USDA United States Department of Agriculture

Forest Service

Rocky Mountain Research Station

General Technical Report RMRS-GTR-114

September 2003

Hayman Fire Case Study

Russell T. Graham, Technical Editor

Abstract

Graham, Russell T., Technical Editor. 2003. **Hayman Fire Case Study**. Gen. Tech. Rep. RMRS-GTR-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 396 p.

In 2002 much of the Front Range of the Rocky Mountains in Colorado was rich in dry vegetation as a result of fire exclusion and the droughty conditions that prevailed in recent years. These dry and heavy fuel loadings were continuous along the South Platte River corridor located between Denver and Colorado Springs on the Front Range. These topographic and fuel conditions combined with a dry and windy weather system centered over eastern Washington to produce ideal burning conditions. The start of the Hayman Fire was timed and located perfectly to take advantage of these conditions resulting in a wildfire run in 1 day of over 60,000 acres and finally impacting over 138,000 acres. The Hayman Fire Case Study, involving more than 60 scientists and professionals from throughout the United States, examined how the fire behaved, the effects of fuel treatments on burn severity, the emissions produced, the ecological (for example, soil, vegetation, animals) effects, the home destruction, postfire rehabilitation activities, and the social and economic issues surrounding the Hayman Fire. The Hayman Fire Case Study revealed much about wildfires and their interactions with both the social and natural environments. As the largest fire in Colorado history it had a profound impact both locally and nationally. The findings of this study will inform both private and public decisions on the management of natural resources and how individuals, communities, and organizations can prepare for wildfire events.

Keywords**:** Wildfire, fuel treatments, wildfire behavior, social and economic wildfire effects, ecological effects of wildfires

Acknowledgments

The Hayman Fire Case Study involved the timely assembling, analyzing, and reporting on large volumes of data. A project of this size cannot be accomplished without the help and understanding of the families, friends, and coworkers of all of those involved. We, the Study Team, thank them all. We thank the many people who attended our public meetings and those who provided critical reviews of our Interim Report and the peers who reviewed our final reports. The devil is in the details of a study such as this, and the Publication Team is thanked by the other Team members for their excellent work in producing the publications.

Cover photo: Photograph taken from the headquarters of the Manitou Experimental Forest located on the eastern perimeter of the Hayman Fire, as the fire approached on June 18, 2002.

Hayman Fire Case Study

Case Study Leader
Russell T. Graham

Research Forester
USDA Forest Service, Rocky Mountain Research Station
Moscow, Idaho

Fire Behavior, Fuel Treatments, and Fire Suppression Team Leader
Mark A. Finney

Research Physical Forester
USDA Forest Service, Rocky Mountain Research Station
Missoula, Montana

Ecological Effects Team Leader
William H. Romme

Professor
Department of Forest, Rangeland, and Watershed Stewardship
Colorado State University
Fort Collins, Colorado

Home Destruction Team Leader
Jack Cohen

Research Physical Scientist
USDA Forest Service, Rocky Mountain Research Station
Missoula, Montana

Postfire Rehabilitation Team Leader
Pete Robichaud

Research Engineer
USDA Forest Service, Rocky Mountain Research Station
Moscow, Idaho

Social/Economic Team Leader
Brian Kent

Research Forester
USDA Forest Service, Rocky Mountain Research Station
Fort Collins, Colordao

Hayman Fire Case Study Team Members and Affiliations

Executive Committee

Marcia Patton-Mallory, Station Director, USDA Forest Service, Rocky Mountain Research Station (RMRS), Fort Collins, CO
Rick Cables, Regional Forester, USDA Forest Service, Rocky Mountain Region, Golden, CO
Jim Hubbard, Colorado State Forester, Colorado State Government, Fort Collins, CO

Case Study Leader

Russell Graham, Research Forester, USDA Forest Service, Rocky Mountain Research Station (RMRS), Moscow, ID

Fire Behavior, Fuel Treatments, and Fire Suppression Team

Mark A. Finney, Team Leader, RMRS, Fire Sciences Laboratory, Missoula, MT
Roberta Bartlette, RMRS, Fire Sciences Laboratory, Missoula, MT
Larry Bradshaw, RMRS, Fire Sciences Laboratory, Missoula, MT
Kelly Close, Poudre Fire Authority, Fort Collins, CO
Brandon M. Collins, Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO
Paul Gleason, Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO
Wei Min Hao, RMRS, Fire Sciences Laboratory, Missoula, MT
Paul Langowski, USDA Forest Service, Rocky Mountain Region, Lakewood, CO
Erik J. Martinson, Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO
John McGinely, NOAA Forecast Systems Laboratory, Boulder, CO
Charles W. McHugh, RMRS, Fire Sciences Laboratory, Missoula, MT
Phillip N. Omi, Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO
Wayne D. Shepperd, RMRS, Fort Collins, CO
Karl Zeller, RMRS, Fort Collins, CO

Ecological Effects Team

William H. Romme, Team Leader,Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO
Geneva Chong, U.S. Geological Survey and Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO
Jan E. Cipra, Department of Soil and Crop Sciences, Colorado State University, Fort Collins, CO
Catherine Crosier, Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO
Lynn M. Decker, USDA Forest Service, Washington Office
Laurie Huckaby, RMRS, Fort Collins, CO
Merrill R. Kaufmann, RMRS, Fort Collins, CO
Eugene F. Kelly, Department of Soil and Crop Sciences, Colorado State University, Fort Collins, CO
Jeffrey L. Kershner, USDA Forest Service, Washington Office, Logan, UT
Natasha B. Kotliar, U.S. Geological Survey, Fort Collins, CO
Zamir Libohova, Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO
Lee MacDonald, Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO
Greg Newman, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO
Rebecca Parmenter, USDA Forest Service, Rocky Mountain Region, Lakewood, CO
Eric Patterson, Rocky Mountain Ecological Services, Fort Collins, CO
Claudia M. Regan, USDA Forest Service, Rocky Mountain Region, Lakewood, CO
David A. Shadis, USDA Forest Service, Rocky Mountain Region, Lakewood, CO
Rosemary Sherriff, Department of Geography, University of Colorado, Fort Collins, CO
Sara Simonson, Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO
Tom Stohlgren, U.S. Geological Survey and Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO
Dave Theobold, Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO
Thomas T. Veblen, Department of Geography, University of Colorado, Boulder,CO
David Winters, USDA Forest Service, Rocky Mountain Region, Lakewood, CO

Home Destruction Team

Jack Cohen, Team Leader, RMRS, Fire Sciences Laboratory, Missoula, MT
Rick D. Stratton, Systems for Environmental Management, Missoula, MT

Postfire Rehabilitation Team

Peter Robichaud, Team Leader, RMRS, Forestry Sciences Laboratory, Moscow, ID
Louise Ashmun, RMRS, Forestry Sciences Laboratory, Moscow, ID
Jeff Freeouf, USDA Forest Service, Rocky Mountain Region
Lee MacDonald, Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO
Deborah Martin, U.S. Geological Survey, Boulder, CO
Dan Neary, RMRS, Southwest Forest Science Complex, Flagstaff, AZ

Social/Economic Team

Brian Kent, Team Leader, RMRS, Natural Resources Research Center, Fort Collins, CO
Greg Alward, USDA Forest Service, Inventory and Monitoring Institute, Fort Collins, CO
Holly Wise Bender, Integrated Resource Solutions, Boulder, CO
David Calkin, Dept. of Marketing, California State University, Long Beach, CA
Matt Carroll, Department of Natural Resources, Washington State University, Pullman, WA
Patricia J. Cohn, Department of Natural Resources, Washington State University, Pullman, WA
Carol Ekarius, Coalition for the Upper South Platte, Hartsell, CO
Krista Gebert, RMRS, Forestry Sciences Laboratory, Missoula, MT
Yoshitaka Kumagai, Department of Natural Resources, Washington State University, Pullman, WA
Wade Martin, Department of Economics, California State University, Long Beach, CA
Ingrid Martin, Dept. of Marketing, California State University, Long Beach, CA
Sarah McCaffrey, USDA Forest Service, North Central Station, Evanston, IL
Ervin Schuster, RMRS, Forestry Sciences Laboratory, Missoula, MT
Dan Williams, RMRS, Natural Resources Research Center, Fort Collins, CO

Spatial Team

Jim Menakis, Team Leader, RMRS, Fire Sciences Laboratory, Missoula, MT

Communications Team

David Tippets, Team Leader, RMRS, Ogden, UT
Doug Young, Congressman Mark Udall's staff, Westminster, CO
Bill Rice, USDA Forest Service, Rocky Mountain Region, Lakewood, CO
John Bustos, Front Range Fuels Partnership, Fort Collins, CO
Katharine Timm, Colorado State Forest Service, Lakewood, CO
Barbara Timock, Pike-San Isabel National Forest, Pueblo, CO
Pam Gardner, USDA Forest Service, Rocky Mountain Region, Lakewood, CO

Publications Team

Louise Kingsbury, Team Leader, RMRS, Team is stationed in Ogden, UT
Nancy Chadwick
Suzy Stephens

Contents

Hayman Fire Case Study: Summary

Introduction

Historically, wildfires burned Western forests creating and maintaining a variety of forest compositions and structures (Agee 1993). Prior to European settlement lightning along with Native Americans ignited fires routinely across many forested landscapes. After Euro-American settlement, fires continued to be quite common with fires ignited by settlers, railroads, and lightning (Pyne 2001). In August 1910 came a pivotal change in how Westerners in particular, and policymakers in general, viewed fire. Starting early in that summer, fires were ignited and continued to burn throughout western Montana and northern Idaho. By mid August over 1,700 fires were burning throughout the region, but most forest managers figured the area could weather these fires if no dry strong winds developed. On August 20 and 21, the dry winds did blow, and by the time the flames subsided over 3.1 million acres of the northern Rocky Mountains burned (fig. 1). These fires killed 78 firefighters and seven civilians and burned several communities including one-third of Wallace, Idaho (fig. 2) (Pyne 2001; USDA 1978). This event solidified the negative aspects of wildfires in the view of the public and policymakers and led to the strong

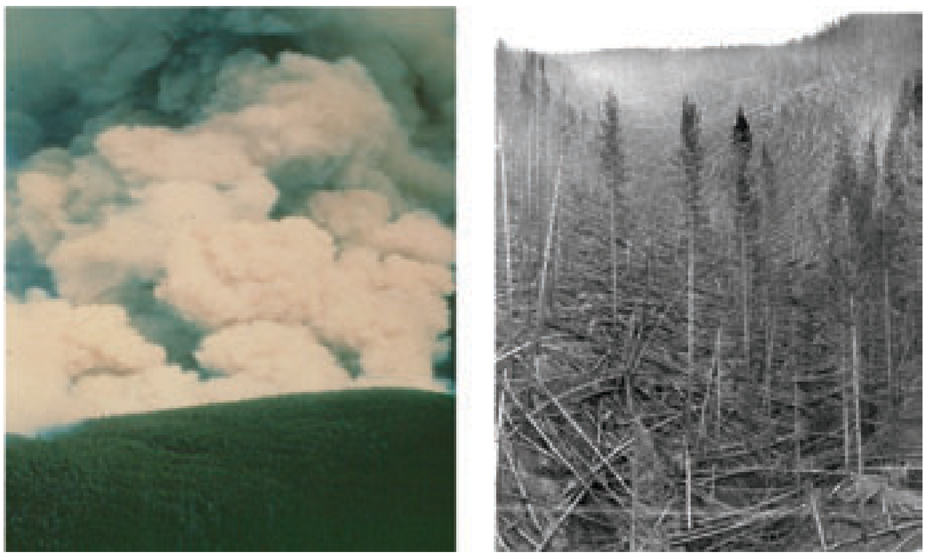

Figure 1—The wildfires of the Northern Rocky Mountains in 1910 burned over 3.1 million acres, destroying valuable timber resources.

Figure 2—Over one-third of Wallace, ID, burned during the wildfires of 1910.

Figure 3—Early fire prevention posters showing the urgency of suppressing wildfires.

firefighting ethic that prevails yet today (fig. 3) (Pyne 2001).

Wildfires continue to be aggressively extinguished with smoke-jumpers, hot-shot crews, retardant bombers, and sophisticated firefighting organizations. Even with this aggressive approach, wildfires continue to burn throughout the West, and the total area burned in the United States decreased until the 1960s when the trend reversed with the number of acres burned each year increasing (Agee 1993). This trend was exemplified by the fires that burned in and around Yellowstone Park in 1988 and once again brought under scrutiny the wildfire policies in the United States (fig. 4) (Carey and Carey 1989). What appears to be different about the recent fires is the number of ignitions that contributed to burning large areas. More than 1,700 fire starts were responsible for burning the 3.1 million acres of the Northern Rocky Mountains in 1910, and 78 starts burned more than 350,000 acres in the Bitterroot Valley in western Montana in July 2000 (fig. 5) (USDA 1978, 2000). Contrast these fire events to the Rodeo-Chediski Fire where only two fire starts burned

Figure 4—Photograph showing one of the many wildfires that burned in Yellowstone Park during the summer of 1988.

Figure 5—Seventy-eight wildfires burned in the Bitterroot Valley of western Montana during the summer of 2000. (Photo by Karen Brokus)

more than 450,000 acres in 2002 in Arizona. Similarly, on June 8, 2002, one start along the Colorado Front Range of the Rocky Mountains led to the Hayman Fire burning more than 138,000 acres in 20 days (fig. 6).

The weather systems along the Colorado Front Range beginning in 1998 tended to bring below-normal precipitation and unseasonably dry air masses. These conditions occurred approximately the same time as the phenomenon known as La Nina began forming in the eastern Pacific Ocean. The winter of 2001 and 2002 saw a marked worsening of drought conditions. The predominantly ponderosa pine and Douglas-fir forests throughout the region became drier with each passing season, and by the spring

Figure 6—The Hayman Fire was ignited on afternoon of June 8, 2002, and by the morning of June 9 it was uncontrollable.

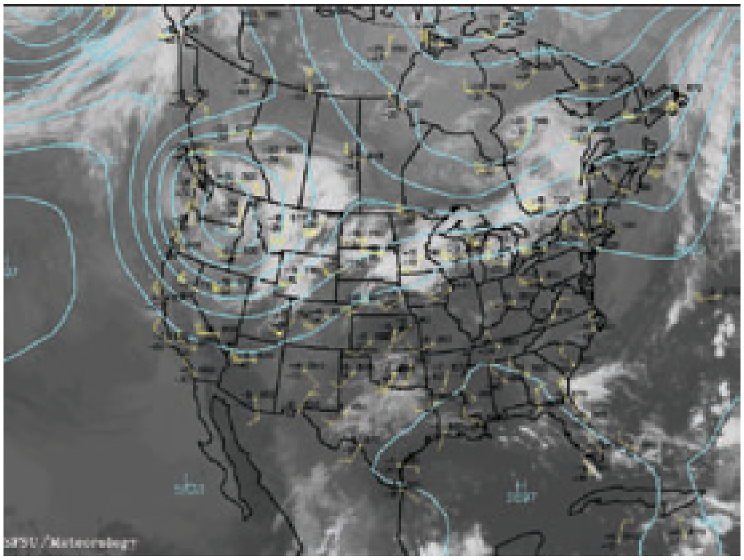

Figure 7—On June 8, 2002, the winds in Colorado, created by a low pressure system centered in eastern Washington, were consistently exceeding 15 mph and gusting to over 30 mph.

of 2002 the fuel moisture conditions were among the driest seen in at least the past 30 years. The moisture contents of the large dead logs and stems along the Front Range were extremely low: most less than 10 percent and some less than 5 percent moisture content.

During the first week of June 2002 a weak weather system passed through forests west of Denver and Colorado Springs, Colorado, dropping some precipitation, but this rain had virtually no effect on the parched surface and dormant live fuels. On Saturday, June 8 the air mass over Colorado was extremely dry and an upper level low pressure system centered over eastern Washington brought winds exceeding 15 mph all day with gusts exceeding 30 mph (fig. 7). The counter clockwise winds circulating around this low aligned perfectly with the topography of the South Platte River corridor (fig. 8). At approximately 4:55 p.m. just south of Tarryall Creek and Highway 77 near Tappan Mountain, the Hayman Fire was reported (fig. 9). An aggressive initial attack response consisted of air tankers, helicopters, engines, and ground crews, but they were unable to contain the fire (fig. 10). Within a few hours torching trees and prolific spotting advanced the fire to the northeast, allowing it to burn several hundred acres.

Saturday night remained warm and dry (60 °F and 22 percent humidity at Lake George near fire start) and by 8:00 a.m. on June 9, the fire was estimated

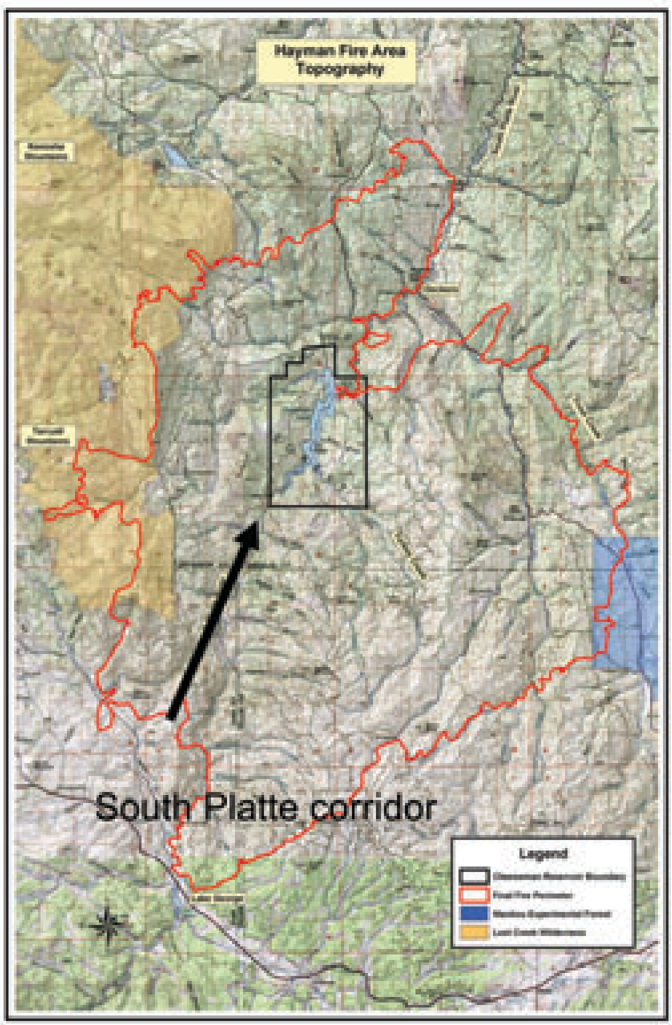

Figure 8—The southwest to northeast orientation of the South Platte River corridor aligned perfectly with the winds blowing from the southwest.

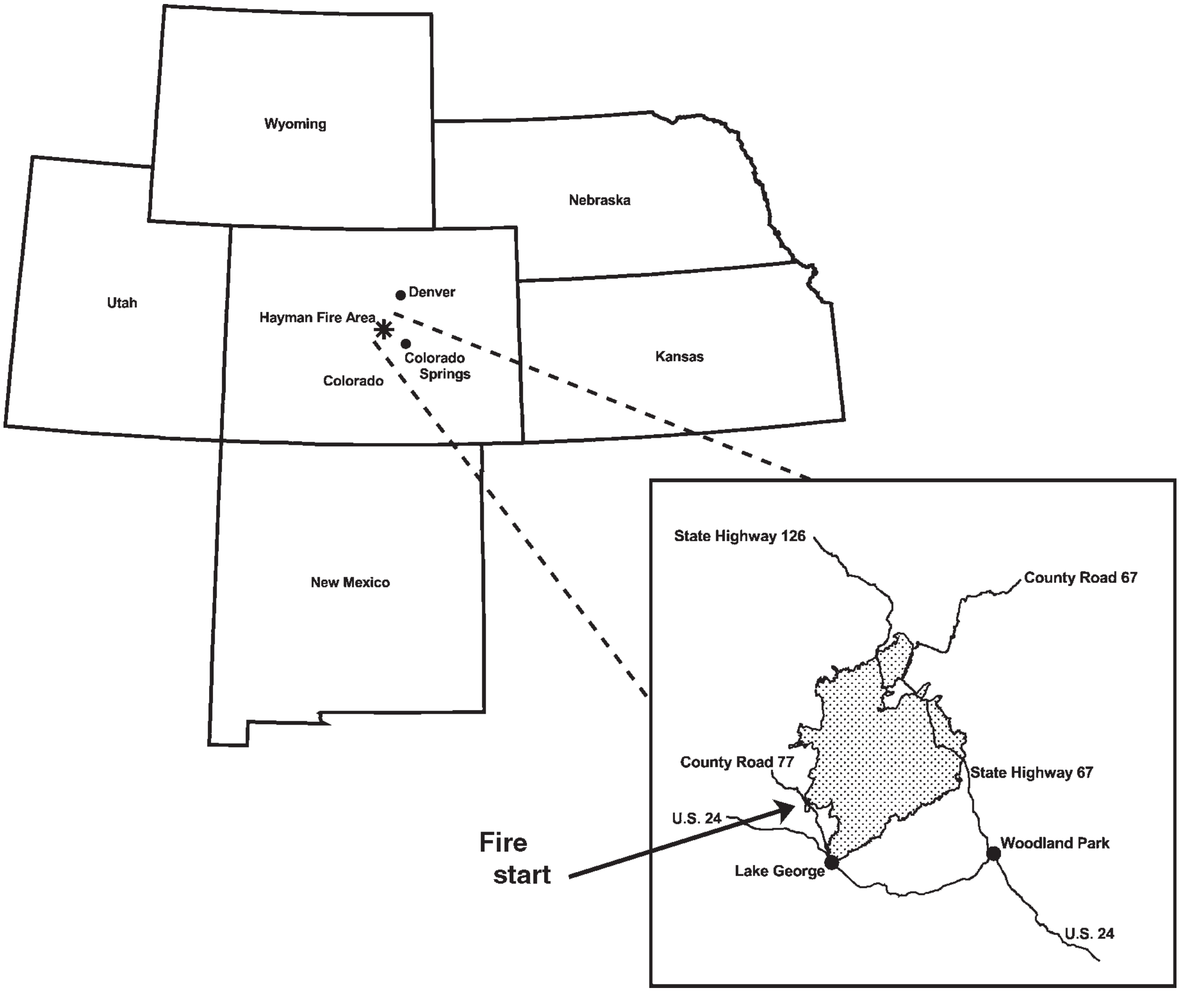

Figure 9—The Hayman Fire started just south of Tarryall Creek and County Highway 77 near Tappan Mountain on the Front Range of the Rocky Mountains between Denver and Colorado Springs, CO.

Figure 10—An aggressive initial attack of the fire consisting of ground crews, fire engines, helicopters, and air tankers could not control the fire. (Photo by Karen Wattenmaker)

at 1,000 to 1,200 acres in size. Downwind from the ignition location for at least 10 miles fuels were generally continuous with little variation in both structure and composition. Surface fuels generally consisted of ponderosa pine duff and needle litter, short grasses, and occasional shrub patches. Low crowns of the ponderosa pine, Douglas-fir, and blue spruce facilitated the transition of the fire from the surface to burning tree crowns (fig. 11).

As the day progressed, the southwest winds gusted to 51 mph and the relative humidity hovered around 5 to 8 percent (fig. 12) enhancing the

Figure 11—The fuels down wind from the ignition point were continuous, consisting of trees with low crowns, shrubs, and a deep layer of needles on the forest floor.

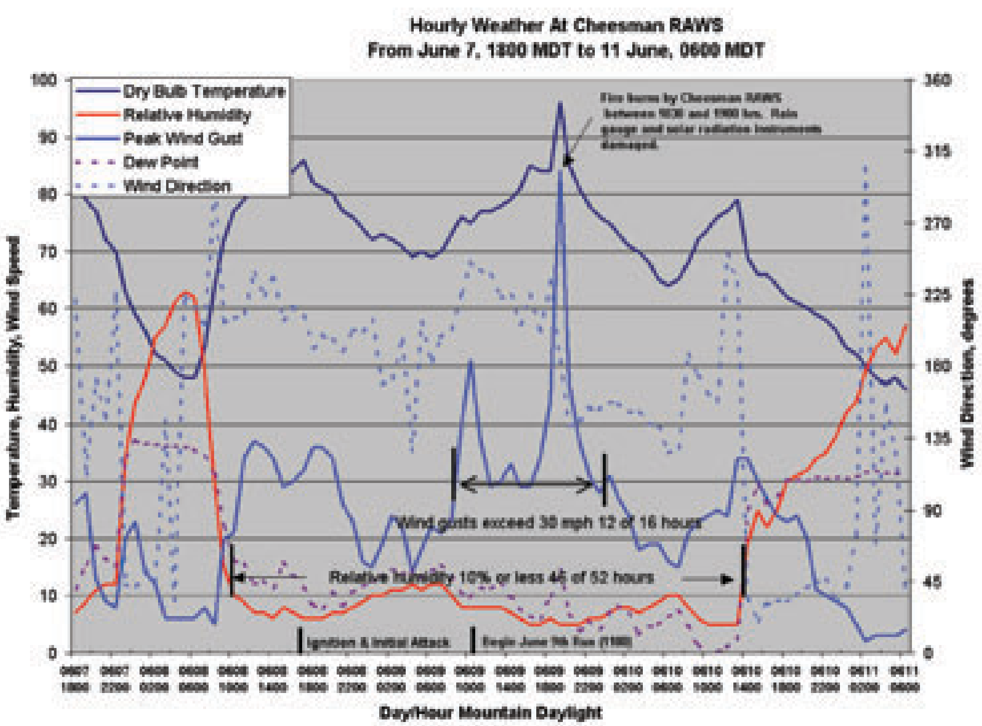

Figure 12—During the first days of the fire the winds were gusty, and the relative humidity of the air was dry, hovering below 10 percent.

Figure 13—Photographs on June 9 showing pyrocumulus clouds developing to 21,000 feet over the fire.

spread of the fire to the northeast. The combination of fuels, weather, and topography positioned the fire for a major run lasting the entire day and burning 60,000 acres along the South Platte River corridor for 16 to 19 miles. Evacuations were performed in front of the fire, but no suppression actions were possible forward (east) of Highway 24 (fig. 9). The fire burned with extreme intensity with long crown fire runs and long-range spotting (1 mile or more). Fire spread rates averaged more than 2 mph and pryocumulus clouds developed to an estimated 21,000 feet (fig. 13).

Figure 14—From June 11 through the afternoon of June 17 the weather moderated as did the fire intensity.

On the afternoon of June 10, the high winds decreased and the relative humidity increased, moderating the weather (fig. 12) and persisting until the afternoon of June 17. During this period, the fire advanced mostly to the south and several miles to the east (fig. 14). The high winds and low humidity returned on June 17 and 18, increasing the fire intensity across the entire east flank of the fire, driven by west to northwest winds

Figure 15—On June 17 and 18 gusty winds and low humidity returned, facilitating intense fire behavior as the fire advanced to the east.

(fig. 15). The fire advanced to the east 4 to 6 miles on June 18, crossing Highway 67 and encircling more than 137,000 acres. Because moist monsoon weather arrived, the fire burned small amounts of additional acres after June 18. By June 28, the Hayman Fire impacted more than 138,000 acres of the Colorado Front Range (fig. 16).

The mountains and forests of the Front Range between Denver and Colorado Springs are critical for supplying water to communities and cities, prized for their scenery, provide numerous recreational opportunities, are home to many fishes and animals, and are the setting for many homes, businesses, and communities. Because of the setting, the Hayman Fire attracted intense local, regional, and national interest. Before the flames had died, Congressman Mark Udall of Colorado on June 26, 2002,

Date	Acres
June 8	290
June 9	60,878
June 10	86,725
June 11	99,689
June 12	104,638
June 13	102,897
June 14	100,186
June 15	104,415
June 16	114,674
June 17	140856
June 18	137,762
...	
June 28	138,114

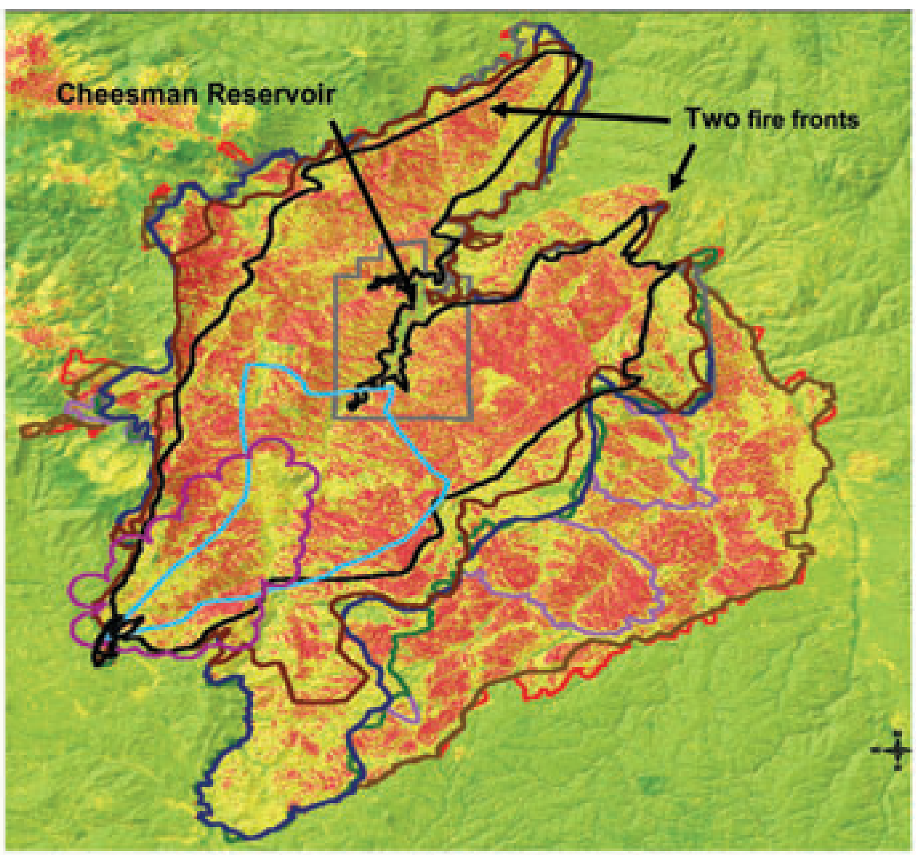

Figure 16—By June 28 the Hayman Fire had impacted over 138,000 acres of the Front Range.

indicated that it would "be instructive to take a close look at the behavior of the fire, examine the factors that led to its intensity, and see if the way it behaved when it encountered previously affected or treated areas can be instructive in designing future risk-reduction projects." He went on to suggest that the Chief of the Forest Service establish a Hayman Fire Review Panel. Its purpose would be to focus on the future rather than attempt to assign blame for past events.

Congressman Udall raised several issues ranging in scope from how the fire behaved to how the fire impacted the soil and water resources of the Front Range. Using Congressman Udall's suggestion as a basis, on July 22, 2002, the USDA Forest Service Rocky Mountain Research Station in cooperation with USDA Forest Service Rocky Mountain Region, and the State of Colorado Forest Service assembled the Hayman Fire Case Study Team. This Team of Federal, State, and local experts from throughout the United States came together and developed an analysis to address the Congressman's issues. Analysis questions were divided among subteams addressing fire behavior, home destruction, social and economic impacts, fire rehabilitation, and ecological effects. Using the Congressman's issues each team developed a set of analysis questions and study direction. Techniques used by the subteams included interviews, analysis of existing data, expert opinion, Hayman Fire reports, and other available information. In November 2002 the Team presented its interim findings to the Congressman, public, forest managers, nongovernmental organizations, and the scientific community. These groups and individuals provided critical input to the findings, and in February 2003 the subteams began assembling their final reports incorporating these reviews and criticisms. The reports underwent scientific peer review before the final drafts were prepared. The following highlights each subteam's findings addressing the analysis questions.

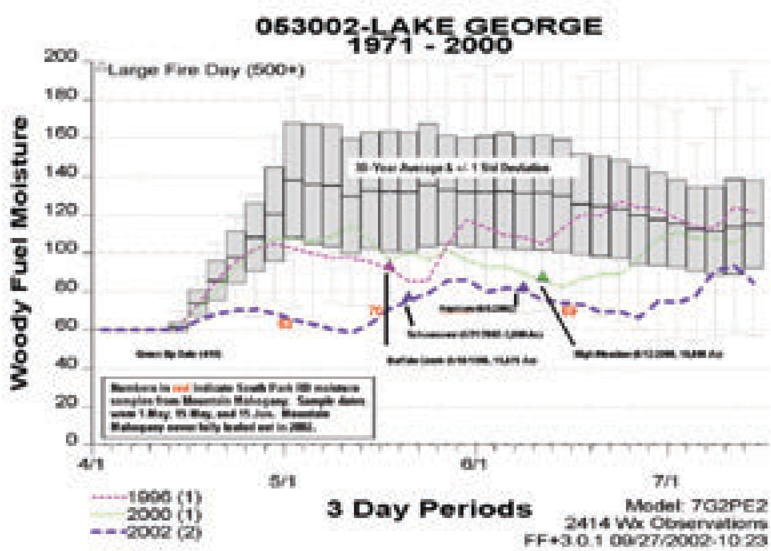

Figure 17—The moisture contents of the woody fuels within the Hayman Fire area in 2002 were much drier than those occurring over the previous 30 years.

Fire Behavior

Team Leader Mark Finney, USDA Forest Service, Rocky Mountain Research Station, Missoula, Montana

This team used existing and new data on fire climatology and meteorology, fire behavior, fuel treatments, road density, fire suppression activities, and fire emissions. Selected findings of the team:

- The potential for extreme fire behavior was predisposed by drought. Below normal precipitation the past several years and the acute drought in 2002 brought about excedptionally low moisture contents of live foliage, duff, and dead fuels of all size classes (fig. 17).

- The Hayman Fire began and ended with extreme weather episodes lasting about 2 days each (June 8 and 9, and June 17 and 18). More moderate weather occurred during the intervening 6 days. Extreme weather conditions consisted of high winds (20 to 50 mph) and low humidity (5 percent). Widespread crown fire and long-range spotting lead to rapid growth and ultimately the large size of the fire. Abatement of winds and higher humidity during less extreme weather moderated fire behavior and effects, even with the abnormally low fuel moisture contents (fig. 12).
- Different wind directions associated with the two extreme weather episodes increased the size of the fire. The east flank of the fire that developed under southwest winds of June 8 and 9 became a heading fire on June 17 and 18 when winds shifted from the northwest and west (fig. 15).
- Continuous surface and crown fuel structure, both horizontally and vertically, in many ponderosa pine and Douglas-fir stands rendered them susceptible to torching, crown fire, and ignition by embers, even under moderate weather conditions (fig. 11).
- Continuous fuels across the landscape surrounding the South Platte River drainage afforded only limited opportunity for significant disruption of growth of the fire or for improved suppression. The few large areas on the Hayman landscape that recently experienced wildfires or management activities (Schoonover wildfire 2002, Polhemus prescribed burn 2001, Big Turkey wildfire 1998) produced significant but isolated effects on fire growth.
- Orientation of the South Platte River drainage was aligned with the strong southwest winds on June 8 and 9 and likely enhanced the direction and rapid spread of the fire on those dates (fig. 8).
- The presence of Cheesman Reservoir and the adjacency of the recent Schoonover wildfire (May 2002) in the center of the spread path created and maintained the characteristic forked shape of the Hayman Fire, which had formed two distinct heads by the afternoon of June 9 (fig. 16).
- The Hayman Fire encountered most of the fuel treatments, prescribed burns, and previous wildfires within the perimeter on June 9 when the weather was extreme. Continuous crown fire and long-range spotting dominated the burning of approximately 60,000 acres that day from late morning through late evening. These extreme conditions and fire behaviors permitted intense surface fire through treated areas, leaving them with high levels of overstory crown damage. Fuel breaks and treatments were breached by massive spotting and intense surface fires.
- The fire was perhaps 20,000 acres when it encountered its first fuel treatments toward the southeastern side of Cheesman Reservoir toward mid-afternoon on June 9. At that time it was in the middle of the burning period and had developed a large convection column (fig. 13).
- Weather conditions were relatively moderate beginning on June 10 through 16 as the fire burned through Turkey Rx1990, Rx1995, Rx1987, and the 1998 Big Turkey wildfire. Fire behavior these days was predominated by surface fire, although torching and some crown fire occurred in some drainages and hillslopes (fig. 14).

- Extreme weather returned on June 17 and 18. Crown fire and long-range spotting was occurring just before the fire burned into fuel treatments in the Manitou Experimental Forest and the North Divide prescribed burns (fig. 15). Observations and weather records suggest a wind shift occurred just before fire entered Manitou.
- Extreme environmental conditions (winds, weather, and fuel moisture) and the large size of the Hayman Fire that developed on June 9 overwhelmed most fuel treatment effects in areas burned by the heading fire that day. This included almost all treatment methods including prescribed burning and thinning.
- Several exceptions to this included the Polhemus prescribed burn (2001), the Schoonover wildfire (2002), and the Platte Springs wildfire (2002) that occurred less than 1 year earlier. These areas did actually appear to stop the fire locally, illustrating that removal of surface fuels alone (irrespective of thinning or changes to canopy fuels) can dramatically alter fire behavior within 1 year of treatment. The potential for prescribed fire to mitigate wildfire behavior will undoubtedly decrease over time. Thus, the recent occurrence of fuel modification in these areas suggests caution in trying to generalize about fuel treatment performance over many years. Fuel treatments are expected to change fire behavior but not necessarily stop fires (fig. 18).

Figure 18—The Polhemus prescribed fire (fall 2001) altered the behavior of the Hayman Fire. Note the boundary between the Polhemus prescribed burn unit and the Hayman Fire (moving from the foreground away from the camera). (Photo by Karen Wattenmaker)

- Fire behavior was modified but not stopped by stand thinning operations conducted at Manitou Experimental Forest. The operations apparently moderated fire behavior and effects during extreme weather on June 18 (fig. 19). A fortuitous shift in winds also contributed to the changes in fire behavior at Manitou. The fire burned rapidly through areas of the Wildcat wildfire (1963) and the Northrup prescribed burn (1992) south of Cheesman Reservoir, but the open forest structure of these areas probably increased the survival of trees and stands within them.
- Under more moderate wind and humidity conditions (June 10 through 16), recent prescribed burns appeared to have lower fire severity than

Figure 19—A low intensity surface fire minimally scorched even the smallest trees in a ponderosa pine stand that had been thinned.

older burns. This is consistent with trends in fuel accretion and changes in forest fuels over time. Examples include the sequence of Turkey (Rx1987, Rx1990, Rx1995) prescribed burns.

- Cutting treatments where activity fuels were not removed experienced high surface fire intensities but were less likely to support crown fire. For example, residual trees in the Sheepnose timber sale (2001) were scorched and probably killed, but their foliage was generally not consumed by crown fire. When these needles fall they mulch the forest floor reducing soil erosion (fig. 20). However, the Goose Creek timber sale was followed by prescribed fire but made little difference to severity on June 19 (fig. 21).
- Several landscape effects of treatment units and previous wildfires were important in changing the progress of the fire. These include the Polhemus prescribed burn (2001), which stopped the forward progress of the eastern head burning as a crown fire under extreme weather conditions (fig. 20), the Big Turkey wildfire (1998) and adjacent prescribed fires (Rx1990, Rx1995), which prevented initiation of crown fire along a 2 mile segment of the perimeter when extreme weather returned on June 17 (fig. 22), and the Schoonover Wildfire (May 2002),

Figure 20—The Sheepnose timber sale where the surface fuels consisting of logging slash were not removed prior to the Hayman Fire. The area burned as an intense surface fire on June 9 rather than a crown fire because of the stand structure created by the treatment.

Figure 21—The Goose Creek timber sale area in the foreground (1986 through 1993) in which the logging slash was piled and burned in 1993 through 1995. Even with these fuel treatments, adequate surface fuel was available for a high intensity surface fire to occur on June 9, 2002.

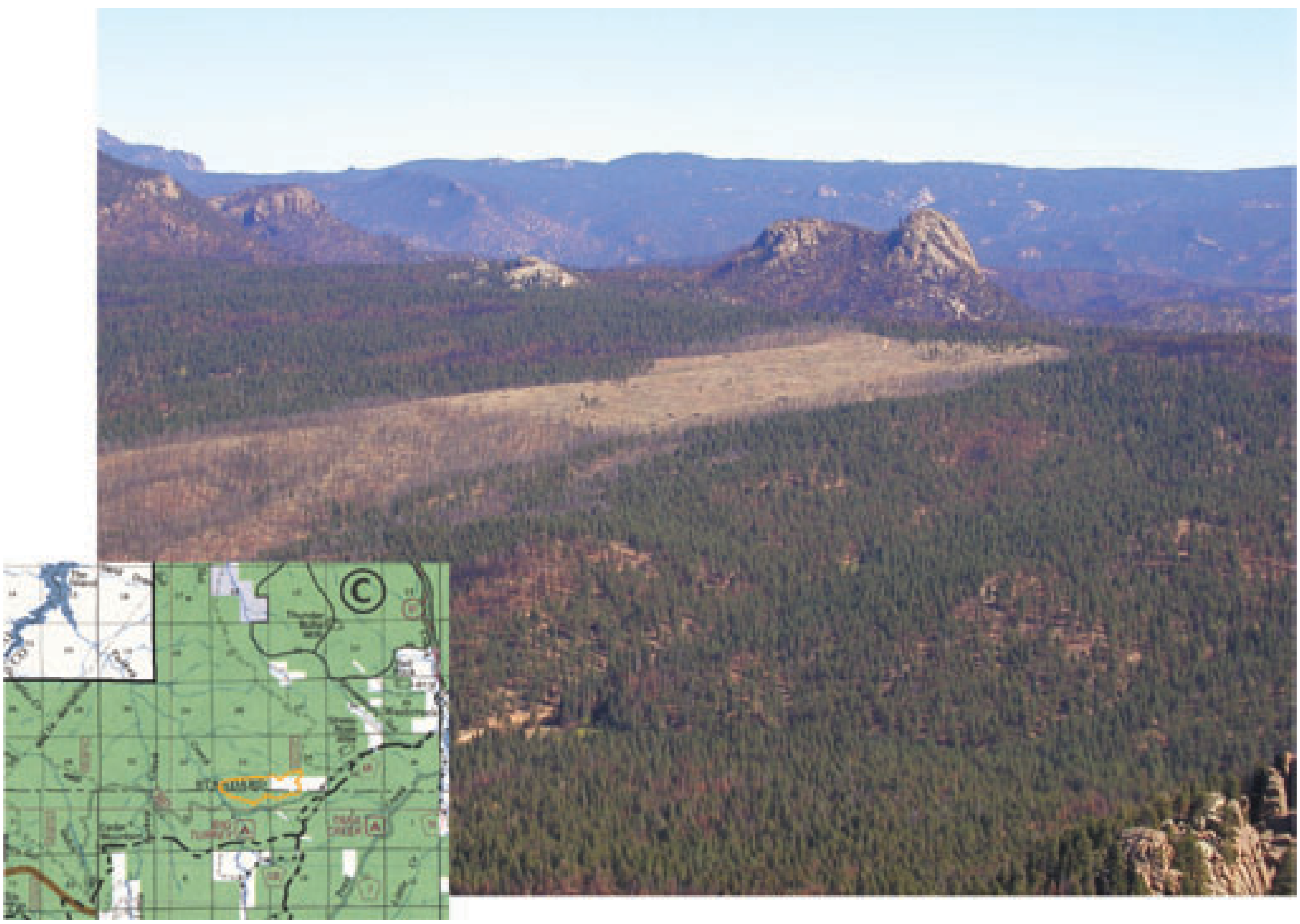

Figure 22—Oblique view of area burned by the Big Turkey wildfire (1998, oriented approximately along an east-west axis) looking northeast. Area in the foreground was inside the prescribed fire unit Turkey 1990. This area was burned between June 10 and 13. (Photo by Rick Stratton)

which, together with Cheesman Reservoir, split the head of the Hayman Fire on June 9 (fig. 23) and prevented it from flanking toward the town of Deckers (fig. 24, 25).

