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Wildland Fire Behavior Case Studies and Analyses: Part 2

United States Department of Agriculture
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Editor's note: This issue of *Fire Management Today* continues a series of reprinted articles, some of them decades old. Although the articles appear in today's format, the text is reprinted largely verbatim and therefore reflects the style and usage of the time. We made minor wording changes for clarity, added intertitles and metric conversions where needed, and occasionally broke up paragraphs to improve readability. All illustrations are taken from the original articles.

Erratum

In *Fire Management Today* 63(3) [Summer 2003], the article by Banks and Little contains an error noted in *Fire Control Notes* 26(1) [Winter 1965], page 15. The third sentence in column 3 on page 76 should read: "More recent burns that left some surface fuel remaining only reduced the damage, but others that removed nearly all the fuels *did* stop the fire."

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On the Cover:

Smoke is drawn into the center of a 3,200-acre (1,300-ha) prescribed burn unit on the Lower Klamath National Wildlife Refuge in California. The growing need for fire use nationwide makes it more important than ever for land managers to fully understand fire behavior. The photo was a winner in Fire Management Today's photo contest for 2003 (see page 85 for more on the contest). Photo: Troy Portnoff, U.S. Fish and Wildlife Service, Tulelake, CA, 2002.

The FIRE 21 symbol (shown below and on the cover) stands for the safe and effective use of wildland fire, now and throughout the 21st century. Its shape represents the fire triangle (oxygen, heat, and fuel). The three outer red triangles represent the basic functions of wildland fire organizations (planning, operations, and aviation management), and the three critical aspects of wildland fire management (prevention, suppression, and prescription). The black interior represents land affected by fire; the emerging green points symbolize the growth, restoration, and sustainability associated with fire-adapted ecosystems. The flame represents fire itself as an ever-present force in nature. For more information on FIRE 21 and the science, research, and innovative thinking behind it, contact Mike Apicello, National Interagency Fire Center, 208-387-5460.

Firefighter and public safety is our first priority.

Contents

Short Features

Wildland Fire Behavior Case Studies and Analyses: Other Examples, Methods, Reporting Standards, and Some Practical Advice

M.E. Alexander and D.A. Thomas

Case studies done in one country can be applied to another, if fuel type characteristics are relevant, by interpreting burning conditions through the other country's fire danger rating system.

This special issue of *Fire Management Today* constitutes the second installment of articles involving fire behavior case studies and analyses of wildland fires. All articles in this series appeared in past issues of *Fire Management Today* or its predecessors. The 18 articles in this issue are in chronological order, from 1967 to 2001.

In the lead article to the first installment (*Fire Management Today*, volume 63(3) [Summer 2003]), we overviewed the value, approaches, and practical uses of fire behavior case studies and analyses (Alexander and Thomas 2003). Here we point out examples of case studies published elsewhere (both nationally and internationally) and offer some general thoughts on wildland fire behavior observation and documentation.

Other Examples of Case Studies

Fire Management Today and its predecessors have certainly not been the only source or outlet for case studies. In the last issue of the journal, we cited some examples of other sources (Alexander and Thomas 2003). Others are cited below.

> The most important thing to record is the position of the head fire at various times—the more observations, the better.

USDA Forest Service fire researchers, in collaboration with other investigators, have published a number of case studies in the form of journal articles, conference papers, and in-house station publications. Notable examples include studies on the:

- 1965 Hellgate Fire, western Virginia (Taylor and Williams 1968);
- 1966 Gaston Fire, central South Carolina (DeCoste and others 1968);
- 1966 Loop Fire, southern California (Countryman and others 1968);
- 1967 Sundance Fire, northern Idaho (Anderson 1968);
- 1968 Canyon Fire, southern California (Countryman and others 1969);
- 1971 Little Sioux Fire, northeastern Minnesota (Sando and Haines 1972);
- 1971 Air Force Bomb Range Fire, eastern North Carolina (Wade and Ward 1973);
- 1980 Mack Lake Fire, northern Lower Michigan (Simard and others 1983);
- 1990 Dude Fire, northern Arizona (Goens and Andrews 1998); and the
- 1994 South Canyon Fire, west-central Colorado (Butler and others 1998).*

In the 1990s, the National Fire Protection Association (NFPA) produced several case studies, in very glossy formats, on the following wildfires:

- 1989 Black Tiger Fire, central Colorado (NFPA 1990);
- 1990 Stephan Bridge Road Fire, northern Lower Michigan (NFPA 1991);
- 1991 Spokane area fires, northeastern Washington (NFPA 1992a); and
- 1991 Oakland–Berkeley Hills Fire, west-central California (NFPA 1992b).

A few of these U.S. case studies are available on the World Wide Web or in hard copy for a nominal fee through the National Fire Equipment System (NFES 2003).

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* For an overview of this excellent publication, see the very fine summary prepared by Butler and others (2001) on page 77 in this issue of *Fire Management Today.*

The challenge of writing a case study report is to distill the mass of information into a coherent summary.

Canadian Forest Service fire researchers have also formally prepared several case studies over the years on the following wildfires:

- 1964 Gwatkin Lake Fire, eastern Ontario (Van Wagner 1965);
- 1968 Lesser Slave Fire, central Alberta (Kiil and Grigel 1969);
- 1971 Thackeray and Whistle Lake Fires, northeastern Ontario (Walker and Stocks 1972);
- 1980 DND-4-80 Fire, east-central Alberta (Alexander and others 1983);
- 1986 Terrace Bay 7/86 Fire, north-central Ontario (Stocks 1988); and
- 2001 Duffield Fire, central Alberta (Mottus 2002).

Australasian fire researchers have also made numerous contributions, including studies on the following wildfires:

- 1955 Balmoral Fire, South Island of New Zealand (Prior 1958);
- 1958 Wandilo Fire, South Australia (McArthur and others 1966);
- 1977 Western District fires, Victoria (McArthur and others 1982);
- 1979 Caroline Fire, South Australia (Geddes and Pfeiffer 1981);
- 1983 Ash Wednesday fires, South Australia (Keeves and Douglas 1983);
- 1991 Tikokino Fire, North Island of New Zealand (Rassmusen and Fogarty 1997);
- 1994 Karori fires, North Island of New Zealand (Fogarty 1996);
- 1995 Berringa Fire, west-central Victoria (Tolhurst and Chatto 1998);
- 2002 Atawhai Fire, South Island of New Zealand (Peace and Anderson 2002); and
- 2003 Miners Road Fire, South Island of New Zealand (Anderson 2003).

The Australians have also published several case studies analyzing the effectiveness of fuel reduction burning on subsequent fire behavior and on fire suppression of high-intensity wildfires (e.g., Buckley 1992; Underwood and others 1985).

Case studies have been undertaken by fire researchers in other countries as well (Cruz and Viegas 1997; Dentoni and others 2001). It is worth noting that one can extend the usefulness of wildland fire case studies done in one country to another, provided that the fuel type characteristics are relevant, simply by interpreting the burning conditions through the use of the other country's fire danger rating system (e.g., Alexander 1991, 1992, 2000; Alexander and Pearce 1992a, 1993).

Field Observations and Records

Whereas no recipe or step-by-step procedural manual on wildland fire observations presently exists, a good number of general references are available (Alexander and Pearce 1992b; Burrows 1984; Cheney and Sullivan 1997; Chester and Adams 1963; Rothermel and Rinehart 1983; Turner and others 1961). Moreover, the various case studies already published offer guidance themselves.

Wildland fire observation and documentation can be broken into four distinct stages or phases:

1. Detection,
2. Initial attack,
3. Later stages of suppression, and
4. After containment.

Some of the information on the early phases of a wildland fire is normally recorded as part of the operational procedures related to completing the individual fire report, although additional data might be requested (e.g., Haines and others 1985). However, if we are to acquire high-quality data (Donoghue 1982), then we need to emphasize the importance of fire behavior observation/documentation for our initial-attack firefighters so that we get their "buy-in."

Although myriad things might be recorded between the time of initial attack and the time when a fire is finally deemed "out," the most important thing to record is the position of the head fire at various times—the more observations, the better. From these observations, the rates of fire spread and intensity can be calculated. At times, these observations are difficult to make, for a variety of reasons, such as limited visibility and logistical issues (see the sidebar on page 6). When they can be made, they must be coupled with observations or measurements of wind velocity.

Although advances in photography, remote sensing and weather monitoring technology over the years have greatly facilitated matters (Anderson 2001; Dibble 1960; Lawson 1975; Ogilvie and others 1995; Schaefer 1959, 1961; Warren and Vance 1981), good representative or site-specific wind readings, for example, are still difficult to obtain. In this regard, one should not discount the relative value of

Make it a habit to always prepare at least a one- to two-page case study—it will hone your skills as a predictor of fire behavior.

field observers using the Beaufort Wind Scale (Jemison 1934; List 1951) as a simple means of acquiring estimates of windspeed.

Several forms exist for eventually developing a wildland fire case study (e.g., Rothermel and Rinehart 1983; Rothermel and Hartford 1992). However, forms can sometimes deter data gathering; an observer might cringe at the thought of completing yet another form. Remember, the most important information to gather is the time/location of the head fire and the corresponding windspeed.

The old adage is true: A picture is worth a thousand words. In case studies, however, it is worth more to record the time and location. One should consider obtaining vertical aerial photography of the fire area relatively soon after the fire's occurrence, especially in forested areas. This is often a very useful tool in carrying out a case study investigation.

Report Preparation and Documentation

Case study reports on wildland fire behavior vary tremendously in length and complexity. They range from short, very simple descriptions (e.g., USDA Forest Service 1960) to very large and extremely detailed, comprehensive accounts (e.g., Graham 2003a, 2003b). One should not be intimidated by the sheer size and level of detail in some case study reports; their bulk should not discourage you from preparing some type of report, no matter how short.

The size of a report is often driven by fire size and duration. A brief account might suffice for a specific issue (e.g., Countryman 1969) or for a particular situation or event during an incident (e.g., Pirkso and others 1965; Sutton 1984). For a long incident, a more voluminous publication might be more appropriate, with numerous appendixes to document the fire (e.g., Bushey 1991). Regardless of size, all reports have some things in common, such as descriptions of the components of the fire environment, although the level of detail might vary.

Distractions From Making Fire Behavior Observations

Brown and Davis (1973) identify some of the distractions on a fire that can keep one from preparing good wildland fire behavior case studies.

A common deficiency of most analyses of large fires is that the detail and sequence of what men did in their efforts to bring the fire under control overshadow what the fire did. This is a natural outcome. Usually all participants are so fully engaged in other emergency duties that no one is available to make objective and continuing firsthand observations of the fire itself. So the fire's overall behavior, and particularly the time and sequence of significant changes in its behavior, are uncertain and are likely to be poorly reconstructed from circumstantial evidence. This seriously limits the validity of conclusions drawn as to the adequacy or inadequacy of the efforts made to control it.

The case study can usually correct this difficulty. Ideally, it is planned in advance and carried out by a trained research team who moves in as soon as it is apparent that a blowup fire is in progress. By means of observation and measurements, such a team develops a detailed time history of the fire. Usually this is the form a detailed log of events and a carefully drawn map showing the spread of the fire at various time intervals. In addition to such information, detailed weather measurements are sought …

As better understanding and prediction of large-fire behavior develops, analysis of action on large fires and the more comprehensive case studies as well will become more meaningful and consequently more valuable in training men and in planning fire suppression strategy.

> If one isn't careful, the plethora of information can stymie even the most dedicated case study author.

After compiling all the information required to produce a case study report, one must write it up. The challenge is to distill the mass of information into a coherent summary. To assist in this process, we suggest a certain format (see the sidebar below). The case study by Pearce and others (1994) is a good example of a very concise report based on this format.

Other sections could be added to the format, such as fire effects on people (both firefighters and the public), homes, and ecosystems. The suppression strategy and tactics could also be addressed, including any associated human factors.

However, as Thomas (1994) points out, not all of us are writers. Some might wish to follow a one- or two-page format (e.g., McAlpine and others 1990 [figure 2]). Ideally, it should include a photograph or two and additional weather products (surface and upper air charts and profiles of temperature/moisture and winds aloft).

Some General Advice and Lessons Learned

We offer the following practical advice in preparing wildland fire behavior case studies. Our thoughts and comments are based on actual lessons learned from preparing case studies (e.g., Carpenter and others 2002; Pearce and others 1994).

Suggested Outline for Preparing a Wildland Fire Behavior Case Study Report

These guidelines are based in part on those originally prepared by M.E. Alexander for use in three advanced fire behavior courses sponsored by the National Rural Fire Authority in New Zealand in 1992–93. The guidelines were subsequently used in six wildland fire behavior specialist courses sponsored by the Canadian Interagency Forest Fire Centre in Hinton, Alberta, in 1996–2001.

1. **Introduction:** Significance of the fire, including regional map with fire location.
2. **Fire Chronology and Development:** Cause; time of origin and/or detection; initial attack action; forward spread and perimeter growth; fire characteristics, such as spotting distances and crowning activity; suppression strategy and tactics employed; mopup difficulty; fire progress map showing point of origin; final area burned and perimeter; ground and aerial photos, where possible.
3. **Details of the Fire Environment:**
   - **Topography**—Review major features; include topographic map and photos, if pertinent.
   - **Fuels**—Describe the principal fuel type(s); include a vegetation cover type map and any photos, if possible.*
   - **Fire Weather**—Describe prefire weather as appropriate; summarize synoptic weather features and include surface map; present daily fire weather observations; present fire danger ratings, including drought indexes, and append monthly fire weather record form; present hourly weather observations, if relevant; denote location of weather station(s) on regional map or fire progress map and comment on the relevance of the readings to the fire area, including notes about the station's instrumentation.**
4. **Analysis of Fire Behavior:** For example, discuss the fire's behavior in relation to the characteristics of the fire environment and the success/failure of the suppression operations.
5. **Concluding Remarks:** For example, what did you learn about predicting fire behavior and fire behavior documentation from this assignment?

*Detailed work on fuel characteristics (e.g., amounts by fuel complex strata, moisture content of live fuels) will depend on the situation and the specific need. Generalizations are often satisfactory for most purposes.

**It is a good idea to cultivate a long-term relationship with your local fire weather meteorologist/forecaster and seek their assistance as a cooperator.

Form your own view of what happened only after interviewing many firefighters and getting multiple perspectives.

Motivation. It is often very difficult to find the motivation to write a case study. On all wildland fires, other demands and the rapidity of events can be discouraging. Moreover, no policy or regulation requires a case study. It must come from your own motivation and sense of professionalism. ***Lesson Learned:*** As a practitioner, make it a habit to always prepare at least a one- to two-page case study. You will be richly rewarded, for it will force you to reflect on why a fire behaved the way it, honing your skills as a predictor of fire behavior (see the sidebar).

Your Standard Is Too High. There is a human tendency to establish goals that are nearly impossible to reach. ***Lesson Learned:*** Limit the length and depth of the report to the time available. Don't think you have to write a research report that meets the quality standards of a fire laboratory publication. A simple, short case study, told from your individual perspective, is better than no case study at all.

Organization. Just as we must practice our fire behavior prediction skills before going on a wildfire, so it is also important to mentally prepare ourselves for writing a case study. ***Lesson Learned:*** Get organized before the fire season begins. Prethink how you are going to prepare your case studies. Ask yourself what generic fire behavior information you are going to need (such as fire danger ratings, remote automatic weather station data, or fuel moisture readings), and prepare yourself to quickly access the information. Useful Webpages include the Western Regional Climate Center (http://www.wrcc.dri.edu) and the U.S. Drought Monitor (http://www.drought.unl.edu). Become familiar with such sources before the fire occurs. Finally, be systematic in your collection of data. An indexed, three-ring notebook constructed around the themes of observed fire behavior, such as fuels, topography, and weather, will help you organize pertinent information for easy retrieval.

Information Overload. The amount of information available about the fire environment can be overwhelming. If one isn't careful, the plethora of information can stymie even the most dedicated case study author. ***Lesson Learned:*** Don't try to use or validate every fire danger, fire weather, or fire behavior model available. Decide which model you want to use for your case study and stick to it. For example, ask yourself whether the BEHAVE fire behavior prediction system would meet your need as opposed to FARSITE. Think about the amount of time you have available to run various models. Pick the

Why Write a Case Study?

Luke and McArthur (1978) give a good rationale for writing wildland fire behavior case studies, even on small incidents:

Inquiries should be made into all fires as soon as possible after they have been controlled. Even short descriptions of very small fires have a value.* Recording the details of large fires is vital because success in the future depends largely on knowledge gained in the past.

A map showing the perimeter of a fire at progressive time intervals provides the best basis for a case history analysis. This should be accompanied by descriptions of fire behavior related to weather, fuel and topography, and details of the manning arrangements, strategy and tactics employed during each suppression phase. Particular attention should be given to initial attack action.…

At the conclusion of the analysis it should be possible to prepare a précis of the reasons for success or failure, not for the purpose of taking people to task for errors of judgment, but solely to ensure that the lessons that have been learnt contribute to the success of future suppression operations.

*It is true that we do naturally tend to focus solely on just the conflagration type wildland fires.

If every fire manager and fire researcher made it a personal goal to produce one case study per year, just think how many case studies could be produced in a 20- to 35-year career!

model that meets the time available. **Sources of Information.** Secondary sources of fire behavior information are often as important as primary sources. In a way, the preparation of a fire behavior case study is like detective work: You are always on the hunt for clues explaining why your fire behaved the way it did. ***Lesson Learned:*** Don't depend solely on the standard sources of fire behavior information, such as models, Websites, and fire weather forecasts. For example, photographs or video taken by newspaper or television* and amateur photographers can be rich sources of fire behavior data. Even articles in general magazines can offer different perspectives on your case study.

Interviewing. Interviews with firefighters are a common source of fire behavior information. But be careful, for recollections are prone to hindsight bias. Recollections of fire events are often flawed, and they always reflect only a single point of view. ***Lesson Learned:*** When interviewing firefighters, be aware of hindsight bias. Always compare one person's memory of the fire with another's. Be skeptical. Seek information that disproves strongly held cause–effect relationships. Form your own view of what happened only after interviewing many firefighters and getting multiple perspectives.

Fire Behavior Model Versus Reality. It is understandable when fire behavior specialists or analysts lament the fact that a fire behavior model did not predict what actually happened. But such discrepancies are simply part of making fire behavior predictions, and they will never fully disappear. One of the most interesting purposes of a fire behavior case study is to compare the projection against reality. ***Lesson Learned:*** In every case study, compare the fire behavior projection or prediction to what actually happened. Then discuss why the fire did or did not behave as predicted. In so doing, you will be honing your fire behavior prediction skills.

Peer Review. A case study, in the end, is the official fire behavior record. Your reputation is on the line. ***Lesson Learned:*** Time permitting, get peer review. Simply ask your colleagues what they think of your case study. It will ease your anxiety and improve your final product. But be prepared for contrary opinions, and don't be intimidated when others think differently. Always remember that fire behavior is complex and not easily captured in a report. You are doing the best you can.

Case Study Publication. You've prepared a case study. Now how are you going to distribute your report so that it will be useful to the fire community? ***Lesson Learned:*** A logical location for case studies are the Websites of local or national fire management agencies, such as the National Interagency Fire Center or the geographic coordination centers. Another possible location is the Lesson's Learned Center at the National Advanced Research Technology Center in Marana, AZ ((http://www.wildfirelessons.net/). But be careful about including color digital photographs with your report. Although photographs are truly worth a thousand words, they can bog down e-mail systems and limit the distribution of your report, although some of these obstacles can be overcome (Christenson 2003).

Just Do It. If fire behavior case studies are to become routine—our hope for more than a decade—then you must make a personal commitment to prepare them. ***Lesson Learned:***

A fire behavior model cannot make a commitment; only an individual can. We hope that nothing will hold you back. When it comes to fire behavior case studies, we hope that you will, as the saying goes, "Just do it!"

More Case Studies Needed!

In 1976, Craig Chandler, then Director of the Forest Service's Division of Forest Fire and Atmospheric Sciences Research, pointed out that many wildland fire behavior case studies were produced by fire researchers and fire weather meteorologists during the 1950s and 1960s, but that he had not seen many lately, presumably due to "higher priorities elsewhere" (Chandler 1976). He suggested that "we reexamine our priorities." Alexander (2002) has proposed establishing permanent, full-time national operational fire behavior research units. But there is also the opportunity to help oneself directly.

* Inquire as soon as possible (within at least 24 hours) about the availability of videotape footage, because the complete record is typically not archived.

Chandler's comment is still valid for everyone involved in wildland fire, not just scientists and forecasters.

We should be observing/documenting wildland fires and preparing case studies not for fear of litigation (Underwood 1993), but rather to improve our understanding of fire behavior for the safe and effective management of wildland fires (Countryman 1972). If every fire manager and fire researcher made it a personal goal to produce one case study per year, regardless of size, just think how many case studies could be produced in a 20- to 35-year career! As it stands now, less than one-tenth of 1 percent of all wildland fires are properly analyzed and documented. We must do better.

Acknowledgments

The authors offer their sincerest heartfelt appreciation to Hutch Brown, Madelyn Dillon, and Carol LoSapio, editors of *Fire Management Today*, for their significant contributions to this special issue, and to April Baily, the journal's general manager, for supporting the concept of these special issues on wildland fire behavior. Their dedication and outstanding editorial abilities have brought "life" to many of the articles contained in this issue that have long been forgotten.

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THE CAROLINA BLOWUP*

Keith A. Argow

April 1, 1966, was not a day for April Fool jokes in the coastal pinelands of North and South Carolina. It was an explosive fire day unrivaled in recent times. In those hot 24 hours, 72,000 acres (29,000 ha) in the two States were burned, 3,000 acres (1,200 ha) per hour. It was a Black Friday for more than 50 families whose homes were destroyed.

A news release from the South Carolina State Forester's office in Columbia summed up the situation: "The driest March in ten years created the forest fire danger that exploded on Friday, April 1st, into an almost uncontrollable situation. In three days, Friday, Saturday, and Sunday, 480 wildfires burned 70,000 acres (28,000 ha) bringing the total; fire loss since July 1965 to 4,800 wildfires burning 120,000 acres (48,000 ha) of woodland.

This was the greatest loss in 11 years. Before the rains came on April 4, the forest area burned in the two Carolinas during this explosive period reached 144,000 acres (58,000 ha). The largest fires were in the coastal pinelands, but damage was not limited to that area as numerous fires sprang up across the Piedmont.

The conflagration came as no real surprise to forest protection personnel. A very dry March had followed a dry winter.

It was a Black Friday for more than 50 families whose homes were destroyed.

On March 30, a meteorologist from the U.S. Forest Service's Southeastern Forest Fire Laboratory in Macon, Ga., telephoned the State forestry headquarters in Raleigh, N.C., and Columbia, outlining the full danger of the unstable weather conditions. Wind and pressure patterns such as these had come to the South before. They usually meant trouble on going fires.

The North Carolina State Forester immediately cancelled all burning permits and prohibited use of fire near woods. Yet even with this preventive measure, fire crews in the Tarheel State fought 273 wildfires covering 18,000 acres (7,200 ha) on the last 2 days of March.

In South Carolina on the same day, the Forestry Commission closed all State parks to public use. On the evening of March 31, the governor issued a proclamation prohibiting the use of fire adjacent to woodlands—the first time this had ever been done. (The authority was provided in a law passed after the disastrous 1954-55 fire season, when 7,000 fires burned 159,000 acres (64,000 ha).)

April 1

April 1 dawned clear and windy. The 10 a.m. report from Jones Lake tower on North Carolina's Bladen Lakes State Forest showed a high spread index, fuel moisture of 6 percent, and a steady wind of 18 miles per hour (29 km/h) from the southwest.

By early afternoon rural residents and travelers in the Carolinas knew there was a serious fire situation. They didn't have to be told over the radio or see it in the news. They could smell the smoke and feel it burn their eyes.

The steady southwest winds were flowing between two areas of high pressure. One of the systems had recently passed out into the Atlantic. The second, a fast-moving cold front, was coming in from the Mississippi Valley. At 7 a.m. the leading edge was over the Great Smoky Mountains. By 1 p.m. it was in the Piedmont crossing over Charlotte and Winston-Salem. That evening it reached the Atlantic coast, bringing thunderstorms to Wilmington, N.C.

As the front hit, prevailing winds were pushed eastward by the strong winds within the system. This meant a 90-degree wind change as it passed. Fires that had made a narrow run to the northeast quickly turned southeast, their long flanks becoming new wide heads.

The Ammon Fire

One of the blazes that got the most publicity threatened the little town of Ammon, N.C., for 2 days and blackened 17,000 acres (6,900 ha) around it. The smoke was first reported at 1:30 p.m. on April 1. Rumor was that someone had been burning off an area to improve duck hunting, but no one was quite sure who it was.

When this article was originally published, Keith Argow was an instructor in the School of Forestry at North Carolina State College, Raleigh, NC.

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By early afternoon rural residents and travelers in the Carolinas knew there was a serious fire situation.

Forty minutes later a forestry truck on patrol radioed that a second fire was coming out to the highway from nearby Black Lake. Crews just completing control lines on the White Oak fire only 15 miles (24 km) away rushed to both new blazes.

Reconnaissance aircraft swung over from the large Newton Crossroads fire a scant 20 miles (32 km) eastward and advised ground crews on the course of the flames and the best control action.

The fire towers, now nearly all socked in by smoke, relayed urgent radio messages between headquarters and the men on the firelines. "Fire reported across from Melvin's store." "Fire has jumped the South River into Sampson County." "Fire burning two homes and a half-dozen farm buildings on Beaver Dam Church Road." Fire was everywhere!

By 3 p.m. the Ammon fire had jumped Cedar Creek Road and was headed toward the settlements. The district dispatcher reluctantly pulled a unit off the Black Lake fire, now only 10 miles (16 km) away, and committed his last reserve tractor plow.

Still the flames continued their advance. Air tankers of the North Carolina Forest Service cooled hot spots and were credited with helping volunteer fire companies save several homes and outbuildings.

Evening came with a smoky orange light. Down in the swamp the fire rumbled. The cane went up with a crackle that sounded like a rifle platoon in action.

The cold front hit the Ammon fire at 7 p.m. As expected, the flames changed direction. Already the Whiteville District Forester was headed toward N.C. Highway 242 which now lay in front of the fire. Control was impossible now, but he wanted to be sure everyone was out of the way.

Flame—150 Feet High

Smoke was intense. The fire could be heard in the distance, and the glow of the flames appeared through the forest. The pines across the highway exploded into what he described as a sheet of flame 150 feet (45 m) high.

Simultaneously, three lightning bolts from the thunderheads overhead accompanying the cold front struck the main fire. As rapidly as it came, the fire moved on, throwing burning limbs and brands 1,000 feet (300 m) ahead of it. Finally, the skies opened up with a brief downpour that knocked the flames out of the trees until there was nothing but flickering snags in the night.

Tractor units spent the night plowing lines, but without the flames to guide them it was hard to locate the leading edges in the dark. The situation was made more difficult by the many small spot fires that were scattered out ahead as far as a quarter of a mile (0.4 km).

The thundershower was only temporary relief. Severe burning conditions were forecast for the next day. Again and again crews sought to strengthen their plowlines, but the backfires would not burn. Without fire, they were unable to construct a fire-break wide enough to hold a new onslaught.

As expected, a drying wind came up with the sun on April 2. By midmorning the scattered embers were fanned to life. Crews worked in vain. Flames were rolling again and took little notice of the lines that had been plowed across their path. The Ammon fire had places to go and another 10,000 acres (4,000 ha) to burn before a general rain and a massive control effort would contain it 2 days later.

Yes, April 1, 1966, will be long remembered in the Carolina pinelands. But the severe test was well met by courageous firecrews and modern equipment.

Black Wednesday in Arkansas and Oklahoma*

Rollo T. Davis and Richard M. Ogden

During the more critical fire seasons there always seems to be one or more days that stand out as "black days." On these days fires burn hotter and are harder to control than on other days. Fires blow up on "black days." Like Black Wednesday, April 8, 1970, in Arkansas and eastern Oklahoma.

Fire Season

The fire season in both states usually ends in late April. Normally by this time, vegetation is turning green. Fire control agencies are shifting to other forestry operations, and seasonal fire control crews are leaving. But April 1970 was unusual.

Rain fell in above-normal amounts during the early spring months. Periods of rain were so spaced that all fuels, except the fine ones, remained wet. Temperatures remained well below the seasonal normal keeping the vegetation in the cured stage. Except for a few border stations, fire danger stations did not go into the transition stage until mid-April. Rainfall, that had been coming in substantial amounts, dropped off in late March to almost nothing. This dry spell continued into mid-April and temperatures started rising to more normal levels. This was just the type of weather the people were waiting for: to begin field clearing by burning, brush pile burning, and garden and household debris burning. During this period, a great number of fires roared out of control.

With fuels already bone-dry, an extremely dangerous fire situation was in the making. Fires by the hundreds were being reported in Arkansas and Oklahoma.

Synoptic Situation and the Black Wednesday Forecast

The dry spell, begun in late March, stretched into April as dry, high pressure spread over Oklahoma and Arkansas. It blocked frontal systems from the area. By April 7, high pressure extended upward to 20,000 feet (6,100 m), but the surface high center had moved to the lower Mississippi Valley. Moderate-to-strong, southwesterly, low-level winds pumped even drier air over Arkansas and Oklahoma. Afternoon relative humidities dropped to the 20-percent level, and some places had humidity readings down in the 'teens. With fuels already bone-dry, an extremely dangerous fire situation was in the making. Fires by the hundreds were being reported in Arkansas and Oklahoma. But most of them were not too difficult to control.

Wednesday morning, April 8, another dangerous weather feature entered the weather picture. The 6 a.m. radiosonde observations at Oklahoma City and Little Rock showed the air to be conditionally unstable to about 15,000 feet (4,800 m). It would become absolutely unstable from the surface up to 4,000 feet (1,200 m) by the middle of the afternoon. Widespread surface whirlwinds or dust devils resulted from the great instability in the lower 1,500 feet (460 m). Warnings were called to the State Fire Control Chiefs, as well as to the Ozark and Ouachita National Forests. The warnings were for potential blow-up conditions. Hard-to-control fire behavior such as rapid crowning, long-distance spotting, and large convection columns was expected.

What Happened

All conditions were favorable for fires in Oklahoma and Arkansas. There was a significant deficiency in rainfall during the last half of March and the first half of April. There had been an extended period of extremely low relative humidities. When these conditions combined with an unstable atmosphere, all conditions were "go" for blow-up fires. And blow-up fires did occur.

At 9 p.m. that Black Wednesday evening the Ouachita National Forest called to report one of their worst fires in 3 years had been

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The key to identifying the stability of the atmosphere is interpretation of the early morning radiosonde observation, including temperature, humidity, and wind from the ground upward.

burning out of control. Aerial tankers, as well as hand crews, had been ineffective against this fire. The Oklahoma Division of Forestry reported a total of 35 fires that burned 7,669 acres (3,103 ha), while one fire roared over 2,080 acres (841 ha). Arkansas (State and National Forests) had a total of 142 fires which burned 12,559 acres (5,082 ha).

Air Stability the Key

When fire weather conditions are conducive to many fires (i.e. large precipitation deficiency, and low relative humidities) the fire weather meteorologist gives special attention to the stability of the atmosphere. The key to identifying this situation is interpretation of the early morning radiosonde observation, including temperature, humidity, and wind from the ground upward, thousands of feet. The fire control agency, informed of dangerously unstable atmospheric conditions by the fire weather meteorologist, is warned to expect erratic fire behavior. ■

Jet Stream Influence on the Willow Fire*

John H. Dieterich

On June 13–17, 1956, the Dudley Lake Fire burned 21,389 acres (8,555 ha) on the Chevelon Ranger District of the Sitgreaves National Forest in Arizona. Nineteen years later, on June 17–19, 1975, the Willow Fire, burning on the same ranger district and under remarkably similar conditions of fuel, weather, and topography, burned 2,850 acres (1,140 ha).

Following the Dudley Lake Fire, Vincent Schaefer, writing in the *Journal of Forestry* (Vol. 55, No. 6, June 1957), summarized the relationship between the jet stream and 23 large fires in the West during the 1955 and 1956 fire seasons. His article was prompted in part by the unusual fire behavior observed on the Dudley Lake Fire, and in part by his interest in the jet stream as a dominant factor in the behavior of these problem fires.

As we began to put together the story of the Willow Fire, it became apparent that here was another case that could be added to Schaefer's list of destructive fires that burned under the influence of the jet stream. While there were some rather obvious differences between the two fires—the most important being in area burned—there were a sufficient number of similarities to make the two fires interesting from a direct comparison standpoint.

> The weather pattern on the two fires, particularly with regard to the jet stream, appeared to have been generated under nearly identical conditions.

Aerial view of wind-driven smoke column from the Dudley Lake Fire, June 14, 1956. The smoke column remained remarkably intact for several miles downward and was still readily identifiable in the vicinity of Mesa Verde National Park, 210 miles (340 km) to the northeast.

Description of the Area

The locations of the Dudley Lake and Willow Fires are shown in figure 1. On the Dudley Lake Fire, 18 percent of the area was in private holdings (Aztec Land Co.) while on the Willow Fire, 41 percent of the area burned was being managed, at least in part, by Southwest Forest Industries. The Forest Service, however, provides fire protection for these lands within the protection boundaries.

Both fires were man-caused, and both occurred in terrain typical of the Mogollon Rim country—a flat

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Forecasting unusually strong surface winds is perhaps the most important single activity for the fire weather forecaster.

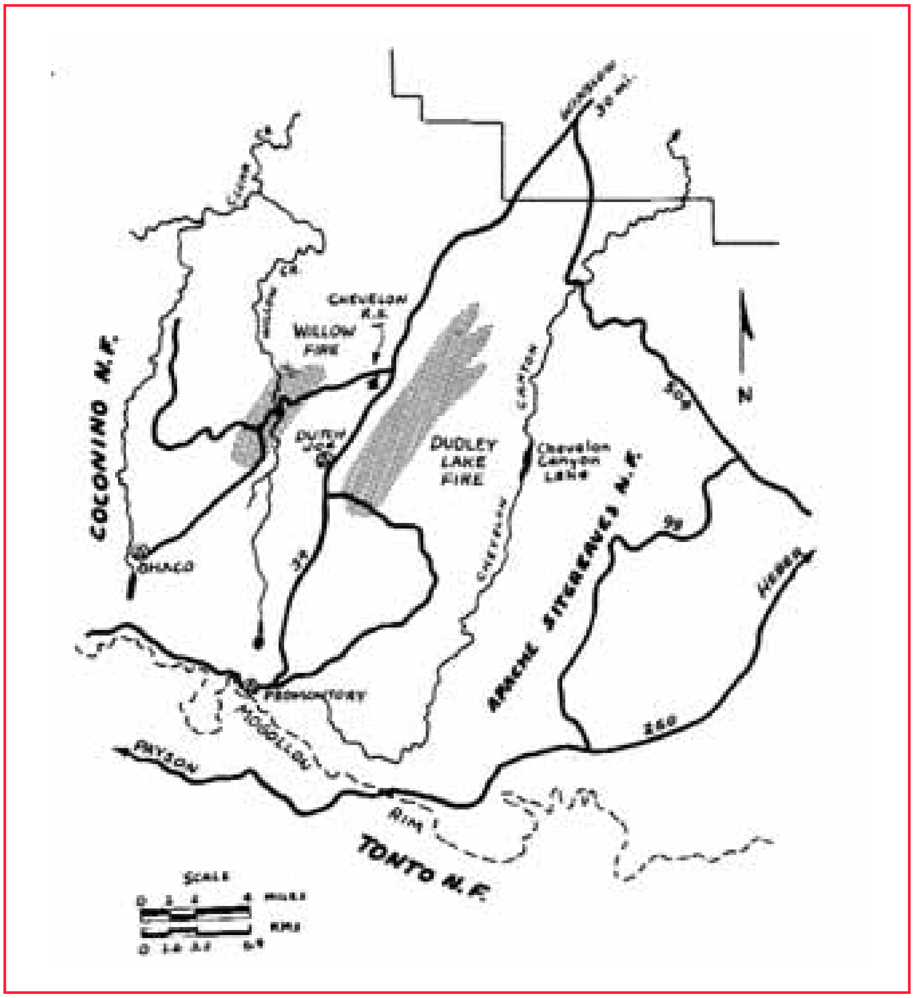

Figure 1—*Location of the Dudley Lake and Willow Fires on the Apache-Sitgreaves National Forest.*

to rolling landform bisected by steep rocky canyons. (The Willow Fire quartered across Willow Creek Canyon, while the Dudley Lake Fire crossed several smaller canyons.)

