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Fire Behavior Associated with the 1994 South Canyon Fire on Storm King Mountain, Colorado

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Dedication

Tragically, 14 firefighters died during the fire run on the afternoon of July 6, 1994, on the South Canyon Fire. We dedicate this study to their memory with the hope that by learning from their sacrifice, future firefighter lives will be saved.

**Kathi Beck
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Executive Summary

Lightning ignited the South Canyon Fire on the afternoon of July 2, 1994. For the next 48 hours, the fire burned downslope in the leaves, twigs, and cured grasses covering the ground surface. By 1200 on July 4 the fire had burned approximately 3 acres. It continued to spread downslope through the day on July 5, covering approximately 50 acres by the end of the day. General fire activity consisted of low intensity downslope spread with intermittent flareups and short duration upslope runs in the fire's interior. The fire remained active through the night covering approximately 127 acres by morning on July 6.

On July 6 the fire continued to burn downslope through the surface fuels. At approximately 1520 a dry cold front passed over the area. Winds in the bottom of the drainage immediately west of the ignition point were estimated to be from the south (upcanyon) at 30 to 45 miles per hour. About 1555 several upslope fire runs occurred in the grass and conifers on the west-facing slope near the southwest corner of the fire's interior. Shortly after the crown fire runs, witnesses observed fire in the bottom of the drainage, directly west of the ridgetop ignition point. Pushed by the upcanyon winds, the fire in the drainage spread rapidly north. As this fire spread north and east, fuel, slope, and wind conditions combined to result in sustained fire spread through the live green Gambel oak canopy. The fire began burning as a high-intensity fast-moving continuous front. We estimate that the fire moved north up the drainage at about 3 feet per second. Steep slopes and strong west winds triggered frequent upslope (eastward) fire runs toward the top of the ridge. These upslope runs spread at 6 to 9 feet per second. A short time later the fire overran and killed 14 firefighters.

The South Canyon Fire tragically demonstrates the fire behavior that can occur given the appropriate combination of influencing factors. While fire behavior during the afternoon of July 6, 1994, can be characterized as extreme, it was normal and could be expected given the environmental conditions. Similar alignments of fire environment factors and the resulting fire behavior are not uncommon. The uncommon and

tragic fact associated with this fire was that 14 firefighters were entrapped and killed by it.

This study focuses on two events: the blowup or transition from surface fire to a fire burning through the shrub canopy, and the fire behavior in the area identified as the West Flank that resulted in the deaths of 14 firefighters.

We identify three major factors that contributed to the blowup on the afternoon of July 6, 1994. The first was the presence of fire in the bottom of a steep narrow canyon. Second, strong upcanyon winds pushing the fire up the canyon and upslope. Third, the fire burning into the green (not previously underburned) Gambel oak canopy.

We have drawn a number of discussion points from the analysis. Some of these points will be readily apparent to firefighters. Others may be less evident. We believe that all are important. They are:

- Topography can dramatically influence local wind patterns.
- Vegetation and topography can reduce firefighter's ability to see a fire or other influencing factors.
- Current and past fire behavior often does not indicate the potential fire behavior that could occur.
- The longer a fire burns and the larger it gets the greater the likelihood of high-intensity fire behavior at some location around the perimeter.
- The transition from a slow-spreading, low-intensity fire to a fast-moving, high-intensity fire often occurs rapidly. This seems to surprise firefighters most often in live fuels.
- Escape route effectiveness should be considered in relation to potential maximum-intensity fire behavior rather than past or present fire behavior.
- The underburned Gambel oak did not contribute to the blowup. It was significant in that it did not provide a safety zone.
- Smoke can significantly reduce the firefighter's abilities to sense changes in fire behavior.

The Authors

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Acknowledgments

We authors express our sincere appreciation to the many firefighters who endured repeated questions regarding often painful memories of the South Canyon Fire. Those deserving special credit for their patience include Sonny Archuleta, Sarah Doehring, Kevin Erickson, Dick Good, Eric Hipke, Dale Longanecker, Tony Petrilli, Michelle Ryerson, Bryan Scholz, Tom Shepard, and Bill Thomas. Special thanks go to Sue Husari for providing detailed information about the specific fire behavior. We appreciate the willingness of author John N. Maclean to share his interview notes with us. We also acknowledge the contribution of time and effort by the many technical reviewers and the Ogden Publications Office. Their comments led to a significantly improved manuscript. Finally, we acknowledge the ultimate sacrifice by the 14 firefighters who died during the South Canyon Fire. We hope that information gained from this work will protect the lives of other firefighters in the future.

Preface

The tragic loss of 14 lives on July 6, 1994, on a fire in western central Colorado stunned both firefighters and nonfirefighters everywhere. Immediately after the incident, one question on everyone's mind was, "Why and how did this happen?" The Federal agencies involved in the fire launched an official investigation. The Occupational Safety and Health Administration launched a separate investigation. The first official report on the accident was released 5 weeks after the incident. Other reports followed within a year. Investigators attempted to reconstruct the sequence of events and decisions that occurred on the fire. However, their efforts were hampered by the short timeframe allocated for the report and difficulties associated with getting witnesses to talk objectively about a fire that killed some of their closest friends.

One year after the original report was published, different theories were still being proposed to explain the specific fire behavior. These theories included speculation about the source of the fire in the West Drainage. For example: was it caused by rolling debris, general downhill fire spread, or spotting? Rumors of arson even surfaced. Other theories postulated the buildup and explosion of a cloud of combustible gases that killed the firefighters.

Ted Putnam, a Forest Service expert on firefighter entrapments and a member of the original accident investigation team, found the position of the bodies and gear to be significantly different from what he had observed on any previous entrapments. This generated in his mind questions about the fire behavior leading up to the entrapments. These questions and those associated with the various fire

behavior theories led Putnam to ask fire researchers to visit the site of the South Canyon Fire and work with him to better understand the fire's behavior.

After a visit to the South Canyon Fire site in August 1995, the group organized an informal team to reconstruct the fire behavior in greater detail than the original accident investigation report.

The original accident investigation report presented important and timely information, but the investigators were limited by time constraints. We have had a much longer time to review all the original witness statements and personally talk with many of the witnesses in considerable detail. The process entailed much more time than originally planned. But, because we had no time limitations, we were able to determine details not covered in the earlier reports.

This report is not meant to replace any of the previous work by the original investigation teams. Rather, our objective is to provide a thorough account of the fire behavior. As with any effort aimed at reconstructing an incident involving humans and complex physical phenomena, it is virtually impossible to know the sequence of events with absolute surety. This report presents what we consider to be the most probable fire behavior scenarios given the available information and current state of fire behavior knowledge. We do not address related issues such as human behavior factors or the ability of currently available fire models to predict extreme fire behavior. These other issues, while certainly germane to wildland fire management and firefighter safety, are left for future studies. Our primary objective is to develop information to help firefighters recognize potentially dangerous conditions, thereby preventing future accidents.

The Authors, September 1998

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Introduction

Wildfires burned millions of acres in 1994 (Russo and Williams 1995). A lightning strike to a ridge ignited one of those fires on July 2, 1994. This fire, named the South Canyon Fire, occurred approximately 7 miles west of Glenwood Springs, CO (fig. 1).

For the next 3 days the South Canyon Fire burned down the slopes in the litter, debris, and grass covering the ground with occasional short duration upslope runs and torching of individual or small groups of shrubs and trees. By late morning on July 6 the fire covered approximately 127 acres. At about 1520 (all times are mountain daylight saving time given in 24 hour format) a dry cold front passed over the area. At about 1600 and for the next 4 hours the fire burned generally north and east through the shrub and tree canopies as a fast moving wind-driven front. It exhibited dramatically greater rates of spread, flame heights, and energy release rates than at any time since its ignition.

The South Canyon Fire eventually burned 2,115 acres and was declared controlled on July 11, 1994. This fire will not be remembered for the acreage burned, but for the lives lost. On the afternoon of July 6, 1994, fire entrapped and killed 14 firefighters, making the South Canyon Fire one of the most tragic wildland fires to occur in the United States this century.

Immediately following the accident an interagency team was formed to conduct an official investigation into the causes of the fatalities. The "Report of the South Canyon Fire Accident Investigation Team" (USDA, USDI, and USDC 1994), hereafter referred to as South Canyon Report, was released in August 1994. A followup report, titled the "Report of the Interagency Management Review Team (South Canyon Fire)" was released in October 1994 (IMRT 1994). This second report presented a corrective action plan for improved firefighter safety based on findings from the first report. A final report titled "Final Report of the Interagency Management Review Team" was issued in June 1995 (IMRT 1995). This report summarized accomplishments since release of the corrective action plan and made further recommendations for improved firefighter safety. The Occupational Safety and Health Administration also investigated the incident and presented a report (OSHA 1995).

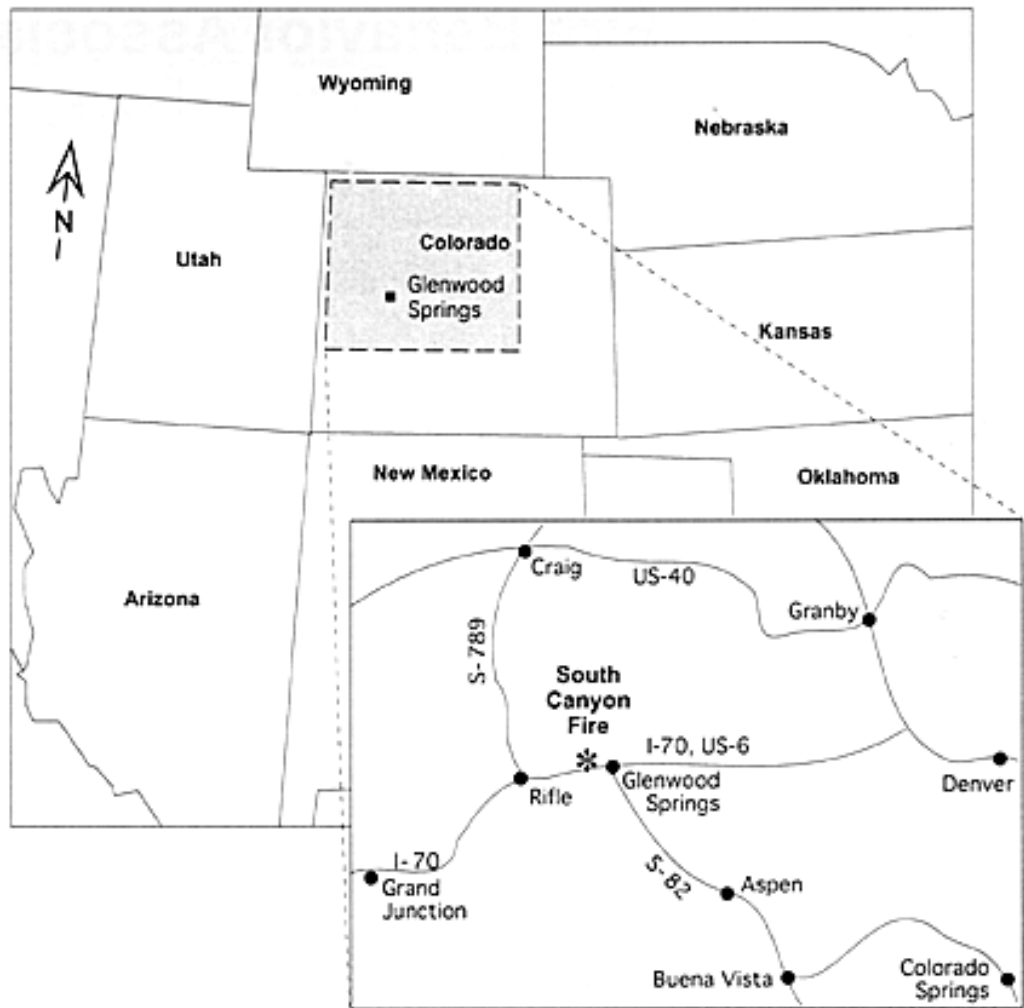


Figure 1—Overview of South Canyon Fire location (not to scale).

Time constraints limited the original accident investigative team from studying the fire behavior in detail. This report presents a more detailed picture, than has been presented previously, of the factors that led to the dramatic change in fire behavior on July 6, 1994. Information and data were gathered from many sources including investigation reports, firefighter interviews, site visits, and related scientific literature. The information presented in this document refines previous work by the accident investigators.

Unfortunately, during most wildfires, there is little documented quantitative information about the fire spread during times when the fire is most active. Such was the case for the South Canyon Fire. Given the lack of quantitative fire behavior data, we reconstructed the fire behavior from witness statements and information about the vegetation, topography, and weather present at the time of the fire. To accomplish this we first developed a detailed chronology of firefighter locations and movement during the time of interest. The chronological history for the afternoon of July 6, 1994, occupies a significant portion of this report. We believe that this information

is necessary to understanding the fire behavior. Using the witness statements about the location and behavior of the fire and the chronology, we were able to develop a sequence of fire perimeters.

The behavior exhibited by the South Canyon Fire on July 6, 1994, was extreme in terms of intensity; but it can also be termed normal for the fuel, weather, and topographical conditions present at the time. Similar alignments of influencing factors and the resulting fire behavior are not uncommon.

We present a summary of the South Canyon Fire and some key factors that influenced the fire behavior. We describe the topography, the vegetation or fuel, and weather present during the fire. This is followed with a chronological narrative of firefighter movements and fire perimeter locations prior to and during the blowup and entrapments. Finally, key fire behavior points are discussed and summarized. Our reconstruction of the fire behavior is based on best estimates of fire spread rates, firefighter travel times, and witness statements. When specific statements or information from witnesses are used, we cite the source.

We frequently use the terms “intensity” and “blowup.” In the general sense, “intensity” implies the size of the flames, the fire’s spread rate, and the rate of energy release from the fire. “Blowup” indicates a rapid change from a low intensity surface fire, to a high intensity fire burning through the whole vegetation complex, surface to canopy, and demonstrating dramatically larger flame heights, higher energy release rates, and faster rates of spread. We define other terms used in this report in appendix A.

Fire Behavior Overview

Figures 2 and 3 present a closer view of the fire location and points of interest to the fire narrative.

Lightning ignited the South Canyon Fire on the afternoon of July 2, 1994, on the south end of the Main Ridge. For the next 48 hours, the fire backed down the slope in the surface litter of leaves, twigs, and grasses. The fire behavior consisted of generally low intensity downslope spread with occasional short duration upslope runs and torching in the Gambel oak (*Quercus gambelii*) canopy and single or small groups of conifers. By 1200 on July 4 the fire had burned approximately 3 acres. It continued burning through the day and covered approximately 11 acres by 2200.

By 0800 on July 5, the fire covered 29 acres. It continued to spread downslope through the day on July 5, leaving many unburned islands of vegetation. By the end of the day, the fire had burned approximately 50 acres. General fire activity consisted of low intensity downslope spread with intermittent flareups and short duration upslope runs in the fire’s interior. The fire remained active through the night covering approximately 127 acres by morning on July 6. Even though the fire more than doubled in size between late evening on July 5 and the morning of July 6, its spread rate remained consistent with that displayed during the previous days.

On the morning of July 6 the fire continued to burn downslope through the surface fuels with isolated torching of individual tree crowns and short upslope runs in the fire’s interior. Flareups, small reburns, and slopovers characterized fire activity through the late morning and early afternoon.

By midafternoon, westerly winds blowing over the tops of the north-south oriented ridges were increasing. At approximately 1520 a dry cold front

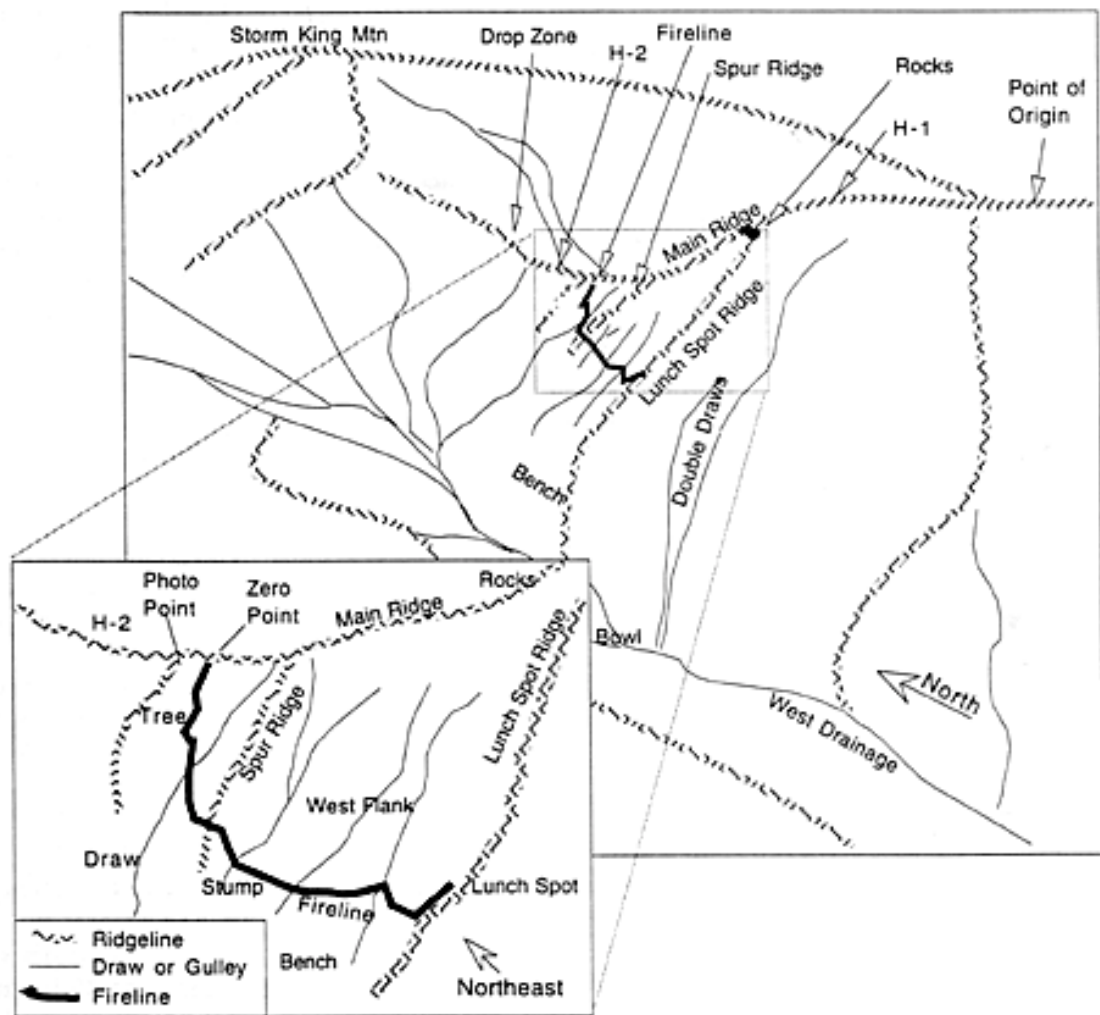


Figure 2—Oblique sketch of west-facing slope of the Main Ridge. Perspective is looking northeast. Inset shows specific topographical features and locations of interest to the narrative. Heavy black line is approximate location of the West Flank Fireline (not to scale).

passed over the area. Winds in the bottom of the West Drainage were estimated to be from the south (upcanyon) at 30 to 45 miles per hour. About 1555 several upslope fire runs occurred in the grass and conifer crowns on the west-facing slope near the southwest corner of the fire's interior. Some narrow upslope fire runs and flareups in the underburned oak canopy on the upper portion of the West Flank near the Main Ridge occurred around the same time. Shortly after the crown fire runs, witnesses observed fire in the bottom of the West Drainage near the base of the Double Draws. Pushed by the upcanyon winds, the fire in the West Drainage spread rapidly north. As this fire spread north and east, fuel, slope, and wind conditions combined to push the fire into the live Gambel oak canopy.

Firefighters on the West Flank Fireline and on the Main Ridge perceived the fire to be burning as a wide front moving north and east up the West Drainage and across the West Flank. We estimate that the fire moved north up the drainage at about 3 feet per second. Step slopes and strong west



J. Kautz, U.S. Forest Service, Missoula, MT.

Figure 3—Aerial photograph of fire site. The perspective is looking southeast across the West Drainage toward the West Flank. The West Flank Fireline can be seen as a faint trail approximately in the center of the photograph. The Lunch Spot Ridge runs from H-1 through the Lunch Spot to a point near the bottom of the drainage. The Colorado River Gorge runs east to west and is behind H-1 and the Ignition point. H-2 is located northeast along the Main Ridge, off the left side of the picture.

winds triggered frequent upslope (eastward) fire runs toward the top of the Main Ridge. These upslope runs spread through the Gambel oak at 6 to 9 feet per second (appendix B, table B-8).

The combination of steep slopes, strong winds, and flammable fuels resulted in a fire that entrapped and killed 12 firefighters on the northeast end of the West Flank Fireline. Two other firefighters, who moved north up the Main Ridge then northwest toward an exposed rocky face, died in a narrow gully when overrun by the fire. The surviving firefighters exited the area by moving out the East Drainage to Interstate Highway 70 along the Colorado River.

Summary of Critical Factors Influencing the Fire Behavior

On the afternoon of July 6, 1996, the fire rapidly changed from a relatively slow-moving fire burning downslope through the dead leaves and stems on the ground to a fast-moving fire burning upslope through the vegetation canopy. Some of the factors that caused the transition were fire at the base of steep slopes containing significant areas of grass and pinyon-juniper (*Pinus edulis* and *Juniperus* sp.), steep terrain, strong turbulent winds, and involvement of the leaves and stems in the vegetation canopy. Following is a brief review of these factors.

Steep, Complex Terrain—Topography was a major contributor to the fire behavior demonstrated on July 6. Fire spread rapidly up steep slopes. Whether ignited by burning brands lofted from a crown fire run or simply a result of the backing fire that had burned through the previous night and day, fire was burning near the bottom of the West Drainage by 1555 on July 6. The presence of fire at the base of steep slopes covered with unburned vegetation had the potential for rapid upslope runs, even in the absence of strong winds.

Strong, Turbulent, and Variable Winds—Low level westerly winds accompanying the cold front increased as they passed from the relatively open and broad canyon west of the fire area into the narrow Colorado River Gorge. The relative orientation of the West Drainage and the Colorado River Gorge redirected a portion of the westerly winds in the Gorge up the West Drainage. These winds caused fire growth and spotting while pushing the fire north and east up the West Drainage. As the flank of the fire burned up the west-facing slope it was increasingly exposed to the westerly flow. The strong westerly winds and steep slopes caused rapid fire runs to the Main Ridge. Therefore, the fire was spreading steadily to the north up the West Drainage with frequent fast-moving eastward-directed runs to the Main Ridge. This type of behavior has been termed “hook and run.” The strong winds increased the number of spot fires and also the spotting distance.

Involvement of Live Fuels—The relatively low intensity fire behavior exhibited by the backing surface fire previous to the blowup did not indicate the potential for high intensity behavior in the live vegetation canopy. The strong updrainage winds and steep slopes caused the flaming zone of the fire burning in the dead litter and grass to increase in size sufficiently that the green Gambel oak canopy began burning. The green nonburned Gambel oak carried the fire into the previously underburned Gambel oak. The critical factors to fire spread in the vegetation canopy were exposure to a large flaming front, steep slopes, strong winds, low fine dead fuel moisture content, and moderately low live fuel moisture content.

Fire Environment

This section is a short summary of the fire environment on the afternoon of July 6, 1994. First we discuss the topography. Next we discuss the condition of the vegetation or fuels in the area. Finally, we summarize the long-term and short-term weather related factors that influenced the fire behavior.

For the purposes of this study, we have attempted to use the same location names as were used in the original investigation report. However, we have

identified a few previously unnamed areas. In most cases we identify the specific locations by a dominant geographical feature.

Topography

The fire occurred in a topographically complex area. The highest peak in the area, Storm King Mountain, is over 8,700 feet in elevation. The terrain south of the peak falls in a series of steep rugged broken ravines, gullies, and ridges to the Colorado River (elevation approximately 5,680 feet). Figures 4 and 5 present an aerial photograph and topographical map of the fire area. Figures 3, 6, 7, and 8 are aerial oblique photographs of the fire site from different view angles.

Main Ridge—Up to the afternoon of July 6, 1994, the South Canyon Fire burned on the southwest side of Storm King Mountain. One of the main ridges between the mountain and the Colorado River Gorge is locally known as Hellsgate Ridge, we refer to it as the Main Ridge. The northeastern end of the Main Ridge begins as a saddle at the southern base of Storm King Mountain. The two firefighters working helitack were killed in a steep rocky chute northwest of this area. From the saddle the Main Ridge runs to the southwest for about 3,700 feet where it abruptly ends at the Colorado River Gorge.

Ignition Point—A lightning strike to the top of the southwest-most knob of the Main Ridge (elevation 6,980 feet) ignited the South Canyon Fire. To the south from the Ignition Point the terrain falls steeply (about a 55 percent slope) to Interstate 70 and the Colorado River.

East and West Drainages—The Main Ridge is flanked on the east and west by two north-south oriented drainages. These drainages are referred to as the East and West Drainages. Both drainages were formed by erosion of the sandstone rock and soil. Fine sand fills the bottom of the drainages with intermittent large sandstone boulders. The West Drainage follows a twisting path north from the Colorado River Gorge. The bottom of the West Drainage is a steep-sided (80 percent slope) ravine. The West Drainage channeled air from the Colorado River Gorge north to the base of Storm King Mountain. The fire changed from a backing surface fire moving down the slope to a fast spreading fire burning upslope and upcanyon through the shrub and tree canopies in the West Drainage. Surviving firefighters exited via the East Drainage. The fire burned through the East Drainage about 30 minutes after the firefighters exited it.

Lunch Spot and Spur Ridges—Two spur ridges that are important to the narrative extend west from the Main Ridge down into the West Drainage. The southernmost ridge, referred to as the Lunch Spot Ridge, was where the firefighters who had been building fireline down the West Flank of the fire ate lunch on the afternoon of July 6 (fig. 3 through 6 and 8). Eight smokejumpers deployed and survived in fire shelters on the upper portion of the Lunch Spot Ridge during the afternoon of July 6, 1994. One smokejumper survived near the Lunch Spot without deploying a fire shelter.

A second smaller ridge, located about 1,400 feet north of the Lunch Spot Ridge, we call the Spur Ridge. The Spur Ridge serves as a point of reference when discussing firefighter, helicopter, and fire location and movement.

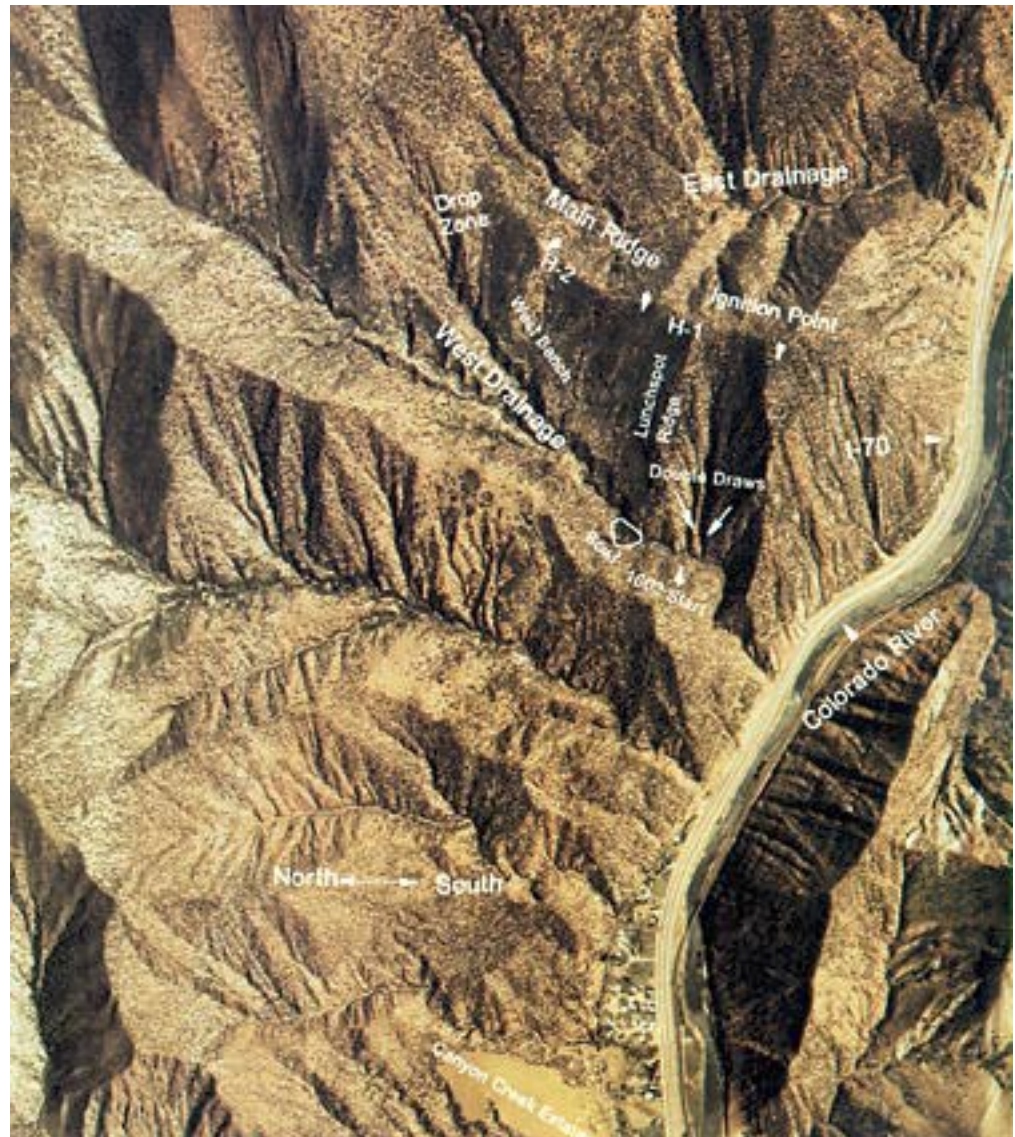


Photo source: Grand Junction District of the BLM, U.S. Department of Interior

Figure 4—Aerial overhead view of South Canyon Fire site. Note the East and West Drainages, the Main Ridge, Interstate Highway 70, and Colorado River Gorge. The Canyon Creek Estates subdivision is shown directly west of the fire site. The helibase was located at the subdivision.