- The size of the fuel treatment unit relative to the size of the wildfire was probably important to the impact on both progress and severity within the treatment unit. Large areas such as the Polhemus prescribed burn (approximately 8,000 acres) were more effective than small fuel breaks (Cheesman Ridge, 51 acres) in changing the fire progress. Under extreme conditions of June 9, spotting easily breached narrow treatments, and the rapid movement of the fire circumvented small units (fig. 26).
- No fuel treatments were encountered when the fire was small. The fire had time and space to develop a broad front and generate a large convection column before encountering most treatment units. Fuel treatments may have been more effective in changing fire behavior if they were encountered earlier in the progression of the Hayman Fire before mass ignition was possible.

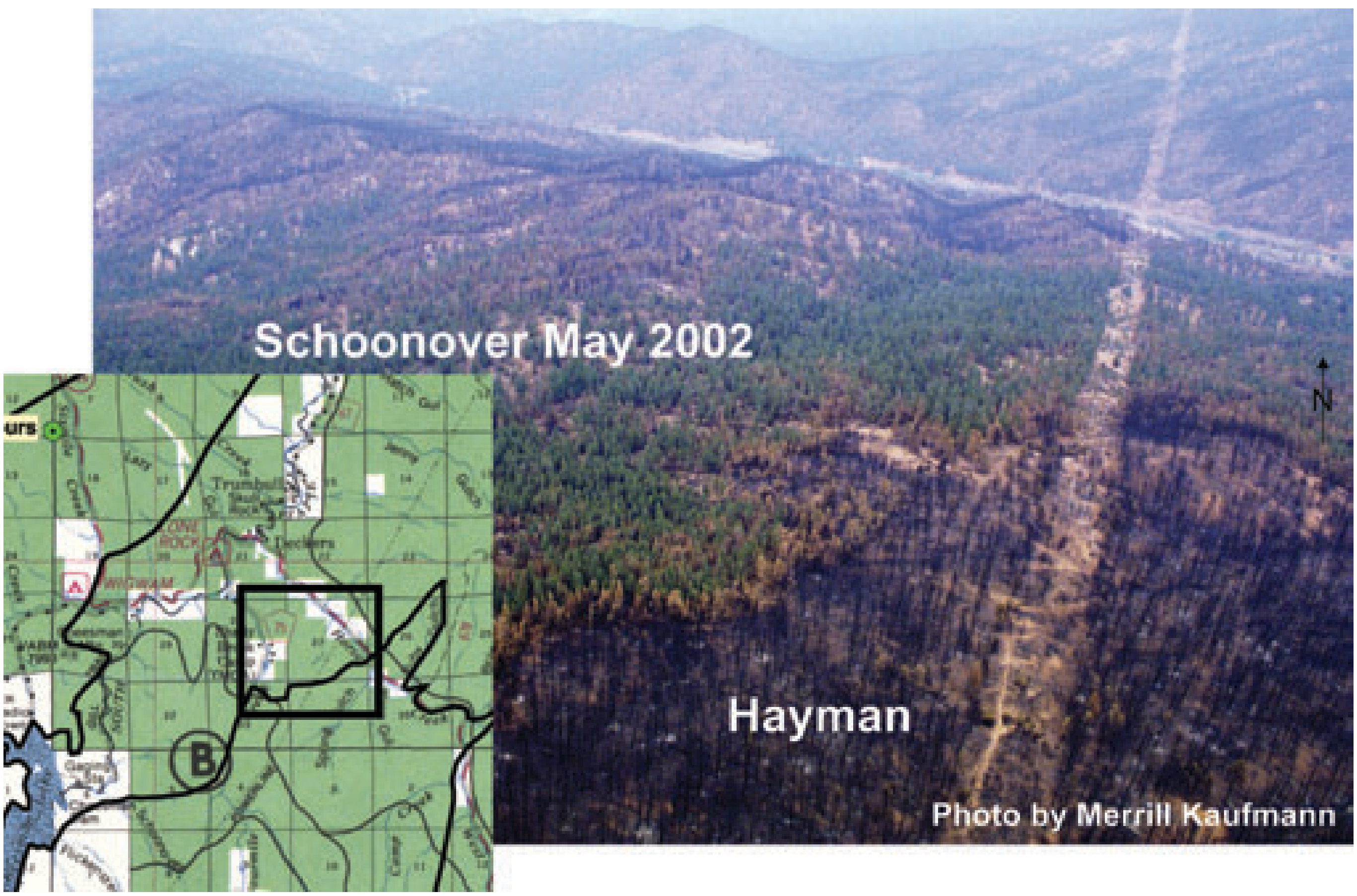

Figure 23—Green strip of underburned forest divides the Hayman Fire (left) and Schoonover wildfire (May 2002, right). The green strip was underburned by the Schoonover Fire 3 weeks before the Hayman Fire occurred and was not reburned by the Hayman Fire. Note the power line corridor in the picture and the inset map. (Photo by Merrill Kaufmann)

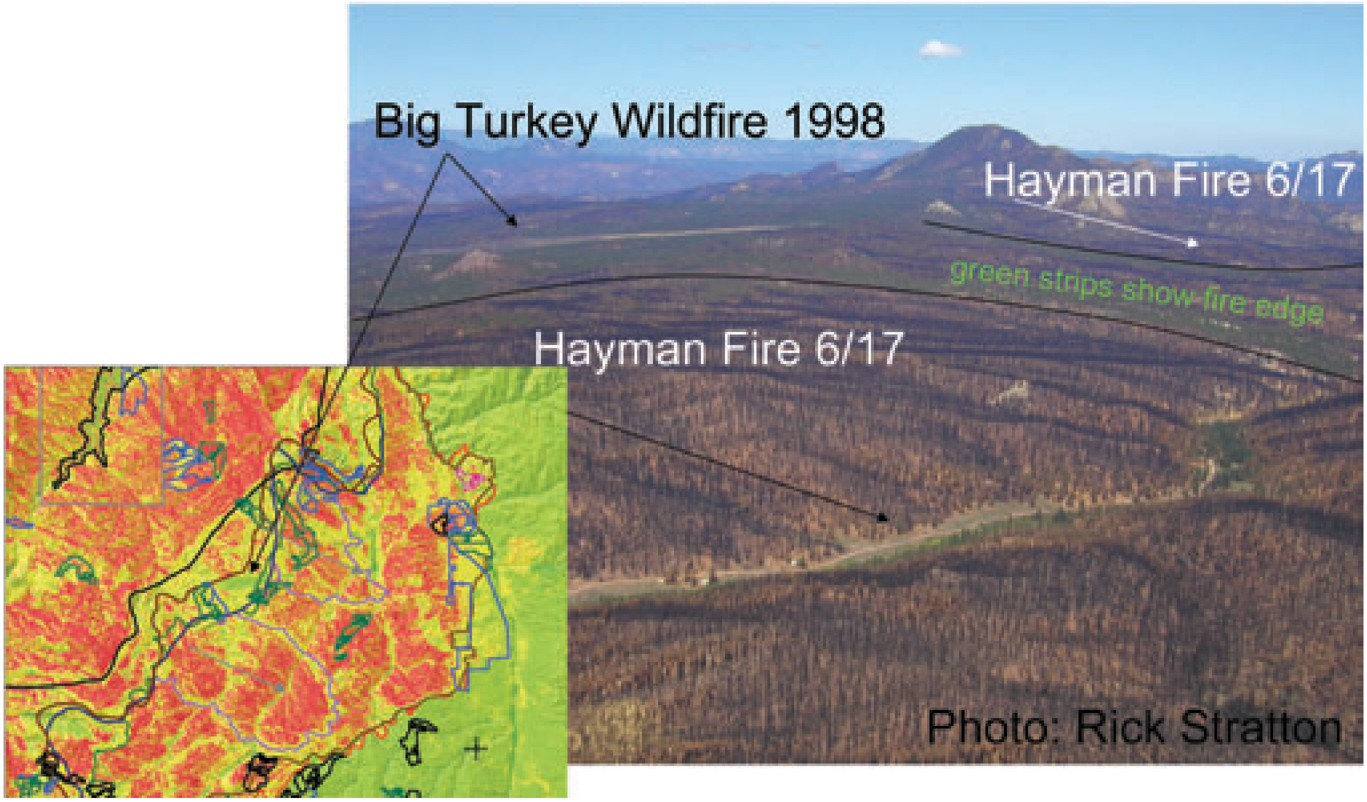

Figure 24—Oblique photograph showing the green bands of conifer forest at the locations where the two heads of the fire stopped after the burning period on June 17. Note that these heads originated from the north and south of the Big Turkey wildfire and adjacent prescribed burns (Rx1990, Rx1995). (Photo by Rick Stratton)

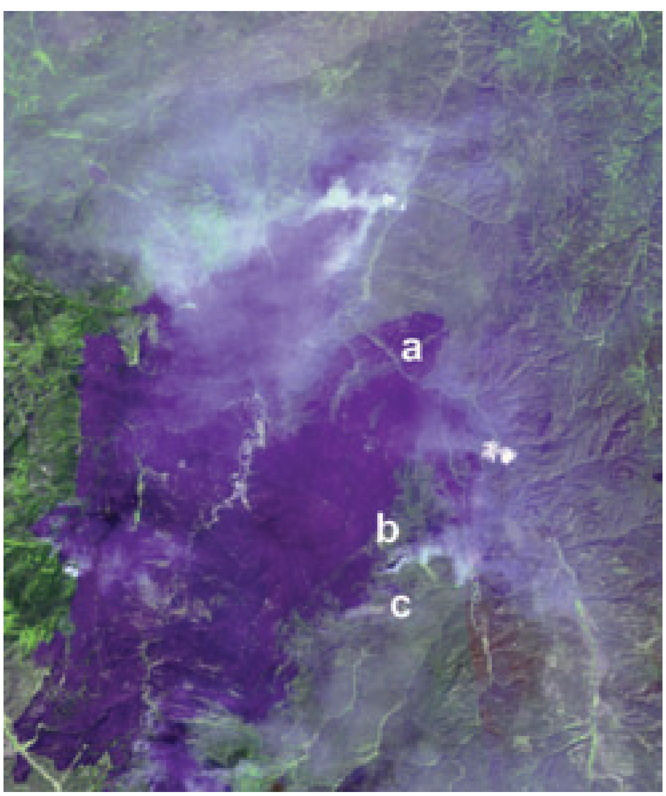

Figure 25—Satellite imagery showing burned area within the Hayman Fire on June 13. Several points are visible, (a) green strip separating the Schoonover wildfire on the north (May 2002) from the Hayman Fire on the south, (b) the green diagonal strip indicating the edge of the fire at the end of the June 9 burning period, and (c) the Big Turkey wildfire (1998).

Figure 26—Strong winds on June 8 and 9 flattened the smoke column, obscuring fire position and making fire progression estimation difficult. Photo is from June 9.

- Few fuel treatments had been performed recently, leaving most of the landscape within the final fire perimeter with no treatment or only older treatments. This is significant because the high degree of continuity in age and patch structure of fuels and vegetation facilitates fire growth that, in turn, limits the effectiveness of isolated treatment units.
- Road density varied considerably within the perimeter of the Hayman Fire but was not found to be associated with fire severity or bio-physical conditions related to fire behavior.
- At the time of initial attack, even the unusually strong compliment of firefighting resources (air and ground) was not sufficient to contain or stop the fire due to extreme weather conditions and fuel structures that facilitated crown fire and spotting (fig. 10).
- On the days of extreme fire growth (June 8 and 9, and June 17 and 18), burning conditions and weather dictated an indirect attack strategy with efforts focused on evacuation, structure protection where safely allowable, and direct methods on the heel and flanks of the fire.
- In the Lost Creek Wilderness little active suppression took place. Efforts were primarily directed at aerial observation, patrolling, and location and evacuation of hikers.
- Suppression efforts had little benefit from fuel modifications within the Hayman Fire. Exceptions include the Polhemus prescribed fire (2001), two previous wildfires (Schoonover 2002 and Big Turkey 1998), and thinning operations at Manitou Experimental Forest. One of the only sections of fireline indicated as controlled through June 16 (fig. 18) was in the Polhemus burn.
- On active burning days direct line was often not held and crews retreated to safety zones until fire conditions moderated, then returned to mop up around structures or defend structures where safely obtainable (fig. 27).
- On days with moderate weather and fire growth, the lines were defendable and structure protection was successful. For example, on June 12 structures in the Sportsman Paradise as well as in the Cedar Mountain, Turkey Creek, and along Turkey Creek were defendable even when fire behavior picked up in the afternoon hours.

Figure 27—A fire crew protecting a structure when the weather conditions allowed. (Photo by Karen Wattenmaker)

- Indirect tactics were used when fire behavior dictated for safety reasons and when access and rough steep terrain came into play. At times, burnout operations did not take place due to unfavorable weather conditions, were not completed due to changing weather conditions, or interrupted during operational periods because work-rest ratio guidelines would have been exceeded.
- Nightshifts were used, but only on focused areas, usually around subdivisions. Night operations primarily focused on patrolling of subdivisions where burnout operations had taken place during the day, structure protection in areas that had recently experienced fire activity, patrolling of divisions, and improving and extending anchor points (fig. 28).
- After overall weather moderated with arrival of monsoon conditions after June 20, construction of and holding of direct firelines was successful (fig. 29).
- The Hayman Fire was a significant source of atmospheric carbon monoxide (CO) and fine particulates (less than 2.5 µm). For Colorado, the CO emitted by the Hayman Fire was at least five times the annual (1999) amount produced by industry, and the fine particulate emitted by the Hayman Fire was about twice that produced annually by Colorado industries (fig. 30).

Figure 28—Night-time operations burning fuels within the fire line that were not consumed. (Photo by Karen Wattenmaker)

Figure 29—When the weather moderated, direct fireline construction was possible and firelines held. (Photo by Karen Wattenmaker)

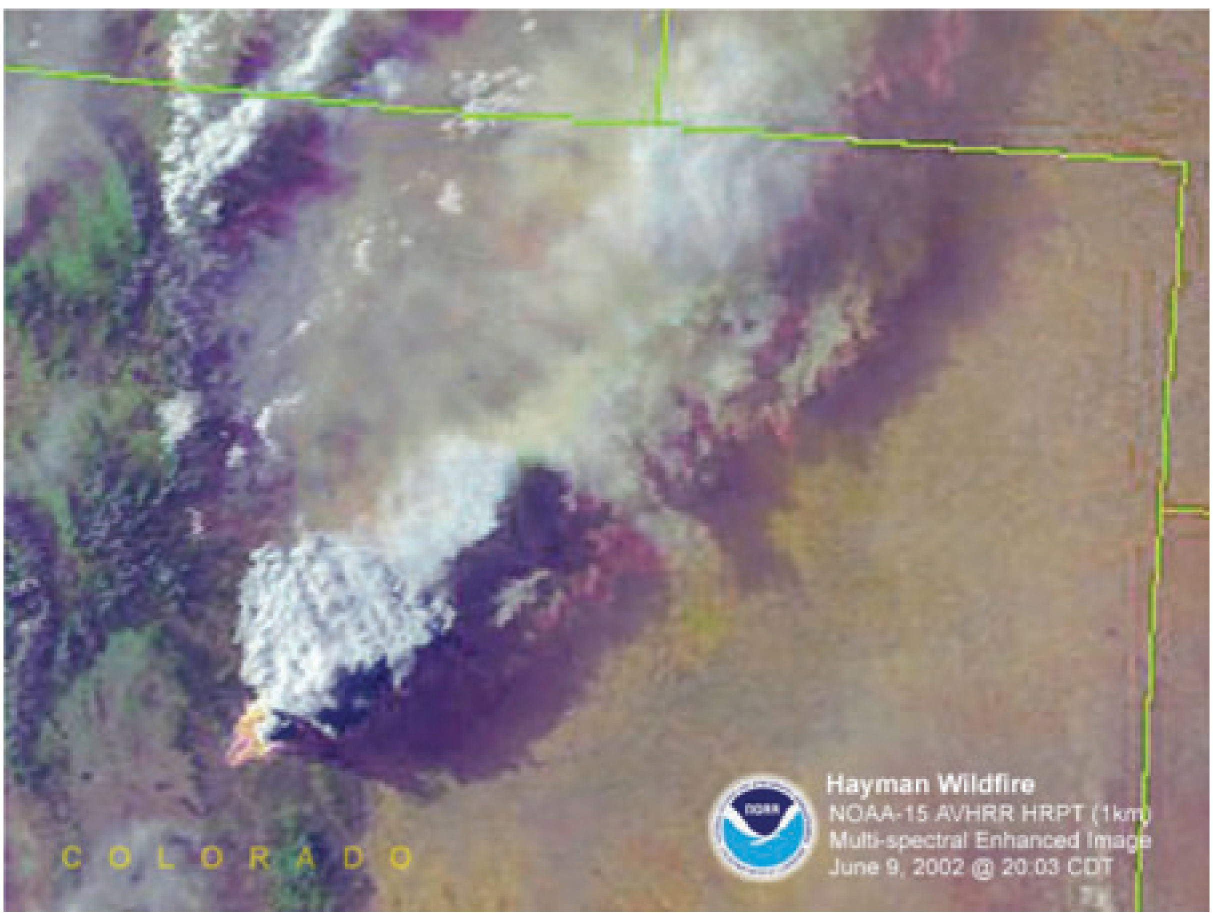

Figure 30—Satellite image of Hayman Fire on June 9 shows the convection column and smoke plume extending across Denver into Wyoming carrying carbon monoxide and fine particulates.

Fire Ecology and Fire Effects

Team Leader Bill Romme, Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, Colorado

The ecology and fire effects team used existing data collected in and around the Hayman area, limited observations by team members within the burned area, and expert opinion. Fire ecology, terrestrial plant ecology, aquatic ecology, soil science, wildlife ecology, and geospatial sciences were included in the information they gathered in 2002 and 2003. This information was supplemented with information from the fields of fire and ecosystem management. Selected findings of the team:

- We have a high degree of confidence in many of our interpretations, but some are offered as tentative hypotheses rather than firm conclusions because of limited prefire research.
- Reconstructions of fire history and forest dynamics in the Cheesman landscape, located near the center of the Hayman burn, reveal (1) an average fire interval of about 50 years during the period 1300 through 1880, but no major fires between 1880 and 2002; (2) a mix of nonlethal surface fire and lethal, stand-replacing fire in the historic burns; and (3) a striking increase in forest density from 1900 to 2002.
- The extent of high-severity burn in 2002 within the Cheesman landscape was unprecedented in the past 700 years, in part because of the dense forest conditions that had developed during the 20th century and in part because of the extreme fire weather conditions that existed in 2002 (fig. 31).

Figure 31—The extent of the high severity burn in the Hayman Fire was unprecedented as exemplified by the large expanses of trees totally blackened.

Figure 32—In many areas within the Hayman Fire area, dense forest conditions existed with tree crowns extending to the forest floor. These conditions facilitated the transition of fire from the surface to the tree crowns.

- Although the extent of high fire severity in the Cheesman landscape was unprecedented, fires of comparable size and severity have occurred elsewhere in the Front Range during the last several centuries (for example, in 1851), especially in high-elevation forests (spruce, fir, and lodgepole pine) and possibly also in ponderosa pine forests. Infrequent but large, severe fires are a normal component of many forests in Colorado and are not an artifact of 20th century fire suppression in all forests.
- In the Colorado Front Range as a whole, 20th-century fire suppression probably has altered fuel conditions and fire regimes most significantly in low-elevation ponderosa pine forests where fires were relatively frequent prior to the late 19th century. In contrast, impacts of fire suppression probably are minimal in high-elevation forests of spruce, fir, and lodgepole pine, where fires have never been frequent but where high-severity fires have always been the norm. Within the middle forest zone of ponderosa pine and Douglas-fir, the extent to which fire suppression has altered forest structure and fire regimes is uncertain, and probably varies from place to place (fig. 32). Additional research is needed to clarify historical fire regimes in mid-elevation forests of the Colorado Front Range.
- Areas of high severity burn are likely to have the greatest alterations in soil characteristics, including loss of surface soil organic matter and fire-induced synthetic water repellency. Areas where organic matter was entirely burned off may not return to the prefire state for decades or centuries, but water repellent soil layers will be more ephemeral, persisting for 2 to 6 years (fig. 33).
- Reduced ground cover in places of high fire severity will likely result in decreased infiltration of water, increased surface runoff and peak flows, and the formation of pedestals, rills, and gullies. Erosion rates should substantially decline by the third summer after burning, and erosion from winter storms is expected to be minimal.

Figure 33—In addition to burning the vegetation of the area, the Hayman Fire in many places burned organic materials in and on the soil surface, decreasing productivity and creating water impermeable layers. (Photo by Theresa Jain)

- The aquatic ecosystems of the South Platte River within the Hayman Fire area represent a highly altered landscape that has been influenced by a variety of activities including mining, vegetation management, road building, urbanization, recreation, and water development.
- The recovery of the hillslope and riparian vegetation will influence how quickly the aquatic environments recover. Clearly, areas that were less severely burned will likely recover to prefire conditions most rapidly. Recovery of aquatic ecosystems within severely burned watersheds will be most dependent on riparian recovery, the juxtaposition to high quality habitats that can provide sources for re-colonization, and the mitigation of additional chronic disturbances.
- Rehabilitation of the aggrading perennial streams downstream from the fire will be difficult and costly because of the large volume of sediment in the system and poor access in many areas. Efforts to accelerate the recovery of the hillslopes will help by reducing the future inputs of sediment, but so much sediment has already been mobilized, or is poised to move into the downstream areas, that relatively little can be done to stop the problem. Hence large amounts of sediment will continue to be delivered into Cheesman Reservoir and the South Platte River, reducing reservoir storage capacity and potentially affecting fish and macroinvertebrate habitat (fig. 34). Over a longer period, however, the trend will likely be toward recovery of aquatic ecosystems if other kinds of chronic disturbances can be minimized.

Figure 34—The greatest risk to the soil and water resource following the Hayman Fire is erosion and sediment delivery to the streams and reservoirs.

- Because the ecosystems that burned in 2002 have a long history of fire, the native species and populations in this area generally have mechanisms for enduring fire or becoming reestablished after fire. Therefore, much or even most of the terrestrial vegetation is likely to recover normally without intervention, and in some areas our well-intentioned rehabilitation efforts actually could interfere with natural recovery processes.
- Where the vegetation is dominated by sprouting species (for example, aspen, cottonwood, many shrub species, many grasses, and other herbaceous species), a rapid return to prefire conditions is generally expected (fig. 35). We also expect a rapid return to prefire conditions in areas dominated by nonsprouting species (for example, ponderosa pine and Douglas-fir forests) wherever the fire burned at low severity and did not kill most of the forest canopy.
- Vegetation that is different from prefire conditions, but within the historical range of variability, is likely to develop in ponderosa pine and Douglas-fir forests where the fire burned with moderate severity, and also in small patches of high-severity burn. We anticipate that a new cohort of ponderosa pine seedlings will become established in these areas over the next several years.
- Development of vegetation that is different from prefire conditions and also is dissimilar to or at extremes of the historical range of variability for this ecosystem is expected in ponderosa pine and Douglas-fir forests within large patches of high-severity burn because of high local seed mortality coupled with long distances to seed sources outside the burned area. Natural reforestation of these areas may require many decades (fig. 31).
- Development of vegetation that is outside historical range of variability for this ecosystem is expected wherever invasive, nonnative species become dominant. Invasion of burned areas by nonnative species is a serious threat throughout the Hayman burn because the invasive species may cause declines of native plant species and changes in fire regimes, nutrient cycling processes, and hydrology.
- Over the short term (next approximately 5 years), riparian areas are likely to be the most vulnerable to invasion by nonnative plant species. Rehabilitation activities may facilitate the invasion of nonnative species and may alter postfire dynamics of riparian ecosystems (fig. 36).

Figure 35—Areas within the Hayman Fire responded rapidly by sprouting new vegetation within weeks of the fire.

Figure 36—Mulch was aerially applied to reduce soil erosion. These activities have the potential to introduce nonnative species and alter natural vegetation development.

Over a longer term (approximately 50 to 100 years), without control measures, nonnative plant species would be expected to persist in riparian and drainage areas, open-canopy areas, and along disturbance corridors such as roads.

- The potential effects of the Hayman Fire on animal and plant species listed as threatened or sensitive species for the Pike National Forest are expected to vary based on the patterns of fire severity and rehabilitation implemented. In areas of mixed-severity burn, we expect that the fire will create habitat for several species such as woodpeckers, cause minimal negative impacts for most species in the short term, and may enhance habitat availability for many native species in the long term.
- Large patches of crown fire will also create habitat for several species of concern but likely will diminish habitat availability and quality in the short term for many species that prefer mature conifer forest (fig. 31). The long-term effects of the large patches of crown fire are more equivocal and will depend on postfire response of vegetation communities.
- Rehabilitation efforts (such as salvage logging, seeding, soil scarification) and hazard tree removal may remove or diminish critical structure (for example, snags, bare mineral soil) for wildlife that was created by fire.
- Concern remains for the threatened Pawnee Montane Skipper because of its restricted habitat and range. Further research is needed to determine how the skipper responds to burn-severity patterns and potential interactions with effects of the 2002 drought.

Home Destruction

Team Leader Jack Cohen, USDA Forest Service, Rocky Mountain Research Station, Missoula, Montana

An onsite assessment of each home destroyed, documentation and photographs during the fire, postfire aerial reconnaissance, and meetings with Federal, County and private individuals were the main sources of information used in the analysis. Although the team specifically assessed the homes destroyed, surviving homes were also considered. Home sites were visited 3 months after the Hayman Fire when much of the specific evidence describing the nature of home destruction and survival was lost. Selected findings of the team:

- Discussions with fire personnel and residents indicate that most homes were not actively protected when the Hayman Fire burned in the residential areas.
- The Hayman Fire resulted in the destruction of 132 homes (that is, homes on permanent foundations, modular homes, and mobile homes—both primary and secondary). Within what is now the final perimeter of the Hayman Fire, 794 homes existed. Thus, 662 homes were not destroyed. The Hayman Fire resulted in about 17 percent destruction of the total homes within the fire area.
- The wildland fire intensity associated with the destroyed homes varied as much as the fire intensity associated with homes that survived. Figure 37 shows the range of wildland fire intensities associated with homes destroyed and a similar range with those that survived.

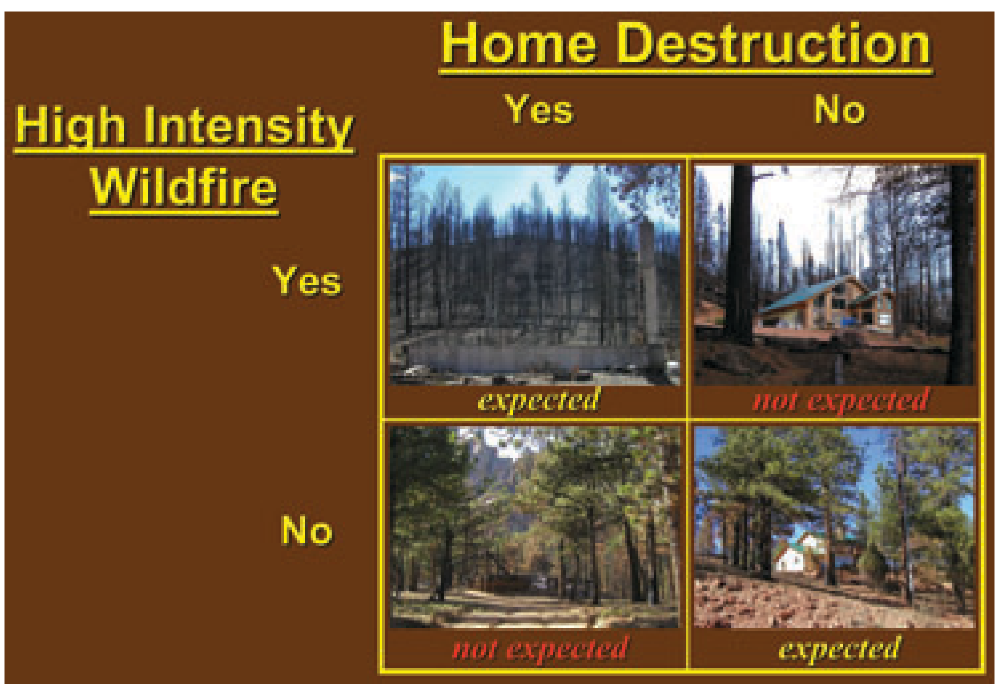

Figure 37—Expectations of home destruction as a result of wildfire. Home survival is expected if low fire intensities occur (lower right cell) and unexpected if the home is destroyed (lower left cell).

- Research has shown that the characteristics of the home in relation to its immediate surroundings (within 30 to 60 m) principally determine home ignitions during wildland fires. This area that includes the home characteristics and its immediate surroundings is called the “home ignition zone.”
- The wildland fire intensity in the general area does not necessarily cause home destruction or survival. This distinguishes the difference between the exposures (flames and firebrands) produced by the surrounding wildland fire from the actual potential for home destruction (home ignition zone) given those exposures.
- The home ignition zone implies that the issue of home destruction can be considered in a home site-specific context rather than in the general context of the Hayman Fire.
- Seventy homes were destroyed in association with the occurrence of torching or crown fire, at least in a portion of the area surrounding a home (fig. 37 upper left case).
- Sixty-two homes were destroyed with no high intensity fire, torching, or crown fire, in the area surrounding the home (fig. 37 lower left case).
- Significant site disturbance in the time lapsed between the fire occurrence and our assessment prohibited any further analysis as to whether these high intensities could have directly caused home ignition.
- Significant patterns of destruction were not observed. This can likely be attributed to the wide variety of home types, designs, building materials, the scattering of destroyed homes, the significant number of surviving homes within the fire perimeter, and the wide range of fire intensities associated with home destruction.
- Teller and Park Counties did not have regulations related to reducing wildland-urban fire risks.
- In 1994 Douglas County adopted an amended version of NFPA 299 (1991) to the Uniform Building Code, making all developments after the adoption date subject to the regulations.
- Jefferson County required “defensible space” permits on the construction of habitable space greater than 400 ft^2 since 1996, but because of little new construction, few—if any—homes fell into this category in the Hayman Fire area.

Postfire Rehabilitation

Team Leader, Pete Robichaud, USDA Forest Service, Rocky Mountain Research Station, Moscow, Idaho

Selected findings of the team:

- Postfire rehabilitation efforts in the Hayman Fire area were designed to reduce the projected increases in peak-flows and soil erosion, and thereby minimize adverse downstream impacts on structures and aquatic ecosystems. The Burned Area Emergency Rehabilitation (BAER) team report included:

    1. Estimates of the potential magnitude of the increases in runoff and erosion.

2. Assessment of the risks posed by the increases.
3. Recommendations for mitigation treatments on National Forest lands.

- The recommended treatments were applied, with some modifications, as soon as fire suppression activities allowed. Land treatments included aerial and ground-based hydromulch (fig. 38), aerial dry mulch (fig. 36), and scarification with either aerial or ground-based seeding. Each of these treatments included a 70 percent barley/30 percent triticale seed mix. In addition to land treatments, road and site protection treatments were applied. By the end of 2003, approximately $18 million will be spent to provide emergency rehabilitation treatment on 45,500 acres (39 percent) of the 116,300 acres that burned.
- Most of the treatments recommended by the postfire rehabilitation team have not been systematically studied, making it difficult to predict expected effectiveness. More quantitative data on rehabilitation treatment effectiveness, based on climate, burn severity, soil types, and so forth, would enable BAER teams to refine their recommendations for each area.
- Previous experience indicates that rehabilitation treatments are least effective in high intensity rainstorms, particularly in the first 2 years after burning. Such storms are common in the Colorado Front Range, but in summer 2002 there were fewer such storms than average.
- Much of the postfire treatment effectiveness monitoring that has been done in the past has been anecdotal and qualitative. The application of such observations to current treatment decisions is difficult without specific information on site conditions, storm events, and measured responses (runoff, erosion rates, and so forth). Without quantitative measurements of runoff and erosion rates, downstream sedimentation rates are difficult to estimate, and predictive models cannot be rigorously tested and calibrated to different burned forest environments. To discern treatment effectiveness, it is also necessary to monitor comparable burned but untreated areas. Treated and control sites have been established in the Hayman Fire area, but these monitoring efforts need to be expanded and continued until recovery to near background conditions. The results of this monitoring need to be regularly and publicly reported.

Figure 38—Ground application of hydromulch aimed at reducing soil erosion.

- The efficient placement of rehabilitation treatments involves the use of predictive models to locate the areas of greatest risk and greatest potential for effectiveness. The development and adaptation of climate, runoff, and erosion models for use in burned forest environments are currently hindered by several knowledge gaps that include:
    1. Improved mapping of burn severity and better characterization of postfire soil water repellency (fig. 33).
    2. Improved prediction of runoff responses at different spatial scales from short-duration, high-intensity thunderstorms.
    3. Relative magnitudes and consequences of hillslope verses channel erosion.
    4. Sediment deposition and routing within drainages.

Social and Economic Issues

Team Leader Brian Kent, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado

The social and economic issues of the Hayman Fire were addressed by conducting four studies: (1) on economic and social effects of the fire; (2) prefire and postfire workshops with the Ridgewood Homeowners Association; (3) interviews with key informants in the Woodland Park area in August 2002, soon after the fire was suppressed; and (4) another set of interviews with Woodland Park area representatives of governmental and nonprofit organization members in February 2003, about 6 months after the fire was suppressed. Selected findings of the team:

- The effects a catastrophic wildfire such as the Hayman has on human social and economic systems are complex. Unlike many ecological effects of a wildfire, the geographic scale of influence for social/economic effects extends considerably beyond the area actually burned.
- Most likely no human alive during the Hayman Fire will live long enough to see the burned area recover to anything like it was prefire. Those who used this area have lost something and they will need to look elsewhere to replace it, and the local economies likely have lost the economic contributions those users made.
- The economic aspects of a large-scale fire occurring in proximity to human populations, such as the Hayman Fire, are difficult to measure and highly variable. Some aspects are straightforward and relatively easy to measure, such as the actual suppression expenditures or property losses. Assessing other aspects, such as the effect on a regional economy, or changes in recreation and tourism, are easily confounded by other factors, such as general economic downturns or a shift of economic activity from one location to another.
- While the Hayman Fire was not extraordinarily expensive on a cost per acre basis, the size of the fire made it one of the most expensive fires in the last several years. No fire in Colorado's history has cost as much to suppress (fig. 39). The $38 million spent by the Forest Service on the Hayman Fire was more than three times the average annual

suppression expenditures (1992 to 2001) for all of USDA Forest Service Region 2 (Rocky Mountain Region). Adding expenditures by the State and the other Federal agencies, suppression expenditures totaled more than $42 million. In addition to the money spent fighting the fire, rehabilitation and restoration expenditures (already expended and planned) connected with the fire are expected to cost at least another $74 million.

- Additional expenditures related to the fire totaled almost $2 million. These expenditures included Federal Emergency Management Agency (FEMA) reimbursements, State of Colorado expenses, and disaster relief by the American Red Cross.
- The proximity of the fire to human populations led to a loss of 600 structures, including 132 residences (fig. 40). Real property losses were substantial, totaling $24 million, with a majority of the losses occurring in Teller County ($14 million) and Douglas County ($8 million) with total insured private property losses estimated at $38.7 million. Loans and grants from Small Business Administration and FEMA for uninsured losses totaled almost $4.9 million. Additionally, damage to transmission lines was estimated at $880,000.
- More difficult to measure are the effects on resource values (including tourism and recreation) and the regional economy. The fire closure order occurred during the busiest time of the tourist season (fig. 41). Concessionaires who manage the developed recreation sites within the affected Ranger Districts of the Pike-San Isabel National Forest reported a total decline in revenue in 2002 of $382,000 from 2001 levels.

Figure 39—The costs to suppress the Hayman Fire were not that excessive on a per acre basis, but because of its size the fire was the most expensive in Colorado history.

Figure 40—Many structures dotted the Hayman landscape, and 600 of them burned during the fire, resulting in real property losses of $24 million.

Figure 41—The Hayman Fire occurred at the peak of the tourist season, impacting many sectors of the travel economy from daily forest visitors to destination resorts.

- It is possible that recreation losses occurring within the vicinity of the Hayman Fire were offset by gains to other areas of Colorado.
- On the Pike-San Isabel National Forest, financial losses attributed to water storage decreases were estimated at $37 million, and the value of timber lost was estimated at $34 million.
- There was little evidence of a substantial economic decline in the Primary Impact Area – the four affected Counties during the months of the Hayman Fire. In some areas and sectors, the Hayman Fire most likely decreased economic activity. That more substantial effects were not detected is probably due to: (1) tourism-related sectors constitute a relatively small part of the economies in the Primary Impact Area and (2) the economies of the Primary Impact Area are large, complex, and able to withstand economic shocks.
- The Ridgewood Homeowner's Association (RHOA), located adjacent to the Manitou Experimental Forest on the eastern perimeter of the fire (fig. 8, 16), comprises residents that have had notable experience with wildfire, are quite knowledgeable on these issues, and yet are still motivated to learn more. These homeowners recognize the need for active management on the Forest and realize the potential dangers that wildfire poses. The homeowners most preferred the mechanical removal of hazardous fuels (even more since the Hayman Fire). Second, they prefer prescribed fire in combination with mechanical removal, and third, they are somewhat neutral on prescribed fire. Interestingly, this preference has remained constant from before to 6 months after the Hayman Fire.
- According to these residents (RHOA), the City and County fire departments are helpful and perceived as highly credible entities, while research reports and environmental organizations were not viewed as helpful or credible sources of help or information. The Colorado State Forest Service is only perceived as somewhat credible as an institution.

The USDA Forest Service, bordering many of these residents' land, is viewed as providing somewhat helpful information and as less credible than the USDI National Park Service, County and City fire departments, State Forest Service, and neighbors and friends. This could explain some of the trepidation associated with prescribed fire; the residents may view prescribed fire as something needed but not preferable since they know the Forest Service is the entity implementing the treatments. These sentiments for prescribed fire may also reflect the knowledge of the Forest Service employee who pled guilty to starting the Hayman Fire.

- The residents of the RHOA feel highly vulnerable to the effects of fire, are highly susceptible to the consequences of fire, and feel that there is a high probability (78 percent) that a wildfire will occur near their home in the near future. Yet the measures of perceived efficiency for both specific and general risk reduction actions only explain a few of the homeowners' mitigating actions. These residents feel that mitigating actions are, for the most part, effective, and they also believe strongly in their ability to carry them out. The question then remains as to why there are not more mitigating actions being implemented on homeowners' lands.
- The residents' (RHOA) strong feelings of vulnerability from wildfire risks are enhanced by inaction of their neighbors, thereby negating the effect of homeowner risk reduction actions. The residents not only believe that they are responsible for defending their property, but also that all neighbors, including homeowners, the Forest Service, and the RHOA, should be involved in mitigating these risks.
- These findings suggest that information on wildfire issues should be disseminated through City and County fire departments, which hold more credibility with homeowners. Education should focus on including the actions of the land management agencies and other community projects so that homeowners feel it is truly a community effort and that it is not something they are doing on their own.
- To gain support for prescribed fire as a treatment option, the Federal, State, and local governments need to educate residents about the benefits of prescribed fire, and perhaps even the benefits of prescribed fire over mechanical removal.
- Postfire experience points to the importance of identifying and establishing relationships with preexisting community assets and organizations early on in a wildfire incident. This can help incorporate local knowledge into firefighting and rehabilitation efforts and establish a recovery base that will continue once emergency Federal agency personnel and resources have left the community.
- Partnerships should be developed as early as possible during the fire by the incident command, and several interviewees thought that they should be developed by local Federal officials well before any fire. Such up front collaboration was seen as a good way to systematize actions, increase efficiency, and decrease potential contention between locals and Federal agencies by building trust.