Fuels

The fuels appeared to be remarkably similar on both fires. Since both public and private land ownership were involved, fuel treatment standards varied from little or no fuel treatment to nearly complete treatment of slash after logging. Estimates of fuel weights were not available for the Dudley Lake Fire, but a detailed fuel inventory on the Willow Fire indicated that fuel loading, including litter, varied from 18 tons per acre (40,353 kg/ha) on the lighter areas to about 54 tons per acre (121,060 kg/ha) where slash remained untreated after heavy cutting. Even on areas where slash disposal had been fairly complete, sufficient ground and surface fuels had accumulated to support an intense fire, influenced by low relative humidities and fuel moistures and by strong winds.

Weather

Both fires burned during the middle of June—generally considered to be the most critical period of fire weather in the Mogollon Rim country. The weather pattern on the two fires, particularly with regard to the jet stream, appeared to have been generated under nearly identical conditions. As indicated by the weather data, the temperature and relative humidity conditions were not as critical on the Willow Fire, but the wind conditions were nearly identical.

One obvious difference between the two fires was in the length of time the severe burning conditions persisted. On the Dudley Lake Fire, the strong winds continued and the relative humidities remained low for nearly 72 hours. On the Willow Fire, the critical burning period was over in about 36 hours. An inspection of the 500-millibar weather map for the Willow Fire indicated that, indeed, the jet stream conditions persisted over the fire for about 36 hours. Then the winds dropped and humidities began to rise.

Two other Class E fires started and burned in New Mexico during the same 3- to 4-day period as the Willow Fire. These fires were undoubtedly influenced by the same strong winds that were passing over the Willow Fire.

Fire Intensity

Maximum fire intensities were estimated for the Dudley Lake and Willow Fires using Byram's formula (Byram 1959). Fire intensity on

By current fuel treatment standards, even our best efforts at fuel reduction do not appear to provide much assistance in the control of high-intensity wind-driven fires.

the Dudley Lake Fire was estimated at 15,300 Btu/s/ft (126,378 cal/s/cm) and on the Willow Fire at 12,750 Btu/s/ft (105,315 cal/s/cm). The difference between these two was not sufficient to explain the difference in the final size of the two fires. More important is the fact that the Dudley Lake Fire burned as a high-intensity fire for nearly twice as long as the Willow Fire.

By way of comparison, the Sundance Fire in northern Idaho—considered a very high intensity fire—yielded an estimated maximum intensity of 22,500 Btu/s/ft (185,850 cal/s/cm) during its maximum run.

Fire Suppression Load

There was a considerable difference between the fire load being experienced by the Forest Service's Southwestern Region in 1956 and the number of fires burning when the Willow Fire broke out. During the 12-day period from June 8 to June 20 in 1956, eight Class E fires in addition to the Dudley Lake Fire were controlled or in the process of being controlled. Over 90,000 acres (36,000 ha) burned in Arizona in 1956—nearly three times the running 5-year average of 32,600 acres (13,040 ha).

During the Willow Fire the Region wasn't experiencing this type of fire load; in fact, the Willow Fire was the first big fire of any consequence in the Region in 1975. Over 1,100 men were used on the Willow Fire, while only 750 men were employed on the Dudley Lake Fire, even though it was several times larger. Fire suppression costs on the Willow Fire were estimated at nearly $700,000, four times the suppression costs on the Dudley Lake Fire ($175,000). The per-acre suppression costs were about 30 times as high on the Willow Fire ($245.61) as they were on the Dudley Lake Fire ($8.18)—a fact that shouldn't surprise anyone.

There were some interesting similarities in the fire suppression measures taken on the two fires. On the Dudley Lake Fire, only hand crews and heavy equipment were used because, in 1955 and 1956, aircraft were just beginning to be tested for dropping water on fires. On the Willow Fire, most of the suppression effort also came from hand crews and heavy equipment because the winds were so strong that aircraft use was limited to the early morning hours.

Lessons Learned

In summary, the following facts are evident:

- First, forecasting unusually strong surface winds, especially those that are associated with the jet stream or abrupt changes in pressure patterns, is perhaps the most important single activity for the fire weather forecaster. Forecasting units may currently be doing this operationally, but additional "red flag" emphasis should be given to these situations when they occur.
- Second, when fires start under these severe wind conditions, or if fires that are burning come under the influence of winds over 30 miles per hour (48 km/h), the chances are good that they will continue to spread until the weather changes, or until they run out of fuel.
- Finally, by current fuel treatment standards, even our best efforts at fuel reduction do not appear to be adequate to provide much assistance in the control of high-intensity wind-driven fires such as the Dudley Lake and Willow Fires. If fuel treatment is the answer, it will need to be done on a level that is far more extensive (area) and intensive (fuel reduction) than we are now accomplishing—even on our best fuel breaks.

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Predicting Major Wildland Fire Occurrence*

Edward A. Brotak and William E. Reifsnyder

During a drought period when the build-up index is very high, wildfires are common. On some days, these small fires quickly get out of hand, and some become major fires. Obviously, any forecasting method which could determine when these major fires were likely to occur would be most useful. The following details such a predictive scheme from readily available weather maps. No calculations are necessary, just recognition of certain clearly defined situations.

Dangerous frontal situations will be characterized by strong winds, a tight pressure gradient, and little or no precipitation with the frontal passage.

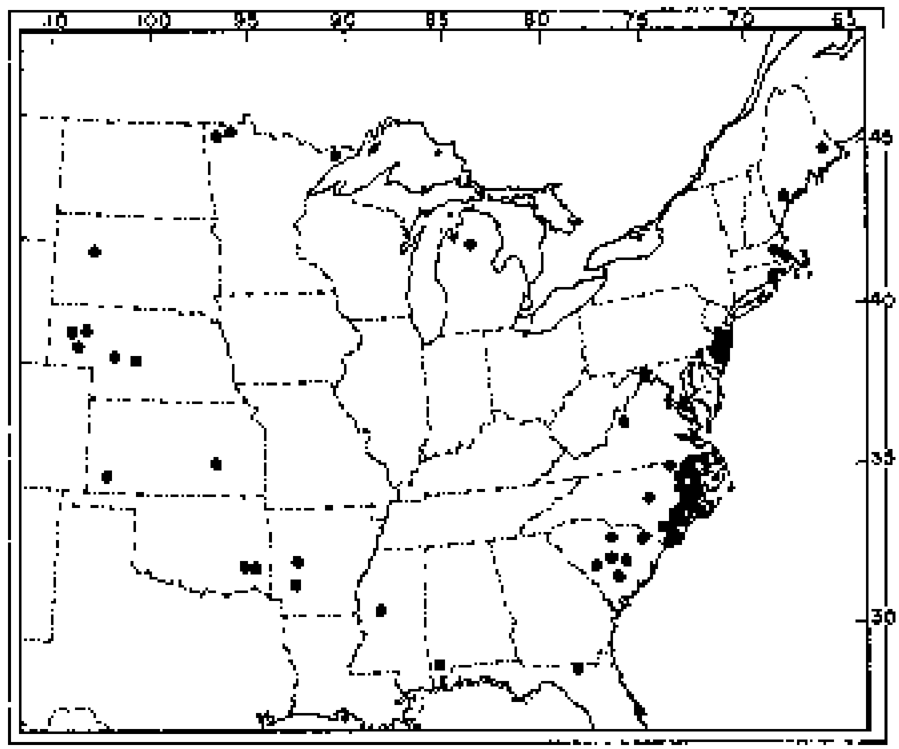

Figure 1—*Locations of all fires.*

Using Weather Maps

The original data analyzed consisted of 52 fires, each burning 5,000 acres (2,000 ha) or more, in the Eastern United States from 1963 to 1973 (see fig. 1). Of particular concern were major fire runs, periods of time when the fire was probably uncontrollable due to the prevailing weather conditions. Figure 2 is an idealized surface map showing where these major fire runs occurred in relation to the existing fronts and high and low pressure areas. Certain regions were obviously prone to large fires.

The region immediately behind a dry cold front is the most dangerous. Strong, shifting winds are the apparent cause. Strong southerly winds ahead of the cold front can also cause control difficulties. Obviously, if significant precipitation occurs with the frontal passage, fire danger will not be great.

Another region of great danger is the warm sector of a strong low pressure area (as indicated by the cluster of runs to the east–southeast of the low in figure 2). There were two different types of low pressure areas involved with major fires. One was the Rocky Mountain low which produced dangerous fire conditions in the Plains and Midwestern States. The other kind of low was a storm which moved easterly through southern Canada producing dangerous fire conditions in the Great Lakes States and in northern New England. Major lows in the Eastern United States are almost always accompanied by precipitation.

If only the surface maps are available, then these dangerous situations can only be distinguished from other similar situations by a closer examination of the map.

When this article was originally published, E.A. Brotak was a research assistant and W.E. Reifsnyder was a professor of forest meteorology at the Yale School of Forestry and Environmental Studies, New Haven, CT.

* The article is reprinted from *Fire Management Notes* 38(2) [Spring 1977]: 5–8. It is based on *A Synoptic Study of the Meteorological Conditions Associated With Major Wildland Fires,* E.A. Brotak's Ph.D. dissertation at the Yale School of Forestry and Environmental Studies.

Fortunately, the development of major low pressure areas and the passage of strong cold fronts are normally associated with precipitation.

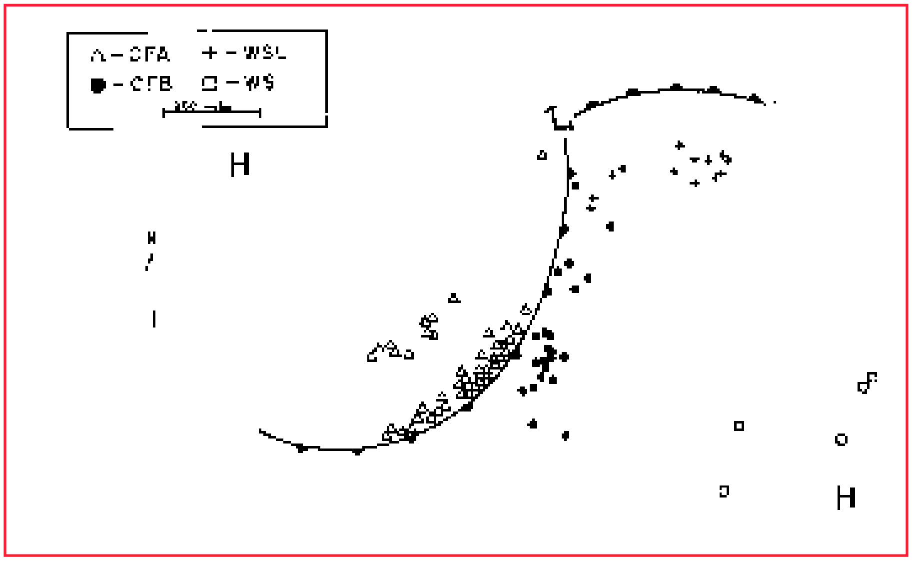

Figure 2—*Idealized surface map showing locations of all fire runs. (CFA = following cold frontal passage; CFB = preceding cold frontal passage; WSL = warm sector of low; and WS = warm sector of high.)*

Dangerous frontal situations will be characterized by strong winds, a tight pressure gradient, and little or no precipitation with the frontal passage. Dangerous conditions around low pressure areas usually depend on precipitation occurrence.

If the upper air maps are available, these dangerous situations are much easier to determine. Strong cold fronts are distinguished from weaker fronts by the presence of intense upper level troughs, readily apparent at the 500-millibar (~18,100 feet [~5,500 m]) level. The intensity of these troughs is determined by the radius of curvature which was usually 400 miles (640 km) or less for the study fires. Figure 3 shows that the most dangerous conditions are associated with the southeastern portion of the trough.

The likelihood of precipitation is best determined from the 850-millibar (~4,900 feet [~1,500 m]) map. Significant moisture advection at this level in conjunction with an upper trough usually produces precipitation. Only if the dewpoint depression of the air at this level upwind of an area is 41 °F (5 °C) or more is precipitation unlikely and major fire occurrence possible.

Fortunately, the development of major low pressure areas and the passage of strong cold fronts are normally associated with precipitation. It is on those rare occasions when precipitation does not accompany these systems and fuel conditions are severe that major fire occurrence is likely.

Using Local Wind and Temperature Profiles

The preceding section describes the use of readily available weather maps for the routine prediction of major wildland fires. In this section, we shall describe how to use local wind and temperature profiles to determine dangerous fire conditions. For all 52 fires, wind and temperature data from the surface to 10,000 feet (3,050 m) were plotted and analyzed for one or two nearby first order weather stations for times just before and just after the fire's run. From these data, characteristic profiles were deter-

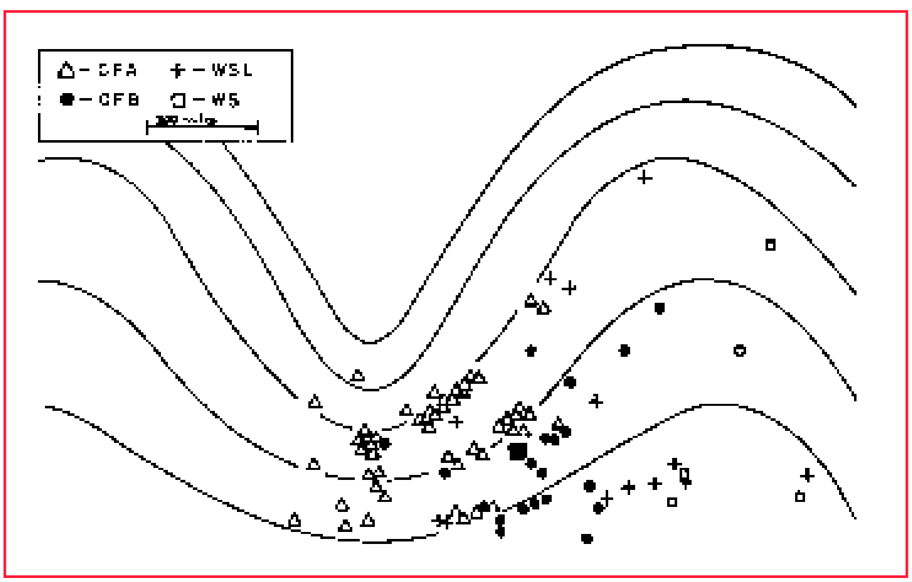

Figure 3—*Idealized 500-millibar map showing locations of all fire runs.*

Observed surface winds are not always representative of actual conditions, especially in the morning, when the nocturnal inversion often produces weak surface winds.

mined which could be used as predictive models.

Strong surface winds are a prerequisite condition for major wildland fires. However, an examination of only the surface winds is not adequate for predictive purposes. Observed surface winds are not always representative of actual conditions. This is especially true in the morning when the nocturnal inversion often produces weak surface winds. If the winds above the inversion layer are strong, the potential for strong surface winds in the afternoon is great. Topographic effects can also produce seemingly low surface wind speeds, but again if the wind speeds above the surface are high, strong gusts can be expected at the surface.

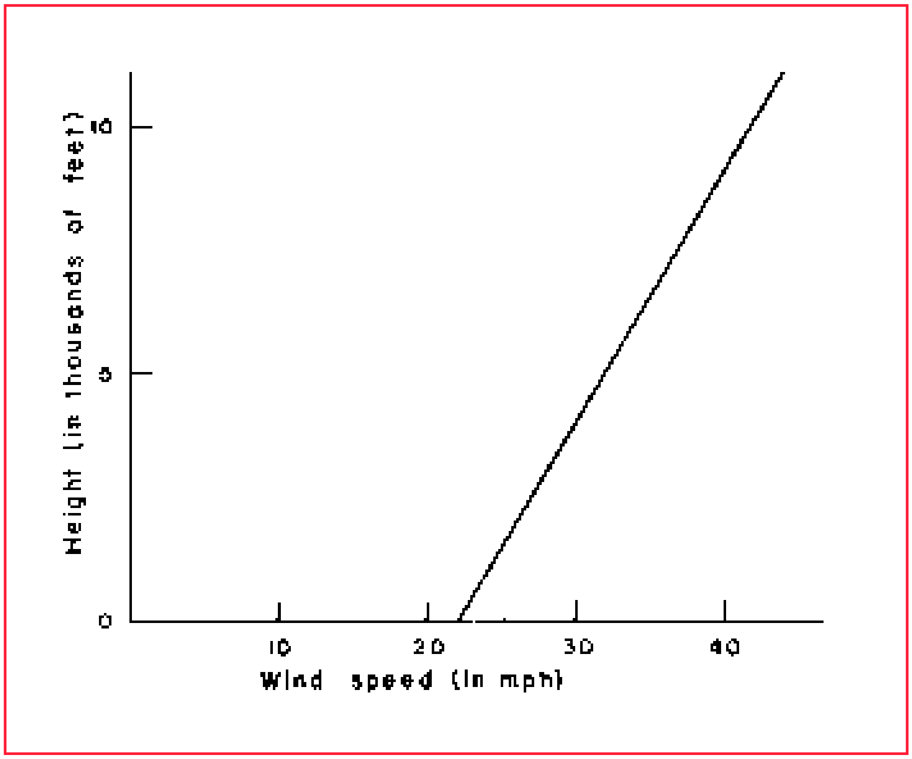

Figure 4—*Characteristic wind profile.*

A wind profile characteristic of most major fire situations is shown in figure 4. Surface wind speeds always reached 15 miles per hour (24 km/h) and are usually 20 miles per hour (32 km/h) or greater. Wind speeds at 10,000 feet (3,000 m) were almost always 40 miles per hour (64 km/h) or greater. The above figures can be considered as critical values for major fire occurrence.

The association of major wildland fires with low-level jets (wind maxima within 10,000 feet [3,000 m] of the surface where the wind speed is 5 miles per hour [8 km/h] greater than a thousand feet [300 m] above or below) was a significant finding of this research. A third of the wind profiles showed such a jet. Certain synoptic situations were more favorable for the jet's occurrence. Most frequent were the prefrontal jets, southerly wind maxima just ahead of the surface cold front. Another southerly jet was often noted in the warm sector of the common Rocky Mountain low pressure area. A postfrontal jet, a northerly wind maximum behind the surface cold front, occurred on a number of occasions. Low-level jets were also occasionally noted along the East Coast and seemed to be associated with the sea breeze front.

Although not a prerequisite condition, the occurrence of a low-level jet happens frequently enough, especially under certain patterns, to be an important factor. If present, the authors believe that the low-level jet will increase surface wind speeds and gustiness by downward transport of momentum. The importance of this, especially on the worst fire days, is probably to make bad conditions even worse.

It has long been believed that atmospheric instability was associated with major wildland fires. In an attempt to determine some characteristic values of this parameter, certain lapse rates were examined for each fire situation. Using the standard pressure levels given in the soundings, the lapse rates that were used were 950–850 millibar, 850–700 millibar, and 850–500 millibar.

The occurrence of a low-level jet happens frequently enough, especially under certain patterns, to be an important factor in major wildland fires.

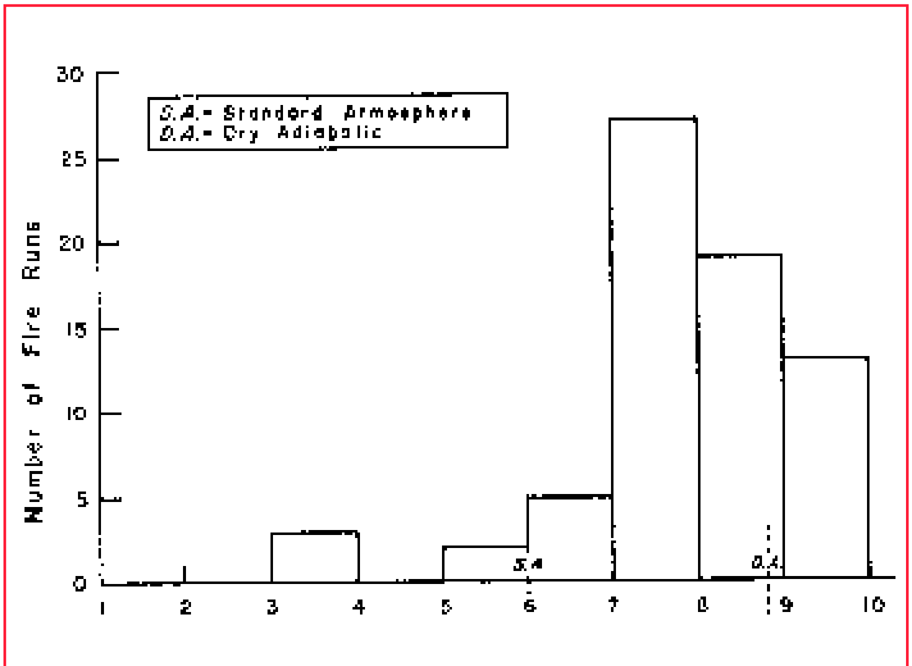

Figure 5—*950–850 millibar temperature difference for all fire runs.*

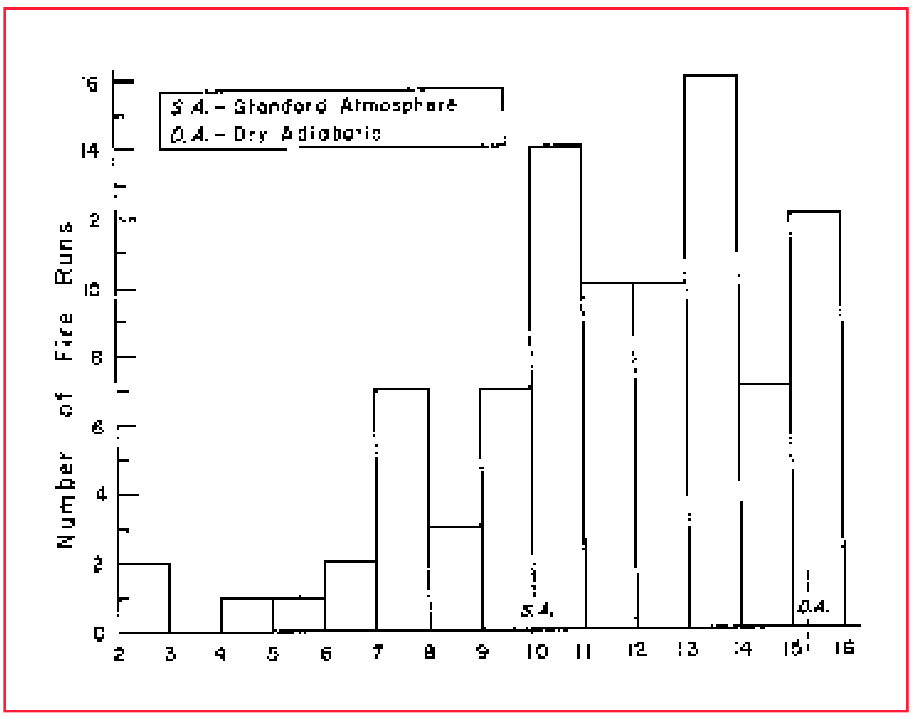

Figure 6—*850–700 millibar temperature difference for all fire runs.*

The 950–850 millibar (~2,000 feet to ~5,000 feet [~600 to ~1,500 m]) temperature (ΔT) avoids the variability of surface temperatures and the occurrence of surface based inversions, but is still greatly influenced by daily solar heating and is probably a local rather than macroscale parameter. As shown in figure 5, the vast majority of fires, 92 percent, occurred when the lapse rate between these levels was steeper than the standard atmosphere value (ΔT = 6.0 °C). Superadiabatic lapse rates were noted on a number of fires. Thus a temperature difference of at least 6.0 °C between the 950 and 850 millibar levels appears to be a necessary condition for major fire occurrence.

The 850–700 millibar (ΔT) depicts the lapse rate between ~5,000 feet (~1,500 m) and ~10,000 feet (~3,000 m), and the instability at those heights would probably be macroscale. As shown in figure 6, in general, a temperature difference of at least 10 °C is associated with major fires. This value is close to the standard atmosphere lapse rate. The 15.0 °C to 15.9 °C category encompasses the dry adiabatic lapse rate which is the maximum that could be expected for these heights.

The 850–500 millibar (ΔT) depicts the lapse rate between ~5,000 feet (~1,500 m) and ~18,000 feet (~5,500 m). A temperature difference of 26 °C is the standard atmosphere lapse rate. A temperature difference of 40 °C to 41 °C is the dry adiabatic lapse rate and would be remarkably unstable for

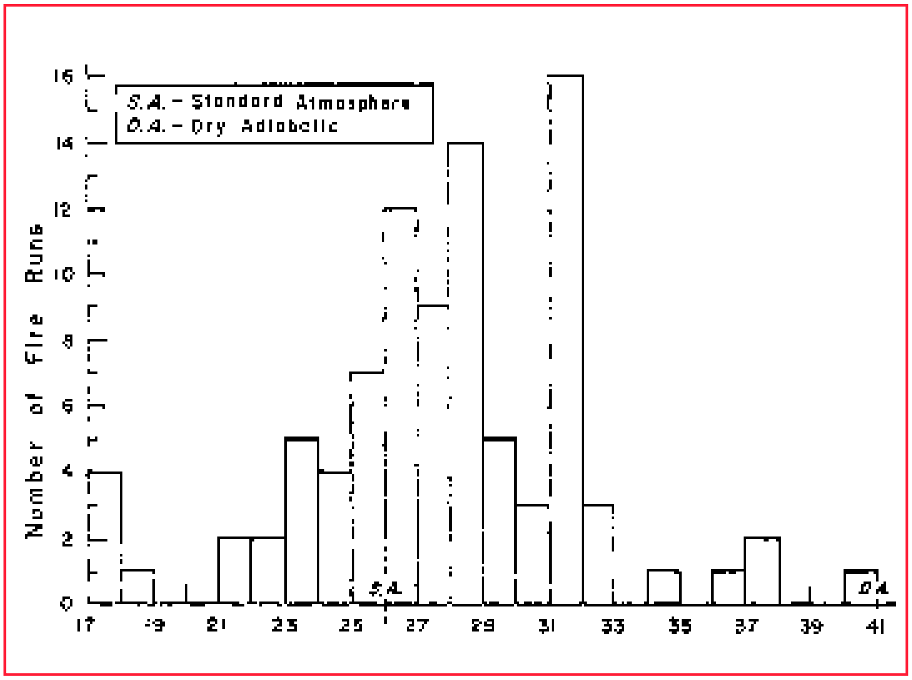

Figure 7—*850–500 millibar temperature difference for all fire runs.*

this level in the atmosphere. As shown in figure 7, about 75 percent of the fire runs occurred with a temperature difference of 26 °C or more.

Acknowledgment

The research project summarized here was supported by the Atmospheric Science Section of the National Science Foundation. ■

The Bass River Fire: Weather Conditions Associated With a Fatal Fire*

E.A. Brotak

Although wildland fires are fairly common in New Jersey, fatalities directly caused by fire are very rare. However, on July 22, 1977, a fire in the Bass River State Forest claimed the lives of four volunteer firefighters. Since these men were well trained and experienced, it is likely the fire exhibited unusual behavior, thus trapping them. This article evaluates possible causes of the unusual fire behavior.

> Shifting winds and the intensity of the fire along the road where the men were trapped made it impossible for them to escape alive.

Setting

Traditionally, the Pine Barrens in southern New Jersey are noted for major wildland fires during times of drought. The unusual combination of fuel, soil, and adverse weather conditions produces rapidly spreading surface and crown fires. Spread rates of these fires are among the greatest in the country.

Drought conditions were present in southern New Jersey all through the first half of 1977. At the Atlantic City National Weather Service, which is representative of the Pine Barrens, moisture for the 6-month period was 41 percent below normal. By July, New Jersey had experienced one of its worst spring fire seasons, with nearly 32,000 acres (13,000 ha) burned.

Summer normally brings green foliage and frequent rains, thus ending the fire season. However, this year, after some rain in June, drought conditions returned in July. A prolonged heat wave occurred from July 13 to July 21, with temperatures above 90 °F (32 °C) on every day at many locations. On July 21, readings above 100 °F (38 °C) were reported at some locations. This produced tinder dry fuels.

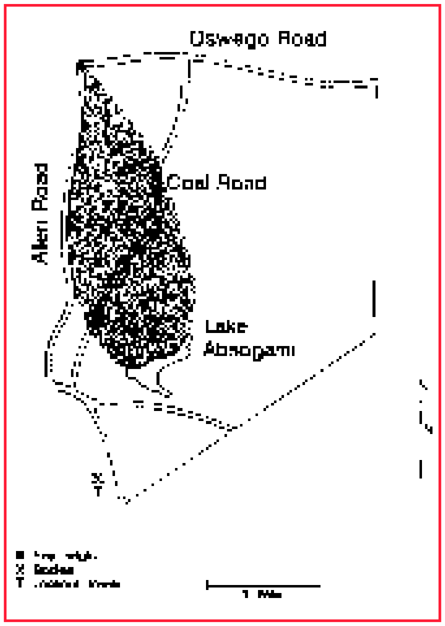

Figure 1—*Map of the Bass River Fire.*

Bass River Fire

The Bass River Fire started at approximately 1500 hours eastern daylight time (EDT) on July 22 near the intersection of Allen and Oswego Roads (fig. 1). The exact cause of the fire has not been determined, but arson is suspected. A thick column of black smoke, indicating rapid burning, was spotted at 1501 EDT by the lookout tower several miles to the south.

An initial attack group was dispatched to the scene. Additional fire equipment was sent at 1525 EDT, so that by 1540 EDT there were nine fire units working the fire. At 1546 EDT, when it was apparent that the initial attack had failed, all units were ordered out of the fire area.

At 1600 EDT, a call was sent out to neighboring volunteer fire companies. They were told to report to the area and await instructions.

A brush truck from the Eagleswood Fire Company with four men aboard responded to the call for help. It is not clear why, but this unit mistakenly proceeded into the fire area. At 1800 EDT, a reconnaissance helicopter spotted the charred truck on a narrow, dirt road between Allen and Coal Roads (fig. 1). At 1815 EDT, a search team located the bodies of the four men. Since more accurate information could not be obtained, the only estimate was that the men were trapped sometime between 1600 and 1800 EDT.

When this article was originally published, E.A. Brotak was an Assistant Professor of Meteorology at Kean College of New Jersey, Union, NJ.

* The article is reprinted from *Fire Management Notes* 40(1) [Winter 1979]: 10–13.

The fire itself was not officially controlled until 1500 EDT the next day. A total of 2,300 acres (930 ha) were burned. Most of this occurred in the 3-hour period from 1500 to 1800 EDT on July 22.

Weather Analysis

Early on the morning of the July 22, a dry cold front pushed across the fire area. By the time of the fire, the Bass River State Forest was in the region behind the cold front (fig. 2). This area is noted for major fires in New Jersey (Brotak 1977). An examination of the 500 millibar map (fig. 3) showed New Jersey to be in the southeastern portion of a fairly well developed short wave trough. Again, this is a region noted for strong winds and major fires (Brotak 1977). Surface weather observations in the area (table 1) indicated warm temperature, decreasing humidity, and moderate winds from the north to northwest during the morning.

It is possible that the fire was affected by a surface pressure trough, causing pressure falls and changes in wind speed and direction.

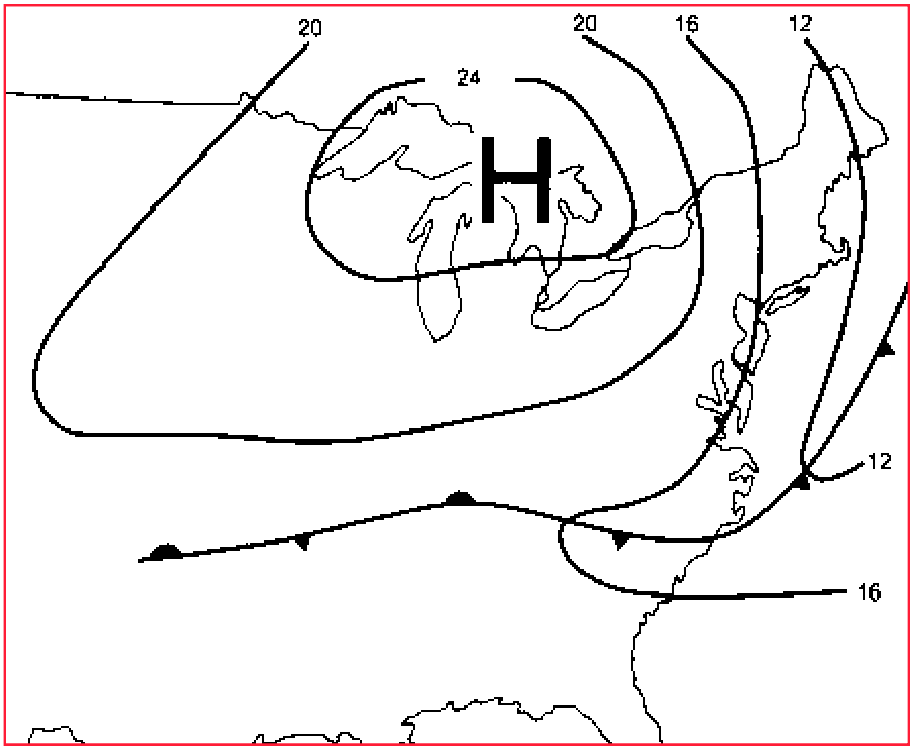

Figure 2—*1400 EDT surface weather map.*

Table 1—*Hourly observations at Atlantic City National Weather Service Office.*

Time (EDT)	*Pressure (milibar)*	*Temperature (°F)*	*Dewpoint (°F)*	*Wind [a]*		*Remarks*
				Direction (°)	*Speed (knots)*	
0155	094	78	66	330	09	—
0252	098	77	66	330	09	—
0353	102	76	66	330	09	—
0451	105	75	66	340	10	—
0553	112	74	67	350	08	—
0651	120	75	66	350	10	—
0755	128	76	65	010	11	—
0850	136	80	64	010	12	—
0951	142	82	58	010	12	Gusts to 20 knots.
1050	146	85	53	010	11	Gusts to 18 knots.
1156	146	86	52	020	12	—
1254	146	86	55	010	10	—
1355	146	86	51	330	12	Gusts to 19 knots.
1450	142	87	49	340	12	Gusts to 19 knots.
1551	140	87	46	350	14	Gusts to 24 knots, smoke layer NE.
1655	146	85	47	330	15	Gusts to 21 knots, smoke layer NE-E.
1755	146	83	45	340	14	Gusts to 20 knots, smoke layer NE-E.
1857	154	80	46	330	12	Smoke layer NE-E.
1955	162	77	47	340	10	Smoke layer NE-SE.
2057	173	70	47	330	06	—
2156	183	70	48	330	08	—
2255	187	69	48	340	08	—
2355	193	67	45	340	08	—

a. Peak wind at 24 knots from the north at 1548 EDT; fastest observed 1-minute wind speed: 17 mph from 330° at 1655 EDT.