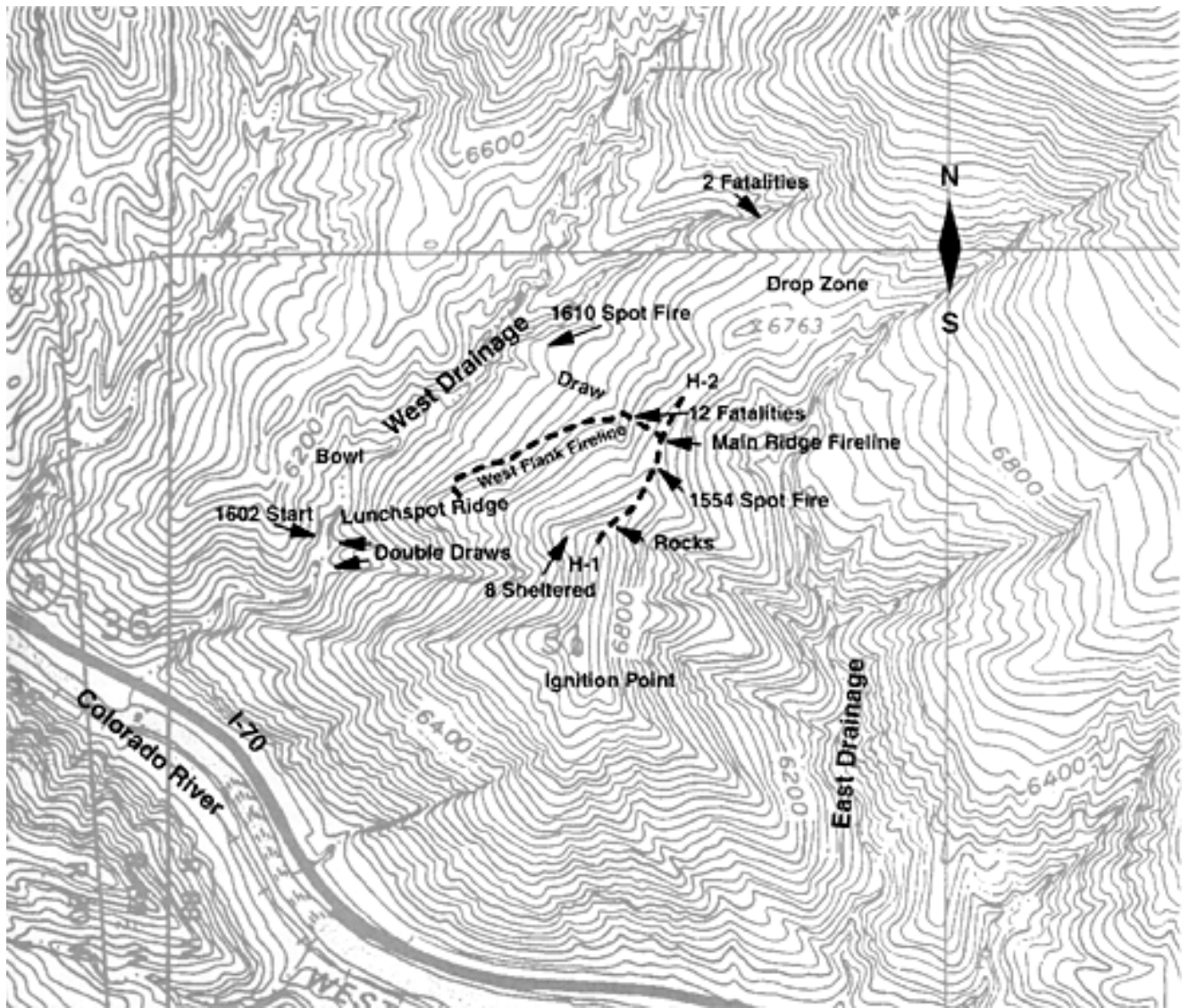
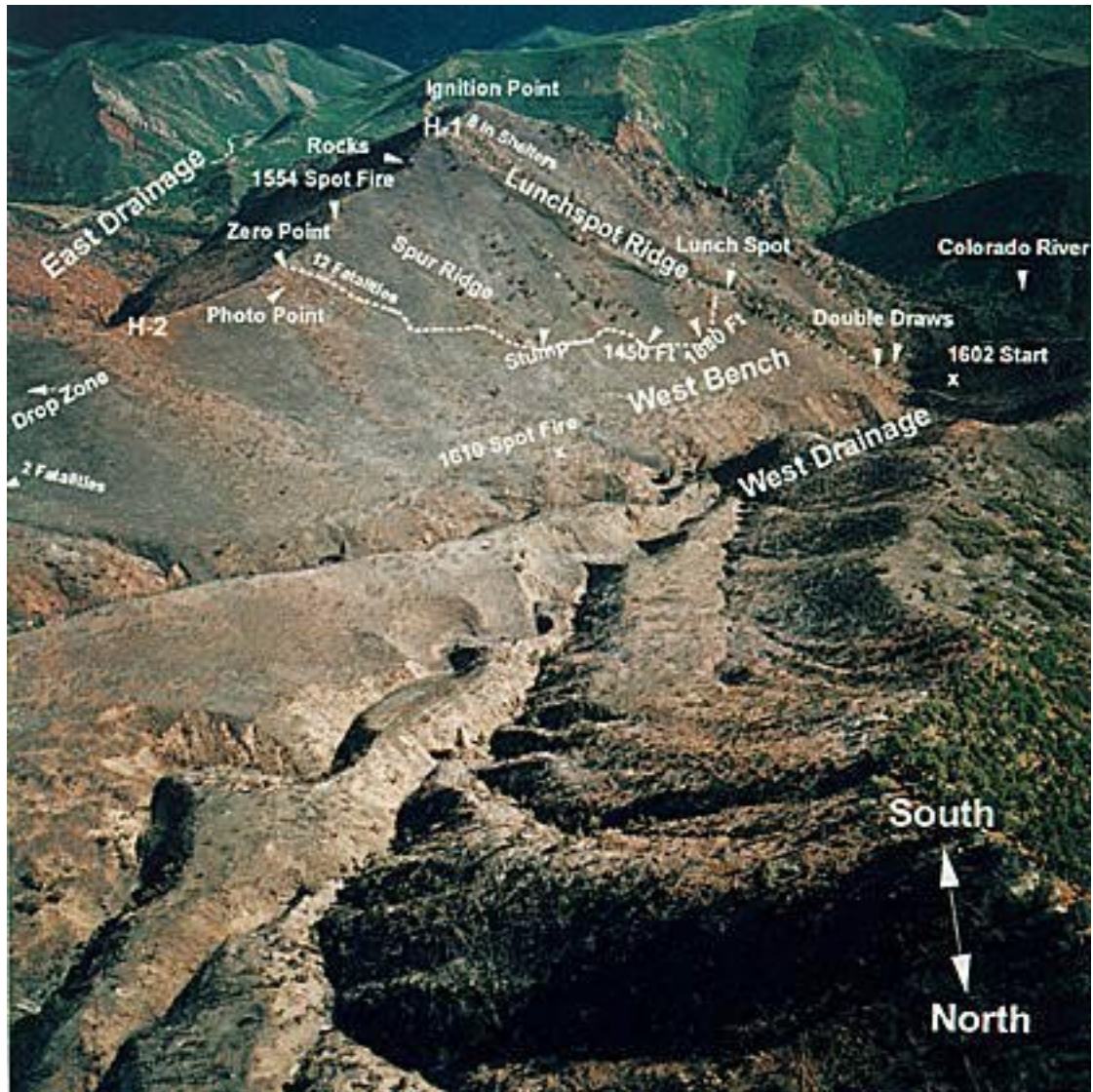


Figure 5—Topographical map of fire area. Heavy dark dashed line identifies firelines on West Flank and on Main Ridge. These firelines were constructed on July 6, 1994.

Helispots H-1 and H-2—Two helispots were constructed on the Main Ridge. The first helispot (designated H-1) was constructed on July 5 and was at the junction of the Main Ridge and Lunch Spot Ridge at about 7,000 feet elevation on an unnamed knob. It consisted of an area approximately 50 feet in diameter that was cleared of brush and trees. Stumps and ground litter remained. A second helispot (H-2) was constructed on the morning of July 6. H-2 was at 6,760 feet elevation and was about $\frac{1}{4}$ mile north of H-1. This helispot was smaller than H-1 and was situated in a small saddle from which the brush had been cleared away.

Double Draws—The southwest face of the Main Ridge near H-1 falls steeply (approximately 55 percent slope) dropping more than 1,000 feet in elevation to the bottom of the West Drainage. The Double Draws are on this



J. Kautz, U.S. Forest Service, Missoula, MT.

Figure 6—Aerial oblique photograph of the West Flank from a position above the north end of the West Drainage. This photo gives a good perspective of the Main Ridge between H-2 and H-1.

steep west-facing slope. They consist of two steep chimneylike gullies leading into the West Drainage. They originate approximately one-third the way down the slope below H-1 and were formed by erosion of the loose soil (fig. 5 and 8). Several crown fire runs occurred south of the Double Draws shortly before the fire suddenly began burning up the West Drainage on the afternoon of July 6, 1994.

Bowl—A small bowl (approximately ½ acre) is in the bottom of the West Drainage about 250 feet north of the intersection of the Double Draws and the

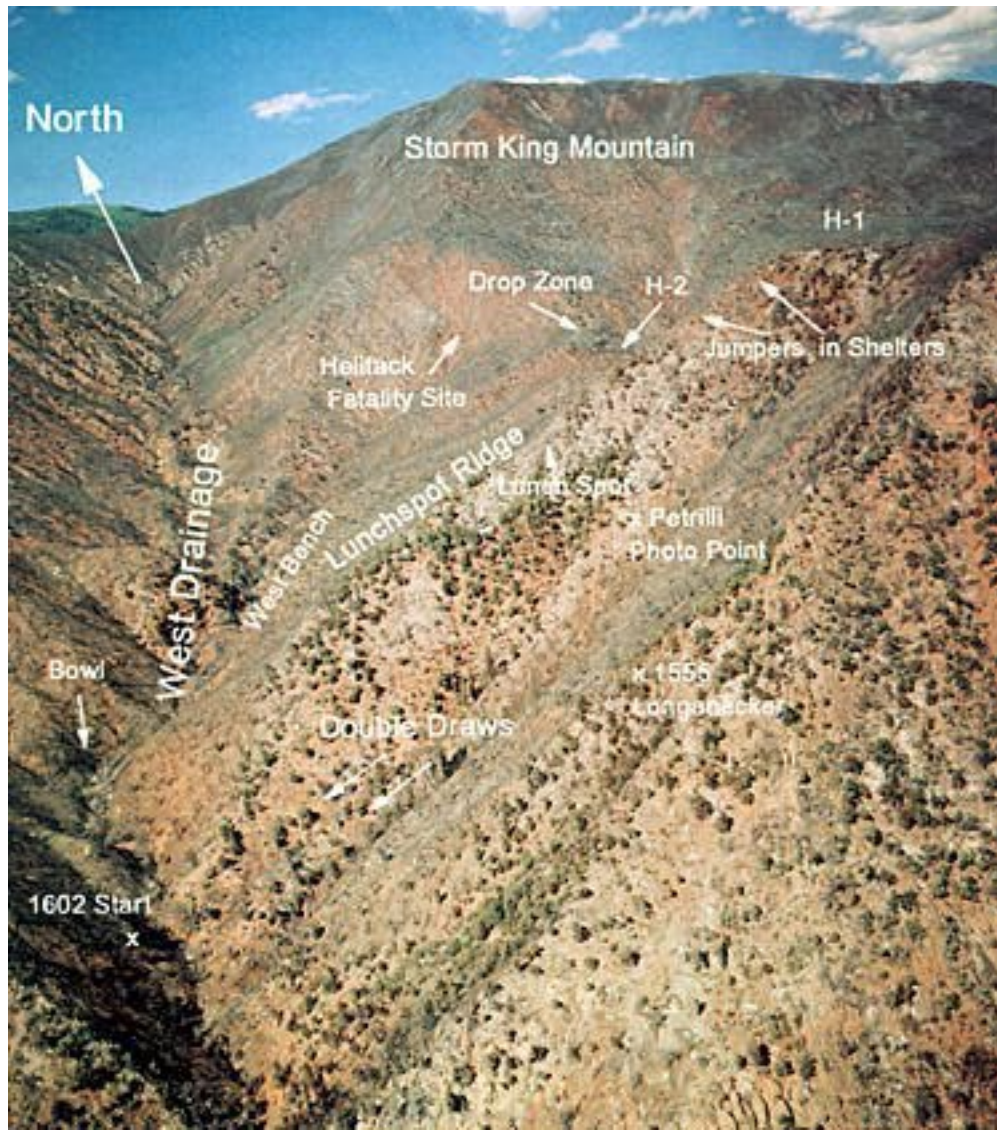


J. Kautz, U.S. Forest Service, Missoula, MT.

Figure 7—Aerial oblique photograph from the upper East Drainage looking southwest. Note the nearly complete consumption of Gambel oak.

West Drainage. This area is referred to as the Bowl. The accumulation of live and dead fuel in the Bowl contributed to the development of the fire that spread up the West Drainage.

West Bench—Northeast of the junction of the West Drainage and the Lunch Spot Ridge is the West Bench. This area is approximately 80 feet above the bottom of the West Drainage. The West Bench is approximately 150 feet wide and 450 feet long with the long side oriented parallel to the West Drainage. While not flat (approximately 15 percent slope), the West Bench



J. Kautz, U.S. Forest Service, Missoula, MT.

Figure 8—Aerial view of South Canyon Fire site looking north up the West Drainage toward Storm King Mountain from a location over the Colorado River. Note green vegetation on south side of the Lunch Spot Ridge.

is significantly less steep than the slopes on either side of it. Gambel oak with grassy openings was the dominant vegetation on the West Bench. Gambel oak completely covered the slopes between the West Bench and the Main Ridge.

West Flank Fireline—This fireline is approximately 2,100 feet long with the Lunch Spot at its southernmost point. From the Main Ridge, the West Flank Fireline leads west down the steep (about 55 percent) slope for 300 feet. From the base of this first steep pitch the fireline continues, at a much flatter slope (about 10 percent), another 380 feet down and across the slope to the Spur Ridge. It leads over the Spur Ridge, turns to the southwest, and follows a contour route across the West Flank slope for about 800 feet. From this point it contours 400 feet diagonally across and down the slope, leading generally southwest, and then climbs 200 feet up a 65 percent slope to the Lunch Spot. Several points of interest on the West Flank Fireline are identified by their major topographical features. Distance along the fireline from the junction of the Main Ridge and the Fireline are given in parentheses. The points are: the Zero Point (0 feet); the Fatality Site (120 to 280 feet); the Tree (200 feet); the Draw at the base of the first steep pitch in the fireline (445 feet); the Spur Ridge (680 feet); the Stump (850 feet); two other locations (1,450 and 1,880 feet) are important to the fire chronology presented later. All of these points are shown in figure 3. All distances are detailed in appendix B, table B-2.

Zero Point—The junction of the Main Ridge and the top of the fireline constructed on the West Flank is an important geographical location when specifying specific firefighter locations and movement. For the purposes of this report, it is referred to as the Zero Point. We found it helpful to reference distances along the Main Ridge and the fireline from this point. For example, helispot H-1 is 790 feet south along the Main Ridge from the Zero Point and helispot H-2 is 560 feet north along the Main Ridge from the Zero point.

Drop Zone—The smokejumper Drop Zone was near the Saddle on the north end of the Main Ridge (approximately 1,000 feet north of H-2).

Fuels

Vegetation in the area consisted primarily of Gambel oak (*Quercus gambelii*) on the north- and west-facing slopes and open, mixed pinyon-juniper (*Pinus edulis* and *Juniperus* sp.) with a cured grass understory on the south-, southwest-, and east-facing slopes. A few “pockets” of Douglas-fir (*Pseudotsuga menziesii*) existed in the area of the Double Draws, the Bowl, and on the lower east-facing slope of the West Drainage. Continuous cured grasses and some shrubs and small stands of pinyon-juniper covered the bottom of the north-south oriented West Drainage (Anon 1994). The Bowl contained a heavier concentration of grasses, mixed shrubs, woody debris, and trees. Figure 9 shows the approximate distribution of the vegetation over the fire site.

The Gambel oak was more than 50 years old and did not contain much dead material (South Canyon Report; Biastoch 1995). It formed a dense, green, continuous closed canopy, 6 to 12 feet tall and appeared to be unaffected by spring frosts (fig. 10). Visibility within the stand was limited. The surface fuels beneath the canopy consisted of a 3 to 6 inch layer of leaf litter (Husari 1996).

Fine dead fuel moisture content was estimated to range from 2 to 5 percent on the afternoon of July 6 (South Canyon Report). Both the large diameter

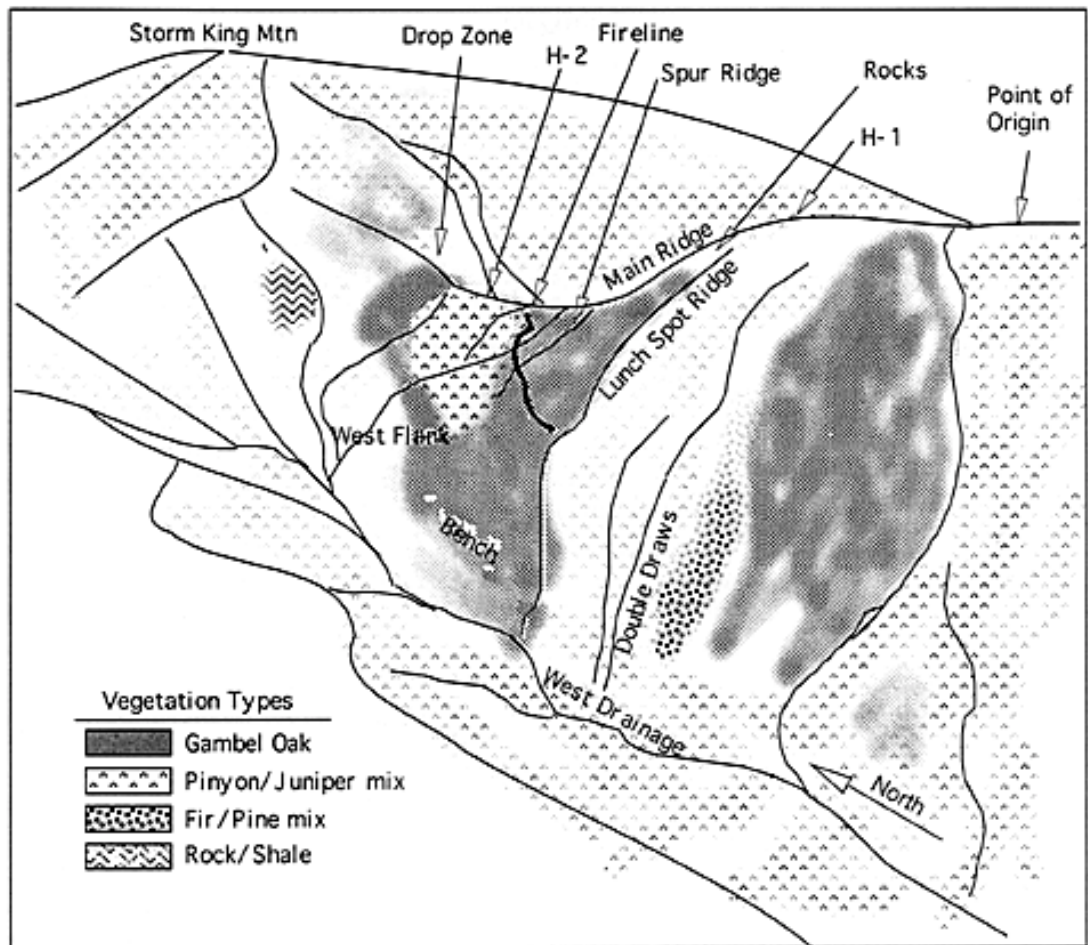


Figure 9—Drawing showing approximate distribution of vegetation in area of South Canyon Fire. Perspective is looking northeast across West Drainage from location over Colorado River (adapted from Accident Investigation Report, not to scale).

(1000 hour) dead fuels and the live fuel moisture contents in the area were several weeks ahead of their historical summer drying trends (South Canyon Report). No fuel moisture content samples were collected at the time of the fire. However, live foliar moisture contents were measured on July 12, 1994, at a site near the South Canyon Fire with an aspect and elevation similar to the west flank of the Main Ridge. Foliar moisture in underburned Gambel oak was about 60 percent while that in green unburned Gambel oak was 125 percent (South Canyon Report). Typically, live fuel moisture levels change relatively slowly in undamaged shrubs. Therefore, we expect the foliar moisture content of the unburned Gambel oak on July 6 would have been similar to the values measured on July 12. No samples were collected in the pinyon-juniper fuels.



Courtesy of T. Petrilli

Figure 10—Photograph of Gambel oak at South Canyon Fire Site taken on July 6, 1994. Note lack of significant amount of dead leaves and stems in the canopy.

Long Term—The South Canyon Fire Investigation report states that “weather significantly contributed to the blowup of the fire.” Below normal precipitation (as compared to the 30 year average) during the winter and spring of 1994 had pushed western Colorado into a severe drought (South Canyon Report). Precipitation levels at Glenwood Springs from October 1, 1993, through July 6, 1994, were 58 percent of normal. Accompanying the below-normal precipitation were much warmer than normal temperatures through May and June. This pattern persisted into July. Fires in western Colorado during the previous weeks had exhibited rapid spread rates and long range spotting, both characteristic of drier than average conditions.

July 5, 1994—On this day, weak high pressure aloft and a hot, dry air mass covered western Colorado. Upper level winds were light from the southwest through 14,000 feet and then increased to 30 miles per hour at 16,000 feet. At Grand Junction, CO, the lower atmosphere was dry and unstable as indicated by a Haines Index of 6 (Haines 1988). That morning a strong cold front developed in western Idaho. The front was associated with an unseasonably cold upper level low pressure system, centered over northern Oregon. By late afternoon the cold front extended from eastern Idaho into central Nevada.

We are not aware of any weather observations taken by firefighters working on the fire. The closest remote automatic weather station (RAWS) was southwest of the airport at Rifle, CO, approximately 10 miles west of the fire site. We assume that the measurements from Rifle are representative of the conditions over the South Canyon Fire.

Between 0100 and 0600 on July 5 the relative humidity at the Rifle RAWS ranged from 10 to 40 percent. Relative humidity remained near 11 percent until after midnight (fig. 11). Winds at the Rifle RAWS were light and variable through the morning and late afternoon of July 5, 1994 (fig. 12). By 1800 on July 5, 1994, winds over the South Canyon Fire area were blowing generally from the south at 10 to 15 miles per hour with gusts to 20 miles per hour (South Canyon Report; Bell 1994).

July 6, 1994—At 0600 this day, the cold front extended from central Wyoming across northwest Colorado into southwestern Utah (fig. 13). Relative humidity at Rifle reached a high of 29 percent at about 0700 as compared to 40 percent the previous date (fig. 11). The lower relative humidity during the early hours of July 6 enhanced burning during the night. This is supported by witness statements that the fire was more active through the night on July 5 than on previous nights.

The front passed over Grand Junction around 1300 and caused the 10 to 15 mile per hour winds to increase to approximately 30 miles per hour (South Canyon Report). The front passed over the Rifle RAWS station between 1400 and 1500, as indicated by increased winds out of the west-southwest. They reached their peak at about 1600 with gusts to 45 miles per hour. The relative humidity at Rifle reached a minimum of 8 percent at 1700 on July 6. The winds at Rifle changed to the northwest at 1900. They gradually decreased through the evening and were blowing less than 6 miles per hour by 2300 (fig. 12).

Firefighters on the fire and at Canyon Creek Estates, a residential subdivision about 2 miles west of the fire, noted an increase in winds between

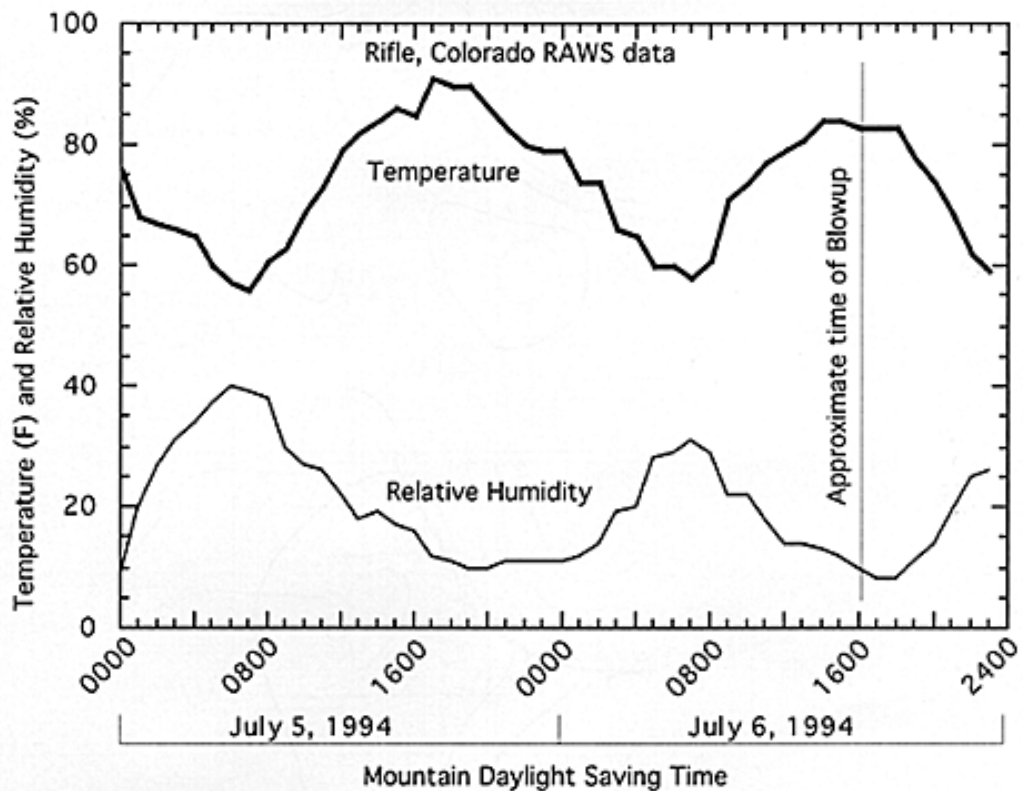


Figure 11—Temperature and relative humidity measurements from the Rifle, CO, Remote Automatic Weather Station for period midnight on July 5, 1994, through 2300 on July 6, 1994.

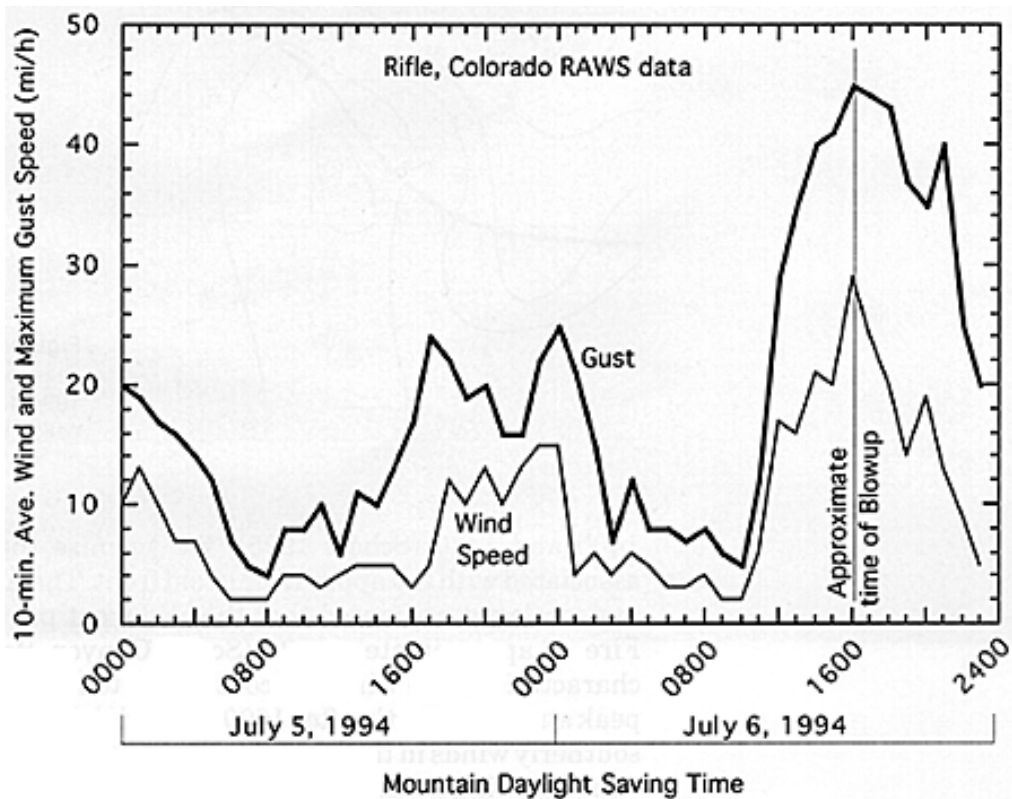


Figure 12—Wind speeds from the Rifle, CO, Remote Automatic Weather Station for period midnight on July 5, 1994, through 2300 on July 6, 1994.

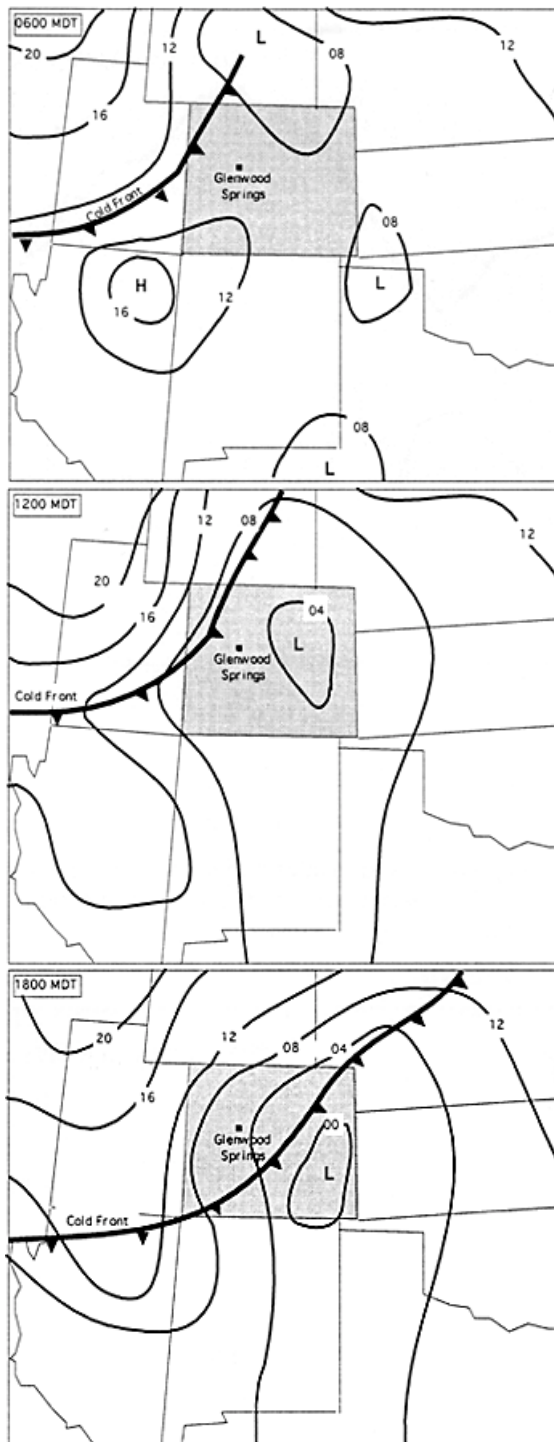


Figure 13—Surface air pressure charts showing progression of cold front on July 6, 1994 (taken from original Accident Investigation Report).

1400 and 1430 (Scholz 1995). We surmise these were prefrontal winds associated with the approaching cold front. The Accident Investigation Team meteorologist estimated that the cold front passed over the South Canyon Fire at approximately 1520 (South Canyon Report). Witness statements characterized the winds as continuing to increase in speed, reaching their peak strength shortly after 1600. The original investigation report estimated southerly winds in the West Drainage of 20 to 35 miles per hour and westerly winds blowing across the ridges of 45 miles per hour at this time. Statements made by firefighters and the helicopter pilot suggest that it is likely that

gusts over 50 miles per hour occurred in the chimneys and saddles along the ridges. Smokejumpers near the Lunch Spot at 1606 estimated upslope winds of 30 to 45 miles per hour (Petrilli 1995). Winds over the fire area remained strong until 2000 (South Canyon Report).

Topography and Wind—There is inconsistent testimony in witness statements regarding winds in the area of the fire. While the general flow was from the west, the direction and intensity of the winds varied significantly from one location to another (South Canyon Report; Shepard 1995). For example, firefighters working on the Main Ridge stated that as they cleared away brush from the fireline they could throw it into the air and the wind would carry it over the side of the ridge. At nearly the same time firefighters working on the northeast portion of the West Flank Fire Line (a location topographically sheltered from the wind) and at an exposed rocky outcropping near H-1 stated they experienced almost no wind at all. Though inconsistent with each other, these observations are consistent with the character of surface winds in complex mountainous terrain, particularly when influenced by strong, synoptic-scale weather patterns.

We feel topography was particularly influential on the surface winds the afternoon of July 6. West of the fire site the Colorado River flows through a relatively open and broad canyon. The low level westerly winds accompanying the cold front passed through this canyon. The canyon narrows dramatically about 2 miles west of the mouth of the West Drainage then opens to the east near Glenwood Springs (fig. 7 and 14). As the wind flowed from the broad canyon into the narrow Colorado River Gorge it increased in speed (fig. 15).

Several factors combined to create unusually strong upcanyon flow in the bottom of the West Drainage. First was the topography near the mouth of the West Drainage. The orientation of the ridge running from the ignition point, west to the Colorado River, acted as a “scoop” redirecting a portion of the westerly flow in the Colorado River Gorge northward up the bottom of the West Drainage (fig. 4 and 5). Second, normal daytime heating of the upper slopes in the West Drainage induced general upcanyon flow. This upcanyon flow resulted in a low pressure region at the entrance to the West Drainage, causing even more air to flow from the gorge into the drainage. Third, the increasingly strong westerly winds associated with the cold front evacuated air from the top of the West Drainage (fig. 16). This resulted in pressure-induced flow from the Colorado Gorge into the West Drainage. Some photographs and video footage taken during the blowup show smoke movement (Bell 1994) and clearly illustrate the complexity and turbulence of the surface winds shortly after 1610. High resolution meteorological modeling (see appendix C) supports the mesoscale wind analysis by the Accident Investigation Team meteorologist.



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Figure 14—Aerial oblique photograph looking north over the Main Ridge and Storm King Mountain from the south side of the Colorado River. Note the widening of the river gorge as it opens into Glenwood Springs. While not shown in this picture, the Colorado River Gorge again widens to the west (off left side of photograph) of the fire site.