- While trust has been shown to be important in all natural resource management matters, it is particularly important with wildfires where a crisis brings in powerful outsiders to work in a community for a limited but highly emotional period of time.
- Many evacuees expressed frustration with being forbidden to go back to their homes. There was little understanding of how thin law enforcement was stretched, and people were restricted from going back to houses not only just for safety reasons but also as the only manageable means of preventing burglaries in evacuated areas on a fire the size of Hayman (fig. 41).
- Informing the public prior to fire events about what is involved in firefighting and rehabilitation efforts, including limitations prior to a major event, should make public expectations more realistic
- The educational process should not be one way. Federal fire managers need to work to better understand the actual capabilities and limitations of volunteer fire departments.
- While agencies have developed effective means of coordinating policy and actions during a fire, similar efforts need to be made with rehabilitation work, particularly between the Forest Service and National Resource Conservation Service.
- Given the complexity and importance of rapidly developing effective solutions to minimize current and future wildfire damage, it is important to think out of the box as much as possible. Instead of relying on traditional and often engrained methods and approaches, the ability to be open to new and adaptive techniques and to meet locally identified needs will be critical.
- The mix of social and economic effects of a large fire such as the Hayman, especially when it occurs within the wildland urban interface, is both complex and far ranging.
- The Hayman Fire has taken on national significance by becoming an example of a consequence of what is wrong with current forest management policy. Consequently, the more we can learn from it, the more we can use the Hayman experience to inform future debates over both forest and wildfire management strategies.

Conclusions

The Hayman Fire was at the wrong place at the wrong time. The fires of 1910, and the resulting views of fire suppression, started the sequence of events that helped facilitate the Hayman Fire. In 2002 much of the Hayman area was rich in dry vegetation as a result of fire exclusion and the droughty conditions that prevailed in recent years. These dry and heavy fuel loadings were continuous along the South Platte River corridor on the Front Range of Colorado. These topographic and fuel conditions combined with a dry and windy weather system centered over eastern Washington to produce ideal burning conditions. The start of the Hayman Fire was timed and located perfectly to take advantage of these conditions, resulting in a wildfire run in 1 day of over 60,000 acres at a distance of 16 to 19 miles.

The Hayman Fire Case Study revealed much about wildfires and their interactions with both the social and natural environments. As the largest fire in Colorado history it had a profound impact both locally and nationally. We hope the findings of this study will inform both private and public decisions on the management of natural resources and how individuals, communities, and organizations can prepare for wildfire events. This study was part of a learning process that began in 1910 and continues today, to provide knowledge on the behavior, severity, and impact of wildfires.

References

Agee, James K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p.

Carey , Alan; Carey, Sandy. 1989. Yellowstone's red summer. Flagstaff, AZ: Northland Publishing. 114 p.

Pyne, Stephen J. 2001. Year of fires: The story of the greast fires of 1910. New York: Penguin Books. 322 p.

USDA Forest Service. 2000. Bitterroot Fires 2000, an overview of the events, effects on people and resources, and postfire recovery priorities. Hamilton, MT: U.S. Department of Agriculture, Forest Service. 108 p.

USDA Forest Service. 1978. When the mountains roared. Coeur d'Alene, ID: U.S. Department of Agriculture, Forest Service, Coeur d'Alene National Forest. 39 p.

Fire Behavior, Fuel Treatments, and Fire Suppression on the Hayman Fire

Mark A. Finney, Roberta Bartlette, Larry Bradshaw, Kelly Close, Brandon M. Collins, Paul Gleason, Wei Min Hao, Paul Langowski, John McGinely, Charles W. McHugh, Erik Martinson, Phillip N. Omi, Wayne Shepperd, Karl Zeller

The Hayman Fire started on June 8, 2002, about 1.5 miles southwest of Tappan Mountain on the south side of County Highway 77, in Park County, Colorado (fig. 1). It was first reported at about 1 acre in size at approximately 1655 hours (appendix C). An aggressive initial attack response consisted of air tankers, helicopters, engines, and ground crews, but they were unable to contain the fire. Torching trees and prolific spotting advanced the fire to the northeast across U.S. Highway 77 by 1831 hours. The entire Front Range of Colorado was predisposed to potential extreme fire behavior by the unusually severe drought conditions this year. The unusual moisture conditions were exemplified by the low moisture contents (3 to 7 percent) of large dead woody fuels (100 hour, 1000 hour) and duff, and conifer foliage (84 to 111 percent). Little or no new growth appeared on perennial grasses and brush, and terminal buds did not elongate or flush on some conifers. Weather at the time of ignition consisted of high winds (from the south averaging 18 mph, with gusts to 33, Lake George RAWS station, appendix A) and low humidity (9 percent) that facilitated rapid fire spread rates, crown fire, and spotting. Fuels across the landscape were generally continuous, with no recent wildfires or fuel management activities occurring downwind of the ignition location for perhaps 10 miles. Surface fuels generally consisted of ponderosa pine duff and needle litter, short grass, and occasional patches of brush. Low crowns of the predominating conifer species (ponderosa pine, Douglas-fir, and blue spruce) facilitated transition from surface to crown fire.

By the following morning (June 9), the fire was estimated at 1,000 to 1200 acres in size (0806 hours,

In Memoriam

Paul Gleason, a member of the Fire Behavior, Fuel Treatments, and Fire Suppression Analysis Team, passed away on February 27, 2003. At the time of his death, Paul was a member of the faculty at Colorado State University, Department of Forestry and Natural Resources. Prior to his teaching association with the university, Paul worked for the USDA Forest Service and USDI National Park Service in a career that spanned 35 years, including 23 seasons with the Interagency Hotshot Crew programs on the Angeles, Mount Hood, and Pike and San Isabel National Forests.

When reflecting on his career as a hotshot, Paul said, “One of the enjoyments of that job is to go into chaos and made sense of it. And this ‘sense’ is to do effective fire management and safe fire management work simultaneously within this environment.” Paul’s desire to make sense out of the chaos and provide for firefighter safety led him to develop the principles of LCES used by wildland firefighters nationwide.

Paul’s work and interaction with the team demonstrated, as always, that Paul was indeed “a student of fire.”

Paul and his contributions will be missed by the team and the wildland fire community.

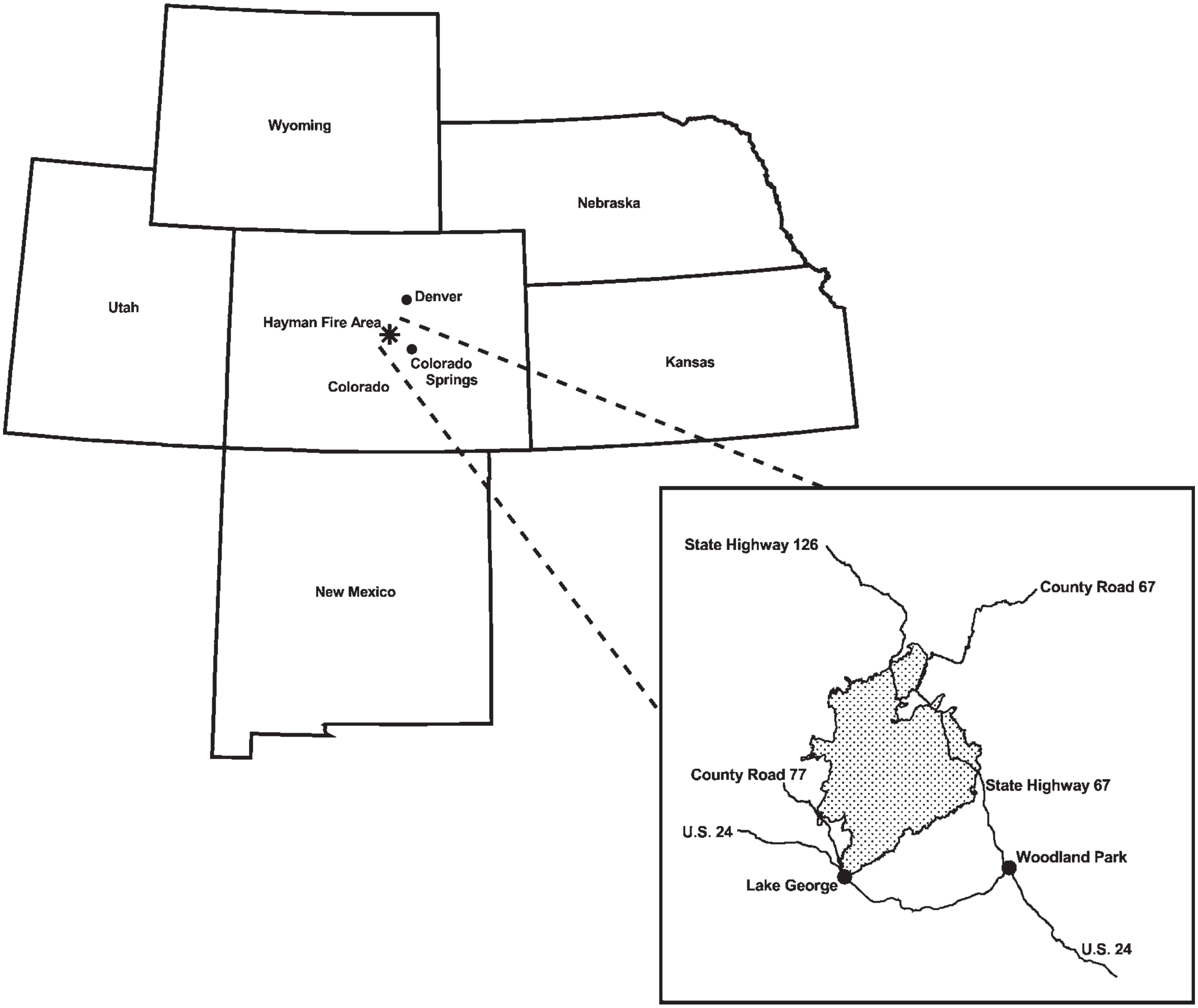

Figure 1—Location of Hayman Fire in Colorado. Fire started on south side of County Road 77 in the southwest corner.

Pueblo Interagency Dispatch Log) in the Tarryall Creek drainage west of the confluence of the South Platte River. This positioned the fire for a major run lasting the entire day and burning 60,000 acres along the South Platte River corridor for 16 to 19 miles. The general alignment of the gradient wind direction (SW) with the orientation of the Platte River drainage enhanced the spread of the fire to the northeast. Extreme weather conditions continued that day. Winds gusting to 51 mph from the southwest and humidity hovering around 5 to 8 percent were recorded at nearby RAWS stations. Evacuations were performed in front of the fire, but no suppression actions were possible forward (east) of U.S. Highway 24. Fire behavior was described by long crown fire runs and long-range spotting (1 mile or more). Fire spread rates from approximately 1700 to 2300 hours averaged more than 2 mph. Pyrocummulus clouds developed to an estimated 21,000 feet. By the end of the day the fire encountered a number of landscape features that served to alter fire behavior. The head of the Hayman Fire acquired a forked appearance after burning on either side of Cheesman Reservoir. The eastern head of the fire stopped at the edge of the Polhemus prescribed burn (October 2001) and was prevented from flanking west toward the town of Deckers by the earlier Schoonover wildfire (May 2002).

Moderate weather arrived the afternoon of June 10 and persisted until the afternoon on June 17. During this period, the fire advanced mostly to the south and several miles to the east. Burnout operations were conducted, and firelines constructed along most of the eastern and southern perimeter divisions. The fire encountered a number of prescribed burns as well as the Big Turkey wildfire (1998) along the eastern flank. Because of moderate weather conditions, most areas burned this period sustained only light to moderate overstory mortality.

Extreme weather returned on June 17 and 18. Fire activity increased across the entire east flank, driven by west-northwest winds. Fuel modifications with two prescribed burns and the Big Turkey wildfire (1998) limited the initiation of crownfire runs on June 17 along a 2 mile section of fire perimeter. The fire advanced to the east 4 to 6 miles on June 18, burning into Manitou Experimental Forest and across Highway 67. The fire made little progress after this because of the arrival of monsoon weather and moisture.

In the aftermath of the fire, our team was directed to address five questions. The questions were approached through the collection and analysis of data on five topics: fire climatology and meteorology, fire behavior, fuel treatments, road density, and fire suppression activities. The following reports address these topics.

Part 1: Fire Weather, Meteorology, and Climate

Larry Bradshaw, Roberta Bartlette, John McGinely, Karl Zeller

The Hayman Fire in June 2002 was heavily influenced by antecedent regional weather conditions, culminating in a series of daily weather events that aligned to produce widely varying fire behavior. This review of weather conditions associated with the Hayman Fire consists of two parts:

- A brief overview of prior conditions as described by a regional climate review and assessment of the state of the fuels as described by the National Fire Danger Rating System.
- A more detailed daily discussion of the synoptic-scale and local meteorological conditions affecting the fire.

Data Sources

Data are presented from a wide variety of sources in formats generally available from public, nonsubscription Internet sites. Because this review was not instigated until several months after the fire, many real-time Internet sites were not available for presenting "as of June 2002" conditions unless they had on-line archives. The weather discussion generally proceeds from a regional climate-based summary to a more site-specific narrative.

Climate information for the region is based on data from the National Weather Service Cooperative Climate Network whose data are usually organized by State climate divisions. Individual station data for three stations near the Hayman Fire are examined in more detail for the 2002 water year (October 2001 to October 2002) prior to the fire. These data were obtained primarily from Internet resources at the Colorado Climate Center (http://climate.atmos.colostate.edu), the National Oceanic and Atmospheric Administration's (NOAA) Climate Prediction Center (http://www.cpc.ncep.noaa.gov), and the National Drought Mitigation Center (http://www.drought.unl.edu).

Archived weather maps (upper air and surface charts) from San Francisco State University, the National Climate Center, and the Storm Prediction Center were obtained for identifying and illustrating synoptic scale weather patterns. Atmospheric soundings are routinely taken via radiosonde (weather balloons) at 00Z and 12Z at several hundred sites around the world. These time notations refer to Greenwich Mean Time (GMT or UTC) which is 6 hours earlier than Mountain Daylight Time (MDT). For example 00Z (June 1) corresponds to 6 p.m. MDT on May 31, and 12Z (June 1) corresponds to 6 a.m. MDT on June 1. We illustrate 500 millibar (mb) maps, which are maps that depict the height, temperature, and wind velocity at a constant pressure surface. The 500 mb map corresponds to heights around 19,000 feet (5,820 m) above ground level. Archived upper air soundings were obtained from the University of Wyoming (Laramie), for Denver, 56 miles (90 km) north of the fire, and for Grand Junction, 250 miles (402 km) southwest of the fire. The soundings were used to compute Lower Atmospheric Stability Index (Haines 1998) and to estimate vertical wind speed profiles over the fire area.

The Lower Atmospheric Stability Index (LASI), more commonly known as the Haines Index, was developed by USDA Forest Service meteorologist Donald Haines to quantify (via index) the lapse rate (stability) and dryness (dew point depression) of lower levels of the atmosphere, and correlate the index with days of large fire growth, particularly in the absence of significant surface winds. An index value of 2 or 3 (a moist stable lower atmosphere) indicates low potential for large fire growth, and 5 or 6 (dry unstable) indicates moderate or high potential. Since 1988 there have been several studies focused on exploring and documenting relationships between the Haines Index and fire growth (for example, Werth and Ochoa 1990). More recently there have been efforts at developing the climatology of Haines Index values throughout the United States in more detail than Haines did in his original research. Werth and Werth (1998) performed a study of the frequency of Haines Index values based on the high elevation layers in the Western United States using data from 1990 to 1995 and reported Denver had Haines Index values of 5 and 6 (moderate and high) 44 percent of the days in June.

Atmospheric conditions related to blow-up fires were described by Byram (1954). He characterized vertical wind speed profiles that he deemed "potential trouble makers" and addressed the concept of a "tug-of-war" between the power of the wind and the power of the fire. Essentially this work suggested that when wind decreases with height above a fire, the power of the fire has more opportunity to influence the behavior and direction of fire growth, and given dry and abundant fuels, a fire may rapidly transition to extreme behavior and erratic in direction and rate of spread. Fires where surface winds predominate may exhibit extreme behavior but tend to be more consistent in their direction and rate of spread. In general, in a well-mixed atmosphere wind speed increases with height; this "trouble maker" wind profile has come to be known as an "inverse wind profile."

On a more intimate scale, hourly weather observations from three active Remote Automatic Weather Stations (RAWS) near the fire are available. The Cheesman RAWS is located just west of the Cheesman Reservoir, the Lake George RAWS is at the Lake George Work Center about 5 miles (8 km) southeast of the fire origin, and the Bailey RAWS is near the town of Bailey, about 20 miles (32 km) northwest of the fire's northern perimeter. The RAWS stations are part of a national fire weather network that supports the weather requirements of the National Fire Danger Rating System (Deeming and others 1977) and are commonly referred to as NFDRS stations. The data from the weather station at the USDA Forest Service Manitou Experimental Forest are also available for analysis, although its sensor configuration and observation format is not consistent with that of the national fire weather network. Near the waning stages of the fire, three specialized Fire Remote Automatic Weather Stations (FRAWS) were positioned near the fire; those data are also summarized. Hourly data from the RAWS and FRAWS stations were obtained from the Western Region Climate Center. Data from the Manitou station were provided by Wayne Shepperd (Rocky Mountain Research Station, USDA Forest Service). Table 1 documents the station metadata to the best of our knowledge, and their locations are depicted in figure 2. Appendix A contains the hourly listing of weather observations from Cheesman, Lake George, and Manitou and also the daily upper air information used for computing the Haines Index from Denver soundings.

Regional Conditions

Colorado had been experiencing variable short-term drought conditions over the preceding 5 years. According to Meteorologist Mike Baker (Summer 2002 Outlook for the Colorado Front Range, NOAA/NWS Boulder, CO, June 15, 2002):

> The current drought began to unfold in Colorado during the summer of 1998, at approximately the same time the phenomenon known as La Niña began forming in the eastern Pacific Ocean. This cold phase ENSO (El Niño-Southern Oscillation) event, characterized by below normal sea surface temperatures and above normal atmospheric pressures in the central and eastern Pacific Ocean, varied from moderate and strong intensity as it continued uninterrupted through the spring of 2001. This was of extraordinarily long duration for a La Niña as the average life span for these events is only about nine months! The hiatus from La Niña was short-lived as by the end of the summer that year a weak La Niña reformed and continued intermittently through May of 2002. The link between La Niña and drought in Colorado appears unmistakable. During the last 40 years, five La Niña events of at least moderate intensity occurred, and during each of these events, drought conditions of at least severe intensity developed within the borders of Colorado. The strength and especially long duration of the latest La Niña event may also have been instrumental in producing the extreme drought conditions observed across Colorado today.

The Climate Prediction Center produces a wide array of climate analysis and assessment products for regional application using state climate divisions for displaying regional conditions. The Hayman Fire burned in four Counties (Park, Douglas, Jefferson, and Teller) of Colorado's Platte River drainage climate division (fig. 3). The winter of 2001 and 2002 saw a marked worsening of drought conditions as expressed by several regional scale analyses. One widely used index to quantify the severity of drought conditions is

Table 1—Weather station metadata used in Hayman Fire report.

Name	NWS number	Type[1]	Latitude	Longitude	Elevation ft (m)	Position	Data begin
Lake George 8 SW	054742-4	Coop	38°55' N	105°29' W	8,510 (2,594)	Valley	1948
Lake George NFDRS	053002	RAWS	38°58' N	105°21' W	8,050 (2,454)	Valley	1964
Cheesman	051528-4	Coop	39° 13' N	105° 17' W	6,890 (2,100)	Valley	1948
Cheesman NFDRS	053102	RAWS	39° 11' N	105° 16' W	7,473 (2,278)	Ridge	1987
Bailey	050454-4	Coop	39° 24' N	105° 29' W	7,740 (2,359)	Valley	1948
Bailey NFDRS	052001	RAWS	39° 23' N	105° 20' W	8,000 (2,438)	Ridge	1970
Fire Raws 12		FRAWS	39°04' N	105°05' W	7,990 (2,435)	Bench	Jun 18
Fire Raws 13		FRAWS	39°16' N	105°34' W	11,300 (3,444)	Ridge	Jun 21
Fire Raws 6		FRAWS	39°15'N	105°20' W	8,200 (2,499)	Ridge	Jun 21
Manitou		Exp	39.127 N	105.116 W	8,174 (2,491)	Valley	Jan 01
Denver	72469	UA	39.75 N	104.87 W	5,362 (1,634)	Valley	
Grand Junction	72476	UA	39.11 N	108.53 W	4,868 (1,484)	Valley	

[1] Station type notes: Coop: National Weather Service cooperative network generally measures precipitation totals and temperature ranges on a daily basis. RAWS/NFDRS: Standard fire weather stations measure 10-minute averages of temperature, humidity, wind, and solar radiation hourly. Rain is accumulated hourly. Maximum wind gusts are recorded for each hour. The wind sensor is 20-feet (~6 m) above ground. FRAWS: Portable incident weather stations measure 10-minute averages of temperature, humidity, and solar radiation hourly. Rain is accumulated hourly. Maximum wind gusts are recorded for each hour. The wind sensor is 6 feet (~2 m) above ground and is a 2-minute average. Exp: Station at Manitou Experimental Forest has hourly averaged temperature, wind, and humidity. UA: Upper air station where radiosondes are launched at least twice daily at 00Z and 12Z (6 p.m. and 6 a.m. MDT)

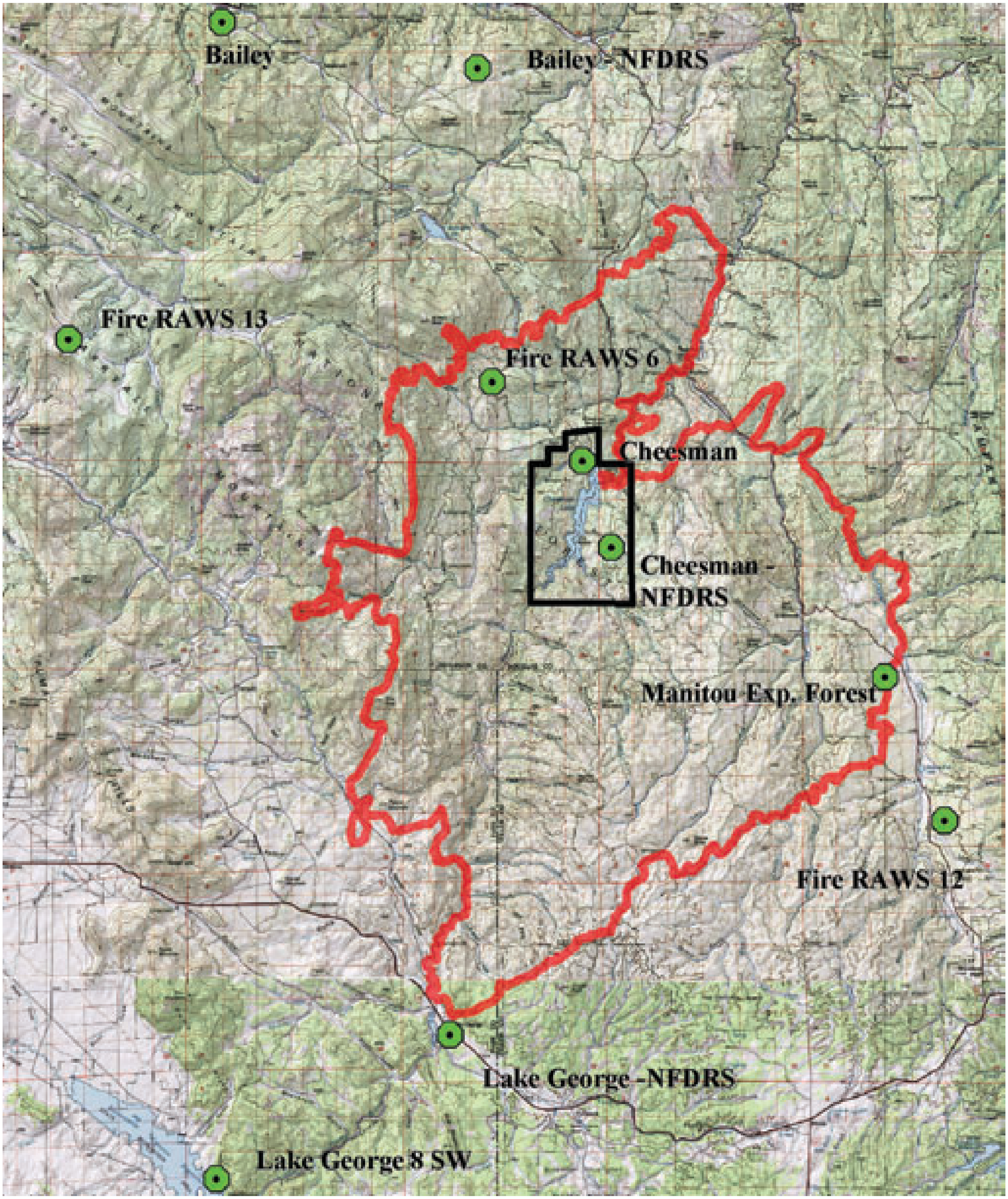

Figure 2—Location of weather stations in the Hayman Fire vicinity.

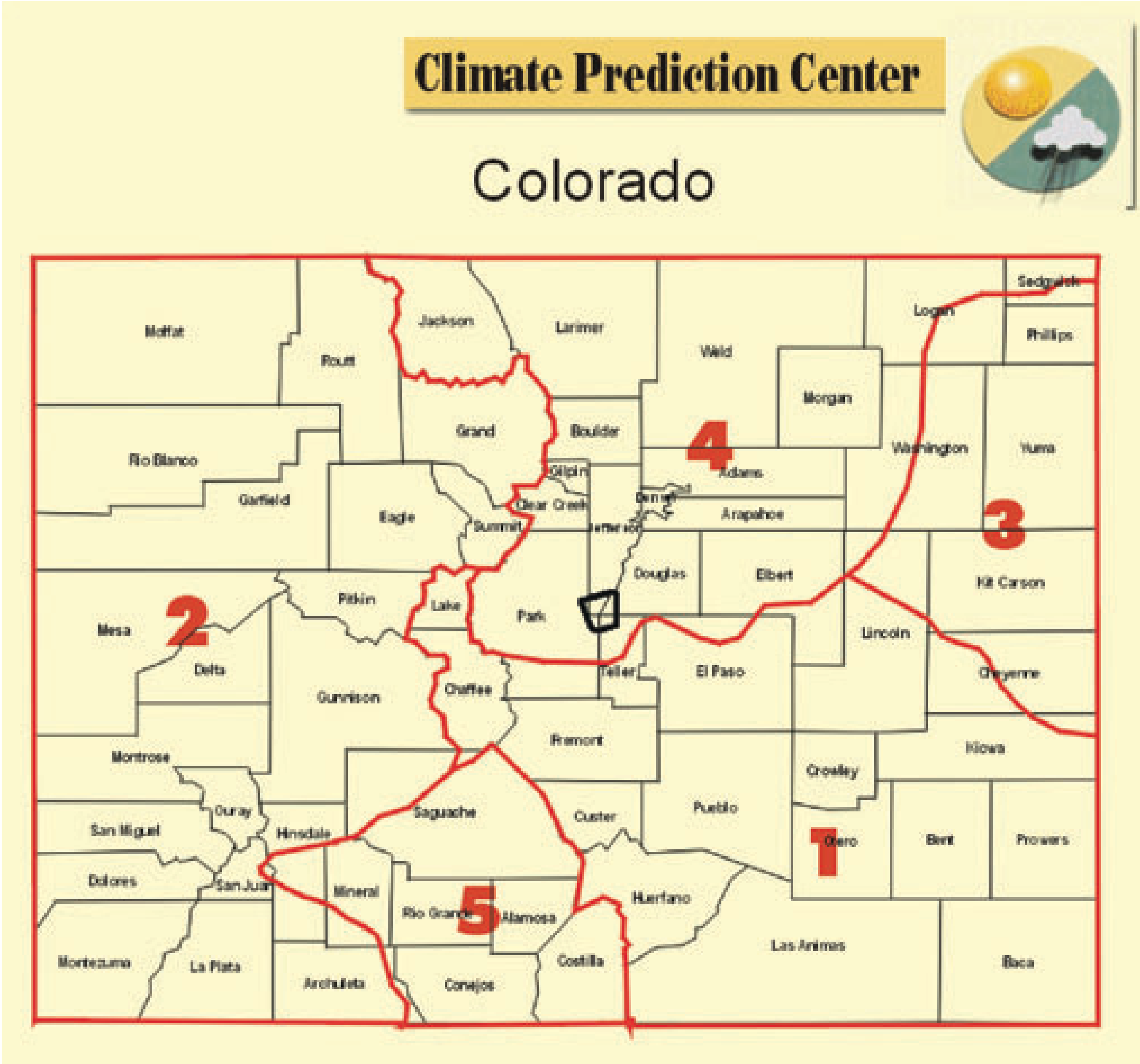

Figure 3—Approximate location of Hayman Fire within Colorado Climate Division 4. The Hayman Fire burned in four Colorado Counties: Park, Teller, Douglas, and Jefferson.

the Palmer Drought Severity Index (Palmer 1965). Based on temperatures and precipitation, the Palmer Drought Severity Index (PDSI) uses a supply and demand model to estimate soil moisture as compared to climatological averages. It is a longer term index that is compiled weekly and reflects the evolution and decay of wet and dry spells.

Figure 4 illustrates the progression of the weekly PDSI for the first week in March, April, May, and June 2002. By the first week of June all of Colorado was experiencing severe to extreme drought. The Platte River drainage was classified as being in severe drought but was surrounded by areas classified as extreme. Figure 5 depicts the Colorado snow pack as of May 1, 2002 showing almost the entire region at less than 50 percent of normal snow pack. Figure 6 illustrates snow water content data from the SNOTEL network for the South Platte Drainage. The 2001 and 2002 winter

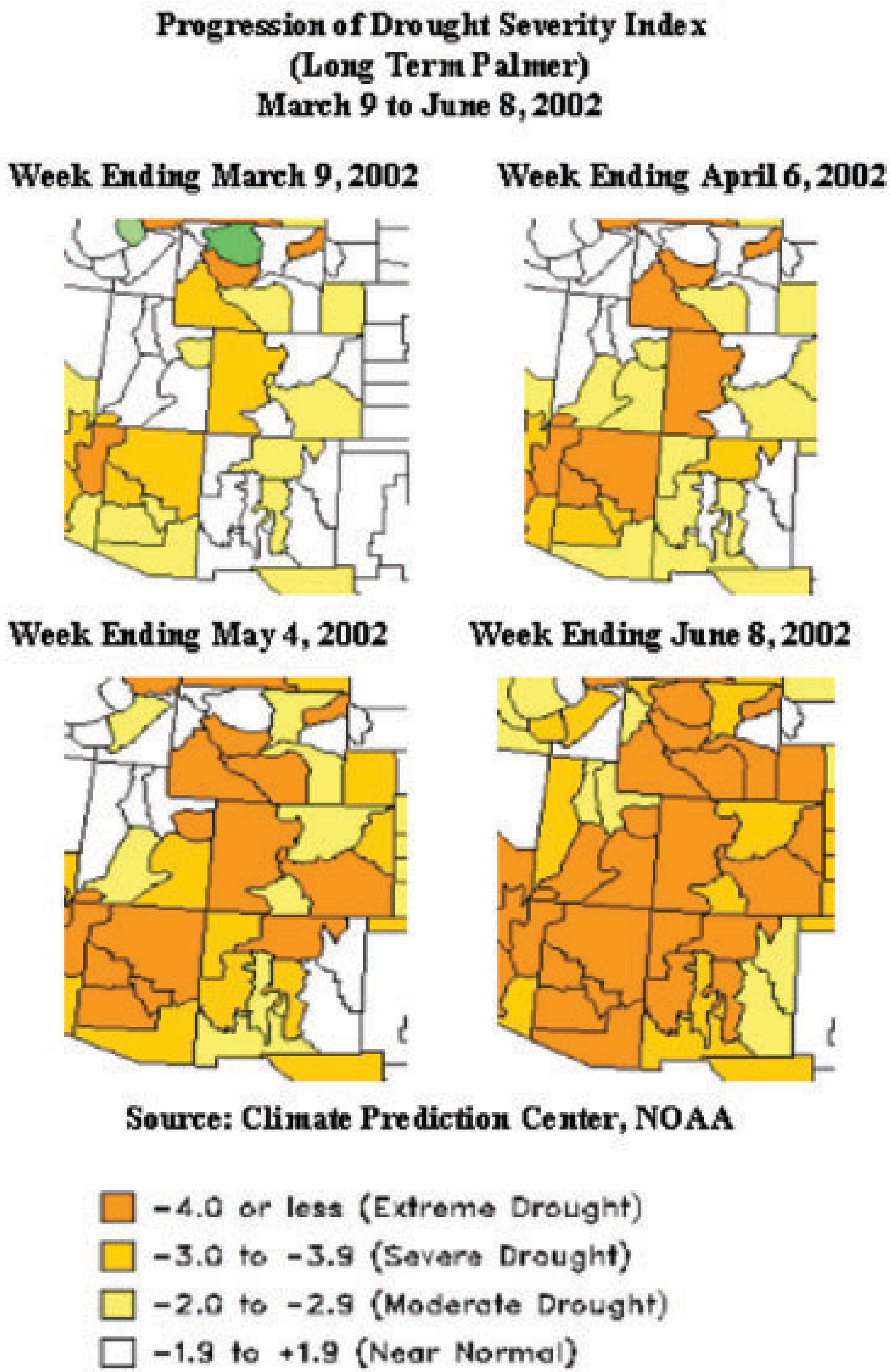

Figure 4—Regional composition of Long Term Palmer Drought Index (PDI) for spring of 2002.

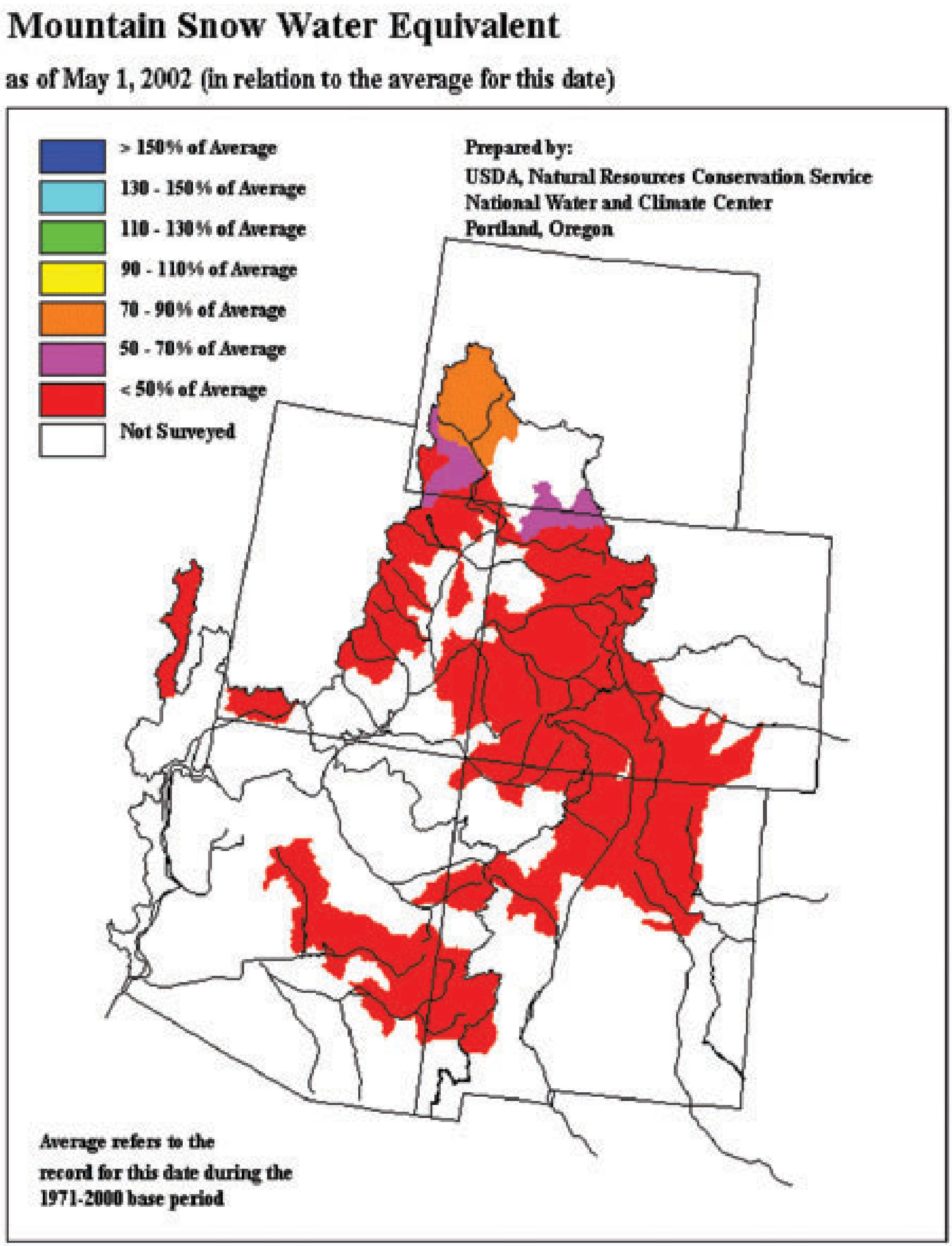

Figure 5—Regional Mountain Snow Water Equivalent as of May 1, 2002. (Source: USDA, NRCS, Portland, OR)

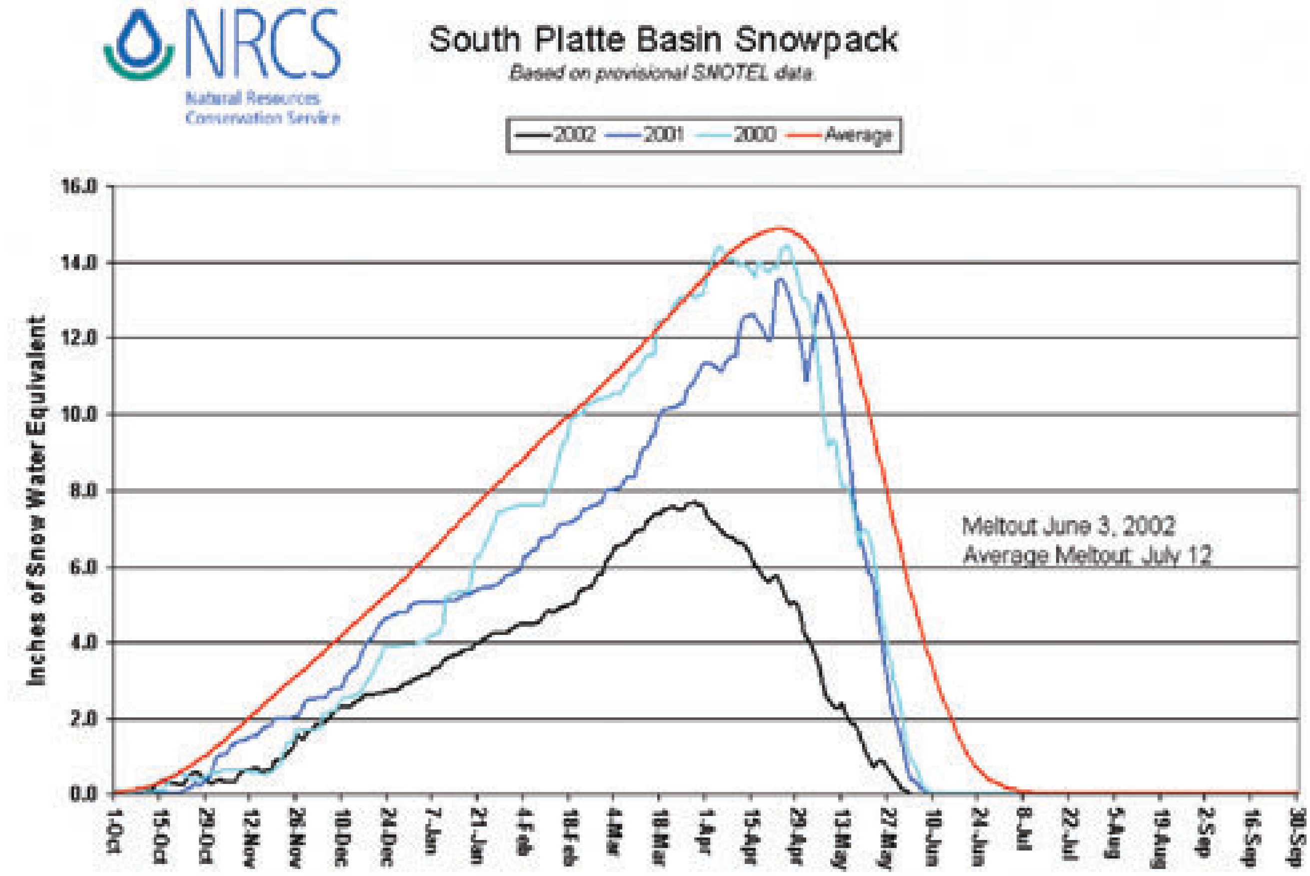

Figure 6—Water year snow water equivalent for the South Platte Basin for 2000-2002 as compared to long-term (1971-2000) average. (Source: USDA, Natural Resource Conservation Services)

precipitation deficit (black line) is clearly shown with basin area melt-out occurring almost 6 weeks sooner than normal.

Each of these regional assessments of drought, snowpack, and snow water content clearly indicates the extent of dryness in central Colorado during the winter and spring of 2002.

Weekly composites of vegetation condition or greenness are created by the Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, SD, using daily afternoon observations from the Advanced Very High Resolution Radiometer (AVHRR) on board the National Oceanic and Atmospheric Administration's (NOAA) polar orbiting weather satellites. A vegetation index, the Normalized Difference Vegetation Index (NDVI) (Goward and others 1990; Tucker and Choudhury 1987) is calculated from reflected red and near-infrared light at a spatial resolution of 0.7 miles (1.1 km), relating to the amount of actively photosynthesizing biomass and illustrating vegetation response to drought. The weekly NDVI composite images can be used to monitor the timing and extent of green-up and curing at a landscape scale (Burgan and Hartford 1993). The NDVI history extends from 1989, offering a historical context for making comparisons. The NDVI images and a calculated Departure from Average image have been shown to relate to wildfire activity (Burgan and others 1996; Bartlette and Burgan 1998). Live vegetation's contribution to fire potential has been estimated by monitoring vegetation change through the year and also by comparing the current condition to average or droughty years for geographic area long range assessments (Zimmerman and others 2000).