Fire managers must know and understand local weather patterns and variance to maximize the efficiency and safety of the suppression job.

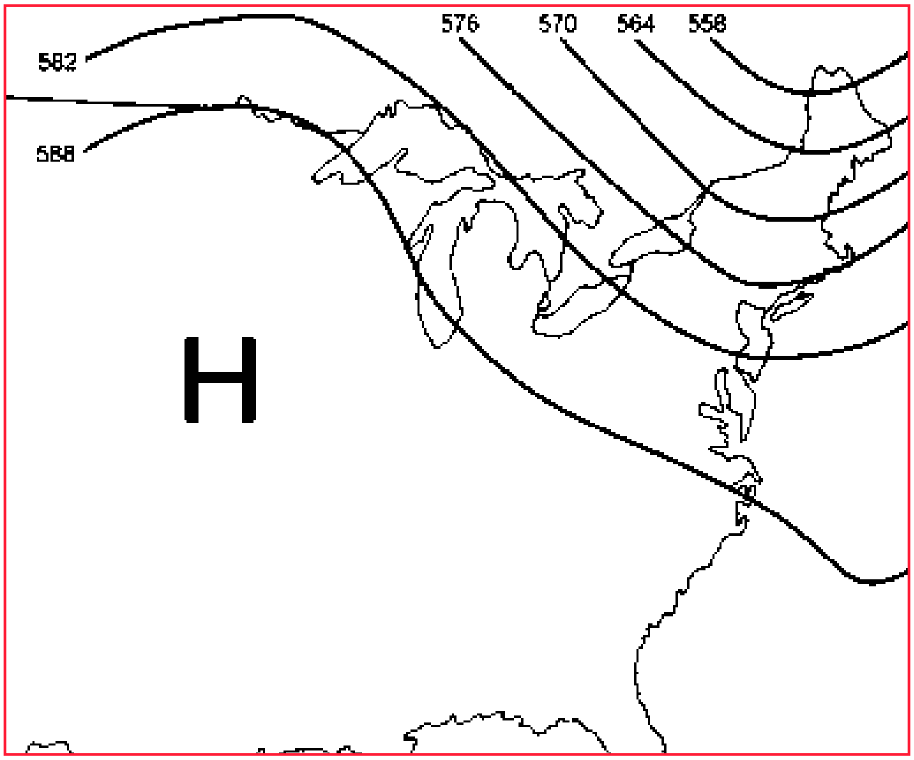

Figure 3—*0800 EDT 500 millibar map.*

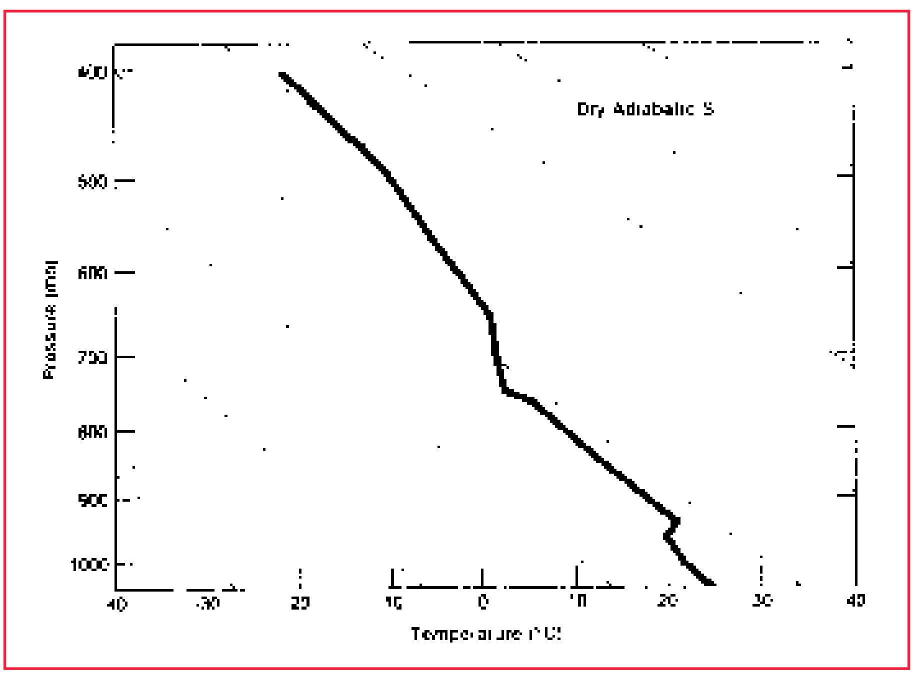

Figure 4—*0700 EDT New York City temperature sounding.*

Fire Behavior

An investigation at the site where the men were trapped indicated two major points. First, from the direction of fire spread, it appears that the wind shifted from the northeast during a part of the fire's run. This is believed to be responsible for trapping the men.

The second point noted was that fire intensity was much greater along this road than in the surrounding burned woods. This would indicate fire storm conditions that made it impossible for the men to survive.

The idea of a classic fire blowup is supported by observations of the fire and its convective column. The spotter in the Bass River fire tower noted flames reaching above canopy height which indicates flame heights of perhaps 40 or 50 feet (12–15 m). An observer a few miles away noted a prominent convective column over the Bass River Fire. It was described as being "capped by a white, billowy cloud"; a classic cumulus top indicating extreme convection.

Although there were other fires in the area, the observer noted that only this fire had a cumulus top. The convective column had maximum development occurring between 1500 and 1800 EDT, the time of blow-up at the surface. The convective column was also picked up on the Atlantic City radar scope, indicating a height of at least several thousand feet.

Atmospheric Instability

One of the prime ingredients for a blow-up fire is inherent instability in the atmosphere. The morning sounding at New York City (fig. 4)

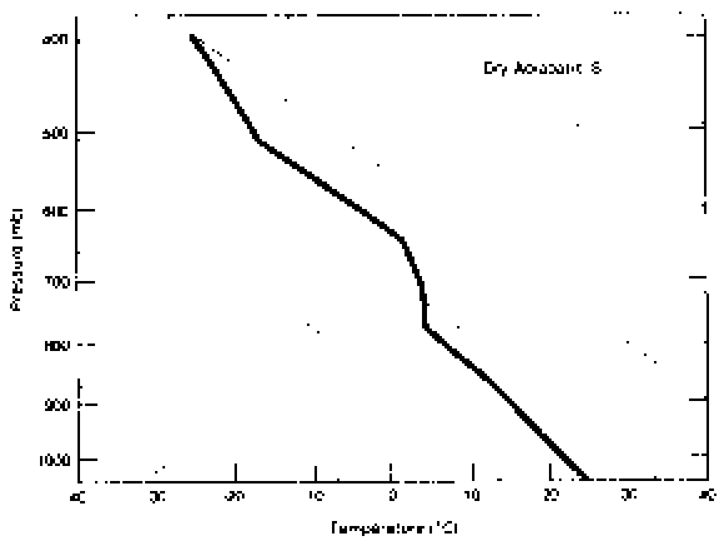

Figure 5—*1900 EDT New York City temperature sounding.*

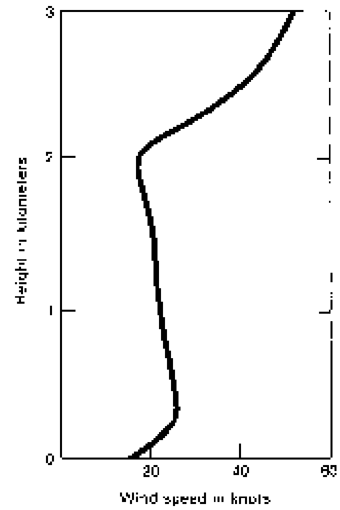

Figure 6—*1900 EDT New York City wind profile.*

showed this inherent instability from the surface to about 6,500 feet (2,000 m). The evening sounding (fig. 5), which is probably more representative of the conditions during the blow-up, showed extreme instability with a nearly dry adiabatic lapse rate from the surface to 6,560 feet (2,000 m). High surface temperatures (table 1) added to the instability. This type of instability probably allowed the convective column over the fire to develop rapidly producing the blow-up at the surface.

An examination of the evening wind profile at New York City (fig. 6) showed moderate sustained surface wind; certainly strong enough to cause fire control problems. It also indicated constant wind speeds with height to an elevation of 6,560 feet (2,000 m). According to Byram (1954), this would allow the convective column to develop more fully, producing blow-up conditions at the surface.

The cause of the wind shift from northwest to northeast was also investigated. A sea breeze was ruled out since conditions were not favorable and such a sea breeze was not observed at Atlantic City. The surface map showed no indications other than the fact that winds are known to be variable behind a cold front. It is possible the fire itself induced such a flow through indrafts.

Pressure Trough

However, another possibility exists that was indicated by the hourly observations at Atlantic City (table 1). The pressure, which had been rising steadily after the frontal passage, fell (from 1400 to 1600 EDT); then began rising again. The temperature climbed steadily throughout the day despite the passage of the cold front, and after 1600 EDT, began to drop off sharply. During the period from 1600 to 1800 EDT, the wind direction went from northwest to north at Atlantic City with increasing speeds and gustiness. The peak gust for the day was from the north at 24 knots and occurred at 1548 EDT.

It is possible that the fire was affected by a surface pressure trough. Such a trough would cause the noted pressure falls and changes in wind speed and direction. The occurrence of a surface pressure trough behind a cold front, with the colder air behind it, is not uncommon in the east. Such a trough could easily be overlooked in the synoptic-scale observation network of the National Weather Service. The relationship of major fires and surface troughs has also been noted before in the east (Brotak 1977).

Summary

In order to avert such tragedies in the future, the possible causes of blow-ups must be determined and understood. Obviously, very heavy fuel loads and tinder dry conditions are contributing factors. Topographic effects, in this case, have been ruled out, since there was only a very slight slope to this basically flat land. Where the terrain is steeper this could have a major impact. Weather conditions play a key role and are extremely complex. Fire managers must know and understand local patterns and variance to maximize the efficiency and safety of the suppression job.

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The Mack Lake Fire*

Albert J. Simard

It was Monday, May 5, 1980. The skies were clear over the Huron National Forest in northeastern Michigan. The plan for the Crane Lake prescribed burning unit called for the establishment of 210 acres (85 ha) of habitat favored by the endangered Kirtland's warbler. After a final check of weather conditions was made, firing started at 10:25 a.m. There was some "spill-over" as firing progressed, but spot fires had been anticipated and were quickly controlled. Around noon, however, the fire jumped into standing timber and quickly ran east toward Highway 33. When it reached the highway, it torched and then spotted 200 feet (60 m) across to the east side of the highway. Thus began the Mack Lake fire.

Rapid Spread

A tractor-plow unit attacked the escaped fire east of the highway within 3 minutes of detection, but to no avail. The fire torched in some reproduction, dropped to the ground briefly in a patch of mature timber, then crowned in a stand of jack pine saplings just 100 feet (30 m) from the highway. The operators of a 6 x 6 tanker unit who caught and passed the tractor later reported that, despite progressing at 4 to 6 miles per hour (6–10 km/hr), they never saw the head of the fire.

Three hours after the fire escaped, it had advanced 6 miles and no amount of line or width of road held or slowed the fire.

While working the north flank about one-half mile (0.8 km) east of Highway 33, the tractor was caught between a crown fire burning northward across its path and a second east-moving crown fire that had crossed the plow line behind the tractor. The operator was trapped and killed in the fire. At this time, the main fire front was advancing eastward at 2 miles per hour (160 chains per hour [3,219 m/h]). This partially resulted from spotting at least a quarter of a mile (0.4 km) ahead of the fire. One hour after the fire had escaped, walls of flame 30 to 50 feet (9–15 m) high passed through the town of Mack Lake, 2 miles (3.2 km) east of the escape. Like so many other large fires, it destroyed many homes while leaving other neighboring houses unscathed.

Three hours after the fire escaped, it had advanced 6 miles (10 km). During the afternoon of May 5th, no amount of line or width of road held or slowed the fire. That afternoon the fire released the energy equivalent of 340,000 barrels of oil, or six times the energy of the Hiroshima atomic bomb.

At 4:30 p.m., a frontal passage brought the usual north wind shift but no rain. By 6 p.m., the fire had advanced an additional 3 miles (5 km) (about 1-1/4 miles per hour [2 km/hr]). Because of the wind shift, however, the fire front had expanded from 2 to 6 miles (3–10 km) wide and was now advancing southward. At this time, firefighters got their first major break—the fire ran out of jack pine. Although the wind did not diminish during the evening and the nighttime relative humidity did not rise above 55 percent, the forward rate of advance dropped to about 7 feet per minute (5 chains per hour [101 m/h]) as the fire burned through hardwood stands.

By daybreak on May 6th, major control efforts were underway. In contrast to the previous day, firefighters experienced little difficulty containing the blaze. The perimeter did not change appreciably after May 5th.

Environmental Conditions

What were the environmental conditions that led to the Mack Lake fire, which took one human life, destroyed or damaged 41 dwellings (including 39 summer homes), and consumed 20,000 acres (8,000 ha) of jack pine in less than 6 hours?

Weather. There was no indication of drought condition at the time of the fire. Total precipitation from January 1979 through April 1980 was near normal. Spring fire danger had been erratic. Except for 2

When this article was originally published, Albert Simard was a project leader for fire management planning. USDA Forest Service, North Central Forest Experiment Station, East Lansing, MI.

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days of moderate danger, it was either too wet to burn (14 days) or the burning index was high to very high (19 days). Although 0.7 inch (0.18 cm) of rain fell on April 30th, midafternoon relative humidities on the 3 days before the fire averaged only 23 percent. As a result, fine fuels had dried completely since the rain. Conditions at 2 p.m. on May 5th were: Temperature, 82 °F (28 °C); windspeed, 18 miles per hour (29 km/h) (gusting to 25+ [40+ km/h]); and relative humidity, 22 percent.

Fuels. The fire made its major run in stands of jack pine that had regenerated after a 16,400-acre (6,600-ha) fire that burned the same area in 1946. Although stocking density, tree height, and stem diameter varied considerably typical stands contained 1,500 sapling- to pole-size stems per acre, 15 to 25 feet (5–6 m) tall. Fine surface fuels (duff, grass, ferns, lichen, and shrubs) averaged 10 tons per acre, and scattered larger material and crown foliage averaged an additional 10 tons per acre.

Jack pine foliage moisture was at the seasonal low (110 percent of oven-dry weight). This is much lower than the post-flush average moisture content and about 30 percent lower than would be expected in late summer. Low foliar moisture probably contributed to the extreme spread rate of the Mack Lake fire, but by itself was probably not a major factor. Surface fuels were in an early transitional stage, but the previous material predominated. Further, because of below normal winter snowfall, the fuels had not been compacted. The fire consumed an average of 11 tons of material per acre. Further evidence of the lack of drought was that most material larger than 1/2 inch (1.3 cm) in diameter was not consumed other than in the piled slash in the prescribed burn area.

Topography. Much of the fire area is rolling with numerous small ridges and valleys. Typical slopes average 20 percent, with elevational differences of less than 100 feet (30 m). Roads are the only barriers to fire spread in the terrain.

The Lessons of Mack Lake

In summary, three key factors contributed to the extreme spread of the Mack Lake fire: Relative humidity of 22 percent, windspeed of 18 miles per hour (29 km/h), and a jack pine timber type. These and similar conditions are not rare in the Northeast. Crown-fire spread rates ranging from 1 to 2 miles per hour (2–3 km/h) and long-range spotting have been reported previously and will be observed again.

Fire managers can learn several important lessons from the Mack Lake Fire:

1. Once a crown fire begins in the jack pine timber type, only a change in weather can slow the fire. Fire managers should consider creating fuel breaks composed of hardwoods.
2. Because residences near jack pine forests are increasing, an expanded program should be developed to tell homeowners about the potential for wildfire damage and how to locate and landscape their homes to prevent loss.
3. Fire managers need to plan carefully the transition from prescribed fire to wildfire control, because abandoning a prescribed fire when control actions begin can allow more escapes that threaten initial attack crews.
4. Because fires in jack pine can develop from initial attack to project scale in 15 to 30 minutes, fire managers need to develop mobilization procedures so that their organizations can respond within that time.
5. Procedures for the safe use and control of heavy-duty equipment need to be emphasized. The speed and ruggedness of the equipment can allow it to outrun backup forces and to lull the operator into a false sense of security.
6. Lake States fire managers need to recognize that, because staff turnovers in this area are more frequent than major fires, special emphasis on training is needed so that firefighters can be prepared for major outbreaks.

Nature works on a much grander scale and longer timetable than people. One or more decades may elapse before all circumstances are just right again, but we must not allow the passage of time to cloud the memory of all the lessons that Mack Lake can teach us. ■

> The fire released the energy equivalent of 340,000 barrels of oil, or six times the energy of the Hiroshima atomic bomb.

Behavior of the Life-Threatening Butte Fire: August 27–29, 1985*

Richard C. Rothermel and Robert W. Mutch

On August 29, 1985, 73 firefighters were forced into safety zones, where they took refuge in their fire shelters for 1 to 2 hours while a very severe crown fire burned over them. The incident took place on the Butte Fire on the Salmon National Forest in Idaho. Five firefighters were hospitalized overnight for heat exhaustion, smoke inhalation, and dehydration; the others escaped uninjured. Investigators estimated that without the protection of the escape zones and the fire shelters, at least 60 of the 73 firefighters would have died. Thanks to preparation of safety zones, the effectiveness of the fire shelters, and the sensible behavior of the firefighters themselves, disaster was averted.

Behavior of the Butte Fire, particularly its explosive movement on the afternoon of August 29, is of vital interest to fire behavior specialists, individual firefighters, and leaders who make tactical decisions based on fire behavior projections. That an already large and intense fire could rapidly escalate to even higher intensity—some have called it a firestorm—and move fast enough to overrun 73 firefighters warrants review by anyone concerned with fire management.

When this article was originally published, Dick Rothermel and Bob Mutch were, respectively, a project leader, Fire Behavior Research Work Unit, USDA Forest Service, Intermountain Research Station, Missoula, MT; and a fire use specialist, USDA Forest Service, Northern Region, Missoula, MT.

* The article is reprinted from *Fire Management Notes* 47(2) [Spring 1986]: 14–24.

> Seventy-three firefighters were forced into safety zones; without escape zones and fire shelters, at least 60 of the 73 firefighters would likely have died.

Immediately after the shelter incident, a review team was dispatched to the Butte Fire to document the meteorological conditions and fire behavior that contributed to the life-threatening run up Wallace Creek. Results of the analysis were distributed to all wildland fire management agencies early the following week. The review team was composed of Dennis Martin and Hank Walters, Forest Service Intermountain Region; Clyde O'Dell, National Weather Service; Dick Rothermel, Intermountain Fire Sciences Laboratory; and Bob Mutch, Forest Service Northern Region. The purpose of this article is to augment and expand the results of the initial review through additional interviews with those who had been on the fireline and an analysis of photographs taken during and after the fire run. Art Jukkala and Ted Putnam of the Missoula Equipment Development Center have also prepared a report on the performance of the fire shelter based on many interviews with those who used it on the Butte Fire (see Jukkala and Putnam 1986).

A separate review of the Butte Fire and adjacent fires in the Salmon River (termed the Long Tom Complex), conducted by the Forest Service Intermountain Region in October 1985, examined such topics as strategy, tactics, and other issues. The results of this review are on file in the Forest Service regional office in Ogden, UT.

Fire Environment

Severe drought characterized weather in the Butte Fire area throughout the summer of 1985, contributing to critically low fuel moisture levels. The fire weather station at nearby Indianola along the Salmon River measured only 0.31 inch (0.79 cm) of precipitation in June and 0.23 inch (0.58 cm) in July. Although more than half an inch (2.5 cm) of precipitation fell on two different days in early August, some of this as snow, only 0.12 inch (0.30 cm) fell between August 13 and August 31. At a remote automatic weather station near the fire, 1,000-hour fuel moisture readings from the National Fire Danger Rating System were rated at 8 percent prior to the run up Wallace Creek.

The weather on the Butte Fire from Monday, August 26, though Friday, August 30, was not unusual considering the location. Elevation at Base Camp was 7,400 feet (2,300 m); elevations on the fire ranged from 6,400 feet (2,000 m) near the confluence of Wallace and Owl Creeks to 8,200 feet (2,500 m) near the two safety zones. Typical late afternoon maximum temperature reached 70 to 78 °F (21–26 °C), with minimum relative humidity in the 12 to 21 percent range at Sourdough Base Camp. The windiest period each day occurred between 1400 and 1500 mountain daylight time. The velocity was generally between 10 and 12 miles per hour (16–19 km/h), with stronger gusts. Inversions occurred each day, breaking between 1130 and 1330. Weather on the day of the blowup, August 29, was not unusual, either. In the afternoon the temperature reached the mid-70's (23–25 °C), and minimum relative humidity was in the upper teens. At base camp, low-level winds were out of the south at 8 to 12 miles per hour (12–19 km) in the afternoon, with occasional gusts to 17 to 20 miles per hour (27–32 km/h). District personnel reported that fuel loadings ranged from 80 to 100 tons per acre in spruce–fir stands in drainage bottoms, to 25 to 40 tons per acre in higher elevation lodgepole pine–fir stands. Fuel models 8 and 10 characterized most of the Wallace Creek drainage.

One unusual feature of the area threatened by fire was the topography. The upper slopes did not converge into sharp peaks as is commonly the case in the Rocky Mountains, but tended to be domelike, with continuous crown cover. Wallace Creek itself was a well-defined north–south drainage that became progressively steeper at its headwaters near the two shelter sites.

General Fire Behavior

The Butte Fire was started by lightning on July 20, 1985. This fire was part of the Long Tom Fire Complex in the Salmon River drainage, which included the Corn Lake, Bear, Fountain, Goat Lake, and Ebenezer Fires. The Butte Fire was first contained on August 5 at just over 20,000 acres (8,100 ha). Strong winds fanned smoldering fuels and spread fire across control lines on August 24 and 25. Fire activity peaked on August 27, 28, and 29, as the fire made runs of 1,000, 2,000, and 3,500 acres (400, 800, and 1,400 ha) respectively. About 3,000 of the 3,500-acre (1,200 of 1,400-ha) growth on August 29 reportedly occurred in about 90 minutes.

> At least three large whirlwinds passed over that were strong enough to knock people off balance.
>
> *—Firefighter Steve Karkanen, describing the fire from a safety zone*

It was during this run up Wallace Creek that the 73 firefighters deployed their fire shelters. Simultaneously, another run of lesser severity occurred in Owl Creek, the drainage east of Wallace Creek. Both columns were characterized by dense black smoke. By midafternoon the Wallace Creek column had reached 15,000 to 17,000 feet (4,600–5,200 m) above terrain and had a firm cumulus cap. Another area of intense fire activity took place on the western flank where the fire spread northward but was apparently pulled into the main fire in Wallace Creek.

Events of August 29

On August 29 wind velocities were not especially high. In the early afternoon, eye level winds were measured at 7 to 8 miles per hour (11–13 km/h) at the confluence of Owl Creek and Wallace Creek. At the higher elevation near the head of Wallace Creek, the local winds were stronger. Division Supervision Jim Steele estimated winds to be 10 to 15 miles per hour (16–24 km/h), with gusts to 20 miles per hour (32 km/h) across the ridges. Measurements nearby confirmed this estimate, but with gusts of 25 to 30 miles per hour (32–48 km/h).

Figure 1 shows the fire area at 0200 in the morning on August 28, the day before the big run, and its extent by 2200 in the evening. By 0200 in the morning of August 29, the fire had spread considerably further, having crossed the lower end of Wallace Creek and moved up the ridge toward Owl Creek. The burned areas in lower Wallace Creek were patchy. Of special importance on the morning of August 29 were the spot fires in the middle portion of Wallace Creek and along Owl Creek at the southeast corner of the fire.

An understanding of the fire control operations is essential to understanding many events during the 29th. Having had little success at close-in direct attack on the 26th and 27th, the overhead team had decided to use an indirect attack strategy. On the 28th and 29th, a tractor line was built along the main ridge on the north end of the fire, approximately 1.5 miles (2.4 km) north of the nearest spot fires in Wallace Creek (fig. 1). Fortunately, the line construction included several safety zones 300 to 400 feet (90–120 m) in diameter at approximately 1/4-mile (0.4-km) intervals. The plan for the 29th was to conduct a burnout operation in the late afternoon when humidity was expected to rise. An aerial drip torch would be used for center firing in the upper end of Wallace Creek. Crews were to be dispersed along the line to burn out from the line after a convection column was developed.

Each time they were hit by a new wave of fire, the firefighters moved, crawling along the ground inside their shelters searching for cooler areas of the safety zone.

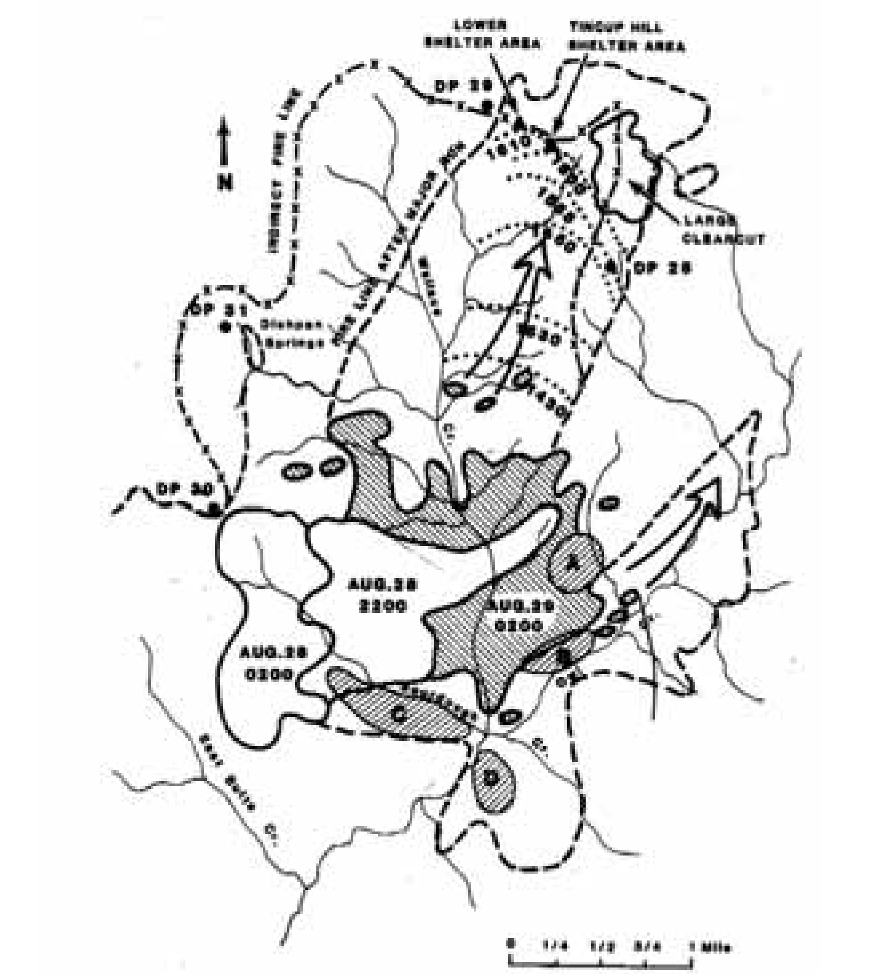

Figure 1—*Arrows depict major fire runs on the Butte Fire during the afternoon of August 29, 1985. The 73 firefighters deployed fire shelters at the lower shelter area and Tin Cup Hill shelter area. Areas A, B, C, and D indicate where the helitorch burnout operation was conducted that afternoon.*

During the morning of August 29, spot fires near the confluence of Wallace and Owl Creeks threatened valuable timber and seemed to have the potential to outflank the control line to the east. Thus, it was decided to use the helitorch early in the day to burn out and stabilize the line in this area. Initial attempts began just to the north of Owl Creek (marked A on fig. 1) about 1200. The area did not burn very well, and ignition attempts were repeated. Bill Williams, the operations chief, reported that this fire was ineffective at developing a significant fire column necessary for improving the fireline.

While attempts to burn out line near Owl Creek were in progress, the fire was developing strength in lower Wallace Creek. Three reports substantiate the development of fire in Wallace Creek. Bill Williams reported a large convection column east of Dishpan Springs. Dave Broberg, division supervisor in Owl Creek, reported two strong columns developing, one near drop point 30 at the upper end of Sourdough Creek and the other east of Dishpan Springs. Gary Orr, the division supervisor on the west side at drop point 30, saw the fire east of him throwing fire brands into Wallace Creek. Orr reported that the fire in this area was becoming active around 1100.

The spots along Owl Creek also became active and developed a strong convection column by 1300 (fig. 2). Smoke from these spots and from the helitorch fire was moving to the north. It appeared to some that these columns were being pulled to the north by the larger column developing to the northwest. With the aid of indrafts to these columns, the helitorch was used to burn out hand line and dozer line in areas C and D near the confluence of Sourdough and Owl Creek.

Meanwhile, Gary Orr at drop point 30 reported lots of fire in lower Wallace Creek. Considerable red coloration could be seen in the smoke columns, and at 1300 or 1400 the fire was intensifying and moving up Wallace Creek. The helitorch continued burning out the line in area C. Later, at approximately 1500, area D was burned according to Bill Williams and Dave Broberg. Photographs looking north taken from a helicopter just to the south of the convergence of Sourdough, Wallace, and Owl Creeks (fig. 2) show the smoke columns building at about 1515. From this vantage point, the strongest column was from the burnout operation and spots in Owl Creek. All of the smoke was moving northward up Wallace Creek. The firing operation at the south end of the fire was completed successfully about 1550, and the fire was contained along the southern line just as it was reaching full strength in upper Wallace Creek.

Wallace Creek Run

About 1515, Jim Steele, at the northeast end of the fire, who later went into his shelter at Tin Cup Hill, reported that he was walking on the trail above the large clearcut and could see fire coming up over a ridge to the south. He reported that at that time he could not see fire in Wallace Creek because of intervening smoke and trees. The fire he saw to the south was probably coming out of Owl Creek.

Bill Williams reported that about this same time a large, strong convection column was standing over the fire. This column was within the main northern dozer line, and Bill still hoped to use indrafts from the column to complete the planned burnout in upper Wallace Creek. Because a very severe crown fire started moving to the north up Wallace Creek on a western exposure (the east side of Wallace Creek) though extremely heavy fuels, the helitorch was never used in this area as originally planned.

Gene Benedict, the incident commander, was returning to the fire by helicopter between 1500 and 1515 and reported that "while viewing this fire I had three other convection columns in view: Goat Creek on the Salmon National Forest, Hand Meadows on the Payette National Forest (a new start), and a fire on the Nezperce near Cotter Bar. All fires were extremely active with apparent strong convective activity and substantial rates of spread, except for Goat Creek, which was topographically confined."

After 40 minutes in their shelters, they came out, but dense smoke forced them back in again for another 30 minutes; air entering the shelters was remarkably free of smoke.

Figure 2—*Convection column development near the confluence of Sourdough, Wallace, and Owl Creeks at about 1515 mountain daylight time on August 29. These columns originated from spot fires and helitorch operations.*

After landing, Gene received reports that the fire in Sourdough Creek had moved into Wallace Creek and had started firestorm.* Initial reports said it covered about 2 miles (3 km) in 15 minutes. (This later proved to be an overestimation.) Right after the major run, a second run started on the west side near drop point 30, apparently outside the dozer line. Initially, it spread rapidly to the north, but then veered to the east, probably due to indrafts from the larger column in Wallace Creek. This secondary run threatened firefighters along the line on the west side, who were evacuated by pickup truck and helicopter. Although this rescue was overshadowed by the fire shelter deployment, it was nevertheless an intensive effort accomplished safely.

Neal Davis, air attack supervisor, flew by helicopter around the fire just after 1400 and again at 1515. He provided estimates of the fire location in Wallace Creek before the fire developed the extreme behavior reported later. On his next flight, at 1550, Neal saw the firefighters in the safety zones preparing to go into their shelters.

Firefighter Steve Karkanen, working between drop point 28 and the large clearcut at the head of Wallace Creek, recorded the movement of the crown fire as it progressed up Wallace Creek. Steve

* Although referred to as a firestorm, it should more properly be called a conflagration, which is a severe spreading fire. The term "firestorm" is normally used to describe a severe stationary fire or burnout of an area within a conflagration.

Viewed from the air, ahead of the fire, the flames were estimated to be two to three times the tree height.

took color photographs of the fire, recording his location, the direction he was shooting, and the estimated time and location of the fire front. His notes were especially helpful in reconstructing the fire movement. His notes at 1600 describe the nature of the fire as it passed around the large clearcut:

> *Experiencing intense heat and high winds from all directions. At least three large whirlwinds passed over that were strong enough to knock people off balance. The area became too smoky and dusty to take photos. The smoke column completely enveloped everyone, and it was impossible to see the fire. Visibility was reduced to zero several seconds at a time, the air was very hot, and the area was showered with burning embers. Personnel within the clearcut did not take to their shelters, a dozer was used to build fireline around the vehicles, and the pumper crew worked on small spot fires in flashy fuels.*

Personnel at the lower shelter area reported that the fire reached them at 1610. Jim Steele reports that the firefighters on Tin Cup Hill went into their shelters approximately 10 to 12 minutes before those in the lower area did. This would have put them in their shelters at just about 1600, or a couple of minutes before. Steele further reports that the fire approached them at about 1545 out of a draw to the southeast. While Steele was preparing to get into his shelter, he talked by radio to Strike Team Leader Ron Yacomella at the lower shelter area approximately 1,000 feet (300 m) away. Ron asked if he should start his backfire at this time, which he did. His crew burned out approximately 200 feet (60 m) in front of the lower shelter zone before the fire hit at 1610. Their backfire started easily. At first strong indrafts pulled the fire and smoke toward the fire front, but later the smoke blew back over the crew.

The Nature of the Fire

From observations by Neal Davis, Steve Karkanen, Jim Steele, and Ron Yacomella, we have reconstructed the probable location and time of the fire front as it moved up Wallace Creek and overran the crews (fig. 1). The rate of spread during the run is derived by scaling the distances from the map at each timeline.