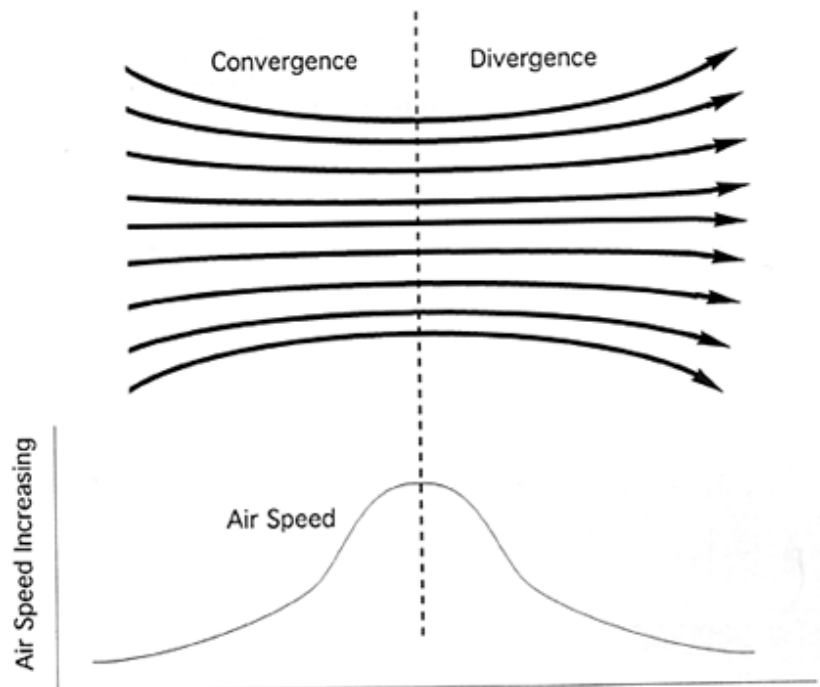
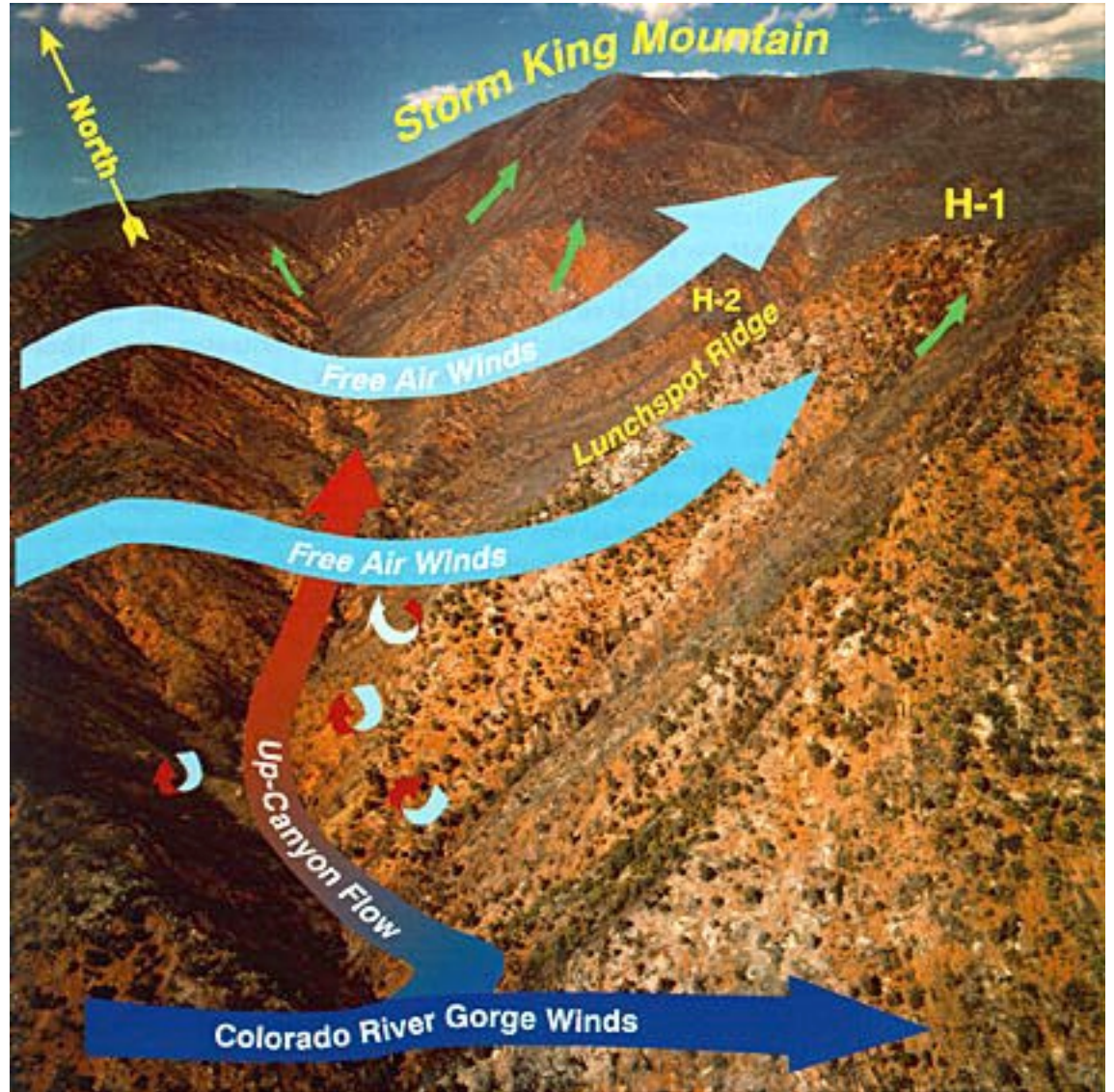


Figure 15—Schematic diagram of venturi effect that caused increased local winds where the West Drainage meets the Colorado River Gorge (not to scale).



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Figure 16—The general air flow over the fire area at the time of the crown fire runs south of the Double Draws (about 1555). The free air westerlies (light blue) evacuate the afternoon upslope flow (green) out of the upper end of the West Drainage. This creates an area of divergence in the north end of the West Drainage. The topography and orientation of the mouth of the West Drainage redirected a portion of the strong winds in the Colorado River Gorge (dark blue) up the West Drainage (red). A shear zone is created where the westerly winds interact with the flow up the West Drainage. Turbulent eddies created by the shear zone may have enhanced burning near the Double Draw and along the Lunch Spot Ridge and West Bench. The eddies transported burning embers north up the West Drainage.

Fire Chronology

One of our major objectives was to estimate fire spread rates during the afternoon of July 6. This can be done using fire spread models or by calculating the distance and time separating successive fire perimeters. We chose the latter method; the original accident investigators used fire behavior models. Our method of analysis required that we develop a chronological history of the movement and location of individual firefighters. We used witness statements, followup interviews, onsite reenactment of firefighter movement, and calculations based on known physiological capabilities for hotshots and smokejumpers (Sharkey 1994). From the chronology and witness statements we constructed fire perimeter maps. These maps were then used to estimate fire spread rates.

The following is a narrative of firefighter movements and fire behavior on the South Canyon Fire for July 2 through July 6, 1994. Whenever possible, we describe events in chronological order.

The location names are the same as those in the original fire investigation report with some additional areas identified. Specific locations are identified in figure 17, an oblique photograph, and figure 18, a labeled topographical



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Figure 17—View looking northeast over West Flank from east-facing ridge across the West Drainage. The West Flank Fireline can be seen starting at the Main Ridge above the Tree and passing down the hill over the Spur Ridge and across the slope to the Lunch Spot.

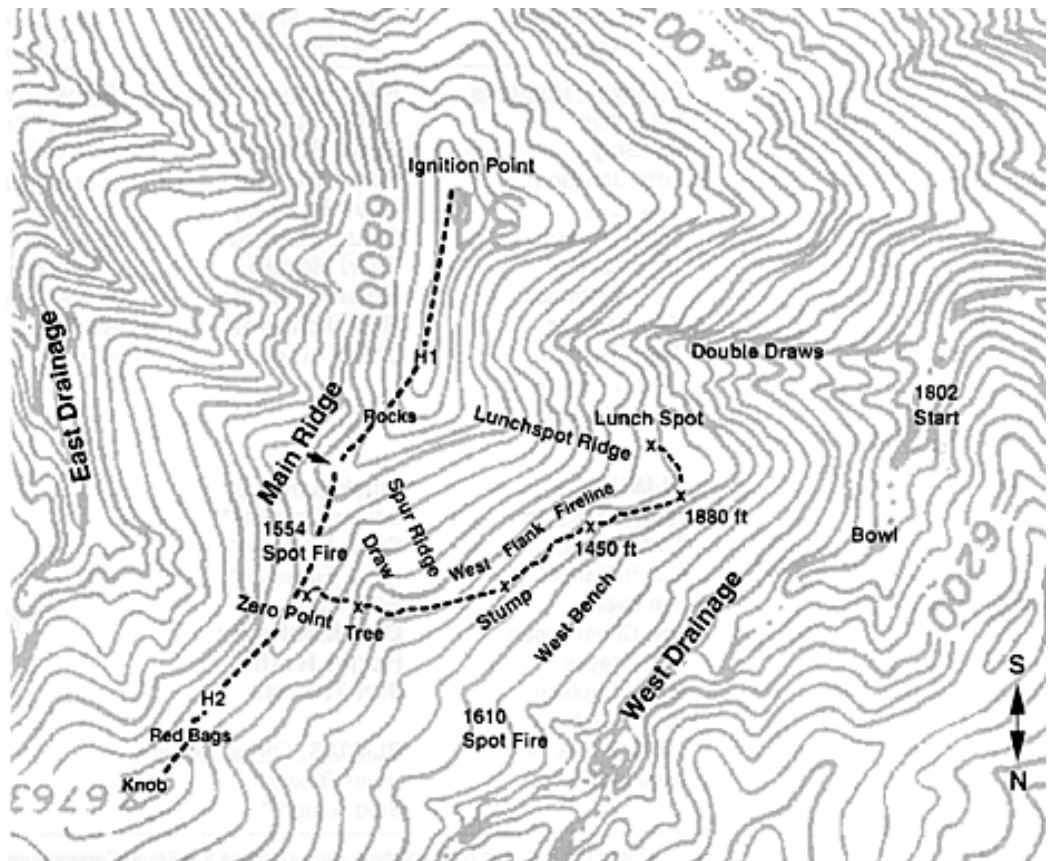


Figure 18—Topographical map showing locations important to narrative. Map is oriented south to north for use with figure 17. Dashed lines indicate firelines along West Flank and Main Ridge.

map. We use surnames when referring to individual firefighters. Some titles are used. Full name and affiliation are available in the South Canyon Fire investigation report.

To make it easier for the reader to follow the chain of events surrounding the fire, we regularly refer to four separate firefighter groups (see table 1). These groups are identified by their general location at approximately 1530 hours on July 6. The groups are: (1) The Main Ridge Group, which consisted of part of the Prineville Interagency Hotshot crew and a Bureau of Land Management (BLM) and U.S. Forest Service crew dispatched from Grand Junction, CO; they all worked primarily along the top of the Main Ridge. (2) The West Flank Fireline Group consisting of nine Prineville Hotshots, seven Forest Service smokejumpers, and two BLM/USFS firefighters who worked on the West Flank Fireline; three of the smokejumpers moved from the West Flank Fireline to the Main Ridge before the entrapment. (3) The Lunch Spot Ridge Group, nine Forest Service smokejumpers who were working primarily south of the Lunch Spot Ridge in the area of the Double Draws just prior to blowup; eight of this group eventually deployed in fire shelters on the upper portion of the Lunch Spot Ridge, the ninth remained near the Lunch Spot. (4) The two helitack crewmembers (one Forest Service and one BLM) make up the fourth group. A helicopter pilot was over the fire a portion of the time.

Table 1—Personnel roster and position at time of blowup.

| Main Ridge Group | West Flank Fireline Group | Lunch Spot Ridge Group | Helitack Group |
|---|--|--|---|
| <u>Prineville Hotshots</u> Bill Baker Kip Gray Tony Johnson Brian Lee Louie Navarro Tom Rambo Alex Robertson Bryan Scholz Tom Shepard* Mike Simmons Kim Valentine | <u>Prineville Hotshots</u> Kathi Beck Tami Bickett Scott Blecha Levi Brinkley Doug Dunbar Terri Hagen Bonnie Holtby Rob Johnson Jon Kelso | <u>Smokejumpers</u> Michael Cooper Mike Feliciano Dale Longanecker Tony Petrilli Quentin Rhoades Eric Shelton Sonny Soto Bill Thomas Keith Woods | <u>Helitack</u> Robert Browning* Richard Tyler* <u>Helicopter Pilot</u> Dick Good |
| <u>BLM/U.S. Forest Service</u> Todd Abbott Butch Blanco* Jim Byers Eric Christianson Mike Hayes Loren Paulson Brian Rush Michelle Ryerson Neal Shunk | <u>Smokejumpers</u> Sonny Archuleta** Sarah Doehring** Kevin Erickson** Eric Hipke Don Mackey*** Roger Roth Jim Thrash | | |
| | <u>BLM/U.S. Forest Service</u> Derek Brixey** Brad Haugh** | | |

Firefighters listed in boldface type were killed on the South Canyon Fire.

*Positioned near H-2.

**Moved from West Flank Fireline to Main Ridge before the entrapment.

***Moved from Lunch Spot Ridge to West Flank Fireline.

Reconstruction of the fire position and spread rates required that we accurately determine each group’s location and activity. Specific times are included in the narrative to indicate the sequence of events and to communicate the speed at which the events occurred. These times were determined by linking elapsed times between events such as helicopter ferry times, reenactment and timing of specific firefighter movements, and human physiological calculations to two known clock times identified in the witness statements. The times presented in the narrative represent a “best fit estimate” and should not be taken as absolute. When estimating fire spread rates, the sequencing and relative time differences between events are of more importance than the absolute times. A great deal of fire and crew activity occurred simultaneously among and between the separate groups making chronological description of both the fire behavior and firefighter positions difficult. We have attempted to divide the narrative into geographical regions and have labeled paragraphs with the central location or group being discussed. We include in the narrative weather and fire behavior as described by firefighters at various locations.

The fire perimeters were developed from witness statements, time and distance measurements and estimates, and topographical, weather, and fuel information. Fire spread rates are estimated from elapsed times and distances between successive fire perimeters. Tables of event times, distances,

firefighter travel rates, fire spread rates and reference sources are included in appendix B.

July 2 to Evening of July 5—Low Intensity Downslope Spread

Lightning ignited the South Canyon Fire on the afternoon of July 2, 1994, near the southernmost point on the Main Ridge. The fire was reported to the county sheriff at 1030 and to the BLM district office at 1100 on July 3, 1994. The fire burned primarily in the open pinyon-juniper fuel type, backing downslope in cured annual and perennial grasses with occasional upslope runs and torching. It grew to 11 acres by the evening of July 4 (fig. 19).

The fire burned through the night of July 4, growing to 29 acres by 0800 on July 5. It continued to spread down the slope in the surface fuels beneath the pinyon-juniper and Gambel oak through the day on July 5. The direction of spread was mostly to the north and west. Burning was not continuous and many unburned islands of fuel remained.

On July 5 seven BLM firefighters, including Incident Commander Blanco, walked into the fire from the East Drainage. They cut a helispot (H-1) and began direct downhill fireline construction. About 1500 an airtanker made a retardant drop on the fire burning on the steep rocky slope above the interstate highway. The BLM firefighters left the fire at 1730 to refurbish their equipment. They hiked out the West Drainage.

At approximately 1745, eight smokejumpers parachuted to the Drop Zone. Jumper-in-Charge Mackey later radioed Incident Commander Blanco that the fire was burning actively and had crossed the fireline prepared by the BLM crew earlier that day. After collecting their gear, the smokejumpers built a fireline along the east flank of the fire until the terrain became too steep. By 2230 on July 5 the fire covered approximately 50 acres.

July 5, 2230 to July 6, 1530—Continued Downslope Spread

The fire continued to burn actively during the night, spreading as a surface fire downhill toward the West Drainage through the pinyon-juniper and grass and laterally to the north through an area covered with Gambel oak. The fire maintained a more continuous flaming front and was much more active through the night of July 5 and early morning of July 6 than it had been the previous night (Bell 1994). We attribute the increased fire activity to lower relative humidities than occurred on previous nights.

Between 0530 and 0600 on July 6, eleven BLM and Forest Service firefighters started hiking up the East Drainage to the fire. At 0800 the BLM/USFS crew constructed H-2, a helispot located about $\frac{1}{4}$ mile north of H-1. Around 0845 Incident Commander Blanco and Jumper-in-Charge Mackey discussed strategy and tactics for the day. They decided to improve the fireline between H-1 and H-2 (using the BLM and Forest Service firefighters) and to start building a fireline along the fire's west flank (using the smokejumpers). At approximately 0930 they took a reconnaissance flight in the helicopter assigned to the fire. In a later interview the pilot, Dick Good, said that on this flight he noticed smoke low in the West Drainage (Good 1996). The fire perimeter map developed after the reconnaissance flight indicated that the fire covered about 127 acres (fig. 19). At 1027 eight more smokejumpers parachuted to the Drop Zone north of H-2. At 1130 the

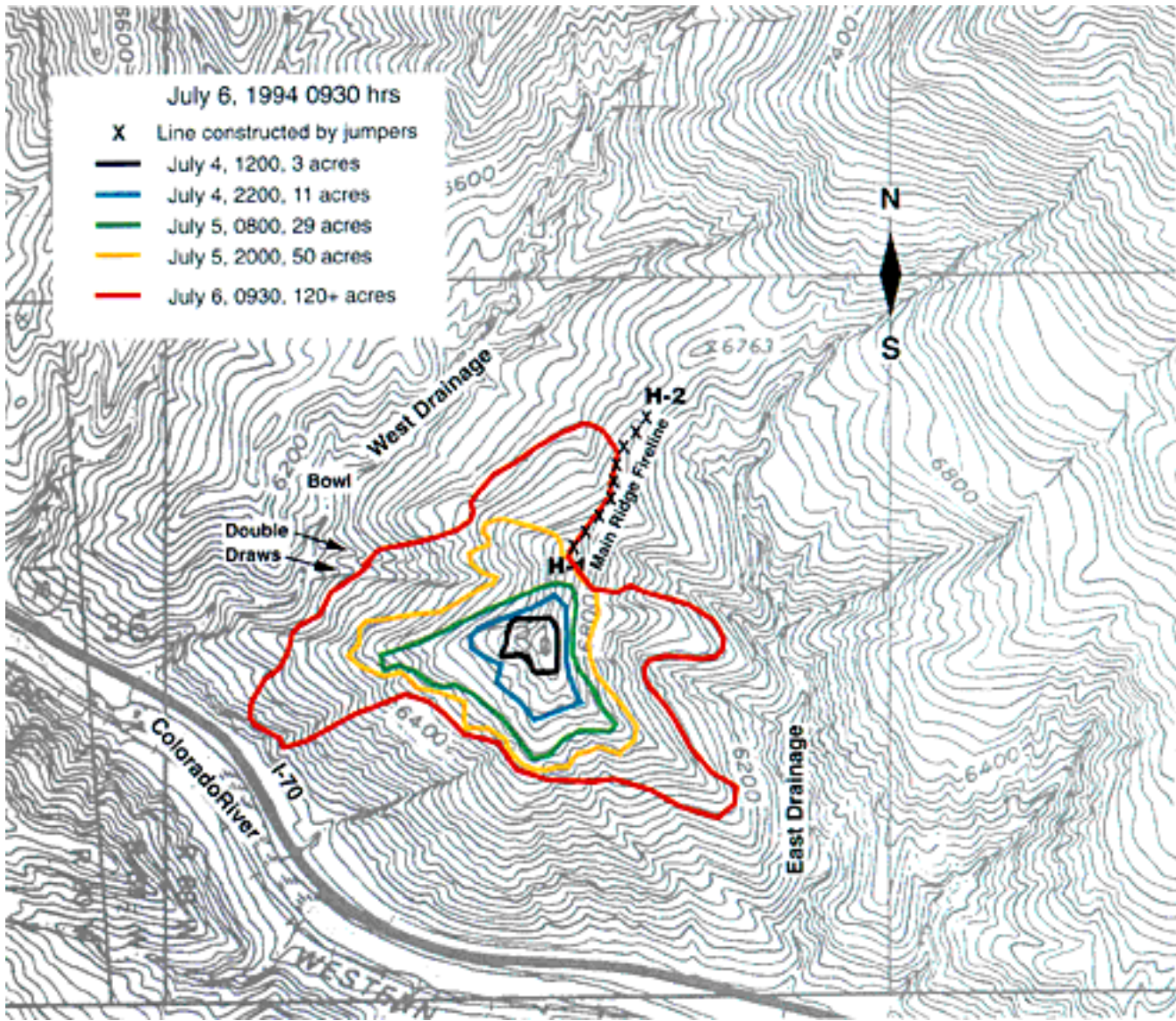


Figure 19—Fire perimeters through morning of July 6, 1994 (adapted from original Accident Investigation Report). The 0930 perimeter is adapted from Mackey’s map drawn during morning recon flight. The July 4 and July 5 perimeters are based on video interpretation by the Investigation Team using Bell’s video (Bell 1994).

combined jumper crews started downhill direct fireline construction on the West Flank.

Flareups, small reburns, and slopovers occurred throughout the fire late in the morning. The figure 20 photograph, taken from Interstate 70, shows smoke from fire activity northwest of H-1 on the West Flank and also southwest of H-1 in the area near the Double Draws. At approximately 1135 a flareup on the West Flank Fireline ran approximately 120 feet up the slope to the top of the Main Ridge in a narrow, about 5 foot wide, run (South Canyon Report). This run prompted discussion to pull out of the West Flank fireline and ignited a spot fire that the firefighters on the Main Ridge worked to extinguish. Bucket drops of water from the helicopter cooled the flareup, and work on the fireline resumed. In response to a flareup in a tree located south



Courtesy of T. Shepard

Figure 20—Photograph taken from the interstate highway looking northeast toward west-facing side of Main Ridge. Photograph was taken by the Prineville Hotshot Superintendent as they were traveling to the fire late on the morning of July 6, 1994. Smoke behind light post on left is near West Flank Fireline. Smoke behind light post on right is near the Double-Draws.

of the Spur Ridge at about 1300, smokejumpers working near the Spur Ridge retreated 480 feet back along the fireline to a point near the Tree (South Canyon Report; Petrilli 1996). A water drop from the helicopter cooled the flareup, and the firefighters returned to the area where the fireline crossed the Spur Ridge. Smokejumper Rhoades cut down the tree that became the Stump reference point, and the firefighters resumed building the fireline.

Between 1230 and 1300, the helicopter ferried 10 of the Prineville Hotshots, including Hotshot Superintendent Shepard, from Canyon Creek Estates to H-2. Around 1330 nine of the hotshots, led by Squad Leader Kelso, were assigned to reinforce the smokejumpers constructing the West Flank Fireline. Shepard remained on the Main Ridge. The remaining 10 Prineville Hotshots remained at the helibase at Canyon Creek Estates. They noted an overcast sky and gusty winds around 1400. Between 1400 and 1430 Hotshot Foreman Scholz radioed Shepard three times to report gusty, erratic winds at the helibase and increased smoke low on the fire's west side. During one of the calls, Shepard responded that winds had increased on the Main Ridge.

Lunch Spot—Between 1400 and 1430 many of the hotshots and smokejumpers working on the West Flank Fireline stopped for lunch on a small knoll midway up the Lunch Spot Ridge (thus the name Lunch Spot). Jumpers Thrash and Roth remained on the West Flank Fireline. At approximately 1445 Smokejumper Longanecker left to scout an area south of the Lunch Spot Ridge. He hiked southwest from the Lunch Spot into the Double Draws (South Canyon Report). At about 1510 Longanecker requested by radio that some smokejumpers come down and start building line around a hotspot that had flared up (South Canyon Report). The smokejumpers stated that they felt some concern about building new line when the fire was still active along the newly completed West Flank Fireline to the north. A few of the smokejumpers moved a short distance south and east into the northeast side of the Double Draws (see Petrilli Photo Point and Longanecker position in fig. 8). Longanecker requested and received a water drop on the hotspot. Witness statements indicate that as the winds increased so did the fire activity in the underburned pinyon-juniper south of the Lunch Spot Ridge and along the Main Ridge (South Canyon Report).

Main Ridge—Around 1515 the helicopter ferried the remaining 10 Prineville Hotshots from Canyon Creek Estates to H-2. They were assigned to widen the fireline on the Main Ridge between H-2 and the Zero Point. West winds between H-2 and the top of the West Flank Fireline were strong enough that when the firefighters working on the Main Ridge tossed brush into the air, the wind carried it over the east side of the ridge (South Canyon Report). In contrast, about 300 feet away, some of the group stopped for a break near the Zero Point and noted that the winds were light, estimated to be less than 5 miles per hour (South Canyon Report). Fire activity in the underburned oak on the west side of the Main Ridge consisted of low intensity flaming and smoldering in the leaves and debris on the ground under the oak canopy with some torching of individual trees.

July 6, 1530 to 1600—Double Draw Crown Fire Runs and Spot Fire on Main Ridge

West Flank Fireline—At about 1530 Smokejumper Mackey commented on the erratic winds. He sent Smokejumpers Erickson and Doehring to patrol the West Flank Fireline for rolling material and hotspots. The winds were increasing in speed (South Canyon Report). Mackey called the hotshots who were working near the Lunch Spot and told them to hold the line and improve the cup trench on the West Flank Fireline.

Main Ridge—Hotshot Scholz left the Main Ridge and started down the West Flank Fireline carrying two 5 gallon containers of water (time, 1530). He noted that while winds were strong and gusty on the Main Ridge, they were relatively calm on the West Flank Fireline (Scholz 1995).

West Flank Fireline—Jumper Hipke had left the Lunch Spot to work on the West Flank Fireline. The Prineville Hotshots and Smokejumpers Hipke, Thrash, Erickson, and Doehring were all working north of the point where the fireline drops off the Lunch Spot Ridge. We estimate that this group was spread along the fireline, approximately 1,450 to 1,880 feet down the fireline from the Zero Point (time, 1530).

Scholz, who was carrying the water containers down the line, met Roth at the Stump. Scholz helped Roth move a log off the line (about 1539). They talked, and then a few minutes later, Scholz headed back up the fireline toward the Main Ridge leaving the water containers for Roth to carry to the firefighters working farther southwest along the fireline (time, 1545). There was little wind, and the previously cloudy sky was clearing (Scholz 1995).

Erickson and Doehring hiked north along the fireline looking for hotspots. They met Roth at the Stump (approximately 1555).

Double Draws—After the helicopter dropped water on a flareup in the Double Draws, Smokejumpers Petrilli, Thomas, and Shelton contoured southeast along the slope from the Lunch Spot (approximately 1545). Another five smokejumpers were scattered between the Lunch Spot and Petrilli, who stopped about 630 feet south and east of the Lunch Spot. A few minutes later Longanecker asked the incoming helicopter to drop another bucket of water on the flareup. At this time a flareup that had occurred on the Main Ridge fireline about 200 feet south of the Zero Point was spotting across the fireline. It was agreed that the next bucket of water should go to the Main Ridge (South Canyon Report; OSHA 1995).

Several of the smokejumpers had gathered near what we have designated the Petrilli Photo Point (fig. 21). From this location they could look southwest

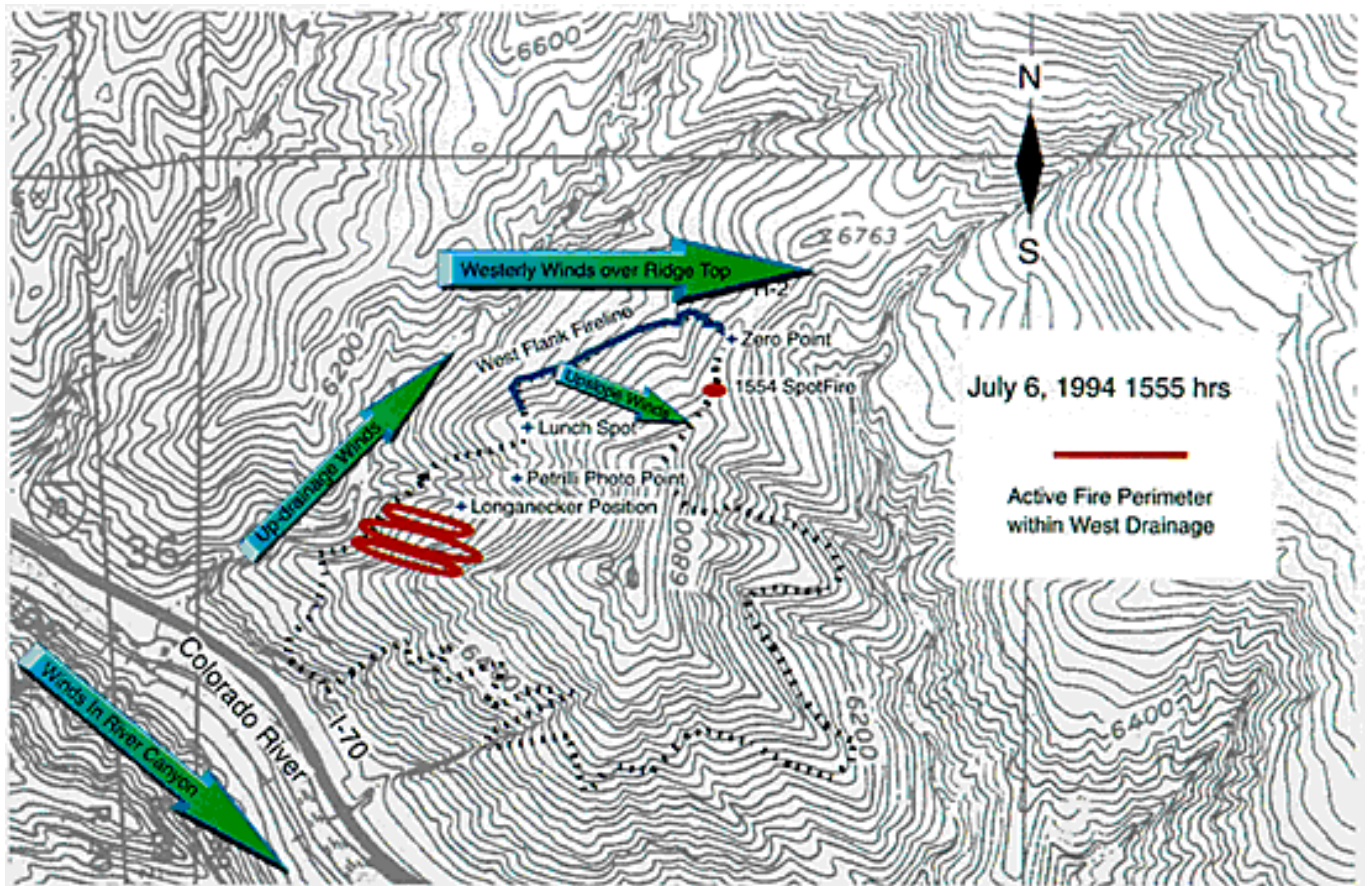


Figure 21—Topographical map with crown fire runs in Double Draws identified by heavy red lines (time, 1555). Vectors show general wind flow over fire area.

into the Double Draws and see the area where Longanecker was working. While the smokejumpers were at the Petrilli Photo Point, individual trees began to torch, and a narrow crown fire started burning up the slope located directly south across the Double Draws from them. This fire burned through the previously underburned Douglas-fir, pinyon, and juniper with estimated flame heights greater than 100 feet (about 1555). The smokejumpers stopped moving downhill (South Canyon Report). Three separate runs occurred in rapid succession (Petrilli 1996). Petrilli indicated that he and the others with him were surprised at the speed of these runs. Petrilli photographed this fire activity from his position (fig. 22). The photograph shows the crown fire run and smoke over the entire area.

Main Ridge—When Scholz reached the Main Ridge, after leaving Roth, he noted that winds were strong, approximately 45 miles per hour (time, 1553). The sky was clear over the fire, but clouds were located over Storm King Mountain. Fire spotted across the Main Ridge Fireline at about 1554 (fig. 23a). When Helicopter Pilot Good attempted to drop water on the spot fire burning on the Main Ridge (around 1555), the winds caused the water drop to miss the fire (fig. 23b). The pilot later estimated the winds were blowing 35 miles per hour. As the pilot flew back to refill the water bucket he noticed fire activity increasing throughout the area (as demonstrated by



Courtesy of T. Petrilli

Figure 22—Photograph of smoke in West Drainage near Double Draws at approximately 1555. Perspective is looking southwest from Petrilli Photo Point. Smokejumper Longanecker is identified. Note flames from crown fires burning in conifers south of the Double Draws.



Courtesy of T. Shepard



Courtesy of T. Shepard

Figure 23—(A) Photograph of spot fire burning on the Main Ridge south of the Zero Point at approximately 1553. Perspective is looking south from knob north of H-2. (B) Photograph of helicopter dropping first bucket of water on spot fire near Main Ridge at approximately 1555. Perspective is looking south from knob north of H-2. Note smoke on right side of picture over Double Draws, and winds blowing smoke and water to the left (east).

increased flaming and smoking) and saw scattered inactive spot fires on the east-facing slope across the West Drainage north of the Lunch Spot Ridge. We believe that the spot fires seen by Good were near the bottom of the West Drainage west of the West Bench (fig. 24). Hearing firefighters over the radio talking about spot fires, Good did not report those he had seen (Good 1996).

