-

*** The fire load index in the Wildland Fire Danger Rating System used in California is a relative measure of the potential fire control job. The index can range from 0 to 100.**

visioned here, resulting in a flow against the south-facing slope, could well have helped the fire climb quickly up the chutes.

FIRE BEHAVIOR IN SANTA ANA CONDITIONS

Santa Ana winds in southern California create one of the most hazardous, difficult wildland fire control problems in the world. Strong air flow with very low humidities quickly desiccates both living and dead fuels. The steep, rough, broken topography combined with high-speed winds creates highly turbulent air flow in the numerous canyons. Wind direction may switch 180 degrees and back again in only a few seconds. Dense smoke clings to the ground and the winds drive a hail of burning embers into the unburned fuel ahead of the fire. The fuel itself also contributes to the problem. Most chaparral fuels are finely divided and have a high oil content. The large surface-to-volume ratio of these fuels makes for easy ignition and rapid energy release.

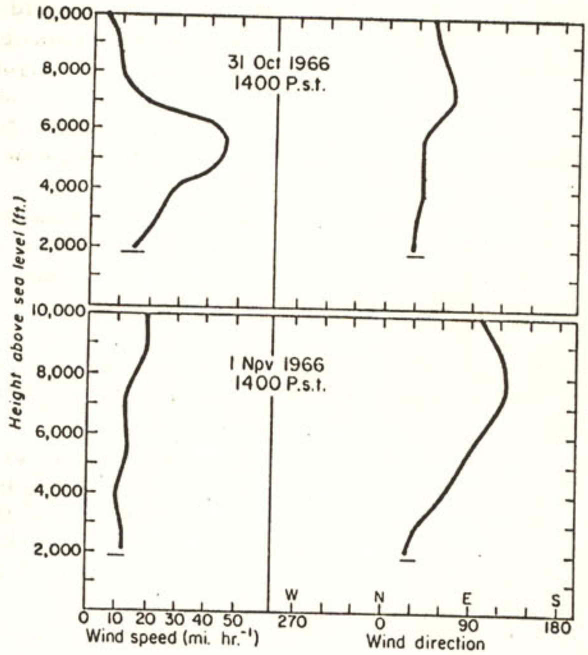

Figure 7. Rocketdyne wind profiles for October 31 and November 1.

Under these conditions, fire spreads rapidly in the direction of the wind. Spot fires start well ahead of the main fire and enlarge rapidly. The fire front is ragged and may be made up of numerous smaller fires spreading in all directions.

In the larger canyons and ravines, it is not unusual for the fire to move slowly up the canyon against the wind. In such case, a characteristic spread pattern frequently develops. Local up-canyon winds, created by the heat from the fire, develop in the canyon bottom where the Santa Ana flow is at a minimum. This up-canyon flow carries the fire along the bottom portion of the canyon, creating a fire front along the toe of the canyon wall. As this fire front becomes larger, enough heat is developed to start an upslope convective flow. The fire then will sweep quickly to the top of the canyon wall.

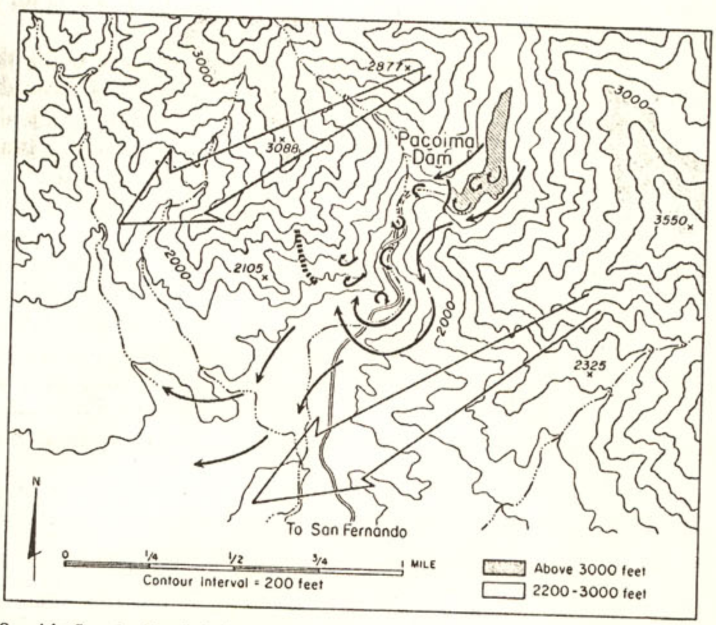

Figure 8. Air flow in the vicinity of Pacoima Canyon during the afternoon of November 1.