It appears that up until about 1530, although crowning and developing strong convection columns, the fire behavior was similar to the behavior observed on the two preceding days (table 1). The spread rate was low, about 1/3 mile per hour (0.5 km/h). After 1530 the fire spread much faster, with an average rate of about 2 miles per hour (3.2 km/h) and a maximum of about 3-1/2 miles per hour (5.6 km/h). This period was described as a firestorm by observers. The fire had to travel slightly over 1 mile (1.6 km) in half an hour to reach the safety zone. In order for the firefighters to reach the large clearcut from the lower safety zone, they would have had to begin the evacuation by 1530.

As with any fire, this one must have moved by surges, with some periods of little or no spread. The reconstructed spread rates are too coarse to show the surges and appear to be slower than the impression received by observers on the ground.

Jim Steele reported that on Tin Cup Hill, firefighters in their shelters were hit by three waves of fire, the first one from the southeast. The second one burned up the north side and then burned back towards them at about the same

Table 1—*Behavior of Wallace Creek fire run on the afternoon of August 29, 1985.*

Time period	*Elapsed time*	*Distance*	*Rate of spread*	
1430–1530	60 min	0.32 mi	0.32 mi/h	26 ch/h
1530–1550	20 min	0.48 mi	1.45 mi/h	116 ch/h
1550–1555	5 min	0.29 mi	3.48 mi/h	278 ch/h
1555–1600	5 min	0.14 mi	1.68 mi/h	134 ch/h
1600–1610	10 min	0.15 mi	0.90 mi/h	72 ch/h

time as the people in the lower safety zone were going into their shelters. The third wave hit from the southwest. Each time they were hit by a new wave of fire, the firefighters moved, crawling along the ground inside their shelters searching for cooler areas of the safety zone. At one time they moved away from the dozer piles of slash that had been made during the clearing of the safety zone. After 40 minutes in their shelters, they came out, but dense smoke forced them back in again for another 30 minutes. The air entering the shelters around the lower edges was apparently remarkably free of smoke.

The fire that overran the crews was very large and very intense. Figure 3 shows the nature of the fire as it passed over the shelters and indicates the size of the column in comparison to the trees. In the original color slide, the convection column shows red coloration for hundreds of feet above the trees. The fire at this time was almost certainly an independent crown fire (Van Wagner 1977).

Viewed from the front, the fire appeared as a wall of flame 200 to 300 feet (60–90 m) high. Viewed from the air, ahead of the fire, the flames were estimated to be two to three times the tree height. The fire front was advancing as a typical standing flame with the base of the fire in the trees. The flames in the front were not seen to be rotating or turbulent. The smoke was rising sufficiently so that the flame could be seen clearly. The column rose nearly vertically, then tilted toward the north. The rear of the column was a turbulent, swirling mass impressive in its extreme behavior. After the run, aerial inspection of upper Wallace Creek revealed a large, intensely burned area in which all crown needles and smaller surface fuels were essentially gone. There was, however, no evidence from the air, or on the ground near the shelter sites, of firestorm activity such as that seen on the Sundance Fire in the Idaho Panhandle in 1967. Trees were not laid down in patterns that would indicate large firewhirl activity. Some firewhirls had been observed during the fire, but trees were not knocked down, uprooted, or broken off as they were in the Pack River Valley as a result of the Sundance Fire.

After the run, aerial inspection of upper Wallace Creek revealed a large, intensely burned area in which all crown needles and smaller surface fuels were essentially gone.

Figure 3—*A view of the fire as it reached upper Wallace Creek and overran the fire crews. The crews deployed their fire shelters in safety zones similar to those seen in the foreground. This photo was taken from a helicopter looking toward the east.*

Inside the Fire Shelters

That all the firefighters in the escape zones survived without serious injury borders on the miraculous. Nevertheless, the approach and passage of the fire was a terrifying ordeal. Many, in fact, doubted that they would live though it. The trauma of the event was reflected in interviews with the survivors.

Witnesses, all of them experienced firefighters, said that this was no ordinary crown fire. To some it was a standing wall of flame that reached 200 feet (61 m) above the treetops. Others described it as a huge, rolling ball of fire with a bright orange glow. Some witnesses reported large balls of exploding gasses in the flame front.

Passage of the flame front was accompanied by a roaring sound, like that of a jet airplane or a train. One firefighter found this the most frightening part of the ordeal: “The noise builds up until you can’t hear yourself think and then the ground begins to shake.” He estimated that the shaking and roaring lasted 10 minutes. Over the roar of the fire he could hear the shouts of nearby firefighters screaming for reassurance, followed by shouts of encour-

Passage of the flame front was accompanied by a roaring sound, like that of a jet airplane.

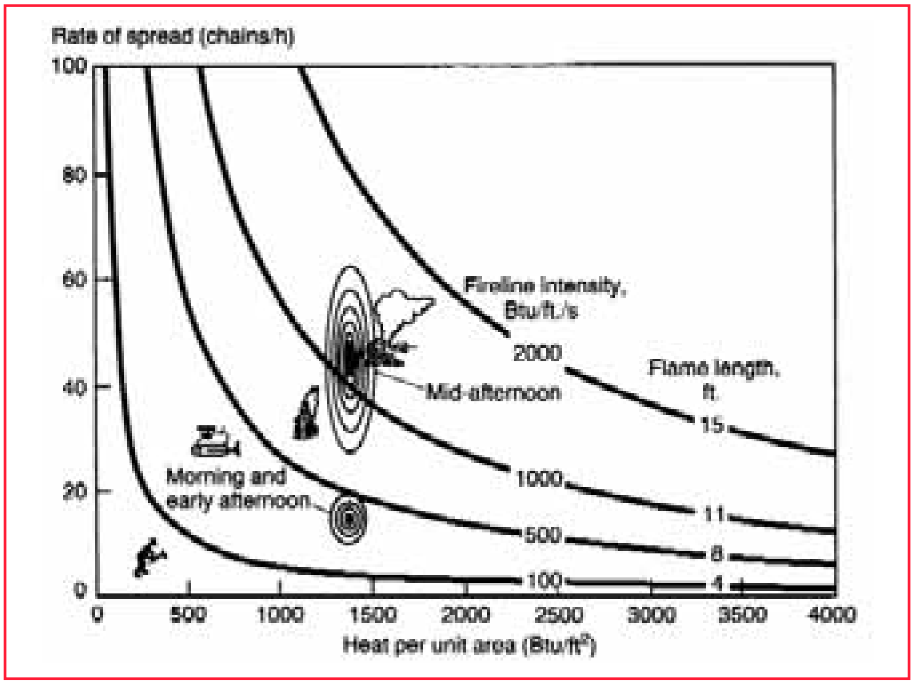

Figure 4—*Fire characteristics on the Butte Fire.*

agement from other firefighters. Strong, fire-induced turbulence made it difficult to deploy shelters and keep them down. One witness reported a feeling of weightlessness, of being lifted off the ground. Another reported the shelter being slammed down against his legs. Within the safety zones, everyone moved as far as possible from the flame fronts by crawling along under the shelter.

Within the shelters, firefighters experienced extreme heat for as much as 10 minutes. Shelters were so hot that they could only be handled with gloves. Light entering the shelter though pinholes changed from dark red at peak intensity, to orange, to white, as the fire passed over. One survivor said that at one point the ground looked as though it had been painted a bright orange. Firefighters learned to evaluate the color of the light as an indication of the fire's intensity in order to judge when it was safe to come out of their shelters.

After leaving the shelters, some firefighters showed symptoms of carbon monoxide poisoning: vomiting, disorientation, difficulty in breathing. Emergency medical technicians administered oxygen to several individuals; five were evacuated to a hospital for treatment and observation. All fully recovered. Among those interviewed, the consensus was that without the shelters none would have survived. A fire fighter with 20 years experience summed it up as follows: "The most frightening, scariest experience I've ever had. The fire was over us, around us, everywhere. I was in Vietnam for a year, but this beats it all."

Factors Contributing to Fire Behavior

Fire activity in the preceding days contributed to the ease with which the fire in Wallace Creek began.

Fire behavior on the afternoon of Thursday, August 29, was a repeat, albeit a much more severe repeat, of the fire behavior of the preceding two days. Each day took out more acreage and consequently left a larger holdover fire for the following day. On the morning of the 29th, the north edge of the fire was uncontained. Fuels were burned in patches, leaving large amounts of scorched fuel and trees within the fire area. The continuous fuels and lack of topographic barriers allowed the fire to move up the slopes of Wallace Creek with only moderate winds. The topography contributed substantially to the fire behavior and difficulty of control. The slopes from the valley bottoms were steep, contributing to rapid upslope runs; the ridge tops were rounded and covered with continuous fuels. Hence, there were no definite fire barriers such as steep rocky slopes, sharp ridges, or scrubby subalpine fuels.

Examination of weather records failed to reveal any factors that would have contributed to the large-scale convective activity observed on August 29. The extremely dry spring and summer probably contributed to the rapid spread of the fire and difficulty in controlling it. As on other fires in the northern Rocky Mountains at that time, tree crowns were extremely easy to ignite. Certainly the dry fuels on the ground also contributed, although the major fire runs at this elevation (6,000 to 8,000 feet [1,800–2,400 m]) carried predominantly though the crowns.

Fire Behavior Analysis

Postfire analysis of the potential fire behavior in surface fuels was made with the BEHAVE fire prediction system (Andrews 1986) and displayed on the fire characteristics chart (fig. 4). Fuel model 10 was used. The values for fuel moistures ranged between 3 and 7 percent. The light winds of the morning and early afternoon would have produced fireline intensities of 250 to 500 Btu/ft.sec, making the fire difficult to control. The stronger midafternoon winds would have produced fireline intensities in the surface fuels of 600 to 1,500 Btu/ft.sec, virtually assuring an uncontrollable crown fire. The range of the conditions is shown by the ellipses on the fire characteristics chart (fig. 4). The inputs to BEHAVE and the outputs produced are shown in table 2.

The calculated rate of spread in the surface fuels was 11 to 19 chains per hour (726–1,254 feet per hour [221–382 m/h]) in the morning and early after noon. The higher windspeeds in midafternoon would have pushed the rate up to 28 to 57 chains per hour (1,848–2,762 feet per hour [563–842 m/h]). We do not have methods for calculating crown fire rate of spread, but it has been found that crown fire spread can be 2 to 4 times faster than the rate of spread calculated for fuel model 10 in fuels exposed to the wind and as much as 8 times faster if the fire is going up steep slopes (Rothermel 1985). If we compare the calculated rate of spread in the surface fuels with the crown fire values given in table 2, we find that for the period 1430 to 1530 the crown fire was 1.4 to 2.3 times faster than the surface fire. In late afternoon, from 1530 to 1610, the crown fire was 2.6 to 5.3 times faster. These values fall within the suggested range mentioned above.

Firefighters learned to evaluate the color of the light as an indication of the fire's intensity in order to judge when it was safe to come out of their shelters.

Table 2a—*Data used in BEHAVE to assess fire behavior in surface fuels on the Butte Fire.*

Element	*Data*
Fuel model	10
Fuel moisture:	
1-hr	3 to 7%
10-hr	6%
100-hr	9%
Live woody	75%
Midflame windspeed:	
Early afternoon (sheltered)	4 to 6 mi/h
Midafternoon (exposed)	10 to 15 mi/h
Percent slope	45%
Wind direction	Directly uphill

There is a great deal of uncertainty in this type of calculation, indicating a strong need for research on crown fire behavior and better guidelines for predicting the onset and spread of crown fires and potential blowup situations.

Conclusions

The type of fire run observed in upper Wallace Creek on August 29 was not unusual for fires in lodgepole pine during the 1985 fire season throughout the northern Rocky Mountains. The high-intensity fire runs were the result of drought-induced, extremely low fuel moistures in all size classes and the speed of the transition from surface fires to torching, spotting, and crowning fires. Because large areas were burning unchecked by either fireline or natural barriers and a southerly gradient wind had reinforced upslope and upcanyon afternoon winds in Wallace Creek, the direction of fire spread and crown fire development before 1530 were not a surprise. The distance the fire spread, from 1530 to 1600, and its severity, were, however, unexpected. The large area of holdover fire adjacent to continuous timber with heavy surface fuels proved to be a juxtaposition capable of generating an

Table 2b—*BEHAVE outputs.*

Time	*Rate of spread*	*Heat per unit area*	*Fireline intensity*	*Flame length*
Early afternoon	11–19 ch/h	1286–1487 Btu/ft^2	251–523 Btu/ft.sec	5.7–8 ft
Midafternoon	28–57 ch/h	1286–1487 Btu/ft^2	664–1563 Btu/ft.sec	8.9–13.3 ft

That all the firefighters in the escape zones survived without serious injury borders on the miraculous.

incredible amount of energy in a short time.

Although crown fires are often associated with strong winds, in this case winds of only 10 to 15 miles per hour (16–26 km/h), with some stronger gusts, were sufficiently strong to channel the flow up the canyon and produce the exceptionally intense crown fire that overran the crews. The question arose as to whether the burnout operation with the helitorch on the south side of the fire directly accelerated the high-intensity run up Wallace Creek. Interviews combined with a careful inspection of burning patterns on a 1/24,000 aerial photo mosaic did not reveal any fire behavior process whereby the helitorch burnout could have accelerated the run up Wallace Creek. The photo mosaic showed a patchy pattern of burned and unburned areas between the helitorch burning at the confluence of Wallace and Owl Creeks and upper Wallace Creek. The burnout operation, however, probably contributed to the shelter incident by preoccupying the attention of some key overhead personnel for so much of the afternoon of August 29. The "eyes in the sky" reconnaissance that had been routinely available on previous days was not available during the critical time on August 29.

Early reports on the Butte Fire estimated that the fire traveled 2 miles (3.2 km) up Wallace Creek in 15 minutes, or a spread rate of 8 miles per hour (13 km/h). This estimate now appears to be considerably higher than the actual rate of spread. Reconstruction of the fire front location at various times indicated that the average spread rate was closer to 2 miles per hour (3.2 km/h) with a maximum of about 3-1/2 miles per hour (5.6 km/h).

The safety zones that were bulldozed into the tractor line at the head of Wallace Creek made it possible for 73 firefighters to safely and effectively use their fire shelters and survive one of the more violent fire runs observed in the northern Rockies in 1985. But, as one crew foreman observed after the incident, "the best safety zone is one where a fire shelter is not needed." This conclusion deserves special emphasis whenever the Butte Fire is discussed.

If an indirect attack strategy is selected, then a fail-safe warning system must be in place to absolutely clear the line of personnel well in advance of a high intensity run.

Preventing Future Incidents

What measures can be taken to prevent such a life-threatening event from recurring in the future? If an indirect attack strategy is selected, then a fail-safe warning system must be in place to absolutely clear the line of personnel well in advance of a high intensity run. Another approach in conifer forests is to select a direct attack strategy, build a line along the flanks of the fire from a well-secured anchor point, and attack the head of the fire only when fuels, weather, and topographic conditions allow firefighters to work safely.

Whatever the strategy selected, the fundamental principles of fire behavior and fire suppression should always guide decisions that affect the health and welfare of the firefighter. Despite the remarkable progress made in fire management in the past quarter of a century—better understanding of fire behavior, better trained and equipped fire crews, more flexibility in attack strategy—conditions like those experienced in the northern Rockies in the summer of 1985 call for extreme vigilance in all aspects of fire suppression. And the safety of the individual firefighter is always the top priority.

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New Jersey, April 1963: Can It Happen Again?*

Joseph Hughes

Whenever New Jersey residents discuss large forest fires, the discussion invariably ends up with what happened in April 1963. As a boy of 14, I remember seeing the headlines and later while traveling to the shore that summer, viewing mile after mile of blackened woodland and burnt foundations.

After I came to work for the New Jersey forest fire service, I was fascinated by the horror stories—tales of a living hell with sheets of fire and houses bursting into flames from the radiated heat. And then there were the acts of heroism, such as the removal of a TV antenna from the tail of a forest fire drop plane that flew too low and the acts of folly, such as the dispatching of useless hook and ladder trucks from Philadelphia. Many of those present during the fires have said that they have never seen anything like it, either before or since. It must have seemed as if the whole world was on fire!

As a firewarden I worry what I would do and how I would react if ever faced with a similar situation. In the last few years, noticing all the development in the South Jersey area, I wonder what would the loss be in terms of human life and damage to improved property if a forest fire disaster of a similar magnitude happened today. The purpose of this case study is to take a look at what actually happened during Apri1 20–22, 1963. What were the preconditions leading up to the event. What was the damage, and finally what we might expect to happen if a similar series of fires occurred today.

I was fascinated by the horror stories—tales of a living hell with sheets of fire and houses bursting into flames from the radiated heat.

Developers in previously wilderness areas of New Jersey often continue to ignore the potential for damage from wildfire.

Weather Conditions

New Jersey, along with most of the East, had experienced severe drought conditions prior to April 20, 1963. The spring had been exceptionally dry and windy, thus far. Only an average of 0.30 inch (0.76 cm) of rainfall had fallen in April, and the total since March 20 at the Lebanon Experimental Forest was only 0.57 inch (1.45 cm). The precipitation deficit had been 3.00 inches (7.62 cm) for March. Precipitation for April was already 2.00 inches (5.08 cm) below normal when April 20 dawned bright, clear, and exceptionally dry. The Build-up Index (Cumulative Drying Factor) was recorded at 115, and the relative humidity was 23 percent at 10 a.m.

In addition to the dryness, wind conditions played a primary role in the havoc that followed. At 9 a.m., wind speeds in a wooded area near the ground were clocked at 12

When this article was originally published, Joseph Hughes was the Assistant State Firewarden for the New Jersey Fire Service, Trenton, NJ.

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It only took three days to devastate New Jersey with some of the worst fires ever reported in the East.

Wildfire in wildland/urban interface area of the New Jersey Pine Barrens.

miles per hour (19 km/h). However, in openings and above treetops velocities averaged 30 to 40 miles per hour (50–65 km/h) with gusts of more than 50 miles per hour (80 km/hr). Not only were velocities high, but the winds were extremely turbulent. Many small whirlwinds developed. Sand and dust storms were prevalent throughout the Delaware Valley wherever plowing or land clearing operations had left soil unprotected.

Prevailing wind directions during the day shifted from northwest to west, back to northwest, then finally shifting to almost north that night. Winds shifted as much as 90 percent within a few minutes.

The turbulent and high velocity winds were caused by the passage of a dry cold front. Later studies of weather records at the Philadelphia Weather Bureau indicated the presence of a low level jet wind over the Philadelphia and South Jersey area on April 20.

Dry and windy conditions combined to make the burning index at Apple Pie Hill Tower 200, highest ever recorded in New Jersey; fire weather conditions were the worst possible.

Origin of the Fires

Several of the fires that reached major proportions started as early as 9 a.m. (table 1). The cause of the largest fire, which burned 76,000 acres (31,000 ha), is well documented. Three fires started between Ongs Hat, Pemberton Road, and Lower Mill in Pemberton Township, Burlington County, between 9 a.m. and 1 p.m. as the result of local blueberry growers burning debris. Permits had been banned and announcements made in newspapers prohibiting burning. However, fires that had been held over in dry fields from the previous day rekindled. Strong winds removed a covering of sand and fanned the smoldering embers to life!

The first of these fires broke out at 9:50 a.m. A strong suppression effort by ground crews, water tankers, and a drop plane operating out of Coyle Field held the fire in check. However, second and third fires broke out in the early afternoon from adjacent properties. These additional fires, combined with winds of 40 miles per hour (65 km/h) and the fact that the plane had been pulled off to fight fires in the Hammonton area, were more than the few tankers and hand crews could handle.

By 8 p.m. the head fire hit the Jersey Central Railroad near Bullock, covering a distance of 9 miles (14 km) in 6 hours, or a sustained average forward rate-of-speed of 1.5 miles per hour (2.4 km/h). However, ground crews and personnel at the scene reported short runs that may have approached 4.5 miles per hour (7.2 km/h).

As the day progressed numerous other fires began to break out throughout the State. Many of the fires burned into the night and through the next day without containment or control. Needless to say, State, county, and municipal firefighting forces were overwhelmed. Reports of large amounts of structural damage began to come in, and some deaths were reported.

Many outside communities, wanting to help in whatever way possible, sent all kinds of equipment and volunteers. As mentioned earlier, hook and ladder and street cleaning trucks came from Philadelphia. Unfortunately, these just added to the chaos and confusion. One volunteer fireman was killed when his truck ran into a State truck in the smoke of Route 72, near Coyle Field, on the 76,000-acre (31,000-ha) fire.

A total of 28 major fires (fires of more than 100 acres [40 ha]) burned on April 20 along with 51 smaller fires, making a total of 79 fires for the day. Damage figures were estimated at 183,000 acres (74,000 ha) burned, the single worst day for forest fires in New Jersey since record keeping began in 1906. Damage to improved prop-

Table 1—*Major fires in New Jersey on April 20, 1963.*

Location	*Start time*	*Acres burned*
Division A—North Jersey		
1. Lebanon Township, Hunterdon County	9:00 am	150
2. Warren Township, Somerset County	9:30 am	100
Division B—Central Jersey		
1. Jackson Township, Ocean County	9:54 am	1,200
2. Berkeley Township, Ocean County	10:00 am	700
3. Jackson/Frenchhold Township, Monmouth & Ocean Counties	10:28 am	4,480
4. Brick Township, Ocean County	10:45 am	600
5. Old Bridge Township, Middlesex County	12:13 pm	275
6. Stafford Township, Ocean County	12:30 pm	190
7. Jackson Township, Ocean County	12:30 pm	14,000
8. Pemberton Township, Ocean County	12:30 pm	1,900
9. Pemberton, Woodland, Manchester, Lacey, Stafford & Barnegat Townships, Ocean & Burlington Counties	12:45 pm	74,475
10. Jackson Township, Ocean County	1:08 pm	11,300
11. Marlboro/Old Bridge Townships, Middlesex County	2:15 pm	2,000
12. Howell Township, Monmouth County	2:38 pm	800
13. Evesham/Medford Townships, Burlington County	3:15 pm	575
Division C—South Jersey		
1. Clayton Township, Gloucester County	9:00 am	1,900
2. Mullica Township, Atlantic County	9:20 am	11,500
3. Franklin Township, Gloucester County	9:45 am	600
4. Buena Township, Atlantic County	10:50 am	12,600
5. Monroe Township, Gloucester County	11 :00 am	2,700
6. Winslow Township, Camden County	11:15 am	2,215
7. Lindenwold/Gibbsboro Townships, Camden County	12:10 pm	260
8. Monroe Township, Gloucester County	12:30 pm	2,000
9. Alloway Township, Salem County	12:30 pm	1,000
10. Hamilton Township, Atlantic County	1:00 pm	4,160
11. Hamilton Township, Atlantic County	1:15 pm	15,000
12. Hamilton/Egg Harbor Townships, Atlantic County	1:20 pm	14,500
13. Egg Harbor Township, Atlantic County	4:20 pm	1,250

Twenty-eight percent of the entire forest acreage burned in the Northeastern States in 1963 occurred in New Jersey.

erty was estimated in the millions of dollars, but it would be months before the damage was completely assessed. Moreover, the worst fire disaster in the State's history did not end on April 20.

When April 21 dawned, all of South and Central Jersey was under a thick layer of smoke. Firefighters were tired, having worked throughout the night, but most fires were still burning out of control. The problem was compounded by fires continuing to break out. Twenty-six new fires occurred on April 21, including two major fires in Gloucester County—one in Monroe Township that began at 11:30 a.m. and burned 500 acres (200 ha), and one in Milville Township that began at 2:05 p.m. and burned 160 acres (65 ha).

Fires continued to burn throughout the second day. However, the wind finally abated. Crews began to make headway; several fires were contained or brought under control.

On Monday, Apri1 22, there were 22 new fires including a 400-acre (160-ha) one in Franklin Township, Gloucester County, and a large jumpover from the 13,000-acre (5,000-ha) fire burning in Buena Township, Atlantic County, which consumed an additional 5,500 acres (2,200) and threatened the town of Mixpah before being brought under control.

On Monday night, rain began to fall. The worst was over. Only two new fires occurred on April 23.

During the 3-day period, there were a total of 127 forest fires, 31 of which reached major status. The acreage burned was 190,300 acres (77,010 ha). Nearly 4 percent of the entire land area of the State was burned during the 3-day ordeal. Twenty-eight percent of the entire forest acreage burned in the Northeastern States in 1963 occurred in New Jersey. It was several months before all the damage estimates were in. As the figures came in a grim total emerged. Damage estimates ranged from 1.5 to 9.5 million dollars! A total of 404 structures had been damaged or destroyed (table 2). Worst of all, seven persons had been killed including a family in Jackson Township, and the fireman previously mentioned.

Prognosis for the Future

It's now been 24 years since April 1963. What has happened in that span of time? The woods have grown back in places. People have built new homes where the previous ones burned down, much as people will return and build on a barrier island right after a hurricane has leveled everything. In addition to what was there originally, there has been major development in the Central and South Jersey areas previously burned and in adjacent, equally hazardous areas. Many residents have forgotten about 1963 and those new to the area may be unaware that such a disaster ever occurred.

What would happen if a similar fire occurred in the South and Central Jersey area today? Just taking inflation into account would increase the damage to improved property to $60 million. A new home that sold for $12,000 to $15,000 in 1963 costs at least $85,000 today. In addition, the $5,000 summer cottages of years ago have been replaced by year-round $100,000 estates. None of this takes into account the increases in development or population. It was estimated by a former section warden, now division firewarden, that if a fire similar to the one that burned 14,500 acres (5,900 ha) in

Table 2—*Damage to improved property caused by fires in New Jersey on April 20, 1963.*

186 Houses damaged or destroyed	2 Sawmills	3 Hunting club buildings
191 Outbuildings (sheds, barns, garages, chicken coops)	1 Bar/restaurant	23 Vehicles
12 House trailers	1 Government office building	2 Blueberry fields
5 Camp buildings destroyed, 1 damaged	1 Laundromat	45 Acres of Cranberries
3 Churches	1 Gas station	$70,000 Pulpwood value

Hamilton and Egg Harbor Townships in 1963 and destroyed 12 houses then broke out today, 100 homes would be lost. If a similar multiplier is applied across the board, the loss would approach 1,500 homes with a total estimated value of over $112 million.

It should be emphasized that estimates are just that … estimates! It is impossible to tell what would happen with any degree of accuracy because there are so many variables and so many things have changed.

People have built new homes where the previous ones burned down, much as people will return and build on a barrier island right after a hurricane has leveled everything.

However, I think it can be said with some degree of certainty that if a similar disaster occurred today it would be much worse, and damage estimates would be considerably higher than in 1963.

The stage is set. Two of the three critical factors are already present:

- Highly hazardous wildland fuel, and
- Numerous human ignition sources.

Weather is the third critical variable. Conditions need only be similar to those on April 20, 1963, for a major wildland fire to occur. ■

Wildland firefighter at work.

Horizontal Vortices and the New Miner Fire*

Donald A. Haines

If you were not a member of a fire suppression crew, the afternoon of Mother's Day, May 9, 1976, was a beautiful time to be in central Wisconsin. Skies were mostly clear with the temperature in the high 70's, relative humidity near 20 percent, and winds, light and variable—just the kind of situation that can lead to explosive wildland fires in the jack pine country at that time of year.

> The smoke column split into two separate, slowly revolving vortices, which periodically spilled over the flanks, dropped to the ground, then reformed into a single column.

New Miner Fire

Fire towers reported smoke at 1415. At 1430, when the first forces arrived at the New Miner Fire, they found 2 acres (0.8 ha) of pine logging slash already burning with spot fires several hundred yards to the northeast. A tractor-plow unit was able to complete a circuit around the head of the fire, but the flames jumped the furrow almost immediately.

Within a few minutes the fire entered a pine plantation and began to crown. The fire grew in momentum as a light southwesterly wind pushed it through dense pine plantations and natural jack pine stands. Fire behavior became the major problem. The pine stands began to burn so intensely that flames reached 300 feet (90 m); at one point, suppression forces were concerned that spotting would carry embers across a 2.5-mile (4-km) drainage area and begin a new series of fires on the other side.

Figure 1—*The smoke column on the New Miner Fire after splitting into a horizontal vortex pair. The ambient wind is blowing toward a point to the left of the observer. Photo: Bill Peterson, Wisconsin Department of Natural Resources.*

Other interesting behavioral features quickly developed. As Bill Peterson of the Wisconsin Department of Natural Resources put it, "It appeared that the fire bucket was so full that flames began to spill over the sides." The smoke column split into two separate, slowly revolving vortices (fig. 1). Periodically these vortices spilled over the flanks, dropped to the ground (fig. 2), then reformed into a single column. Horizontal vortex activity along the flanks (fig. 3) threw so many firebrands into unburned fuels that, in some sectors, several lines were plowed parallel to and 200 feet (60 m) out from the (initial) main body before suppression forces contained the lateral spread.

Cylinders of Fire

A tractor operator plowing along the flanks about 20 feet (6 m) from the main body of the fire was trapped as flames from a horizontal

When this article was originally published, Donald Haines was the principal research meteorologist for the USDA Forest Service, North Central Forest Experimentation Station, East Lansing, MI.

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vortex came over the top of his unit. His planned escape route was perpendicular to the flank of the main body of the fire, but this would have taken him into a region of intense fire activity. He escaped, but his tractor unit was destroyed.

Obviously this type of fire activity threatened suppression forces. What was happening? The horizontal vortices that formed in this fire were like slowly rolling cylinders of fire and ash, akin to lazy tornadoes lying on their sides. This type of vortex is a common feature of fluids. However, unlike vertical vortices, such as tornadoes or most fire whirls where the spin is rapid, the angular velocity of this type is usually quite low. These vortices, which may spiral out to the sides while moving downwind, are related to other phenomena: the slow swirls of air in the atmosphere that cause long parallel lines of clouds called "cloud streets" as well as the helical motions in lakes that cause the formation of parallel lines of surface debris.

Wind Tunnel Simulation

We carried out a series of experiments, attempting to create horizontal vortices in a wind tunnel by first placing an electronically heated metal ribbon along the length of the tunnel floor. The heated ribbon simulated the flank of a wildland fire. Smoke generated upstream of the simulated fire flank made the airflow visible.

As expected, buoyant forces caused by the heated ribbon created an upflow of air passing along and above the ribbon. A vertical slit cut into the wind tunnel's side allowed light into the tunnel. The light outlined a thin cross-section of the

> "It appeared that the fire bucket was so full that flames began to spill over the sides."
> *–Bill Peterson, Wisconsin Department of Natural Resources*

Figure 2—*The split smoke column with the counterrotating vortex on the left side of the picture "collapsing and spilling" over the flank of the fire. The ambient wind is blowing toward a point to the left of the observer. Photo: Bill Peterson, Wisconsin Department of Natural Resources.*

Figure 3—*A vortex with a diameter of about 15 feet (4.6 m) on the flank of the fire. Implied airflow is outlined by the curving arrows. Flames are moving out of the main body of the fire at 30- to 50-degree angles and making "rolls" back into the fire. The ambient wind is blowing from right to left in the photograph. Photo: Donald Krohn, Nekoosa Paper Inc., Port Edwards, WI.*

A tractor operator plowing along the flanks about 20 feet from the main body of the fire was trapped as flames from a horizontal vortex came over the top of his unit.

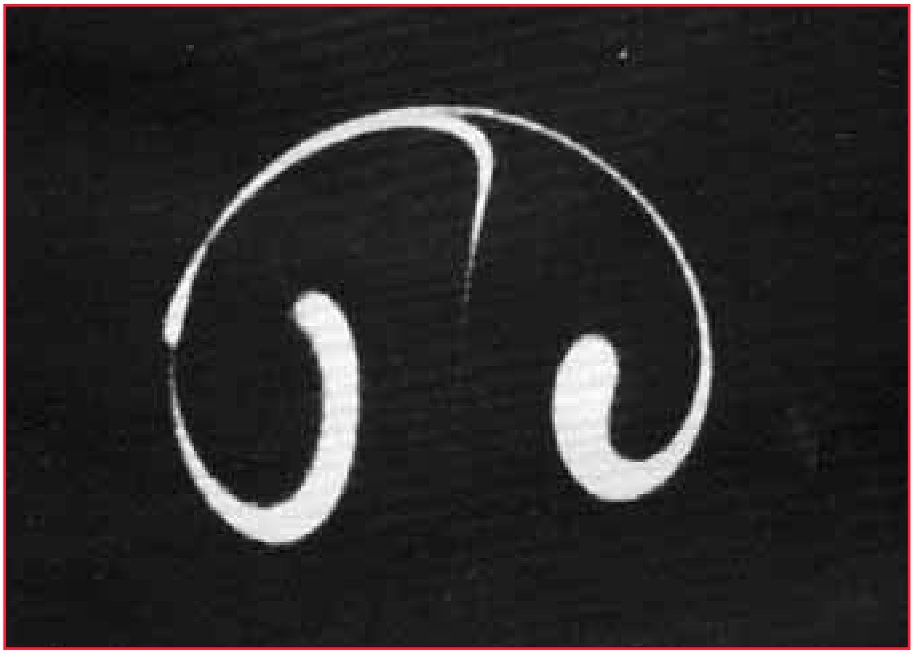

Figure 4—*A laser-illuminated, thin cross-section of a vortex pair generated in a wind tunnel over a heated, longitudinally embedded nichrome wire simulating a fire's flank. The photograph was taken with the camera positioned downstream at the tunnel exit directly on the axis of flow.*

smoke-filled air flow showing that a pair of horizontal vortices had formed, topping the smoke plume (fig. 4). The wind tunnel vortices are so similar to those seen in wildland fires that we believe that the laboratory simulation is close to the real thing.

We still don't understand several facts about these vortices. For example, they form under relatively low windspeeds; therefore, what are the upper limits of windspeed and turbulence intensity that will still allow formation? What is the cause of vortex collapse? We have generated a somewhat similar vortex collapse in a wind tunnel experiment using upstream obstacles that produced a wake effect, but we don't know if this is the same cause and effect relationship seen in nature.

Unlike vertical vortices, such as tornadoes or most fire whirls where the spin is rapid, the angular velocity of this type is usually quite low.

Have You Seen Them?

We would appreciate information from firefighters telling of their experiences with horizontal vortices so that we can compare our wind tunnel results to the wildland situation. Film, pictures, personal anecdotes, and action evidence of horizontal vortices will be gratefully received and acknowledged. Field feedback is essential to our understanding of this process; and understanding the characteristics of these vortices is important in fire behavior, in fire control, and in

An Overview of the 1987 Wallace Lake Fire, Manitoba*

Natural Resources Canada / Ressources naturelles Canada
Canadian Forest Service / Service canadien des forêts

Kelvin G. Hirsch

Wallace Lake is located in eastern Manitoba approximately 100 miles (160 km) northeast of Winnipeg. The surrounding area comprises mainly mature jack pine and black spruce stands and is a popular location for summer cottage developments. Spring fires in this area are not uncommon, but the 1987 Wallace Lake Fire was one of the most devastating wildfires in modern times.

It also has special significance for two main reasons. First, it was the first campaign fire in Manitoba during which the Canadian Forest Fire Behavior Prediction (FBP) System (Lawson and others 1985) was used operationally to forecast probable fire behavior on a near real-time basis. Second, the fire produced one of the worst wildland/urban interface incidents in the province's history.