July 6, 1600 to 1603—Fire Crosses West Drainage

Main Ridge—Short duration torching and runs through the vegetation canopy were occurring inside the fire perimeter. The BLM/U.S. Forest Service firefighter crew on the Main Ridge had been working to extinguish the spot fire located about 200 feet south along the Main Ridge from the Zero Point. The spot fire continued to burn on the east side of the Main Ridge Fireline (1600). The wind was strong enough that it blew Crewmember Byers hardhat off (South Canyon Report). Scholz called the Prineville crew members working on the Main Ridge Fireline near H-2 to move up (south) to help the BLM/U.S. Forest Service crew working on the spot fire.

Double Draws—A few minutes after the crown fire runs south of the Double Draws, Petrilli saw smoke coming from the bottom of the West Drainage (1602). Fire was starting to burn north up the east-facing slope across the drainage from him (South Canyon Report; Petrilli 1996). Petrilli radioed Mackey about the fire across the drainage. Then he and the smokejumpers with him started back toward the Lunch Spot. The fire in the West Drainage quickly developed into a running flaming front 50 yards wide burning diagonally up the east-facing slope and up the West Drainage (South Canyon Report) (fig. 24). Petrilli estimated that winds at his location were blowing 35 miles per hour (time 1603). Longanecker heard a call for retardant (he thought it came from Mackey). The person making the call stated, “We have a real bad situation here” (South Canyon Report). Longanecker began moving toward the Lunch Spot, which he had identified as a safe area.

July 6, 1603 to 1609—Fire Moves Up West Drainage

West Drainage—The winds blowing up the bottom of the West Drainage pushed the fire quickly through the fine fuels into the Bowl (about 350 feet north from the base of the Double Draws). Postfire inspection suggests that the Bowl contained a heavier concentration of vegetation than on the surrounding slopes. As the fire burned into the cured grasses, small shrubs, and standing live and dead trees in the bowl, the size and height of the smoke column over the fire increased.

Lunch Spot—The smokejumpers, who had been observing the fire in the Double Draws, continued back to the Lunch Spot (about 5 minutes walking time). The fire on the east-facing slope across from them ran 770 feet to the top of the ridge and continued to burn north along the slope. Smokejumper Petrilli estimated the upslope winds at his location were blowing about 45 miles per hour (Petrilli 1995).

West Flank Fireline—Smokejumper Hipke, who had been working on a hotspot about 100 feet north along the West Flank Fireline from the Lunch Spot, moved farther north around the hotspots in front of him and continued up the fireline (generally toward the northeast). He met Smokejumper

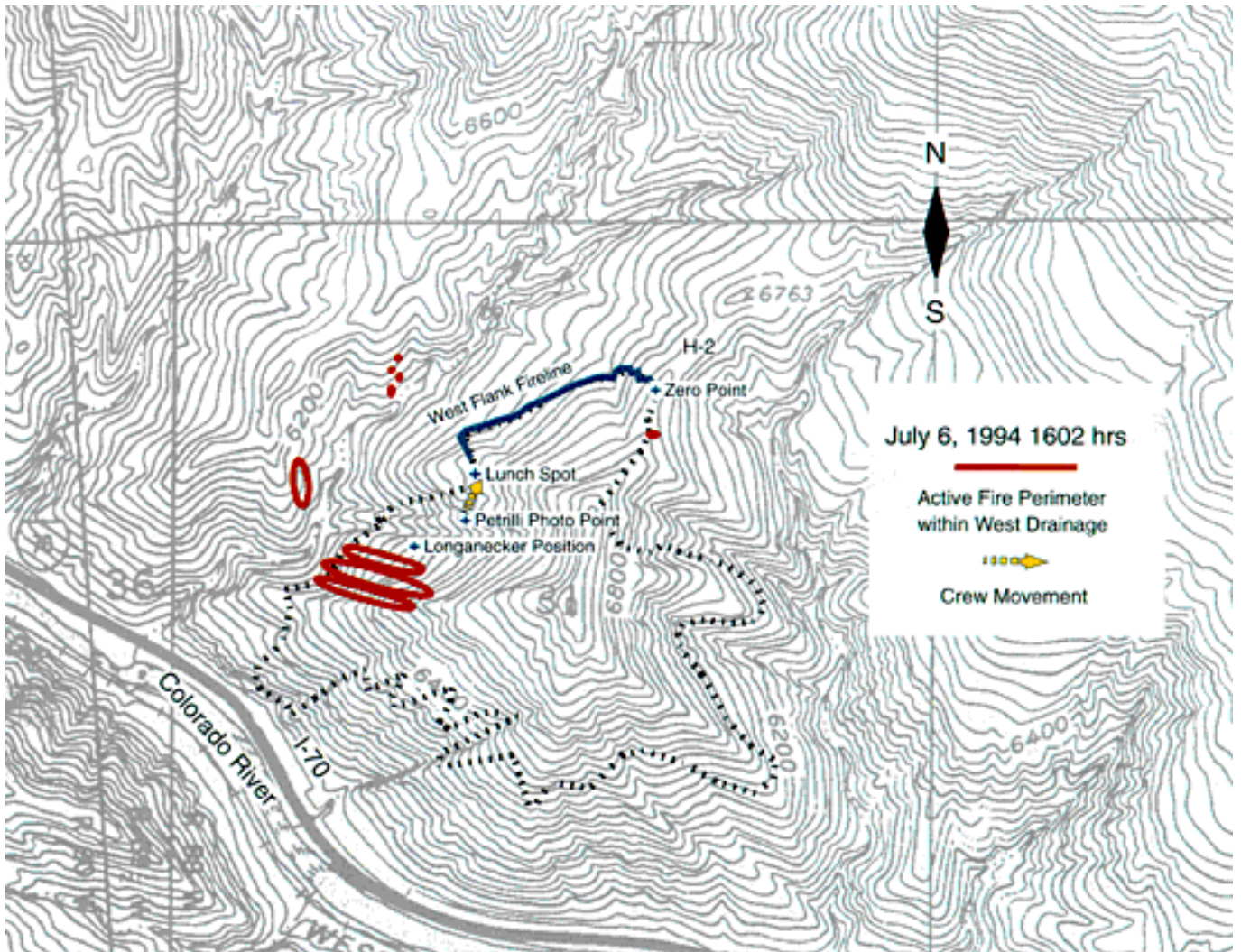


Figure 24—Topographical map showing fire south of Double Draws and starting to burn across the bottom of the West Drainage and toward the Bowl (approximate time, 1602). Red dots in West Drainage indicate approximate locations of inactive spot fires based on helicopter pilot Goods statements.

Thrash at about 1603. Within a minute, Thrash and Hipke were joined by Smokejumper Roth, who had come down the line carrying the two water containers Hotshot Scholz had left with him. About 1604, Smokejumpers Hipke, Roth, and Thrash, and Hotshot Hagen, who was nearby, noticed the smoke column building over the West Drainage. After a short discussion the four of them started hiking northeast up the West Flank Fireline toward the Main Ridge. It appeared to them that the area around the Double Draws and Lunch Spot would be overrun first, so moving north up the West Flank Fireline was the only alternative (Hipke 1995). At the same time, Hotshot Kelso, who was working on the West Flank Fireline between Thrash and the Lunch Spot, radioed Shepard to inform him that “a spot fire [had] crossed the draw [West Drainage] below them” (South Canyon Report). Shepard told them “to get out of there” and go to the designated safety zone at H-1 (Scholz 1995; South Canyon Report). Kelso and the other hotshots working on the fireline were also moving northeast up the fireline by the time the three smokejumpers and Hagen started out the fireline (about 1605).

Main Ridge—Noting the increased activity on the Main Ridge, the incoming helicopter, the strong winds, and Kelso’s call, Scholz commented, “Things are getting complicated.” Shepard and Blanco told the Main Ridge Group to go to H-1 (South Canyon Report; OSHA 1995). Hotshot Gray noted the time on his watch as 1604 and commented, “Remember this time” (South Canyon Report; Scholz 1995). Scholz told his group to wait for the incoming bucket drop (Scholz 1995). Many spot fires had developed on the Main Ridge. The firefighters who had been working on the Main Ridge abandoned their efforts to control them (Scholz 1995).

Helicopter Pilot Good estimates he was flying through westerly winds of 45 to 50 miles per hour on his return with the second bucket of water for the Main Ridge spot fire. Due to strong westerly winds, he had to circle around and approach the Main Ridge from the east. This time he hit the spot fire with the water drop (about 1605). The water cooled the spot fire sufficiently (fig. 25) for the firefighters to pass through it and move south, uphill toward H-1. As Good finished the water drop and started back to refill the bucket, he noted the large smoke column building over the Bowl. The smoke was blowing directly over his position above the Main Ridge. He was not able to



Courtesy of T. Shepard

Figure 25—Photograph taken shortly after the second water drop on Main Ridge at approximately 1601. Perspective is same as in figures 23a and b, looking south from top of knob north of H-2. Note column developing over West Drainage and significantly more smoke over west flank of fire than shown in photograph taken from same point approximately 10 minutes earlier.

see into the base of the column from his position. However, recognizing the change in the situation, he headed to the helibase at the Canyon Creek Estates subdivision to disconnect the bucket so he could return to ferry firefighters off the ridge (Good 1996).

Lunch Spot—Mackey and the other smokejumpers who had been with Petrilli met on the Lunch Spot Ridge about 100 feet below the Lunch Spot. The smokejumpers were moving toward the Lunch Spot. Mackey told them there was a good “black” area farther up the Lunch Spot ridge and to go there. As the smokejumpers continued up the ridge, Mackey called to check on Longanecker’s position. Longanecker replied, “We’re in a safe zone” (1606) (South Canyon Report). After leaving the eight smokejumpers, Mackey continued across West Flank behind the hotshots and smokejumpers who were hiking up the West Flank Fireline to the Main Ridge.

West Flank Fireline—As Smokejumpers Hipke, Roth, and Thrash neared the Stump, Hipke looked back to the southwest and saw fire burning in the bottom and up both sides of the West Drainage, the fire front was advancing north and was forming a “U” shape in the bottom of the West Drainage (fig. 26) (Hipke 1994).

The Tree—Jumpers Doehring and Erickson met Smokejumper Archuleta near the Draw (450 feet below and west of the Zero Point). Archuleta had walked down the fireline from the Main Ridge. They moved up the fireline to the Tree located 200 feet below the Zero Point where BLM Firefighters Brixey and Haugh were working with a chain saw (1606). Brixey and Haugh shut off their saw. The three smokejumpers pointed out the smoke column over the West Drainage and relayed the message to move to the safety zone. Following a short discussion Archuleta, Doehring, and Brixey headed up the fireline toward the Main Ridge (1608). Erickson and Haugh remained at the Tree (South Canyon Report).

July 6, 1609 to 1610—Fire on West Flank

Smokejumper Mackey caught the firefighters hiking up the West Flank Fireline as they passed the Stump (about 1609). Using known values for walking speeds in rough terrain and distances along the fireline, we estimate that Mackey must have run to catch the last of the hotshots at this location. By this time the smokejumpers and hotshots were hiking in essentially one group, hereafter referred to as the West Flank Fireline Group. The group continued to follow the West Flank Fireline. They hiked over the Spur Ridge and then east up the fireline toward the Main Ridge.

West Flank Fireline—The fire moved onto the West Bench. It rapidly increased in size, burning across a wide front. It was spreading north up the West Drainage and upslope on a path parallel to the Lunch Spot Ridge (approximately 1608).

As Smokejumper Hipke reached the top of the Spur Ridge he looked back and saw Mackey at the rear of the group (approximately 1609) (Hipke 1995). Behind Mackey the fire burned in a wide front above and below the West Flank Fireline (fig. 27). Hipke states that due to the height of the Gambel oak and the drainage topography, the firefighters had only brief glimpses of the fire burning behind and below them.

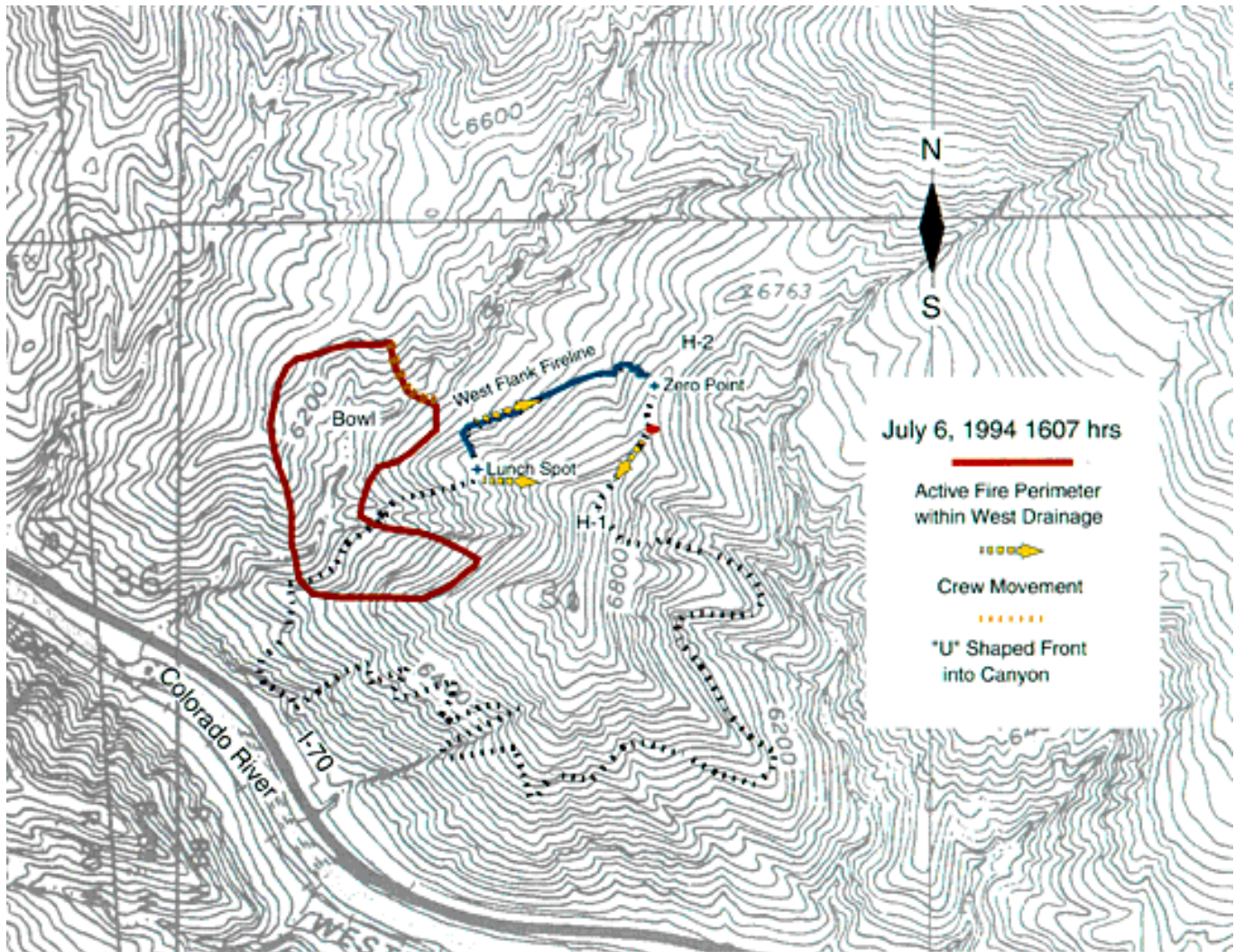


Figure 26—Fire perimeter at 1607 as Smokejumper Hipke looked down canyon (southwest) from the Stump. Fire was burning on both sides of the West Drainage and below the West Flank Fireline.

The Tree—Firefighters Haugh and Erickson at the Tree could hear a loud roaring sound from the fire. They saw the first few smokejumpers in the group cresting the Spur Ridge and walking northeast along the West Flank Fireline toward them. They saw fire burning behind and below the West Flank Fireline Group. Erickson called Mackey and told him about the fire, Mackey did not respond (time, about 1610).

Main Ridge—The firefighters hiking along the Main Ridge neared the rocky outcropping north of H-1. They saw fire nearly all the way up the slope below and to the west of them (estimated time 1609). Several firefighters near the front of the group felt they could not make it to the safety zone at H-1 before the fire reached the top of the ridge. This was the same fire run Hipke saw from the Spur Ridge. The terrain was steep, the firefighters were fatigued, and spot fires on the Main Ridge between them and H-1 were actively burning (South Canyon Report; OSHA 1995). Hotshot Scholz told the Prineville firefighters to “Reverse and move”—meaning to return the

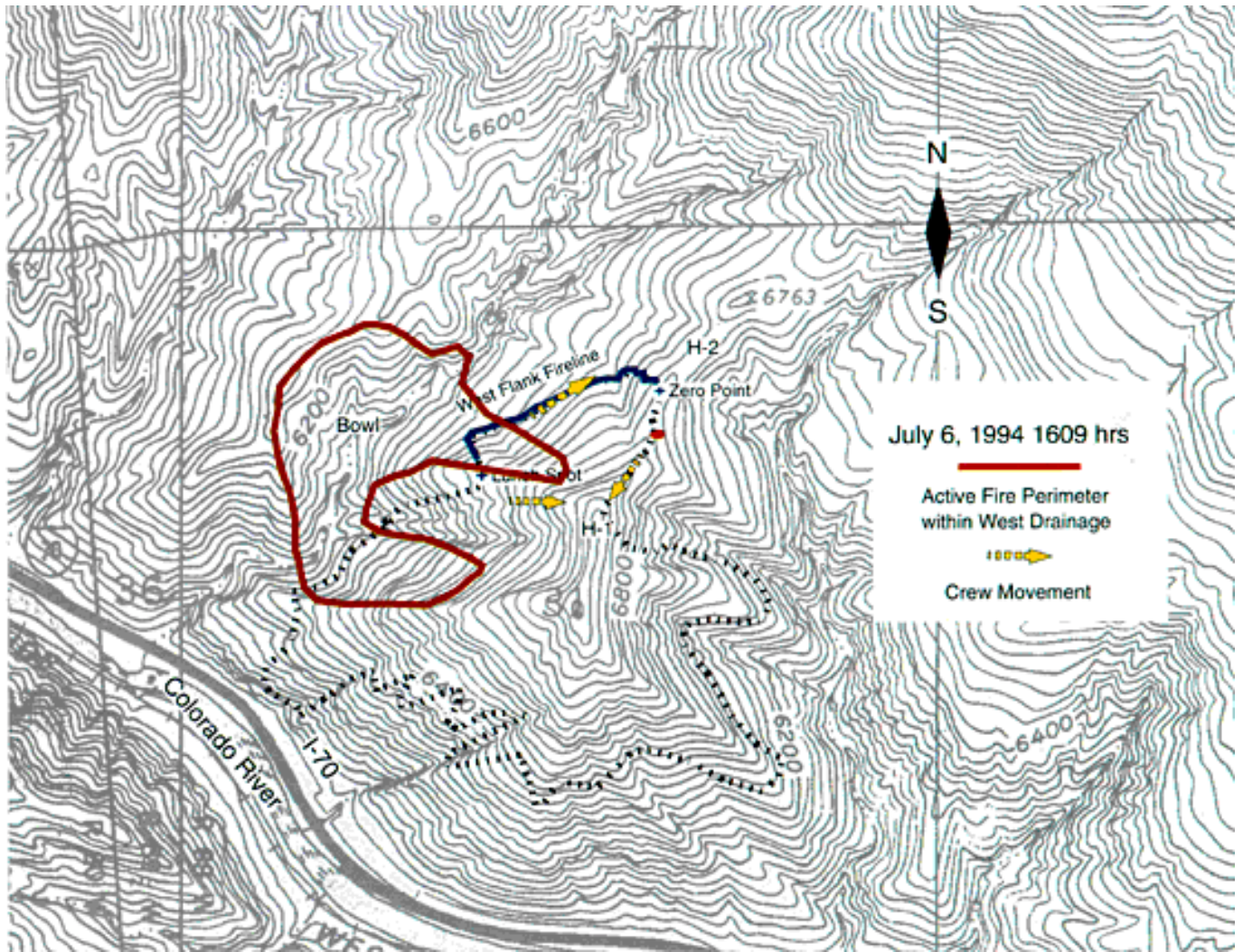


Figure 27—Fire perimeter at 1609 as Smokejumper Hipke looked south from point where fireline crested the Spur Ridge. The fire had crossed the southern portion of the West Flank Fireline. It was burning up the West Flank Fireline, north up the West Bench, and east to the Main Ridge. Hipke estimates that at this time the fire burning east up the slope was about two-thirds of the distance up the slope below H-1.

way they had come (Scholz 1995). BLM Squad Boss Ryerson also told her crew to go to H-2. Both crews turned back and began walking and running north down the Main Ridge toward H-2.

Hotshot Crewmember Navarro, intending to maintain his place near the end of the line, let others pass him. As he was looking south toward H-1 he saw Hotshots Valentine and Robertson. It appeared as if “they came running right out of the fire” (South Canyon Report; OSHA 1995). The two firefighters ran through fire, but it consisted of scattered, relatively short flames along the Main Ridge Fireline. The fires burning along the top of the Main Ridge behind (south of) the firefighters were several times taller than a person and burning on both sides of the Main Ridge Fireline. These larger flames were caused by the main fire cresting the ridge between the Rocks and H-1.

July 6, 1610 to 1611—Fire Below West Flank Fireline

Main Ridge—As BLM Firefighter Brixey and Smokejumpers Doehring and Archuleta, who were hiking up the fireline from the Tree, neared the Zero Point, the first members of the Main Ridge Group passed them, heading toward H-2. Joining the Main Ridge Group, Archuleta, Doehring, and Brixey continued about 110 feet north along the Main Ridge. At this point Archuleta and Doehring moved west about 10 feet off the Main Ridge to a location where they could see southwest diagonally down the slope toward the fireline and lower part of the Spur Ridge. We have designated this location the Photo Point (fig. 6 and 7).

West Flank Fireline—The West Flank Fireline group was approaching the Draw. Hipke stated that Thrash stepped off to the left of the fireline and said, “Shelter?” almost as a question and Roth stepped off to the right (estimated time 1610) (Hipke 1996). Hipke stepped past Thrash and Roth and continued a fast hike up the line.

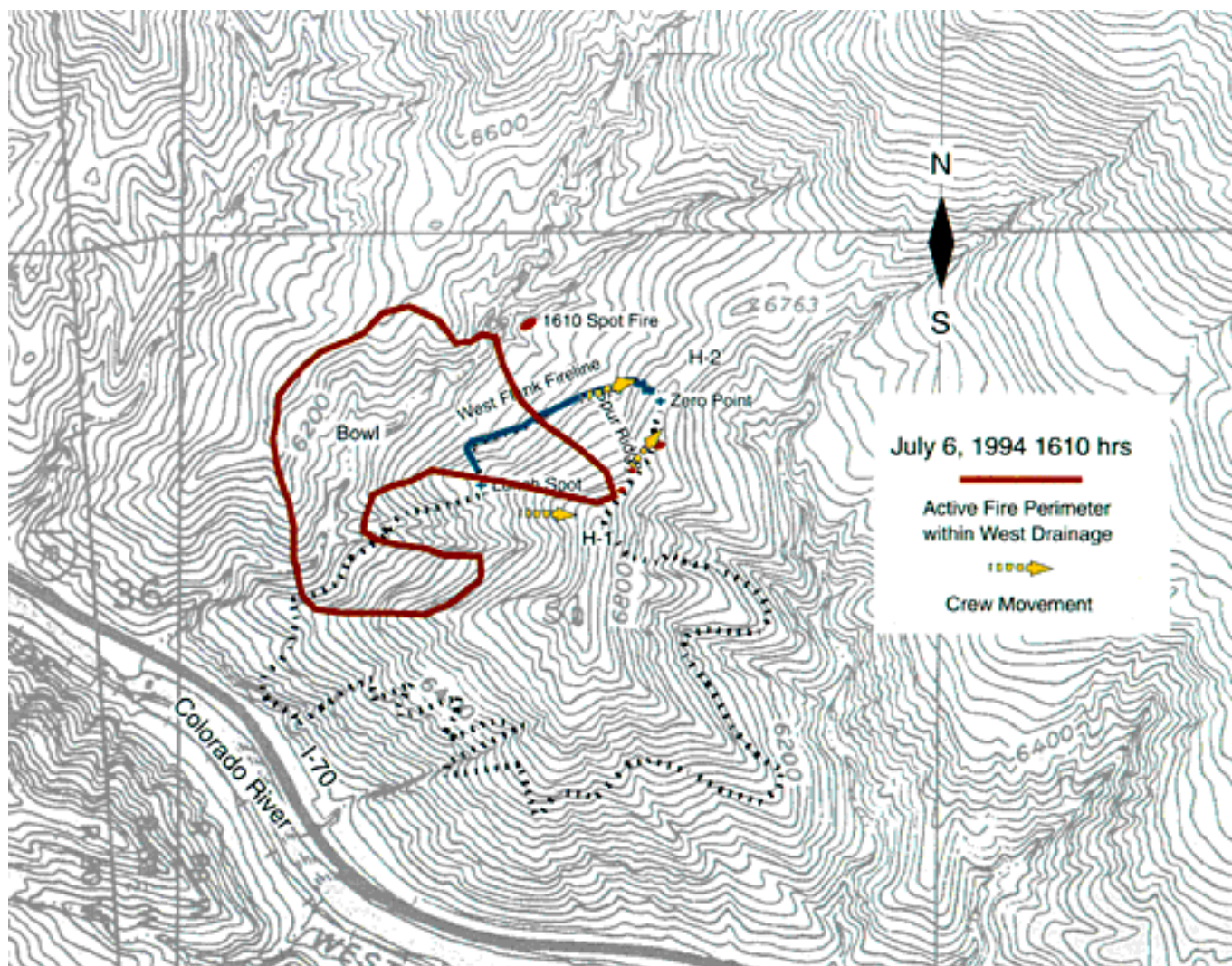


Figure 28—Fire perimeter at 1610. The fire continued to spread up the West Drainage and east to the Main Ridge. Fire has reached top of Main Ridge near the Rocks. Smokejumper Erickson called Smokejumper Mackey to inform him of spot fire on north end of West Bench.

The Tree—Firefighters Haugh and Erickson remained at the Tree, shouting and waving at the West Flank Group to hurry. Erickson saw a spot fire on the West Bench. Later, Erickson identified the location of the spot fire to be about 1,000 feet in distance down the slope below the Tree and 190 feet above the bottom of the West Drainage (fig. 28). Erickson called to inform Mackey of the spot fire (South Canyon Report). Erickson stated, “The spot moved fast [north up the canyon]. I did not feel a perceptible change in winds. I could tell that they [the West Flank Fireline Group] were moving as fast as they could. At that time the lead guy and the group were 75 yards away. We were yelling at them to go faster. They looked tired and were not going fast. Thrash was in the lead and Mackey was second to last. They were in a close group.” Erickson asked Haugh to pull out his camera. As Erickson looked through the viewfinder (about 1611) he saw the last three firefighters in the group with fire everywhere behind them (South Canyon Report). Because Erickson’s camera was at the end of the roll of film, this attempted photograph had no film on which to be exposed.

Main Ridge—Archuleta and Doehring took four photographs from the Photo Point on the Main Ridge (fig. 29a-d). Their photos show the last three members of the West Flank Fireline Group coming over the top of the Spur Ridge (estimated time 1611). After taking the photographs, Doehring joined the firefighters heading north along the Main Ridge toward H-2.

Archuleta and Doehring’s photographs show the fire burning upslope toward the Main Ridge immediately south of the Spur Ridge. It was later determined that these photographs were taken at essentially the same time, angle, and view that Erickson tried to photograph (Erickson 1996). From near H-2 Blanco called for air support from Grand Junction.

West Flank Fireline—Approximately 100 feet beyond the point at which he had stepped past Roth and Thrash, Hipke looked back and saw the group following 20 to 30 feet behind him with Roth in the lead (1611). Ahead, through the brush, he could see Haugh and Erickson at the Tree waving for them to keep coming.

The Tree—Immediately after Erickson attempted to take the photo he turned to follow Haugh. Haugh had gone up the fireline toward the Main Ridge and was no longer in view. Erickson looked back over his right shoulder and saw a wall of fire coming up the hill below the fireline (South Canyon Report). Our analysis indicates that this fire was burning upslope on the south side of the Spur Ridge. Erickson did not see Hipke who was climbing the fireline below him.

Witness statements and the photos taken by Archuleta and Doehring indicate that fire extended from the West Bench 800 to 900 feet northwest of and below the Tree, then south around the base of the Spur Ridge 400 feet southwest of the firefighters, and up the south side of the Spur Ridge to the top of the Main Ridge (South Canyon Report). Figures 28 and 30 show the approximate position of the fire front.

July 6, 1611 to 1614—Firefighters on West Flank Fireline Overrun

Main Ridge—As they retreated north along the ridge, the Main Ridge Group passed through active spot fires burning along the Main Ridge Fireline. Several of the firefighters later stated that fire was burning on both sides of the ridge (South Canyon Report). Some indication of the severity of



Figure 29—Photographs taken at 1611 from Archuleta/Doehring Photo Point looking down (southwest) toward fireline and fire burning behind the Spur Ridge. The four photographs are arranged in chronological sequence.

Courtesy of S. Archuleta



Courtesy of S. Doehring



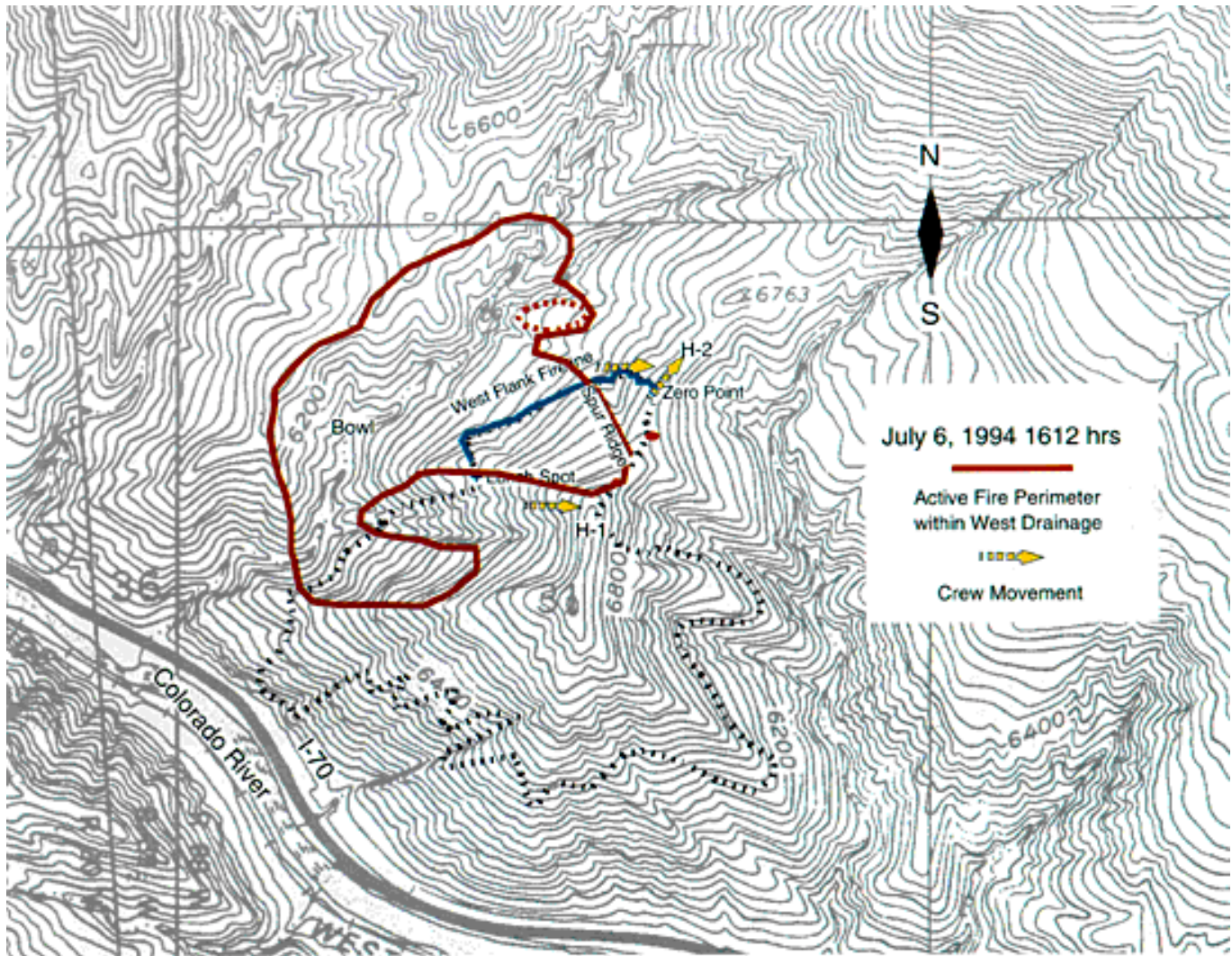


Figure 30—Fire perimeter at 1612. Fire is 400 ft south and 450 ft southwest of firefighters on West Flank Fireline. Main Fire has merged with spot fire and is burning up slope north of fireline. Concave shaped fire front begins to form around top (northeast) section of West Flank Fireline.

the situation is indicated by the fact that they abandoned the chainsaw fuel containers on both sides of the trail. The main fire was producing a loud roar (South Canyon Report). Hotshot Scholz said that they felt that the fire was moving north at a pace equal to theirs (Scholz 1995). As they passed the Zero Point, the air contained burning embers and smoke. Hotshot Navarro, who was near the back of the group, said that when he neared the Zero Point, “The fire was only on my left or west” (South Canyon Report). At this time, Scholz and some of the other firefighters dropped off the east side of the Main Ridge and followed a trail that contoured along the side of the ridge toward H-2. Some firefighters recall hearing chainsaw fuel containers exploding behind them.