The progression of Departure from Average images from early March, April, May, and June (fig. 7) shows increasing effects of drought on vegetation in the Intermountain Southwest. In the images, areas of white and light gray indicate clouds and snow. Areas that are green indicate vegetation that is more green

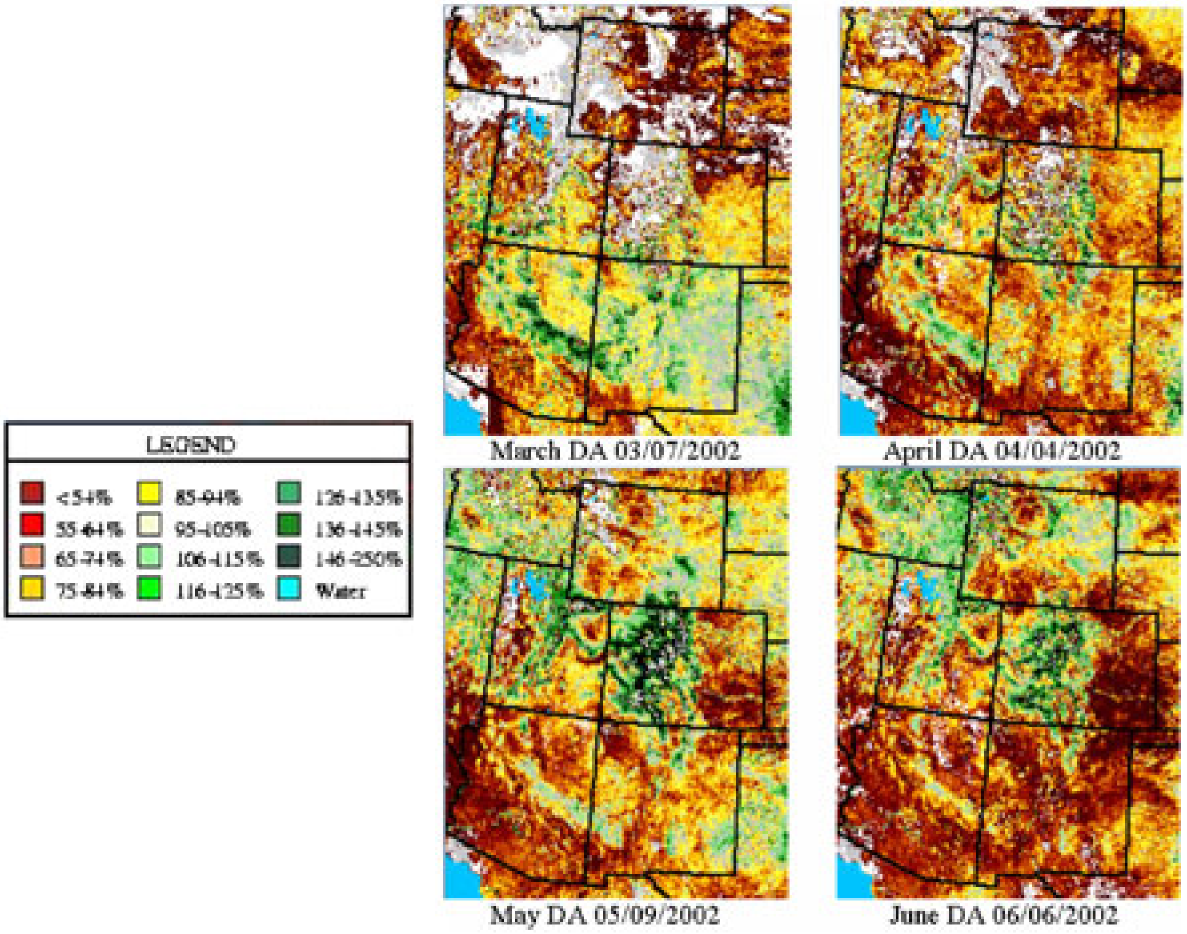

Figure 7—Water year percent of average accumulated precipitation at Lake George, Cheesman, and Baily. Data begin in 1948 at all locations. (Source: Colorado Climate Center)

than average for the time of year. Mountainous areas appear more green than average because they were snow-free at an earlier date than normal. Most of the area displays yellow to brown colors indicating vegetation that ranged from somewhat less green than average to much less green than average for that time of year. By June, even the mountainous areas are showing the effects of continued dry weather.

Figure 8 compares the NDVI image for the first week of June 2002 with images from that period of the previous two recent significant fire years 1996 and 2000, further illustrating that the 2002 drought effect on vegetation of Colorado was most severe.

Local Conditions

Individual climate monitoring locations provide more detail of prior conditions near the fire area. There are two climate stations near the fire perimeter and one inside the perimeter (fig. 2). The locations outside are Bailey, about 12.5 miles (20.1 km) northwest of the northern perimeter and 25 miles (40 km) north-northwest of the origin, and Lake George, within several miles of the point of origin. Within the fire perimeter is the Cheesman station near the Cheesman Reservoir, which provides domestic water for the Denver area. These stations have recorded daily precipitation and maximum/minimum temperature since 1948. Figure 9 illustrates the accumulated percent of average precipitation for these stations for the 2002 water year. By the end of May a slight south to north gradient of increased moisture was apparent with Lake George at 26 percent of normal, Cheesman at 37 percent, and Bailey at 60 percent of normal accumulated moisture.

The National Fire Danger Rating System (Deeming and others 1977) is a weather and climate system that describes how antecedent and current weather conditions affect moisture, and thus fire potential, of wildland fuels. The National Fire Danger Rating System (NFDRS) integrates the cumulative effects of fire

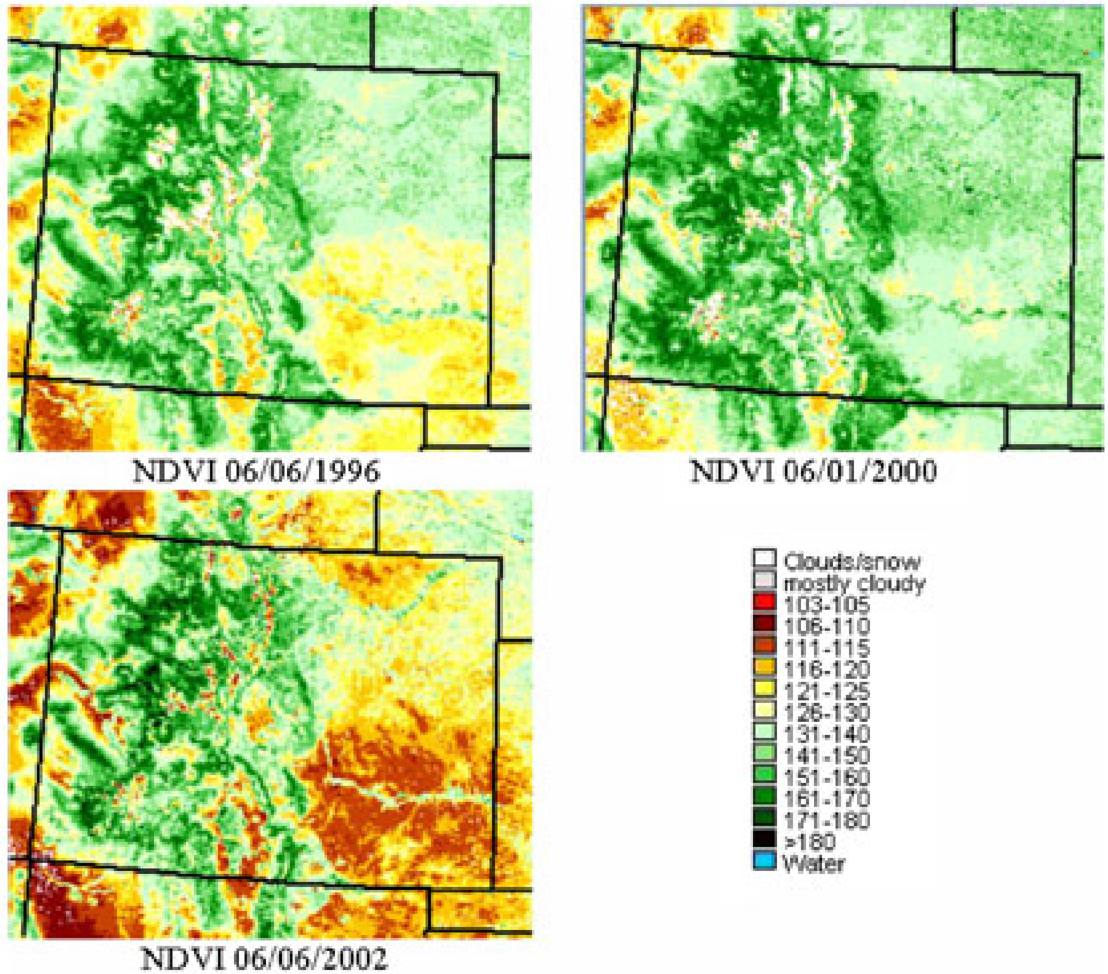

Figure 8—NFDRS comparison of 2002 versus average and two other fire years.

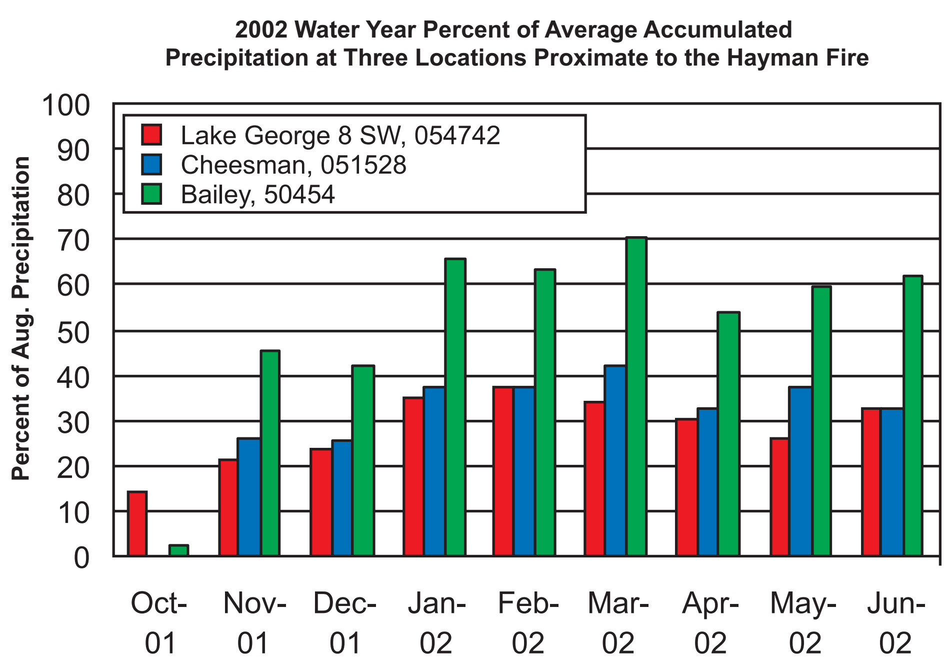

Figure 9—Progression of departure from average greenness.

weather observations into indices or components that reflect an area's fire potential. The NFDRS is based on a network of some 1,200 wildland fire weather stations that report to a central processing and archiving site. The fire weather observation is more complete than the cooperative climate observation. It includes hourly observations of temperature, relative humidity, wind speed and direction, rainfall, near-ground fuel temperature, and solar radiation. State and Federal land management agencies in Colorado operate about 70 fire weather stations during the fire season. Near the Hayman Fire, three fire weather stations were operational during the spring of 2002 (fig 2). Three additional portable "Fire-RAWS" were placed at strategic locations on the fire on June 19, 21, and 22. The models in the NFDRS process daily fire weather observations to estimate the moisture content of both dead and live fuels. Of the three stations, Lake George and Cheesman have the best climate records; Bailey has an inconsistent historical record and is not appropriate for climate comparisons.

FireFamily Plus (Bradshaw and McCormick 2000) is software for computing and analyzing NFDRS indexes from archived daily weather observations. It was used to contrast 2002 to previous fire seasons with large fires in the area near the Hayman Fire. The Buffalo Creek Fire in May 1996 and the High Meadow Fire in June 2000 both burned in excess of 10,000 acres (4,000 ha). Prior to the Hayman Fire, Buffalo Creek and High Meadow were the largest fires and the only ones exceeding 1,000 acres (400 ha) in the area since 1970.

Figure 10 illustrates the extent of the dryness of the fuels as compared to long-term averages and recent large fires of 1996 and 2000. The Cheesman station graph compares NFDRS model values of 1000-hour fuel moisture for 2002 to the 14-year history (1987 through 2000). The 1000-hour fuel moisture represents the moisture content of dead logs on the forest floor from 3 to 6 inches (7.6 to 15.2 cm) in diameter, and also the forest litter and duff several inches below the forest floor. 1000-hour fuel moisture is computed from daily observations of maximum and minimum temperature and relative humidity, and hours (not amount) of precipitation for the previous 7 days.

The Lake George graph in figure 10 contrasts NFDRS modeled woody fuel moisture for 2002 to the 30-year normal (1971 to 2000). Woody fuel moisture is a measure of the woody fuels in shrubs; it is not a model of tree moisture. The NFDRS woody fuel moisture model is based on the 1000-hour fuel moisture. Annotated on these graphs (in red) are representative values from field locations in the Hayman Fire area based on a fuel moisture monitoring program at the South Park Ranger District.

The fuel moisture trends are really quite remarkable. At Cheesman, the 1000-hour fuel moisture is at record low values during the entire month of April and most of May and June. The model value near 6 percent in early May is approaching the theoretical lower limit of the 1000-hour fuel moisture. In contrast 1996 and 2000 fuel moisture values were within normal ranges until late May. The woody fuel moisture at Lake George is even more revealing in its integration of the antecedent weather. During 2002, the NFDRS modeled woody shrub moisture content never approached that of green vegetation. Even the comparison years of 1996 and 2000 had enough moisture to allow the live fuels to reach about 100 percent, which was still below the normal rise to between 120 and 130 percent by early May.

Each piece of this analysis shows a different perspective on the integrated process of assessing the fuel moisture in the Hayman Fire area. In total, they make a compelling argument that the fuel moisture conditions in the spring of 2002 in central Colorado were among the driest seen in at least 30 years; perhaps much longer. And, unlike other years where near-normal spring conditions gave way to short-term drying and largely wind-driven fires of short duration, the fuel moisture conditions for the Hayman Fire were set up in April and May.

Weather During the Fire

The two major fire activity periods, June 8 to10 and 17 to 19, were both associated with the prefrontal air of associated surface cold fronts and moderate upper level troughs that brought increasing winds, and warmer temperatures as well as subsidence (slow downward motion of air over a large area) conditions. The prefrontal air was warm and exceptionally dry. There were significant surface winds during the fire activity on June 8 and 9. The period June 17 through 19 also saw the passage of the short wave ridge prior to the trough that enhanced subsidence conditions.

Both periods were associated with high Haines Indexes at Denver. The Haines Index was 5 or 6 (moderate and high) on 63 percent of the days in June 2002 compared to the June "normal" of 44 percent described by Werth and Werth (1998). The stability term of the Haines Index was 3 on 68 percent of the soundings in June 2002, and the moisture term was 2 for 27 percent of the soundings and 3 for 38 percent of the soundings. The implication of this is that lower atmospheric moisture fluctuated more than the stability did in terms of Haines Index.

Both periods had estimated vertical wind speed profiles (based on the Denver sounding) that were favorable to large column development. The first growth period had a well-defined low-level wind maximum

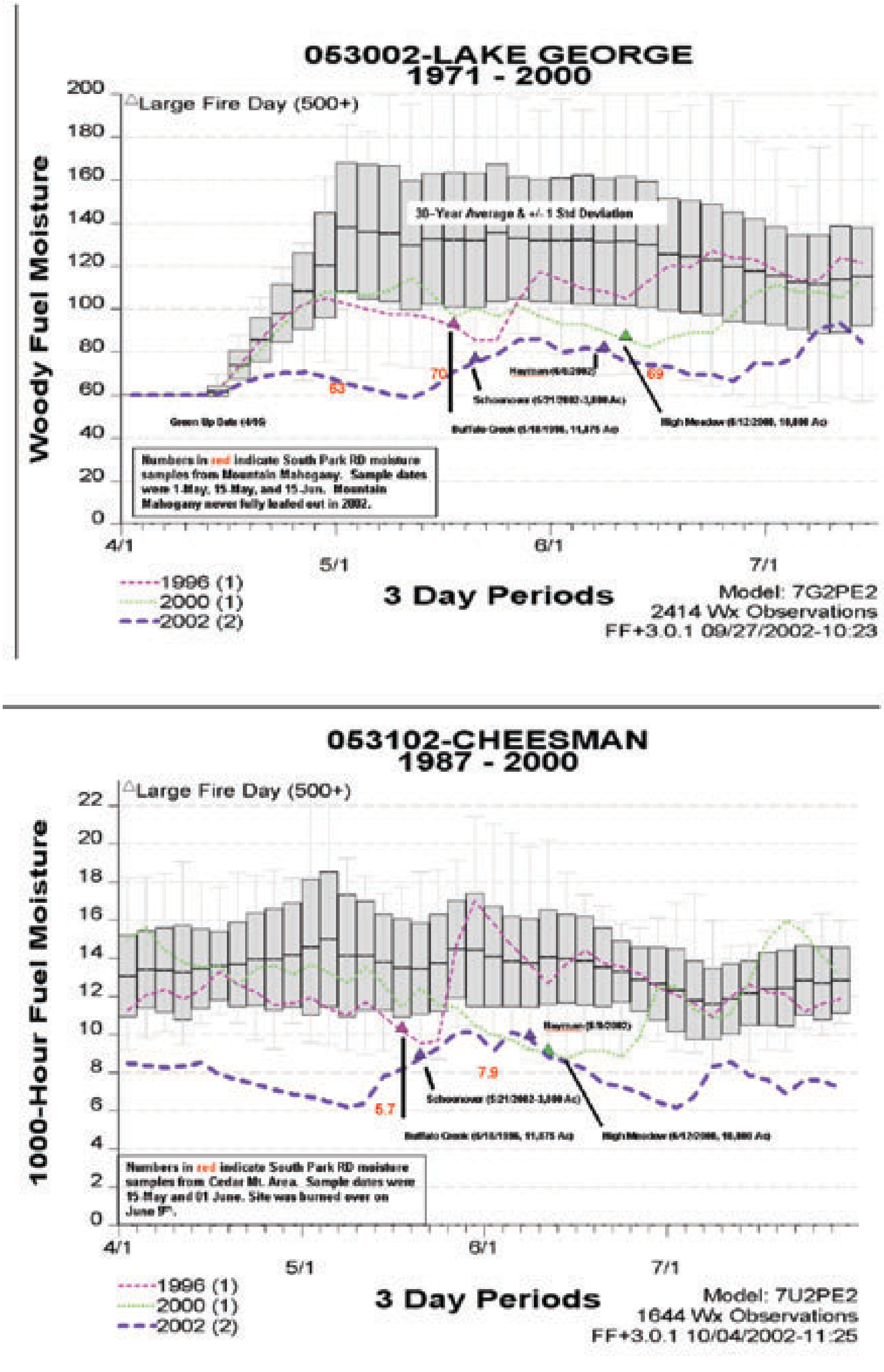

Figure 10—NDVI comparison for three severe fire years.

with wind speeds exceeding 30 mph (48 km/hr) around 1,500 feet (457 m) above the fire area that decreased to 15 mph (24 km/hr) around 4,500 feet (1,372 m) above the fire area. The second period of significant fire growth also had an inverse wind profile, but of much lower speeds and without a pronounced low-level wind maximum.

Also notable was that these events coincided with strong anticyclonic shear in the mid-level winds. Anticyclonic shear is often associated with subsidence that brings air to the surface from mid-levels of the atmosphere. This air often originates with dew points near or below 0 °F (-18 °C) and often results in single digit surface humidity as the air warms during its descent.

The high fire activity periods ended with the passage of the fronts and associated upslope winds that increased relative humidity above critical levels (12 to 15 percent). The arrival of the first monsoonal surge of the summer on June 21 started the process of increasing shower activity. A second, stronger surge on July 6 brought significant rainfall throughout the fire area allowing containment of the Hayman Fire.

Daily Weather

We break the discussion on daily weather into five 1-week periods beginning on June 1 and ending on July 7. Meteograms (time series graph of weather parameters) for the hourly fire weather observations are shown for each week.

June 1 to June 7: A low pressure trough was generally in place over the Western United States (fig 11). On June 1 and 2, eastern Colorado was east of the trough. On June 1 and 2, south winds and low relative humidity preceded the passage of a weak surface front on June 3. Surface winds out of the east and northeast on June 3 resulted in upslope flow with surface dew point temperatures rising from near 0 °F (-18 °C) on the afternoon of June 2 to near 50 °F (10 °C) on the morning of June 4. On June 4 all three weather stations received rainfall with about 0.85 inch (21.6 mm) at the northern location of Bailey, 0.12 inch (3.1 mm) at Cheesman, and only 0.04 inch (1 mm) at the more southern Lake George site near the fire's origin. This rain had virtually no lasting effect on the parched surface fuels, and

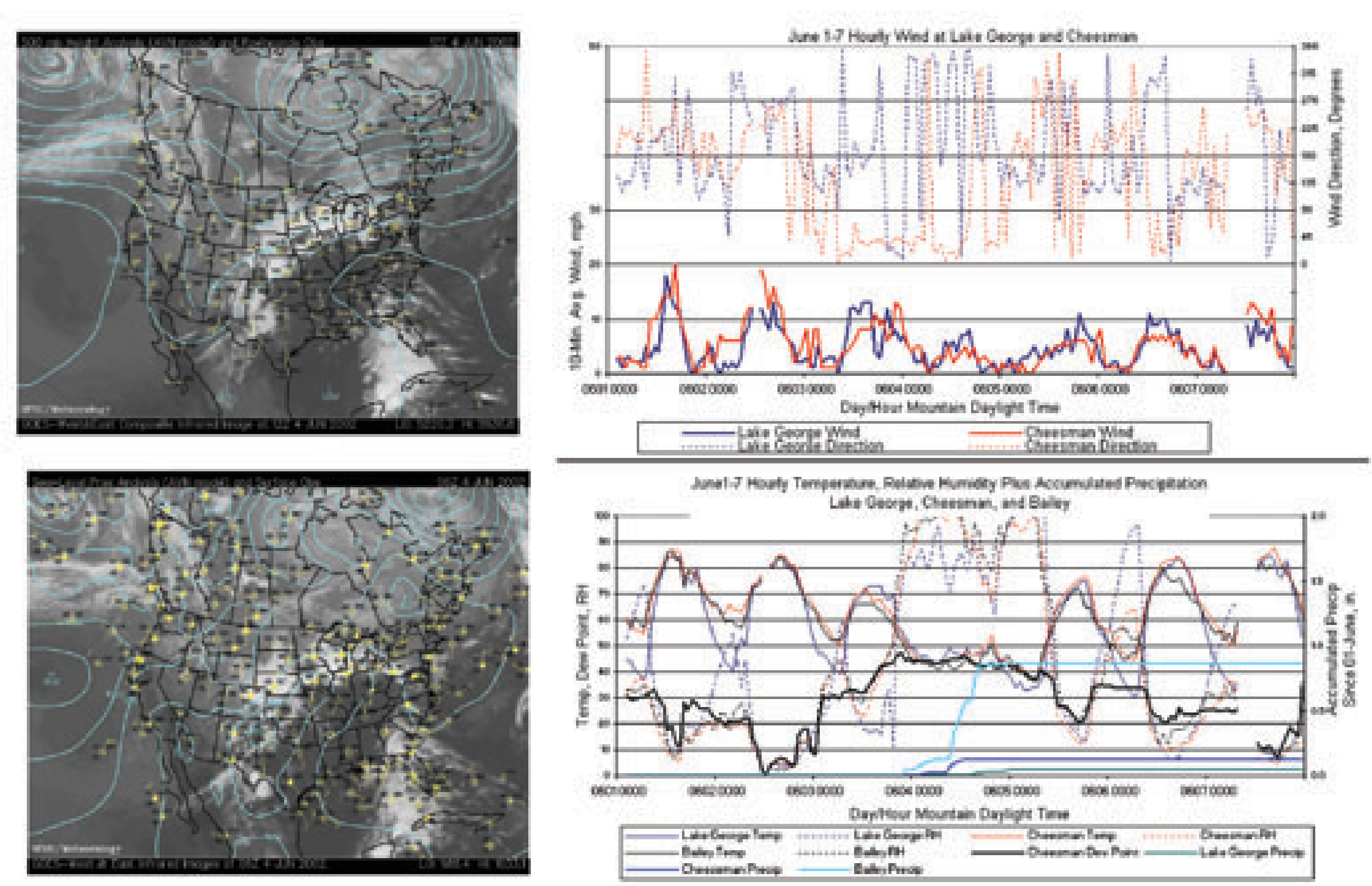

Figure 11—Upper air and surface chart for June 4 (12Z), and meteogram for week of June 1-7.

because the live fuels were essentially dormant, there was little beneficial effect on them either.

June 7 to 14: A cut-off low centered over southern British Columbia on June 7 dug south to southwestern Idaho by June 9 (fig. 12). It then moved northeasterly to southeastern Manitoba by June 12. Upper air (500 mb) winds over the Hayman Fire during that period were generally southwesterly exceeding 35 mph (30 kts). With the passage of the cut-off low, a weak ridge slowly filled in from the west by June 13 as the cut-off low filled and established a large trough over the Eastern United States.

Friday, June 7**—**A weak upper level ridge over the Central United States and a short wave trough entering the West Coast were the major weather features. This trough was amplifying and digging toward the southeast. A surface cold front extended from Minnesota through Nevada. South of the front conditions were dry with dew points in the 10 to 20 °F (-12 to -7 °C) range. In the fire area, afternoon winds turned southerly and relative humidity dropped into the single digits (table 2).

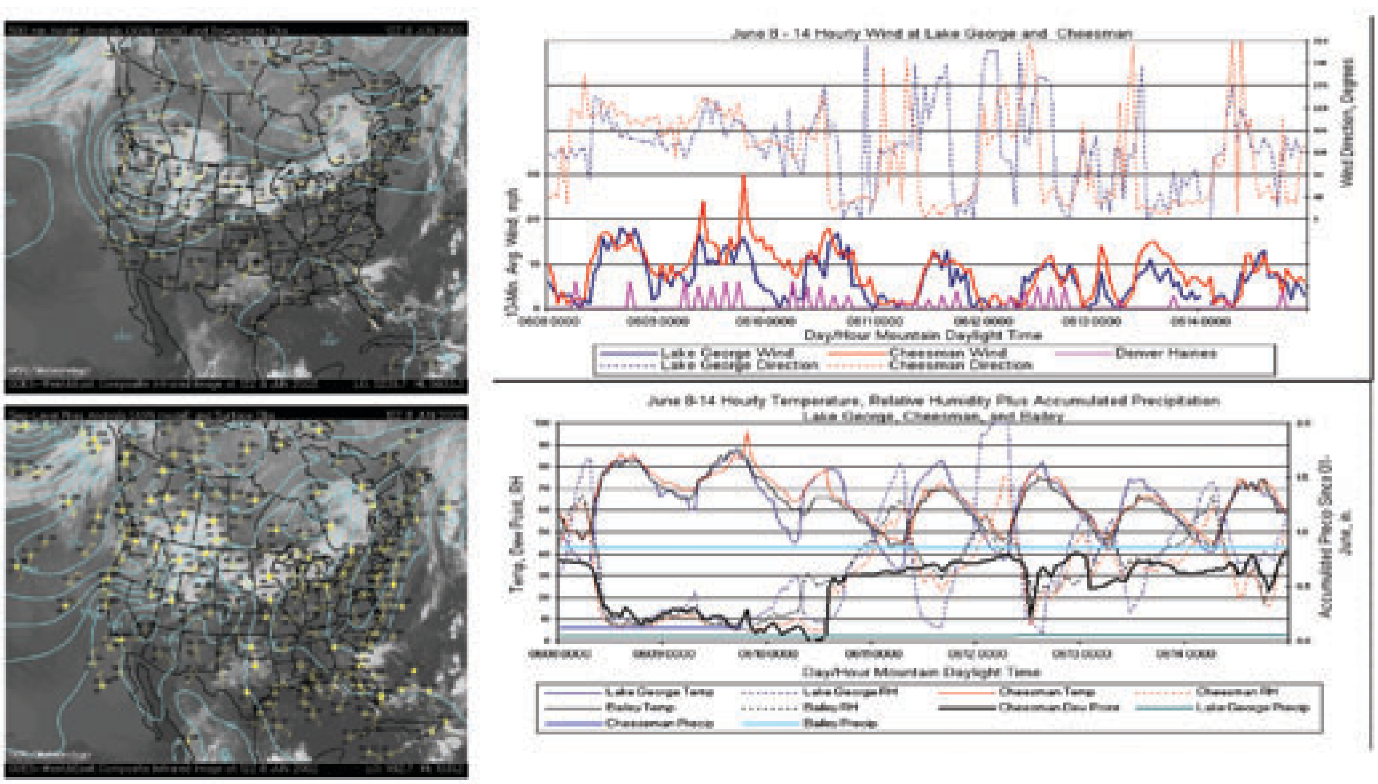

Figure 12—Upper air and surface chart for June 8 (12Z) and eteogram for week of June 8-14.

Table 2—Significant fire weather observation summary for Friday, June 7, 2002.

Station	Temp max °F	(°C)	RH min %	RH max %	Wind avg. mph	(km/hr)	Wind direct.	Wind gusts mph	(km/hr)	Gust direct.	Rain in. (mm)
Cheesman	88	(31)	5	36	10-12	(16-19)	S,SW	30	(48)	SW	
Lake George	85	(29)	7	66	7-10	(11-16)	W	32	(52)	NW	
Bailey	81	(27)	7	38	6-7	(10-11)	SW	23	(37)	W	
Manitou	83	(28)	10	70	9-10	(15-16)	SW				
Denver Haines Index			AM	6-High	PM		6-High				

Saturday, June 8 — The upper level tough over northeastern Oregon amplified and closed off, and the upper level ridge over the east held its place causing increasing southwesterly winds over Colorado. The lower atmosphere was warm and dry; the morning and evening Haines Index at Denver was 6. The surface front intensified, running from a low over central Montana to western Wyoming, and northern Utah and central Nevada. Conditions ahead of the front were dry with dew points near 10 °F (-12 °C) and gusty westerly winds. Prefrontal winds in the fire area became southerly around 10 a.m. on Saturday as the front approached from the north. Winds remained above 15 mph (24 km/hr) all day with gusts exceeding 30 mph (48 km/hr) (table 3). Near midnight the winds subsided to below 10 mph (16 km/hr), but the relative humidity was only 14 10, and 11 percent at Lake George, Cheesman, and Bailey, respectively.

Sunday, June 9 — The closed upper level low moved over Idaho with a broad low pressure system over the Great Basin. Upper level flow over the Rockies was strong from the southwest. Strong anticyclonic shear associated with the onset of a band of stronger upstream winds (a jet streak) was evident over central Colorado. Winds at 500mb were 109 mph (95 kts) at Salt Lake City, UT, 52 mph (45 kts) at Grand Junction, CO, and 23 mph (20 kts) at Denver. The forward, anticyclonic-shear sides of jet streaks are associated with subsidence that can transport extremely dry air aloft toward the surface. This subsidence condition started on the afternoon of June 8 and continued through midday on June 10. A strong surface cold front ran from a low in central South Dakota through northern Colorado, central Utah, and southern Nevada. Strong southwest surface winds were blowing from the Great Basin to Colorado. The lower atmosphere was warm and dry; temperatures at 500 mb over Colorado were a warm 21 °F (-6 °C). Steady southerly winds during the night of June 8 and morning of June 9 inhibited radiational cooling and kept the surface exposed to warm dry air in the lower levels of the atmosphere. Minimum overnight temperatures only reached 69 °F (21 °C) at Cheesman (the warmest overnight low temperature of the month) and 60 °F (16 °C) at Lake George. With dew points in the teens, overnight (Sunday morning) humidity only recovered to 22 percent at Lake George and 12 percent at the ridge-top Cheesman location (table 4). At midnight on

Table 3—Significant fire weather observation summary for Saturday, June 8, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	86 (30)	6	63	14-17 (23-27)	SW	30-37 (48-60)	SW	
Lake George	84 (29)	8	83	14-18 (23-29)	S,SW	32-36 (52-58)	S,SW	
Bailey	84 (29)	8	83	14-18 (23-39)	S,SW	32-36 (52-58)	S,SW	
Manitou	83 (28)	10	92	10-12 (16-19)	S,SW			
Denver Haines Index		AM	6-High	PM	6-High			

Table 4—Significant fire weather observation summary for Sunday, June 9, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	85* (29)	5*	12	15-20 (24-32)	S-SW	30-45* (48-72)	S-> SW, SE	N/A*
Lake George	87 (31)	7	22	10-15 (16-24)	S-SW	28-38 (45-61)	S-> SW, SE	
Bailey	88 (31)	5	15	8-11 (13-18)	SW	20-25 (32-40)	SW	
Manitou	86 (30)	8	33	10-15 (16-24)	S-SW			
Denver Haines Index		AM	6-High	PM	6-High			

* The 18:53 observation at Cheesman had a temperature spike to 96 degrees F (36 °C) with a wind gust to 84 mph (135 km/hr) as the fire burned around the weather station. The temperature at 17:53 was 84 °F (29 °C) and at 19:53 was 85 °F (29 °C). Both these readings are fire induced. The fire damaged the solar radiation sensor and most likely the precipitation gauge (there was 0.01 in (0.3 mm) recorded on the gauge at the 18:53 observation; no more until the station was rehabilitated on June 27). There are two periods on June 17 and 18 where the relative humidity sensor is suspect but overall the Cheesman station appeared to be operating sufficiently to use wind, temperature and humidity.

June 9 the relative humidity at Cheesman was 6 percent and had been 12 percent or less for 38 straight hours, and from 9 a.m. until midnight wind gusts exceeded 30 mph (48 km/hr) for 11 of the 16 hours. Figure 13 displays hourly weather at Cheesman from the evening of June 7 prior to the ignition on June 8, through June 11.

On Sunday, Denver launched radiosondes for upper air soundings at 12 15 18, 21, and 00Z (6 a.m., 9.a.m., noon, 3 p.m., and 6 p.m.) The Haines Index was 6, 5, 5, 6, and 6 at those times. Windspeed profiles above the fire area were estimated from the soundings at Denver using a base fire area altitude of 8,500 feet (2,591 m). Figure 14 illustrates the estimated windspeed profiles above the fire area at four times. From 9 to 11 a.m. wind gusts were 41, 50, and 37 miles per hour (66, 81, and 60 km/hr), which are consistent with the low-level jet identified at the 12Z and 15Z soundings in fig 14.

Monday, June 10 — The closed upper level low moved over Montana with strong flow over most of the Rockies with some veering of wind direction. Anticyclonic shear was still located over central Colorado. At the surface the low had moved over northern South Dakota with a cold front from the low to northwestern Kansas and northeastern Colorado. The cold front was moving down the Front Range Highs were in the 100s °F (38 °C) south of the front with 90s °F (32 °C) elsewhere. Conditions south of the front were dry, and gusty southwesterly winds were evident west of the Front Range.

The front in northeastern Colorado began affecting the northern locations near Bailey by 8 a.m. when winds shifted to the northeast, causing upslope conditions rising dew point and relative humidity. Winds shifted to the northeast at Manitou and Cheesman between 1 and 2 p.m., and humidity rose steadily all afternoon. At Lake George winds finally turned north by about 1700 hours, and relative humidity rose from the teens to the 30s (table 5). The evening Haines Index dropped to a 3 as a result of the moistened lower atmosphere (the 700 mb dew point depression dropped from 75 to 46 °F [24 to 8 °C] during the day). There was some light precipitation in the fire zone but no measurable rain was recorded at the fire weather stations.

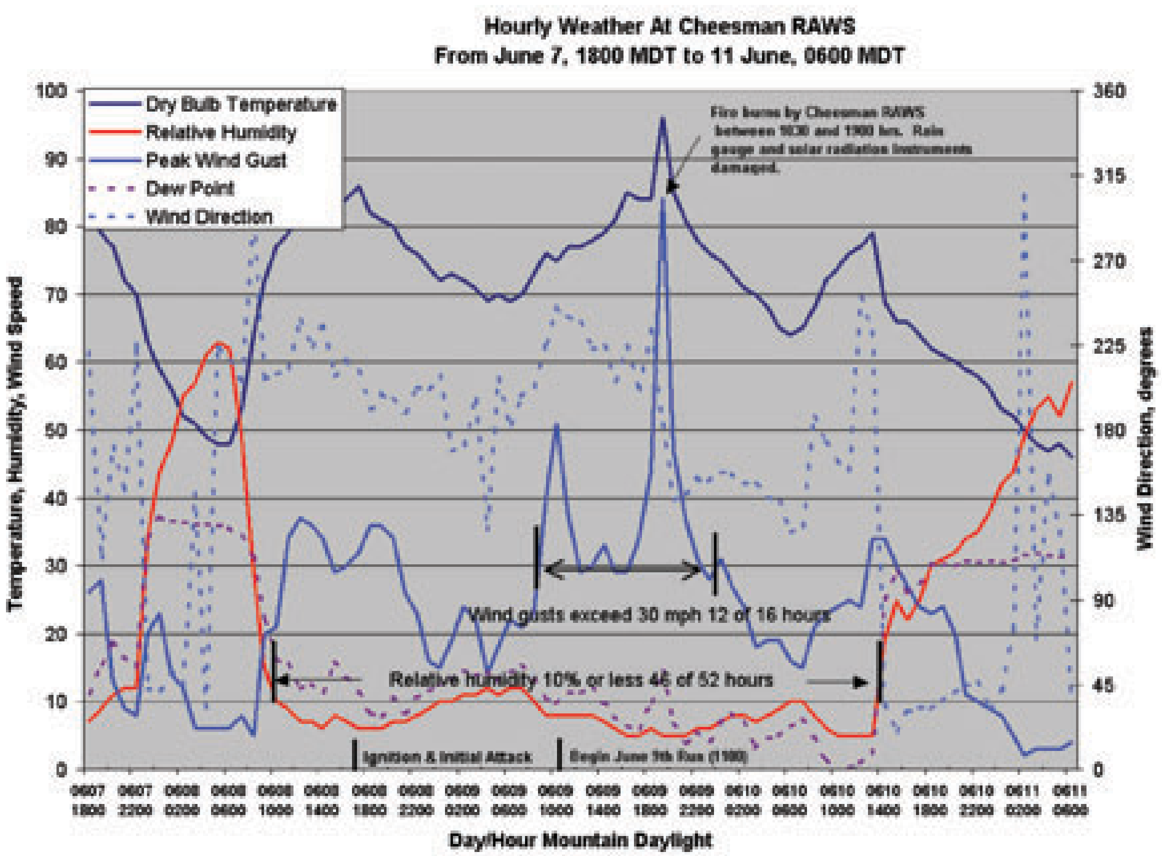

Figure 13—Hourly weather at Cheesman during initial attack and fire run on June 9.

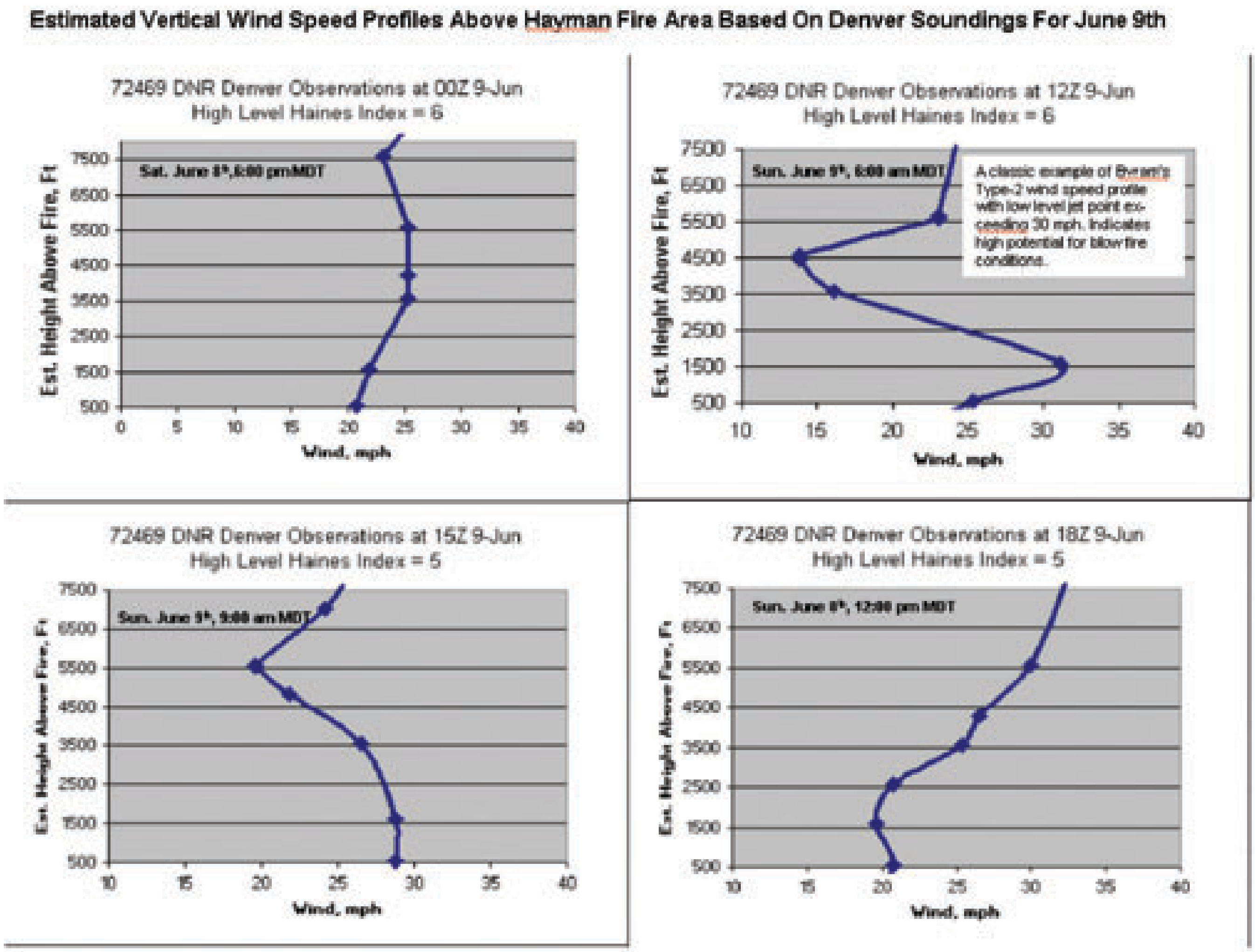

Figure 14—Estimated wind speed profiles at elevations above the fire area based on four soundings from Denver. 12Z 9 Jun and 15Z 9 Jun soundings illustrate low-level jets that are conducive to large column development.