Dry Conditions

The Wallace Lake Fire started on Tuesday, May 5, and by May 13 reached its final size of 51,520 acres (20,850 ha). The winter of 1986–87 was unusually warm and much of the fire area experienced below-normal precipitation. Snowmelt occurred rather rapidly in early April due to a strong and persistent upper ridge pattern over the area that produced record maximum temperatures on numerous days. Total precipitation following snow-free cover was minimal. Four weather stations in the general area reported an average of only 0.13 inches (3.4 mm) of rain. The combination of these factors contributed significantly to the low moisture content of the dead forest fuels and in part to the extreme fire behavior that occurred during the first half of May 1987.

> The fire produced one of the worst wildland/urban interface incidents in Manitoba's history.

The majority of the area burned by the Wallace Lake Fire was the result of three separate runs, which took place on May 5, 8, and 12 (fig. 1). The primary cause of these major fire runs was the strong surface winds associated with the passage of three successive cold fronts. Average wind speeds were in excess of 19 miles per hour (30 km/h) on each of these days, with gusts up to 38 miles per hour (60 km/h) being reported. Minimum relative humidity ranged from the high teens to low thirties and maximum air temperature varied from 73 ºF (23 ºC) to 90 ºF (32 ºC).

Valuable Asset

The FBP System was used to predict potential fire behavior (e.g., spread rate and type of fire) and proved to be a valuable asset to the overhead team assigned to the fire. The fire spread projections were sufficiently accurate and reliable to be a major factor in determining evacuation requirements. For

Figure 1—*The Wallace Lake Fire during the initial stages (around 1500 CDT) of its major run on May 8, 1987. Photo: Manitoba Natural Resources.*

When this article was originally published, Kelvin Hirsch was a fire research officer for the Canadian Forest Service, Manitoba District Office, Winnipeg, Manitoba.

* The article is reprinted from *Fire Management Notes* 49(2) [Spring 1988]: 26–27.

The Canadian Forest Fire Behavior Prediction System, first used on this fire, proved to be a valuable asset to the overhead team.

Figure 2—*Aftermath of the Wallace Lake Fire at the shoreline cottage subdivision on May 8, 1987 around 1800 CDT. Photo: Manitoba Natural Resources.*

example, on May 8 the fire jumped the established control line and raced eastward towards the subdivision on the west shore of Wallace Lake at a rate of 2.4 miles per hour (3.9 km/h). A lodge, campground, and 54 of 69 cottages were either damaged or destroyed by this fire (fig. 2). However, no lives were lost, because of the precautions taken by the overhead team.

The extensive property losses at Wallace Lake coupled with the $2.26 million fire suppression costs made the Wallace Lake Fire one of the most expensive wildfires to be fought in Manitoba. This fire did, however, illustrate the value and usefulness of the FBP System on a going fire and showed the potential consequences that many of the other cottage subdivisions in this general area could possibly face in the future.

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Documenting Wildfire Behavior: The 1988 Brereton Lake Fire, Manitoba*

Natural Resources Canada / Ressources naturelles Canada
Canadian Forest Service / Service canadien des forêts

Kelvin G. Hirsch

The documented behavior of free-burning wildfires can be a valuable source of information for both fire researchers and operational staff. For example, in an active fire situation, fire behavior observations provide a basis for suppression personnel to take action and advise personnel. Such information allows them to do the following:

- On a timely basis, inform and update district, regional, and provincial staff of the fire's status.
- Provide information that can be used to brief both the media and the public. Ensure the safety of firefighting personnel by directing them away from potentially dangerous situations.
- Make immediate comparisons between actual and predicted fire behavior.

Also, future benefits can be gained from formally recording the influences of weather, fuels, and topography on a fire's behavior. That information can then be used as an effective training tool for suppression staff since individuals relate well to recent real-life experiences in which they may have been involved.

From a fire research perspective, observations of extreme fire behavior can supplement or verify the data presently used in the development of the Canadian Forest Fire Behavior Prediction (FBP) System. The FBP System database currently consists of 245 experimental and operational prescribed fires and 45 documented wildfires (Lawson and others 1985). Presently, most of the information regarding fire behavior under extreme fire weather conditions is collected from wildfires since it is difficult to arrange and conduct experimental fires successfully under such conditions. A detailed example of a documented wildfire in the Northwest Territories is provided by Alexander and Lanoville (1987).

> Fire behavior information can be an effective training tool for suppression staff since individuals relate well to recent real-life experiences in which they may have been involved.

This article summarizes the information needed to document wildfire spread rates and illustrates that this is not a complicated process but merely one that requires a few key observations. An example, taken from the information recorded by the suppression staff at the 1988 Brereton Lake Fire in southeastern Manitoba, has also been included.

Information Requirements

A summary of the information required to document accurately wildfire spread rates is given below. The FBP System user guide provides a more detailed account of the information needed (Alexander and others 1984).

Forward Rates of Spread. The position of the head fire at various times during a major run needs to be recorded. Observations can be made easily if landmarks such as roads, creeks, and hydro lines are used to plot the progression of the fire on a topographic map, forest inventory map, or recent aerial photograph.

Position of the Flanks. Mapping or noting the positions of the fire's flanks (along with that of the head fire) permits the length-to-length ratio of the fire to be calculated.

Other Fire Behavior Observations. Other observations not directly required to document the rate of spread but which can be useful in understanding other aspects of fire behavior are as follows:

- Type of fire (surface fire, torching, crown fire);
- Firewhirl development, occurrence of spot fires, and associated distances;
- Flame lengths or flame heights; Smoke column characteristics such as height of column or angle of tilt;

When this article was originally published, Kelvin Hirsch was a fire research officer for the Canadian Forest Service, Manitoba District Office, Winnipeg, Manitoba.

* The article is reprinted from *Fire Management Notes* 50(1) [Winter 1989]: 45–48.

It is worth noting that a photograph can be an exceptionally useful tool in documenting many aspects of a fire's behavior.

- Suppression effectiveness (for example, hand-constructed fire guards are challenged but water bombers are effective);
- Depth of burn;
- Mop-up difficulty; and
- Postfire evidence such as narrow "streets" of unburned trees associated with horizontal roll vortices.

It is worth noting that a photograph can be an exceptionally useful tool in documenting many aspects of a fire's behavior. A photograph is especially valuable if the time it was taken is also recorded. This may be done manually or a camera with a "dateback" attachment can be used.

Fire Weather Observations and Fire Danger Indexes. The most significant fire weather parameter to measure during a major fire run is windspeed and direction. Hourly observations of the wind, along with temperature and relative humidity, if possible, should be made at a weather station near the fire. However, if this is not possible, then estimate these parameters at the fire site by using, for instance, the Beaufort Scale to estimate windspeed. The information could also be obtained from a nearby fire weather station or Atmospheric Environment Service (AES) station. Inclusion of the daily fire weather observations that preceded the fire is important for calculating the values of the Canadian Forest Fire Weather Index (FWI) System and for possible future analysis.

Topography and Fuel Type Characteristics. For documentation purposes, details on the topography and fuel type mosaic in the fire area can often be described after the fire has occurred. This may consist of information from 1:50,000 NTS topographic maps, FBP System fuel type maps prepared from Landsat imagery, or forest inventory data. However, observations of the fire's behavior in the various fuel types and on different topographic features should be noted.

Brereton Lake Fire Case Study

Observations of the fire behavior at the 1988 Brereton Lake Fire were made by a number of Manitoba Natural Resources staff members who were coordinating the fire suppression activities and positioned primarily in helicopters. This information was recorded verbally on tape and also onto the district radio logs. Given below is a summary of the recorded fire behavior at various times during the major run on May 1 (fig. 1) and how it relates to the information required for documentation.*

Forward rates of spread:

- 1540 hours: The fire was detected and reported to the Manitoba Natural Resources office in Rennie. It was located just west of the south railway crossing on Highway No. 307 and was less than 0.25 acres (0.1 ha) in size.
- 1550 hours: The fire crowned almost immediately and was heading northward towards the Brereton Lake subdivision.
- 1634 hours: The head fire was estimated to be approximately halfway to Brereton Lake, a distance of 0.9 miles (1.5 km) from the point of ignition.
- 1706 hours: The fire was on the last ridge before the swamp, a distance of 1.5 miles (2.4 km) from the point of ignition.
- 1753 hours: The head fire crossed the north tracks near the subdivision, approximately 1.9 miles (3.1 km) from the point of ignition.

In summary, the fire spread 1.9 miles (3.1 km) in 2 hours and 13 minutes (133 minutes) for a rate of spread of 76.4 feet per minute (23.3 m/min) or 0.88 miles per hour (1.4 km/h).

Position of the flanks:

- 1746 hours: The fire was spreading at the back.
- 1806 hours: The west side of the fire was crowning in black spruce and spreading rapidly.
- 1924 hours: A small spot fire was just east of Highway No. 307.

Other fire behavior observations:

- 1734 hours: The head fire was too intense for crews to work in front of the fire, so suppression efforts were restricted to the flanks.
- 1920 hours: The first cottage was lost to the fire.

It was also noted that the fire was not continuously crowning; that is, some torching was occurring but spread was not sustained through the tree crowns. The fire spread primarily on the jack pine ridges and only occasionally burned through the black spruce stands. Also, some mop-up difficulty was experienced in areas with a southern exposure; however, this was not the case on north-facing sites due to the presence of ground frost at or near the surface.

* Time is central daylight time.

By the evening of May 1, crews were able to secure a fireline completely around the fire using both natural fuelbreaks and constructed fireguards. A major suppression effort on May 2, which included the use of three CL–215 water bombers, prevented any further flare-ups from occurring and effectively brought the fire under control.

Fire weather observations and fire danger indexes:
Fire weather information was not available from the Manitoba Natural Resources office at Rennie, but a number of other sources were used to establish the conditions that existed before (table 1) and during the fire run on May 1. This included the 1300-hour observations from the fire weather stations at West Hawk Lake and Nutimik Lake; the hourly readings on May 1 from the AES stations at Kenora, Winnipeg, and Sprague, Manitoba; and estimates of the conditions by the suppression staff at the fire. At 1700 hours, during the May 1 fire run, the fire weather and fire danger condition observations provided in table 2 were made by fire suppression personnel and substantiated with data from the AES weather stations.

Topography and fuel type characteristics:
The fire area is situated at an elevation of 1,082 feet (330 m) above mean sea level. The terrain is gently undulating and had a minimal effect on the fire's behavior.

The fuel types in this area were primarily mature jack pine (FBP System Fuel Type C–3) with some small stands of boreal spruce (C–2) and trembling aspen prior to leaf flush (D–1). The forest inventory information for the area within the perimeter of the fire has been broadly categorized according to the FBP System fuel type classification. A map depicting these fuel types is shown in figure 1.

The most significant fire weather parameter to measure during a major fire run is windspeed and direction.

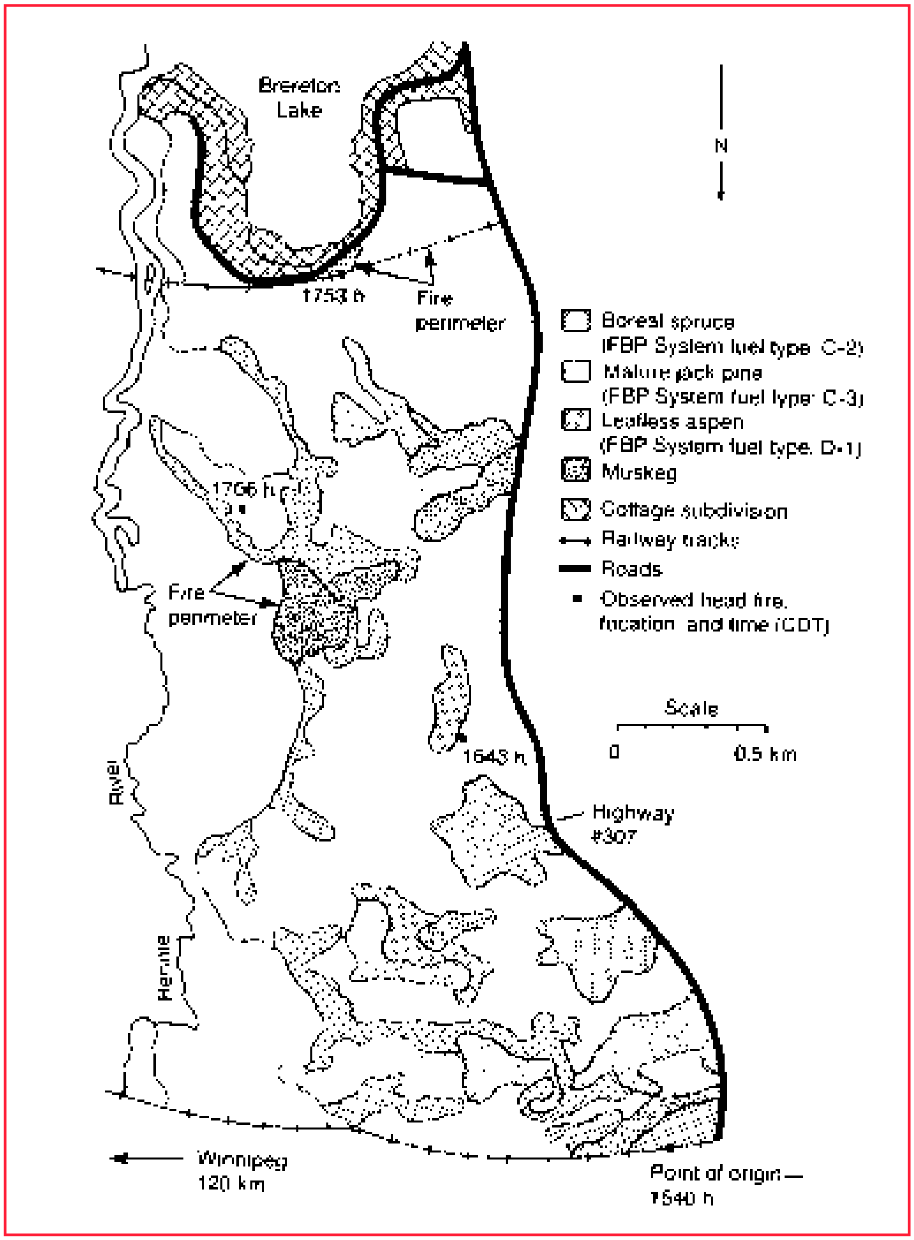

Figure 1—*Fire Behavior Prediction System fuel type and fire progress map for the Brereton Lake Fire, May 1, 1988.*

Observations by Suppression Personnel

During wildfires, suppression personnel are often in the best position to make fire behavior observations. This was true at the Brereton

For documentation purposes, details on the topography and fuel type mosaic in the fire area can often be described after the fire has occurred.

Lake Fire. The efforts of the suppression staff resulted in the collection of useful data. Information of this type serves many purposes such as use at postfire boards of review and verification of the FBP System relationships. Operational staff should be encouraged to make similar observations in the future.

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Table 1—*Fire weather and fire danger conditions that preceded the occurrence of the 1988 Brereton Lake Fire.*

	1300-hr weather observations [a]							*FWI System components* [b]					
	Temperature		*Relative humidity*	*Wind*		*Rain*							
Date	*°F*	*°C*	*(%)*	*mph*	*km/h*	*in*	*mm*	*FFMC*	*DMC*	*DC*	*ISI*	*BUI*	*FWI*
04/21	36	2.0	73	7.8	12.5	0	0	83	30	236	3.1	46	9
04/22	38	3.5	72	0.9	1.5	0	0	83	31	238	1.7	46	5
04/23	43	6.0	49	4.3	7.0	0	0	84	31	240	2.7	47	8
04/24	49	9.5	47	7.8	12.5	0	0	86	33	243	4.3	49	12
04/25	38	3.5	86	8.1	13.0	0.19	4.7	44	22	235	0.1	35	0
04/26	42	5.5	45	5.6	9.0	0.01	0.1	65	23	237	0.8	36	1
04/27	50	10.0	33	9.0	14.5	0	0	81	24	239	2.5	39	6
04/28	64	18.0	19	10.3	16.5	0	0	91	28	244	11.3	44	23
04/29	72	22.0	18	7.8	12.5	0	0	94	33	249	13.6	49	27
04/30	72	22.0	32	9.9	16.0	0	0	93	36	254	14.4	54	30
05/01	73	22.5	40	17.1	27.5	0	0	91	40	260	20.9	58	39

a. Observations from the West Hawk Lake (1,085 feet [331 m] above m.s.l.) and Nutimik Lake (991 feet [302 m] above m.s.l.) fire weather stations were averaged to obtain the values for the Brereton Lake area. These stations are operated by Manitoba Natural Resources and located approximately 19 miles (30 km) southeast and north of the fire area, respectively.
b. FFMC = Fire Fuel Moisture Code; DMC = Duff Moisture Code; DC = Drought Code; ISI = Initial Spread Index; BUI = Buildup Index; and FWI = Fire Weather Index. FWI System calculations began on April 21 with the following moisture code starting values: FFMC = 85; DMC = 30; and DC = 235.

Table 2—*Fire weather and fire danger conditions during a major fire run on the Brereton Lake Fire, May 1, 1988.*

1700-hour fire weather observations: [a]	*Adjusted FWI System values:*
Temperature………………………. 79 °F (26.0 °C)	Fire Fuel Moisture Code………….. 91
Relative humidity…………………. 21%	Initial Spread Index……………….. 22.4
Wind………………………………. SSE 19 mph (30 km/h)	Fire Weather Index………………... 42
Days since rain [b]………………….. 6	

a. Estimates were made by fire suppression personnel and substantiated with data from the AES weather stations at Kenora, 47 miles (75 km) east, 1,348 feet (411 m) above m.s.l.; Winnipeg, 75 miles (120 km) west, 784 feet (239 m) above m.s.l.; and Sprague, 56 miles (90 km) south, 1,079 feet (329 m) above m.s.l.
b. Greater than 0.02 inches (0.6 mm).

Horizontal Roll Vortices in Complex Terrain*

Donald A. Haines and L. Jack Lyon

Observations of horizontal roll vortices (HRVs) are well documented for intense wildland fires occurring on flat terrain (Haines 1984; Haines and Smith 1987). However, there have been no reported observations of HRVs associated with complex terrain. Haines and Hutchinson (1988) suggested that the additional atmospheric turbulence caused by rough terrain might dominate the balance of fluid forces necessary for HRVs and quickly destroy formations. However, we conclude that HRVs did form during an intense Montana wildland fire on a mountain face that was observed by the junior author. This article describes the phenomenon.

What Are HRVs?

HRVs are bent over, very slowly rotating fire whirls that typically form as pairs. HRVs sometimes collapse outside of the fireline, dropping firebrands on suppression crews (Haines and Hutchinson 1988). They are, therefore, a threat to personnel working the flanks, especially near the head of the fire.

HRVs form most often during extreme burning conditions with unstable air and light winds. Higher windspeeds and crossflows cause increased turbulence, which, in turn, causes HRVs to break up. We found that fires with HRVs were among the most intense ever encountered by firefighters.

Horizontal roll vortices sometimes collapse outside of the fireline, dropping firebrands on suppression crews working the flanks of a fire.

Horizontal vortices are common features of fluids, including the atmosphere. However, unlike vertical vortices, such as tornadoes or most fire whirls that spin rapidly, the angular velocity of a horizontal vortex is quite low. HRVs that form in fires develop vertically but bend over easily in light to moderate winds. They typically form as counterrotational pairs at or near the head of a fire and look like slowly rolling cylinders of smoke, flame, and ash, akin to lazy tornadoes lying on their sides (Haines and Hutchinson 1988). Fire-generated HRVs, which may spiral out to the sides while moving downwind, are related to other fluid phenomena: the slow swirls of air in the atmosphere that cause long parallel lines of clouds called "cloud streets" as well as the helical motions in lakes that cause the formation of parallel lines of surface debris.

The Hellgate Fire

The Hellgate Fire began near Missoula, MT, during late afternoon on July 12, 1985. When a suppression crew arrived on the scene 17 minutes after ignition, the fire had already increased to 5 acres (2 ha). Fire behavior included 10-foot (3-m) flame lengths along with crowning and spotting. An 8-mile-per-hour (13-km/h) southwest wind aided fire spread from the ignition point in a valley bottom, up a canyon face with a 50-percent slope. A temperature of 98 °F (37 °C) and a relative humidity of 12 percent resulted in rapid fire spread in cured grass. Fuels in the ignition area were classed as Fuel Model 1 in the Fire Behavior System (Anderson 1982).

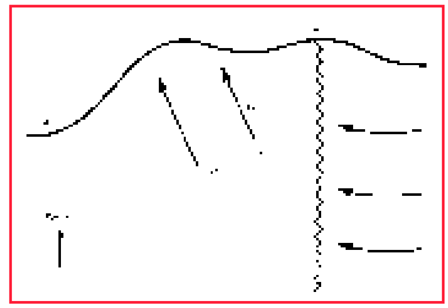

Figure 1—*Terrain and progress of the Hellgate Fire on the late afternoon of July 15. The arrows on the right indicate the direction of the main fire spread along a north–south front (A–A'). The fire had reached the ridge line (B–A) above the Hellgate north face. Spot fires (S1 and S2) then began a simultaneous run to the ridge, their smoke columns forming horizontal roll vortices.*

The fire was not controlled until July 18 after 1,568 acres (635 ha) of forest land had burned. More than 900 firefighters were involved, as well as 23 ground tankers, 8 dozers, 4 rotary-wing aircraft, and 2 fixed-wing air tankers. In total, the strong containment effort indicates the intensity of this fire.

When this article was originally published, Donald Haines was a research meteorologist for the USDA Forest Service, North Central Forest Experimentation Station, East Lansing, MI; and Jack Lyon was a supervisory research wildlife biologist for the USDA Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Missoula, MT.

* The article is reprinted from *Fire Management Notes* 51(2) [Spring 1990]: 15–17.

Horizontal roll vortices form most often during extreme burning conditions with unstable air and light winds over flat topography.

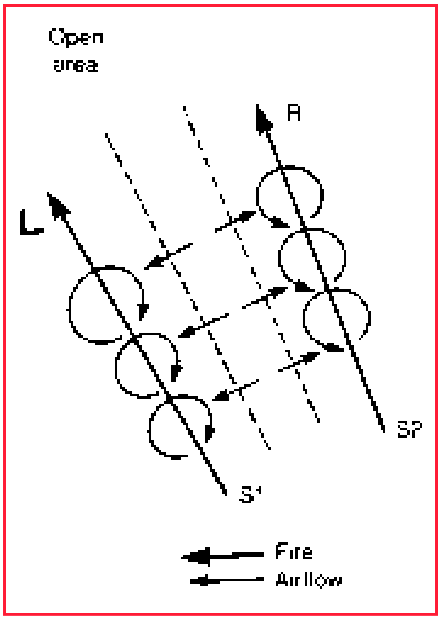

Figure 2—*Suggested airflow into and around the columns on the Hellgate north face. Airflow in the left column (S1) turned clockwise, while airflow in the right column (S2) rotated counterclockwise. Oxygen descended from above into the open area between the columns and spread left and right to feed the columns.*

Description of HRV Activity

HRVs formed during late afternoon on July 15. Observations were made from a distance of 3 miles (5 km) looking south–southeast. The fire had spread horizontally along a canyon wall (fig. 1, A–A') and had reached the ridge line (fig. 1, B–A). A firebrand from the ridge caused a spot fire in unburned timber to the east of the main fire (fig. 1, S1). The area of this spot fire increased rapidly, causing downhill airflow from the ridge. This activity apparently caused a second spot fire (fig. 1, S2). The two spot fire areas both crowned in Douglas-fir and lodgepole pine, and then began a simultaneous run up the Hellgate north face to the main ridge (fig. 1, B–A).

This fire activity took place about midslope on a steep hillside with a vertical rise of 2,600 feet (790 m) from the canyon floor to the ridge. The two columns, each about 300 feet (90 m) in diameter, began to slowly rotate (fig. 2). Banding and rotation of smoke showed that airflow in the left column (fig. 2, L) turned clockwise, while airflow in the right column (fig. 2, R) rotated counterclockwise (fig. 3). Flames were also an integral part of the columns, although they are not apparent in fig. 3.

The space between the two smoke columns was relatively smoke free. This suggests that the major source of oxygen to sustain these fire columns descended from above into the open area (300 feet [90 m] wide) between them and spread both left and right near the surface to feed the two columns (fig. 2). The fire continued this behavior until the two columns reached the ridge. At that point, erratic fire behavior dominated and the two columns stopped rotating.

Implications

Because of the complex airflow and resulting turbulence, HRVs do not form as easily in rough terrain as they do over flat land. However, the behavior exhibited by the Hellgate Fire shows that these fluid structures can form in complex topography. In a typical situation, a single smoke column separates into two columnar vortices. In the Hellgate Fire, HRV formation was aided by two well-defined spot fires that produced two columns. The final results are the same in either situation.

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Figure 3—*The two smoke columns on the Hellgate north face, showing counterrotational banding as well as the clear area between the columns..*

Fire Behavior in High-Elevation Timber*

[logo: Forest Service and CDF (take from FMN 56(3), p. 17)]

Mark Beighley and Jim Bishop

The Fayette Fire was started by lightning on August 21, 1988, near Fayette Lake, on the Pinedale Ranger District of the Bridger–Teton National Forest. On August 24, a major fire run overtook Spike Camp 2. Government and personal gear was lost, but no personal injuries were reported. The fire was controlled on September 14 at a final size of 38,507 acres (15,500 ha).

Unruly Fire Behavior

It became evident early in the incident that standard fire prediction methods, based on the procedures taught us at the Fire Behavior Analyst course (S–590) at NARTC (National Advanced Resource Technology Center, Marana, AZ), were not applicable to the kind of fire behavior we were experiencing on the Fayette Fire. The fire did not spread continuously in surface fuelbeds. Torching, crowning, and spotting were common. In fact they were not just incidental, they were absolutely essential to the movement of the fire. Adjusting the fire model outputs by the use of recommended correction factors also provided unsatisfactory results. Fire spread rates and intensities were extremely sensitive to small variations in fire environmental factors, with quantum steps up or down in spread rate and intensity from small changes of relative humidity or wind.

It became evident early in the incident standard fire prediction methods were not applicable to the kind of fire behavior we were experiencing on the Fayette Fire.

Office for the firm of Beighley, Bishop, and Berkovitz.

We began to look carefully at the fire behavior, noting details of how the fire spread and monitoring the fire environment. Initially an attempt was made to measure spread rates that would allow us to calibrate fire behavior model outputs. Eventually we classified and correlated the fire behavior with important factors such as humidity and wind.

Matching fire behavior "activity levels" with fire history data allowed us to make serviceable spread rate predictions. When weather predictions held true, our forecasts of fire intensity, forward spread rates, and fire perimeter increase proved reasonably accurate. The fire behavior information developed was incorporated into the tactical decision making

When this article was originally published, Mark Beighley was a fire management officer for the USDA Forest Service, Deschutes National Forest, Bend Ranger District, Bend, OR; and Jim Bishop was a State forest ranger, California Department of Forestry and Fire Protection, Butte Ranger Unit, Oroville, CA.

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Torching, crowning, and spotting were not just incidental, they were absolutely essential to the movement of the fire.

process and interpreted in the Incident Action Plan for fireline overhead and firefighters, allowing them to anticipate large increases in fire intensity.

Ignition of tree crowns would occur within minutes of the initiating spot fire.

The fire burned mostly within the Bridger Wilderness on the southwest flank of the Wind River Mountains in Wyoming. Elevations on the fire ranged from 8,000 to over 10,000 feet (2,400–3,000 m). Most of our information relates to elevations between 9,000 and 10,000 feet (2,700–3,000 m), the zones of the fire that remained most active during our tenure from August 24 through September 16, 1988.

Description of the Fire Environment

The environment in which the Fayette Fire took place provided a combination of variables that resulted in a broad range of fire behavior extremes, from total inactivity to conflagration.

The fuels were predominantly mature to overmature lodgepole pine and subalpine fir stands with a high standing dead component. The density of the timber stands varied greatly from nearly closed canopies to scattered stringers of timber on mostly rocky sites. Ground fuels consisted of a light to moderate dead-and-down component of windfallen tree boles with many decomposed logs. A large portion of the understory area was carpeted with grouse whortleberry, a 4- to 8-inch (10- to 20-cm) high herbaceous plant, portions of which were dead. Duff and litter were deep in rocky areas where fallen needles concentrated in crevices, and shallow, less than one-quarter inch (0.6 cm), on flatter, less broken terrain. The surface fuel complex tended to be discontinuous over most of the area.

The terrain varied from well-defined drainages with a 60-percent slope on the lower elevations (8,000 to 9,500 feet [2,400–2,900 m]) to flatter but more broken terrain, dotted with small pothole lakes at higher elevations (9,500 to 10,500 feet [2,400–3,200 m]).

A wide variety of weather conditions were experienced.

The Continental Divide became the final fireline stopping the Fayette Fire. Horseshoe Lake is in the foreground.

Typical fuelbed of discontinuous ground fuels and lots of jackstrawed timber, viewed from the air.

Temperatures approaching 80 °F (27 ºC) and relative humidities in the 10- to 12-percent range occurred on several days, with winds up to 30 miles per hour (48 km/h). During the period from September 10 to 12, measurable precipitation fell, with high temperatures in the 30's (–1 to 4 °C) and minimum relative humidities in the 50's and 60's (10 to 20 °C). Several cold fronts passed through the fire area, and on one occasion strong east winds up to 40 miles per hour (64 km/h) developed unexpectedly.

Fire Behavior Observations

Fire behavior in the previously described fuelbed was observed at close range on several occasions, for periods totaling approximately 30 to 40 hours. In addition to visual observation, measurements were made of spread rates, spotting distances, and time required for an initiating spot fire to generate enough heat to ignite tree crowns and start new spot fires. Simultaneously, observations were made of relative humidity, temperature, wind, and slope. The following description of fire behavior begins with conditions at the low end of the scale of fire activity and progresses to more severe conditions and higher levels of activity.

Low-Level Activity. The daily cycle of fire activity begins with a previous day's holdover fire that is burning in heavy, dead-and-down fuels. No spread is sustained overnight in the fine surface fuels, and even smoldering in the duff is minimal, much of it having gone out during the night when it reached thinner areas. As the day progresses and increasing temperatures and decreasing relative humidity lower fine fuel moisture, the fire begins

The environment in which the Fayette Fire took place provided a combination of variables resulting in a broad range of fire behavior extremes, from total inactivity to conflagration.

to burn more intensely in heavy dead fuels, and it spreads into adjacent lighter fuels including dead, attached branches of trees; low-growing live evergreens such as juniper and lower portions of subalpine fir; and smaller dead-and-down material. Any spread into fine surface fuels at this point is limited to areas immediately adjacent to flaming, larger dead fuels.

Eventually heat builds up under a tree canopy, fire climbs the ladder fuels (which are abundant), and the tree or compact cluster of trees

View of the Fayette Fire from the Pinedale, WY, perspective on August 25, 1988.

Heavy down logs loaded drainage bottoms. These drainages formed wicks which propagated loaded fire spread.

Ground fire spread alone became such an insignificant component that the use of the standard fire behavior spread model was abandoned.

torches out. This kind of sporadic torching commonly begins by midmorning, earlier on drier days and later on more humid days.

When the radiant heat from the torching trees is available to boost the fire, it spreads in the fine surface fuels. As the surface fire spreads away and the radiant heat diminishes, the fine surface fuels generally go out. Occasionally a small "run" takes place in the whortleberry but it requires a little wind and slope to keep it going. One such run measured 9 chains (594 feet [181 m]) per hour (of slope 15 percent, midflame wind of 3 miles per hour [5 km/h], and a relative humidity of 17 percent). Often the flanks of such runs go out and only the head keeps burning.

Torching tree crowns toss out firebrands to distances in the 100- to 200-foot (30- to 60-m) range. The more potent firebrands are commonly branch tips approximately one-quarter inch (0.6 cm) in diameter and fir cones. Firebrands shower an area downwind, but only a small fraction ignite new fires. Nearly all the active spot fires are in dead material in all stages of decay, from sound to decomposed wood. Firebrands landing in sparse grass, grouse whortleberry, or sparse needle litter usually do not light the material but if they do, the new fire goes out quickly.
The spot fires positioned under aerial fuels begin to increase in intensity until the ladder fuels are ignited. Common ladder fuels are a low bushy juniper that grows under the lodgepole pine, the lower foliage of subalpine fir, and dead branches attached to the lower portions of trees. The time for a spot fire to build sufficient intensity to torch out new crowns varies widely and depends a lot on the details of how the fuels receiving the firebrand are positioned relative to the ladder fuels. However, the time to crown torching is frequently an interval of 20 to 90 minutes.

We have termed the activity described above as "low-level." The torching is sporadic and isolated. No fire is sustained in surface fuels or crowns. Occasionally, where continuous fuels are positioned upslope or downwind of torching crowns, sluggish crown fire will move a short distance in the trees. The crowning overall would be classified as "passive." Perimeter advance in areas of continuing activity rarely exceeds 0.3 mile (0.5 km) during a burn period.

Typical spot fire scenario. Spotting, up to 1 1/2 miles (2.4 ha) ahead of the front, was common.

Typical ember landing in grouse whortleberry to start spot fires ahead of the main front.

Spot fire beginning to spread into surrounding fuel.

Moderate-Level Activity. At a level we have termed "moderate," the torching of crowns in isolated trees or small groups of trees is already occurring.

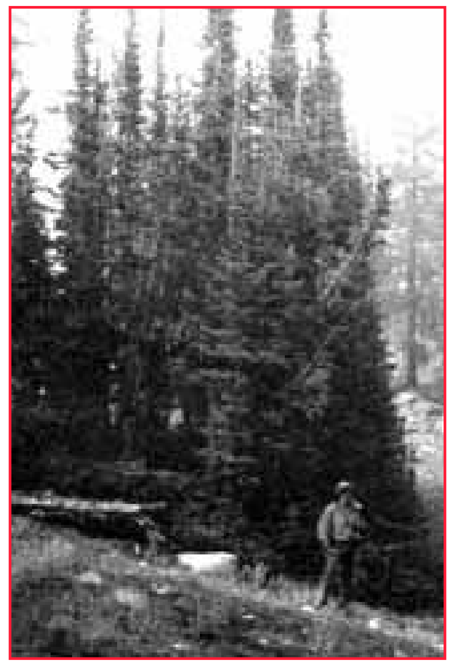
> Fire spread predictions were made using a combination of maximum spotting distances and the probability that a certain level of fire activity would occur for that day.

A key process in raising the overall level of activity is the maintenance of fire spread in the surface fuels. Even in the more severe conditions, spread in fine surface fuels is minimal and limited until it is aided by the radiant heat provided by torching trees or flaming, heavy, dead fuels. Fire in the surface fuels then spreads until it reaches new trees. Some time is required for the new trees to torch out. However, more-or-less continuous crown fire activity can involve patches of trees up to an acre or two (0.4 or 0.8 ha) in size before it dies away. The activity dies out when surface fuel discontinuity prohibits the continued involvement of new trees in torching. The crowning at this point is still essentially passive and dependent upon spread in the surface fuels. This is in contrast to that which occurs in low-level activity, which depends more on the preheating of canopies over individual spot fires and is not dependent on surface fire spread.

Spotting activity continues, of course, and reaches out to approximately one-quarter mile (0.4 km).