After leaving the Photo Point, Archuleta moved south toward the Zero Point to make sure that none of the firefighters in the Main Ridge Group turned down the West Flank Fireline. As the last of the Main Ridge Group firefighters passed him heading toward H-2, Archuleta also started toward

H-2 (about 1612) (South Canyon Report). About 80 feet north of the Zero Point, Scholz looked back to the south along the ridge and saw the fire curling over the Main Ridge behind a firefighter running down the trail toward him (Scholz 1995). The fire burning up the slope behind the Spur Ridge had crested the Main Ridge 200 feet south of the Zero Point.

Main Ridge Near H-2—Robertson, Archuleta, and Ryerson remained on the Main Ridge. Ryerson, who was ahead of Archuleta and Robertson, stated that as she neared H-2 there was heat, intense smoke, and sparks everywhere, and the fire was close on the west side (South Canyon Report ; Good 1996; OSHA 1995). As they moved along the Main Ridge toward H-2, Robertson and Archuleta could feel heat behind and to their left. The remaining chainsaws and fuel containers were abandoned north of H-2. The firefighters were told to go down into the East Drainage.

Zero Point—Shortly after the last of the Main Ridge Group passed the Zero Point, BLM Firefighter Haugh, reached the top of the West Flank Fireline and continued a short distance over the ridge into the East Drainage. The heat was intense enough that Haugh received some first-degree burns (Husari 1996). Smokejumper Erickson, who followed shortly behind Haugh, received second-degree burns to his upper back, neck, and elbows (Hospital Report 1994).

West Flank Fireline—Based on our reconstruction of crew and fire movement and interviews with witnesses, we estimate that Jumpers Thrash and Roth stopped near the Tree about the time Haugh and then Erickson reached the Zero Point. The rest of the West Flank Fireline group following in a line behind them stopped. We estimate that after a short hesitation, Hotshot Blecha stepped around the group, and continued up the hill. Our timeline places Hipke about 45 seconds behind Erickson. We estimate that Blecha followed about 40 seconds (100 feet) behind Hipke.

H-2 and the East Drainage—Helicopter Pilot Good returned and hovered about 100 feet above and northeast of H-2 (between 1612 and 1613). He estimated his return time after dropping the water bucket at the subdivision to be 5 to 7 minutes (Good 1996; Hopf 1996; South Canyon Report). The pilot saw people running north along the Main Ridge and then moving off the ridge from a point south of H-2 down into the East Drainage. The pilot was unable to make radio contact with any of the firefighters. Winds were from the west and blowing harder than when the pilot had made the previous water drop on the Main Ridge. Grit and debris were blowing through the open cockpit doors. He could see fire burning along the top of the Main Ridge from H-1 to the intersection of the Spur Ridge and the Main Ridge. Flames were 150 to 200 feet high. Fire was burning 100 to 200 feet below (west) H-2. Fire had progressed north up the West Drainage and was spreading east toward the Saddle (Good 1996; OSHA 1995).

As the first members of the Main Ridge Group began descending into the East Drainage, Shepard, Blanco, and Helitack Crewmembers Tyler and Browning moved some red packs that had been left north of H-2 to a small depression nearer the helispot (approximately 1613). Shepard estimated that they only looked down for 20 seconds but were surprised when they looked up from moving the packs to find that the fire was nearly to H-2 (Shepard 1995). Smoke and burning embers were flying into the area and fuseses with the gear at H-2 were igniting (Shepard 1995).

West Flank Fireline—Using all of the available information, our best estimate of the fire location between 1612 and 1613 is shown in figures 30 and 31. Fire was burning upcanyon and upslope as a continuous front that stretched from the Rocks to the junction of the Main Ridge and the Spur Ridge then down the Spur Ridge across the north end of the bench and partially up the slope toward the Photo Point and H-2.

The fire burned quickly up the hill. Prineville Hotshot Scott Blecha died 120 feet from the top of the fireline. Prineville Hotshot Crewmembers Kathi Beck, Tami Bickett, Levi Brinkley, Doug Dunbar, Terri Hagen, Bonnie Holtby, Rob Johnson, and Jon Kelso; and Smokejumpers Don Mackey, Roger Roth, and James Thrash were entrapped and died 200 to 280 feet below the Zero Point.

While Hipke hiked up the last section of the fireline he felt his arms and neck getting hot. He dropped his pulaski, which was later found 82 feet below the Zero Point, and tried to remove his fire shelter to use as a shield. Hot air and embers blew past him. He could feel his ears getting burned and it

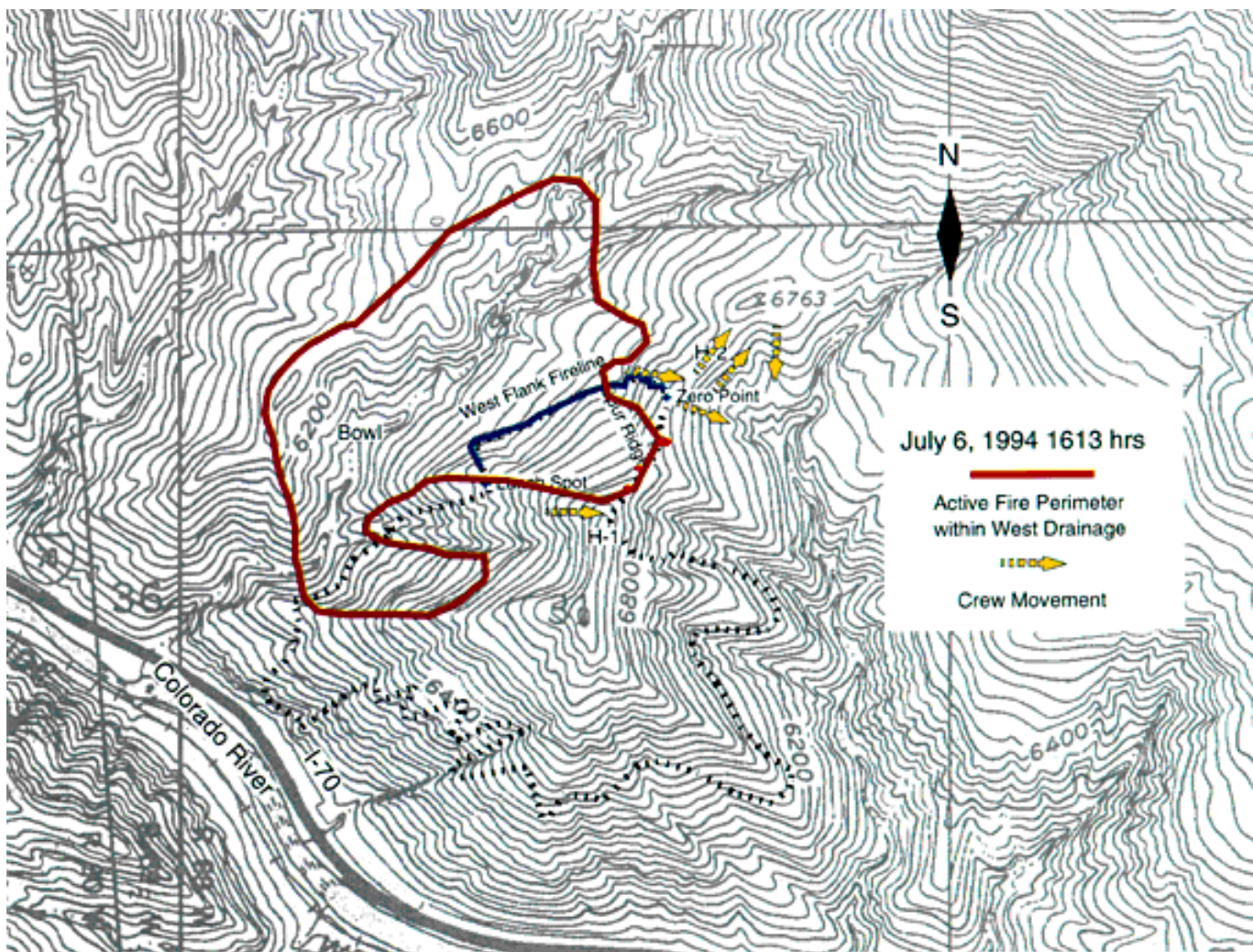


Figure 31—Fire perimeter at 1613. Fire is burning on three sides of the last section of the West Flank Fireline.

seemed to be getting hotter. His hardhat was on backwards, and the bill provided some protection to the back of his neck while he used his hands to shield his ears and face from the increasingly unbearable heat. He had difficulty getting the shelter out of its wrapper and dropped it 15 feet from the Zero Point when he tried to leap forward to escape the heat. As he jumped forward, hot air hit him forcibly from behind and he fell forward to the ground, yelling as he fell and catching his fall with his hands (estimated time 1614). After falling forward, he jumped back up and hiked across the top of the ridge, shielding his face and ears from the heat with his hands. Hipke, though burned on both sides, did not recall seeing fire as he hiked over the top of the Main Ridge. Figure 32 shows the location of the fire at this time. The shoulder straps on Hipke's backpack had melted or fallen off, leaving the pack hanging by its belt strap and bumping against the backs of his thighs (Hipke 1994). Reaching the east edge of the Main Ridge he unsnapped the backpack belt strap, left the pack, and ran down the steep slope into the East Drainage. Hipke suffered third-degree burns over 10 percent of his body

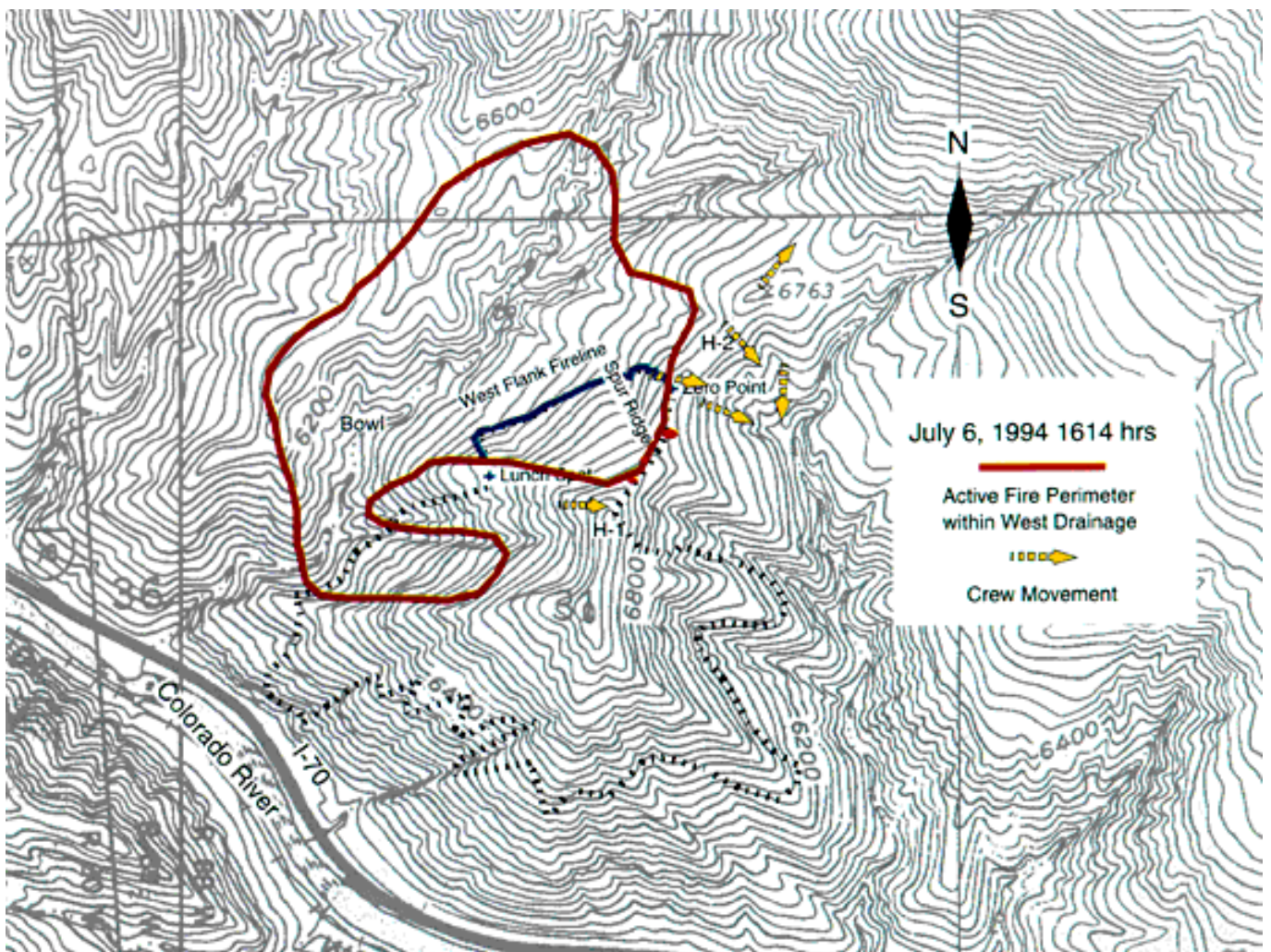


Figure 32—Estimated fire position at 1614. Fire had reached Main Ridge from H-1 to Zero Point and was approaching H-2. Some firefighters were entering the East Drainage.

including his hands, arms and elbows, buttocks, thighs, calves, right shoulder, face, and back of his head. He received lesser burns on his left side (Hospital Report 1994). A few hundred feet down the slope Hipke met Haugh and Erickson who wrapped the burned portion of his arms and hands in a T-shirt and poured water over the makeshift bandage. Together they moved down the East Drainage. They were the first firefighters to reach the Interstate highway (Hipke 1995).

July 6, 1614 to 1623—Helitack Firefighters Overrun

As the fire approached H-2, Helitack Crewmembers Browning and Tyler headed toward the smokejumper Drop Zone located about 1,000 feet to the northeast (South Canyon Report). The helicopter pilot tried to make radio contact with the two helitack crewmembers; he could not see them and they did not respond to his radio calls. The high winds, air turbulence, smoke, and the approaching fire forced the helicopter to leave the area. Firefighters entering the East Drainage radioed and yelled for the two helitack crewmen to follow them down the drainage (OSHA 1995). Tyler and Browning replied that they needed to go up the hill—to “run the ridge” (OSHA 1995). It is not clear where the two firefighters were headed. Perhaps they felt the East Drainage to be unsafe, or they expected to be picked up by the helicopter that was flying over H-2 at this time.

Fire quickly engulfed the entire Main Ridge from the Rocks near H-1 to the smokejumper Drop Zone. A portion of the fire ran northeast across the saddle between H-2 and the Drop Zone, cutting the two helitack crewmen off from the East Drainage (fig. 33). This fire caused the firefighters below H-2 to turn and go straight down the East Drainage rather than follow a contour route toward the northeast (South Canyon Report; OSHA 1995).

The helitack crewmembers were forced by the fire to go northwest from the Drop Zone toward a bare rocky outcropping. As they neared the rocky face, they encountered a 50 feet deep gully. Evidence gathered during the postfire inspection suggests that after entering the gully, they set their gear down and moved about 30 feet down the gully where they attempted to deploy their fire shelters. Based on a reenactment of the travel time between the red bags near H-2 and the helitack fatality site, we estimate that the two firefighters reached the gully and attempted to deploy their shelters between 1622 and 1623 (fig. 34). The postfire evidence suggests that the two firefighters, Robert Browning and Richard Tyler, were incapacitated and died when they were engulfed in hot air and smoke before they could fully deploy and enter their fire shelters.

East Drainage—Blanco, Shepard, and Scholz followed the Main Ridge Group down the East Drainage (approximately 1614 to 1615). They arrived at the Interstate between 1715 and 1730 (Scholz 1995).

July 6, 1622 to 1830—Smokejumpers Deploy in Shelters on Lunch Spot Ridge

Lunch Spot Ridge—The eight smokejumpers hiking up the Lunch Spot Ridge reached their shelter deployment site at approximately 1619. They deployed in two groups, six nearest H-1 and two a short distance farther down the ridge. The deployment area had burned in previous days and was a short distance (235 to 430 feet) below the junction of the Main Ridge and Lunch Spot Ridge (H-1). Smokejumper Petrilli called Mackey over the radio about

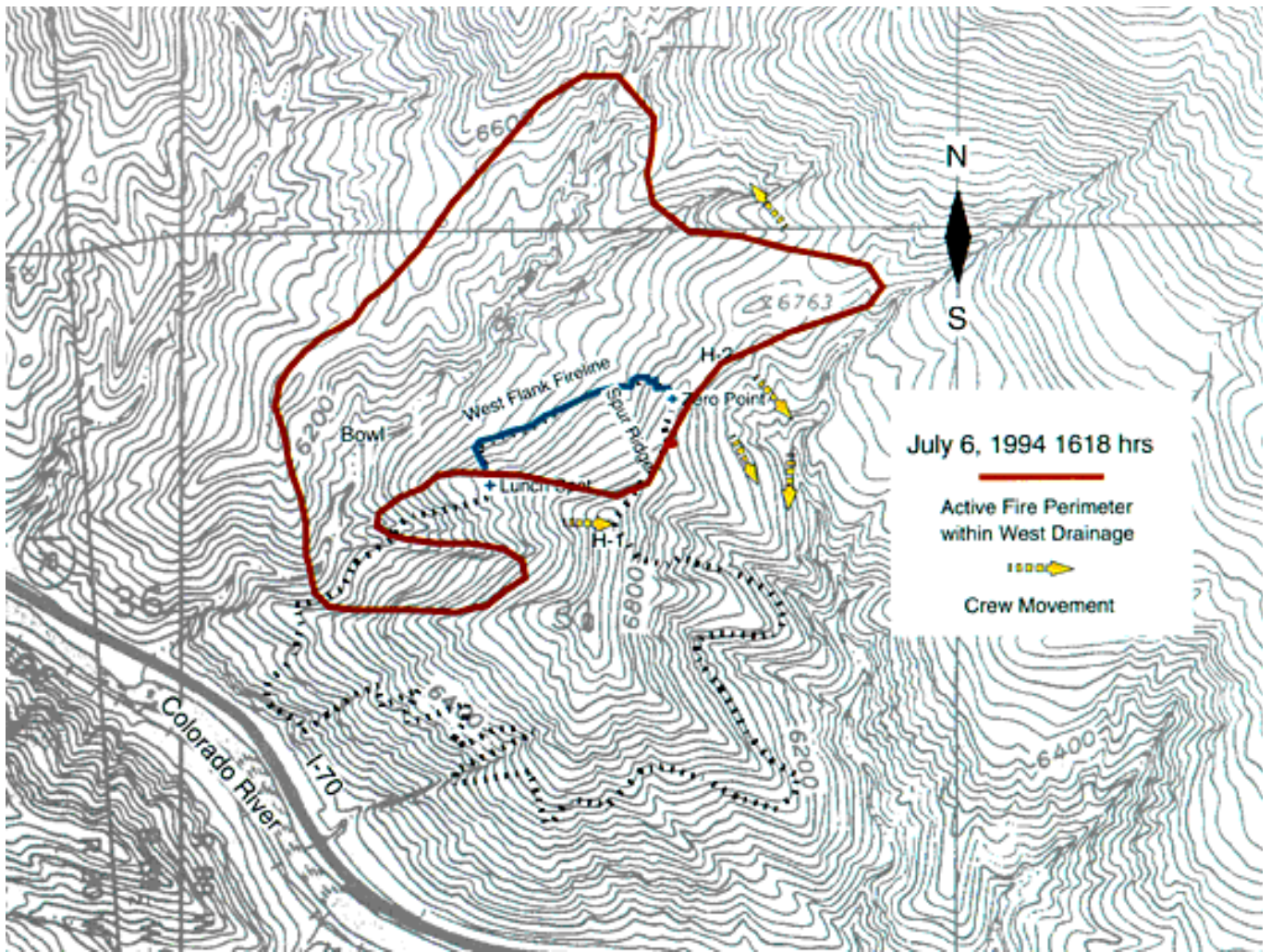


Figure 33—Fire perimeter at 1618. Fire is burning along the Main Ridge from H-1 to the Smokejumper Drop Zone. It is also burning northeast across the saddle, cutting Helitack Crewmembers Tyler and Browning off from East Drainage (1618).

1619 but did not receive a response. Petrilli checked his watch as they entered their shelters; the time was 1624. Over the next 45 minutes the eight smokejumpers felt heat from three separate fire runs that occurred about 500 feet south of them (Petrilli 1996).

Following Blanco's call for support, airtankers were dispatched to the fire from Grand Junction. They were off the ground around 1630 and were over the fire within 20 minutes. High winds and heavy smoke prevented the planes from getting near the fire. Photos and video (Bell 1994) taken from the heliport at the Canyon Creek Estates subdivision at about this time show a large smoke column building over the entire West Flank (fig. 35). The pilots spotted the shelters of the eight firefighters who deployed on the Lunch Spot Ridge below H-1 and dropped retardant around the deployment site (fig. 36). Smoke totally obscured the slopes north of the Lunch Spot Ridge. Because the smoke and high winds showed no signs of quickly abating, the airtankers were released (South Canyon Report).

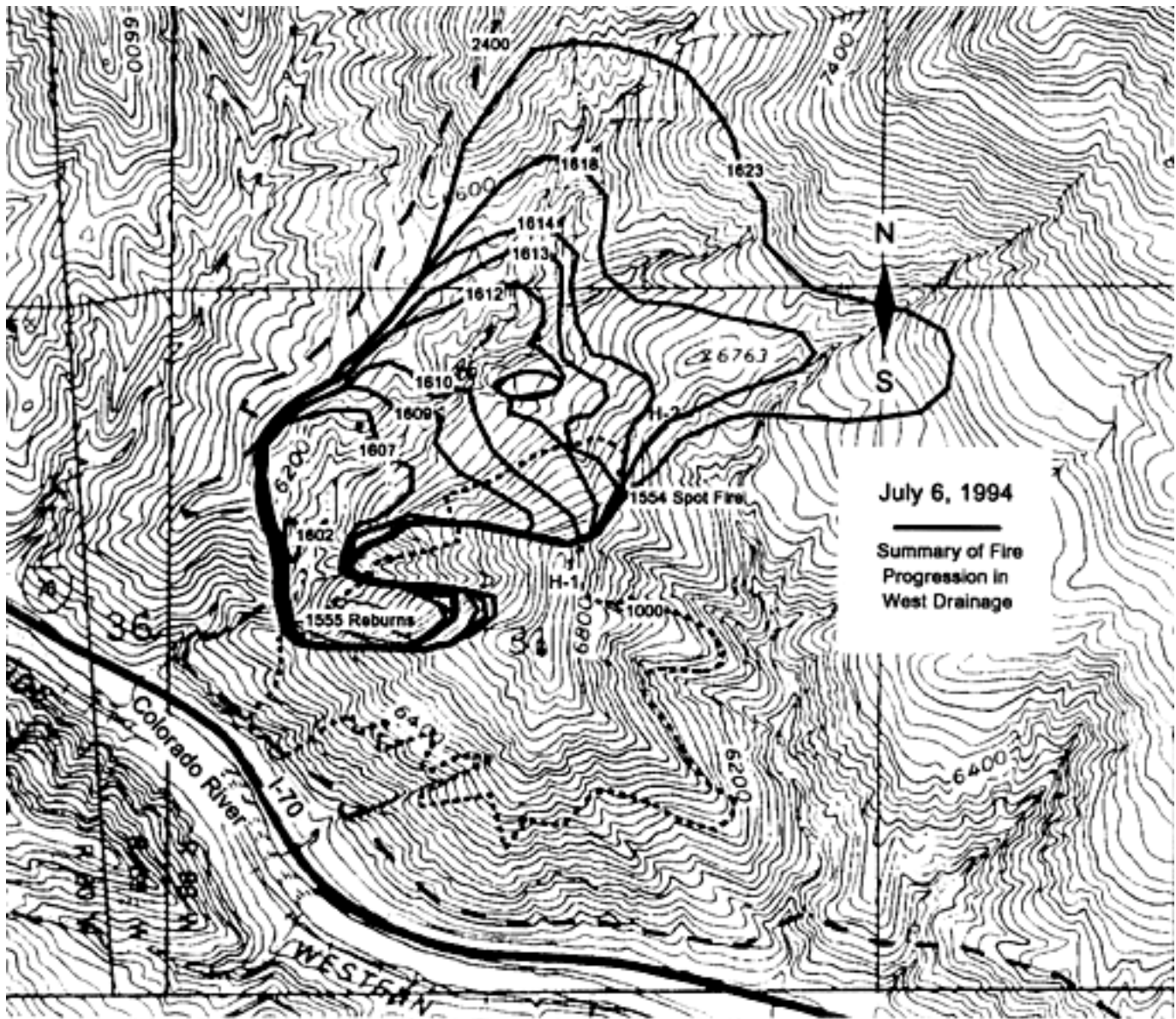
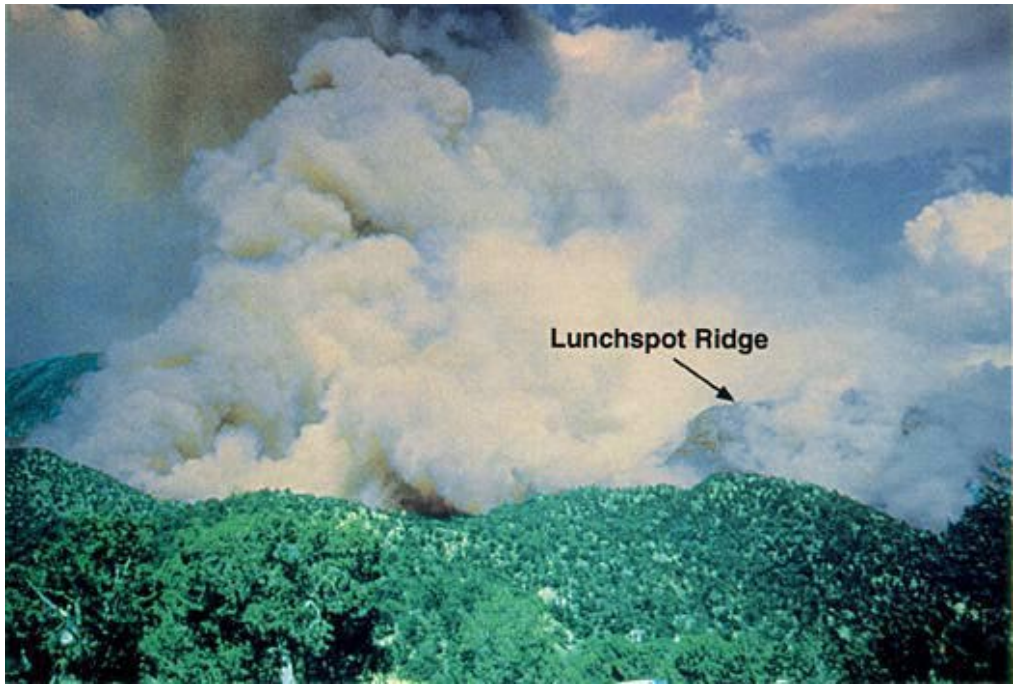


Figure 34—Fire perimeters from blowup (1602) to 1623.

Longanecker, who had hiked up the Lunch Spot Ridge, joined the eight smokejumpers near the top of the Lunch Spot Ridge as they emerged from their shelters (1800 to 1830). The fire had almost totally consumed the Gambel oak on the entire west-facing slope of the Main Ridge, leaving scattered, burned stobs. The area was cool enough to cross on foot, and the smokejumpers began looking for the other firefighters. Seeing objects that looked out of place with the surroundings near the top of the West Flank Fireline, some of the smokejumpers walked over to the area. There they found 12 firefighters who had died in the fire. After notifying the authorities of the fatalities, the nine smokejumpers hiked to H-2 to wait for the helicopter to ferry them off the mountain.



Courtesy of C. Johnson

Figure 35—Photograph taken from Canyon Creek housing subdivision looking east at smoke column. Note that the smoke columns show both the upcanyon winds above the West Drainage and the west winds blowing across the ridges.



Courtesy of W. Williams

Figure 36—Photograph taken from Canyon Creek Subdivision looking east at tanker plane dumping fire retardant near eight smokejumpers deployed on upper portion of the Lunch Spot Ridge.

July 6, 1830 to July 11—Search and Rescue, and Fire Burns to Glenwood Springs

Archuleta, who had hiked out the East Drainage, joined 28 smokejumpers at the helibase at Canyon Creek Estates (directly west of the fire site). About 25 of the smokejumpers were ferried by helicopter to the Main Ridge to continue search and rescue operations. On the return trips, the helicopter ferried the smokejumpers who had sheltered on the Lunch Spot Ridge back to the helibase. Those searching for the two missing helitack crewmembers walked out the West Drainage after dark. The bodies of the two helitack crewmen were found on July 8, 1994.

The fire continued to spread eastward toward Glenwood Springs covering approximately 2,000 acres by nightfall. Maps of the fire perimeter made on July 10 indicate that the fire had burned about 2,115 acres (fig. 37). The fire was declared controlled on July 11, 1994.

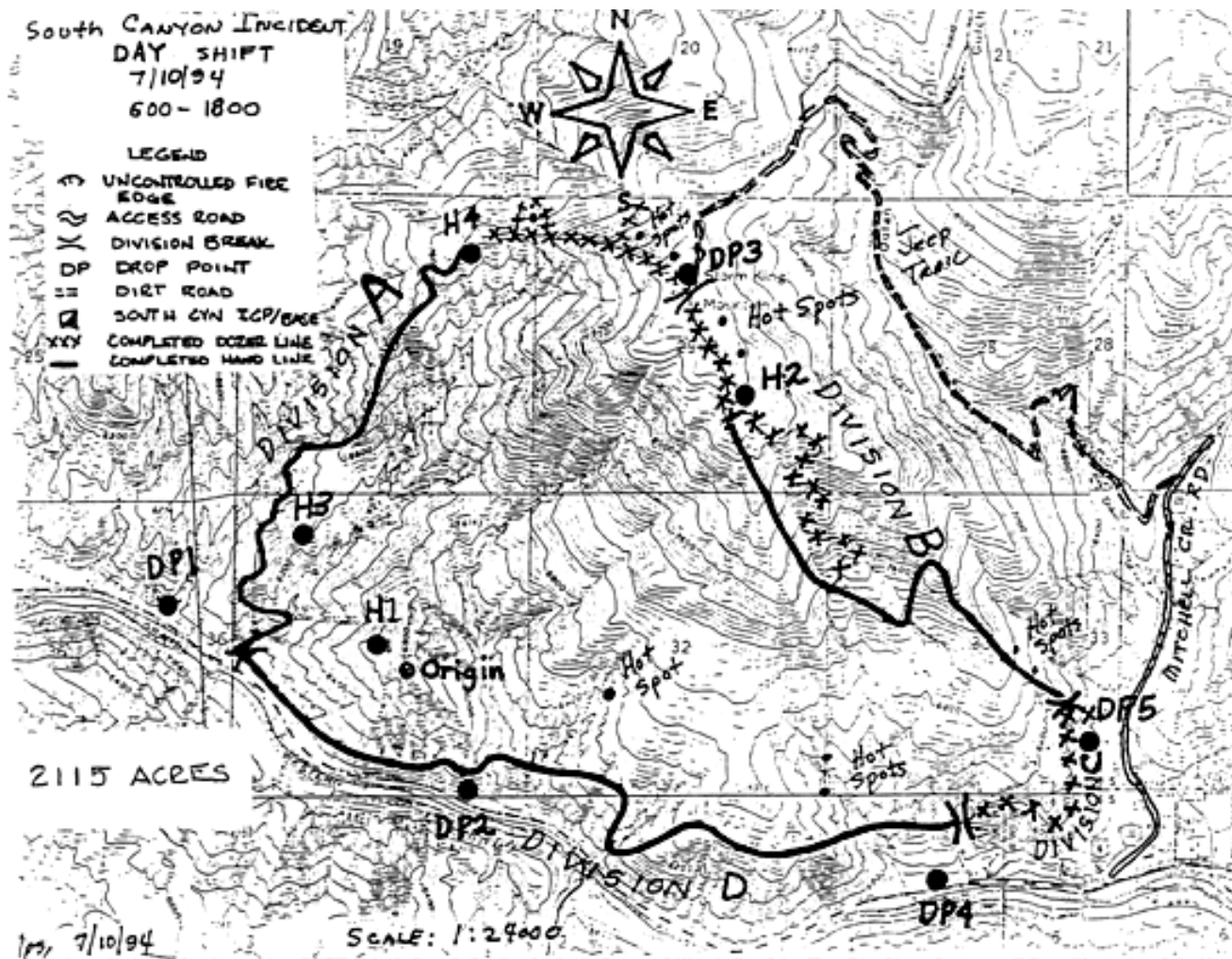


Figure 37—South Canyon Fire Day Shift Fire Map for July 10, 1994. This map shows the approximate final fire perimeter and fire size of 2,115 acres.