Steep-side draws and ravines that can act as natural chimneys to concentrate the convective flow increase the number of, and intensify, upslope runs. Patches of heavier fuel in or near the canyon bottom often provide sufficient added heat to trigger a fire run. Even a small amount of fire at the canyon rim or at the head of a side ravine can trigger and intensify a fire run on the slope.

FUELS

Fuels in the Pacoima Canyon area were rather sparse and consisted chiefly of chamise, sage, and sumac, with an understory of grass and other low-growing plants. Most of the sumac grew in the lower portions of the numerous steep draws and ravines. From information gathered in the unburned areas, we estimated that the fuel loading in areas *A* and *B* (Figure 9) was about 0.45 psf (pounds per square foot) of chamise and 0.04 psf for grass and other plants. This amount gives a total fuel of about 0.49 psf for these areas. Potential energy release for this fuel was about 4,000

Btu/sq ft. However, since the fuel was only partially burned it is estimated that about 2,500 Btu/sq ft were released in area *A*, and 1,100 Btu/sq ft in area *B*.

The below normal precipitation and the desiccating effects of the Santa Ana winds resulted in very low fuel moisture by the end of October. These effects were apparent on the living as well as the dead fuels. Samples of chamise foliage taken in the fire area on November 1 were found to have a moisture content of 59.9 per cent — nearly the minimum possible for living fuels of this species.

Probably the most critical fuel was the sumac in area *C*. This fuel gave by far the heaviest fuel loading. Inspection of unburned areas showed a heavy accumulation of litter in sumac areas and a large amount of dead and very dry material. Little is known about the fuel loading potential of sumac. But from data on fuels of similar size, we estimated that a characteristic fuel loading would be in the order of 1.60 psf. This loading would give a potential energy release of about 12,800 Btu/sq ft. In the immediate area of the accident, practically all sumac was consumed, hence near maximum energy was released.

An estimate of the fuel that figured directly in the accident was obtained by dividing the ravine or "chute" in which the men were trapped into 25-ft strips across the chute. Stubs of burned plants were then located and mapped along with unburned and scorched plants. The amount of fuel present and the amount burned were then estimated from this map (Table 2).

TABLE 2. *Estimates of the Amount of Fuel Present and the Amount of Fuel Burned in the Loop Fire in 1966*

Area (strip line Nos.)	*Fuel weight (lbs/sq ft)*	*Total weight (lbs)*	*Heat output (Btu's)*
3–5	0.50	1,961	15,688,000
6–8	0.54	2,206	17,648,000
9–12	0.46	2,714	21,712,000
13–16	0.39	3,427	27,416,000
17–20.5	0.42	3,924	31,392,000
		Totals 14,232	113,856,000

The total amount of fuel burned between lines 3 and 8 was calculated to be 4,167 lbs. On the basis of information from eyewitnesses, the burning time for this fuel was above 4 min. This rate would give a total energy output rate of 1,104 Btu/sq ft/min. However, since about 40 per cent of the fuel could be expected to burn in the first 30 sec, the peak energy output rate would be about 3,332 Btu/sq ft/min for this area. With such rapid burning rates, flame temperatures probably were 2,500° F or higher.

FIRE BEHAVIOR IN THE LOOP FIRE

Fire behavior in the Loop Fire was typical of fires starting under Santa Ana conditions. From its origin near the ridge line dividing Loop and

Coyote Canyons, the fire was driven by strong northeast winds downslope toward the more gentle topography and lighter fuels of the developed areas in the lower front country. Its progress toward the southwest was halted in this area. In this initial phase, fire spread by direct flame contact with unburned fuel, from spotting, and from burning material rolling down the steep slopes.

By early afternoon on November 1 the fire had become established well down on the west slope of Pacoima Canyon near its mouth. Under the slackening Santa Ana wind the fire began the typical up-canyon spread against the wind. By mid-afternoon most of the active fire here was in area *A* (Figure 9), where it was moving slowly downslope against the wind and was being held with little difficulty along a bulldozed line.