At the upper end of moderate-level activity, crown fire runs are sustained that usually end when they reach the top of the slope. During these runs, the fire spread in surface fuels, driven by radiant heat

Fire behavior analyst takes spread rate measurements and observations on an initiating spot fire.



Dead logs under ladder fuel complex. Ignition under low relative humidity conditions caused instant torching of crowns.

Predicting Fire Behavior—The Skillful Art of Combining the Past With the Present To Determine the Future

The Fayette Fire demanded something extra from fire behavior analyst—on-the-line fire prediction improvisation. Spotting was not just incidental to the fire, it was an essential element to fire spread. What was the environment like where this fire burned?—overmature lodgepole pine and subalpine fir where at some points canopies were nearly closed and at others stringers of timber trailed through rocky sites, terrain ranging from well-defined drainages to flatter broken terrain, and a wide variety of weather conditions. Combining maximum spot fire distances with the probable level of fire activity for the day (determined largely by relative humidity and wind) finally proved the successful method of predicting fire spread.

from burning crowns, keeps pace with the crown fire. Short-range spotting, within a zone extending approximately 15 feet (5 m) ahead of the flame front in surface fuels, aids surface spread. There is an essential, mutually reinforcing interaction between the radiant heat from crowns impinging on surface fuels and the heating of new crowns by the spreading surface fire. The entire fuel complex is aflame, including surface fuel already blackened by passage of the surface flaming front, ground to crowns. This is classified as an "active" crown fire. One such run on slightly sloping terrain with 8- to 12-mile-per-hour (13- to 19-km/h) winds moved at 100 chains (6,600 feet [2,012 m]) per hour.

Spotting reaches out to one-half mile (0.8 km). New long-range spots do not usually spawn new crown runs of significant proportions. They commonly trigger torching and crown fire over small areas. Fire spread during the burn period typically amounts to three-quarters of a mile (1.2 km).

High-Level Activity. On days of "high-level" activity, active crown fire is usually occurring by early afternoon. Low humidities make sustained spread in fine surface fuels prevalent. Without the low humidities and attendant, continuously advancing surface fire, continuous crowning cannot be maintained.

Major runs often develop in zones "seeded" with spot fires by previous days' activity. Significant areas (tens or hundreds of acres) become involved in active crown fire within a few tens of minutes, and major runs take off, driven by wind or slope. When winds reach approximately 15 miles per hour (24 km/h), some independent crowning takes place. Crown fire moves out ahead of the surface fire, at least for awhile. Without higher winds, the independent crown runs are usually narrow and not sustained.

Long-range spotting reaches out to three-quarters of a mile (1.2 km), perhaps more in extreme cases. The long-range spots build rapidly enough to initiate new major crown runs. The fire moves across ridges and basins, with an advance of 3 miles (5 km) in a burning period being typical.

Summary. In summary, the salient features of each activity level are described as follows:

- *Low*—Overall spread is maintained by torching and spotting. Surface fire spread does not aid crowning.
- *Moderate*—Spread is sustained by surface fire, active crowning takes place, but independent crowning is rare and long-range spotting does not give rise to new major runs.
- *High*—Active crowning is common, and independent crowning becomes important. Long-range spotting can initiate new major crown runs.

Prediction Procedures

It is obvious that the mechanism of spread on this fire violated most of the basic assumptions on which the fire spread model is built (that is, no crowning, spotting, or fire whirls; uniform, continuous fuelbed; and source of ignition no longer influencing fire). Occasionally fire spread was limited to surface fuels, specifically in the grouse whortleberry and dead-and-down fuel component. Spread rates using Northern Forest Fire Laboratory Fuel Model No. 10 were well within the range of acceptance for such fire spread. But, overall, ground fire spread alone became such an insignificant component in predicting overall perimeter movement and fire intensity that the use of the standard fire behavior spread model was abandoned. The spot fire program in the BEHAVE System was very useful in predicting maximum spot fire distances. Fire spread predictions were made using a combination of maximum spotting distances and the probability that a certain level of fire activity would occur for that day.

The level of activity and consequent spread rate were closely correlated to two primary factors, relative humidity and wind. To oversimplify a little, the humidity basically determined the level of activity achieved by the fire, and the wind dictated the spread produced by that activity. Without low humidities to accelerate the torching process, the fire was confined to limited spread in the surface fuels, with modest spotting. On several occasions, high winds, 30 to 40 miles per hour (48–64 km/h), failed to produce significant fire spread in the presence of humidities over 20 percent. The wind's major contribution was twofold:

- Provides the horizontal trajectory component necessary to transport firebrands well ahead of the crown fire.
- When the relative humidity conditions supported active crowning, provides the horizontal thrust necessary to convert an active crown fire into an independent crown fire.

The basic activity level was determined by the combinations of humidity and wind that are summarized in the matrix illustrated in table 1. Topography and fuel continuity in the active fire areas were considered and used to modify our initial judgments, up or down.

Not Exactly by the Book

The fire prediction approach outlined above, though not refined, was workable in a situation that defied the conventional approach. We were able to provide useful guidance to the planners and to the firefighting crews.

Some Useful Advice—Observe, Analyze, and Apply. We hope that some of what we have reported is useful to others dealing with fires that have similarities to the Fayette Fire. At the least, we encourage the general approach we took on this fire. Begin with careful observation, continue with analysis of what is seen, and apply what is learned.

Clearinghouse for Fire Behavior Analysis. We encourage comment and input that relates to the information in this report. Furthermore, we would like to see the fire behavior analysis of a given incident routinely summarized and shared with other analysts. The report should address the general nature of the fire behavior, verification, measurements, the adequacy of the prediction system, and any techniques developed to improve prediction capability. Perhaps a central repository and clearinghouse could be created to make available or distribute the information. ■

Table 1—*Fire activity level matrix.*

Relative humidity (percent)	*Wind speed (miles per hour)*				
	0–5	*5–10*	*10–15*	*15–25*	*25+*
10–13	M–H	H	H	H	H
14–16	M	M	M–H	H	H
17–19	L	L–M	M	M	M–H
20–25	L	L	L–M	L–M	M
25–30	L	L	L	L	L–M
30+	L	L	L	L	L

Note: L = low-level activity, M = moderate-level activity, and H = high-level activity.

The Haines Index and Idaho Wildfire Growth*

Paul Werth and Richard Ochoa

The Haines Index is the first attempt to construct a formal fire-weather index based upon features of the lower atmosphere. Does it work?

The growth of wildfires is related to three broad factors: fuel type, topography, and weather. The National Fire Danger Rating System and the Fire Behavior Prediction System combine these factors to predict the probability and severity of wildland fires. However, these systems have mixed results in predicting extreme fire behavior conditions characterized by intense crowning and spotting. Extreme fire behavior is rare, but when it occurs, fires burn with intense heat and spread rapidly, endangering life and property.

An atmospheric index, the Lower Atmospheric Severity Index (LASI) developed in 1988 by Donald Haines, a research meteorologist with the USDA Forest Service, addresses the problem of how weather promotes extreme fire behavior conditions. This index uses the environmental lapse rate (temperature difference) within a layer of air coupled with its moisture content to determine a LASI number.

This paper compares the values of LASI or the Haines Index, as we will call it, with what occurred on recent large Idaho fires in an attempt to determine its predictive capabilities with regard to large fire growth.

When this article was originally published, Paul Werth and Richard Ochoa were fire weather meteorologists for the National Weather Service, Boise, ID.

* The article is reprinted from *Fire Management Notes* 51(4) [Fall 1990]: 9–13. A related article, "Evaluation of Idaho Wild-Fire Growth Using the Haines Index and Water Vapor Imagery," appeared in the proceedings of the Fifth Conference of Mountain Meteorology; 1990 June 25–29; Boulder, CO, Boston, MA: American Meteorological Society: 187–193.

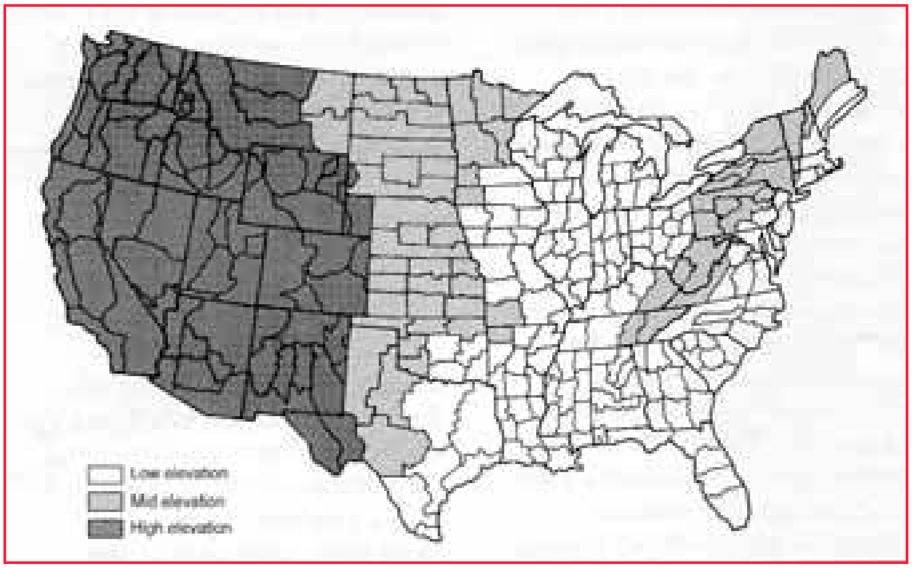


Figure 1—*Map of the United States divided into three regional elevations (Haines 1988).*

Haines Index—Background Information

Research conducted earlier on fires in the Eastern United States had identified unstable air and low moisture as major contributors to fire severity. Haines contacted wildland fire management units throughout the country requesting information on their worst fire situations over a 20-year period. Information was received from 30 States regarding 29 major fires in the West and 45 fires in the East. Data from one to three radiosonde stations closest to each fire were examined to determine air-mass lapse rates and moisture values over the fires. (Radiosonde weather stations launch instrumented balloons that measure atmospheric temperature, relative humidity, pressure, and wind.) The 0000 Greenwich Mean Time/1800 mountain daylight time (MDT) temperature and dewpoint profile for the evenings on which the fires were reported were constructed for one of three layers between 950 and 500 millibars (approximately 2,000 and 18,000 feet [600–5,500 m] above mean sea level [msl]), depending upon the elevation of the fire. Due to large differences in elevation across the United States, three combinations of atmospheric layers were used to construct the LASI.

Figure 1 shows a map of the United States divided into three regional elevations. Much of the Eastern United States, excluding the Appalachian Mountains, uses a low-elevation index computed from 950–850 millibar data (approximately 2,000 and 5,000 feet [600–1,500 m] msl). A mid-elevation index was developed for the Great Plains and the Appalachian Mountains using 850–700 millibar data (approximately 5,000 and 10,000 feet [1,500–3,000 m] msl). A high-elevation index is used for the mountainous Western United States using 700–500 millibar data (approximately 10,000 and 18,000 ft [3,000–5,500 m] msl).

Comparing large fires and nearby upper air data, Haines developed his Lower Atmospheric Severity Index, which indicates the potential for large fire growth. Temperature lapse rate—stability—and moisture values are combined, resulting in the Haines index using:

Haines Index

$$= Stability + Moisture$$
$$= (Tp_1 - Tp_2) + (Tp_1 - Tdp_1)$$
$$= A + B$$

where T is the temperature at two pressure surfaces (p_1, p_2); and Tp_1 and Tdp_1 are the dry bulb temperature and dewpoint temperature at a lower level. All temperature values are written in centigrade.

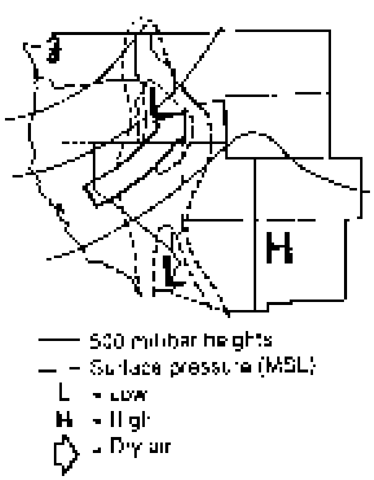


Figure 2—*Typical synoptic situation that produces a moderate to high Haines Index value.*

Extreme fire behavior was exhibited when the Haines Index was 5 or 6, but when the index lowered to 4 or less, fire activity significantly diminished.

Table 1—*Stability and moisture limits in the low-, mid-, and high-elevation Haines indexes.*

Elevation	*Stability term*	*Moisture term*
Low	950–850 mb °T	850 mb °T – dewpoint
	A = 1 when 3 °C or less	*B* = 1 when 5 °C or less
	A = 2 when 4–7 °C	*B* = 2 when 6–9 °C
	A = 3 when 8 °C or more	*B* = 3 when 10 °C or more
Mid	850–700 mb °T	850 mb °T – dewpoint
	A = 1 when 5 °C or less	*B* = 1 when 5 °C or less
	A = 2 when 6–10 °C	*B* = 2 when 6–12 °C
	A = 3 when 11 °C or more	*B* = 3 when 13 °C or more
High	700–500 mb °T	700 mb °T – dewpoint
	A = 1 when 17 °C or less	*B* = 1 when 14 °C or less
	A = 2 when 18–21 °C	*B* = 2 when 15–20 °C
	A = 3 when 22 °C or more	*B* = 3 when 21 °C or more

Illustrated in table 1 are the lapse rate and moisture limits used in the low-, mid-, and high-elevation Haines Indexes.

The Haines Index equals the sum of factor *A* (stability) and factor *B* (moisture):

Haines Index (A + B)	*Class of day (potential for large fire)*
2 or 3	very low
4	low
5	moderate
6	high

Haines found that only 10 percent of large fires occurred when the class of day was very low (Haines Index 2 or 3) though 62 percent of the fire-season days fell in the very low class. Forty-five percent of the fires were associated with the high-class days (Haines Index 6), while only 6 percent of the days fell in that class.

Instability and dry air are key parameters that must be present to result in a high Haines Index num-

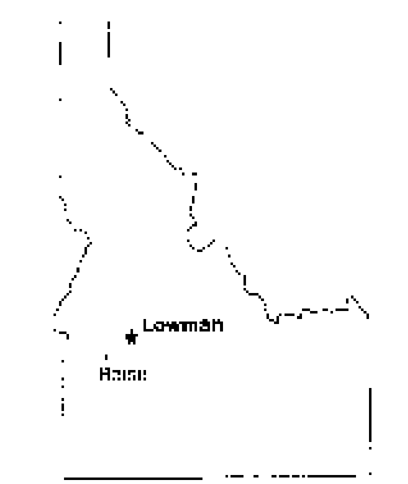


Figure 3—*Map of Idaho with wildfire location.*

Between July and September, the Haines Index showed a high potential for large fire growth on only 6 percent of the days—and those accounted for over 75 percent of the burned acreage.

ber. Instability can be caused by either warming the lower levels of the airmass or by cooling the upper levels. When warming below and cooling aloft occur at the same time, the airmass rapidly destabilizes. In the Western United States, this occurs when cooling, associated with an upper trough of low pressure, moves over a surface thermal trough or "heat low." An increase in moisture usually accompanies the upper trough, but at times a "tongue" of very dry air wraps around the leading edge of the upper trough resulting in low relative humidities at the surface.

Figure 2 displays a typical weather pattern that produces a high Haines Index in the Western United States: a thermal trough at the surface, a 500-millibar trough moving onto the West Coast, and a "tongue" of dry air across the Sierra Nevada Range into the Great Basin and Northern Rockies. This is the classic pattern associated with the "breakdown of the 500-millibar ridge." Nimchuk and Janz (1984) state that the breakdown of the 500-millibar ridge is clearly associated with severe wildfire behavior. However, not every "breakdown of the 500-millibar ridge" will produce extreme fire weather conditions—both instability and dry air must be present. Haines has addressed these two parameters in developing his index.

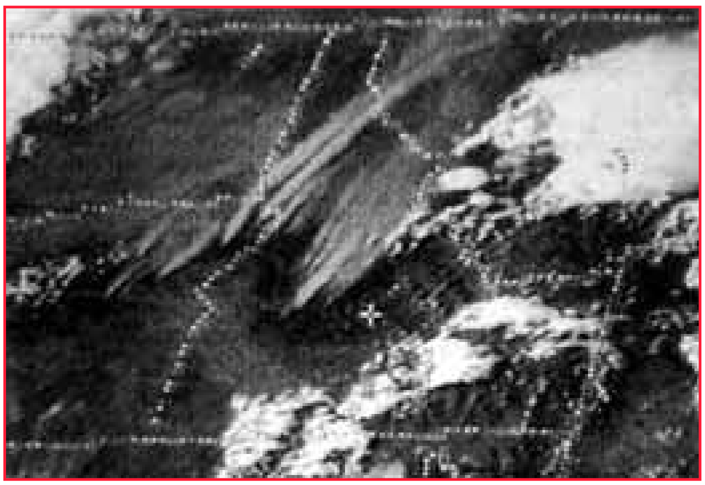


Figure 4—*Late afternoon satellite picture showing large smoke plumes from fires in central Idaho and northeastern Oregon.*

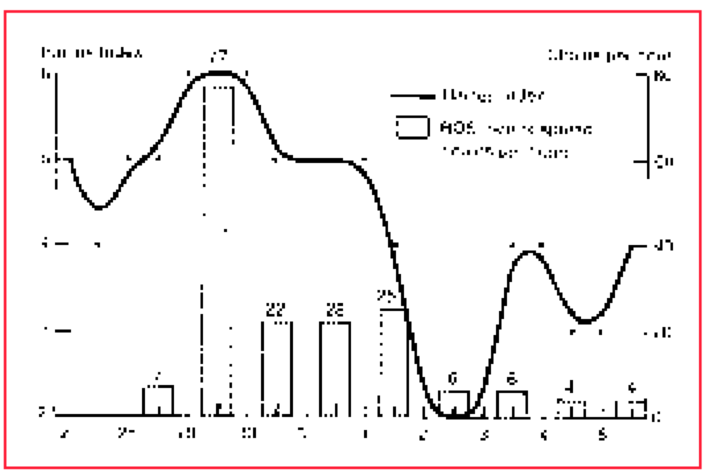


Figure 5—*Haines Index compared with rate of spread for the Lowman Fire, July 27 to August 5, 1989. Key: 6 = high, 5 = moderate, 4 = low, and 2–3 = very low.*

Idaho Wildfires and the Haines Index

The Haines Index is the first attempt to construct a formal fire-weather index based upon features of the lower atmosphere. Does it work? To answer that question, wildfires in central Idaho (fig. 3) were investigated in an attempt to correlate the Haines Index and large fire growth. One of these wildfires was the devastating Lowman Fire of late July and early August of 1989.

The Lowman Fire. The Lowman Fire was one of many fires that started on the Boise National Forest during an outbreak of dry lightning on July 26, 1989. The fire spread only a short distance the following day, but by July 28, fire activity began to increase. Extreme burning conditions developed the afternoon of July 29 (see fig. 4). Crowning and spotting pushed the fire 5.75 miles (9.25 km) to the northeast. The fire burned through the eastern edge of the small town of Lowman destroying 25 buildings and a number of vehicles and closing State Highway 21. All residents of Lowman were evacuated. Fortunately there were no injuries or deaths. The fire continued to spread toward the northeast during the next 3 days, but at a lower rate. Cooler temperatures and higher relative humidities moved over the fire August 2 with very little acreage lost after that date. The size of the Lowman Fire (over 46,000 acres [19,000 ha]), its extreme fire behavior, and the loss of homes and personal belongings will make the Lowman Fire one to remember for many years.

The rate of spread (ROS) exhibited by the Lowman Fire is plotted against the Haines Index in figure 5. On the morning of July 29 (from the 0600 MDT Boise radiosonde), the Haines Index number 6 (fig. 6) indicated a high potential for large fire growth. At approximately 1400 MDT, the fire made a rapid run toward the northeast at well over 75 chains (4,950 feet [1,500 m]) per hour. Temperature at the time was between 90 and 95 °F (32–35 C°) with the relative humidity as low as 8 percent. Surface winds were measured at 5 to 10 miles per hour (8–16 km/h) with occasional gusts to 15 miles per hour (24 km/h), but were much stronger near the fire front due to strong indrafts into the smoke column. For the next 3 days, the Haines Index fell to 5, still indicating a moderate potential for large growth. Although the ROS dropped to 25 chains (1,650 feet [500 m]) or less per hour, the fire continued to move too quickly to fight effectively. The Haines Index (fig. 7) dropped into the low-to-very low range August 2, resulting in a significant drop in the fire's ROS (5 chains (330 feet [100 m]) or less per hour).

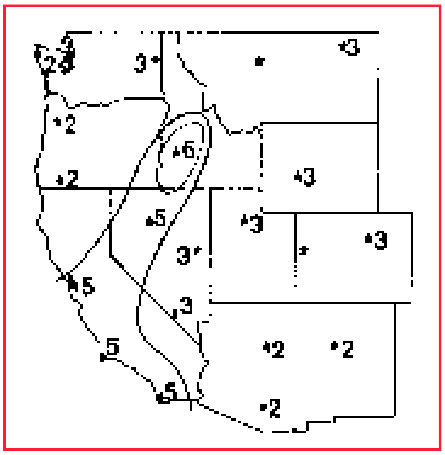


Figure 6—*Haines Index map for 0600 mountain daylight time, July 29, 1989. Solid contour indicates a value of 5 or greater; dashed contour, 6. (The Great Falls, MT, and Grand Junction, CO, data are missing for July 19, 1989.)*

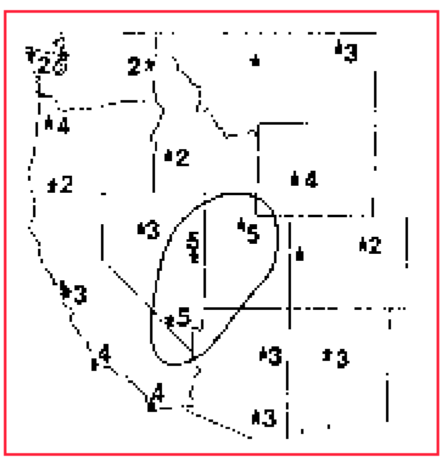


Figure 7—*Haines Index map for 0600 MDT, August 2, 1989. Solid contour indicates a value of 5. (The Great Falls, MT, and Grand Junction, CO, data are missing for August 2, 1989.)*

Extreme fire behavior, with crowning and long-range spotting, was exhibited by the fire when the Haines Index was 5 or 6, but when the index lowered to 4 or less, fire activity significantly diminished.

1990 Results. During the 1990 fire season, the Boise Fire Weather Office included the Haines Index in the daily fire weather forecasts. A computer-generated map of Haines Index values across the Western United States was also produced twice a day, based upon the 0600 and 1800 MDT upper air data. The Haines Index was then compared with the acreage burned on the Boise Fire Weather District (southern Idaho, western Wyoming, and extreme southeastern Oregon) to see if there was a correlation between days in which the index was in the high category and the occurrence of large fires.

Between July and September, the Haines Index was 6 (high potential for large fire growth) on only 6 percent of the days. Over 75 percent of the burned acreage occurred on these days. The Haines Index was 2, 3, or 4 (very low or low potential) on 68 percent of the days. Only 7 percent of the acreage burned on those days. Needless to say, fire activity on the Boise Fire Weather District in 1990 verified the Haines Index.

Summary

The Haines Index, which combines values for instability and dry air, is a valuable indicator of the potential for large fire growth. Dry air affects fire behavior by lowering fuel moisture, which results in more fuel available for the fire and by increasing the probability of spotting. Instability affects fire behavior by enhancing the vertical size of the smoke column, resulting in strong surface winds as air rushes into the fire to replace air evacuated by the smoke column. This is the mechanism by which fires create their own wind.

When the Haines Index number is 5 or 6, the probability of extreme fire behavior (crowning and spotting) significantly increases. Fire behavior is usually low, with only minimal fire growth, when the index number is 4 or less. The Haines Index is best suited to plume-dominated fires: that is, fires where the power of the fire is greater than the power of the wind or the atmosphere. Wind is not a parameter of the Haines Index. The index has yet to be tested on fires driven by winds, such as Santa Ana and Sundowner where the power of the wind is greater than that of the fire.

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Low-Level Weather Conditions Preceding Major Wildfires*

Edward A. Brotak

Since fires are three-dimensional phenomena, managers need to know how the vertical structure of the lower atmosphere as well as the standard surface conditions affect fire behavior.

Knowledge of fire behavior is critical for those who control wildfires. Fire managers must know spread rates and intensity—not just to eventually contain and extinguish the fire but also to keep their fire control personnel safe. Managers realize that weather is paramount in importance when determining how a fire will behave. Besides affecting fuel moistures, meteorological factors also physically change fire. Since fires are three-dimensional phenomena, managers need to know how the vertical structure of the lower atmosphere as well as the standard surface conditions affect fire behavior.

Haines (1988) developed a Lower Atmosphere Severity Index (LASI) for wildfires. This index combined two factors that could influence fire behavior: the vertical lapse rate and the amount of moisture in the air. The vertical temperature structure of the lower atmosphere would influence the convection over the fire. Steep lapse rates, indicating instability, would enhance the convection over the fire, thus increasing the chances of extreme or erratic behavior. The amount of moisture in the lower atmosphere is a factor that influences fuel moisture at the surface. Low humidity values contribute to extreme fire behavior.

When this article was originally published, Edward Brotak was a Professor in the Atmospheric Sciences Department, University of North Carolina–Asheville, Asheville, NC.

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Since the fires in Haines' study occurred at various elevations, he used different pressure levels to indicate the low-level lapse rates. Depending on the actual elevation of the fire, he used either the 950 to 850 millibar (mb) temperature difference, the 850 to 700 mb difference, or the 700 to 500 mb difference. As indicators of moisture content, he used either the 850 or 700 mb temperature and dewpoint difference. The actual LASI that Haines developed is shown in the following equation:

$$\text{LASI} = a(T_{p1} - T_{p2}) + b(T_{p1} - T_{dp}).$$

where T is the temperature at two pressure surfaces (p1, p2), T_p and T_{dp} are the temperature and dewpoint at one of the levels (all temperatures in °C and a and b are weighting coefficients given equal value for this study).

Haines calculated LASI values for 74 fires using radiosonde measurements at 0000 Greenwich Mean Time (GMT). In North America, these are late afternoon or early evening soundings and should usually represent actual conditions when the extreme fire behavior was noted. A vast majority of the fires occurred on days with steep lapse rates and low humidities. Comparisons with the Standard Atmosphere and with a simple climatological data set computed for this study showed that these extreme fire conditions were indeed abnormal. Approximately 5 percent of all fire season days fell into the high-index category of the LASI, but 45 percent of days with large fires or erratic behavior were in this category.

The current study differs from Haines' work in two ways. First, 1200 GMT data were analyzed. These are the morning soundings and would represent typical data available to fire weather forecasters who are trying to predict fire conditions later in the day. As previously mentioned, the LASI was developed using 0000 GMT data when extreme fire behavior was actually occurring. A goal of this study was to see if the instability and dryness of the lower atmosphere, common during the occurrence of extreme fire behavior, is discernible 12 hours earlier. The second difference from Haines' study is the analysis of the vertical wind profile.

The effects of the change in wind speed with height on wildfire behavior have been discussed in several previous studies. Byram (1954) stressed the importance of a low-level jet—stronger winds at low levels with decreasing winds aloft. An interpretation of Byram's work indicates that he was not as much concerned about an actual low-level wind maximum as he was about minimal amounts of vertical wind shear. It has been long realized that a lack of vertical wind shear allows convection to develop. Such a wind profile over a wildfire would allow the convective column above the fire to develop more fully. This would increase the fire's intensity and its potential for extreme behavior. Brotak and Reifsnyder (1977) analyzed 60 fires in the Eastern United States. They found that strong winds throughout the vertical profile were common and in most cases wind speeds increased with height. Although a third of the wind profiles in their study showed low-level jets, even in these cases, wind speeds were much stronger than the Byram model would allow for. It was their conclusion that fires in the Eastern United States, which were mostly at low elevations, were primarily driven by strong winds and that convection above the fire was usually not as important. The current study examines fires at various elevations and in various terrains to see if any correlations exist with the vertical wind profile.

Data

The fires examined were the same used in Haines' study. These consisted of 29 major fires in the West and 45 fires in the East. Soundings from one to three nearby radiosonde sites were analyzed to determine both the vertical temperature and wind profiles. The 1200 GMT data were used, which represented conditions in the morning prior to the extreme fire behavior.

To allow for the varying elevations, the country was divided into three broad regions as shown in figure 1.

A goal of this study was to see if the instability and dryness of the lower atmosphere, common during the occurrence of extreme fire behavior, is discernable 12 hours earlier.

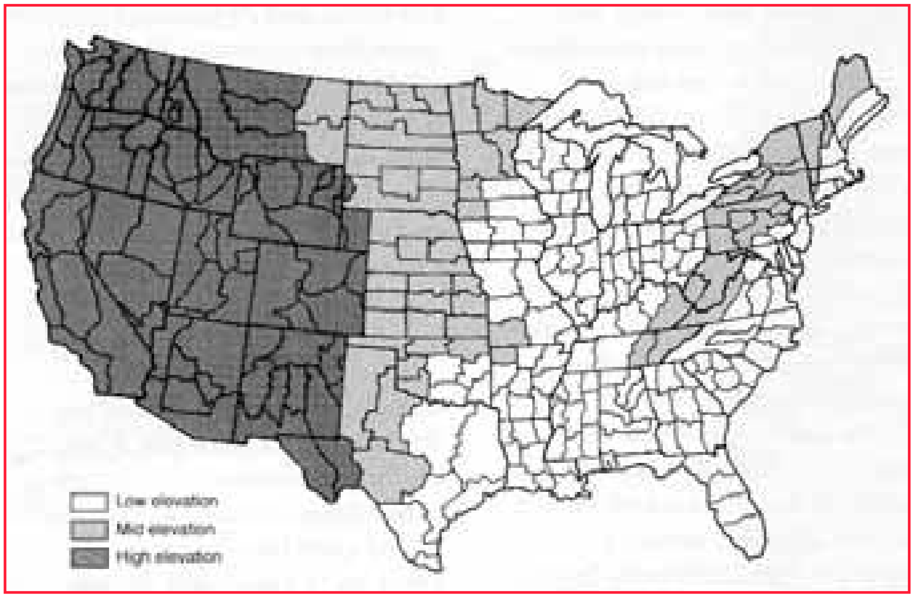

Figure 1—*Map of the United States climatic divisions showing regional elevation aspects of the LASI.*

For much of the eastern part of the country, the 950 to 850 mb temperature difference, the 850 mb dewpoint depression, and the surface to 700 mb wind profile were examined. For the Appalachian Mountains and much of the Great Plains, the 850 to 700 mb temperature difference, the 850 mb dewpoint depression, and the surface to 600 mb wind profile were used. For the high elevations of the Western United States, the 700 to 500 mb temperature difference, the 700 mb dewpoint depression, and the surface to 500 mb wind profile were analyzed. The lapse rate component was broken down into three categories for each level. For a reference point, the Standard Atmosphere (NOAA and others 1976) lapse rate was used. The standard value for the 950 to 850 mb temperature difference is ~6 °C, for 850 to 700 mb it is ~10 °C, and for 700 to 500 mb it is ~17 °C. The

LASI was computed using the following:

$$LASI = A + B$$

A = 1 if 950–850 T < 4 for low-elevation fires or 850–700 T < 6 for mid-elevation fires or 700–500 T < 18 for high-elevation fires.

A = 2 if 950–850 T = 4 to 8 for low-elevation fires or 850–700 T = 6 to 11 for mid-elevation fires or 700–500 T = 18 to 22 for high-elevation fires.

A = 3 if 950–850 T > 8 for low-elevation fires or 850–700 T > 11 for mid-elevation fires or 700–500 T > 22 for high-elevation fires.

B = 1 if 850 $(T - T_d) < 6$ for low- and mid-elevation fires or 700 $(T - T_d) < 15$ for high-elevation fires.

B = 2 if 850 $(T - T_d)$ = 6 to 10 for low-elevation fires or 6 to 13 for mid-elevation fires or 700 $(T - T_d)$ = 15 to 21 for high-elevation fires.

B = 3 if 850 $(T - T_d) > 8$ for low-elevation fires or 11 for mid-elevation fires or 700 $(T - T_d) > 21$ for high-elevation fires.

Analysis

Table 1 shows the breakdown of the fires into the various lapse rate, humidity, and LASI categories. The humidity component of the LASI, either the 850 or 700 mb dewpoint depression, was comparably low for both the 1200 GMT data used in this study and the 0000 GMT data used by Haines. Therefore, dry conditions in the lower atmosphere certainly seem to be a necessary factor prior to the occurrence of extreme fire behavior. The analysis of low-level lapse rates did show differences between the two data sets; the 1200 GMT soundings used in this study indicated less instability.

Table 1—*Percentage of occurrence of fires by LASI variants for 1200 GMT soundings, with 0000 GMT data in parentheses for comparison.*

Low-Elevation Fires (21 Fires)		
Lapse rate 950–850 mb T	*Humidity 850 $(T - T_d)$*	*LASI*
< 4: 24% (4%)	< 6: 10% (9%)	2–3: 14% (2%)
4–8: 62% (13%)	6–10: 19% (22%)	4: 24% (13%)
> 8: 14% (83%)	> 10: 71% (69%)	5: 57% (34%)
		6: 5% (51%)
Mid-Elevation Fires (28 Fires)		
Lapse rate 850–700 mb T	*Humidity 850 $(T - T_d)$*	*LASI*
< 6: 7% (7%)	< 6: 0% (9%)	2–3: 4% (6%)
6–11: 57% (35%)	6–13: 32% (31%)	4: 25% (16%)
> 11: 36% (58%)	> 13: 68% (60%)	5: 43% (45%)
		6: 28% (33%)
High-Elevation Fires (25 Fires)		
Lapse rate 700–500 mb T	*Humidity 700 $(T - T_d)$*	*LASI*
< 18: 12% (13%)	< 15: 4% (7%)	2–3: 4% (10%)
18–22: 48% (34%)	15–21: 24% (17%)	4: 24% (21%)
>22: 40% (53%)	> 21: 72% (76%)	5: 44% (24%)
		6: 28% (45%)

Only 14 percent of the low-elevation soundings were decidedly unstable at 1200 GMT as compared to 83 percent at 0000 GMT. The mid-elevation soundings were only slightly more unstable with 36 percent falling into the least stable category in this study in comparison to 58 percent in the Haines' analysis. The high-elevation soundings showed the least difference between 1200 and 0000 GMT. In both studies, nearly 90 percent of the soundings showed lapse rates greater than the Standard Atmosphere rate.

Low-level lapse rates are significantly affected by the radiation budget of the underlying surface. At night, the surface loses heat, and the lower atmosphere is cooled from below. This produces stable lapse rates at low levels. During the day, the surface gains energy from solar radiation, and the lower atmosphere is heated from below. This produces steep lapse rates and unstable conditions. The result of these processes is a major change in low-level lapse rates from 1200 to 0000 GMT with the 1200 GMT sounding not being particularly representative of conditions later in the day.