Fire Behavior Discussion

The chronology presented in the previous section describes firefighter locations, movement, and actions. The scenario presented in the chronology and the fire behavior analysis presented in this section represents our best estimate of the sequence of events given the available information.

This study would be incomplete without an analysis of the physical factors that caused the change from a relatively low-intensity, slow-moving fire, backing downslope in the leaves and sticks on the ground, to a high-intensity, fast-moving fire, burning through the entire vegetation complex. In the following discussion we attempt to identify the most significant factors leading to the dramatic transition in fire behavior.

We concentrate on two events: the blowup or transition from surface fire to a fire burning through the shrub canopy, and the fire behavior in the area identified as the West Flank that resulted in the entrapment and deaths of 14 firefighters.

We identify three major factors that contributed to the blowup on the afternoon of July 6, 1994. The first factor was the presence of fire in the bottom of a steep narrow canyon. Second, strong upcanyon winds pushing the fire up the canyon. Third, the fire moving into the green (not previously underburned) Gambel oak canopy.

Fire in South End of West Drainage

The presence of fire in the West Drainage at the base of the Double Draws is important to the later fire behavior because it places fire at the bottom of a steep narrow canyon. After the original investigation report was published, various theories continued to circulate regarding the source of the fire in the West Drainage. These theories ranged from burning logs rolling down the slope to possible arson. The available evidence most strongly suggests that this fire originated from one or both of the following sources: (1) fire spreading downslope through the previous night and morning of July 6 and (2) fire brands lofted into the drainage from the crown fire runs that occurred south of the Double Draws. We discuss both.

Witnesses report that the fire remained active through the night of July 5. On the July 6 morning reconnaissance flight, smoke was visible low in the West Drainage. This condition continued through the day (Good 1996). On July 2 through 6, fire burned downslope in the surface litter beneath both Gambel oak and pinyon-juniper. The total burned area approximately doubled each day. This rate of area growth is consistent with an approximately constant rate of fire spread.

By midmorning on July 6 the fire had burned into the Double Draws and was approximately 75 percent of the way down the slope between H-1 and the bottom of the West Drainage (fig. 19). As the relative humidity dropped and the sun heated the slopes through the day, the fire continued to spread downhill. Photographs taken at the time of the crown fire reburn south of the Double Draws show smoke near the bottom of the West Drainage (fig. 22).

It is easily shown that while total burned area increased exponentially, the actual rate of spread remained remarkably constant after July 3. We evaluated fire spread through July 6 by projecting the fire spread for the day based on the fire area data from the previous days. The last measured fire perimeter before the blowup was made during the morning reconnaissance flight on July 6. Assuming continued spread at the rate exhibited during the

previous 2 days, the fire would have been within 100 feet of the bottom of the West Drainage by 1600 on July 6 (fig. 38). The original accident investigators estimated a downslope fire spread rate of 70 feet per hour during the night of July 5 and early morning of July 6. Our calculations indicate a rate of spread of approximately 32 feet per hour. While, this analysis includes some uncertainty, it clearly supports the possibility that fire reached the bottom of the West Drainage by 1600 on July 6, 1994. The downhill spread, the location of the fire at midmorning, and the presence of smoke relatively low in the West Drainage make it probable that the fire reached a point in or near the bottom of the West Drainage by early afternoon.

Fire spotting occurs when burning embers are lofted into the air by the buoyant smoke column above a flame, carried by the wind, and then redistributed on the ground causing new fire starts. Short distance fire spotting occurred throughout the day on July 6, 1994, as individual trees

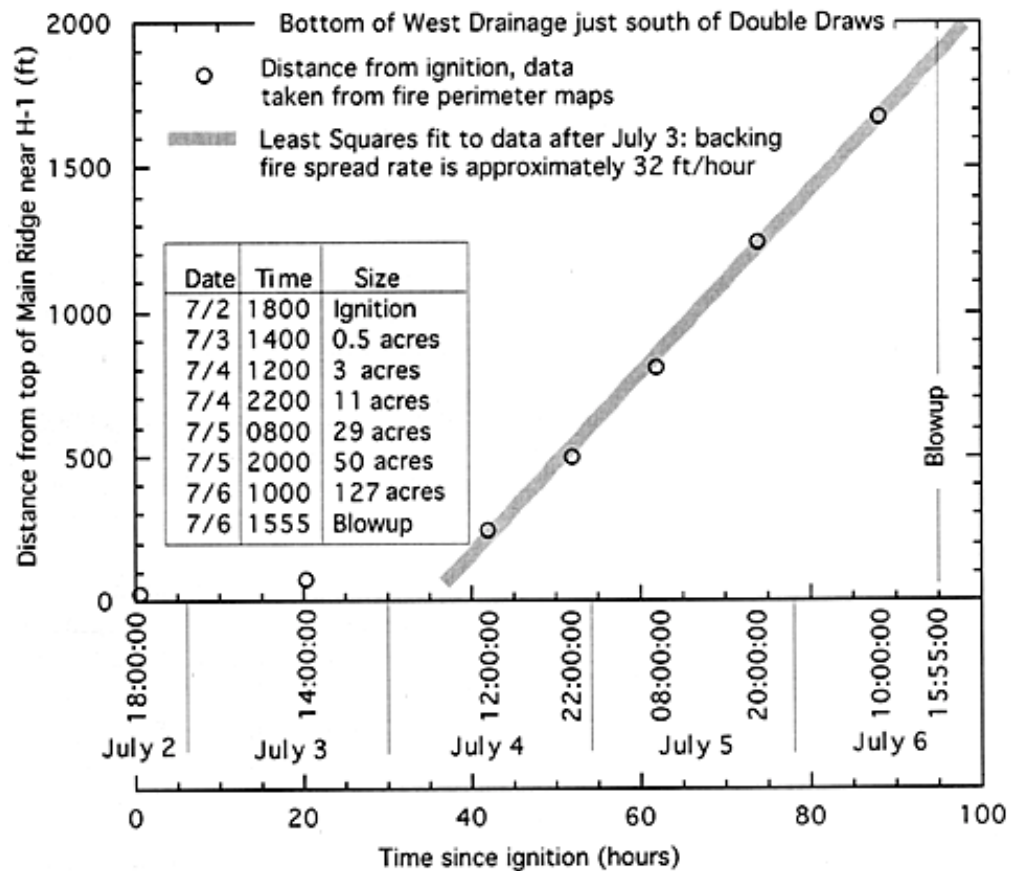


Figure 38—Projected fire location on afternoon of July 6, 1994, based on fire perimeter maps from previous days. The fire spread distances were estimated measuring the distance down the slope on a line running from a point midway between the ignition point and H-1 to a point in the bottom of the West Drainage just to the south of the Double Draws. A least squares linear approximation was then fitted to the data after July 3; this is represented by the heavy shaded line. All distances are increased by 14 percent (assumes 55 percent slope) to account for the actual distance down the slope. The burned area data are included in the table shown in the figure. Dates and some critical times are also shown on the horizontal axis to assist the reader in relating fire growth to the chronology.

burned and the fire made short runs. Given the wind flow patterns in the West Drainage, it is probable that a shear layer formed where the upcanyon (southerly) flow met the westerly flow blowing over the ridges (fig. 16 and 39). Smoldering and burning embers lofted into this turbulent air mass by the crown fire south of the Double Draws would have been distributed generally northward along the bottom of the West Drainage. The original investigators reported 90 to 100 percent probability of ignition based on information from area National Fire Danger Rating System Stations.

Witness statements and later interviews suggest that the attention of the smokejumpers was focused on the crown fire runs rather than the source of smoke farther down the slope. However, shortly after the crown fires south of the Double Draws, the smokejumpers saw fires starting to burn actively



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Figure 39—Schematic showing interaction of westerly flow over ridgetops and northerly flow up bottom of West Drainage forming a shear layer (dashed line). The turbulence generated by this shear layer enhanced the spread of burning embers up the West Drainage and surface wind turbulence in the area of the Double Draws and the West Bench.

near the bottom of the east-facing slope across the West Drainage (Petrilli 1996). This suggests that burning embers from the crown fires may have ignited the fire in the bottom of the drainage.

While it is not possible to identify with absolute certainty the exact ignition mechanism for the fire in the bottom of the West Drainage, the evidence suggests that the fire resulted from one or a combination of the two mechanisms discussed above.

Winds Push Fire into Bowl

Relying on witness statements and fire behavior knowledge, we suspect that the area identified as the Bowl contributed to the blowup on the afternoon of July 6. Postfire investigation of the site revealed nearly complete consumption of the surface fuels in the Bowl. Scorch marks caused by increased burning on the north side of the trees in this area suggest the presence of strong upcanyon (southerly) winds during the fire. We surmise that the concentration of debris on the ground carried the fire into the crowns of the conifers in the Bowl. This increased the size and height of the convection column over the fire. Several witnesses observed the smoke column build rapidly over the area identified as the Bowl. We believe that strong vertical momentum associated with the fire in the Bowl lofted embers up and onto the slopes on both sides of the drainage (South Canyon Report). These embers ignited spot fires.

Fire Transitions to Gambel Oak Canopy

General wind direction and topography caused the fire to spread up the West Drainage. Witness statements support this. Pushed by the winds up the steep slopes, the fire burned past the junction of the Lunch Spot Ridge and West Drainage and up onto the West Bench (see fig. 4).

Although the fire area was exposed to wind on July 4, 5, and 6, the Gambel oak canopy did not sustain continuous fire spread, even in previously underburned areas. As the fire burned downslope in the litter fuel beneath the pinyon, juniper and oak canopies, it was generally sheltered from the wind by the vegetation canopy. Upslope fire spread was confined to unburned islands within the fire perimeter or initiated by ladder fuel concentrations under individual trees (for example, the tree on the West Flank Fireline that became the Stump). Significant change in fire behavior occurred only after fire burned into fine fuels at the base of steep slopes and was exposed to strong winds. Such a transition occurred on the west-facing slope south of the Double Draws where the surface fire burned into the conifer crowns spreading upslope in several high-intensity crown fire runs.

Following the crown fire runs, the fire burned in litter and cured grass fuels along the bottom of the West Drainage spreading up the steep east- and west-facing slopes and up the West Drainage past the Lunch Spot Ridge onto the south end of the West Bench. The vegetation canopy was less dense on the east-facing slopes and along the West Bench. This exposed the surface fire to the strong winds. The steep slopes and exposure to strong winds resulted in significant increases in the size of the flames and energy release rates. This resulted in ignition of the pinyon-juniper canopy on the east-facing slopes and the green Gambel oak canopy on the West Bench. The following discussion focuses on the physical mechanisms that resulted in the fire spreading into and through the live fuel canopy as a continuous fire front.

The mechanisms driving the transition from surface to crown fire are not fully understood. In general, fire in the vegetation canopy follows an increase in the amount of energy entering the canopy, or a decrease in the amount of energy necessary to ignite the complex, or both. Increased slope, wind exposure, or decreased moisture status of live or associated dead fuels may individually, or in combination, result in such transitions.

Fire spread from the surface into the vegetation canopies often occurs rapidly; however, the factors leading up to the transition may develop relatively slowly. For example, fires often burn downslope relatively slowly, but when a backing fire reaches a position where an upslope run in unburned fuels is possible, the transition from backing to a fast-moving upslope fire may happen suddenly. Another example is fire burning through an area where it is sheltered from the wind into a location where it is more exposed to wind. The increased wind exposure can lead to a sudden change in fire behavior with little or no apparent change in the environment. In both of these examples the fire burned from one area to another resulting in an abrupt change in the slope or wind exposure. Solar heating can also influence the tendency for a fire to spread into the vegetation canopy. Exposure to the sun can cause a decrease in relative humidity and subsequent decreases in dead fuel moisture levels. This effect may occur both under and within the live vegetation complex. Decreased fine dead fuel moisture reduces the amount of energy needed for ignition. This drying may occur throughout the day or, as in the examples above, be caused by the fire burning into a sun-exposed aspect. When the fire reaches an area of drier fine dead fuel, the flaming zone can increase in size and intensity, again leading to sustained combustion in the vegetation canopy.

When a fire begins burning in the vegetation canopy, the flaming zone often significantly increases in height and depth. This increase is linked to the overall increase in total burning fuel load and decrease in bulk density (mass of fuel per unit volume). Increased fuel load leads to larger flames and energy release. Decreased bulk density often results in faster fire spread rates (Catchpole and others 1998). These two factors contribute to sustained burning in the live vegetation.

Another factor contributing to fire spread in vegetation canopies is live fuel moisture content. In an effort to assess the impact of fuel moisture on the blowup of the South Canyon Fire, we compare the conditions present on the Battlement Creek and South Canyon Fires.

A high intensity fire run occurred on the Battlement Creek Fire on July 17, 1976. This fire was approximately 30 miles west of the site of the South Canyon Fire, both burned in similar terrain and vegetation. The live Gambel oak foliar moisture content at the Battlement Creek Fire was 167 percent (USDI 1976). A killing frost on June 14, 1976, followed by dry weather significantly increased the quantity of fine dead fuel in the oak canopy over historical levels. Surface winds were light and consisted of normal upslope convective flow characteristic of summertime conditions in the area. Winds aloft were 5 to 15 miles per hour from the southwest. Slopes ranged from 10 percent near the bottom to 75 percent near the ridgetop. The fire burned on slopes that were generally west-facing and fully exposed to solar heating from about 1100 (USDI 1976).

In contrast, the Gambel oak at the South Canyon Fire site was not frost damaged, and consequently the canopy did not contain an abnormally high amount of dead leaves and stems. However, low precipitation levels during

the previous 8 months had pushed the area into an extreme drought. Green, nonunderburned Gambel oak vegetation was sampled on July 12, 1994, at two sites located east of the South Canyon Fire area. The sites were at a similar aspect and elevation to the area identified as the West Flank. The measured live fuel moisture contents were 125 percent. The live fuel moisture content would not have changed significantly between July 4 and July 12, 1994. The West Flank was west-facing with 10 to 60 percent slopes and was exposed to solar radiation from about midmorning. The South Canyon Fire site was exposed to strong winds on July 4 and 5, 1994, and for some time prior to and during the blowup on July 6.

Both the Battlement and the South Canyon Fires experienced similar flame sizes, energy release, and spread rates. Fire reaching the base of steep slopes was the triggering mechanism to ignition of the canopy at the Battlement Creek Fire. Large quantities of dead matter in the otherwise relatively high live moisture canopy contributed to fire spread into the canopy on the steep slopes. Strong winds were not a contributing factor. In contrast, the transition in fire behavior on July 6, 1994, on the South Canyon Fire can be linked to strong winds pushing the surface fire into fuels of sufficient quantity that the green Gambel oak began burning. Sustained fire spread through the green Gambel oak canopy was supported by steep slopes, wind, and moderately low live fuel moisture. Crown fire spread continued with reportedly much reduced windspeeds on the steep slopes of the West Flank Fireline. Once the canopy was ignited, the increase in energy release rates substantially contributed to continued crowning on both the Battlement Creek and the South Canyon Fires. It was only after the fire began burning in the nonunderburned green Gambel oak that it spread into the previously underburned Gambel oak.

Conclusions based on only two samples cannot be considered definitive. But this comparison suggests that sudden transitions from surface fire to fire in live vegetation canopies can be linked to a combination of factors, including but not limited to: live and dead vegetation moisture content, the spatial distribution and quantity of live and dead components in the canopy, exposure to wind, fire site aspect and slope, and the intensity of an initiating fire burning within, adjacent to, or under the vegetation canopy. Not all of these factors are necessary for a surface fire to spread into the vegetation canopy.

Fire on West Flank

As the fire burned through the bottom of the West Drainage, up onto the Bench, and up the slopes, it was influenced by two windflow patterns: the upcanyon (southerly) flow in the bottom of the West Drainage and the westerly flow associated with the passing cold front. There is strong evidence in the form of witness observations, photographs (fig. 35), and postfire meteorological modeling to support the existence of strong upcanyon winds in the West Drainage. These winds pushed the fire up the drainage. As fire burned along the bottom of the West Drainage, it spread up onto the West Bench where it began burning in the Gambel oak canopy. Once the fire burned above the Bench, it was increasingly exposed to the westerly winds blowing across the north-south oriented ridges. The result was short duration rapid fire runs east to the top of the Main Ridge. The fire was essentially spreading in two directions, one front moving northeast and one front east

(fig. 27). It was the first series of the eastward runs that caused the firefighters moving south along the Main Ridge toward H-1 to turn around at the rocks and retreat back toward H-2.

Our analysis suggests that the fire was spreading north, up the canyon, at approximately 3 feet per second. Spread rates of 7 feet per second occurred on midslope runs and northeast directed runs between Erickson's Spot Fire and H-2. We estimate that the upslope runs from the West Bench to the Main Ridge occurred at a rate of 6 to 9 feet per second (see table B-8).

Although there were no eyewitnesses to the fire event in which 12 firefighters perished on the West Flank Fireline near the tree, the available information suggests three possible fire behavior scenarios. They are presented below. We believe the three scenarios represent the most likely events. The actual sequence of events may have included parts of all three scenarios. We also discuss the fire behavior that resulted in the deaths of the two helitack crewmembers. Finally, we address the possibility of a fuel-air explosion.

One scenario, referred to as the "U" shaped fire front, involves fire burning on three sides of the firefighters as they started up the last section of the fireline. A second scenario, termed the surfacing smoke column, is based on the assumption that strong westerly winds blowing across the top of the north-south oriented ridges pushed the column of smoke and hot gases against the slope. This simultaneously ignited the vegetation over a relatively wide area around the firefighters. A third scenario simply assumes that the fire on the West Bench below the firefighters ignited a rapid upslope run. This run, assisted by westerly winds, burned quickly up the Draw, overtaking the group of firefighters hiking up the fireline.

The fire conditions and events last observed and recorded by witnesses in the area of West Flank Fireline are common starting points for all three scenarios. The following is a short review of those conditions and observations.

At approximately 1608:30 BLM Firefighter Haugh and Smokejumper Erickson were at the Tree. They heard the fire roar as it burned into the previously underburned Gambel oak near the 1,450 foot mark on the West Flank Fireline. Haugh and Erickson then saw firefighters coming up the fireline where it passes over the top of the Spur Ridge. The fire on the West Bench was starting to catch up to the crew hiking up the fireline. Erickson called Smokejumper Mackey to warn him of the fire approaching from behind the Spur Ridge. There was no noticeable wind at the Tree, but the firefighters could see wind pushing the flames and smoke on the east-facing slopes across the West Drainage from them.

As the firefighters on the West Flank Fireline came closer (about 500 to 550 feet below the Zero Point) Erickson saw a bearded McCall Smokejumper (Roth) in the lead. There was a yellowish glow over the West Bench. Erickson also recognized Mackey, who was the second person from the end as the group came over the Spur Ridge. Erickson then saw a spot fire appear directly below and west of him. He later located this spot fire on the West Bench near the West Drainage and about 75 feet north of the small draw that runs directly up the slope towards the Tree (fig. 40). Almost instantly the spot started to grow and Erickson called Mackey on the radio and warned him of the spot fire (about 1610:30). Erickson then took out his camera to take a picture of Mackey near the end of the oncoming firefighters. His camera was out of film.

At about 1611, Archuleta and Doehring, who were at the Photo Point located on the Main Ridge and north and east of Erickson, took a series of four



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Figure 40—Approximate fire perimeter positions between 1607 and 1614 on July 6, 1994. These perimeters are estimated from reconstruction of events, firefighter movements and witness statements. As such, the perimeters are subject to some uncertainty.

photographs. The first two photos show the last three West Flank Firefighters before they disappeared into the Draw 445 feet down the fireline from the Zero Point. Haugh, Erickson, Archuleta and Doehring all report that the fire behind the Spur Ridge roared as it crossed the fireline. Our analysis indicates that this occurred near the Stump. The fire burned quickly up the slope to the top of the ridge. We later determined from the photos that at this time the northeastern edge of the fire on the West Bench was about 200 feet south of the Draw and directly below the Tree. The West Bench fire had been advancing in a hook and run or “J” pattern, and the bottom edge of the “J” was now 200 to 300 feet from Erickson’s spot fire. Erickson said the sky was all orange and the spot fire was growing rapidly as he turned and headed up the fireline toward the Zero Point (time, 1611:15). This was the last observation about the fire below the West Flank Firefighters and leads into our three most probable scenarios.

At this time (1611:15) both the leading edge of the West Flank Fire and the spot fire could have been the source for the fire that burned east up the slope and overran the 12 firefighters and a short time later H-2. Erickson's spot fire quickly merged with the main fire and continued burning toward H-2 and the saddle below the Drop Zone. The fire coming through the saddle below the Drop Zone cut the two helitack crewmen off from the East Drainage.

“U”-Shaped Fire Front—As one moves northeast from the area where Erickson saw the spot fire, the vegetation changes from predominantly Gambel oak to pinyon-juniper and grass with some scattered Douglas-fir. The conifers and grass extend up the slope to the Photo Point. Erickson said that fire on the east-facing slopes (covered mostly with pinyon-juniper and grass) was more advanced than the fire on the west-facing slopes. This suggests that the fire was spreading faster in the pinyon-juniper and grass than in the oak. This is consistent with observations from other fires. As the spot fire observed by Erickson spread into the grass and pinyon-juniper, it moved northeast up the slope reaching a point on the Main Ridge approximately 100 feet north of the Zero Point. This fire could have been the source of the heat felt by Robertson and Archuleta as they traveled north along the Main Ridge directly east of the Photo Point.

When the West Flank Fireline Group neared the draw at the base of the last steep pitch in the fireline, the main fire front was 450 feet west and 400 feet southwest of them (about 1612). Fire extended up the south side of the Spur Ridge to the Main Ridge, around the bottom of the Spur Ridge, across the Draw below the Tree, and partially up the slope below the Photo Point. The fire burning up the slope in the pinyon-juniper and grass north of them may have been even closer.

This suggests that by 1613 the fire front formed a “U” or concave shape with the West Flank Fireline Group in the middle (fig. 40). From a physical perspective, such a “U” shaped fire front is inherently unstable. The unburned area within the concave fire front received heat from three sides rather than one. The presence of fire on multiple sides increased the amount of energy incident on the vegetation around the firefighters. This caused rapid ignition and fire spread up the last section of the fireline. The sequence of rapid preheating, ignition, and fire spread would likely have been perceived by the firefighters, especially those in the lower portion of the West Flank Fireline Group, as nearly instantaneous ignition of the vegetation around them. Movement of air in front of the fire as it ignited a large area and accelerated up the fireline could have been the source of the blast of hot air felt by Hipke. It could also have caused convective heating followed by radiant heating as the flames progressed up the slope.

Doehring and Archuleta's photographs and Erickson's observations place fire below the West Flank Fireline Group. The wind, slope, and vegetation combined to result in the fire spreading rapidly north up the West Drainage and east to the top of the Main Ridge. The sequence of fire perimeters shown in figure 40 would have been essentially the same in all cases presented in this report.

Surfacing Smoke Column—A turbulent gust associated with strong westerly winds pushing against or through the smoke column is an alternate source for the blast of air that hit Hipke. This assumes that fire was burning up the south side of the Spur Ridge and northeast up the West Drainage directly west of the West Flank Fireline Group. It is possible that the strong

west winds blowing across the tops of the north-south oriented ridges pushed the column of smoke and burning gases against the slope around the firefighters. As the gust hit the slope it carried hot air, smoke, and embers. Evidence suggests that smoke existed in sufficient quantities to impair their breathing, vision, or both. The embers and hot air enhanced preheating, ignition, and fire spread around the firefighters hiking up the fireline. Firefighters breathing in the hot gases were quickly incapacitated.

As Hipke hiked up the last 80 feet of the fireline and crossed over the Main Ridge, he suffered burns although he was attempting to shield his ears and face with his hands. The most severe occurred on his right side and back, with some lesser injury to his left side. Hipke states that the burns occurred shortly before and during the blast of hot air. Neither Hipke nor Erickson remember seeing flames nearby when they exited the fireline and crossed over the Main Ridge. If the column of hot air and smoke above the fire was pushed against the slope, convective heating would have occurred before the vegetation ignited. Radiant heating would have followed. It is also possible that smoke could have obscured the firefighter's view of flames in the area while not fully shielding them from the radiant heat emitted by the flames. While they do not recall seeing flames near the Zero Point, the lack of fire at the top of the ridge, and Hipke's testimony about the blast of air, lend some support to the possibility that the smoke column surfaced against the slope.

General Upslope Spread—While the West Flank Fireline Group hiked up the lower portion (south of the Spur Ridge) of the fireline, they were moving in the same general direction as the fire (predominantly north). The fire was spreading north up the West Drainage at about 3 feet per second while the firefighters were moving at 4 to 5 feet per second. As the group passed the Stump and started up and over the Spur Ridge their rate of travel slowed to less than 2 feet per second. After crossing the Spur Ridge, the fireline turns eastward upslope to the Main Ridge. While the path between the point where the fireline crests the Spur Ridge and the Draw is not steep, the footing was rough and uneven due to the multiple oak stobs along the ground. We estimate that the firefighters traveled between 3 and 4 feet per second. Of even greater importance is the relative direction of travel. As the firefighters hiked over the Spur Ridge and started along the last segment of the fireline, their direction of travel relative to the fire's major direction of spread changed. They were moving generally east, while the fire was spreading generally northeast. Thus, as the group passed the Stump, the distance separating them and the fire began to decrease.

As the crew moved through the Draw and started up the last and steepest section of the West Flank Fireline their rate of travel decreased to between 1 and 3 feet per second. The fire spread upslope as fast as 9 feet per second.

Between 2 and 3 minutes elapsed between the time the first members of the West Flank Fireline Group passed the Draw until they were caught by the fire. We plotted the high and low estimated fire spread rates against the rate of firefighter movement for the period 1607 to 1614. Figure 41 presents these data. Our analysis indicates that when the first members of the West Flank Fireline Group neared the Draw (time, 1610), the fire was approximately 450 feet south and southwest of them. By 1611 the fire was directly below them.

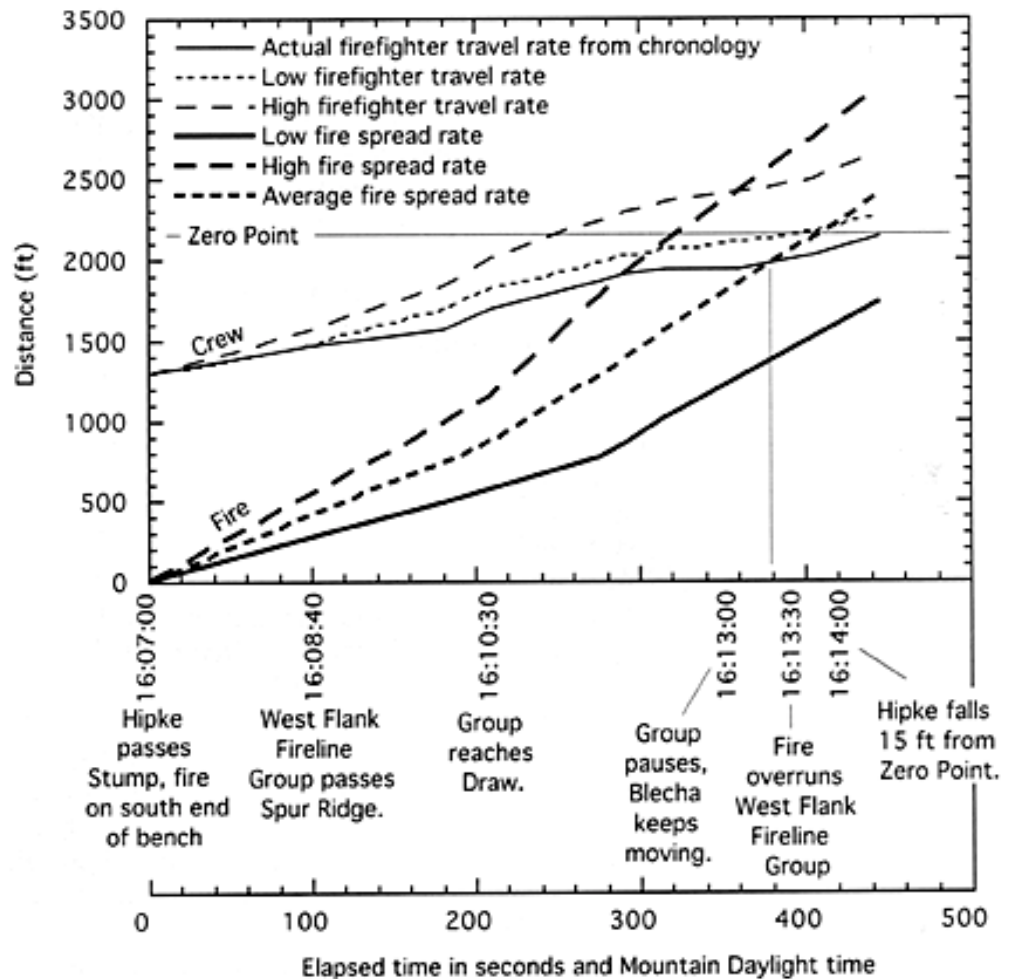


Figure 41—Time/distance diagram depicting the speed and distance covered by the firefighters hiking up the last portion of the West Flank Fireline versus that for the fire. The data used for this figure were obtained from appendix B. The high and low firefighter travel rates were obtained by actual reenactments by two physiologically different adult males (see table B-4). Note that the actual speed of the West Flank Fireline Group was slower than the lowest reenacted values. The fire spread rates are approximate values taken from table B-8.

Using crew travel rates taken from the chronology and the average fire spread, we estimate that the fire reached the firefighters at 1613:15.

Figure 41 illustrates the speed with which the fire caught and overburned the firefighters. In the previous sections we presented two scenarios by which the fire caught and overran the firefighters. This analysis suggests general fire spread up the Draw below the last section of the West Flank Fireline could have overrun the firefighters: a third scenario. The blast of hot air felt by Hipke could have been associated with the expansion of air in front of the fire as it quickly spread up the slope.

Helitack—After leaving H-2, the two helitack crewmembers moved along the top of the Main Ridge, moving generally north, perhaps in an attempt to reach the Drop Zone where they hoped to meet the helicopter. As the fire burned eastward across the saddle, it would have blocked the helitack crewmembers from following the others out the East Drainage. Possibly in an effort to reach an outcropping of rocks, the two firefighters continued northwest. They died in the bottom of a steep narrow gulley. The gulley would have acted as a chimney, channeling hot gases and smoke up the slope to their location about a minute after they entered the gulley.

Contributing Factors—Each of the three proposed fire scenarios provide some explanation for the rapid entrapment of the crew and the blast of hot air felt by Hipke. Witness statements indicate that the firefighters were aware that the fire was burning as a wide front behind them. There has been some question why the firefighters did not increase their rate of travel or did not drop their gear to exit the area more quickly. We have not addressed psychological or emotional factors in this report, but leave that topic for future analyses.

Other factors reduced the ability of the firefighters to fully identify the location of the fire. Postfire evidence did not indicate an organized attempt by the group to deploy their fire shelters. This suggests that the group was surprised by the fire. As the firefighters hiked up the West Flank Fireline they could see the fire from some selected locations (for example, Hipke saw the fire below them from a location near the Stump). However, much of the time, the 6 to 12 foot high oak brush hindered their view of the fire. The smoke in the air further reduced the ability of the firefighters to see the fire. Witnesses state the noise from the fire was as loud as that produced by a train or jet airplane.

It is likely that the area around the fatality site was quickly engulfed in smoke just prior to or during the burnover. The lack of a clear view of the fire and the loud noise created by the fire would have prevented the group from fully sensing how fast the fire was closing the gap between it and them. Their likely inability to identify the location of the fire is one explanation for the evidence suggesting that the group was surprised by the fire and did not realize how close the fire was or where to go to escape it.

We suspect that the “U” shaped fire front occurred. However, we also believe it likely that the strong westerly winds pushed the column of hot air and smoke against the slope. Our analysis suggests that general upslope fire spread was two to three times faster than the firefighters’ upslope travel rates.