Table 5—Significant fire weather observation summary for Monday, June 10, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	79 (26)	5	38	10-14 (16-23)	SE->NE	20-24 (32-39)	NE,W	
Lake George	79 (26)	8	43	7-17 (11-27)	SW,W,N	24-32 (39-52)	S->N	
Bailey	71* (22)	11*	46	5-8 (8-13)	SW->NE	25,10-15 (40, 16-24)	W-> SE	
Manitou	76 (24)	11	72	6-11 (10-18)	S->N			
Denver Haines Index		AM	5-Mod	PM	3-Low			

* Bailey's minimum Max Temp/Min RH occurred at 0100 on the 10th. By 10 am winds had switched from NW to NE and humidity was up to 29 percent and continued to rise throughout the day.

Tuesday, June 11 — The upper level low continued to move eastward over northeast Montana and cooler air moved in aloft over Colorado. The surface low moved into Minnesota with a front extending from the low to Kansas to southeastern Colorado and north-central Colorado. Cooler conditions were experienced. A few rain showers occurred north of the front. The frontal convergence zone was over the fire. Winds aloft were southwest. Surface winds were light and southeasterly in the morning and humidity was high. The cooler air mass kept temperatures lower and humidity higher all day. Lake George may have been near the frontal boundary as a brief wind shift mid-morning from the southeast to southwest allowed the temperature to reach 83 °F (28 °C) (relative humidity was 6 percent) for a few hours (table 6). Manitou recorded a light shower at midnight; no other stations recorded rainfall.

Wednesday, June 12 — The upper level low moved into southeastern Saskatchewan as it moved over the long wave ridge. Winds over the Rockies aloft began to weaken. Temperatures over Colorado at 500 mb were 18 °F (-8 °C). Other upper level features were a ridge in western Texas that had retrograded from the Southeastern United States and a ridge off the West Coast. A surface high was moving southward over Montana. A surface low formed in New Mexico. This generated upslope flow over all of Colorado. Morning dew points at the fire weather stations rose to the 40s °F (4 °C), and there was good overnight humidity recovery at all locations The upslope flow generated scattered showers in northeastern Colorado; in the fire zone Lake George and Manitou saw showers in the early morning. By 11 a.m. at Lake George and noon at Cheesman, there was a brief period of southwest wind that dropped relative humidity to single digits (table 7). This lasted 1 hour at Cheesman and 4 hours at Lake George where the relative humidity was 4 percent at 3 p.m. By 4 p.m. the wind turned northeast again, and the dew point rose to 37 °F (3 °C).

Thursday, June 13 — The upper level low moved east-southeast into Minnesota and deepened, and an upper level ridge moved over West Coast. A closed high at 500 mb was located over northern Mexico. Flow over the Rockies was west-northwest around the closed high and air at 500 mb cooled. At the surface, a clockwise circulation around a surface high pressure moving southeast out of eastern Montana created upslope (north, northeast) flow over Colorado. All locations were 10 °F (5 °C) cooler with good overnight humidity recovery at all locations. Some showers formed in southeastern Colorado (table 8).

Friday, June 14 — The upper level low moved into southern Wisconsin and deepened. The upper level ridge on the West Coast moved onto an Idaho-Four Corners-northwestern New Mexico axis. The upper level flow was now northwesterly over Colorado. Temperatures aloft remained at 14 °F (-10 °C). The surface front pushed well south from central Alabama to Louisiana, southern Texas, and northern Mexico. A

Table 6—Significant fire weather observation summary for Tuesday, June 11, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	72 (22)	23	61	9-11 (15-18)	N,NE	20-25 (32-40)	N,NE	
Lake George	83 (28)	6	81	8-13 (13-21)	SE,W,N	21-32 (34-52)	N,NW	
Bailey	70 (21)	29	64	4-6 (6 -10)	NW-> NE	14-17 (23-27)	E-SE	
Manitou	72 (22)	28	91	5-7 (8-11)	N,SE			.03 (.8)
Denver Haines Index		AM	2-V. L.	PM	4-Low			

Table 7—Significant fire weather observation summary for Wednesday, June 12, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	78 (26)	8	76	8-12 (13-19)	NE	15-25 (24-40)	SW-> NE	
Lake George	82 (28)	4	76	6-10 (10-16)	NW,N	15-31 (24-50)	NW.N	.01 (2.5)
Bailey	75 (24)	22	58	7-9 (11-15)	NE	17-21 (27-34)	E	
Manitou	75 (24)	10	99	7-10 (11-16)	SW->SE			.04 (1.0)
Denver Haines Index		AM	3-Low	PM	5-Mod			

Table 8—Significant fire weather observation summary for Thursday, June 13, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	67 (19)	28	49	12-15 (19-24)	N,NE	24-28 (39-45)	N,NE	
Lake George	74 (23)	13	59	7-11 (11-18)	N,NE	18-23 (29-37)	N	
Bailey	65 (18)	30	49	5-8 (8-13)	NE	13-17 (21-27)	E,NE	
Manitou	67 (19)	34	96	6-8 (10-13)	NE			
Denver Haines Index		AM	2-V. L.	PM	3-V. L.			

surface high over northeastern Colorado and Nebraska was still producing upslope flow with light winds. A few showers occurred in southeastern and central Colorado. Cumulus formed on the southern half of the Front Range, thunderstorms were evident over the fire zone by 2 p.m. Radar estimates of precipitation in the fire area were 0.10 inch (2.5 mm), but no rain was recorded at the fire weather stations (table 9). The lower atmosphere was moist and Haines Indexes were low.

June 15 to June 21: The period started off with a deep trough over the eastern Great Lakes, a cut-off low off the Washington-Oregon coast, and a weak ridge over the Great Basin (fig. 15). The western low moved eastward enhancing an upper level ridge over the Central Rockies with northwest flow on June 16. By June 18 the ridge had moved east with an axis from Minnesota to New Mexico. The trough moved quickly across northern Idaho, Montana, and North Dakota again creating southwest flow over the Central Rockies on June 19. By June 20 another weak trough formed along the West Coast, but this time it was much farther south and was able to entrain some subtropical moisture as it deepened over southern California and Baja.

Saturday, June 15 — An upper level ridge was the main feature over the Rockies extending from southeastern British Columbia to Idaho and northern Baja. Winds aloft weakened to northwest at 23 mph (20 kts). Temperatures warmed to 16 °F (-9 °C) at 500 mb. The upper level low was now over Lake Huron. Another upper level low was over the Pacific 500 miles (805 km) west of Portland, Oregon. A weak surface low formed over Utah, and the Plains high pressure had moved over Oklahoma and weakened. This kept an easterly, upslope component to the wind most of the day. A few showers occurred in southeastern Colorado, and a thunderstorm formed west of the fire causing some local gusts around noon. Under the ridge, western Colorado was dry with dew points in the 5 to 20 °F (-15 to -7 °C) range. Significant local weather events for June 15 are listed in table 10.

Sunday, June 16 — An upper level trough from Great Lakes to Louisiana and a ridge from British Columbia to Idaho-Utah-Baja kept flow over the Rockies from the northwest and increased winds to 46 mph (40 kts). Temperatures over central Colorado cooled at 500 mb to 14 °F (-10 °C). A thermal low over Utah with a surface high over northwestern Kansas kept moist flow over Colorado. Rain was common in the southeast gradient flow all over Colorado. Dew points were in the 40s and 50's °F (4 to 10 °C) over the entire State during the morning hours, promoting good overnight humidity recovery. Cumulus formed on the mountains with thunderstorms over the fire area by 5 p.m. Radar estimated rain amounts were 0.1 inch (2.5 mm) scattered near the fire. However, no rain

Table 9—Significant fire weather observation summary for Friday, June 14, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	74 (23)	16	61	8-12 (13-19)	N,NE	20-29 (32-47)	NE,S	
Lake George	73 (23)	35	73	6-13 (10-21)	SE	20-28 (32-45)	SE,S	
Bailey	73 (23)	17	67	5-8 (8-13)	NE	15-18 (24-29)	NE	
Manitou	71 (22)	30	95	8-10 (13-16)	SE			
Denver Haines Index		AM	2-V.L.	PM	4-Low			

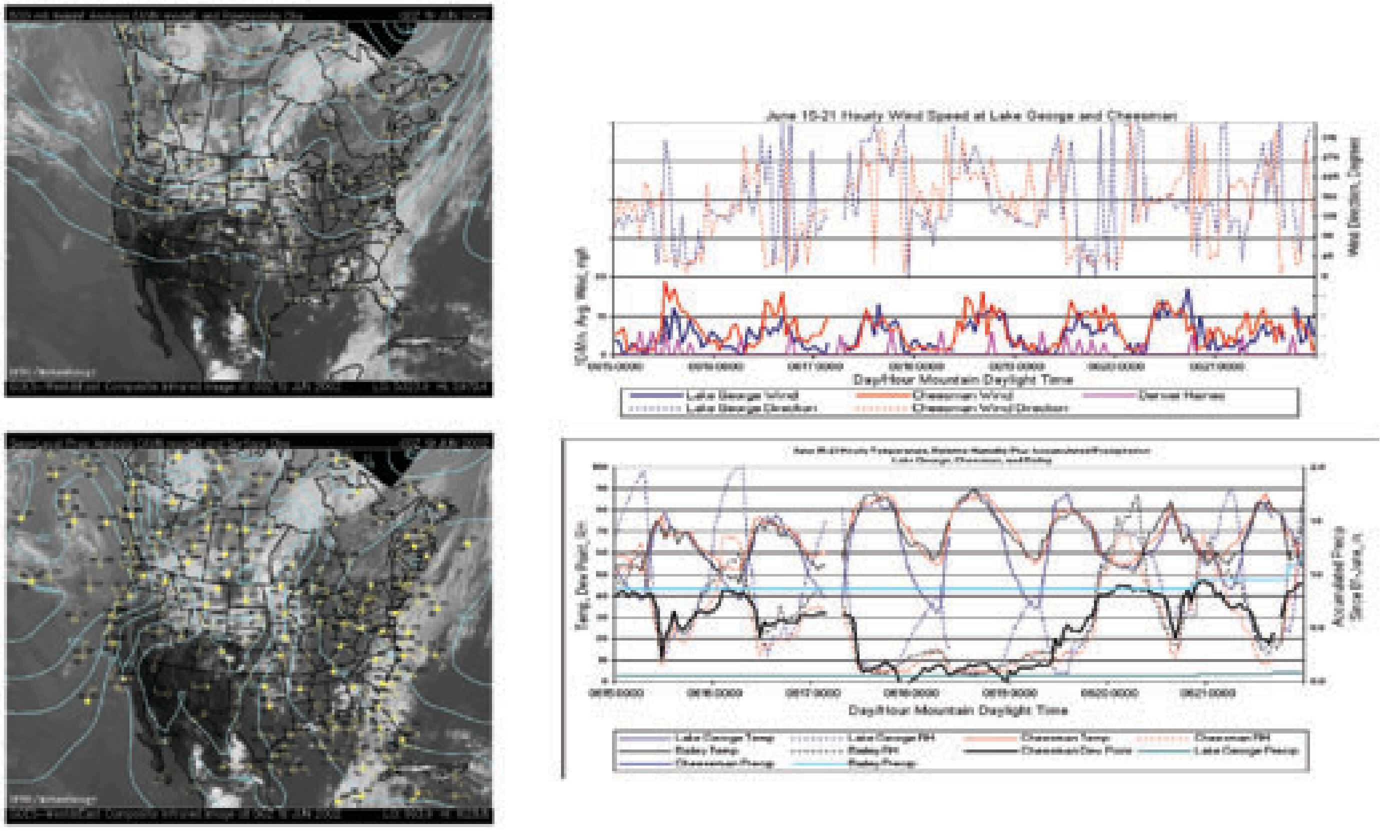

Figure 15—Upper air and surface chart for June 19 (00Z) and meteogram for week of June 15-21.

Table 10—Significant fire weather observation summary for Saturday, June 15, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	77* (25)	8*	64	11-19 (18-31)	NE	20-30 (32-48)	N,NE	
Lake George	79 (26)	11	98	9-12 (15-19)	NW,NE	26-31 (42-50)	NW, NE	
Bailey	75 (24)	20	59	3-5 (5 -8)	NE	15-19 (24-31)	N	
Manitou	75 (24)	16	98	8-12 (13-19)	N			
Denver Haines Index		AM	6- High	PM	4-Low			

* At 10:53 Cheesman recorded one hour of 77 degrees F (25 ° C) and 8 percent humidity following 3 hours of light southeast winds. By 11:53 the wind had become northeast, temperature dropped to 67 °F (19 °C) and humidity rose to 17 percent and generally increased all day under a northeast wind.

was recorded at the four fire locations. Surface winds were light with easterly components (table 11).

Monday, June 17 — The upper level ridge shifted eastward over the Northern Rockies with the axis from eastern Montana-Wyoming-Utah-Baja. Winds aloft shifted to more westerly at 23 to 35 mph (20 to 30 kts). An eastward moving upper level low over British Columbia supported a surface low in southern Saskatchewan. A surface trough in the lee of the Rockies produced southeast flow on the plains and southwesterly flow over western Colorado. A few showers and thunderstorms formed in extreme eastern Colorado. In the fire area, morning winds were southwest at the surface and west-southwest aloft. Cumulus formed over the fire in the mid-afternoon, but no rain resulted. Temperatures rose to the mid 80s °F (upper 20's °C) and dew points dropped from morning values in the 30s °F (0 °C) to single digits by early afternoon as subsidence conditions from the ridge began influencing the area (table 12). Relative humid-

Table 11—Significant fire weather observation summary for Sunday, June 16, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	77 (25)	12	68	10-16 (16-26)	NE	21-28 (34-45)	NE	
Lake George	78 (26)	12	100	7-10 (11-16)	NW,NE	18-21 (29-34)	NW	
Bailey	75 (24)	23	60	6-8 (10-13)	NE	13-21 (21-34)	NE	
Manitou	73 (23)	23	98	8-10 (13-16)	NNE			
Denver Haines Index		AM	4-Low	PM	5-Mod			

Table 12—Significant fire weather observation summary for Monday, June 17, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	88 (31)	5*	35	8-10 (13-16)	SW-> NW	27-29 (44-47)	SW, NW	
Lake George	85 (29)	5*	81	10-13 (16-21)	W->NW	26-57 (42-92)	W, NW	
Bailey	88 (31)	*4	44	4-6 (6-10)	W->NW	21-24 (34-39)	SW	
Manitou	81 (27)	9	91	6-8 (10-13)	S,SW,SE			
Denver Haines Index		AM	5-Mod	PM	6-High			

At 10:53 Cheesman relative humidity dropped from 14 to 6 percent, then 5 percent at 11:53 where it remained until midnight. Lake George was below 10 percent from 10:53 to 21:53 (11 hours), Baily from 10:53 to 22:53. Manitou was below 10 percent for 3 hours.

ity dropped to single digits by noon as surface winds became west to northwest. The evening Haines Index at Denver of 6 reflected the drying and warming of the lower atmosphere.

Tuesday, June 18 — The upper level low was now over northwestern Washington. The ridge continued to move eastward, rapidly passing over Colorado early with an axis from Minnesota-Nebraska-New Mexico. This short wave ridge brought increased anticyclonic flow with warmer and drier air over the Central Rockies. The relative humidity at 700mb (approximately 10,000 feet [3,048 m]) was 11 percent at Grand Junction and 14 percent at Denver. The anticyclonic flow generated subsidence conditions. By evening the Denver relative humidity had dropped to 11 percent at 700 mb and 7 percent at the surface. The surface trough in the lee of the Rockies deepened and formed a surface low over Nebraska. A dryline formed from the surface low in Nebraska to New Mexico, and a cold front extended from southern Manitoba to northern Montana. The location of the Nebraska low northeast of Colorado continued producing westerly flow over central and eastern Colorado. The winds were not excessively strong. Winds aloft were west-southwest at 17 mph (27 km/hr), but the air was warm and dry. There was poor overnight humidity recovery at all locations, and both the morning and evening Haines Index values at Denver were 6 (high) (table 13).

Table 13—Significant fire weather observation summary for Tuesday, June 18, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	88 (31)	5*	15	14-16 (23-26)	SW	27-32 (44-52)		
Lake George	89 (32)	4*	40	10-12 (16-19)	SW,SE	28-37 (45-52)	SW, SE	
Bailey	90 (32)	3*	14	5-7 (8-11)	S,SW	19-43 (31-69)	SE,S, SW,N	
Manitou	80 (27)	7	52	3-6 (5-10)	S			
Denver Haines Index		AM	6-High	PM	6-High			

After poor overnight recovery humidities again fell to single digits by mid-morning and remained below 10 percent until the early hours of the morning of the 19^{th}.

Wednesday, June 19 – The upper level trough moved to an axis from north-central Montana-northwest Wyoming-Utah. Winds were southwesterly over the Rockies with speeds to 23 mph (20 kts) over Colorado. The 500 mb temperatures warmed to19 °F (-7 °C). The upper level ridge axis extended from Mexico-Oklahoma-Michigan. A surface cold front developed from a surface low in southern South Dakota and pushed into western Nebraska-northern Colorado-southern Nevada. A strong dryline ran from the surface low southward into extreme western Texas. This kept the fire area in the dry, prefrontal air until the front affected the fire area during the day. Winds in the fire area strengthened and became gusty with the passage of the front, but humidities rose as dew points returned to values in the 20s and 30s °F (-7 to 0 °C) from north to south over the course of the day (table 14). By evening, thunderstorms formed over the fire zone with several locations receiving moisture around midnight.

Thursday, June 20 — A strong upper level trough moved to Minnesota leaving a weaker residual trough along the West Coast. Temperatures aloft remained at 19 °F (-7 °C) at 500 mb. The short wave pushed a surface front through Colorado with a frontal position extending from a low in Manitoba to Minnesota-Iowa-northern Kansas-northern New Mexico. This combined with a surface high in eastern Montana to establish a southeast gradient with weak upslope flow over Colorado. Rain was common in the northeastern, northwestern, and southeastern parts of Colorado. Overnight humidity recovery was good at all locations (table 15). Thunderstorms formed to the west and moved over the fire late in the afternoon. Winds aloft were west-southwest. Surface winds were generally south-southwest during the afternoon.

Friday, June 21 — The weak trough along the West Coast amplified in place bringing southerly flow over most of the Rockies. The monsoon flow that had been bottled up in Mexico for the previous several weeks surged northward. An upper level high developed over the plains with a center over Illinois. The desert thermal low increased in size and was centered over Nevada. Another weak low was centered over northern Colorado. A warm front extended eastward from this low to southeastern South Dakota-Iowa-Illinois.

Table 14—Significant fire weather observation summary for Wednesday, June 19, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	81 (27)	7*	50*	10-12 (16-19)	S->NE	23-33 (38-53)	NE	
Lake George	88 (31)	4	59	7-11 (11-18)	NE,E	21-24 (34-39)	NW, NE,E	
Bailey	79 (26)	9*	54	6-8 (10-13)	NE	14-18 (23-29)	NE	
Manitou	79 (26)	12	97	8-10 (13-16)	NNE			.30 (7.6)
FRWS-12**	81 (27)	11	91	6-8 (10-13)	SE,E	16-21 (26-34)	SE	.15 (3.8)
Denver Haines Index		AM	6-High	PM	4-Low			

* Minimum humidity values at Cheesman and Bailey were recorded at 00:53 and generally increased thru the day. The more southern stations (Manitou, Lake George) did not see the effect of the font until mid or late afternoon.

** FRWS-12 started transmitting at 1600 on June 18th.

Table 15—Significant fire weather observation summary for Thursday, June 20, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	82 (28)	11	69	12-14 (19-23)	S,SW	24-34 (39-55)	SE-> NW	
Lake George	78 (26)	29	70	10-17 (16-27)	S	20-30 (32-48)	S,SW,NE	.01 (.25)
Bailey	84 (29)	15	87	5-7 (8-11)	VRB*	18-25 (29-40)	NE, SW	.09 (2.3)
Manitou	77 (25)	31	99	10-14 (16-23)	S			
FRWS-12	75 (24)	36	93	5-12 (8-19)	SW	18-21 (29-34)	SW-> SE	
FRWS-13**	62 (17)	32	81	7-8 (11-13)	SW	20-24 (32-39)	SW	.17 (4.3)
Denver Haines Index		AM	3-V.L.	PM	5-Mod			

* Wind direction at Bailey was variable all day.

** FRWS-13 began transmitting at 1500 June 20th.

In the fire area it was clear early, but a moisture swath became evident by afternoon. Winds aloft were southwest with upslope surface winds from the southeast. Thunderstorms formed over the mountains and moved over the fire by 3 p.m. Rainfall was recorded at all fire weather stations (table 16).

June 22 to June 30: The trough passed through the area, and by June 26 a broad ridge was centered over the Central Rockies with light flow throughout the Western United States (fig. 16). This set up a period of rather benign weather with light winds, better overnight humidity recovery, and low to moderate Haines Indexes. By June 30, the ridge had moved east over the Great Lakes, and westerly flow aloft again dominated the northern tier of the Western United States.

***Saturday, June 22* —** A weak upper level trough from Nevada to Utah brought southerly flow to most of the Rockies including Colorado. Temperatures cooled

Table 16—Significant fire weather observation summary for Friday, June 21, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	88 (31)	8	64	5-12 (8-19)	SW->NE	18-20 (29-32)	SW	
Lake George	84 (29)	15	76	6-12 (10-19)	S	28-41 (45-66)	VRB*	.02 (.50)
Bailey	84 (29)	15	76	6-12 (10-19)	S	28-41 (45-66)	VRB	.23 (5.8)
Manitou	82 (28)	14	94	5-9 (8-15)	SE			.05 (1.3)
FRWS-12	85 (29)	11	66	3-7 (5-11)	S,SW	10-16 (16-26)	SW	.07 (1.8)
FRWS-13	66 (19)	20	90	6-9 (10-15)	SW	15-17 (24-27)	S,SW	.16 (4.1)
FRWS-6**								.05 (1.3)
Denver Haines Index		AM	5-Mod	PM	5-Mod			

* Wind gusts were from thunderstorms and directions were variable.
**FRWS-6 began transmitting at 1900 on June 21st.

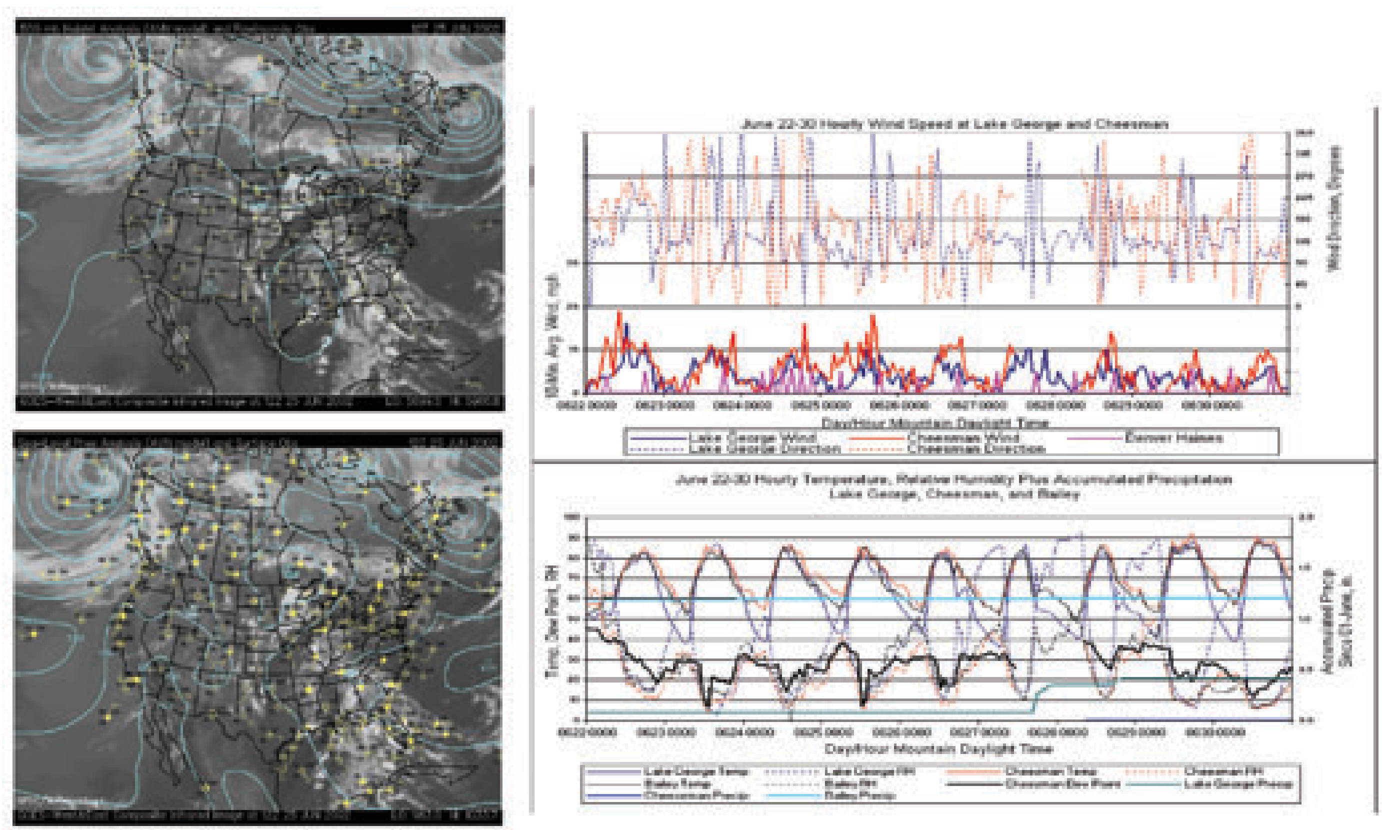

Figure 16—Upper air and surface chart for June 25 (12Z) and meteogram for week of June 22-30.

a bit to 16 °F (-9 °C) over Colorado. The upper level ridge was far to the east in Iowa. A surface low was located in western South Dakota with a trough extending southward to northeastern New Mexico. Another surface low was in northern Utah. Gradient flow over Colorado was southerly at all levels with widespread showers. A monsoonal cloud band was over the State in the morning with cumulus forming over the fire area near noon. Winds at the surface were southwest, but this was a moist flow with relative humidity generally reaching the teens (table 17). Scattered showers were evident, but none of the fire weather stations recorded precipitation. The low and moderate Haines Indexes reflect the increased moisture in the lower atmosphere.

July 1 to July 7: The beginning of the period saw a broad band of westerly winds over Washington and the Northern Rockies with weak high pressure trying to establish over the Four Corners region (fig. 17). At the end of the period a second monsoonal flow was established. Cheesman recorded 0.50 inch (12.7 mm) of rain on July 4, and widespread precipitation covered the fire area on July 5 and 6.

Table 17—Significant fire weather observation summary for Saturday, June 22, 2002.

Station	Temp max °F (°C)	RH min %	RH max %	Wind avg. mph (km/hr)	Wind direct.	Wind gusts mph (km/hr)	Gust direct.	Rain in. (mm)
Cheesman	95 (35)	11	68	10-13 (16-21)	SW	25-32 (40-52)	SW	
Lake George	83 (28)	16	89	6-10 (10-16)	SW	20-29 (32-47)	SW	
Bailey	83 (28)	14	90	7-8 (11-13)	SW	16-21 (26-34)	SW	
Manitou	80 (27)	18	92	8-10 (13-16)	SW		SW	
FRWS-12	83 (28)	15	90	8-9 (13-15)	SW	18-23 (29-37)	SW	
FRWS-13	63 (17)	26	92	10-15 (16-24)	SW	30-38 (48-61)	SW	
FRWS-6	81 (27)	20	83	6-8 (10-13)	SW	17-21 (27-34)	SW	
Denver Haines Index		AM	4-Low	PM	5-Mod			

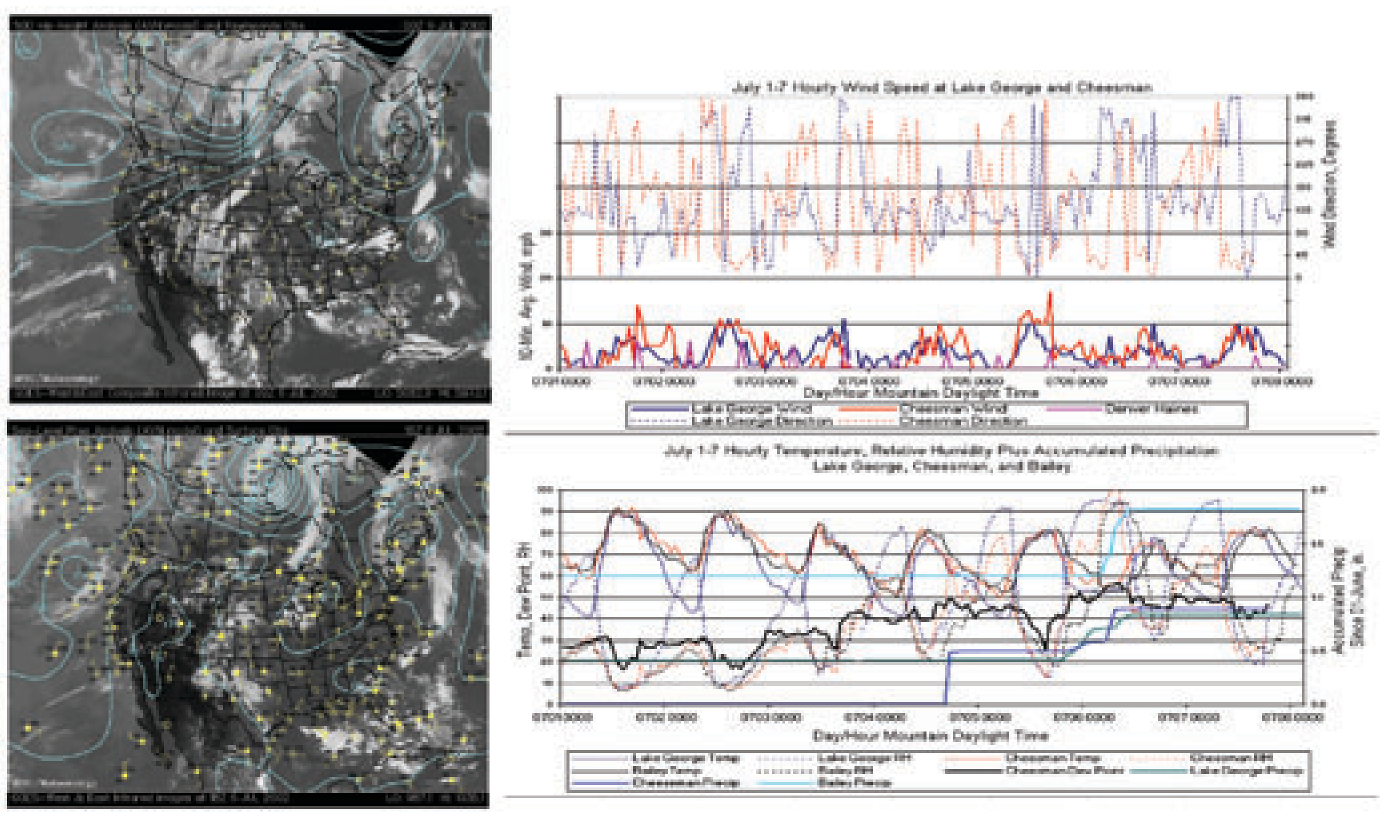

Figure 17—Upper air and surface chart for July 6 and meteogram for week of July 1-7.

Part 2: Description and Interpretations of Fire Behavior

Mark A. Finney, Charles W. McHugh, Roberta Bartlette, Kelly Close, Paul Langowski

This report summarizes the progress of the Hayman Fire, its behavior, and the influence of environmental conditions. Data were obtained from narratives from fire behavior analysts assigned to the fire management teams, discussions with fire management staff, meteorology from local weather stations and Bradshaw and others (2003), photographs, satellite imagery, and public internet sites. Possible explanations are advanced for observed fire behavior and effects. A fire chronology details as fully as possible the fire behavior and progress associated with specific days and weather conditions.

The Hayman Fire was first reported on the afternoon of June 8 at approximately 1655 hours just south of Tarryall Creek and Highway 77 near Tappan Mountain (fig. 1). Within a few hours the fire had spotted about 0.25 mile to the northeast and burned a total of several hundred acres. High winds, low humidity, exceptionally low fuel moistures, continuous surface fuels, and low tree crowns, were conducive to rapid spread rates, torching of trees, and frequent spotting. The fire burned actively into the early morning hours of June 9. Beginning before noon on June 9 and continuing until about 2300 hours, the Hayman Fire experienced it greatest growth, moving about 19 miles to the northeast and developing a large pyrocumulus column. It grew from an estimated 1,200 acres to approximately 61,000 acres that day. Observers attributed its rapid movement to long-range spotting (approximately 0.5 to 0.75 mile), active crown fire, and mass ignition of whole drainages. Fire growth on June 10 occurred from all flanks but was lessened by increasing humidity and the arrival of a cold front before the middle of the burning period. Fire behavior moderated over the next 6 days (until June 17), remaining predominantly a surface fire with isolate torching or small crown runs along the southeast flank. Extreme weather returned on June 17 with low humidity and high winds from the northwest advancing two portions of the southeast flank of the fire 4 to 5 miles toward the southeast. Fire behavior on June 18 was also extreme as the entire east flank became active, and by torching and crowning was pushed 5 miles more to the east by strong west winds. No major spread events followed, although the fire continued to smolder and spread from isolated segments of the perimeter until June 28. The final perimeter of the Hayman Fire contained approximately 117,417 acres of National Forest land (85 percent) 11,945 acres of private land (9 percent), 8,386 acres belonging to the City of Denver (surrounding Cheesman Reservoir)(6 percent), and 363 acres of Colorado State land (0.3 percent). The fire burned parts of four Colorado Counties: Park, Teller, Jefferson, and Douglas.

Topography

The area burned by the Hayman Fire is a landscape bounded on the west by the high elevations of the Tarryall and Kenosha Mountains within the Lost Creek Wilderness (approximately 11,000 to 12,000 feet) and roughly by Trout Creek and U.S. Highway 67 on the east (approximately 7,500 feet) (fig. 18). The South Platte River forms the main drainage and bisects the burned area in a direction running southwest to northeast. It is dammed to form Cheesman Reservoir (elevation 6,843 feet) in the north central portion of the burned area. Cheesman reservoir is about 1,000 acres in size and generally linear in shape as constrained by the drainages of the South Platte River and Turkey Creek. The other major drainage, surrounding Trout Creek, runs roughly parallel with the South Platte, but to the east by about 10 miles. Tributaries in both the South Platte and Trout Creek watersheds are aligned generally perpendicular to this axis (that is, east-west). The South Platte watershed is bounded on the east by ridges about 1,000 feet above the river. It is more steeply dissected than the watersheds farther east and south that include Trail Creek. Slopes are typically 10 to 30 percent but reach more than 50 percent in the South Platte watershed compared to more rolling topography elsewhere having slopes generally less than 25 percent. No major topographic barriers besides the reservoir exist within the burned area that would impede the progress of the Hayman Fire (for example, cliffs, transverse ridges, and so forth).

Vegetation and Fuels

Forest vegetation within the final perimeter was dominated by ponderosa pine and Douglas-fir (fig. 19, table 18). Blue spruce and aspen were frequent components of many stands although neither was typically dominant over large areas. The forest type map from the RIS database (Resource Information System) on the Pike San Isabelle National Forest shows trends typical of the Colorado Front Range at these elevations (6,500 to 9,000 feet). Douglas-fir forests were more common on northerly aspects and ponderosa pine dominated south and west facing slopes (fig. 19). Drier and steeper south aspects supported more open stands of ponderosa pine, particularly along south facing slopes within the South Platte watershed. These areas were characterized as shrublands or grasslands

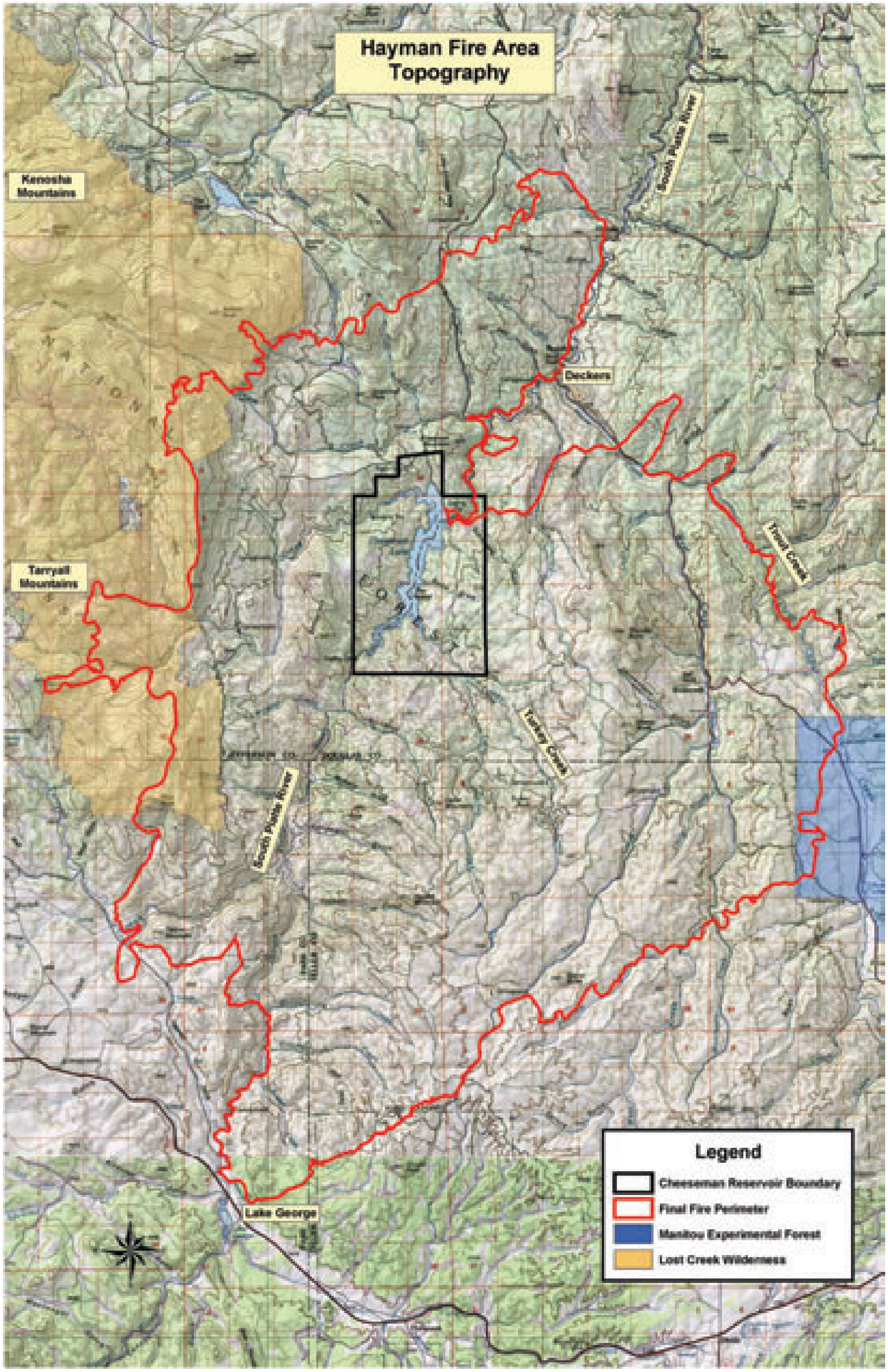

Figure 18—Topography of the Hayman Fire and surrounding landscape.