The computational problems caused by radiational cooling at night could be dealt with if these effects were concentrated within a nocturnal inversion layer. Lapse rate calculations could be adjusted for some level above the top of the inversion. The soundings were examined specifically for the occurrence of nocturnal inversions. The lowest levels used to calculate lapse rates were almost always above the nocturnal inversion. Only in three cases did the nocturnal inversion reach the 950 mb level for low-elevation soundings.

Although nocturnal inversions were not a problem, other types of inversions were more prevalent. Fourteen of the soundings did display low-level inversions which affected the lapse rate calculations. Strong surface heating during the day could have easily destroyed many of these inversions leading to more unstable conditions by 0000 GMT. As a result of this, the calculated LASI values were lower and were not good predictors of extreme fire behavior.

As previously mentioned, only the high-elevation soundings showed consistency from 1200 to 0000 GMT. This is due to the location of the radiosonde station. Often the radiosonde station is at a much lower elevation than the fire site. The 700 mb temperature, which is considered a near surface temperature for the fire site, is a "free air" reading at the radiosonde location and is not as affected by radiational effects of the surface as lower temperatures like the 850 mb would be.

The analysis of the 12 GMT low-level wind profiles is shown in table 2. There are definite regional differences in these data. Nearly three-fourths of the high-elevation fires in the West occurred with light surface winds and little vertical wind shear. Again, it must be pointed out that the radiosonde sites may not truly represent conditions at the fire location. Certainly, topographic and other local effects could produce stronger surface winds in the mountains.

The lack of strong winds aloft is probably a function of the time of year. As shown in table 3, most of the western fires (high-elevation fires) occurred in the summer when overall pressure patterns are weak. The worst conditions in terms of low fuel moistures also usually occur under an upper-level ridge that favors weak synoptic-scale winds. Fires in the West seem to follow Byram's model where convection over the fire is an important factor. Almost all of the mid-elevation fires occurred when the surface winds were moderate to strong and with substantial vertical wind shear. Low-level jets were noted on 33 percent of the soundings. These fires seemed to fit into Brotak and Reifsnyder's model of wind-driven fires. The majority of these fires occurred in the spring and fall (table 3) when weather systems are stronger. Surprisingly, the low-elevation eastern fires showed no distinctive pattern in the wind analysis. It should be remembered that surface winds usually increase from 1200 to 0000 GMT due to the turbulent mixing during the day.

Summary and Recommendations

Haines' LASI for classifying atmospheric conditions during periods of extreme fire behavior using 0000 GMT soundings was not as useful in predicting these conditions as when 1200 GMT data are used. The destabilization of lapse rates due to solar heating during the day seems

Table 2—*Number and percentage of fire occurrence by low-level wind profile in knots (m/sec).*

Fire elevation	*Wind profile*		
	Light [a]	*Moderate* [b]	*Strong* [c]
Low	12 (6) (48%)	7 (4) (24%)	6 (4) (28%)
Middle	1 (1) (4%)	11 (6) (46%)	12 (6) (50%)
High	13 (7) (72%)	4 (2) (16%)	3 (2) (12%)

a. Surface winds ≤ 5 knots (3 m/sec); upper winds ≤ 25 knots (13 m/sec).
b. Surface winds 5 to 9 knots (3–5 m/sec) and/or upper winds 26 to 34 knots (13–18 m/sec).
c. Surface winds > 9 knots (5 m/sec) and/or upper winds > 34 knots (18 m/sec).

Table 3—*Fires by elevation and month.*

Elevation	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1	—	6	9	2	1	—	2	1	—	—	—
Middle	—	—	—	12	2	—	5	—	4	1	—	—
High	—	—	—	—	1	8	4	9	5	—	1	—

to be the main problem. One possible solution would be to use a predicted afternoon surface temperature to do the calculations with the 1200 GMT soundings. Another possibility is to compare the 1200 GMT values with climatology. This study could only use as reference points the Standard Atmosphere lapse rate and the 0000 GMT results from Haines' study. For the most accurate comparisons long-term averages for each radiosonde station need to be developed.

The analysis of low-level wind profiles also produced mixed results. In many circumstances strong surface winds in conjunction with low fuel moistures cause fire-control problems. Climatologically these conditions are more prevalent in the East. In the West, where the lowest fuel moistures often occur in the summer, strong winds on the synoptic scale are rare. These fires seem to be controlled more by local or topographically induced winds and by convection over the fire.

Acknowledgment

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Those Really Bad Fire Days: What Makes Them So Dangerous?*

Dan Thorpe

After some fires, you often hear comments like this: "There was no way to catch that thing," or "We couldn't have caught that fire even if we'd been there when it started." Unfortunately, such comments are all too often true. In southern Oregon, we started to ask why that was so and what we could do about it. Why do we catch every fire on some days but lose control of fires right from the start on others, even when conditions are apparently the same?

The Problem Fires

The Southwest Oregon District of the Oregon Department of Forestry has about 2 million acres (800,000 ha) and a quarter of a million people. It ranges in elevation from about 500 feet (150 m) in the Rogue River corridor to more than 6,000 feet (1,800 m) in the Cascade and Siskiyou Mountain ranges. The valleys are characterized by annual grasses; at middle elevations, brushy fuels prevail; and second-growth coniferous forest dominates above about 2,500 feet (750 m). Landownership is divided among rural residents, industrial forestry operators, small nonindustrial landowners, homeowners in the wildland–urban interface, and the Bureau of Land Management, which contracts with the State of Oregon for fire protection.

When this article was originally published, Dan Thorpe was the unit forester for the Southwest Oregon District, Oregon Department of Forestry, Central Point, OR.

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Why were we catching some mid-elevation fires but losing others under what seemed to be identical circumstances?

Figure 1—*The 1981 Tin Pan Peak Fire is an example of a plume-dominated fire burning in brushy fuels in the mid-elevation zone. Such fires are responsible for 90 percent of the total acres burned in the Southwestern Oregon District. Photo: Southwest Oregon District, Oregon Department of Forestry, Medford, OR, 1981.*

National forests border the district in the west and east. The district handles more than 1,000 alarms annually, of which about 250 are statistical (bonafide) wildland fires and the rest smoke chases, mutual-aid calls, and no-action responses. About 25 percent of the fires are caused by lightning and the rest by humans. Fire seasons typically run from late May through mid-October and average about 150 days.

On the Southwest Oregon District, we began by mapping past fires that had escaped initial attack. Then we asked our supervisors and firefighters how we could have stopped each fire. All agreed that some fires had been impossible to control during initial attack, no matter how many resources we threw at them; but on others, the right resource at the right time would have made the difference between quickly controlling the fire and watching it grow into a project fire. We compared the answers we got to the results of our computer-modeled initial-attack analysis through the National Fire Management Analysis System. Interestingly, the answers and results corroborated each

> By integrating the Haines Index with information on the fuel condition, we identified 10 days when high fire intensities were likely.

other—anecdotal evidence from our managers agreed with our computer models.

Next, we tried to isolate the common threads among the escaped fires. On a planimetric map, we looked for a common geographical feature that contributed to the escapes. Did a wind corridor, a lightning alley, a roadless area, or steep slopes contribute to preventing control?

When we overlaid the large fires with some crude fuel typing, we found that the major fires—the ones responsible for 90 percent of our total acres burned—all started in the mid-elevation zone (fig. 1). Further analysis revealed that we were very successful in controlling the grass fires in the valley zone. In fact, 96 percent of the valley fires were controlled at 10 acres (4 ha) or less. The same was true for the fires in the upper elevation coniferous forest. Although the coniferous zone had more lightning ignitions than the valleys, we succeeded in holding 94 percent of the upper elevation fires to 10 acres (4 ha) or less. So why were we less successful in the mid-elevation zone?

We began to describe what was different about the mid-elevation zone so we could later evaluate potential changes using the computer models. We discovered four major differences:

1. The fuel type was brush rather than timber or grass;
2. Slopes were steeper in the mid-elevation zone—frequently too steep for engines and dozers to be fully effective;
3. Because the mid-elevation zone was in the thermal belt, average temperatures were higher and the relative humidity was lower; and
4. The road system was much less developed in the mid-elevation zone, due to steeper slopes and fewer timber resources.

These four factors contributed to greater contiguous fuel beds, longer response times, higher fire intensities, and greater resistance to control. None of this was news to our fire managers. During their careers, they had controlled hundreds of fires in the mid-elevation zone. The real question was this: Why were we catching some mid-elevation fires but losing others under what seemed to be similar circumstances?

The Atmospheric Factor

The answer came from the atmosphere by way of the Haines Index. Historically, our large fires frequently occurred during a significant weather event that can now be measured in terms of factors other than just wind or lightning. The Haines Index allows us to determine what the atmosphere is doing in terms of temperature and lapse rate (the rate at which temperature changes with changing height in the Earth's atmosphere). Changes in the atmosphere have regional effects, and we found it interesting to note that our national forest neighbors frequently had trouble with large, plume-dominated fires on the same days that we did. As a result, resources for extended attack frequently became limited due to their use elsewhere in our region. In particular, fire retardant aircraft have often been busy on fires elsewhere right when we needed them.

By integrating the daily Haines Index with information on the daily and seasonal condition of our fuels, we were able to identify days when high fire intensities were more likely. We completed analysis to determine normal curing dates for annual grasses and the bottoms of the live fuel moisture curves. We then compared these data with data on the thousand-hour fuels to obtain indices of extreme fire danger. By examining past Haines Indices, we determined that the district would have about 10 days per year when the Haines Index was high enough during periods of extreme fire danger to significantly change fire behavior, making a fire much more difficult to control. We dubbed the 10 bad fire days "Ira days" after Ira Rambo, the principal author of our project. Later, we formalized the term by making it into the acronym "IRA" (Increased Resource Availability).

So now we knew what type of days were really our worst. The National Weather Service agreed to give us a daily prediction of the next day's Haines Index, providing us with at least 12 hours' advance notice whenever one of those really bad fire days might be coming. Now it was time to put the information to practical use. But how?

Our Response

We took the same approach we do in dealing with the threat of lightning: we increased our available resources. We asked our fire managers, "What do you need in the mid-elevation zone to control a fire sooner on days when plume-dominated fires are likely?" Again, the answers were corroborated by our computer models. On those bad fire days—the IRA days—we found that we needed:

- Additional aircraft, and sooner;
- Larger engine crews (three people per type 6 engine rather than two);
- Air attack to improve crew safety and aircraft efficiency; and
- Additional dozers (more than just two), and sooner, for initial attack.

But additional resources would come at a cost—up to $5,000 per day on 10 days per year. Was it worth it?

The answer was a resounding yes. A break-even examination found that if we stopped just one fire in 100 years from becoming a project fire, we would still save the taxpayers money! Put another way, if we spent an additional $50,000 per year, we had 100 years to be successful and still make it pay. Our board of directors enthusiastically embraced the idea of spending money on IRA days to save money in the long run.

Our board of directors enthusiastically embraced the idea of spending money on those bad fire days to save money in the long run through preparedness.

We also made a few other changes that cost little or nothing. On IRA days, we now:

- Keep resources patrolling in the mid-elevation zones to minimize response times on potential problem fires (and to help keep fires from starting);
- Automatically order retardant;
- Immediately launch our type 2 contract helicopter for initial attack;
- Preassign structural task forces and liaisons; and
- Immediately notify cooperators of fire starts.

We discussed our findings with our cooperators, who embraced our proposed response and changed their methods accordingly. Rural fire districts agreed to increase staffing on IRA days to cover the valley zone while our crews patrol the mid-elevation zone. Landowners and our Federal cooperator agreed to provide staffing for additional engines on IRA days and to have dozers prepared to respond immediately from logging sites. The USDA Forest Service, which manages the fire retardant program in Oregon, agreed to keep an airtanker locally available on IRA days.

Wildland agencies have known about and successfully used the Haines Index for years. The concept of IRA days now allows us to integrate the Haines Index into our daily preparedness.

Acknowledgments

The author wishes to thank Forest Officer Ira Rambo for leading the project team that developed the concept of IRA days; Protection Planner Jim Wolf for participating on the project team; Southwest Oregon District protection and management staff for contributing to the project team's work; and National Weather Service staff for collaborating with the project. ■

A Race That Couldn't Be Won*

Richard C. Rothermel and Hutch Brown

Editor's note: This article summarizes an incident analysis by Richard C. Rothermel under the title, Mann Gulch Fire: A Race That Couldn't Be Won *(Gen. Tech. Rep. INT–299; USDA Forest Service, Intermountain Research Station; 1993). To obtain the full analysis, contact Publications—Ogden Service Center, Rocky Mountain Research Station, USDA Forest Service, 324 25th Street, Ogden, UT 84401, 801-625-5437 (tel.), 801-625-5129 (fax), pubs/rmrs_ogden@fs.fed.us (e-mail).*

It was 4 p.m. on August 5, 1949. A USDA Forest Service crew of 15 smokejumpers had just completed a jump onto a small fire in Mann Gulch, part of a roadless area in western Montana that is now the Gates of the Mountains Wilderness. The fire was burning on the canyon crest across Mann Gulch, nearly a mile (1.6 km) away. Although the firefighters were downwind from the fire, it didn't look ominous; the day was ending, and at least one smokejumper thought that cooling temperatures were laying the fire down for the night.

By 5 p.m., the crew had gathered its gear. Joined by a Forest Service fire guard who had been single-handedly fighting the fire, the smokejumpers moved down the gulch. The crew planned to reach the mouth of Mann Gulch on the Missouri River, about 2 miles (3.2 km) away, then move around the canyon crest to the upwind side of the fire for initial attack.

View of the Mann Gulch drainage from near its head. In 1949, a wildfire blowup cost the lives of 13 firefighters not far from this spot. Twenty years later, when this photo was taken, signs of severe fire damage were still evident. Photo: Courtesy of National Agricultural Library, Special Collections, Forest Service Photograph Collection, Beltsville, MD (Philip G. Schlamp, 1969; 519698).

By 6 p.m., barely an hour later, 13 of the 16 firefighters lay dead or dying. What went wrong?

Prevailing Conditions

Weather. The day was hot; temperatures in Mann Gulch possibly exceeded 97 °F (36 °C). Around 3:30 p.m., the wind increased and shifted direction; by 5:30 p.m., it was blowing up Mann Gulch toward the crew at speeds of up to 40 miles per hour (64 km/h). Perhaps due to firewhirls or downdrafts from local cumulus cells, firebrands were carried from the canyon crest into the mouth of Mann Gulch. By 5:45 p.m., the firefighters found that spot fires 150 to 200 yards (140–180 m) ahead of them were blocking further progress down the gulch.

Terrain. With the way to the Missouri River cut off, the firefighters turned around and headed back up the gulch. They were in a rock-strewn canyon with treacherous footing. To one side, across the gulch, was the canyon crest with the main fire. To the other side, the slope steepened to 76 percent and was topped by a perpendicular rimrock 6 to 12 feet (1.8–3.6 m) high. Although broken in places by narrow crevices, the rimrock posed a

When this article was originally published, Dick Rothermel was a retired research physical scientist for the USDA Forest Service, Intermountain Fire Sciences Laboratory, Missoula, MT; and Hutch Brown was the editor of Fire Management Today.

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formidable obstacle to anyone trying to cross to safety on the far side of the ridge.

Fuels. Vegetation in Mann Gulch ranged from mature ponderosa pine with a thick Douglas-fir understory at the canyon mouth to grasses and shrubs farther up the canyon. Fuels were tinder dry and highly flammable; dry fuel moisture values reached as low as 3 to 3.5 percent.

Fire Behavior

Under the prevailing conditions, the fire's behavior in Mann Gulch can be calculated with reasonable certainty. The spot fires first encountered by the firefighters were spreading at the slow rate of about 20 feet per minute (6 m/min). However, thick surface fuels at the mouth of the gulch soon sent intense flames into the canopy. Within minutes, the wind-driven crown fire was spreading at the much faster rate of 80 to 120 feet per minute (24–36 m/min).

As the fire chased the firefighters up the gulch, it reached grassier fuels where the trees thinned out, increasing its rate of spread to 170 to 280 feet per minute (52–85 m/min). Even farther up the gulch, where the thinning timber finally gave way to grassland, midflame windspeeds might have reached 20 miles per hour (32 km/h), pushing the fire's rate of spread as high as 750 feet per minute (230 m/min)—much faster than the firefighters could run uphill over broken terrain. In the flashy fuels, flame lengths might have reached 40 feet (12 m), with flame temperatures ranging from 1,500 to 1,800 °F (815–980 °C). The high flame temperatures proved lethal, primarily due to respiratory damage.

Human Factors

Lost Communications. Although the jump had gone smoothly, heavy turbulence had forced the pilot to climb before dropping the cargo. The crew's gear was scattered and its only radio was broken, causing the crew to lose touch with the outside world.

Tactics and Training. Instead of heading straight uphill for the rimrock while the fire was still moving slowly, the firefighters retreated up the gulch while angling uphill toward the rim. At first, their retreat showed little urgency—one firefighter even stopped to take photos. However, after 450 yards (410 m), with the fire gaining ground and now only a minute behind, the foreman ordered the crew to drop all heavy gear. At this point, the crew probably broke up as the firefighters began running as fast as they could. But the faster the crew moved up the gulch, the lighter and flashier the fuels became, the stronger the wind blew at ground level, and the faster the fire spread.

Realizing that the crew was in a race it couldn't win, the foreman stopped to ignite an escape fire in the grass, with the main fire only 30 seconds behind. Although the escape fire saved the foreman's life, the other firefighters failed to understand his purpose and ignored or couldn't hear his entreaties to lie down with him inside the black. Eleven of the remaining crew continued racing ahead of the main fire at a slight uphill angle; all were caught by the fire within 3 to 4 minutes after the foreman lit his escape fire. Ten died almost immediately and the 11th on the following day.

In the lee of a convection current caused by the main fire, the escape fire was unaffected by wind and therefore spread at an almost 90-degree angle to the path of the main fire, directly toward the rimrock. Four firefighters followed its course, perhaps thinking that it would deflect the main fire. Two of them found a fissure in the rimrock and climbed through to the safety of a rock slide on the far slope. The third firefighter turned away from the fissure and perished in the main fire below the rimrock. The fourth, although caught by the main fire, made it over the rim only to die the next day of his burns.

Lessons Learned

Deeply shocked by the Mann Gulch tragedy and subsequent firefighter fatalities in California, the Forest Service initiated reforms to prevent future disasters. Thanks to improved training, equipment, and safety techniques, another tragedy was averted on August 29, 1985, during the Butte Fire on the Salmon National Forest, ID. Seventy-three firefighters were entrapped for up to 2 hours by a severe crown fire. By calmly moving to preestablished safety zones and deploying their fire shelters, all 73 firefighters escaped serious injury. In part, they owe their lives to the lessons learned from the Mann Gulch Fire. ■

The South Canyon Fire Revisited: Lessons in Fire Behavior*

Bret W. Butler, Roberta A. Bartlette, Larry S. Bradshaw, Jack D. Cohen, Patricia L. Andrews, Ted Putnam, Richard J. Mangan, and Hutch Brown

On July 6, 1994, 14 firefighters died in a wildfire on Storm King Mountain in western Colorado. Their deaths made the South Canyon Fire a landmark event in the annals of wildland firefighting, next to such major firefighting tragedies as the Big Blowup of 1910 and the Mann Gulch Fire of 1949.**

Within weeks after the fire, the Report of the South Canyon Fire Accident Investigation Team (USDA/USDI/USDC 1994) outlined many of the circumstances that led to disaster. Later, John Maclean (1999) described additional factors, such as resource use decisions in the days before the blowup.

This article summarizes a detailed study by the authors on the fire behavior associated with the South Canyon Fire (Butler and others 1998). What fire-related factors contributed to the tragedy? And what lessons do they teach?

Winds whipping from the west through the Colorado River Gorge were funneled up the ravine where the fire was worst, playing a key role in the blowup.

Figure 1—*View of the South Canyon Fire site looking northeast across the West Drainage at the west flank of Main Ridge. Note the west flank fireline, helispots (H–1 and H–2), Lunch Spot Ridge, and West Bench. Illustration: USDA Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT, 1998.*

Topography

The Colorado River cuts through a series of north–south ridges on its way west through the Rocky Mountains. At Glenwood Springs, the river bisects a ridge of shale and sandstone, forming a narrow canyon at the base of Storm King Mountain, at 8,700 feet (2,700 m) the highest peak in the area. The mountain rises about 3,000 feet (900 m) above the river's north bank. Broken spurs and steep ravines reach south from the peak to the river.

Main Ridge (fig. 1), the site of the South Canyon Fire, starts in a saddle south of the peak and runs southwest for about 3,700 feet

When this article was originally published, Bret Butler was a research mechanical engineer, Roberta Bartlette was a forester, Larry Bradshaw was a meteorologist, and Jack Cohen and Pat Andrews were research physical scientists for the USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; Ted Putnam was an equipment specialist (retired) and Dick Mangan was the Fire and Aviation Program Leader for the Forest Service's Technology and Development Center, Missoula, MT; and Hutch Brown was the editor of Fire Management Today.

* The article is reprinted from *Fire Management Today* 61(1) [Winter 2001]: 14–26.

** On the Big Blowup, see Stephen J. Pyne, "A Story To Tell," *Fire Management Today* 60(4): 6–8; on the Mann Gulch Fire, see Mike Dombeck, "The Mann Gulch Fire: They Did Not Die in Vain," and Richard C. Rothermel and Hutch Brown, "A Race That Couldn't Be Won," *Fire Management Today* 60(2): 4–9.

Most of the fireline on the fire's west flank cut through Gambel oak, where visibility was limited and the fuels were unusually flammable under the drought conditions.

(1,100 m) before ending at a knob overlooking the Colorado River. From the knob, the canyon walls fall steeply about 1,100 feet (330 m) to the river below.

Though adjacent to an interstate highway, Main Ridge is difficult to approach. No roads or trails lead up from the highway. The ridge is flanked on the east and west by deep, twisting ravines running north and south, called the East

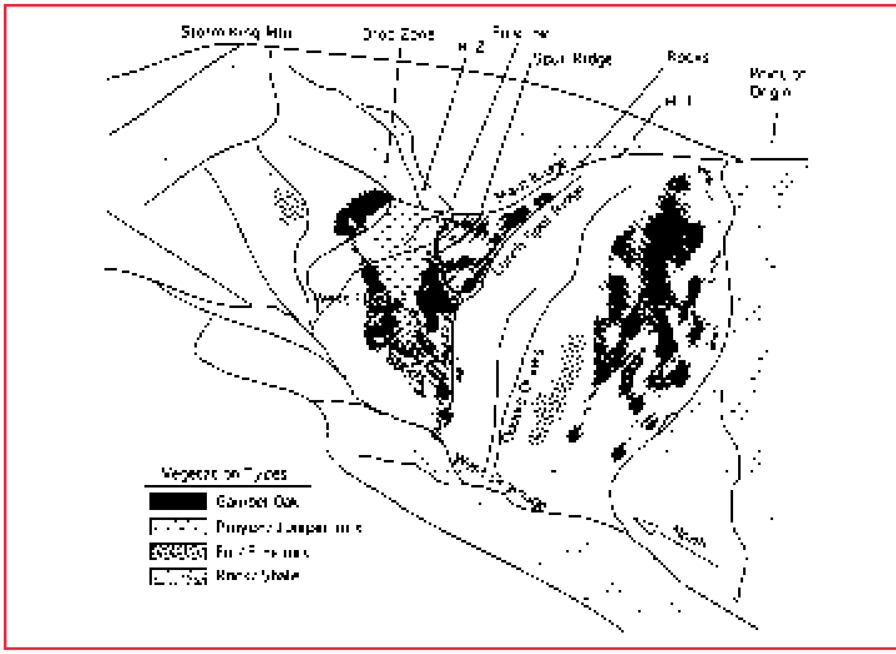


Figure 2—*Approximate distribution of vegetation in the area of the South Canyon Fire (not to scale). Gambel oak occupied north- and west-facing slopes, including most of the terrain traversed by the west flank fireline. Open pinyon–juniper forest predominated elsewhere, except for an area of ponderosa pine and Douglas-fir south of the Double Draws. Illustration: USDA Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT, 1998.*

A Firefighting Tragedy

In the summer of 1994, Colorado suffered its worst drought in decades. Severe fire weather was certain to come. On July 2, a major storm hit the State with dry lightning strikes, igniting thousands of wildland fires.

One fire started on the flanks of Storm King Mountain near Glenwood Springs, a resort community in western Colorado. The mountain overlooks an interstate highway in a canyon carved by the Colorado River. On the morning of July 3, drivers on the highway could see a puff of smoke on a mountain spur called Main (or Hell's Gate) Ridge, where a lightning fire smoldered in a tree.

A caller reported the fire from across the river in a gulch known as South Canyon. The caller was unsure exactly where the smoke originated, so Federal officials named the fire after the caller's location.

At first, the South Canyon Fire seemed insignificant compared to much larger fires burning elsewhere. For days, fire managers and aerial observers monitored the slowly spreading fire from a distance. None thought it wise to divert thinly stretched resources from higher priority fires.

On July 5, more than 2 days after the fire's ignition, a hand crew finally reached Main Ridge. Joined by smokejumpers and hotshots, the firefighters began a concerted effort to contain the fire, now dozens of acres in size. By the afternoon of July 6, they seemed to be making headway, cutting fireline along two flanks of the fire.

Suddenly, the fire blew up. Witnesses at the helibase below Storm King Mountain watched in helpless horror as smoke billowed across the slopes, enveloping the fire shelters they could see deployed. Within minutes, 14 of the 49 people on Storm King Mountain—more than a quarter of the firefighting force—lay dead. Others, some badly burned, escaped over the ridge, while still others survived in their fire shelters. It took hours for many of the traumatized survivors to descend the mountain to safety. Meanwhile, the fire continued to rage, burning 2,115 acres (856 ha) before finally coming under control on July 11.

The relative humidity dropped from July 5 to July 6, allowing the fire to continue spreading downhill overnight toward the bottom of the drainage.

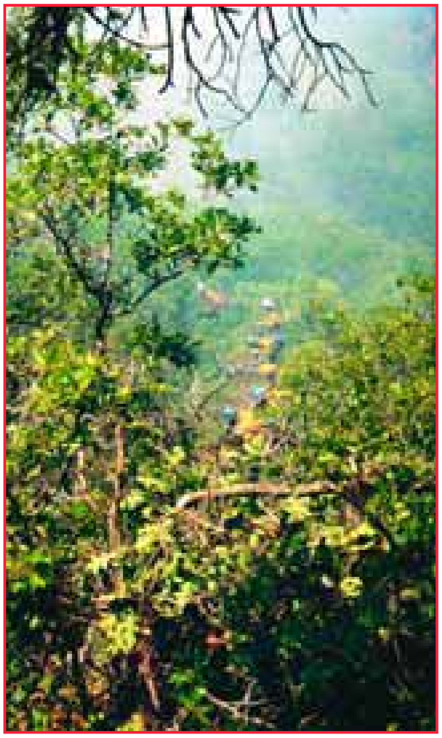


Figure 3—*Firefighters constructing fireline on the west flank of Main Ridge on the South Canyon Fire, July 6, 1994. The heavy Gambel oak severely limited visibility and remained combustible despite partial underburning. Photo: USDA Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT.*

and West Drainages. The first firefighters reached the fire by hiking for hours up the East Drainage.

The fire burned mostly on the west flank of Main Ridge, so the firefighters built fireline down into the West Drainage (fig. 1). They traversed steep slopes of up to 55 percent, with treacherous footing in the crumbling shale. Side spurs and draws angling from Main Ridge down into the drainage slowed travel and blocked the firefighters' view of the fire. The most prominent side spur, where many firefighters ate lunch on July 6, became known as Lunch Spot Ridge.

The bottom of West Drainage is especially steep, with a slope of about 80 percent. The bottom widens into a half-acre (0.2-ha) level area called the Bowl about 250 feet (80 m) upcanyon from the base of two long, vertical gullies, the Double Draws. Upcanyon from the Bowl, the steep slope flattens into an area called the West Bench.

The narrow mouth of West Drainage, facing southwest, opens onto the highway and river. Winds whipping from the west through the river gorge are funneled up the ravine. They played a key role in the blowup.

Fuels

Vegetation in the area of the fire was mixed (fig. 2). Gambel oak thickets covered north- and west-facing slopes. Gambel oak reached from Main Ridge down to the West Bench just north of Lunch Spot Ridge, the area traversed by most of the fireline on the fire's west flank. More than 50 years old, the oak formed a closed canopy 6 to 12 feet (1.8–2.4 m) tall, with leaf litter 3 to 6 inches (8–16 cm) deep and limited visibility (fig. 3). Elsewhere, except for a pocket of ponderosa pine and Douglas-fir south of the Double Draws, open pinyon–juniper forest prevailed, with a grassy herbaceous layer.

The vegetation was generally thickest toward the top of Main Ridge, giving way to shrubs and thick cured grasses below. The bottom of the drainage was generally covered with grass, with occasional pockets of dead brush that had rolled or washed downhill. The Bowl supported heavy live vegetation, including numerous conifers.

Due to the drought, all fuels were several weeks ahead of their summer drying trends. Fine dead fuel moisture content was about 2 to 5 percent. Live foliar moisture was probably about 125 percent in green Gambel oak and about 60 percent in underburned oak.

Weather

Conditions were drier and warmer than average. Precipitation levels at Glenwood Springs from October 1, 1993, to July 6, 1994, were 58 percent of normal. Temperatures were higher than usual from May through July.

On July 5, the air in western Colorado was hot and dry, with light winds from the south. A cold front building over Idaho reached Colorado early on July 6. With the approaching cold front, the relative humidity dropped from a high of 40 percent on July 5 to 29 percent on July 6, allowing the fire to remain active overnight. The cold front reached Glenwood Springs at about 3:20 p.m., bringing strong winds from the west.

Wind combined with topography to create turbulence in the West Drainage (fig. 4). The westerly winds speeded up as they pushed through the narrow Colorado River Gorge. Caught by the angle of Main Ridge, they swept north up the West Drainage. Rising daytime temperatures on the upper mountain slopes increased the upcanyon flow by reducing pressure at the canyon mouth, as did strong higher elevation westerly winds pouring across Main Ridge. By about 4 p.m., winds of 30 to 45 miles per hour (50–70 km/h) were rushing upslope from the mouth of West Drainage, with gusts reaching 50 miles per hour (80 km/h). Cross-cutting higher elevation winds created a shear layer and turbulence in the canyon.

Early Fire Behavior

From its point of ignition on Main Ridge (fig. 5), the fire backed slowly downhill, burning in cured grasses under juniper and pinyon pine and in the leaf litter under Gambel oak. Sheltered from the low to moderate winds by canopy cover, the fire torched only where ladder fuels carried it into individual trees. The fire advanced mostly north and west, making occasional upslope runs through canopy fuels. From July 2 to July 6, the fire backed downhill at a nearly constant rate.

On July 5, firefighters arrived on Main Ridge and constructed the first helispot (H–1) but failed to build effective firelines. The next morning, the firefighters built another helispot (H–2), then cut a fireline along the ridgetop between the helispots.

Next, the leaders scouted the fire by helicopter and made the fateful decision to continue fighting the fire from Main Ridge instead of evacuating the ridge and attacking the fire from the highway below. They decided to improve the ridgetop fireline while building fireline down into the West Drainage to hook around the west flank of the fire. By 3:15 p.m., 49 firefighters were on the mountain, about evenly divided between the ridgetop and west flank firelines.

During the night of July 5, low humidity kept the fire advancing at a probable rate of about 32 feet per hour (10 m/h) By midmorning on July 6, the fire had burned into the

For days, the fire did not seem ominous. It backed slowly downhill in surface fuels, making occasional upslope fingered runs through unburned canopy fuels.

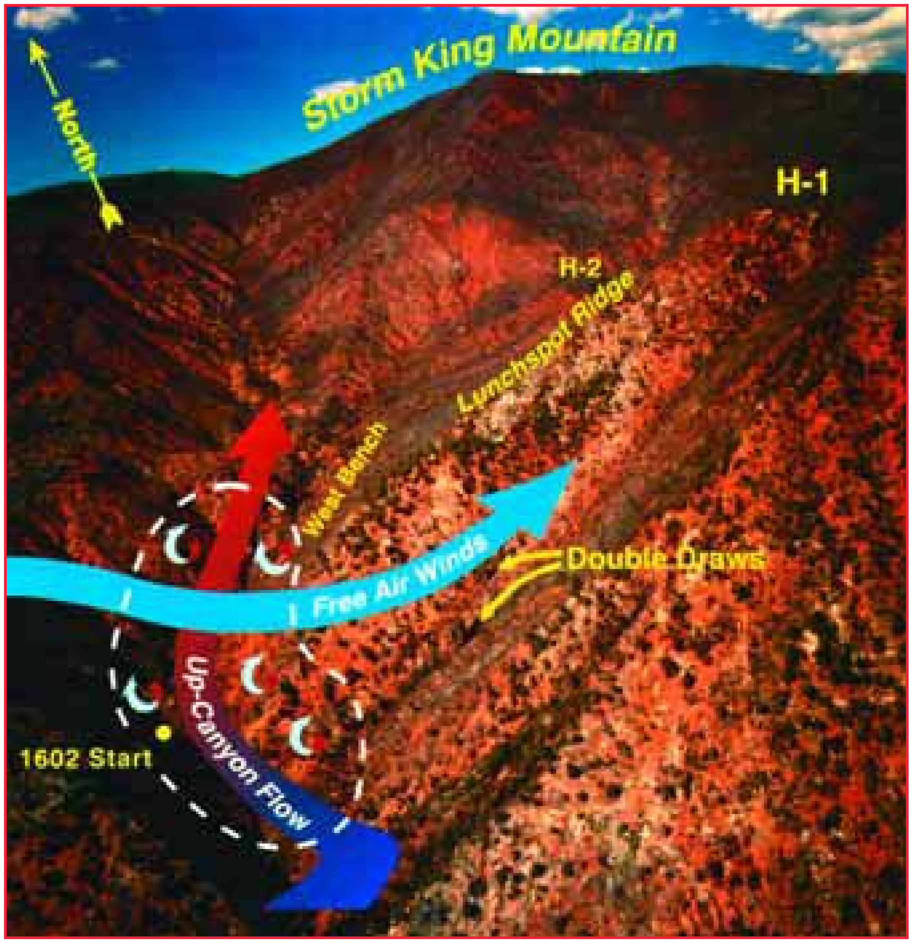


Figure 4—*Interaction of the westerly wind flow over the ridgetops burned by the South Canyon Fire and the northerly wind flow up the West Drainage, forming a shear layer (dashed line). The shear layer generated turbulence that helped spread fire and burning embers up the West Drainage and onto the ridgetops. Illustration: USDA Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT, 1998.*

Double Draws and was about three-fourths of the way down to the bottom of the drainage. Assuming that the rate of spread remained constant during the day, the fire would have reached the bottom of the drainage by about 4 p.m.

The Blowup

At about 3:55 p.m., the fire, fed by growing winds, made three upslope canopy runs through the patch of pine and Douglas-fir south of the Double Draws. Flame lengths exceeded 100 feet (30 m). Photos show smoke rising from well below the crown fire runs, indicating that fire was reaching the bottom of the drainage.

By this time, strong westerly winds were flowing across the tops of the ridges while a strong upcanyon (southerly) wind was blowing up the bottom of the West Drainage; this combination created severe turbulence over the West Drainage.