Fuel-Air Explosion—Hot air, smoke, and burning embers hit Smoke-jumper Hipke 15 feet west of the Zero Point; he jumped and fell forward. When he stood up he had to raise his hands to continue to shield his face from the heat. He was burned on his back and sides with some indication of slightly more severe burning on his right side (Hospital Report 1994). The hot air blast originated from behind him. There has been considerable discussion as to the source of the blast of air. In fact, this evidence raised questions about the possibility of a fuel-air explosion over the West Flank Fireline. The other factor suggesting a fuel-air explosion is the apparent suddenness with which the fire overran the 12 firefighters on the West Flank Fireline. The firefighters were burned while still in line, many with their packs still on, and only a few showed signs that they had tried to deploy their fire shelters.

We do not believe that a fuel-air explosion occurred. This theory assumes that combustible gases accumulated in sufficient concentration to result in an explosion. Although several firefighters testify that winds on the West Flank Fireline were calm, we believe that strong winds and turbulence existed in the air above the fireline. This turbulence, the general instability, and the topography lead us to believe it unlikely that combustible gases could have accumulated in sufficient concentrations to support an explosion.

Conclusions

The South Canyon Fire tragically demonstrates the fire behavior that can occur given the appropriate combination of weather, topography, fuels, and fire. One of our most frustrating observations was that while fire behavior during the afternoon of July 6, 1994, can be characterized as extreme, it was normal given the environmental conditions. The fire was a direct consequence of the fuel, weather, and topographical factors. Similar alignments of fire environment factors and the resulting fire behavior are not uncommon.

We have summarized the weather, fuel, and topographical information, and presented a brief overview of the firefighter movements relative to the fire. Using the fire environment analysis and chronology, we presented what we believe are the most likely fire behavior scenarios.

Until the afternoon of July 6, the high intensity fire behavior consisted of occasional short duration torching of individual trees and narrow uphill runs in the fire's interior. At approximately 1600 the wind, slope, and fire location combined to result in a dramatic transition wherein the fire began burning through the live fuel canopy as a continuous flaming front. This report focused on the mechanisms that led to the dramatic transition from a low intensity ground fire to a fire that was burning through the vegetation canopy. The second part of the discussion addressed the specific fire behavior that led to the entrapment of 14 firefighters.

We have drawn a number of discussion points from the analysis. Some of these points will be readily apparent to firefighters. Others may be less evident. We believe that all are important.

- **Topography can dramatically influence local wind patterns.** Surface winds in mountainous terrain are highly variable. Areas of low or calm winds can exist while other areas experience dramatically different wind direction, windspeed, or both. These changes can occur without visible warning across relatively short distances, especially when the area is subjected to large-scale weather influences such as frontal passages. Wind information is needed from multiple locations around the fire perimeter. This information should be communicated to all fire personnel.
- **Vegetation and topography can reduce a firefighter's ability to see a fire or other influencing factors.** Complex topography and dense shrub or tree canopies can restrict the ability of firefighters to sense, visually or otherwise, changes in wind, fire behavior, and fire location. This emphasizes the need for adequate observers and lookouts.
- **Current and past fire behavior often does not indicate the potential fire behavior that could occur.** Maximum possible fire spread, flame heights, and energy release are determined by comparing present and near-term future fuel, weather, and topography to their state during past demonstrations of extreme fire behavior, possibly at other fires. The

fire behavior exhibited by the South Canyon Fire from July 2 through the morning of July 6 consisted of low-intensity downslope spread. At no time previous to the afternoon of July 6 did it exhibit continuous high-intensity burning in the Gambel oak canopy. Previous experience and observations of high intensity fire behavior and training in fire environment assessment are tools that can be used to anticipate potential fire behavior.

- **The longer a fire burns and the larger it gets, the greater the likelihood of high-intensity fire behavior at some location around the perimeter.** Not always is a fire ignited in an ideal location for high-intensity burning. However given sufficient time, a low-intensity fire will often reach a position where fuel, weather and terrain combine synergistically to produce high-intensity fire behavior. While we have not evaluated such probabilities analytically, intuitively it seems that the greater the range of conditions, the greater the potential for a rapid change in fire behavior at some location along the fire perimeter. Such was the case for the South Canyon Fire on July 6. Knowledge about the location of a fire perimeter is necessary to adequately assess fire potential.
- **The transition from a slow-spreading, low-intensity fire to a fast-moving, high-intensity fire often occurs rapidly.** This seems to surprise firefighters most often in live fuels, possibly because green vegetation is associated with reduced ignition risk. We do not fully understand the exact mechanisms triggering these transitions. But observations of past fire behavior indicate that such transitions often occur when there are significant changes in windspeed or wind direction, fire location (that is at the top of the slope versus the base of the slope), or in the quantity of live and dead components in the vegetation canopy. Live green vegetation can support and even promote high-intensity burning. Monitoring fire position relative to alignment of wind, slope, and live and dead fuels can assist firefighters in recognizing potentially hazardous fire behavior.
- **Escape route transit time is related to both topography and route length.** Escape routes should be considered in relation to potential maximum-intensity fire behavior rather than past or present fire behavior. The ideal escape route includes a downhill direction over the shortest possible distance to the safety zone, thereby maximizing firefighter travel rates while minimizing fire spread rates.
- **The underburned Gambel oak was significant in that it did not provide a safety zone.** The blowup did not occur in the previously underburned Gambel oak. The blowup occurred when the fire changed from a relatively low-intensity surface fire to a high-intensity fire burning in the canopy of the green (nonunderburned) Gambel oak near the bottom of the West Drainage. As the fire burned up the slopes from the nonunderburned into the previously underburned Gambel oak, energy release rates and spread rates would have increased over their already high values (appendix B, table B-8). Thus, the underburned Gambel oak caused increased fire intensity as the fire burned above the West Flank Fireline, but it was not a factor for the burning below the fireline and therefore did not contribute significantly to the entrapment of the 14 firefighters. However, the amount of unburned vegetation remaining above the West Flank Fireline precluded it from being an

adequate safety zone. Firefighters do not have “one foot in the black” when working adjacent to underburned shrub vegetation.

- **Smoke can significantly reduce the firefighter’s abilities to sense changes in fire behavior.** This is certainly realized by any firefighter who has had to breath smoke. There is some evidence that the area around the fatality site was quickly engulfed in smoke just prior to or during the burnover. The lack of a clear view of the fire and the loud noise created by the fire would have prevented the group from fully sensing how fast the fire was closing the gap between it and them and may have distracted the group from their objective of reaching safety. Their likely inability to identify the location of the fire is one explanation for the evidence suggesting that the group was surprised by the fire and did not realize how close the fire was or where to go to escape it. Lookouts positioned outside the burn area or overhead can communicate urgency and help firefighters identify the best escape routes relative to the fire position, direction, and rate of spread.

Our analysis emphasizes the often dramatic changes in fire behavior that can occur when fire is exposed to steep slopes, winds, and relatively continuous fuels. Perhaps even more important is the observation that not all of these factors are needed, rather only one or two are needed for a blowup to occur. None of the findings and observations discussed in this study represent new breakthroughs in wildland fire behavior understanding. Rather the findings support the need for increased understanding of the relations between the fire environment and fire behavior. We can also conclude that fire managers must continue to monitor and assess both present fire behavior and potential future fire behavior given the possible range of environmental factors.

During the review process, some of the reviewers commented that they were left with a feeling of “so what” after reading the manuscript. In fact, this is one of the points that can and should be drawn from our study of the fire. While relatively high-intensity fire behavior was demonstrated, it was normal and even ordinary behavior given the combination of environmental factors. Tragically, what was not normal or ordinary was that 14 firefighters were caught in the middle of the fire and could not escape.

As a last note to the readers, we want to say that the most difficult task in this whole process has been achieving a balance between analysis, calculations, and extrapolations on one end of the scale, and heartache, feelings of loss, and even anger on the other end. Peace of mind, if at all possible, can come only by accepting the fact that humans are part of nature, yet understand just parts of it and master even less. Our efforts were directed toward increased understanding, with the hope that the knowledge gained will help to avert similar future incidents.

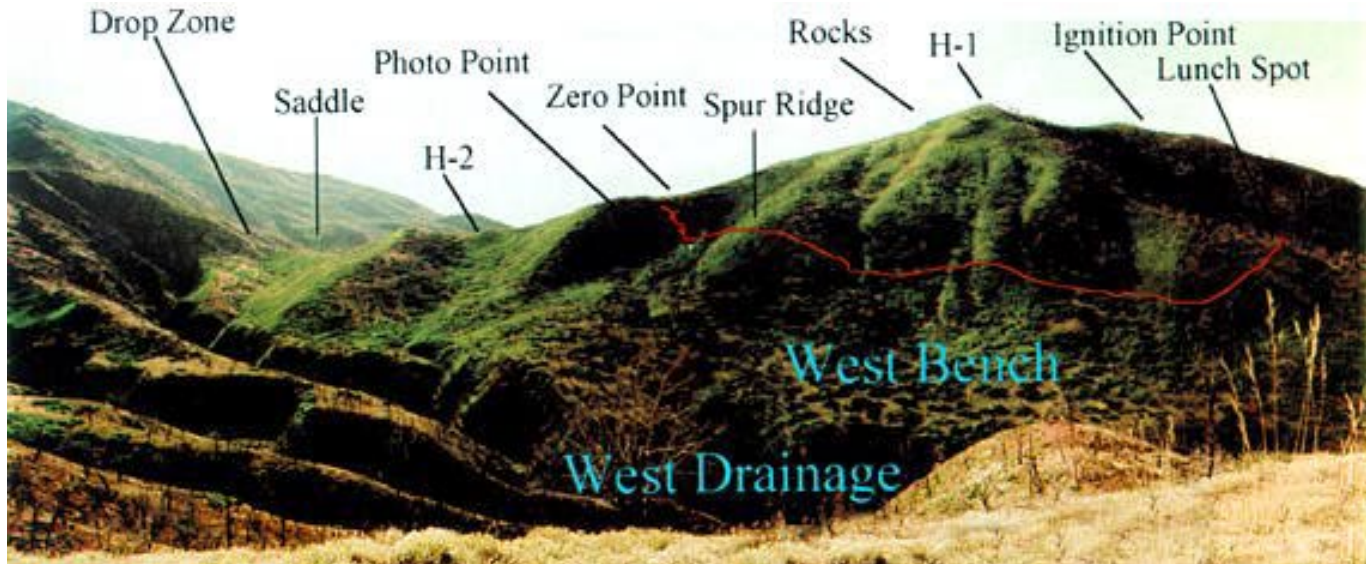


Figure 42—Panorama of the South Canyon Fire site taken 2 years after the fire from the ridge directly west across the West Drainage from the West Flank (Photo is a composite of two photographs taken by T. Putnam).

References

- Anon. 1994. Personal communication between local residents and T. Putnam.
- Bell, A. 1994. Personal communication with T. Putnam. Video taken at various times from July 4 through afternoon of July 6 from Canyon Creek Estates.
- Biaostoch, W. 1995. Personal communication with R. Bartlette. November.
- Bossert, J.E.; Harlow, F.H.; Linn, R.R.; Reisner, J.M.; White, A.B.; Winterkamp, J.L. 1998. Coupled weather and wildfire behavior modeling at Los Alamos: an overview. Proc. of Second Conference on Fire and Forest Meteorology. January 11-16, 1998, Phoenix, AZ. Boston, MA: American Meteorological Society. 8 p.
- Catchpole, W.R.; Catchpole, E.A.; Butler, B.W.; Rothermel, R.C.; Morris, G.A.; Latham, D.J. 1998. Rate of Spread of Free-Burning Fires in Woody Fuels in a Wind Tunnel. *Combust. Sci. and Tech.* V. 131:1-36.
- Erickson, K. 1996. Personal communication with T. Putnam. August.
- Good, D. 1996. Personal communication with R. Bartlette. January.
- Haines, D. A. 1988. A lower atmosphere severity index for wildland fires. *National Weather Digest*. 13(2): 23-27.
- Hipke, E. 1994. Personal communication with T. Putnam. August.
- Hipke, E. 1995. Personal communication with T. Putnam and R. Bartlette. November.
- Hipke, E. 1996. Video reconstruction of Smokejumper Eric Hipke's escape route along West Flank Fireline.
- Hopf, M. 1996. Personal communication with B. Butler.
- Hospital Report. 1994. On file with T. Putnam of USDA Forest Service Missoula Technology and Development Center, Missoula, MT.
- Husari, S. 1996. Personal communication with B. Butler, R. Bartlette, L. Bradshaw, J. Cohen, and P. Andrews. February.
- IMRT. 1994. Report of the Interagency Management Review Team (South Canyon Fire). October 17, 1994. Boise, ID: U.S. Department of Agriculture, U.S. Department of the Interior, National Weather Service, National Park Service, National Interagency Fire Center. 77 p.
- IMRT. 1995. Final Report of the Interagency Management Review Team. June 26, 1995. Boise, ID: U.S. Department of Agriculture, U.S. Department of the Interior, National Weather Service, National Park Service, National Interagency Fire Center. 80 p.
- OSHA. 1995. Occupational Safety and Health Administration's Investigation of the South Canyon Fire, February 8, 1995. Washington DC: U.S. Occupational Safety and Health Administration. 9 p.
- Petrilli, T. 1995. Personal communication with T. Putnam and R. Bartlette. November.
- Petrilli, T. 1996. Personal communication with B. Butler, L. Bradshaw, R. Bartlette, and J. Cohen. Spring.
- Pielke, R.A.; Cotton, W.R.; Walko, R.L.; Tremback, C.J.; Nicholls, M.E.; Moran, M.D.; Wesley, D.A.; Lee, T.J.; Copeland, J.H. 1992. A comprehensive meteorological modeling system-RAMS. *Met. Atmos. Phys.*, 49: 69-91.
- Russo, W.; Williams, W. 1995. Pushed to the Limit. *NFPA Journal*, March/April 1995:36-50.
- Scholz, B. 1995. Personal communication with T. Putnam, R. Bartlette, and B. Butler. November.
- Scholz, B. 1996. Personal communication with T. Putnam, R. Bartlette.
- Sharkey, B. 1994. Personal communication with T. Putnam on physiological analysis of firefighter movement.
- Shepard, T. 1995. Personal communication with R. Bartlette. October.
- USDI. 1976. Accident Report Battlement Creek Fire Fatalities and Injury, July 17, 1976. Washington DC: U.S. Department of the Interior. Unpublished report. 125 p.
- USDA, USDI, and USDC. 1994. South Canyon Fire Investigation (Report of the South Canyon Fire accident investigation team). Washington, DC: U.S. Department of Agriculture, U.S. Department of the Interior, U.S. Department of Commerce. U.S. Government Printing Office, Region 8. Report 573-183. 243 p.

Appendix A: Glossary

- Backing fire**—Fire spreading into the wind or downslope.
- Bench**—Topographical feature characterized as an area on a slope that is approximately level or at least significantly more so than the surrounding terrain.
- Blowup**—A rapid transition from a surface fire exhibiting relatively low intensity, to a fire burning in the whole vegetation complex, surface to canopy, and demonstrating dramatically larger flame heights, higher energy release rates, and faster rates of spread.
- Crown fire**—A fire that burns through the entire vegetation canopy. It may or may not include a surface fire burning through the dead leaves and litter near the ground surface.
- Drainage**—Topographical feature that is a deep gulley, draw, or valley.
- Fire front**—Usually refers to the leading edge of the fire, but may also include any part of the flaming perimeter of a fire.
- Fireline**—A fire control line formed by removing surface litter and organic matter to expose mineral soil. Often appears much like a rough narrow trail.
- Flareup**—A relatively short duration sudden increase in fire intensity or rate of spread over a small area. Usually involves one or a small group of trees or shrubs.
- Foliar**—Pertains to leaves or stems in vegetation canopy. Often used in the term “foliar moisture content.”
- Head fire**—A fire spreading with the wind, or upslope, or both.
- Helitack**—In this report the term applies to the firefighters that perform helicopter management and attack activities.
- Hotspot**—A small ignition often due to burning or smoldering debris rolling down hill across a fireline. This can also mean to patrol along a fireline looking for burning debris and embers that have crossed the fireline.
- Hotshot**—Intensively trained fire personnel, usually assembled in 20-person teams and especially noted for their effectiveness in building fireline.
- Intensity**—In the general sense intensity implies the size of the flames, the fire’s spread rate, and the rate of energy released from the fire.
- Plume**—This term refers to the smoke column produced by a fire.
- Reburn**—Fire burning through an area that has previously burned but still includes some flammable fuel.
- Shear layer**—Meteorological phenomenon generated at the intersection of two air masses flowing in different directions. The location in space where these masses interact is subject to viscous shear stresses. These stresses can generate severe turbulence.
- Slopovert**—Fire crossing a fireline or some other barrier to fire spread.

- Spot fire**—A small fire ignited by burning or smoldering debris that has been lofted into the air above a larger burning fire and then redistributed over the ground, often ahead of a fire front.
- Spur ridge**—A small ridge extending from a larger much more prominent main ridge.
- Stob**—A stake or stump of a shrub or small tree left after the upper portion of the plant has been removed by cutting or burning.
- Surface fire**—Fire burning in the litter and organic debris on or near the ground.
- Torching**—The rapid intense burning from the ground up through the canopy in a single or small group of trees or shrubs. Similar to a flareup.
- Transition**—The change from fire burning in one fuel stratum to another along with associated change in intensity. Most often refers to the change from a relatively low intensity surface fire exhibiting slow spread rates and low energy release to one burning with much higher intensities, faster spread rates, and higher energy release rates.
- Venturi effect**—This term refers to the increase in velocity of a stream of gas or liquid as it passes from one area through another area of smaller size or diameter. Conversely, if the area through which the stream is passing becomes larger, the velocity of the stream will decrease.

Appendix B: Chronology, Fire Behavior, Weather, Distances, Firefighter Travel Rates, and Fire Spread Rates

The chronology and data tables in this appendix are based on witness statements, synchronous events, distances, and measured times from actual on-site reenactments of crew movement between key locations.

The information relies heavily on interviews conducted by the original accident investigation team, interviews conducted by the OSHA investigators, interviews by the author John N. Maclean, and follow-up interviews conducted by the authors of this report. Attempts were made to resolve conflicting testimony. However, in the event that the conflict could not be resolved, earlier interviews took precedent over later interviews, some of which were collected 1 to 2 years after the incident.

Certain key events and times were crucial because they linked so many people together. The first event was the initial column of smoke that was observed in the early development of the blowup. The small column developed into a large plume of smoke in a short time (about 60 seconds). Several firefighters saw fire spread up the east side of the West Drainage within 2 to 3 minutes. Firefighters Petrilli, Kelso, Shepard, Hipke, Erickson, and others saw this event, which initially synchronized their movements. Within a minute, Hotshot Gray noted the time as 1604 hours. The firefighters started to move to their safety zones. The next key synchronous event was when Smokejumpers Archuleta and Doehring took the picture of Smokejumper Mackey and two Prineville firefighters hiking up the West Flank Fireline. Although Erickson did not get a photo because his camera was out of film, his memory of what he saw through the viewfinder indicates that his attempt was made about the same time that Archuleta and Doehring's photos were taken. This links Archuleta and Doehring to Erickson. Hipke's testimony links him to Erickson and the first half of the Prineville Hotshots to arrive at the fire, and to Smokejumpers Roth, Thrash, and Mackey on the West Flank Fireline. Archuleta's testimony links him to the firefighters working on the Main Ridge (the Group consisted of the BLM/U.S. Forest Service firefighters out of Colorado and the second half of the Prineville Hotshots to arrive at the fire; we have labeled them the Main Ridge Group). The Main Ridge Group headed into the East Drainage at 1614. Firefighters Blanco and Shepard and Helitack Crewmembers Browning and Tyler can be linked together because they moved some red personal equipment bags near H-2 as the Main Ridge Group was going into the East Drainage.

Distances between most locations were measured on site. Others were estimated from measurements on topographic maps. We used the measured distances and travel times to calculate rates of travel between specific locations and to estimate the sequence of events. Taking into account the sequence of events and physiological constraints on firefighter travel times between geographic points, we estimate that, while the times in the narrative are not absolute, they are accurate to within 1 minute and in many cases within 15 seconds.

Chronology, Fire Behavior, and Weather

We have attempted to include a reference to the primary information source for each time segment in table B-1. In many cases this is a single

witness statement. However, we also use the original accident report quite frequently. In the table we use the acronym SCR (South Canyon Report) to designate the original investigation team report (USDA, USDI, and USDC 1994). When the source is listed as time: Putnam, then the time is calculated from reenacted travel rates.

Table B-1—Chronology, fire behavior, and weather.

| Time | Firefighters | Fire/Weather | Source |
|---------------------------|---|---|-----------------|
| ----- July 2 ----- | | | |
| 1800 | | South Canyon Fire ignited by lightning. | Jo Temple |
| ----- July 3 ----- | | | |
| 1000 | Observer in South Canyon calls in fire. Unsure which side of the river it is on. Tentatively called South Canyon. | | Putnam |
| 1030 | Call to Sheriff accurately locates fire on north side of river on BLM land. | | Jo Temple |
| 1100 | Sheriff reports South Canyon Fire to BLM. | | SCR |
| 1410 | Sheriff's office reports fire at half an acre and very active and Sheriff approves use of aircraft. | | SCR |
| 1416 | BLM dispatch requests one load of smokejumpers, an air tanker (T-140), and lead plane (64) to initial attack fire. | | SCR |
| 1508 | Dispatcher cancels initial attack, routes smokejumpers to another fire. | Fire 1.5 acres in size and burning in continuous fuels. | SCR |
| ----- July 4 ----- | | | |
| 1200 | | Fire covers approximately 3 acres. | SCR |
| 1450 | Local resident reports increased fire activity. | | SCR |
| 1630 | BLM crew watches fire from freeway. Decides to wait until morning to initial attack. | | |
| 2109 | Aerial observer reports fire burning in all directions. Recommends bucket drops. | | SCR |
| 2200 | | Fire covers about 11 acres. | SCR |
| ----- July 5 ----- | | | |
| 0630 | BLM crew (Blanco and six firefighters) start up East Drainage. | | SCR |
| 0819 | Blanco requests more resources. | Fire reported to be 29 acres in size. | SCR |
| 1500 | Air tanker makes drop on freeway side of fire. | | SCR |
| 1730 | BLM firefighters start to exit area via West Drainage to repair saws. | | SCR |
| 1745 | Eight smokejumpers orbit fire; they jump in light, erratic winds. Mackey is Jumper-in-Charge and is in radio contact with Blanco. | Fire 30 acres in size, smokejumpers report erratic winds. | SCR Doehring |
| 1944 | Mackey reports fire burning actively. | Active burning. | SCR |
| 2000 | Smokejumpers start building fireline down east side of Main Ridge. | | SCR |
| 2230 | BLM firefighter crew finish repairing saws and gear. | Fire covers 50 acres. | SCR |
| 2300 | Mackey requests two Type-1 crews. | | SCR |

| Time | Firefighters | Fire/Weather | Source |
|--------------------|---|--|------------------------|
| ----- July 6 ----- | | | |
| 0030 | Eight smokejumpers stop building line due to poor footing and rolling rocks. | | SCR |
| 0300 | | Fire burning actively. | SCR |
| 0530-0630 | Eleven person BLM/USFS crew start up East Drainage to fire. Blanco is Incident Commander (IC). | | Ryerson |
| 0528 | Mackey requests helicopter and fixed-wing aircraft. | | SCR |
| 0800 | Blanco's crew (BLM/USFS) reach Main Ridge and construct second helispot (H-2). | | SCR |
| 0815 | Smokejumpers and BLM crew begin building fireline between H-2 and H-1. | | SCR |
| 0845 | Blanco and Mackey plan strategy and tactics. | | SCR |
| 0930 | Helicopter 93R arrives. Blanco, Tyler, and Mackey take a recon flight. Mackey tells smokejumpers to start building fireline down the West Flank. Smokejumpers question decision and request discussion. | Smoke observed low in West Drainage. | SCR |
| 1027 | Eight more smokejumpers arrive over fire. Jumper-in-Charge Hipke requests that Longanecker become Jumper-in-Charge for this plane load. | Very little wind. Fire covers about 127 acres. | SCR |
| 1113 | Completed jumping and cargo drop. | | SCR |
| 1130 | Combined smokejumper crews start down route flagged by Mackey. Longanecker is line scout. | | SCR |
| 1135 | Firefighters discuss pulling out of West Flank Fireline. | Tree 40 yards below main ridge torches. 5-ft wide run through Gambel oak burns to the top of the ridge. Water drops cool it. | Petrilli Doehring |
| 1200 | Prineville Hotshots arrive at Canyon Creek Estates helibase. | | SCR |
| 1230 | Ten Prineville Hotshots leave helibase for H-2. | | SCR |
| 1300 | Most firefighters retreat 400 ft to the Tree. Water drops are effective so group returns to the Stump and continues working. | Fire flares up on West Flank. The tree that flares up is cut down, leaving the Stump. | SCR |
| 1330 | Nine Prineville Hotshots start down West Flank Fireline, Kelso in charge, meet smokejumpers at Stump. | | Scholz |
| 1400 | Scholz and second half of Prineville Hotshots at Canyon Creek Estates. | Strong gusty winds, overcast skies. Front approaching. Windssock horizontal (15 miles per hour winds). | Scholz |
| | West Flank Fireline Group and smokejumpers eat lunch on Lunch Spot Ridge. | | SCR |
| 1415-1430 | Scholz calls Shepard to report increased wind and fire becoming more active. Shepard confirms it was windy on Main Ridge. | Increased smoke on fireline low in canyon and south of fireline below crew. | Scholz Photos: Frey |
| 1445 | Longanecker starts down Double Draw to scout fireline. | Hotspots in Double Draws. | SCR |
| 1510 | Longanecker calls for sawyers. A few jumpers start to move south from Lunch Spot and east in to Double Draws. | Flareup in Double Draws. | Petrilli, SCR |
| 1515 | Scholz and second half of Prineville Hotshots arrive at H-2. Blanco, Shepard, Scholz confer. | Squirrely winds on H-2. Winds very light at Zero Point. | SCR |
| 1520 | | Cold front arrives. Steadily increasing but erratic winds. | SCR |

| Time | Firefighters | Fire/Weather | Source |
|------|--|---|--|
| 1530 | Second half of Prineville crew lined out on Main Ridge. Start at H-2 improving line toward H-1. Told to make it 20 ft wide. | When firefighters throw brush up into air on Main Ridge, strong winds blow it over ridge to east. | Scholz |
| | Scholz carries 2 cubitainers of water down West Flank Fireline. Haugh and Brixey about 150 ft below Zero Point. | Winds gusty on top of line. No wind down West Flank Fireline. Sun begins to break through. | Scholz |
| | Some BLM/USFS eat lunch on Main Ridge, others working near H-1. | Calm wind, fire burning in litter under oak brush. | Byers |
| | Doehring, Erickson, sent by Mackey to go back toward Main Ridge and hotspot line. Hipke working along the fireline from Lunch Spot toward Zero Point. Most of the West Flank Group working between 1450 and 1880 ft from Zero Point. | Winds pick up on Lunch Spot Ridge but subside on West Flank Fireline. | SCR, Erickson Doehring |
| 1539 | Scholz meets Roth at stump (850 ft). They move log off line and talk briefly. | No wind on West Flank. Sunny, skies clearing. | Scholz Time: Putnam |
| 1545 | Longanecker gets water drop. Smoke-jumpers spread between Lunch Spot and Petrilli Photo Point. | Continued fire activity south of the Double Draws. | Petrilli Longanecker |
| | Some members of BLM crew take break at base of rocks under H-1. | Wind at rocks calm to 5 miles per hour. | Byers |
| | Scholz leaves water with Roth and starts back up line to Main Ridge. | No wind on West Flank, fire calm. Sunny on West Flank. | Scholz |
| 1553 | Scholz at top of Main Ridge. | Winds blowing about 45 miles per hour from the west. | Scholz Photo: Shepard |
| 1554 | Ryerson requests next water drop to go to main ridge. | Spot crosses Main Ridge fireline and burning actively in green fuel. Spot fire on west side of Main Ridge, 200 ft south of Zero Point getting active. | Ryerson Byers Scholz |
| 1555 | Erickson and Doehring move up West Flank Fireline, meet Roth at 850 feet. Roth says he will take water on toward Lunch Spot. | Wind and fire calm on West Flank. | Erickson Doehring |
| | Ryerson gets water drop on Main Ridge but water blew to east and misses fire. Pilot leaves to get another bucket of water. | Spot fire active on Main Ridge south of Zero Point. Winds on Main Ridge estimated at 35 miles per hour. | Ryerson Good Photo: Shepard |
| | Petrilli and other smokejumpers south of Lunch Spot photograph crown fire south of Double Draws area. Call to Longanecker to pull out. | Increased winds south of Lunch Spot (estimated at 35 miles per hour). Fire spreads rapidly upslope in pinyon-juniper and firs within fire perimeter. Three fire runs occur, flames are about 100 ft long. | Petrilli Longanecker |
| 1556 | Good sees spot fires in West Drainage. Heard firefighters talking about spots. | Numerous spot fires near bottom of West Drainage. | Good |
| 1558 | Erickson and Doehring leave Roth and start up West Flank Fireline. | No wind on West Flank. | Erickson Doehring |
| 1600 | Scholz requests Main Ridge Group move to Zero Point to help with spot fire. | Skies clear overhead, clouds over Storm King Mt. Winds 45 miles per hour from the west. Fire runs inside perimeter. | Scholz |
| | Wind blows Byer's hat off near spot fire on Main Ridge. | | SCR Byers |
| | Roth left Stump with cubitainer of water. | | Time: Putnam |
| 1601 | Eight smokejumpers 630 ft south of Lunch Spot. Longanecker lower on the south side of Double Draws. | Smoke in bottom of West Drainage below smoke jumpers. Main Ridge spot fire active in brush across line. | Photos: Petrilli Shepard Good |

| Time | Firefighters | Fire/Weather | Source |
|-----------|---|---|---|
| 1602 | Petrilli sees fire 35 yds north of base of Double Draws, calls Mackey. Mackey tells them to get out of draws. Petrilli and other smokejumpers hike toward Lunch Spot. | Fire starts rapid run up the east-facing slope across the West Drainage from smokejumpers. Fire also burning up the West Drainage. Petrilli estimates winds of 35 miles per hour at his location. | Petrilli |
| 1603-1607 | Someone calls dispatch requesting retardant, heard to say "we have a real bad situation here." | | Longanecker |
| 1604 | Kelso calls Shepard to report spot fire had crossed West Drainage below West Flank Fireline Group. Shepard, "Get out of there." Kelso, "We are on our way." Scholz, "Things are getting complicated." | Fire in West Drainage. Strong winds on Main Ridge, Spot fire on Main Ridge is active. | Shepard Scholz |
| | Roth meets Thrash, Hipke, Hagen on West Flank Fireline at 1,450 ft. Talked 30 sec then saw column. | Column of smoke in West Drainage behind (south of) and below Lunch Spot Ridge. | Erickson Hipke |
| | Shepard relays message about spot fire to Main Ridge Group, Blanco relays to Ryerson, Mackey. Gray checks his watch. Statement by Main Ridge Group individuals "remember this time." | Strong winds. | Scholz Gray-SCR |
| | Erickson and Doehring meet Archuleta on West Flank Fire line near 450 ft, they hear order to get out. | No wind on West Flank but building column of smoke visible to south over West Drainage. | Erickson Doehring |
| | Blanco and Shepard at H-2 tell crews on Main Ridge at Zero Point to go to H-1. | Column building in West Drainage. | Photo: Shepard |
| 1605 | Three smokejumpers and West Flank Fireline Group leave 1,450 ft with Thrash, Roth, Hipke and Hagen. | Column of smoke noticeably bigger. | Erickson Hipke |
| | Last water drop on Main Ridge. Good sees very large column and spots, returns to helibase to drop bucket so that he can ferry firefighters off hill. | Column greatly increases in size, west winds 45 miles per hour or greater over Main Ridge. Chin strap needed on hard-hats. | Good Ryerson |
| | Crews at Zero Point on Main Ridge start moving toward H-1 through cooled spot fire. | Bucket drop cooled spot on Main Ridge. Winds very strong. | Scholz |
| | Thirty smokejumpers arrive by bus ¼ mile west of base of West Drainage. They go to Canyon Creek Estates when fire blows up. | | |
| 1606 | Erickson, Doehring, and Archuleta at Tree, they meet Haugh and Brixey. Tells Haugh of order to go to H-1. Haugh calls Blanco about spot fire across drainage, Blanco responds to get out. | Gray-black smoke in column, then flames reach top of east-facing slopes across West Drainage from jumpers. Fire is moving north up the drainage. | Doehring Erickson Brixey Haugh |
| | Petrilli and seven smokejumpers meet Mackey 100 ft below Lunch Spot. Mackey tells smokejumpers to head up ridge toward H-1. | Fire rolls up the east-facing slopes across West Drainage. Winds blowing 45 miles per hour. | Petrilli Thomas Shepard |
| 1607 | Mackey checks on Longanecker by radio then moves north toward West Flank Fireline Group. | | Time: Putnam Longanecker |
| | Hipke near Stump at 830 ft. Sees fire on their (east) side of West Drainage. | Fire on West Bench north of Lunch Spot Ridge. Fire front forms a "U" shape in bottom and up both sides of West Drainage. | Hipke Time: Putnam |
| | Petrilli and seven smokejumpers pass Lunch Spot and continue toward H-1. | | Time: Putnam |
| 1608 | Mackey at 1,450 ft, running. | Fire on West bench behind Mackey. | Time: Putnam |
| | Doehring, Archuleta, Brixey head to top of West Flank Fireline. | | |
| 1608:30 | Haugh, Erickson hear fire roar. They see first smokejumpers in West Flank Fireline Group coming across top of Spur Ridge. | Fire on Bench near Jumper Start Point (1,450 ft) and near West Flank Fireline. | Haugh Erickson Time: Putnam |