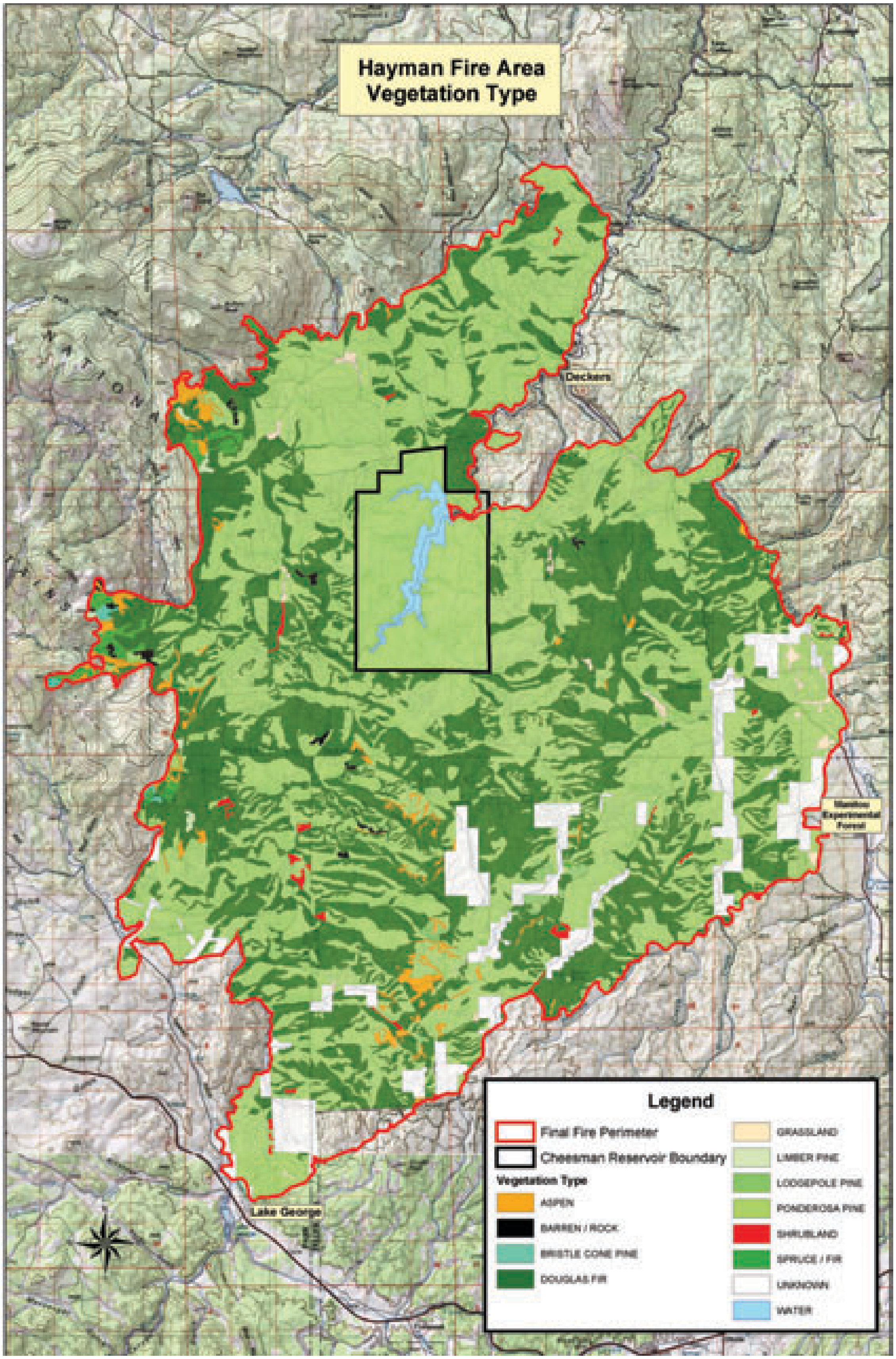

Figure 19—Vegetation classification for the Hayman Fire area.

Table 18—Acres by vegetation type. Note that the acreage total does not correspond to the official final fire size because data are absent from non-National Forest land on the periphery of the burned area.

Vegetation type	Acres	Percent of total
Ponderosa Pine	72862	52.76
Douglas-fir	50235	36.38
Shrubland	484	0.35
Grassland	718	0.52
Spruce/Fir	1029	0.74
Aspen	2019	1.46
Barren / Rock	333	0.24
Limber Pine	171	0.12
Water	836	0.61
Bristle Cone Pine	153	0.11
Unknown(Private)	8839	6.40
Lodgepole Pine	416	0.30
Total	138096	100.00

with sparse coverage of ponderosa pine. Meadows and riparian areas punctuated this forested landscape along drainages, particularly within the flatter terrain in the southeast part of the fire. The high elevations along the western boundary of the fire were dominated by stands of aspen, Englemann spruce, and sub-alpine fir, but were largely excluded from the burned area.

Fire behavior calculations made by analysts associated with managing the Hayman Fire were estimated from surface fuels (fig. 20, appendix B). This map suggests that fuels at the landscape scale were essentially continuous, having few large wildland fires, prescribed fires, or harvest operations occurring recently within the burned area (see fire history map, fig. 21). Surrounding areas, however, recently experienced severe stand-replacing fires that were clearly evident on satellite imagery from before the Hayman Fire (fig. 22). The fuel map suggests surface fuels at the landscape scale were dominated by long-needle pine litter (fuel model 9, Anderson 1982) (fig. 23) for purposes of fire behavior modeling (table 19). These fuels are characterized by ponderosa pine stands with low loadings of dead and downed woody fuels and no live vegetation contributing to fire spread. Litter and duff layers in these forests were approximately 2 inches deep as estimated from an examination of unburned areas around the periphery of the fire. Stands dominated by aspen or lodgepole pine were classified as a compact needle litter (fuel model 8, Anderson 1982) (fig. 24). South facing slopes (fig. 25) with lower canopy cover were classified as fuel model 2 (timber grass and understory) or fuel model 1 (short grass) depending on the proportion of grasses and shrubs carrying the fire (fig. 26). Several thousand acres of open forest were dominated by grass and shrub fuel types (fuel models 1 and 2, Anderson 1982) about 3 miles southwest of Cheesman Reservoir corresponding to the 1963 Wildcat burn and South Platte river valley (fig. 21). Due to difficulties with detecting dead and downed fuel components by interpreting aerial photography or satellite imagery, timber-litter understory fuels (fuel model 10, Anderson 1982) was not commonly assigned on this map. However, evidence of dead and downed fuel accumulations consistent with fuel model 10 was present, often in Douglas-fir and blue spruce forests (fig. 27).

Canopy fuels that contribute to torching and facilitate crown fire were not sampled directly. Canopy cover and vegetation estimated from 1997 aerial photographs (Kauffman and others 2001) suggests that Douglas-fir forests on north-facing slopes had higher cover compared to ponderosa pine (fig. 28). A patch of low forest cover southwest of Cheesman Reservoir was identified as corresponding to the 1963 Wildcat fire (fig. 21). The effects of other recent wildland fires (Schoonover 2002, Big Turkey 1998) were not captured by the cover estimates because they occurred more recently than 1997. Photographs of ponderosa pine and Douglas-fir forests suggest that the base of live tree crowns in many places were low to the ground (fig. 29). The crown bases in some areas within the Hayman Fire were high because low branches were scorched and pruned by prescribed surface fires (fig. 30). Higher crown bases decrease the vertical continuity between the surface fuels and the canopy fuels, thereby limiting the potential for a surface fire to transition to a crown fire (Van Wagner 1977).

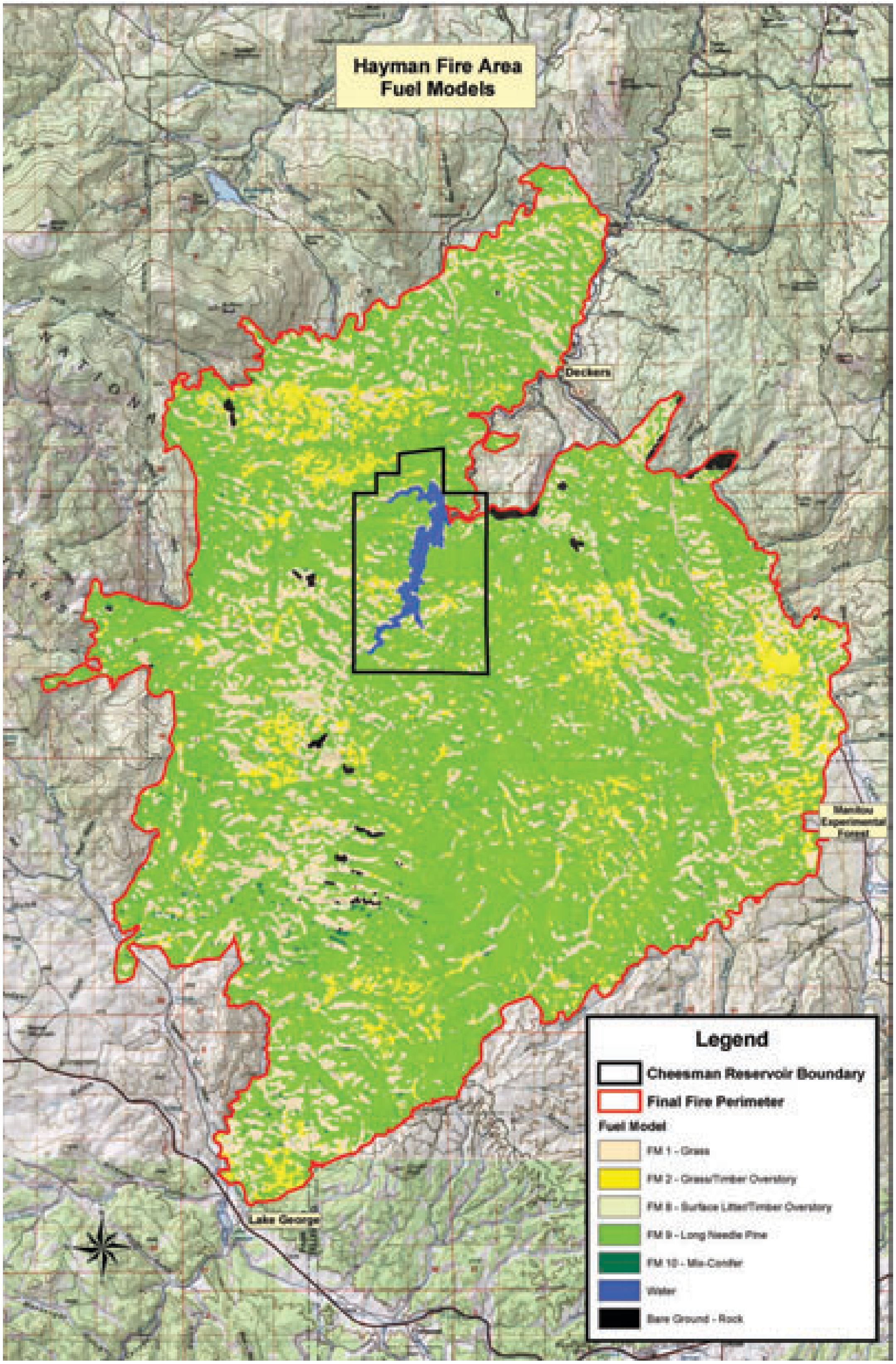

Figure 20—Fuel models assigned to the Hayman Fire area based on forest composition and structure (see appendix C for methodology).

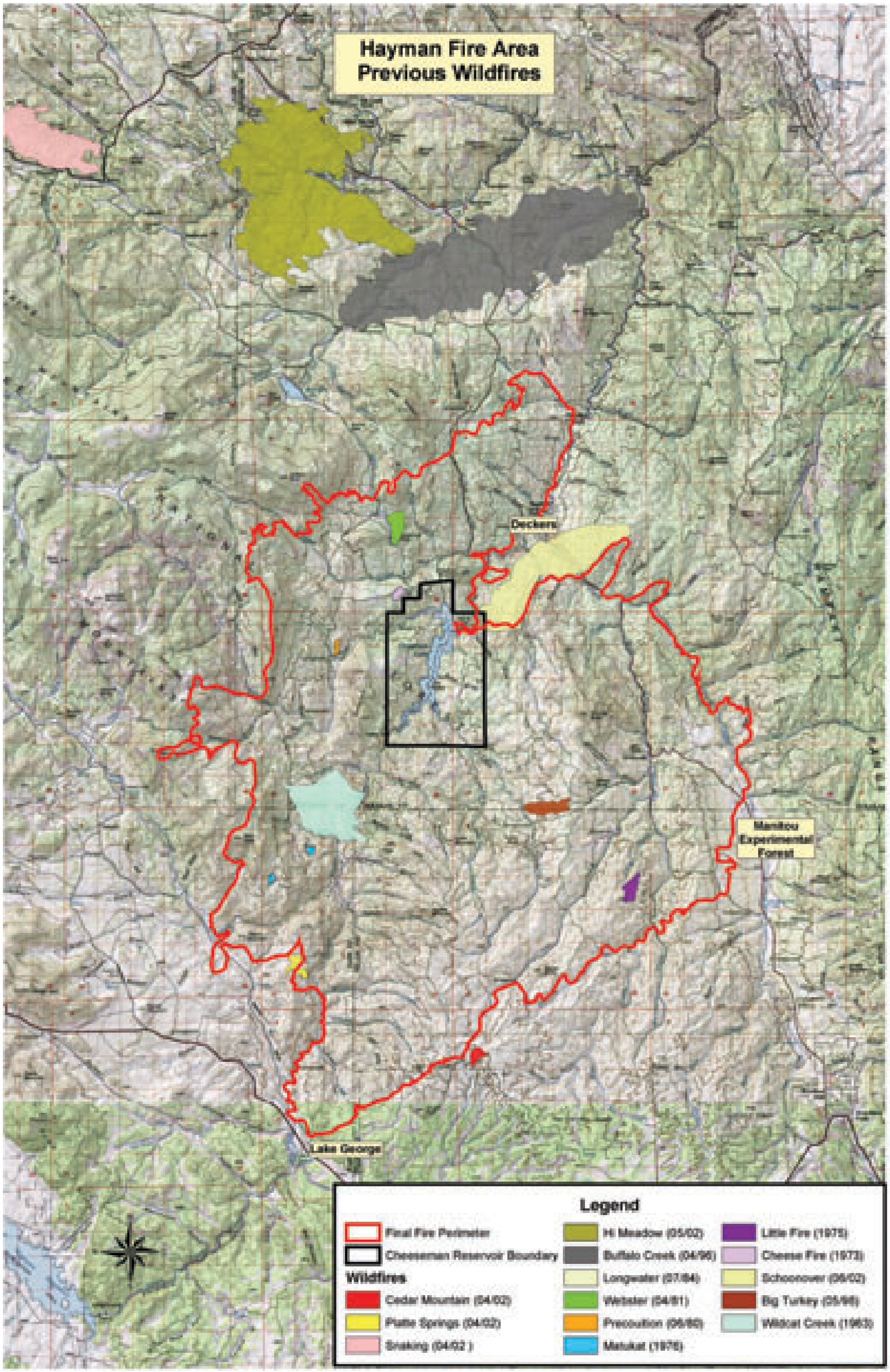

Figure 21—Recent wildland fires occurring in the area burned by the Hayman Fire and surrounding landscape.

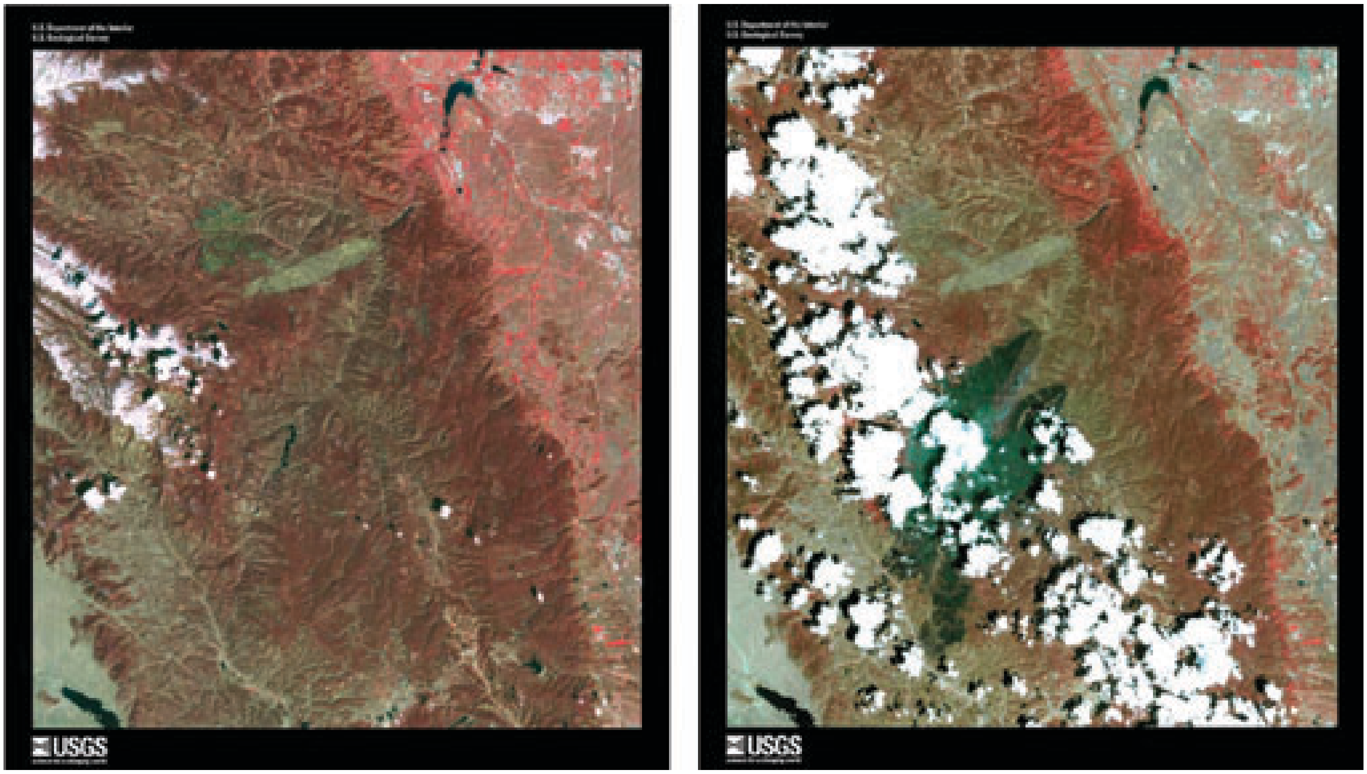

Figure 22—Comparison of false-color thermal infrared satellite imagery before and after Hayman Fire showing the continuous nature of forest cover. Severely burned areas are visible in the 1996 Buffalo Creek Fire (horizontal ellipsoid upper center) and 2000 Hi Meadows Fire (greenish area to the west of Buffalo Creek Fire).

Figure 23—Pine needle litter dominates surface fuels typical of untreated ponderosa pine stands in the Hayman Fire area. Photo taken near Manitou Experimental Forest (see fig. 18).

Table 19—Acres by fuel model as derived by Kelly Close (see appendix C for methodology).

FBPS fuel model number	Acres	Percent of total
1	26512	19.20
2	29288	21.21
5	3331	2.41
6	4510	3.27
8	6593	4.77
9	52208	37.80
10	13688	9.91
Water	835	0.60
Barren	1147	0.83
Total	138112	100.00

Figure 24—Aspen stands were classified as compact litter fuel model 8 and generally supported high coverage of herbaceous understory vegetation.

Figure 25—South facing slopes were dominated by grasses or shrubs and were classified as either fuel model 1, 2, or 5 depending on proportions. (Photo by Kelly Close)

Figure 26—Grass fuels (fuel model 1) dominate ponderosa pine savannahs and meadows. (Photo by Tim Sexton)

Figure 27—Mixed stands of ponderosa pine, Douglas-fir, and blue spruce were classified as fuel model 10 because they contained more dead woody material and shrub fuels.

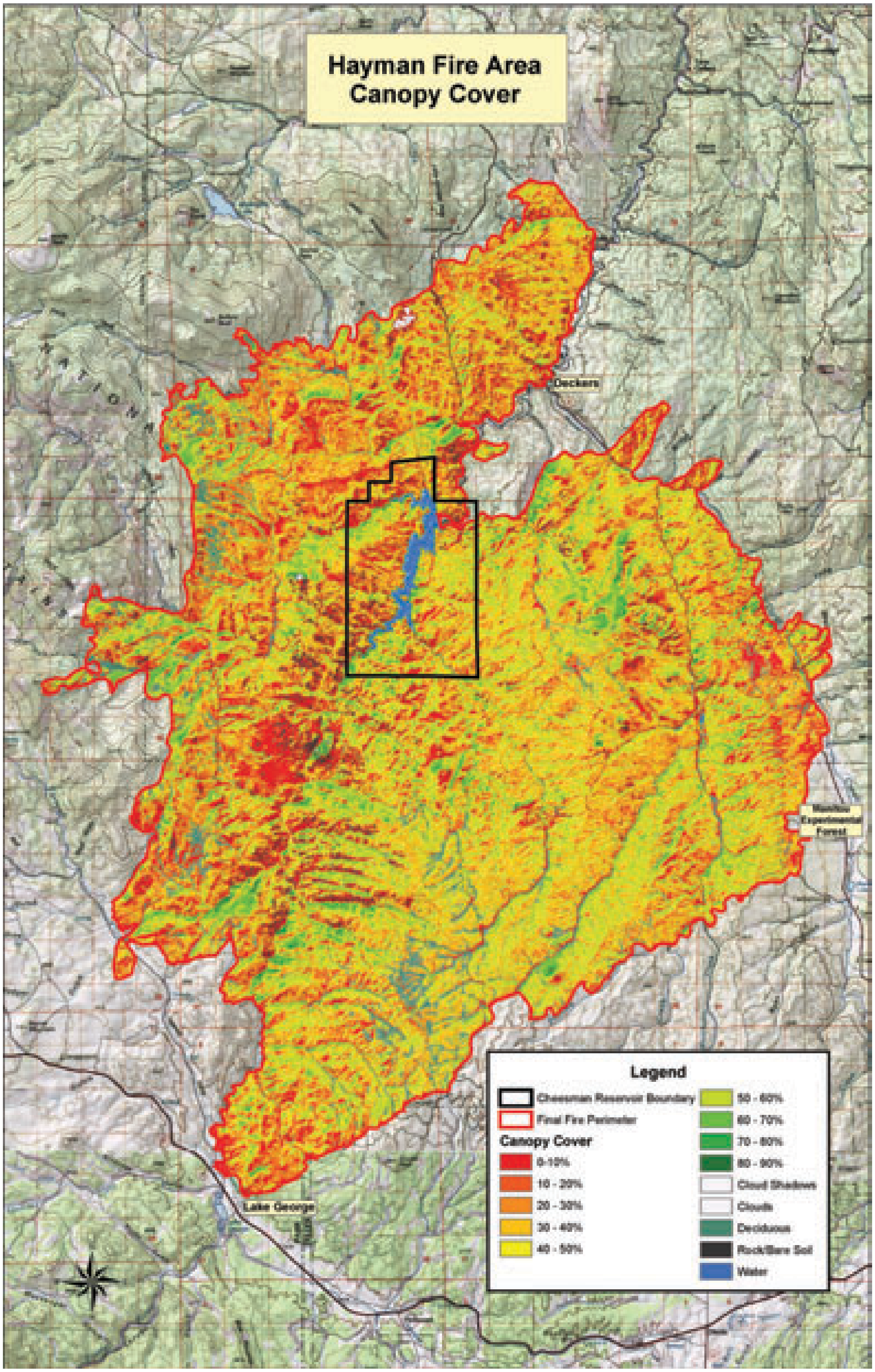

Figure 28—Canopy cover within the Hayman Fire area developed by Merrill Kaufmann from 1997 LANDSAT imagery. The open forests were found southwest of Cheesman Reservoir and burned in the 1963 Wildcat Fire (see fig. 21).

Figure 29—Crown base height in many stands was low and easily ignited by surface fire, especially under extreme conditions experienced June 9 and 18, 2002.

Figure 30—Crown base height in some treated areas was higher because of pruning from previous surface fires. Photo taken near the west end of the Big Turkey fire 1998. Records indicate this area was underburned in 1990, 1998 (Big Turkey Fire) and again by the Hayman Fire in 2002.

Fuel Moisture

The moisture contents of the conifer foliage, shrub foliage, and dead fuels were found to be unusually low this year. The moisture content of live fuels is normally high at this time of year due to active growth. Sampling and local observations however, indicated little new growth this year and unusually low moisture of live fuels (table 20). Low foliar moisture contents play a significant role in the initiation and spread of crown fires (Van Wagner 1977; Agee and others 2002). Low moisture content of large woody fuels and duff increases the availability, consumption, flame residence time, and total energy release of surface fires (Albini and Reinhardt 1995). Samples from the area surrounding the Hayman Fire suggest that the normal trend of increasing moisture content in conifer foliage during the growing season was substantially reduced (tables 21 and 22) with some sites containing foliar moisture at levels equivalent to spring and fall minima at the time of the fire. The variability in live foliar moisture content for a particular date is likely caused by site differences (aspect, elevation, soil depth), tree and stand differences (age, size, density), and perhaps sampling methodology concerning the age of the foliage collected. Many conifers, including Douglas fir, and ponderosa pine, retain foliage for several years, with older foliage having substantially lower moisture content than younger needles and especially the current year's growth (Agee and others 2002). Similarly, moisture contents of large woody fuels (1000 hour timelag category) were extraordinarily low (fig. 8). Samples from all sites consistently show large woody fuels and lower duff had moisture contents less than 10 percent and sometimes less than 5 percent (tables 20, 21, and 22). Moisture of leaves of mountain mahogany, a common shrub species in this area, ranged from 60 to 70 percent in the weeks leading up to the time the Hayman Fire started.

The dryness of live fuels is illustrated by comparing the foliar moisture contents among the past several years. Satellite imagery processed to calculate live

Table 20—Fuel moisture contents sampled at Manitou Experimental Forest at 8,000 foot elevation (east edge of Hayman fire final perimeter).

	Manitou Experimental Forest—8,000 ft elevation					
Date	Ponderosa pine	Douglas-fir	1000-hr	10-hr	Litter	Duff
04/09/02		113.1	7.1		32.1	
04/28/02	98.4	103.3			1.4	6.3
05/22/02	94.5	106.1	5.6	2.9	4.8	11.9
06/08/02	120.9	117.7	4.8	4.7	4.6	4.7
06/29/02	114.7	122.7	5.6		13	17.2
07/14/02	115.2	105.1	3.8	2.5	3.8	6.4
07/28/02	110.2	110.7	7.5	7.2	6.4	13
08/11/02	112.2	96.8	10.3	8.4	4.6	13.6
08/24/02	117.3	94.6	8	5.9	6.5	9.1

Table 21—Fuel moisture contents (percentages) sampled at South Rampart site at 8,765 foot elevation (east of Hayman fire final perimeter).

	South Rampart—8,765 ft elevation					
Date	Ponderosa pine	Gambel Oak	1000-hr	10-hr	Litter	Duff
04/10/02	87.8	No leaves				18.5
04/28/02	65.9	No leaves			6.3	3.2
05/22/02	92.6	140.1	8.4	8.3	3.3	11.7
06/08/02	101	221.3		8.1	7.5	10.9
06/29/02	108.6	112.6		7.5	6	11.1
07/14/02	110	94.9	5.7	7.5	3.7	7
07/28/02	105.5	93.4		8.9	3.7	6.4
08/11/02	96.2	84.2	9.3	10.1	3.2	5.6
08/24/02	108.1	98.4	8.1	10.5	8.4	13.5

Table 22—Fuel moisture contents sampled at Lake George at approximately 8,000 foot elevation (topographic aspect indicated with conifer foliar moisture content).

	Lake George—8,000 ft elevation					
Date	**Ponderosa pine**	**Douglas-fir**	**1000-hr**	**10-hr**	**Litter**	**Duff**
05/31/02	95-96		8.4	2.5-2.9	2.25-2.6	8.7-9.8
06/21/02	90 (south)		5.4	1	2.4	4.5
06/21/02		84 (north)	7	2.7		3
06/24/02	95		6.5	10		8

foliar moisture content from the Normalized Difference Vegetation Index (NDVI) (Burgan and Hartford 1993) suggests that moisture contents in 2002 were much below normal (fig. 9 and 10). The 2002 NDVI declines in May, falling well below the average values from mid-May through mid-July. Sampled ponderosa pine and Douglas-fir needle values (fig. 31) illustrate the timing of their decline in moisture content relative to the NDVI trend. The foliar moisture content increases as the trees prepare to flush new growth. The NDVI is not expected to perfectly match the upward foliar moisture trend because the satellite's sensors measure reflectance from all vegetation within the 1-km resolution. Understory vegetation showed little or none of its normal spring and early summer green up in 2002. A comparison of field samples corroborates these trends (fig. 32).

Fire Behavior

Fire perimeter positions were obtained from several data sources: (1) incident management maps, (2) satellite imagery (Landsat, IKONOS, MODIS), and 3) observers. Fire perimeter positions were found to contain typical kinds of imprecision in labeling and location. The progress of the fire on June 8 and 9 is the least certain because of the rapid progress of the fire, long-range spotting (transporting fire activity well ahead of the main front), visibility obscured by smoke, and inaccessibility to observers. This uncertainty is illustrated by the divergent times associated with fire position on June 9 (see Fire Chronology below). Daily estimates of fire location through June 14 overlap considerably because of these sources of imprecision. Perimeter locations after June 15 were based on aerial

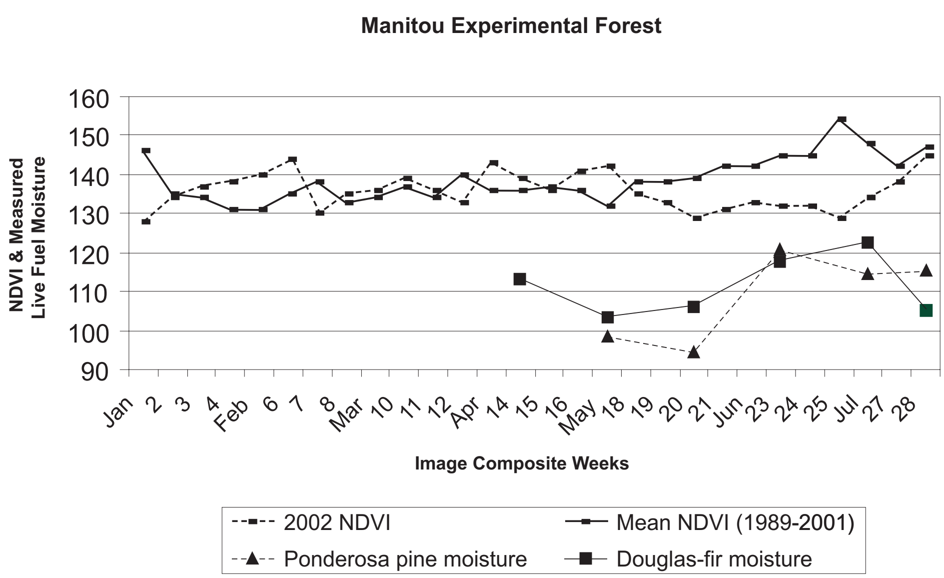

Figure 31—Comparison of 2002 live foliar moisture content sampled at Manitou Experimental Forest with (Normalized Difference Vegetation Index, NDVI) at 1km resolution. Note that samples and remotely sensed moisture content would not be expected to be identical because of different data resolution.

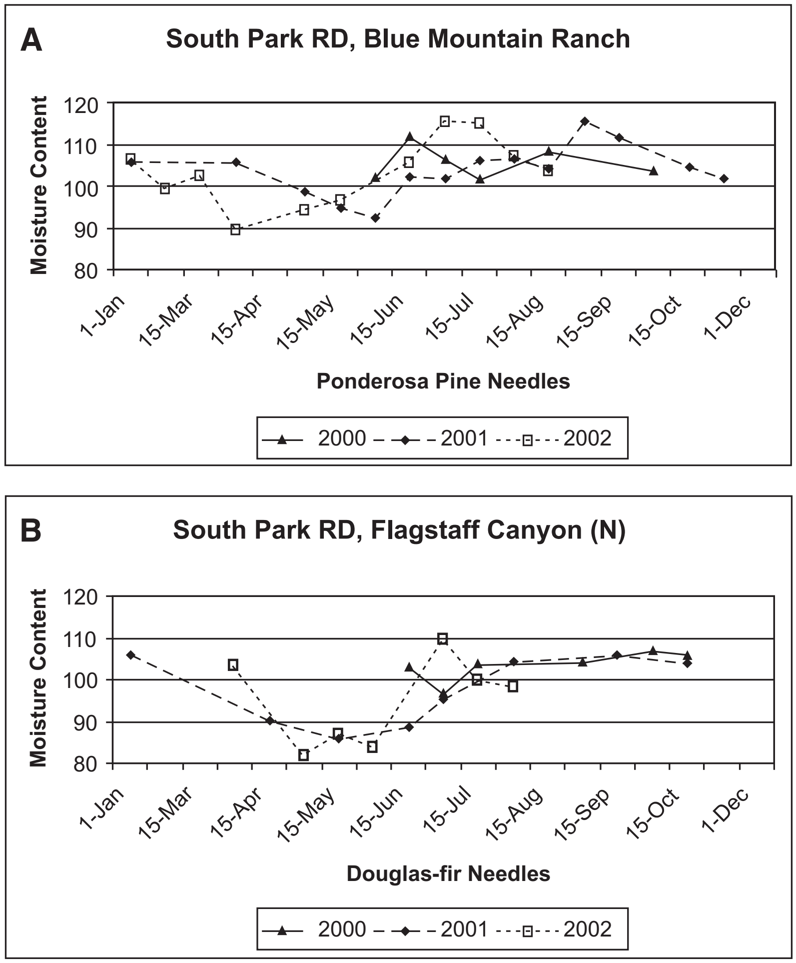

Figure 32—Comparison of moisture content of live foliage fuel samples among the past 3 years from along South Park Road at (A) Blue Mountain Ranch, and (B) FlagStaff Canyon.

infrared imagery and were mapped more accurately but often labeled to indicate the day the data were recorded (usually after midnight) rather than the previous day when the fire achieved its growth. These issues serve to confuse fire progress and lead to overlapping positions for successive days. For purposes of clarity, we represented the salient episodes of fire progress by (1) labeling the fire perimeter positions to reflect the day of fire growth, and (2) omitting observations from several low-growth days (6/11, 6/13-6/14). The days omitted contained frequent overlaps that suggested minor growth in fire perimeter was within the precision of the mapping (fig. 33 and 34). Fire perimeter locations from 6/19-6/27 were also removed from this map because they do not differ substantially from the final perimeter.

The Hayman Fire displayed active fire growth for about 12 days (June 8 through 20), although final fire containment was not declared until weeks later (table 23). Fire behavior characteristics of the Hayman Fire can be distinguished according to fast and slow episodes of fire growth. The Hayman Fire began and ended with a period of rapid growth (June 8 to early on June 10 and June 17 and 18). Fire behavior on these days took place during prolonged burning periods (daily periods of active fire behavior) that began in mid-morning to nearly midnight. These periods were characterized by torching, crown fire, and spotting. Spotting facilitates the rapid fire growth by spanning natural barriers such as roads, ridges, rivers, and rock outcroppings. Shortly after its inception on June 8, a surface fire spread rapidly through short grass and ponderosa pine needles and ignited nearby tree crowns (fig. 35). Torching progressed from individual trees and small groups of trees to large groups and stands within a few hours. Torching and crownfire are strongly

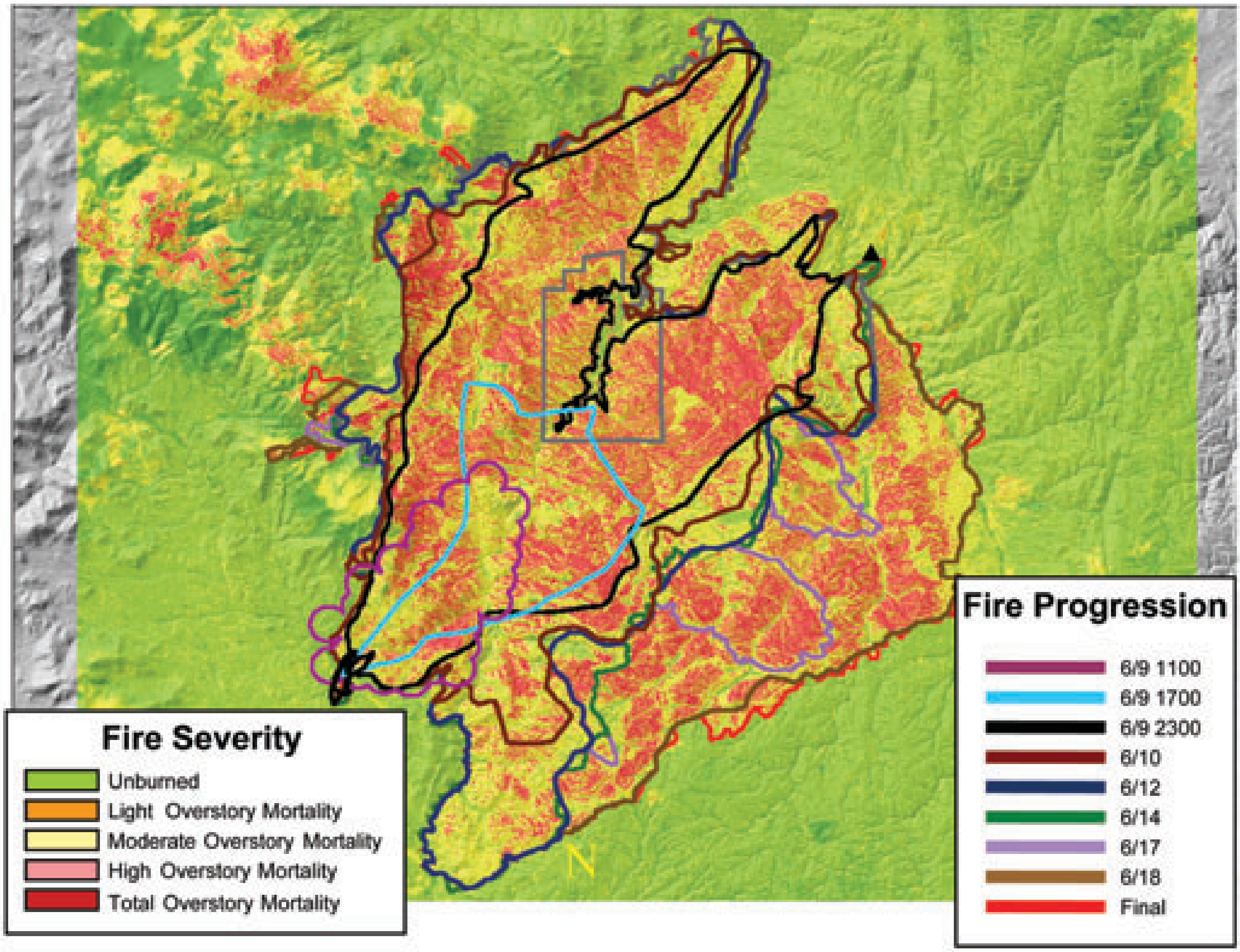

Figure 33—Fire progression map as corrected for perimeter precision and dates and times overlayed with burn severity data (Difference-Normalized Burn Ratio, DNBR) from USGS (http://edc2.usgs.gov/fsp/severity/fire_main.asp). Note that not all days are present because imprecisely mapped perimeters on slow-growth days overlapped—Burn severity data show most of the area burned on June 9 was "high severity," which is interpreted as complete overstory mortality.

associated with spotting because firebrands are copiously produced (small twig segments or bark flakes supporting glowing combustion) and injected high into the windstream by vertical convection above the flame plume (Albini 1979). Firebrands are then carried by winds, which on June 8 and 9 averaged 20 mph (gusts to 30mph) and were observed to carry brands hundreds of feet from their sources. Subsequent and numerous ignitions were facilitated by low humidity (approximately 8 percent) and continuous fuels. This process was repeated as the fire moved the course of several miles that first day (fig. 36). Over time, the broadening fire front and its involvement with steeper topography contributed to crown fire runs through entire stands and hillsides, which further advanced the fire by spotting (fig. 37). The smoke plume was flattened by the high winds, keeping it low to the terrain and obscuring fire activity on the ground (fig. 38). Throughout the following day (June 9) crown fire and long-range spotting (0.25 to 0.75 mile) were observed to dominate growth of the fire. Spots were observed to rapidly accelerate in intensity and begin torching. Average heading spread rates were calculated as 1 to 2 miles per hour (88 to 176 ft/min). Flame lengths were reported at 100 to 200 feet during crown fire runs, with crown fire and torching evident even along the flanks of the fire. Haines Index was reported at 6, the highest level of atmospheric instability indicated by vertical contrasts of temperature and humidity, that is conducive to vertical convective

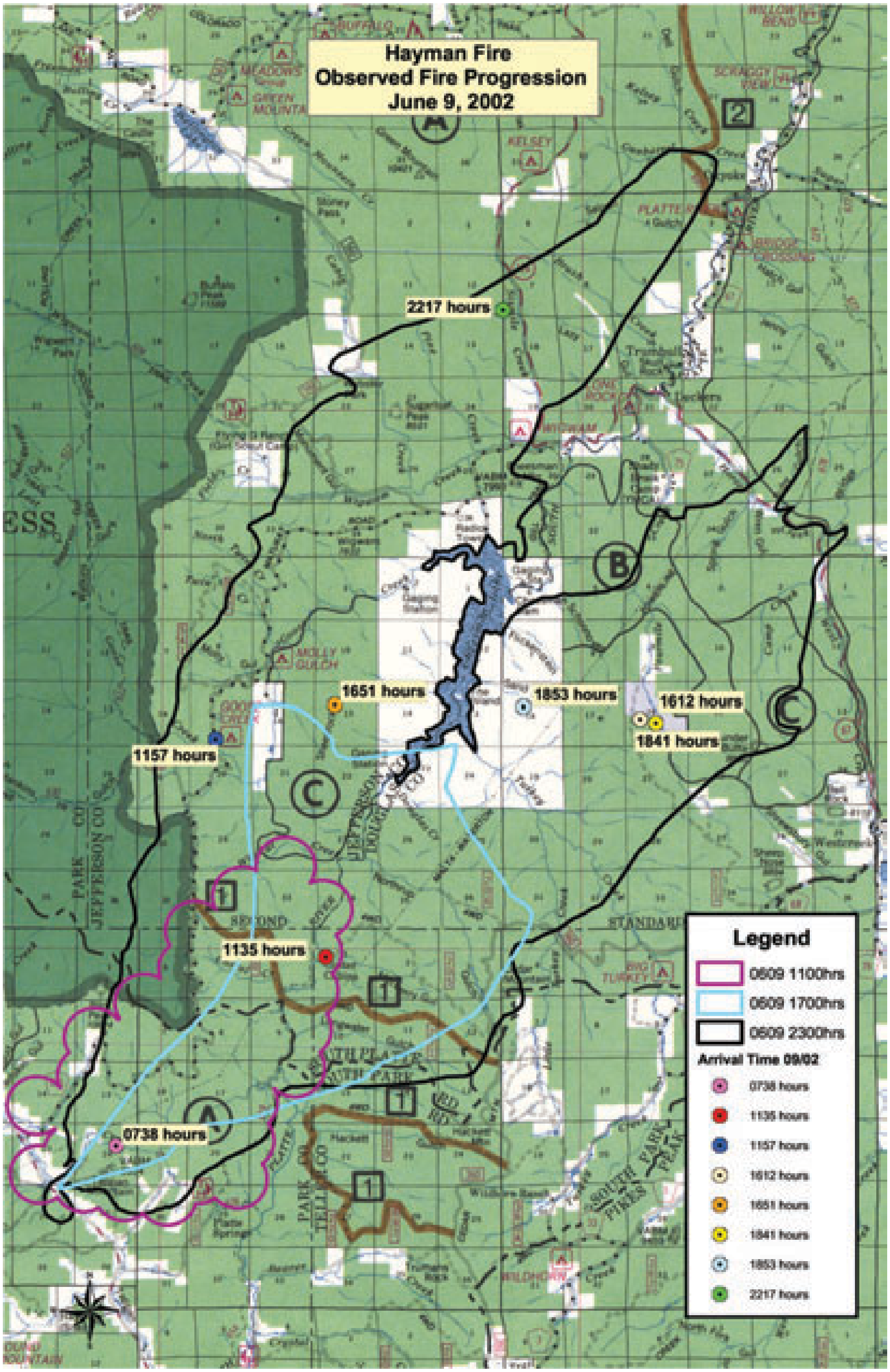

Figure 34—Fire progression map for June 9 showing observed fire locations for comparison.