When the fire reached the end of the bulldozed line in the steep draw adjacent to the accident site, a combination of heavier fuels, eddy currents, and thermal effects triggered a small fire run up the side of the draw and into the base of the steep and narrow chute in which the crew was working. This run appeared to have occurred at about point *D* (Figure 9). Relatively heavy fuels in this area provided additional heat which was all directed up the natural chimney formed by the chute. Although the fuel in the middle and upper reaches of the chute was probably too sparse to carry fire under normal conditions, the heat and hot combustion products from the fire in the lower part were sufficient to ignite the fuel patches. This fuel then provided a continuous source of energy and maintained the rapid fire spread.

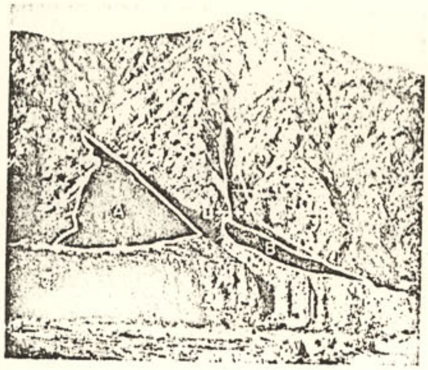

Figure 9. Pacoima Canyon area showing sections involved in fire (A, B, and C) and the site of the tragedy (D).

Probably not more than 5 min elapsed from the time the fire flared up at the end of the tractor line until it was well established in the base of the chute. And the fire probably spread to the top of the chute in less than 1 min.

After the rapid fire run had trapped and burned the men, the fire continued a typical up-canyon movement against the wind. It progressed slowly along the base of the canyon slope with occasional rapid and hot runs up the narrow and steep draws to the top of the ridge.

EVALUATION OF FIRE BEHAVIOR

We found no indication that the behavior of the Loop Fire was anything but typical of fire burning under Santa Ana conditions. Fire behavior similar to that in Pacoima Canyon very likely occurred in other parts of the fire as well.

The topographic configuration of the chute in which the men were trapped played an important role in severity of the heat conditions in the accident area. A short distance above the base, the chute was constricted into a narrow throat. This constriction would tend to increase the flow rate of the air and combustion products and hence to increase burning rates. The steep slope on the east side of the chute could also act as a reflector to concentrate the heat within the chute area.

The topographic configuration made the situation somewhat analogous to a fireplace. The men in the lower part of the chute were at a point where the damper is found in the fireplace and subject to near maximum temperature. And those near the top of the chute were at a point similar to the top of the fireplace chimney where heat conditions would be less severe.

Under Santa Ana conditions, fuels — both living and dead — become extremely dry. This is particularly true when the fuels have been exposed to dry winds and high temperatures for extended periods such as those that preceded the Loop Fire. Under such conditions the potential energy of the fuels can be released very quickly and violent fire activity results.

The spread of fire against the wind can be slow — even in dry fuels, but the situation can often be one of delicate balance. A quick and violent change in the fire behavior can be triggered by any slackening of air flow, a surge of heat from heavier fuels, an eddy current, the fire reaching different topography, or a combination of two or more of these factors. Such an event appears to have occurred in the Loop Fire.

ACKNOWLEDGMENTS: We thank Mr. R. S. Helfman for his assistance in analyzing the data — particularly for programming the numerical computations for computer analysis — and the University of California Computing Center for giving this work priority to meet the deadlines of the Fire Review Board. Special thanks go to the Los Angeles Air Pollution District for its cooperation and to the Rocketdyne Corporation for providing data on such short notice.

REFERENCES

[1] "The Loop Fire Disaster, Angeles National Forest, California Region, November 1, 1966," U.S. Department of Agriculture, Forest Service, Washington, D. C.

[2] Schroeder, Mark J., *et al.*, "Synoptic Weather Patterns Associated with Critical Fire Weather," 1964, U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California, 492 pp.

[3] Edinger, J. G., Helvey, Roger A., and Baumhefner, David, "Surface Wind Patterns in the Los Angeles Basin during 'Santa Ana' Conditions," 1964, Department of Meteorology, University of California at Los Angeles, 70 pp.

[4] Fosberg, M. A., "A Case Study of the Santa Ana Winds in the San Gabriel Mountains," Research Note PSW-78, 1965, U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California, 8 pp.

[5] Fosberg, M. A., O'Dell, Clyde A., and Schroeder, Mark J., "Some Characteristics of the Three-Dimensional Structure of Santa Ana Winds," Research Paper PSW-30, 1965, U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California, 35 pp.