| Time | Firefighters | Fire/Weather | Source |
|---------|--|---|--|
| 1608:40 | Hipke on top of Spur Ridge (680 ft), sees Mackey at end of West Flank Fireline Group. | Fire's northward spread keeping pace with northward movement of firefighter crews. Fire crosses the West Flank Fireline near 1,450 ft. | Hipke Time: Putnam |
| 1609 | Main Ridge Group, BLM/USFS group near Rocks on Main Ridge. Scholz commands Hotshot Crew to "Reverse and move!" Ryerson tells her Crew to go to H-2. A jumper radios "We're headed for a good spot." Sounds winded, urgent. | Fire rapidly moving up slope toward Rocks and H-1. | Robertson Scholz Byers Time: Putnam Shepard |
| 1610 | Walking steadily from the Double Draws, Longanecker arrives at Lunch Spot. Doehring, Archuleta, Brixey reach Main Ridge. First part of Main Ridge Group passing Zero Point on their way to H-2. | | Time: Putnam Doehring Time: Putnam |
| | Erickson, who is at the Tree, sees hardhats of the West Flank Fireline Group as they cross over Spur Ridge. Thrash is in the lead and Mackey is second to last in line. Erickson can see fire behind and below the hardhats. He and Haugh yell at the firefighters to go faster. Erickson calls Mackey to tell him about the fire behind the Spur Ridge. | Fire front burning on south side of Spur Ridge near Stump. | Time: Putnam |
| 1610:30 | Thrash nears Draw (445 ft), says "Shelters?" Hipke keeps moving up fireline. Erickson sees Spot Fire down the slope directly west and below the West Flank Fireline Group. Erickson at Tree (200 ft) radios Mackey to warn him about Spot Fire. | Spot Fire is burning on northwest corner of West Bench, about 75 ft north of the Draw that runs down the slope from the Tree to the West Drainage. Growing rapidly. Fire on south side of Spur Ridge "roars" as it burns up the slope past the Stump and crosses the fireline. | Hipke Erickson Time: Putnam Erickson Time: Putnam |
| 1610:45 | Archuleta and Doehring at Photo Point on Main Ridge. Archuleta asks Doehring for her camera. Haugh and Erickson at Tree. Erickson asks Haugh to get his (Erickson's) camera out of his pack. | Fire burning uphill behind Spur Ridge near Stump and across west slopes of West Drainage. | Erickson Time: Putnam |
| 1611 | Blanco at H-2 calls Dispatch and says that they are losing the fire and to send air tankers. Archuleta and Doehring on Main Ridge 110 ft north of top of West Flank Fireline at Photo Point, Archuleta takes two photos of Mackey and two of the firefighters located about 580 ft down the fireline from the Zero Point. Doehring takes two photos of same area then starts moving to H-2. Erickson at Tree frames one photo at similar angle to Archuleta, but is out of film. | Sky is orange. | Blanco Photos: Archuleta Doehring Time: Putnam Erickson Time: Putnam |
| 1611:15 | Haugh, Erickson start up fireline. Hipke at 325 ft. Archuleta walks to the "Y" (a fork in the trail located about 60 ft south of the Zero Point). | Fire "roars" on way up to Main Ridge south of Spur Ridge. | Erickson Archuleta Time: Putnam |
| 1612 | Hipke at Tree (200 ft). Helicopter approaches H-2, pilot sees firefighters running north along Main Ridge, towering smoke column obscures area to the south near H-1. Last of Main Ridge Group and Byers pass top of West Flank Fireline (Zero Point) and follow trail that drops off east side of ridge on a contour toward H-2. | Fire along top of Main Ridge between H-1 and Spur Ridge, 150 to 200 ft flame lengths. Fire front at base of Spur Ridge about to enter draw below "Tree." | Time: Putnam Good Time: Putnam |

| Time | Firefighters | Fire/Weather | Source |
|---------|---|---|--|
| 1612:15 | Roth and Thrash start to deploy. West Flank Fireline Group stop behind them. Scholz, about 80 ft north of Zero Point, looks back to southwest and sees fire "curling" over the ridge behind firefighter running down the trail toward him. | Fire on south side of Spur Ridge crests Main Ridge 150 to 200 ft south of Zero Point. | Time: Putnam Scholz |
| 1612:30 | Haugh crosses over Main Ridge at top of West Flank Fireline and starts down into the East Drainage. Haugh receives slight burns. Blecha steps around West Flank Fireline Group and continues up fireline. | Hot air and radiant heat in area near top of West Flank Fireline as fire crests the Spur Ridge. Fires active on Main Ridge. Wind blowing toward H-2. | Erickson, Haugh, Scholz, Robertson Time: Putnam Time: Putnam |
| 1612:45 | Erickson crosses over the Main Ridge at the top of the fireline and receives second degree burns. | | |
| 1613 | Doehring reaches H-2, heads into East Drainage. Archuleta and Robertson walk on Main Ridge trail near Photo Point and feel heat. Shepard, Blanco, Browning, Tyler move red bags near H-2. | Smoke and sparks in air. Hot air or radiant heat, smoke and sparks on top of Main Ridge. | Doehring Time: Putnam Robertson Time: Putnam Shepard |
| 1613:15 | Scholz approaches H-2 from trail on east side of Main Ridge. | Dolmars on Main Ridge between Photo Point and H-2 explode. | Scholz |
| 1613:30 | Ryerson feels heat at H-2. Saws and dolmars left near red bags. Fire overruns and kills 12 members of West Flank Fireline Group (200 to 280 ft down West Flank Fireline from Zero Point). Tyler, Browning run north of H-2 along Main Ridge. | Fire, hot gases and smoke at bottom of fatality site. | Ryerson Byers Robertson Time: Putnam |
| 1613:45 | Blecha caught by hot gases/flames. He dies 121 ft from top of Main Ridge. | | Time: Putnam |
| 1614 | Blast of hot air hits Hipke, he hits ground 15 ft west of Zero Point. Hipke gets up, removes pack as he crosses east edge of Main Ridge and headed down into East Drainage. Hipke receives third degree burns over 10 percent of his body. Main Ridge Group, BLM/USFS, Smokejumpers heading off Main Ridge into East Drainage. | Hot air, flames, and smoke on Main Ridge between H-1 and Zero Point. Heat pushes firefighters over edge of Main Ridge. | Hipke Time: Putnam Ryerson, Scholz, Byers, Good |
| 1614:30 | Last of Main Ridge Group below red bags head farther into East Drainage. | Smoke, hot air, sparks at H-2 and on red gear bags. Fusees with gear ignite. | Robertson Scholz Shepard Time: Putnam |
| 1615 | BLM/USFS, Main Ridge Group, Smokejumpers several hundred feet down East Drainage. Two helitack crewman cut off from East Drainage. Turbulence and smoke force helicopter to leave. | Flames near top of Main Ridge at H-2. Fire advances through saddle below Drop Zone and into top of East Drainage. Dolmars (probably near red bags) explode. | Navarro, Scholz, Byers, Ryerson Time: Putnam Good |
| 1618 | Six of eight jumpers hiking up ridge reached burned area on Lunch Spot Ridge below H-1. | | Time: Putnam |

| Time | Firefighters | Fire/Weather | Source |
|----------------------------|---|---|------------------------------------|
| 1619 | Eight smokejumpers on Lunch Spot Ridge deploy fire shelters. They form two groups, six approximately 230 ft below edge of H-1, two others about 100 ft further down ridge. Jumpers call Mackey and get no response. | | Petrilli |
| 1622:30 | Two Helitack (Tyler and Browning) overrun and are killed in tight draw (1,960 ft northwest of H-2). | Fire advances to draw below rock outcrop northwest of H-2. | Time: Putnam |
| 1624 | All eight smokejumpers under shelters. Petrilli checks his watch. | During next 45 minutes the fire makes three runs toward upper end of Double Draws approximately 500 ft south of eight smokejumpers. | Petrilli |
| 1715-1730 | Main Ridge Group, BLM/USFS, Smokejumpers reach I-70 freeway. | Firefighters moving down East Drainage, see spot fires in East Drainage. | Scholz Haugh |
| 1800 | Main Ridge Group, BLM/USFS, Smokejumpers on freeway taken to Glenwood Springs. Archuleta returns to helibase at Canyon Creek Estates. | Fire burns to mouth of East Drainage. | SCR |
| | Longanecker hiked to Lunch Spot Ridge deployment site. Smokejumpers out of shelters, they spread out, some walk to West Flank Fireline fatality site and begin search and rescue. | Fire burns through entire West Flank, but area between Lunch Spot Ridge and H-2 is cool enough to walk through. | Petrilli |
| 1900-2000 | Smokejumpers from Lunch Spot Ridge deployment site arrive at H-2. Archuleta and 25 or 26 smokejumpers are ferried in by helicopter to continue search and rescue. Smokejumpers from shelter deployment on Lunch Spot Ridge ferried from fire. Smokejumpers conducting search walk out West Drainage after dark. | | Petrilli Little |
| 2100 | | Fire activity diminishes. Fire estimated to have burned 2,000 acres. | |
| ----- July 11 ----- | | | |
| | Fire is declared controlled. | Total burned area is 2,115 acres. | Russo and Williams 1995, SCR |

Distances

Table B-2—Measured distances along West Flank Fireline from Zero Point.

| Feet | Description |
|-------|--|
| 0 | Zero Point: Junction of Main Ridge and top of West Flank Fireline |
| 15 | Hipke's shelter |
| 82 | Hipke's pulaski, no handle |
| 121 | Firefighter fatality nearest top of Fireline (Blecha) |
| 142 | Bent handle shovel, handle charred |
| 200 | Tree and upper end of fatality site |
| 240 | Middle of fatality site |
| 283 | Lower end of fatality site |
| 392 | Pulaski head, no handle |
| 445 | Location of narrow Draw where Hipke passed Thrash and Roth |
| 580 | Firefighters shown in photos taken by Archuleta and Doehring from Photo Point |
| 680 | Top of Spur Ridge |
| 850 | Stump and felled tree |
| 1,450 | Smokejumper (Hipke) starting point for hike back line toward Main Ridge |
| 1,665 | Location of midpoint of Prineville crew prior to order to get out |
| 1,880 | Location of end of Prineville Hotshot crew prior to order to get out, fireline to south leads uphill to Lunch Spot |
| 2,100 | Lunch Spot |

Table B-3—Other measured distances.

| Location | Description | Location | Description |
|--------------------|---|-----------------------|---|
| <i>feet</i> 400 | Zero Point (top of West Flank Fireline at Main Ridge) to turnaround at Rocks on Main Ridge below H-1. | <i>feet</i> 1,940* | Base of Double Draws (origin of blowup) to Erickson's spot fire. |
| 790 | Zero Point to center of H-1. | 815* | Base of Double Draws to bench under West Flank Fireline. |
| 60 | Zero Point to "Y". | 650* | Bench under West Flank Fireline to Hipke's start point (1,450 ft) for hike out. |
| 110 | Zero Point to Main Ridge Photo Point. | 900* | Hipke's start point (1,450 ft) to Rocks under H-1 (straight uphill). |
| 560 | Zero Point to H-2. | 2,040* | Erickson's spot fire to Helitack fatality site. |
| 1,148 | Zero Point to fire edge on West bench shown in fig. 29a. | 600 | Hipke's start point to Stump. |
| 1,195* | Zero Point to spot fire seen by Erickson. | 975* | Stump to Main Ridge (straight uphill). |
| 2,640* | Lunch Spot to I-70 by way of West Drainage. | 120 | H-2 north to red bags. |
| 630 | Lunch Spot to Petrilli's Photo Point near Double Draws. | 270 | H-2 north to Shepard lookout position on knob. |
| 984 | Lunch Spot to Longanecker's position in Double Draws. | 790 | H-2 north to Saddle. |
| 775 | Lunch Spot to lower two jumper deployment sites below H-1. | 925 | H-2 to bottom of jumper Drop Zone. |
| 970 | Lunch Spot to upper six jumper deployment sites below H-1. | 1,960 | H-2 to Helitack fatality site. |
| 1,200 | Lunch Spot to edge of H-1. | 400* | Erickson's spot fire to base of Spur Ridge. |
| 1,225 | Lunch Spot to H-1 center. | 876* | Bottom of main fatality site to base of Spur Ridge. |

* Measurements estimated from map.

Firefighter Travel Rates

Firefighter travel times were estimated in two ways. Table B-4 presents actual travel rates for two physiologically different adult males (J. Cohen and T. Putnam). Their times probably bracket the actual transit times of the West Flank Fireline Group. We also reenacted the firefighter travel times for other routes (tables B-5 through B-7). All of these other rates were reenacted by Putnam except for the time between the Longanecker position in the Double Draws to the Lunch Spot, which was reenacted by Butler.

Table B-4 presents the transit times on the West Flank Fireline. This is the route followed by the smokejumpers and the first half of the Prineville Hotshots as they traveled along the West Flank Fireline from the Lunch Spot to the top of the line at the Main Ridge (the Zero Point). Table B-5 presents reenacted travel times and rates for the BLM/U.S. Forest Service firefighters and the second half of the Prineville Hotshots who traveled from the intersection of the West Flank Fireline and the Main Ridge Fireline south toward H-1, turned around near the rocky outcropping below H-1 then back

along the Main Ridge toward H-2. Table B-6 presents times, distances, and rates for the smokejumpers in the Double Draw area. They traveled from a point southwest of the Lunch Spot, to the Lunch Spot, then up the ridge to their deployment site. Table B-7 presents times, distances, and rates for the two helitack. Their path started at the red bags, led north of H-2 along the Main Ridge toward the Drop Zone, and then northwest into the narrow chutes on the northeast side of the West Drainage.

Table B-4—Reenacted travel rates on West Flank Fireline.

| Location* | Segment distance | Putnam | | | Cohen | | |
|--|------------------|--------------|--------------|-------------|--------------|--------------|-------------|
| | | Elapsed time | Segment time | Rate | Elapsed time | Segment time | Rate |
| | <i>Feet</i> | | | <i>Ft/s</i> | | | <i>Ft/s</i> |
| Lunch Spot | 0 | 0:00 | 0:00 | | | | |
| Southernmost firefighters on fireline | 220 | 1:26 | 1:26 | 2.6 | | | |
| Hipke start point, northernmost members of group on fireline | 430 | 2:41 | 1:15 | 5.7 | 0:00 | 0:00 | |
| Stump | 600 | 4:57 | 2:16 | 4.4 | 2:30 | 2:30 | 4.0 |
| Spur Ridge | 170 | 6:38 | 1:41 | 1.7 | 3:34 | 1:04 | 2.7 |
| 580 ft (firefighters in Archuleta photo) | 100 | 7:13 | 0:35 | 2.9 | 4:03 | 0:29 | 3.5 |
| Draw | 135 | 7:46 | 0:33 | 4.1 | 4:28 | 0:25 | 5.4 |
| Bottom of fatality site | 162 | 8:52 | 1:06 | 2.5 | 5:14 | 0:46 | 3.5 |
| Middle of fatality site | 43 | 9:10 | 0:18 | 2.4 | 5:27 | 0:13 | 3.3 |
| Tree | 40 | 9:33 | 0:23 | 1.7 | 5:42 | 0:15 | 2.7 |
| Blecha | 79 | 10:44 | 1:11 | 1.1 | 6:30 | 0:48 | 1.6 |
| Zero Point | 121 | 11:32 | 0:48 | 2.5 | 7:00 | 0:30 | 4.0 |
| Total from Hipke start point to Zero Point | 1,450 | | 8:51 | 2.7 | | 7:00 | 3.5 |

*See table B-2 for distances from Zero Point.

Table B-5—Reenacted firefighter travel rates on Main Ridge.

| Location | Segment distance | Elapsed time | Segment time | Rate |
|---|------------------|--------------|--------------|-------------|
| | <i>Feet</i> | | | <i>Ft/s</i> |
| Zero Point | 0 | 0:00 | | |
| South from Zero Point to Rocks below H-1 | 400 | 4:31 | 4:31 | 1.5 |
| North from Rocks to Zero Point | 400 | 7:22 | 2:51 | 2.3 |
| North from Zero Point to "Y" | 60 | 7:37 | :15 | 4.0 |
| North from "Y" to H-2 | 450 | 9:10 | 1:33 | 4.8 |
| North from H-2 to Red Bags | 120 | 9:31 | :22 | 5.7 |
| Total distance—South from Zero Point to Rocks, then north from Rocks along Main Ridge to Red Bags | 1,480 | 9:31 | 9:31 | 2.6 |

Table B-6—Reenacted smokejumper travel rates in Double Draw Area.

| Location | Segment distance | Elapsed time | Segment time | Rate |
|--|-------------------------|---------------------|---------------------|-------------|
| | <i>Feet</i> | | | <i>Ft/s</i> |
| Petrilli Photo Point | 0 | 0:00 | | |
| Petrilli Photo Point to 100 ft below Lunch Spot where jumpers met Mackey | 533 | 4:16* | 4:16 | 2.1* |
| From jumper/Mackey meeting site to Lunch Spot | 100 | 5:04 | 0:48 | 2.1 |
| From Lunch Spot up ridge to lower deployment site - two smokejumpers | 775 | 11:52* | 6:48 | 1.9 |
| From lower deployment site to upper deployment site - six smokejumpers | 192 | 13:34 | 1:42 | 1.9 |
| Total distance from Petrilli Photo Point to upper deployment site | 1,600 | 13:34 | 13:42 | 2.0 |
| Longanecker locations in Double Draws to Lunch Spot | 984 | 7:40 | 7:40 | 2.0 |

* Estimated.

Table B-7—Reenacted travel rates along Helitack route.

| Location | Segment distance | Elapsed time | Segment time | Rate |
|---|-------------------------|---------------------|---------------------|-------------|
| | <i>Feet</i> | | | <i>Ft/s</i> |
| Red Bags | 0 | 0:00 | | |
| North from red bags to south edge of knob directly north of H-2 | 150 | 1:00 | 1:00 | 2.5 |
| North from south side of knob to north side of knob | 180 | 1:55 | 0:55 | 3.3 |
| North from knob to Saddle | 344 | 2:45 | 0:50 | 6.9 |
| North from South edge of Drop Zone | 132 | 4:09 | 1:24 | 1.6 |
| Edge of gulley where the helitack crew were found | 761 | 7:04 | 2:55 | 4.4 |
| From edge of gulley to middle of site where the two helitack crewmembers died | 274 | 9:01 | 1:57 | 2.3 |
| Total distance traveled by helitack crew from red bags to fatality site | 1,841 | 9:01 | 9:01 | 3.4 |

Fire Spread Rates

Table B-8 is a compilation of distances, times, and estimated fire spread rates. The rates were estimated by dividing the distance that the fire traveled by the time that it took the firefighters to move from one point to the next or by observations at estimated times for each specific event.

Table B-8—Estimated fire spread rates.

| Fire movement | Distance | Time reference | Elapsed time | Fire spread rate |
|--|-------------|---|--------------|------------------|
| Fire movement north up West Drainage | | | | |
| | <i>(ft)</i> | | <i>(s)</i> | <i>(ft/s)</i> |
| Double Draw - South end of West Bench. | 815 | Fire at base of Double Draws (1602) - Fire on West Bench (1607). | 300 | 2.7 |
| South end of West Bench - West Bench below Spur Ridge. | 690 | Fire on south end of West Bench (1607) - Fire in Archuleta - Doehring photograph* (1611:15). | 255 | 2.7 |
| Erickson Spot Fire - Helitack Site. | 2,040 | Erickson left Tree* (1611:15) - Helitack overrun (1622:30). | 675 | 3.0 |
| 1,450 ft Hipke start point - Stump (midslope position of series of hook north and run east). | 600 | Hipke observation from Spur Ridge (1608:40) - Mackey at Spur Ridge (1610:30). | 110 | 5.5 |
| Fire movement from Bench to Main Ridge | | | | |
| South end of West Bench - Rocks north of H-1. | 1,735 | Hipke observation from Stump (1607) - Fire crested Main Ridge at Rocks (1610). | 180 | 9.6 |
| Stump - Main Ridge at 200 ft Main Ridge Spot Fire. Fire run photographed by Archuleta and Doehring (time, 1611 - 1611:15). | 975 | Fire run heard ("fire roared") (1610:30) - Scholz observed fire curl on Main Ridge (1612:15). | 105 | 9.3 |
| Fire on West Bench under Spur Ridge - Middle of Fatality Site. Fire run in green oak. | 910 | Fire in photograph (1611:15) - (1613:30). West Flank Fireline Group overrun. | 135 | 6.7 |
| Middle Fatality Site - Zero Point. Fire run in underburned oak. | 240 | Crew overrun (1613:30) - Hipke down near Zero Point (1614). | 30 | 8.0 |
| Fire on West Bench under Spur Ridge - Zero Point (full run). | 1,150 | Fire in photograph (1611:15) - Hipke down near Zero Point (1614). | 165 | 7.0 |
| Erickson Spot Fire - Middle of Fatality Site. Fire run in grass and green oak. | 955 | Erickson left Tree (1611:15) - West Flank Fireline Group overrun (1613:30). | 135 | 7.1 |
| Erickson Spot Fire - Zero Point (full run). | 1,195 | Erickson left Tree (1611:15) - Hipke down (1614). | 165 | 7.2 |
| Erickson Spot Fire - H-2. | 1,350 | Erickson left Tree (1611:15) - fusees igniting at H-2 (1614:30). | 195 | 6.9 |
| Spot Fire - Saddle below Drop Zone. | 1,420 | Erickson left Tree (1611:15) - Fire cut off helitack crew (1615). | 225 | 6.3 |

*1611:15 is a critical time in many of the calculations of this table. The later photographs by Archuleta and Doehring were shot at about this time. Based on travel rate calculations, Erickson left the Tree at about this same time. Based on Erickson's statements from his vantage point, the spot fire grew toward the north but not uphill before he left the Tree. It is assumed that the main fire burning on the north end of the Bench and the spot fire he observed began to spread uphill as he left the Tree.

Appendix C: Mesoscale Meteorological Model

Because the wind was so critical to this event, it sparked the interest of mesoscale meteorology modelers. Could such a wind be modeled, or even forecast by a high resolution mesoscale model? One interested group was the Mesoscale Meteorology Section at Los Alamos National Laboratory (in association with Crisis Forecasting Research being conducted by the Advanced Computing Laboratory). Figure C-1 presents predicted wind vectors 33 feet above the ground in a surface following coordinate system at approximately 1600 hours on July 6, 1994 (Bossert and others 1998). These predictions were made using a four-level nested grid of the RAMS (Pielke and others 1992) mesoscale model at a final grid resolution of 33 feet using 100 foot elevation data. Model initialization was facilitated by a (MAPS) analysis provided by the Forecasting Systems Laboratory, Boulder, CO.

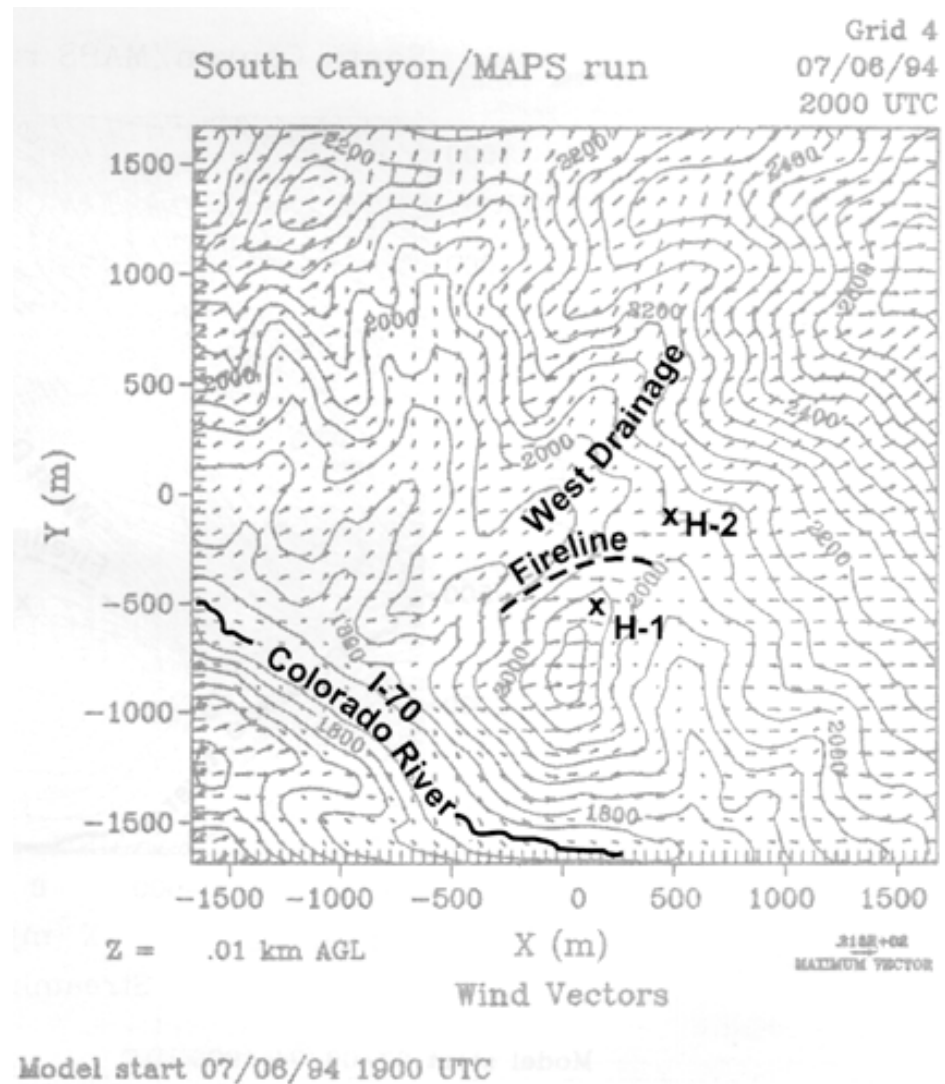


Figure C-1—Wind vectors from MAPS run. Heavy dashed line is approximate location of West Flank Fireline. X's are approximate locations of helispots.

While these results are preliminary and not feasible on a real-time basis, the high resolution simulation supports the 25 to 35 mile per hour winds blowing upcanyon in the West Drainage and the 45 to 50 mile per hour westerly winds blowing over H-1 and the Saddle. The predictions support the other evidence suggesting less wind in the area of the Double Draws and along the lower half of the West Flank Fireline. This is consistent with several witness statements (Scholz 1995; Hipke 1995). The streamlines shown in figure C-2 suggest that local areas of lower winds in the vicinity of the lower portion of the West Flank Fireline are possible and provide an excellent visualization of the channeling of air up the West Drainage (Bossert and others 1998).

The Los Alamos simulations support the mesoscale wind analysis by meteorologists on the Accident Investigation Team (USDA, USDI, and USDC 1994).

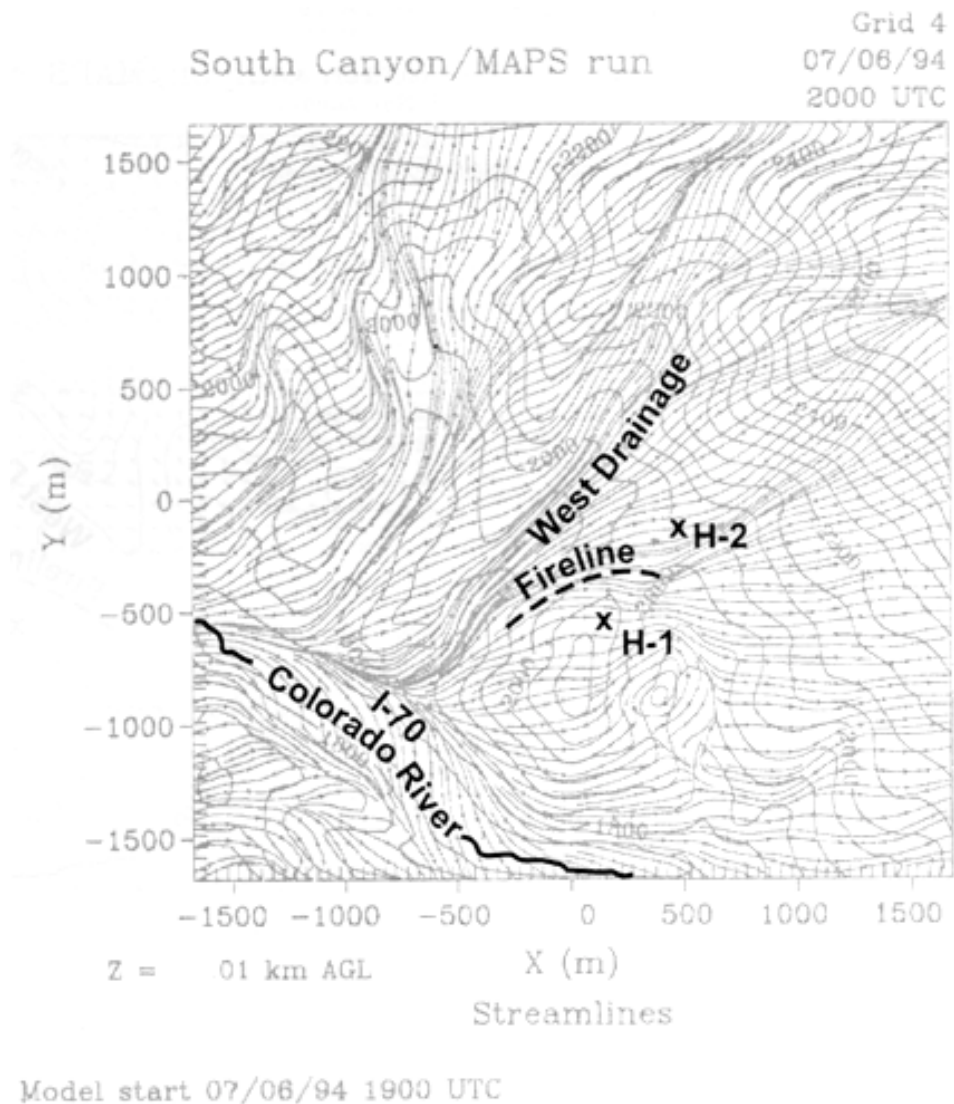


Figure C-2—Streamlines from MAPS run. Heavy dashed line is approximate location of West Flank Fireline. X's are approximate locations of helispots.

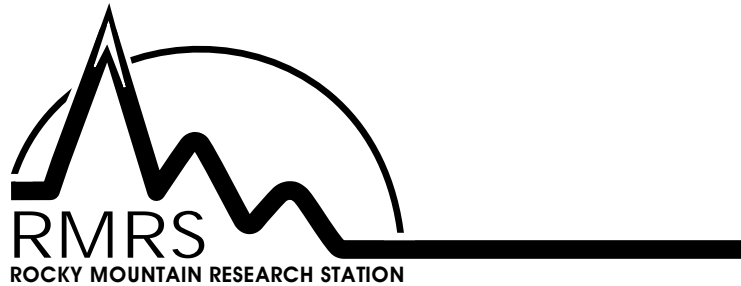
Butler, Bret W.; Bartlette, Roberta A.; Bradshaw, Larry S.; Cohen, Jack D.; Andrews, Patricia L.; Putnam, Ted; Mangan, Richard J. 1998. Fire behavior associated with the 1994 South Canyon Fire on Storm King Mountain, Colorado. Res. Pap. RMRS-RP-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 82 p.

In the aftermath of the deaths of 14 firefighters during the South Canyon Fire in July 1994, fire scientists assessed what occurred and suggested guidelines that may help firefighters avert such a tragedy in the future. This report describes the fuel, weather, and topographical factors that caused the transition from a relatively slow-spreading, low-intensity surface fire to a high-intensity, fast-spreading fire burning through the entire fuel complex, surface to crown. The analysis includes a detailed chronology of fire and firefighter movements, changes in the environmental factors affecting the fire behavior, and crew travel rates and fire spread rates. Eight discussion points apply directly to firefighter safety.

Keywords: wildland fire, rate of spread, fireline intensity, fire fighting, safety, accidents, fire size, firefighter travel rates.

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