Figure 35—Hayman Fire origin was reportedly in this campfire ring. Sparse grass fuels carried fire through the foreground to low crowns of trees in back ground resulting in torching and spotting. (Photo by Kenneth Wyatt Nature Photography 56 Aspen Dr., Woodland Park, CO 80863)

Figure 36—Area northeast from Hwy 77 (in foreground) near ignition point. Fire on June 8 spotted to forested hillsides in background and beyond. (Photo by Charles W. McHugh)

Table 23—Burned acres by day obtained from the fire perimeter data (see fig. 33).

Date	Acres
June 8	290
June 9 1100 hours	12802
June 9 1700 hours	15641
June 9 2300 hours	60133
June 10	81463
June 11	
June 12	97027
June 13	
June 14	97939
June 15	97544
June 16	99590
June 17	109609
June 18	135174
June 19	
June 20	136146
June 21	136137
June 22	136260
June 23	136260
June 26	136792
June 27	137091
June 28	137119
Final Perimeter	138114

Figure 37—Area east from Hwy 77 near ignition point. Fire on June 8 spotted to forested hillside. Large portions of ponderosa pine/Douglas-fir stand were burned by torching and crowning. (Photo by Charles W. McHugh)

Figure 38—Strong winds on June 8 and 9 flattened smoke column, obscuring fire position and making fire progression estimation difficult. Photo is from June 9.

development above with large fires (Werth and Werth 1993). Such vertical development occurred by early afternoon, producing a large pyrocumulus cloud reportedly rising to 21,000 feet (Pueblo Dispatch Log). Extreme fire behavior experienced during June 9 and June 18 likely involved behaviors that are not yet well understood. Fire whirls (Byram and Martin 1970) and mass ignition (Byram 1966; McRae and Stocks 1987) can create tremendous local convective velocities and burning rates beyond the scope of operational fire behavior or fire effects models.

Days with slow fire spread consisted of surface fire with occasional torching in the late afternoon toward the latter half of the burning period (June 11 through 16). These burning periods were characteristically shorter compared to the extreme days, beginning around noon and ending around sunset (approximately 2000 hours). Surface fire is defined as burning in grass, brush, litter, and woody material on the ground surface. With the calmer winds, changes in wind direction (primarily from the NW or SE), and higher humidity, flamelengths were typically 2 to 5 feet, but varied from inches to tens of feet depending on the orientation on winds and/or slope. Observed and predicted head fire spread rates varied by fuel type, with fire in litter fuels moving several feet per minute and in grass fuels up to 50 feet per minute. Portions of the fire, particularly along the southeast flank experienced periodic afternoon increases in torching especially in association with certain drainages and slopes when the fire edge became aligned with topography and general afternoon upslope winds (fig. 39). Torching trees were common, with observers reporting spotting occurred up to 1,000 feet.

Fire Chronology

A timeline was constructed to detail the daily progression and behavior of the Hayman Fire in relation to the weather, fuels, topography, fire suppression activities, and fuel treatment locations.

June 8: An upper level trough over northeast Oregon began strengthening, increasing prefrontal winds from the south and southwest along the Colorado Front Range, and decreasing humidity below 10 percent by 1100 hours. By mid-afternoon, winds were gusting to upper 30 mph range from the southwest and temperatures had climbed to the upper 80's.

A detailed account of the behavior and the progression of the fire following its reporting at 1655 was provided by Ted Moore, fire management officer of the Pike San Isabelle National Forest (appendix C) and the Pueblo Dispatch Log (appendix D). From this account, a general description of the fire behavior that

Figure 39—A convection column developed early on June 9 because of the extreme weather conditions (winds sustained at 20+ mph with humidity about 8 percent).

afternoon and evening is clear. Fire behavior rapidly became more extreme than the aggressive initial attack resources could control. Near the fire origin (fig. 35), high winds, low fuel moisture content, and flashy short grass and pine-litter fuels allowed the fire to spread rapidly along the ground surface beneath a relatively open ponderosa pine stand. Repeated torching of trees advanced the fire by spotting toward the northeast, ultimately crossing County Road 77 (Park County) and Tarryall Creek (fig. 36 and 37). The high winds blew smoke horizontally (fig. 38) and obscured observations of fire progression. Steep topography and more continuous conifer stands increased the areas of torching trees and led to crown runs and longer range spotting. The fire spread actively after dark and into the early morning hours of the next day, moving past Tappan Mountain (fig. 18) and eventually about 3 miles from the ignition point. The fire size at that point is uncertain but by the following day it was estimated to have burned about 1,000 acres.

June 9: The upper level low pressure system that established in the northwest moved southeast over Idaho (fig. 12). This strengthened the upper-level flow over the Rocky Mountain front, producing a subsiding airmass and forcing dry and warm upper air toward the ground surface. Humidity remained between 5 and 8 percent at Cheesman RAWS station all day and temperatures climbed to the mid-80's (°F) (appendix A). High winds persisted all day, with Cheesman and Lake George RAWS stations reporting sustained 20 foot winds from the southwest in the upper teens and gusts from the 30 mph to upper 40 mph range (appendix A). Toward late afternoon (1900 hours) the winds remained strong but tended to shift more from the south.

The fire position was reported (Pueblo Dispatch Log, appendix D) approximately 3 miles from its origin at 0016 hours. By 0806 it was estimated by the Air Attack lead plane (Pueblo Dispatch Log, appendix D) that the fire was about 1,000 to 1,200 acres in size. Because of smoke and inaccessibility, field crews reported at 1047 hours that the location of the fire's leading edge could not be determined. The fire was active in the morning, spreading by crown fire and spotting primarily on the west side of the South Platte River (fig. 39). The rapid progress was recorded by satellite imagery as a crude outline of fire during its overpass at approximately 1100 hours (fig. 40). The fire size from this image is roughly 12,800 acres although the 1 km resolution of the MODIS satellite likely overestimates the total size. This fast forward movement was generally verified by Pueblo Dispatch log reports that northeastern edge of the fire crossed (presumably to the east side of) the South Platte at Custer Cabins at 1135 hours (fig. 34) and the north western edge "bumping" Matukat Road south of Stage Stop Camp Ground at 1157 hours. A significant factor in the persistent rapid advancement of the fire the entire day was the alignment of the

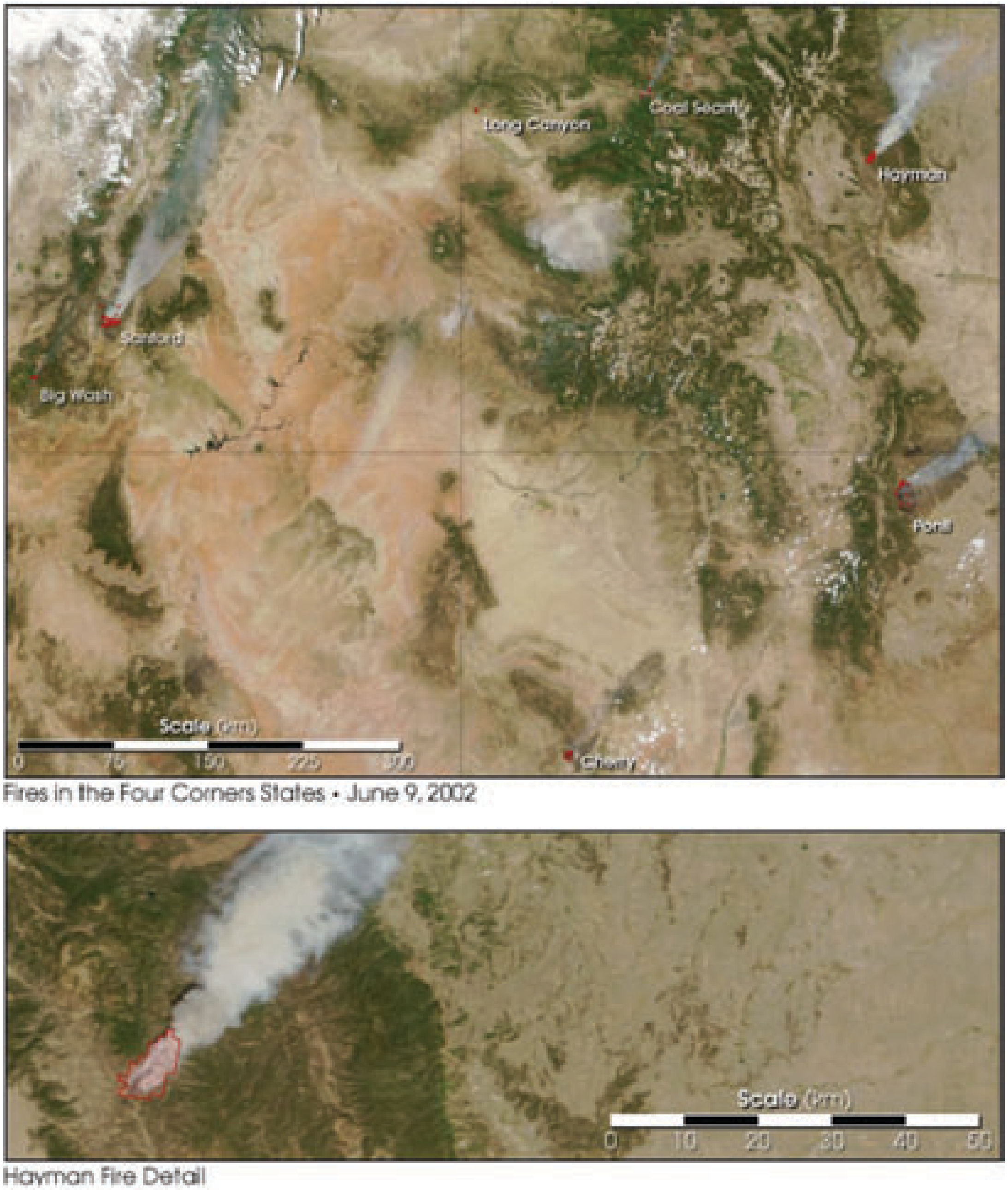

Figure 40—Satellite imagery at approximately 1100 hrs on June 9 shows the early fire activity and large size of fire.

strong gradient winds (from the SW) and the direction of the South Platte River valley (fig. 18).

The next observations of the fire position were recorded on an incident management map showing approximate location of fire at 1700 hours (fig. 33). This perimeter suggests that the fire had not yet reached Cheesman Reservoir and is considerably behind point observations from the Pueblo Dispatch log that locates fire at T10s R71W sec.10 on west flank at 1651 hours (north of Sheeprock) and east flank at T10S R70W sec 16 at 1612 hours (south slopes of Thunder Butte) (fig. 34). Curiously, the east flank of the fire was reported at this same location at 2.5 hours later at 1841 (Pueblo Dispatch Log), suggesting it did not move for more than 2 hours (fig. 34). Other evidence exists, however, that corroborates the observed later arrival time of the east head of the fire at this forward position. The Cheesman RAWS weather station is located about 1 mile east of the eastern shore of Cheesman Reservoir (fig. 3) and recorded a temperature of 96 °F (+12 °F above the previous hour) at 1853 hours. This reflects the average temperature occurring within the 10 minutes prior to the recording time. This same RAWS recorded a peak wind gust of 84 mph occurred within the previous hour (1754 to 1853 hours). Inconsistencies in the fire progression timeline may be partially explained by the reported difficulty in observing the fire edge from the air because of smoke obscuring the true fire position and the prevalence of long-range spotting that could extend fire far ahead main front.

Regardless of the exact timing, however, the fire rapidly increased in size that afternoon and early evening and developed a large pyrocumulus column reportedly to an altitude of 21,000 feet (fig. 41 and 42). Sometime between 1600 and 1800 hours the Hayman Fire burned around Cheesman Reservoir, forming two heads and convection columns (fig. 33). This split was caused by the obvious presence of the water body and exposed barren shoreline of Cheesman Reservoir. Despite the persistent southwest winds, the fire progression maps and observations reveal that the western flank of the fire moved northward via Sheep Rock and maintained a more northerly direction than the eastern flank (fig. 33). This could have been facilitated by the general uphill wind flow on the slopes surrounding the South Platte River canyon south of Cheesman reservoir that would enhance fire spreading uphill on the east and west facing slopes, diverging from the river canyon itself. These two distinct heads of the fire persisted throughout the remainder of the burning period, being prevented from merging on the north side of Cheesman by the adjacency of the Schoonover wildlfire (occurring 3 weeks earlier in May 2002) (fig. 21). These two heads were visible from satellite imagery at approximately 2300 hours (fig. 43).

Little was recorded on fire position after 1900 hours. For example, no observations were discovered for the time that the fire crossed Highway 67 east of the town of Deckers. Several observations place the western head of the fire at Hwy 126 at 2217 (Pueblo Dispatch Log) Report of west flank fire location 1.5 miles northeast of Trumbull (Dispatch Log). Toward the end of the day, the western head of the fire moved north about 19 miles and the eastern head about 16 miles. This disparity in extent was most likely caused by the joint positioning of the Polhemus prescribed burn (8000 acres in fall 2001) and the Schoonover wildfire in the direct path of the eastern head. The fire progression and fire severity map reveal a hand-and-glove fit between the edges of the three burns (see below). No further spread of the Hayman Fire occurred along the boundaries with these previous burns.

Fire effects had been generally severe throughout the entire area burned that day, as revealed by a comparison of 30 m resolution satellite imagery from before and after the fire (fig. 33). Near its north western extent, the severity pattern of the western head formed a symmetric arrowhead pattern which several possible explanations acting separately or together (fig. 44). The first scenario results primarily

Figure 41—Large convection column and pyrocumulus developed in the afternoon of June 9. Cloud tops were reported at 21,000 feet with thunder and lightning. (Pueblo Dispatch Log, appendix B)

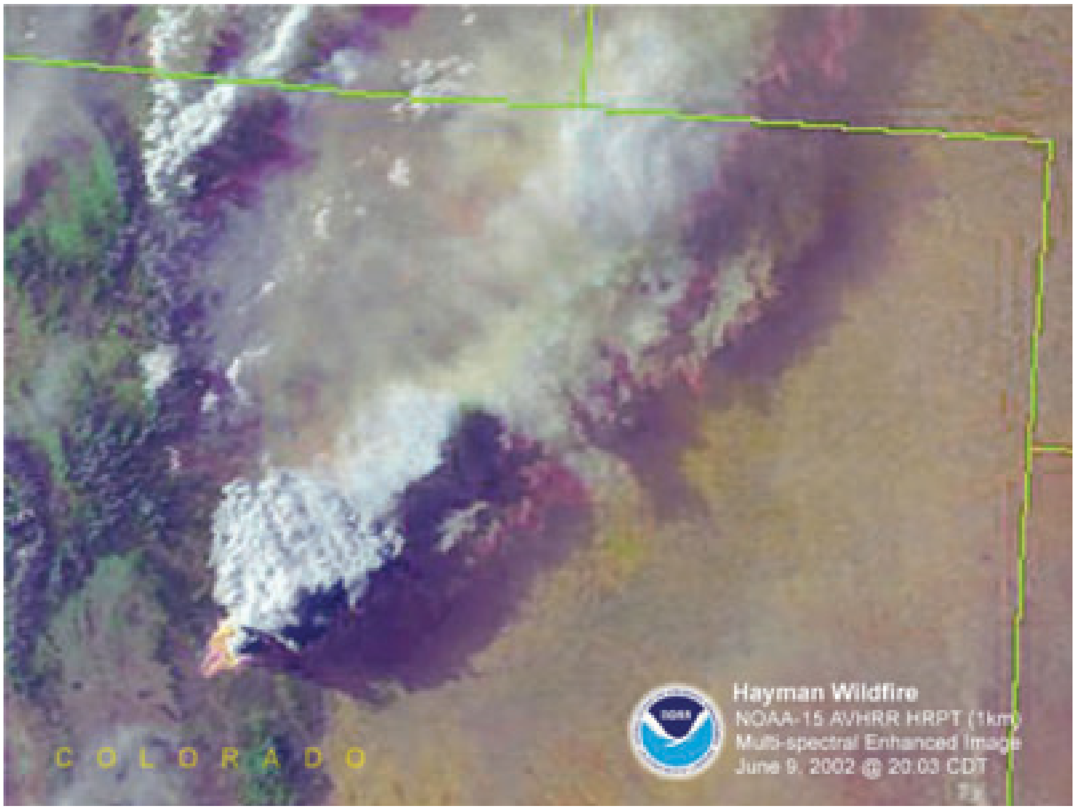

Figure 42—Satellite image of Hayman Fire at 1903 hrs on June 9 shows convection column and smoke plume extending across Denver into Wyoming.

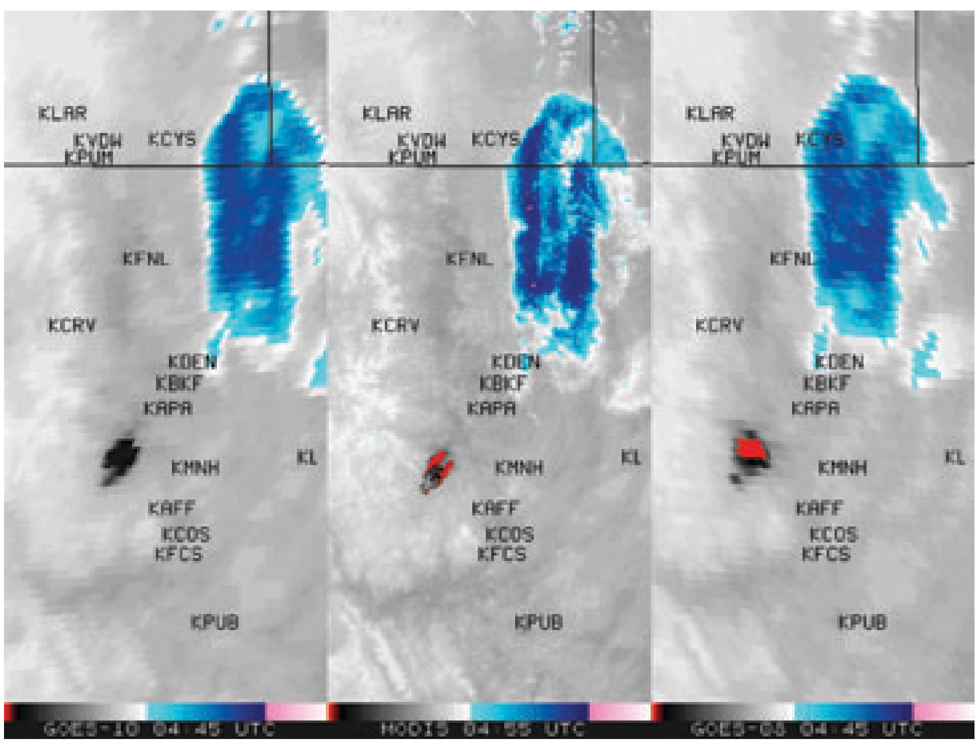

Figure 43—Thermal signature from MODIS satellite imagery (center) clearly shows forked shape of Hayman Fire at approximately 2300 hrs on June 9 that resulted from the presence of Cheesman Reservoir and the Schoonover fire (see fig. 34).

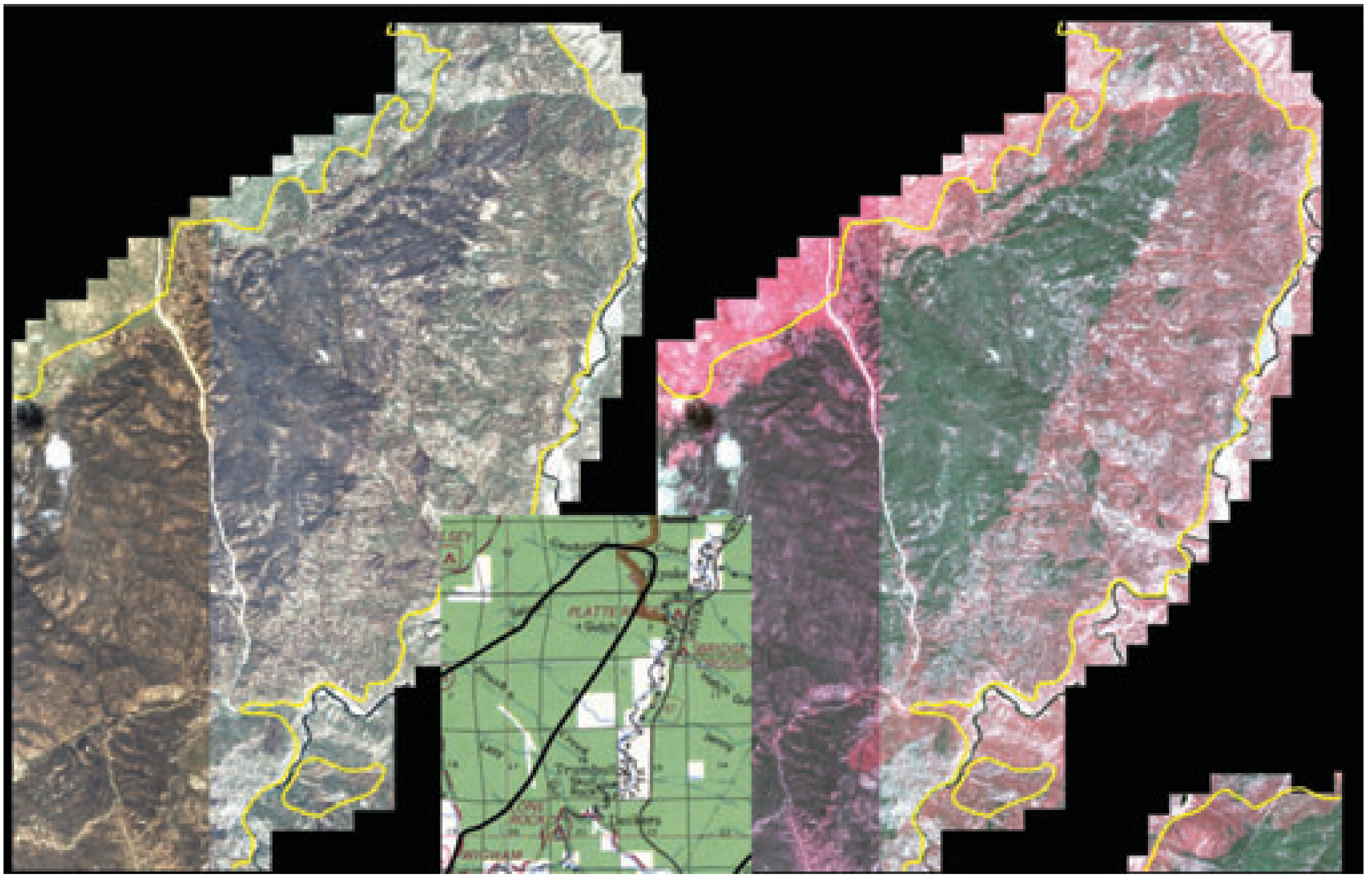

Figure 44—Satellite images of the "arrowhead" severity pattern at the north end of the western head of the fire. Fire severity is more difficult to differentiate in the visible image (left) than the false color infrared image that depicts live plant tissues as pink. This burned toward the end of the day on June 9 and suggests effects of increasingly marginal conditions "pinched" the crown fire spread from the flanks. Images are from the IKONOS satellite (Space Imaging Inc.) from June 20 and June 28, 2002. False color was created using combinations of spectral bands red, blue, and near infrared.

from increasingly marginal conditions for supporting crown fire associated with nightfall. With sunset, decreasing air temperature and sunlight, and increasing humidity results in a gradual rise in the fine fuel moisture over the course of a few hours. The fireline intensities then gradually decrease in response to this and the concomitant slowing of upslope convective winds. Since the frontal fireline intensity supports the initiation and spread of crown fires as a threashold phenomenon (Van Wagner 1977) a general decline in crown fire will be noticeable first at the flanks. This occurs because the head of the fire is shaped as an elliptical or parabolic curve with intensities and spread rates diminishing with angle away from the maximum spread direction (Catchpole and others 1982). The spread rate and intensity thresholds will become progressively limiting to the initiation and spread of crown fire from the flanks toward the head, resulting in a narrowing of the heading crownfire. The second scenario is suggested by the often-pointed shape of the head of some fast moving, single-run crown fires attended by prolific spotting (for example, Sundance Fire in Idaho, Anderson 1968). A rapid change in the critical environmental conditions (for example, decreased winds or rain) could quickly terminate crown fire spread, leaving a footprint of high-severity effects to define the location of the crown fire at that time. A review of the weather data from the RAWS stations does not exclusively support either hypothesis, suggesting that humidity was generally increasing after about 1900 hours and that wind speeds were diminishing after about 2100 hours.

Descriptions by field crews indicated that the fire alternated between wind-driven and plume-dominated (Rothermel 1991), suggest behaviors similar to those described by Wade and Ward (1973). The sequence begins with a wind driven phase where torching and crowning produces long- and medium-range spotting ahead of the continuous fire front. High energy release rates from the large areas ignited by spotting produces mass ignition (Countryman 1964; Byram 1966) and the consequent rapid development of a vertical column above the fire. The column size and velocity decline with the cessation of flaming combustion within the mass-ignited area, permitting the wind to increasingly tilt the smoke plume. Spotting then resumes from trees torching as winds dominate the spread of the fire at the head.

Winds were critical to the behavior and effects of the fire on June 9. Evidence of this is found in the form of "tree crown streets" along the east flank of the fire within the perimeter of June 9 (fig. 45). These tree crown streets are narrow bands of green or scorched foliage within an otherwise blackened forest. These features extend approximately from the headwaters of Northrup creek northeast to the southwest slopes of Thunder Mountain and are visible on the burn severity map as a thin diagonal line just west of the eastern edge of the June 9 perimeter position (fig. 45 and 46). They parallel the main direction of fire movement on June 9 and define the lateral locations of the active eastern flank of the fire and its forward extent around 1853 hours. This timing corresponds to a windshift from the southwest to the south recorded by both the Cheesman and Lake George RAWS stations (appendix A). Furthermore, fire position was approximately located at this northward extent at this time according to (1) the Cheesman RAWS station, which recorded an 84 mph wind gust and 96 °F temperature spike at 1853 hours, and (2) the observation of the fire edge at T105 R79 Section 16 at 1841 hours (Pueblo Interagency Dispatch Log). The phenomenon of a "tree-crown-

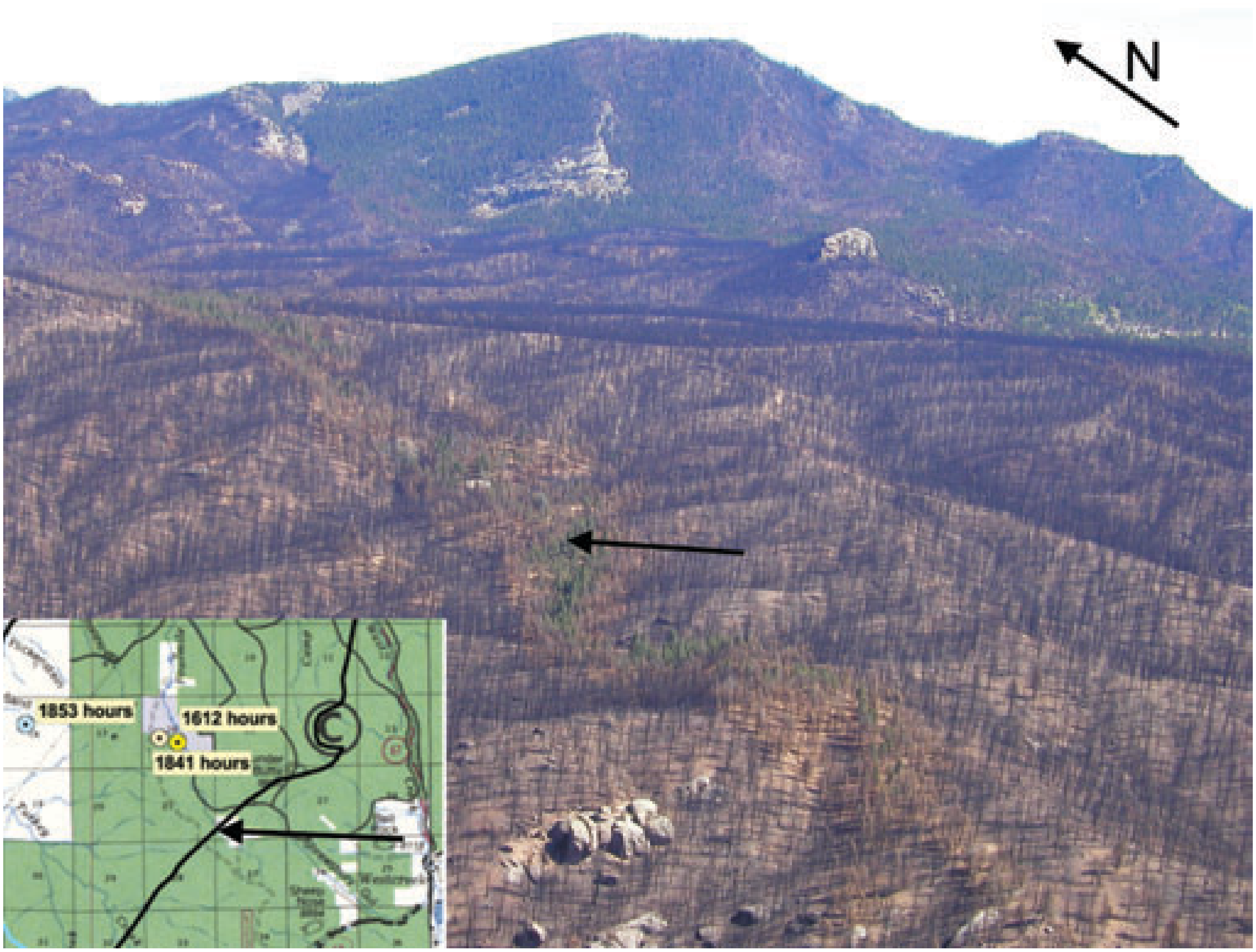

Figure 45—Oblique aerial photo looking northeast toward Thunder Butte clearly shows a "tree crown street" parallel to the flank of the fire as it exists around 1900 June 9 (see arrow). This results from transition from a crown fire to a surface fire following a wind shift. (Photo by Rick Stratton)

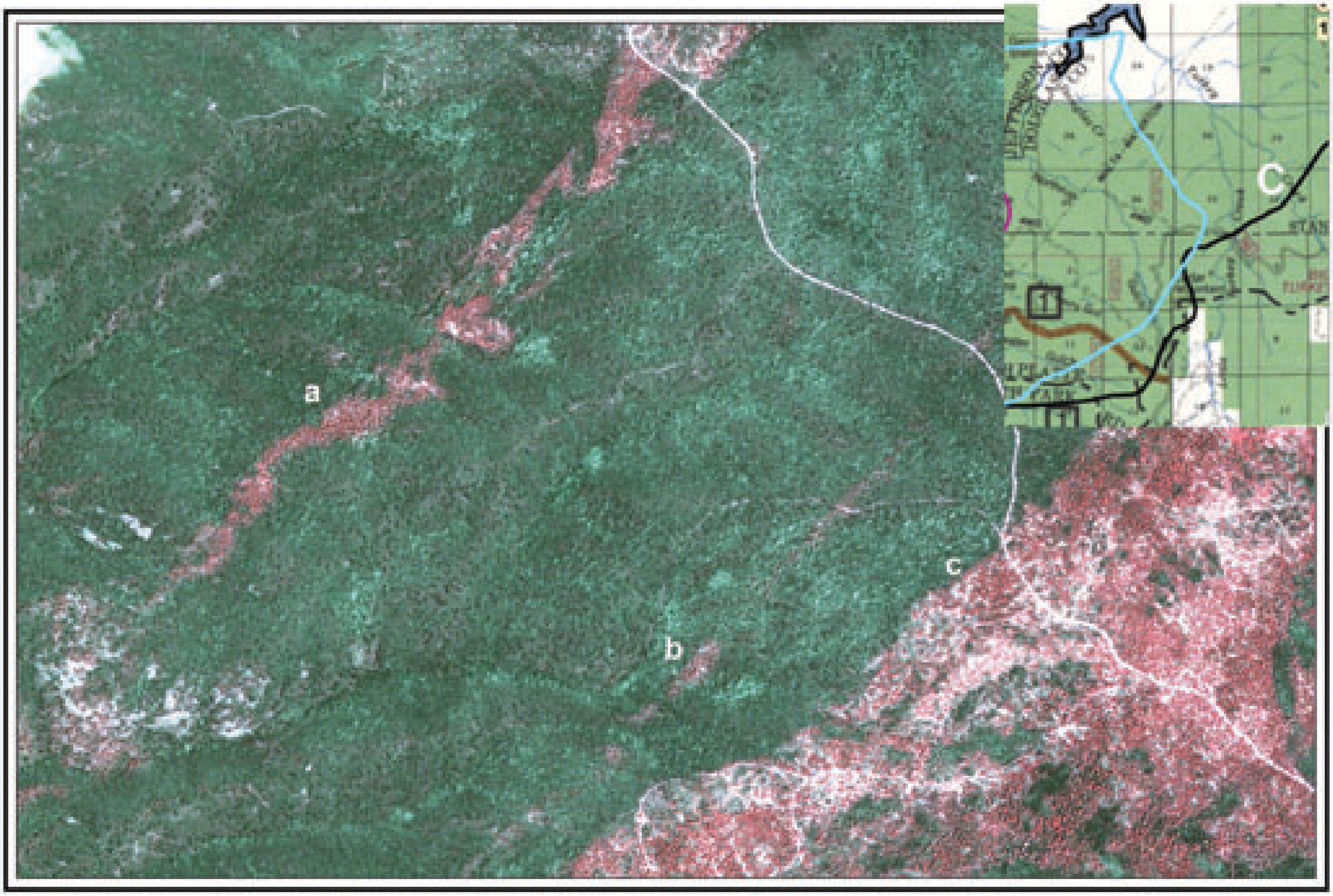

Figure 46—False color infrared satellite image showing "tree crown streets" created along the eastern flank of the Hayman Fire on June 9. These represent the flank positions that were underburned during windshifts (see text). Points (a) and (b) represent tree crown streets caused by temporary wind shifts and point (c) indicates the ending position of the flank at about 2300 on June 9. Shown is a composite of IKONOS (Space Imaging Inc.) images from June 20 and June 28, 2002. False color was created using combinations of spectral bands red, blue, and near infrared.

street" is produced by temporary shifts in the direction or speed of the winds that briefly reorient the heading fire spread and intensities (Fendell 1986; Finney 1998; Richards and Wahlberg 1998). During this period, an area formerly along the flank or head of the fire can be underburned by lower intensities of the fire burning into the wind or in the up-wind direction. When the wind oscillates back to its original direction, the fire resumes spreading with the previously high intensities, leaving behind the underburned strip. This phenomenon was formerly thought to be associated with "horizontal roll vortices" (Haines 1982). However, the complex factors required by this theory have not been documented under field conditions and are not necessary to explain the characteristics and relatively common occurrence of these "streets" in forests and grasslands.

The large acreage burned on June 9 brought the fire in contact with numerous mechanical fuel treatments, previous wildfires, and prescribed fires. From the detailed analysis of fuel treatment effects (see Martinson and others, this report), major impacts of these fuel changes on fire progress June 9 occurred only from the Polhemus prescribed fire (fall 2001) and the Schoonover Wildfire (May 2002). Fuel changes in these burned areas stopped the forward spread of the Hayman Fire (fig. 47, 48, 49), producing an edge-match between perimeters of the Hayman Fire and the borders of the Schoonover and Polhemus burns and a strong contrast between the high fire severity and canopy consumption in the Hayman Fire and adjacent burns (fig. 50). This was not unexpected or novel, however, given how recently all three areas were burned. Fuel accumulation, new deadfall, or vegetation recovery could not have occurred before the Hayman Fire. Speculation that weather changes were instead responsible for cessation of the Hayman Fire

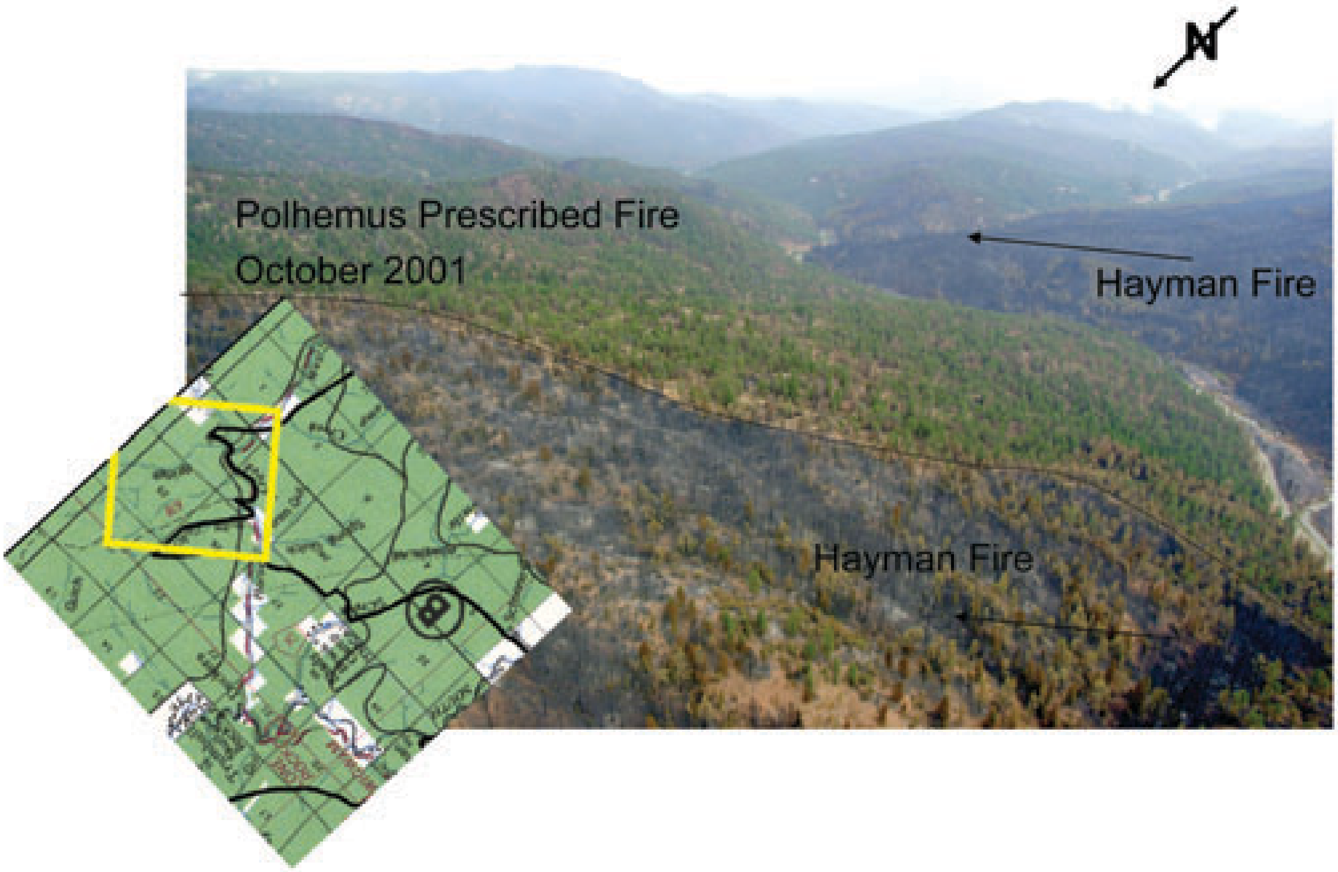

Figure 47—Photograph of border of the Polhemus (fall 2001) prescribed burn and the Hayman Fire. The Hayman Fire moved from the southwest (right side) and did not burn into the Polhemus prescribed fire unit (green) but burned as an intense surface fire and crown fire in the adjacent area on the same slope. (Photo by Karen Wattenmaker)

Figure 48—Same as figure 49 but looking toward the northeast. Note the boundary between the Polhemus prescribed burn unit and the Hayman Fire (moving from the foreground away from the camera). (Photo by Karen Wattenmaker)

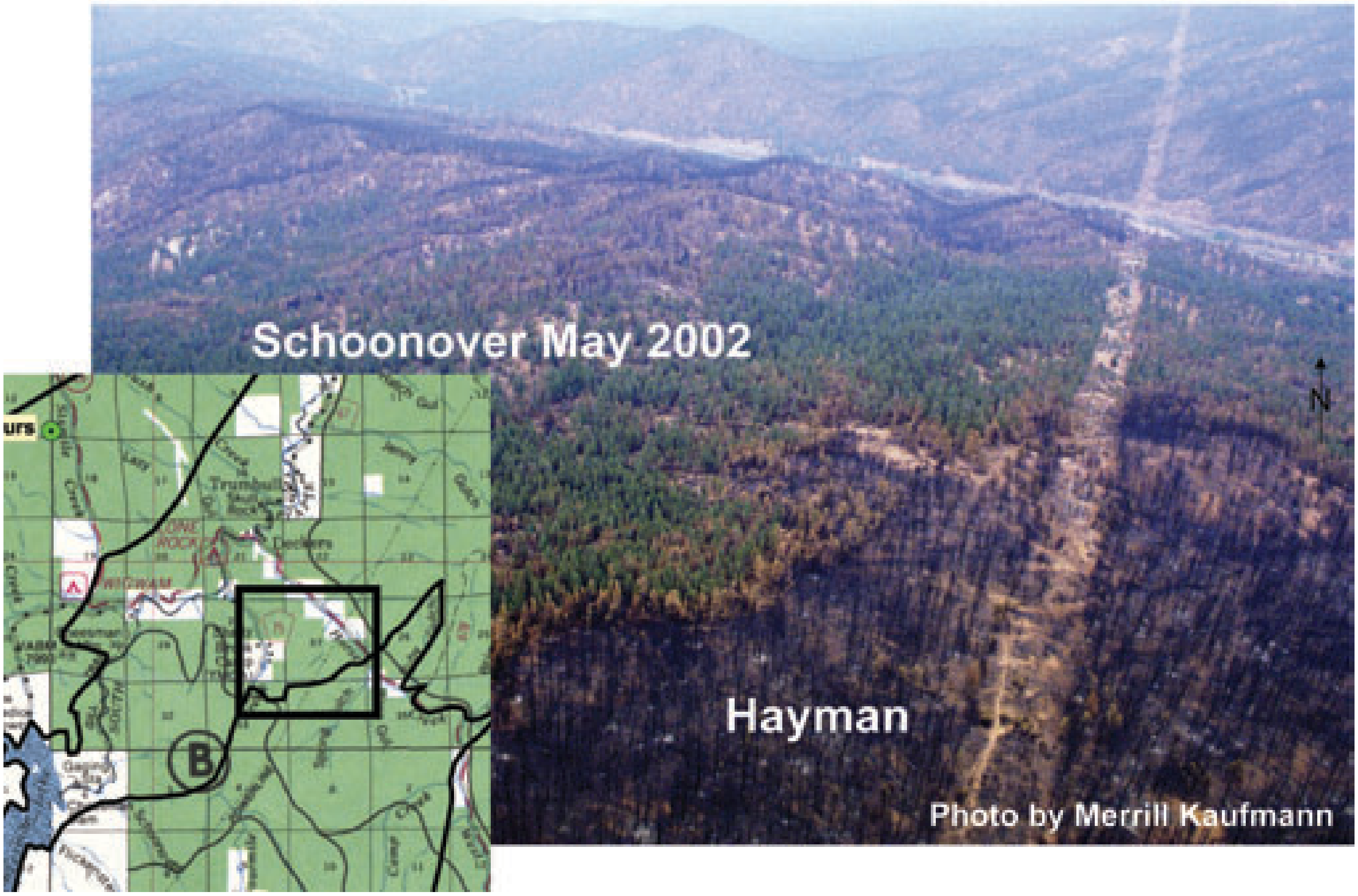

Figure 49—Green strip of underburned forest divides the Hayman Fire (left) and Schoonover wildfire (May 2002, right). The green strip was underburned by the Schoonover fire 3 weeks before the Hayman Fire occurred and was not reburned by the Hayman Fire. Note the power line corridor in the picture and the inset map.

is not supported by weather records (appendix A) showing winds subsiding somewhere between 2000 hours on 6/9 and 0100 on 6/10, while the west flank of the Hayman Fire was observed about 4 miles from its final position at 2217 (fig. 34). This indicates that crown fire was still dominating the behavior for a prolonged period after the weather began moderating for the evening. Discrepancies in the timeline of fire progression are approximately equal for the east and west flanks of the fire, suggesting no bias in the progress of the west or east heads of the Hayman Fire (that is, there is no evidence that they traveled at different rates). Lasting effects of the Schoonover and Polhemus burns were evident from the fire progression data that recorded continued growth of the Hayman Fire for several days following June 9 along the entire perimeter except the segments that coincided with the previous burns.