On the morning of July 6, the leaders made the fateful decision to continue fighting the fire from above.

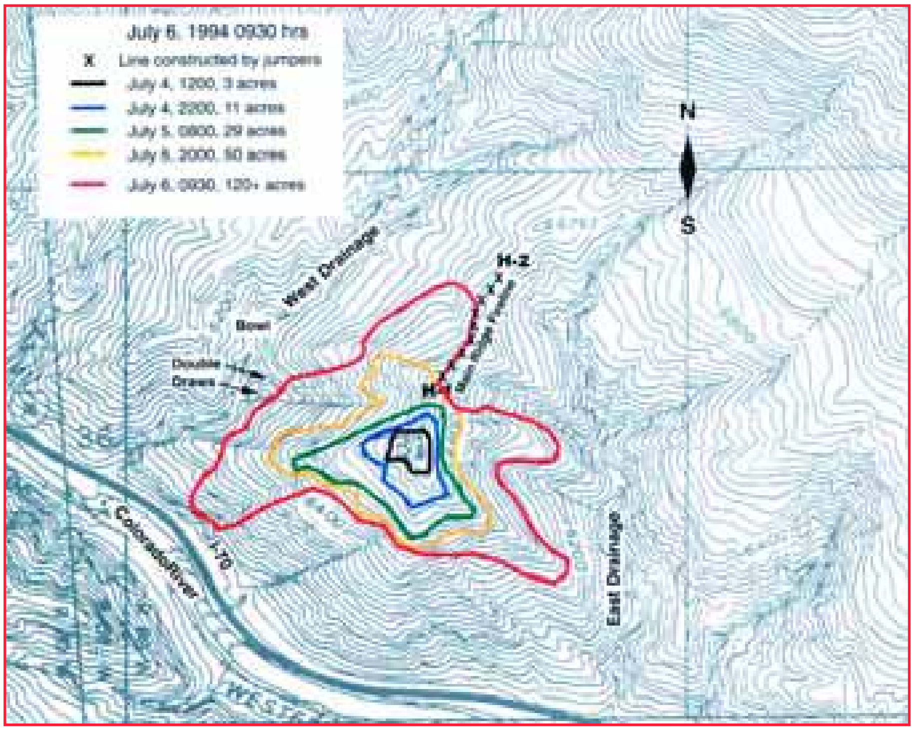


Figure 5—*South Canyon Fire perimeters from the time of ignition on July 2 through the morning of July 6, before the blowup (3 acres = 1.2 ha; 11 acres = 4.5 ha; 29 acres = 12 ha; 50 acres = 20 ha; and 120 acres = 50 ha). Illustration: USDA Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT, 1998.*

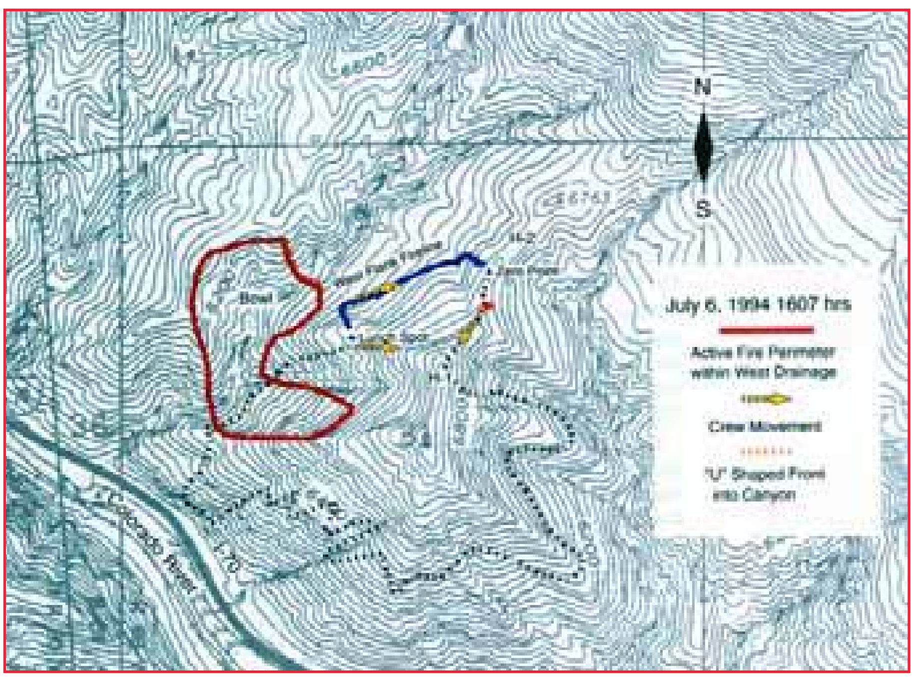


Figure 6—*South Canyon Fire perimeter at 4:07 p.m., minutes after the blowup began. The fire had jumped across the West Drainage and was advancing upcanyon in a "U" shape below the west flank fireline. Illustration: USDA Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT, 1998.*

Embers from the crown fire runs and from the flames in the bottom of the drainage scattered in the turbulence, igniting spot fires up and across the canyon. By 4:02 p.m., firefighters reported spot fires actively burning on the opposite (east-facing) slope of the West Drainage.

Pushed by winds, the fire swept up the east-facing slope and upcanyon toward the Bowl in a running flame front 50 yards (45 m) wide. In the Bowl, relatively dense surface fuels pushed the fire into the crowns of the conifers there, increasing the size and height of the convection current over the fire and lofting embers high up both sides of the drainage. On the ridgetop, spot fires were multiplying across the fireline by 4:03 p.m.

By 4:04 p.m., recognizing the danger, the firefighters on the west flank were all in retreat. Those observing the fire south of Lunch Spot Ridge returned to their lunch spot, while those north of Lunch Spot Ridge began moving up the west flank fireline toward Main Ridge. At about the same time, the firefighters on the ridgetop abandoned efforts to control the spot fires spreading around them and headed toward H–1 for helicopter evacuation.

By 4:07 p.m., the fire front was rushing upcanyon in a "U" shape past the Bowl (fig. 6). Two minutes later, it jumped onto the West Bench (fig. 1), entering the Gambel oak directly under the west flank fireline. The high winds, minimally impeded by the relatively thin canopy cover on the bench, whipped up the flames in the surface fuels and sent them into the canopy. The intense heat from the burning oak canopy, coupled with relatively low live fuel moisture levels, led to continuous combustion of every fuel type as the fire raced upslope in the Gambel oak north of Lunch Spot Ridge.

Above the West Bench, the fire was more exposed to the westerly winds sweeping over Main Ridge. The flames spread upcanyon at about 3 feet per second (0.9 m/s) while making upslope runs before the winds at 6 to 9 feet per second (1.8–2.7 m/s). One run carried all the way over Main Ridge, forcing the firefighters who were moving toward H–1 to turn around and head instead for H–2.

At 4:10 p.m., a spot fire ignited on the West Bench ahead of the main fire front and began sweeping upslope below the fleeing west flank firefighters. Within minutes, it had merged with the main fire and overrun the entire west flank fireline. By 4:14 p.m., the fire was cresting on Main Ridge and threatening H–2 (fig. 7). All but two of the firefighters who were on or had reached Main Ridge dropped into the East Drainage and fled downcanyon to safety.

The Entrapments

Before the blowup, an advance scout and a group of eight firefighters were observing the fire south of Lunch Spot Ridge. By 4:06 p.m., all nine had retreated to Lunch Spot Ridge. The scout found a safety zone on the ridge, which remained largely unburned during the blowup. The other eight moved upridge to an area of black several hundred feet below H–1. At 4:24 p.m., they deployed their fire shelters. Over the next 45 minutes, they felt the heat from three separate fire runs just south of Lunch Spot Ridge, about 500 feet (150 m) away. All survived unhurt.

Cross-cutting winds created a shear layer and turbulence in the canyon, scattering embers and igniting spot fires up and across the canyon.

The rest of the west flank firefighters were north of Lunch Spot Ridge before the blowup, widely dispersed along the fireline. All retreated back up the fireline toward Main Ridge—a distance of up to 1,880 feet (575 m) for some. Twelve firefighters who had been working on the lower portion of the fireline were caught by the fire at about 4:13 p.m. Most were in a group about 280 feet (85 m) below Main Ridge. All died within seconds of each other (see the sidebar).

At 4:14 p.m., two helitack personnel watched the fire front approach them at H–2. Instead of dropping into the East Drainage with the other ridgeline firefighters, they ran up the ridge toward the mountain, perhaps trying to reach higher ground for helicopter evacuation.

By 4:18 p.m., a finger of the fire cut off any possibility of escape into the East Drainage. Angling toward a rock outcropping, the two died crossing a gully at about 4:23 p.m., probably from inhaling lethal hot gases funneled up the draw.

Lessons Learned

The South Canyon Fire tragically illustrates the deadly fire behavior that can occur under certain conditions of fuel, weather, and topography. Though extreme, such fire behavior is normal under the conditions that prevailed on Storm King Mountain on the afternoon of July 6. Until then, the fire was a low-intensity surface burn, with high-intensity fire behavior limited to the torching of individual trees and narrow runs within the fire's perimeter. But by 4 p.m., changing

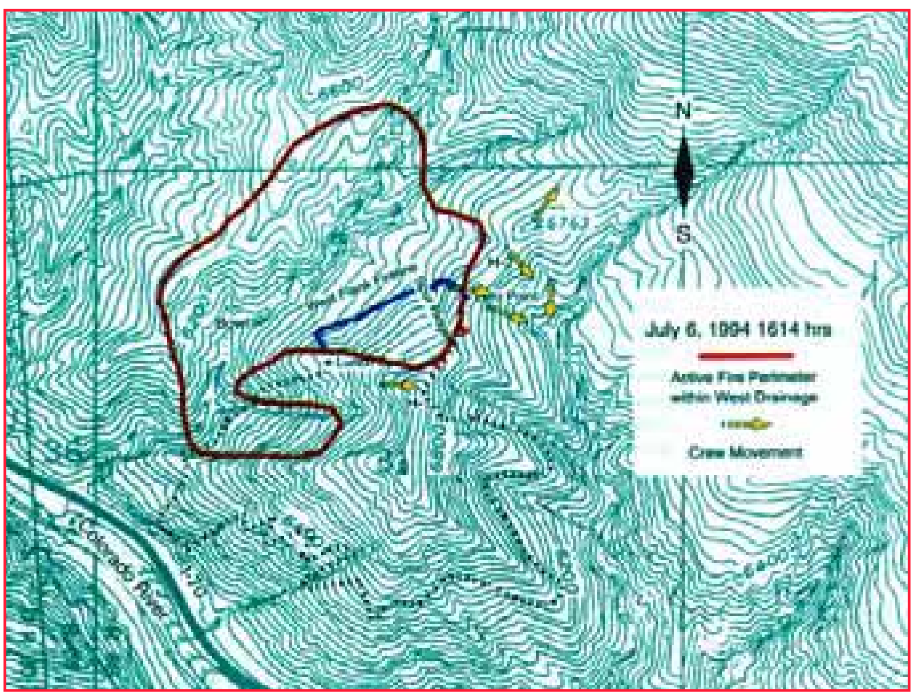


Figure 7—*South Canyon Fire perimeter at 4:14 p.m., just after the entrapment on the west flank fireline. The fire had completely overrun the west flank fireline and was threatening H–2. Illustration: USDA Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT, 1998.*

Within minutes after the firefighters began to retreat, the fire had entirely overrun the west flank fireline, claiming the first fatalities.

wind conditions, combined with slope and fire location, dramatically altered the fire's behavior. Within minutes, flames swept through the live fuel canopy in a continuous blazing front that caught the firefighters before they could reach their safety zone, resulting in 14 fatalities.

Several conclusions can be drawn from what happened on Storm King Mountain:

- **Topography can strongly affect local wind patterns.** In mountainous terrain, surface winds can be highly variable and subject to sudden dramatic change, especially during frontal passages. Winds should be constantly monitored all around the fire perimeter.
- **Vegetation, topography, and smoke can prevent firefighters from noticing changes in fire behavior.** Evidence suggests that the 12 firefighters overrun on the west flank fireline were caught by surprise, perhaps because they failed to realize how close the fire was getting. Lookouts positioned outside the burn area or overhead can communicate urgency and give escape directions.
- **Extreme fire behavior often occurs abruptly.** The low-intensity backing fire gave no hint of what was to come; the transition to a high-intensity fire was sudden and perhaps unexpected in the live fuels. Under certain conditions, green vegetation can support and even promote high-intensity burning. A fire's position should be constantly monitored in relation to wind, slope, and fuels; training in fire environment assessment might help firefighters anticipate potential fire behavior.
- **The longer and farther a fire burns, the more likely it is to change behavior.** Given sufficient time, a low-intensity fire can often reach a position where fuel, weather, and terrain combine to produce high-intensity fire behavior. The location of the fire perimeter should be constantly monitored.

How Were the West Flank Firefighters Overrun?

Before reaching Main Ridge, the last survivor on the west flank fireline was knocked from his feet by a blast of hot air from the rear. Most of the twelve who died were still in line, many with their packs on. They had neither discarded their tools nor made any organized attempt to deploy their fire shelters. The dense Gambel oak and smoke in the air likely prevented them from seeing how close the fire really was. Circumstances suggest that the fire overran them with unusual rapidity, perhaps catching them by surprise; the vegetation all around them might have seemed suddenly to explode in flames. Three scenarios, perhaps in combination, might explain such fire behavior:

- ***Collapsing Pocket in the Fire Front.*** Toward the top of Main Ridge, northeast of the west flank fireline, the vegetation changed from Gambel oak to a pinyon–juniper mix (fig. 2). The fire could advance faster in the flashier pinyon–juniper fuels to the left of the firefighters than in the Gambel oak behind them. To their right, the fire had already reached Main Ridge. The firefighters were in a pocket, with fire burning around them on three sides. The intense energy projected from three sides might have rapidly ignited the vegetation around the firefighters, collapsing the pocket and sending a blast of hot air upslope.
- ***Descending Smoke Column.*** As the fire gained on the fleeing firefighters, a gust from the strong westerly winds sweeping over the West Drainage might have pushed the column of smoke and burning gases directly onto the firefighters. The embers and hot air would have quickly ignited the surrounding vegetation, and the gust of hot gases might have been experienced upslope as a blast from the rear.
- ***Rapidly Spreading Fire.*** The fire spread upslope much faster than the firefighters were traveling. By 4:13 p.m., as the firefighters stumbled over oak stobs up the last and steepest section of fireline below Main Ridge, their rate of travel would have fallen to 1 to 3 feet per second (0.3–0.9 m/s). They simply couldn't outrun the fire, which by this time was traveling up to 9 feet per second (2.7 m/s). The rapid rate of spread might have pushed a blast of hot air upslope.

- **The safety of an escape route is a function of its length and direction.** Escape routes should be chosen based on the potential for extreme fire behavior. Ideally, they are short and downhill.
- **Underburned Gambel oak provides no safety zone.** The blowup began in green Gambel oak but continued into the underburned areas above the west flank fireline, which offered no safety. Firefighters do not have "one foot in the black" when working adjacent to underburned shrub vegetation.

On Lunch Spot Ridge, a group deployed fire shelters and survived three separate fire runs in about 45 minutes.

None of the lessons from the South Canyon Fire is particularly new, and most will be readily apparent to firefighters. Perhaps the most important lesson is that the blowup was normal under the circumstances. A similar alignment of environmental factors and extreme fire behavior is not uncommon and will happen again. What was not normal is that 14 firefighters were caught in the blowup and could not escape. By learning from their experience, firefighters can help prevent a similar tragedy from occurring elsewhere.

Literature Cited

Butler, B.W.; Bartlette, R.A.; Bradshaw, L.S.; Cohen, J.D.; Andrews, P.L.; Putnam, T.; Mangan, R.J. 1998. Fire behavior associated with the 1994 South Canyon Fire on Storm King Mountain, Colorado. Res. Pap. RMRS–RP–9. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station.

Maclean, J.N. 1999. Fire on the mountain: The true story of the South Canyon Fire. New York, NY: William Morrow and Co.

USDA/USDI/USDC (U.S. Department of Agriculture/U.S. Department of the Interior/U.S. Department of Commerce). 1994. Report of the South Canyon Fire Accident Investigation Team. Washington, DC: USDA/USDI/USDC. ■

Websites on Fire*

Lessons Learned Center

"Train as you work and work as you train"—that's the motto of the Wildland Fire Lessons Learned Center. Established in March 2002, the Center aims to improve safe work performance and organizational learning for Federal and State wildland firefighting agencies. After-incident reports and information teams provide valuable research and analysis, a growing online library supports knowledge management, and two online publications encourage information transfer.

Lessons Learned is an interagency program sponsored by the USDA Forest Service and USDI Bureau of Indian Affairs, Bureau of Land Management, National Park Service, and U.S. Fish and Wildlife Service. The Center works in cooperation with the Federal Fire Aviation Safety Team, National Wildfire Coordinating Group, and National Association of State Foresters.

Found at <http://www.wildfirelessons.net>

* Occasionally, *Fire Management Today* briefly describes Websites brought to our attention by the wildland fire community. Readers should not construe the description of these sites as in any way exhaustive or as an official endorsement by the USDA Forest Service. To have a Website described, contact the managing editor, Hutch Brown, at USDA Forest Service, Office of Communication, Mail Stop 1111, 1400 Independence Avenue, SW, Washington, DC 20250-1111, 202-205-1028 (tel.), 202-205-0885 (fax), hutchbrown@fs.fed.us (e-mail).

Fire Management Today Announces Winners of 2003 Photo Contest

Madelyn Dillon

Surpassing our expectations and any previous year's entries, *Fire Management Today* received more than 400 images from about 50 people for our 2003 photo contest. Thanks to everyone who contributed their best fire-related images to this year's competition.

We asked people to submit images in six categories:

- Wildland fire,
- Prescribed fire,
- Wildland/urban interface fire,
- Aerial resources,
- Ground resources, and
- Miscellaneous (fire effects, fire weather, fire-dependent communities or species, etc.).

After the contest deadline (the first Friday in March), we evaluated the submissions and eliminated all technically flawed images, such as those with soft focus or low resolution. Many of these images were otherwise outstanding.

Next, our judges reviewed, scored, and ranked the remaining images based on traditional photography criteria. They asked questions such as:

- Is the composition skillful and dynamic?
- Are the colors and patterns effective?
- Does the image tell a story or convey a mood?

If the judges thought that only one or two images in a category deserved an award, then they made only one or two awards in that category—First, Second, or Third Place, based on the merit of the image.

Finally, the winning images were reviewed by a fire safety expert to ensure that they did not show unsafe firefighting practices (unless that was their purpose). If an unsafe practice was evident, the image was disqualified from competition, and the award went to the next highest ranked image.

Do you have an image that tells a story about wildland firefighting? Would you like to see your photo in print? Turn to the back inside cover for information about our 2004 photo contest. ■

Madelyn Dillon is the editor of Fire Management Today, *Fort Collins, CO.*

Thanks to Fire Photo Experts

We assembled an excellent panel of judges, people with years of photography experience:

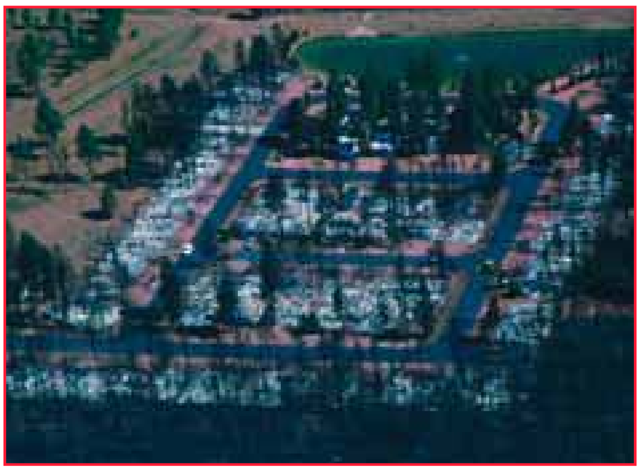
- Joe Champ is a professor of journalism and technical communication at Colorado State University, Fort Collins, CO. Joe is President of Champ Communication Research. Before his academic career, Joe worked for 10 years as an award-winning news anchor, reporter, and photographer.
- Lane Eskew is an editor with the USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. As part of his job, Lane evaluates photos for publication. His own photos have been published in outdoor magazines, books, brochures, and other media.
- Barbara Menzel is a computer programmer for the Forest Service, Forest Management Service Center, Fort Collins, CO. Barb has been an amateur photographer for nearly 15 years. A collection of her photos was recently showcased at a local photography lab.

We also made sure that a professional safety expert evaluated all winning photos:

- Ed Hollenshead is the Forest Service's national fire operations safety officer at the National Interagency Fire Center, Boise, ID. Throughout his 30-year career, Ed has been actively involved in wildland fire, serving in nearly every capacity, from "ground-pounder" to incident commander.

We sincerely appreciate the time and skill that our panel members gave to this effort!

First Place, Wildland Fire. Trees silhouetted against the advancing flames on the Hayman Fire between Denver and Colorado Springs, CO. Photo: Steven Smith, Colorado Springs Fire Department, Colorado Springs, CO, 2002.



Second Place, Wildland/Urban Interface. Standing in the path of the Rodeo–Chediski Fire on the Apache–Sitgreaves National Forest, AZ, this mobile home park in the community of Heber-Overguard was almost totally consumed by the intense firestorm. Photo: Thomas Iraci, USDA Forest Service, Pacific Northwest Region, Portland, OR, 2002.

Second Place, Prescribed Fire. A member of the Bandelier Fire Crew gathers limbs to toss on burning piles, part of a thinning project to create a fuel break in the Jemez Mountains, NM. Photo: Kristen Honig, National Park Service, Los Alamos, NM, 2003.

First Place, Prescribed Fire. A backfire consumes dry vegetation during a prescribed burn on the Stillwater National Wildlife Refuge, NV. Photo: John Wood, U.S. Fish and Wildlife Service, Klamath Basin National Wildlife Refuge Complex, Tulelake, CA, 2002.

Second Place, Wildland Fire. Flames leap into action on the Monument Fire, Malheur National Forest, OR. Photo: Ben Croft, USDA Forest Service, Missoula Technology and Development Center, Missoula, MT, 2002.

Third Place, Wildland/Urban Interface. Grazing llamas watch calmly as a wildfire draws dangerously close to homes on the Deer Creek Ranch near Selma, OR. Photo: Thomas Iraci, USDA Forest Service, Pacific Northwest Region, Portland, OR, 2002.

Second Place, Aerial Resources. A member of the Mesa Verde National Park helitack crew guides helicopter 910 in for a safe landing at an unimproved helispot during the East Canyon #2 Fire in southwestern Colorado. Photo: Bill Pool, National Park Service, Phoenix, AZ, 2002.

Third Place, Wildland Fire. The Eightmile Lookout is peacefully outlined against distant smoke from the Missionary Ridge Fire, San Juan–Rio Grande National Forest, CO. Photo: Mark Roper, USDA Forest Service, San Juan–Rio Grande National Forest, Pagosa Ranger District, Pagosa Springs, CO, 2002.

Third Place, Prescribed Fire. Smoke from all directions is drawn into the heart of a 3,200-acre (1,300-ha) prescribed burn on the Lower Klamath National Wildlife Refuge, CA. Photo: Troy Portnoff, U.S. Fish and Wildlife Service, Klamath Basin National Wildlife Refuge Complex, Tulelake, CA, 2002.

First Place, Aerial Resources. Airtanker 22 drops a load of retardant on the Missionary Ridge Fire, San Juan–Rio Grande National Forest, CO, 2002. Photo: Ben Croft, USDA Forest Service, Missoula Technology and Development Center, Missoula, MT, 2002.

Second Place, Ground Resources. A crew of firefighters snakes up the line to work on a large burnout operation on the Toolbox Fire, Fremont National Forest, OR. Photo: Thomas Iraci, USDA Forest Service, Pacific Northwest Region, Portland, OR, 2002.

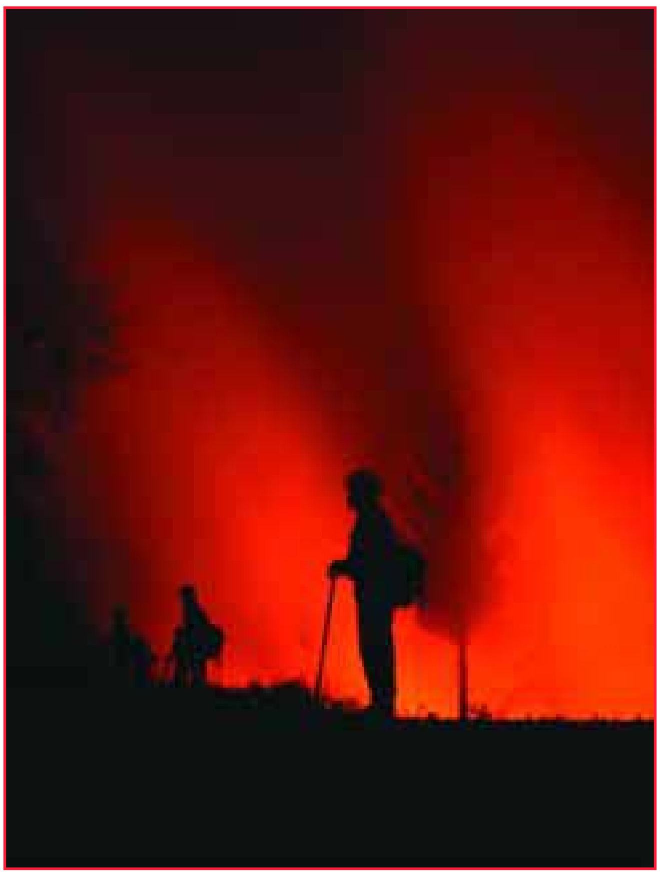
First Place, Miscellaneous. Smoke from the Eyerly Fire on the Deschutes National Forest, OR, creates a stunning sunrise. Photo: Eli Lehmann, USDA Forest Service, Mount Baker–Snoqualmie National Forest, Willard, WA, 2002.

Third Place, Aerial Resources. Airtanker 23 drops retardant on the approaching Rodeo–Chediski Fire, Apache–Sitgreaves National Forest, AZ, as it engulfs Mule Canyon. Photo: Tom Schafer, Show Low, AZ, 2002.

Third Place, Ground Resources. A firefighting crew works diligently to build a line along a burn on the Manti–La Sal National Forest, UT. Photo: Victor Bradfield, USDA Forest Service, Caribou–Targhee National Forest, Pocatello, ID, 1989.

2003 Photo Contest Winners

Honorable Mention, Ground Resources. Lassen and Plumas Hotshots prepare to set an offroad backfire on the Blue Cut Fire, San Bernardino National Forest, CA. Photo: Wade Salverson, Susanville, CA, 2002.



First Place, Ground Resources. Fire from below casts striking shadows in the smoke during a night burnout by the Baker River Hotshots on the Tiller Complex Fire, Umpqua National Forest, OR. Photo: Eli Lehmann, USDA Forest Service, Mount Baker Snoqualmie National Forest, Willard, WA, 2002.

Third Place, Miscellaneous. Aftermath of a structure fire on the West Plains near Spokane, WA. Firefighters must be ready at a moment's notice. Photo: Torben Dalstra, Spokane County Forest District #10, Airway Heights, WA, 2002.

Second Place, Miscellaneous. The historic Eightmile Lookout on the San Juan National Forest, CO, was used until the 1970s. Photo: Mark Roper, USDA Forest Service, San Juan–Rio Grande National Forest, Pagosa Ranger District, Pagosa Springs, CO, 2002.

Guidelines for Contributors

Editorial Policy
Fire Management Today (*FMT*) is an international quarterly magazine for the wildland fire community. *FMT* welcomes unsolicited manuscripts from readers on any subject related to fire management. Because space is a consideration, long manuscripts might be abridged by the editor, subject to approval by the author; *FMT* does print short pieces of interest to readers.

Submission Guidelines
Submit manuscripts to either the general manager or the managing editor at:

USDA Forest Service
Attn: April J. Baily, F&AM Staff
Mail Stop 1107
1400 Independence Avenue, SW
Washington, DC 20250-1107
tel. 202-205-0891, fax 202-205-1272
e-mail: abaily@fs.fed.us

USDA Forest Service
Attn: Hutch Brown, Office of Communication
Mail Stop 1111
1400 Independence Avenue, SW
Washington, DC 20250-1111
tel. 202-205-1028, fax 202-205-0885
e-mail: hutchbrown@fs.fed.us

Mailing Disks. Do not mail disks with electronic files to the above addresses, because mail will be irradiated and the disks could be rendered inoperable. Send electronic files by e-mail or by courier service to:

USDA Forest Service
Attn: Hutch Brown, 2CEN Yates
201 14th Street, SW
Washington, DC 20024

If you have questions about a submission, please contact the managing editor, Hutch Brown.

Paper Copy. Type or word-process the manuscript on white paper (double-spaced) on one side. Include the complete name(s), title(s), affiliation(s), and address(es) of the author(s), as well as telephone and fax numbers and e-mail information. If the same or a similar manuscript is being submitted elsewhere, include that information also. Authors who are affiliated should submit a camera-ready logo for their agency, institution, or organization.

Style. Authors are responsible for using wildland fire terminology that conforms to the latest standards set by the National Wildfire Coordinating Group under the National Interagency Incident Management System. *FMT* uses the spelling, capitalization, hyphenation, and other styles recommended in the *United States Government Printing Office Style Manual*, as required by the U.S. Department of Agriculture. Authors should use the U.S. system of weight and measure, with equivalent values in the metric system. Try to keep titles concise and descriptive; subheadings and bulleted material are useful and help readability. As a general rule of clear writing, use the active voice (e.g., write, “Fire managers know…” and not, “It is known…”). Provide spellouts for all abbreviations. Consult recent issues (on the World Wide Web at <http://www.fs.fed.us/fire/planning/firenote.htm>) for placement of the author’s name, title, agency affiliation, and location, as well as for style of paragraph headings and references.

Tables. Tables should be logical and understandable without reading the text. Include tables at the end of the manuscript.

Photos and Illustrations. Figures, illustrations, overhead transparencies (originals are preferable), and clear photographs (color slides or glossy color prints are preferable) are often essential to the understanding of articles. Clearly label all photos and illustrations (figure 1, 2, 3, etc.; photograph A, B, C, etc.). At the end of the manuscript, include clear, thorough figure and photo captions labeled in the same way as the corresponding material (figure 1, 2, 3; photograph A, B, C; etc.). Captions should make photos and illustrations understandable without reading the text. For photos, indicate the name and affiliation of the photographer and the year the photo was taken.

Electronic Files. See special mailing instructions above. Please label all disks carefully with name(s) of file(s) and system(s) used. If the manuscript is word-processed, please submit a 3-1/2 inch, IBM-compatible disk together with the paper copy (see above) as an electronic file in one of these formats: WordPerfect 5.1 for DOS; WordPerfect 7.0 or earlier for Windows 95; Microsoft Word 6.0 or earlier for Windows 95; Rich Text format; or ASCII. Digital photos may be submitted but must be at least 300 dpi and accompanied by a high-resolution (preferably laser) printout for editorial review and quality control during the printing process. Do not embed illustrations (such as maps, charts, and graphs) in the electronic file for the manuscript. Instead, submit each illustration at 1,200 dpi in a separate file using a standard interchange format such as EPS, TIFF, or JPEG, accompanied by a high-resolution (preferably laser) printout. For charts and graphs, include the data needed to reconstruct them.

Release Authorization. Non-Federal Government authors must sign a release to allow their work to be in the public domain and on the World Wide Web. In addition, all photos and illustrations require a written release by the photographer or illustrator. The author, photo, and illustration release forms are available from General Manager April Baily.

Contributors Wanted

We need your fire-related articles and photographs for *Fire Management Today*! Feature articles should be up to about 2,000 words in length. We also need short items of up to 200 words. Subjects of articles published in *Fire Management Today* include:

- Aviation
- Communication
- Cooperation
- Ecosystem management
- Equipment/Technology
- Fire behavior
- Fire ecology
- Fire effects
- Fire history
- Fire science
- Fire use (including prescribed fire)
- Fuels management
- Firefighting experiences
- Incident management
- Information management (including systems)
- Personnel
- Planning (including budgeting)
- Preparedness
- Prevention/Education
- Safety
- Suppression
- Training
- Weather
- Wildland–urban interface

To help prepare your submission, see “Guidelines for Contributors” in this issue.

Photo Contest Announcement

Fire Management Today invites you to submit your best fire-related images to be judged in our annual competition. Judging begins after the first Friday in March of each year.

Awards

All contestants will receive a CD with the images and captions (as submitted) remaining after technical review. The CD will identify the winners by category. Winning photos will appear in a future issue of *Fire Management Today*. In addition, winners in each category will receive:

1st place—Camera equipment worth $300 and a 16- by 20-inch framed copy of your photo.
2nd place—An 11- by 14-inch framed copy of your photo.
3rd place—An 8- by 10-inch framed copy of your photo.

Categories

- Wildland fire
- Prescribed fire
- Wildland-urban interface fire
- Aerial resources
- Ground resources
- Miscellaneous (fire effects; fire weather; fire-dependent communities or species; etc.)

Rules

- The contest is open to everyone. You may submit an unlimited number of entries from any place or time; but for each image, you must indicate only one competition category. To ensure fair evaluation, we reserve the right to change the competition category for your image.
- An original color slide is preferred; however, we will accept high-quality color prints with negatives.
- Digitally shot slides (preferred) or prints will be accepted if they are scanned at 300 lines per inch or equivalent. Digital images will be accepted if you used a camera with at least 2.5 megapixels and the image is shot at the highest resolution or in a TIFF format. To ensure fair evaluation, digitally manipulated images will be accepted only if the manipulation corrected technical flaws (such as exposure and focus) that could also be corrected in a conventional darkroom.
- You must have the right to grant the Forest Service unlimited use of the image, and you must agree that the image will become public domain.
- The image must not have been previously published.
- For every image you submit, you must give a detailed caption. For example:
  A Sikorsky S–64 Skycrane delivers retardant on the 1996 Clark Peak Fire, Coronado National Forest, AZ.
- You must complete and sign a statement granting rights to use your image(s) to the USDA Forest Service (see sample statement below). Include your full name, agency or institutional affiliation (if any), home or business address, telephone number, and e-mail address, if any.
- Images are eliminated from competition if they have date stamps; show unsafe firefighting practices (unless that is their express purpose); or are of low technical quality (for example, have soft focus or show camera movement).
- The contest judges have significant photography experience, and their decision is final.

Postmark Deadline

First Friday in March

Send submissions to:

USDA Forest Service
Fire Management Today Photo Contest
Madelyn Dillon
2150 Centre Avenue
Building A, Suite 361
Fort Collins, CO 80526

Example Release Statement and Contact Information

Enclosed is/are _________(*number*) slide(s)/print(s)/digital image(s) for publication by the USDA Forest Service. For each image submitted, the contest category is indicated and a detailed caption is enclosed. I have the authority to give permission to the Forest Service to publish the enclosed image(s) and am aware that, if used, it/they will be in the public domain and appear on the World Wide Web.

Contact information:

Name ______________________________ Institution affiliation, if any ______________________________

Home or business address ____

Telephone number ______________________________ E-mail address ______________________________