Minor effects of altered fuels were evident in the areas burned in 1963 Wildcat Fire, the Northrup prescribed fire (1992), and the 2001 Sheepnose thinning operation. In summary, however, the extreme nature of the weather, large fire size, long-range spotting, and generally continuous fuels surrounding these limited and isolated areas, greatly diminished effects of these areas on growth of the Hayman Fire.

June 10: The dry and windy prefrontal weather pattern that began 2 days earlier (June 8) continued during the morning hours. Strong and gusty winds alternated between the southwest and southeast, temperatures climbed to the high 70's, and humidity hovered between 5 and 9 percent. The weather changed abruptly by about 1400 hours with the arrival of the cold front. As recorded by the Cheesman and Lake George RAWS stations (appendix A), the front brought sudden shift in the wind from the SW to the NE and rapid rise in humidity from 5 to 25 percent within 1 to 2 hours. The timing of this frontal system significantly altered fire behavior and overall fire growth pattern

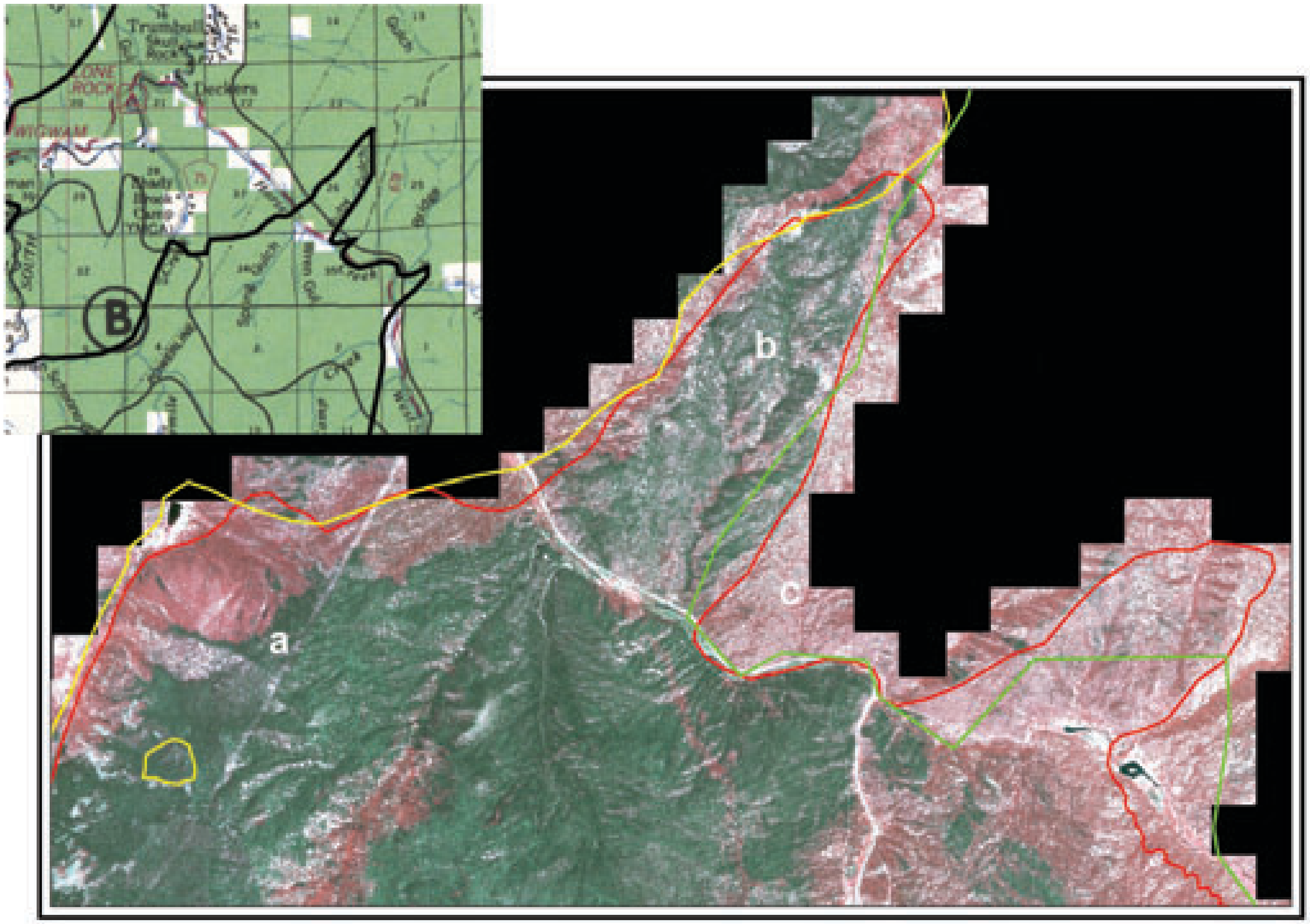

Figure 50—False-color infrared satellite image (IONOS, Space Imaging Inc.) shows consumed forest canopy (black) inside Hayman Fire (a) and (b) compared to live forest canopy (pink) in adjacent Schoonover wildfire, left of (a) and (b), and the Polhemus prescribed burn (c). Fire perimeters mapped for the Hayman Fire and previous burns (lines) are nearly coincident. The Hayman Fire burned largely as a crown fire up to the point of contacting the areas previously burned.

because it arrived in the early-middle part of the daily burning period. Up to this point, the fire had been accelerating in terms of intensity, initiating spot fires along several flanks (fig. 51). Satellite images reveal the expansion of fire-column development from the east and west flanks (fig. 52). By 1400 hours, however, the sequence of satellite images show the sudden effects of the cold front in terms of an expansive blossoming of moist cumulus clouds above the along the entire Rocky Mountain Front and the wind shift contorting the smoke plume trajectory.

Fire behavior prior to the arrival of the front was described as active. The fire perimeter expanded on the west and east flanks, driven by varying wind directions and local topography. Intense surface fire (flame lengths of 6 to 8 feet), crown fire and spotting were observed along portions of the southeast flank and upslope into the Lost Trail Wilderness from the west flank. Winds remained strong after the cold front arrived (gusting to the mid-20 mph range) but the high humidity and cloud cover limited subsequent fire activity.

Several fuel treatments were encountered by the fire on June 10. The east flank of the fire (roughly east of Cheesman) Reservoir encountered the Turkey prescribed burns (Rx1987, Rx1990, Rx1995) and the Big Turkey wildfire (1998) (fig. 53). As detailed by Martinson and others on fuel treatment effects (this report), the Rx1990 and Rx1995 prescribed burns appeared to have be associated with moderate fire behavior and consequent severity as visible on false color infrared satellite imagery (fig. 53) and the burn severity map (fig. 33). The area within the prescribed burn Rx1987, however, experienced moderate to high levels of crown damage in its interior. The southwest wind direction during the morning hours produced

Figure 51—Elliptical burn patterns started by spot fires separated from the main fire front on June 10. Photo from east side of Hayman Fire.

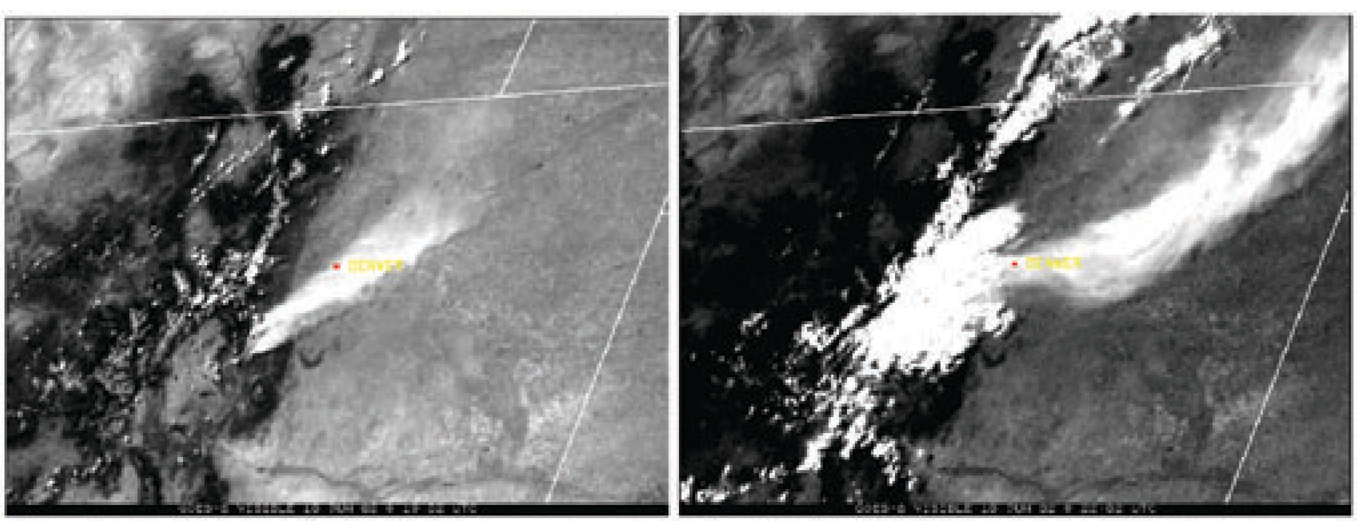

Figure 52—Two satellite images show effects of the arrival of the cold front at about 1400 hrs on June 10. (A) before cold front fire was building two convection columns (1300 hrs). (B) after cold front passage cumulus clouds formed over Front Range and wind shift distorted smoke plume trajectory.

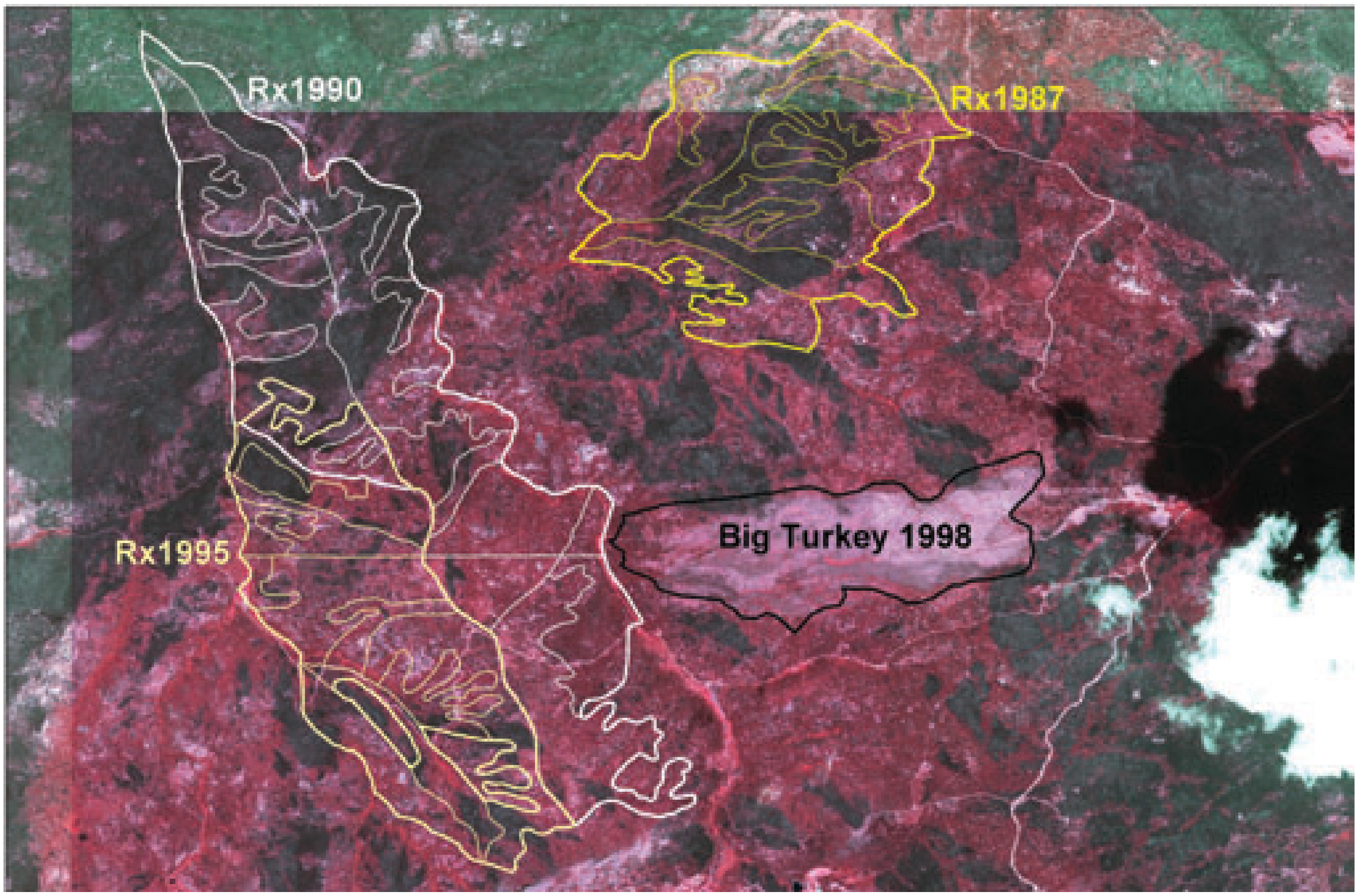

Figure 53—False-color infrared satellite imagery (IKONOS, Space Imaging Inc.) shows fire severity patterns within the Turkey prescribed burns (1987, 1990, and 1995). Pink areas are live vegetation compared to dark burned areas. Stand boundaries are delineated within treatment units and suggested that severely burned areas within treatment units are partially associated with Douglas-fir dominated stands compared to ponderosa pine.

visible crown streets within the 1987 burn area that are parallel with those produced nearby the afternoon of the preceding day (fig. 46), suggesting fire spread and conditions were nearly identical to the previous day. Crown fire spread to the east in the area between the 1990 and 1987 Turkey prescribed burns was obstructed by the roughly perpendicular orientation of the Big Turkey wildfire in 1998 (fig. 21, 53, 54, 55). The area abutting the western edge of the Big Turkey Fire was prescribed burned in 1990 and also within the burnout operation conducted to support suppression of the Big Turkey fire in 1998 (fig. 30) and gently underburned sometime between June 10 and 13.

June 11 through 16: Weather conditions initiated by the arrival of the cold front the previous day persisted for the next 5 days. Winds (NE, E, SE) associated with upslope conditions, generally cooler temperatures (60s-70s), relatively high humidity (typically 20 percent to 60 percent), and afternoon cloud cover with light rain (0.01 in) recorded at Lake George RAWS on June 12, and 0.07 total recorded on June 12 and 13 at Manitou.

Much of the fire perimeter was observed to be burning as a surface fire with flame lengths reported less than 2 feet and spread rates slower than 2 feet per minute. Along the east flank, the fire continued to move slowly and generally as an underburn creating a mosaic of mixed severity. On June 11, 12, and 13, the southern flank of the fire made afternoon runs of about 2 miles each day to the south (toward Lake George) with frequent torching and spotting. The Beaver Creek drainage burned on June 11, Crystal Creek on June 12, and Vermillion Creek on June 13. IKONOS satellite imagery (Space Imaging Inc.) verifies that the extent of the fire on June 13 was little changed on the east flank but shows the expansion resulting from the daily runs to the southeast (fig. 55).

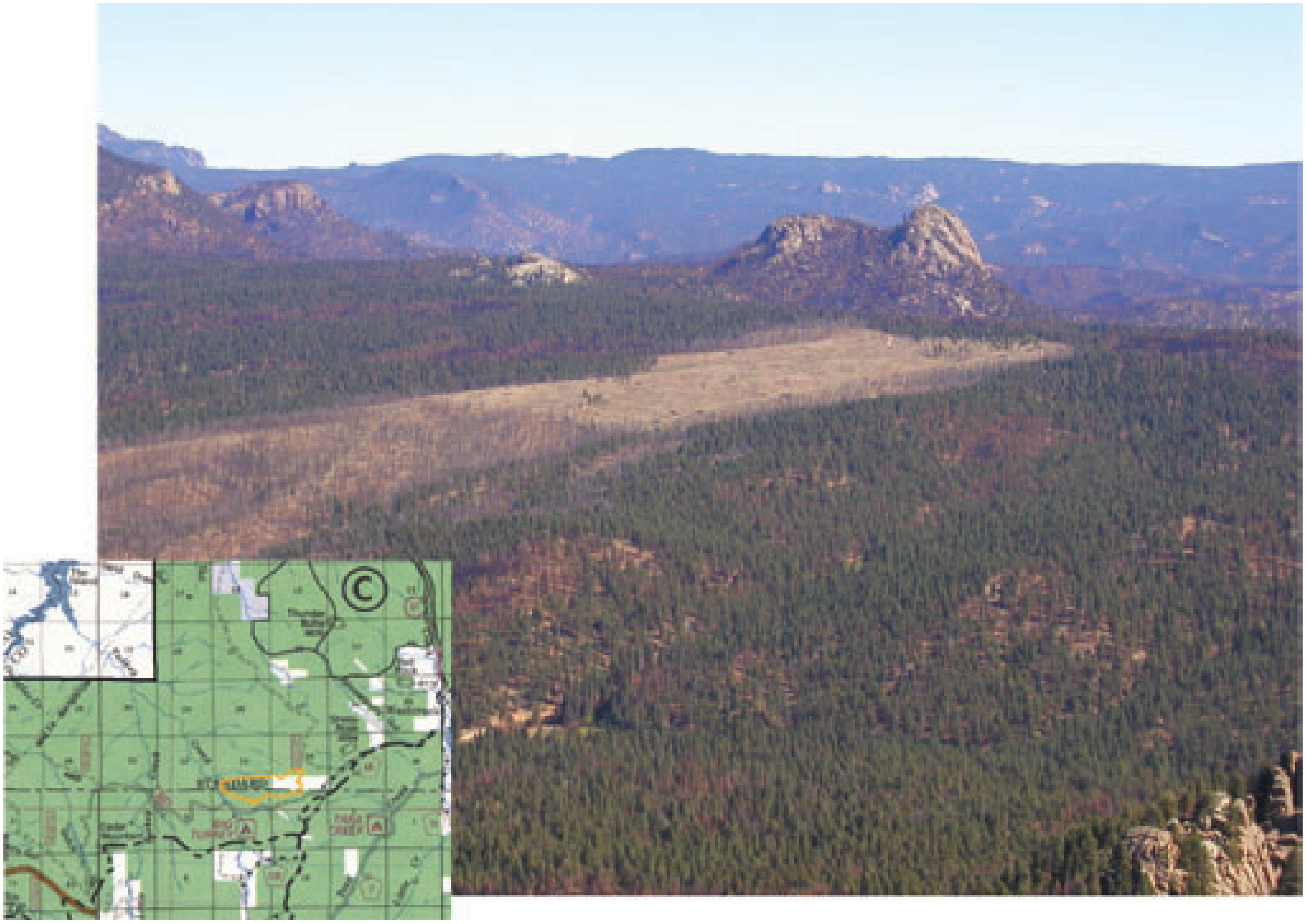

Figure 54—Oblique view of area burned by the Big Turkey wildfire (1998) looking northeast. Area in the foreground was inside the prescribed fire unit Turkey 1990. This area was burned between June 10 and June 13. (Photo by Rick Stratton)

June 17: The weather conditions of the previous 6 days changed at about 1100 to 1200 hours with a steep drop in humidity to around 5 percent and an increase in mid-day temperature to the upper 80's. Winds increased from the west-northwest, with the maximum gust of 57 mph reported by Lake George RAWS station at 1800 hours (perhaps caused by a passing thunderstorm). These changes were associated with the eastward movement of a large upper-level high-pressure ridge located to the west of Colorado (fig. 15).

The renewal of hot, dry, and windy conditions caused a dramatic increase in fire behavior from several portions of the east flank. Sustained crown fire and spotting occurred along two segments on either side of the Big Turkey wildfire (1998) which proceeded to move 3 to 4 miles each. The southern segment burned over the Turkey Rock subdivision. The northern segment advanced nearly to the Westcreek subdivision and crossed Westcreek. The position of these fire fronts when the burning conditions moderated that evening were clearly recorded as a continuous strip of green tree crowns outlining the entire perimeter (fig. 56). These strips survived because the crown fire subsided in the evening, resumed spreading as a surface fire for the night and early morning of June 18, leaving the conifer canopy largely intact. The green outlines are coincident with the infrared maps of fire location recorded early morning the following day and produced for the incident management teams.

The noticeable gap between these two large runs is likely related to the presence of the Big Turkey wildfire and adjacent Turkey prescribed burns (Rx1990 and Rx1995). Crown fire and torching initiated in the untreated fuel to the north and south of this area when extreme weather conditions returned that afternoon (fig. 57), but not from the prescribed burn units or Big Turkey wildfire. The burn-severity map (fig. 57) and satellite imagery (fig. 58) suggest the crown fire began

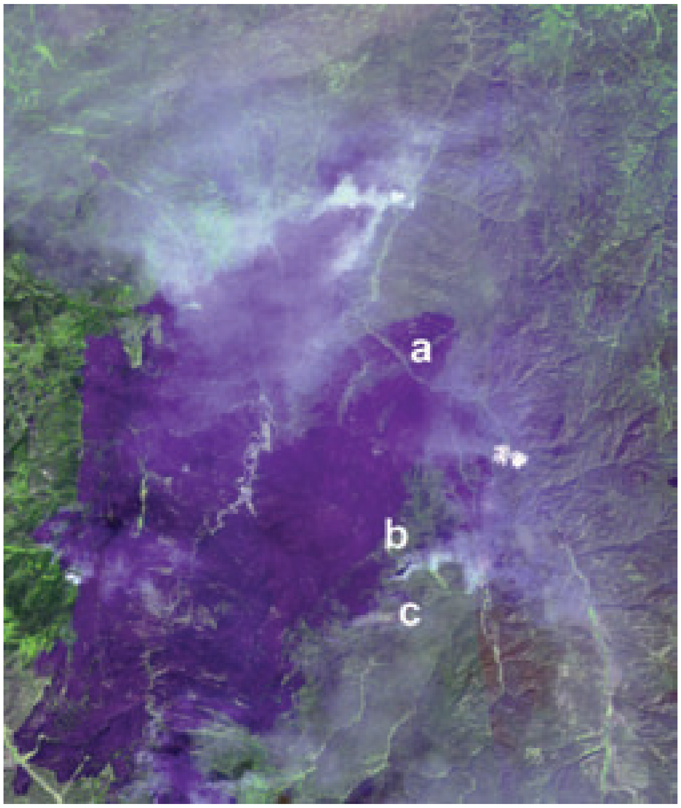

Figure 55—Satellite imagery showing burned area within the Hayman Fire on June 13. Several points are visible, (a) green strip separating the Schoonover wildfire on the north (May 2002) from the Hayman Fire on the south, (b) the green diagonal strip indicating the edge of the fire at the end of the June 9 burning period, and (c) the Big Turkey wildfire (1998).

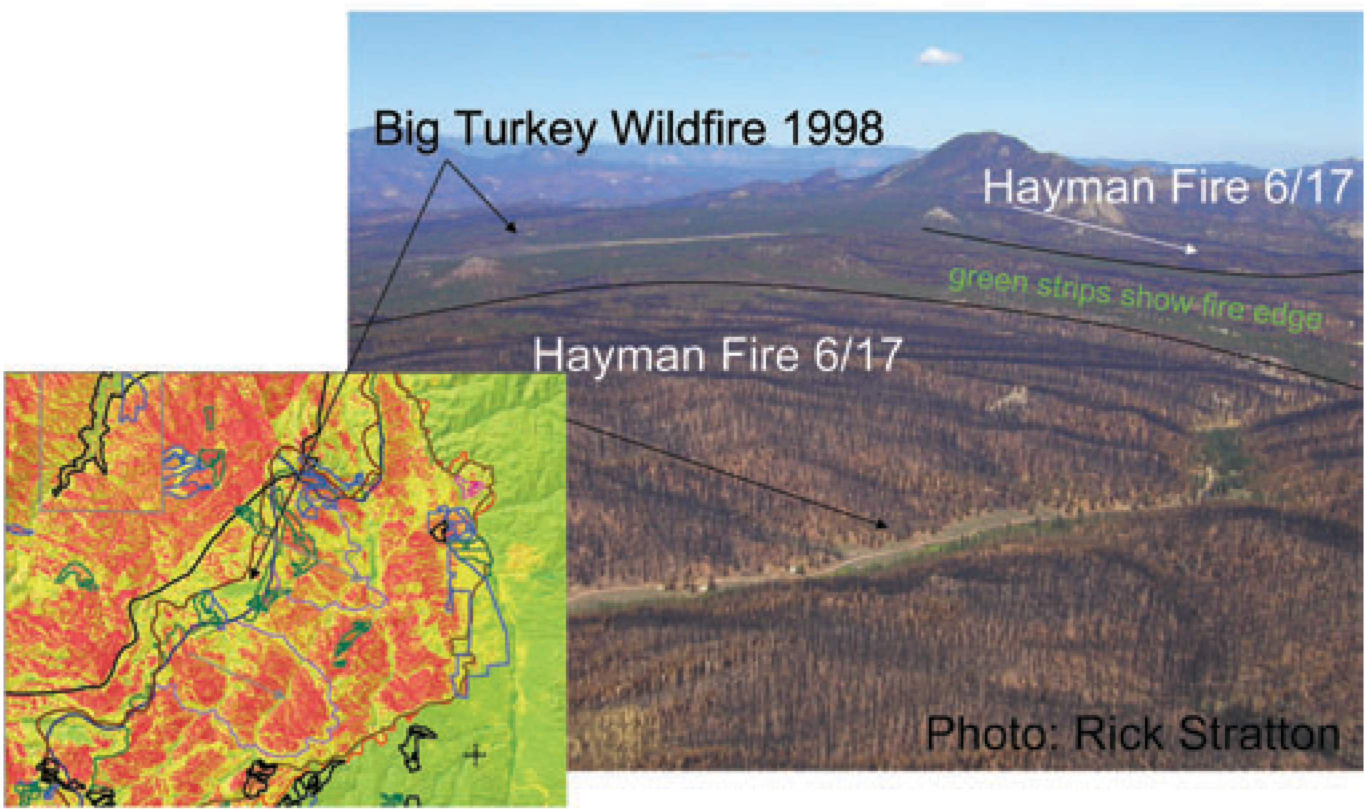

Figure 56—Oblique photograph showing the green bands of conifer forest at the locations where the two heads of the fire stopped after the burning period on June 17. Note that these heads originated from the north and south of the Big Turkey wildfire and adjacent prescribed burns (Rx1990, Rx1995). (Photo by Rick Stratton)

Figure 57—Photo looking south to Thunder Butte showing the beginning of crown fire run on June 17 (1430 hrs). (Photo by R. Moraga)

from the southern edge of the Rx1995 prescribed burn. The fire perimeter south of these runs did not expand that day, perhaps due to the burnout operations conducted along Cedar Mountain Road on previous days (see McHugh and others, this report). The combination of the Big Turkey wildfire and adjacent prescribed burns produced a significant, but temporary, landscape-scale disruption of the Hayman Fire.

June 18: The weather situation of the previous day persisted through June 18. A high-pressure system moved eastward. This brought a subsiding airmass that significantly lowered humidity and raised afternoon temperatures. Humidity recovery overnight was poor (15 percent), dropping to 5 percent by about 1000 to 1100 hours. Southwest winds were sustained in the mid-teens and gusted that afternoon to a maximum of 37 mph. Air temperatures rose to the upper 80's.

Extreme fire activity began early with the entire 15 miles of the eastern flank becoming active (fig. 33). Pushed by winds from the west-southwest, the fire displayed prolific torching, crown fire runs, and long-range spotting (fig. 59 and 60). Large pyrocumulus columns developed along the entire east flank (fig. 61). The gap between the runs on the previous day (east of Big Turkey Fire) was burned because of the shift in wind direction (from NW to W). Burnout operations and fireline improvements, which had apparently held the section along Cedar Mountain Road were breached. By late morning the fire had moved eastward and crested the ridge west of Manitou Experimental Forest (MEF). By 1300 hours it was observed to be approaching MEF headquarters when two forward heads of the fire merged (appendix F). Witnesses described changes in local wind direction resulting from the junction of the two columns. Specifically winds on the

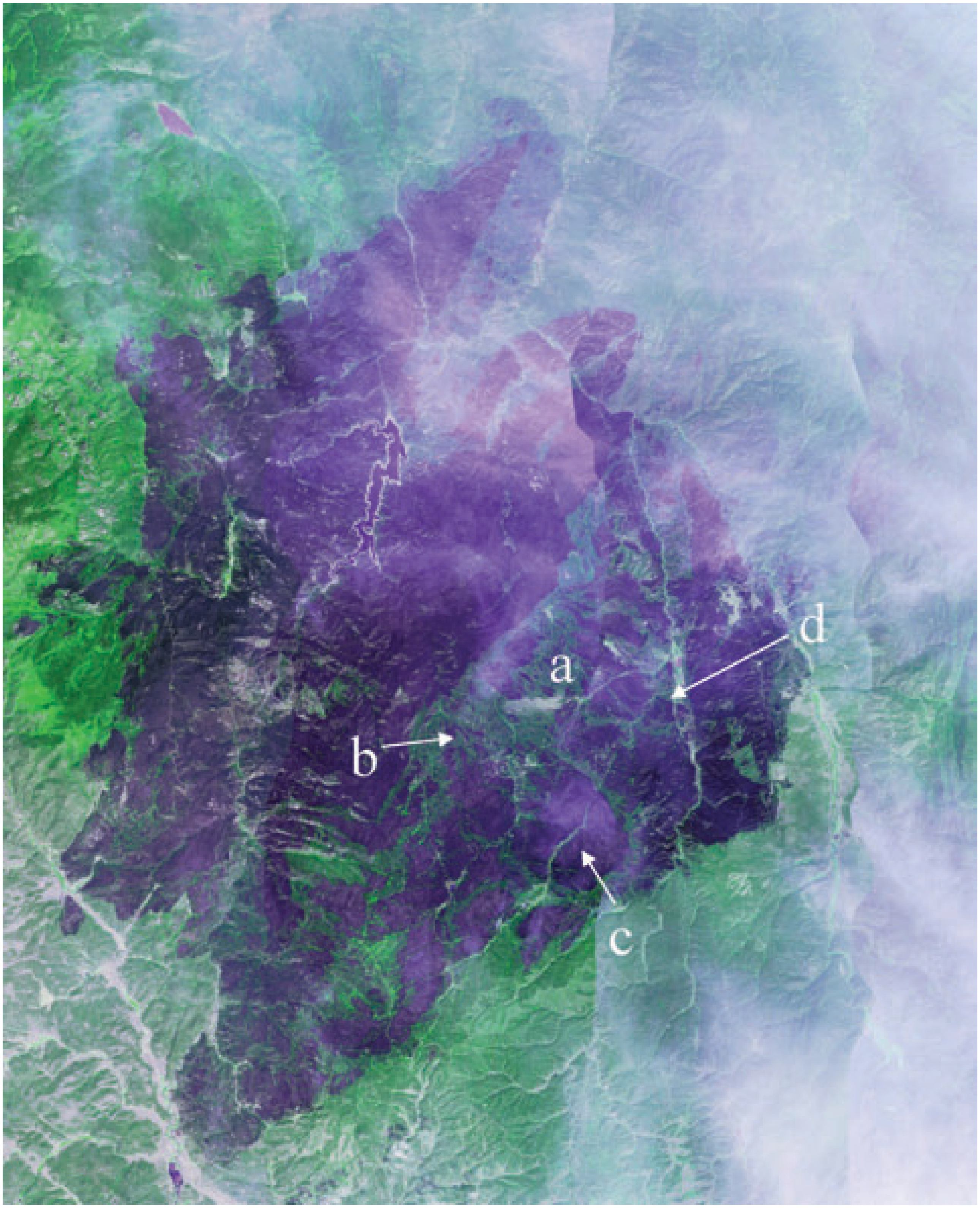

Figure 58—Satellite imagery showing burn pattern of the Hayman Fire on June 20. Several features are well illustrated: (a) the Big Turkey wildfire (1998), (b) the origin of the southern major crown fire run on June 17 in untreated fuels south of the Turkey 1995 prescribed burn, (c) the area burned by this southern run on June 17 and enclosed by the green band of undamaged crowns indicating the ending position of the fire at the close of the burning period that day, and (d) the northern run that initiated by Thunder Butte (see fig. 57).

Figure 59—Crown fire on the east flank of the fire June 18.

Figure 60—Crown fire on the east flank of the fire June 18.

lee-side of northern column (east side of fire) shifted noticeably, blowing first from the west and then from the north (fig. 62). The Manitou RAWS station (appendix A) also clearly recorded winds shifting from the west to the east between 1300 and 1400 hours as the fire was observed entering Manitou Experimental Forest. This likely accounts for some of the changes in fire behavior and effects witnessed in the Manitou thinning treatment areas at this time (see Martinson and others, this report).

June 19 to June 28: Weather and fire behavior began a sustained period of moderation on June 19, which lasted the remainder of the fire. The upper level ridge that dominated the previous day flattened and wind speeds subsided. Relative humidity briefly dropped into the single digits for a few hours on June 19. Cumulus

Figure 61—Convection column developed from east flank of the Hayman Fire on June 18 as it approaches U.S. Highway 67. (Photo by Kelly Close)

Figure 62—Photo looking west at main convection column approaching near Manitou Experimental Forest, not local smoke plume directed toward base of convection column. Since winds were from the west, this may indicate rotational windflow on lee-side of column. (Photo by R. Moraga)

clouds developed daily with rain amounts recorded each day on some RAWS stations through June 23. Some torching and spotting was observed from several places along the eastern flank on June 19, but the fire perimeter did not change appreciably after June 20.

Conclusion

All elements of the fire environment were found to have greatly influenced the fire behavior of the Hayman Fire. Continuous surface and canopy fuels throughout the South Platte River drainage facilitated crown fire and uninterrupted growth of the Hayman Fire for up to 20 miles on June 9. Several years of severe drought predisposed live and dead fuels to rapid combustion and ignition. Extreme episodes of high winds and low humidity drove the fire rapidly across the landscape by crowning and spotting. The coincident orientation of the South Platte River drainage and gradient wind direction produced an alignment that directed fire spread to the northeast during its first 2 days.

Part 3: Effects of Fuel Treatments on Fire Severity

Erik Martinson, Phillip N. Omi, Wayne Shepperd

Summary

The role played by the fuel conditions within the Hayman Fire severity was complex and does not lend itself to a single conclusion or simple summary. Uncertainties in the original treatment prescription, its implementation, discerning the coverage, extent, and condition at the time of the fire made it difficult for us to clearly determine treatment effects and relate them to treatment type or amount. Available fire documentation such as the fire growth and severity maps compiled by the fire management and BAER (Burned Area Emergency Rehabilitation) teams were immensely helpful, but they oversimplify inherent complexities in fire behavior and ephemeral weather conditions and may contain random or systematic errors (for example, classification of burn severity).

Nevertheless, each of the different types of fuel modification encountered by the Hayman Fire had instances of success as well as failure in terms of altering fire spread or severity. The most obvious effects were produced by the Polhemus prescribed burn, the Sheepnose timber harvest, and the prescribed fires associated with the Big Turkey wildfire in the Turkey Rock area (fig. 63). The Hayman Fire was clearly unable to burn into the Polhemus burn area even as a heading fire under the most extreme weather conditions. Without surface fuel removal, most of the trees in Sheepnose sale were killed, but the thinning obviously restricted fire behavior to a surface fire with reduced fire severity compared to crown fire in surrounding untreated stands. Acting together, two prescribed burns (Turkey Rx1990, Rx1995) and the Big Turkey wildfire (1998) appeared to have temporarily prevented a crown fire on June 17 along a 2-mile section of the eastern perimeter, although this area burned the following day.

There is much variation and uncertainty in effects of individual treatment units or types. However, the detailed analysis of treatments encountered by the Hayman Fire supports the following general conclusions:

- Extreme environmental conditions (winds, weather, and fuel moisture) and the large size of the Hayman Fire that developed on June 9 overwhelmed most fuel modifications in areas burned by the heading fire that day. Exceptions include the Polhemus prescribed burn (2001) and the Schoonover wildfire.
- Except for the Polhemus prescribed burn (2001), the Schoonover wildfire (2002), and the Platte Springs wildfire (2002), which occurred less than 1 year earlier, fuel treatments did not stop the fire but did in many cases change fire behavior and effects. These are special cases because of their recent occurrence that should not be generalized for expectations for fuel treatment performance. Fuel treatments can be expected to change fire behavior but not stop fires from burning.
- Under more moderate wind and humidity conditions (June 10 through 16), recent prescribed burns appeared to have lower fire severity than older burns. This is consistent with typical trends in fuel accretion and changes in forest fuels over time. Examples include the sequence of Turkey (Rx1987, Rx1990, Rx1995) prescribed burns (fig. 53). In Rx1987, stands dominated by Douglas-fir within treatment boundaries also seem have with higher severity than those dominated by ponderosa pine.
- Landscape effects of treatment units and previous wildfires were important in changing the progress of the fire. These include the Polhemus prescribed burn (2001), which stopped the forward progress of the eastern head burning as a crown fire under extreme weather conditions, the Big Turkey wildfire (1998) and adjacent prescribed fires (1990, 1995), which prevented initiation of crown fire along a 2 mile segment of the perimeter when extreme weather returned on June 17, and the Schoonover Wildfire (May 2002) which, together with Cheesman Reservoir, split the head of the Hayman Fire on June 9 and prevented it from flanking toward the town of Deckers.
- Fuel treatment size relative to the size of the wildfire was probably important to the impact on both progress and severity within the treatment unit. Large areas, such as the Polhemus prescribed burn, were more effective than small fuel breaks (Cheesman Ridge). Under extreme conditions, spotting easily breached narrow treatments and the rapid movement of the fire circumvented small units.
- No fuel treatments were encountered when the fire was small. The fire had time and space to become large and generate a convection column before encountering treatment units. Fuel treatments may have been more effective in changing fire behavior if they were encountered earlier in the progression of the Hayman Fire.
- Few fuel modifications had been performed recently (see table 24), leaving most of the landscape within the final fire perimeter with no treatment

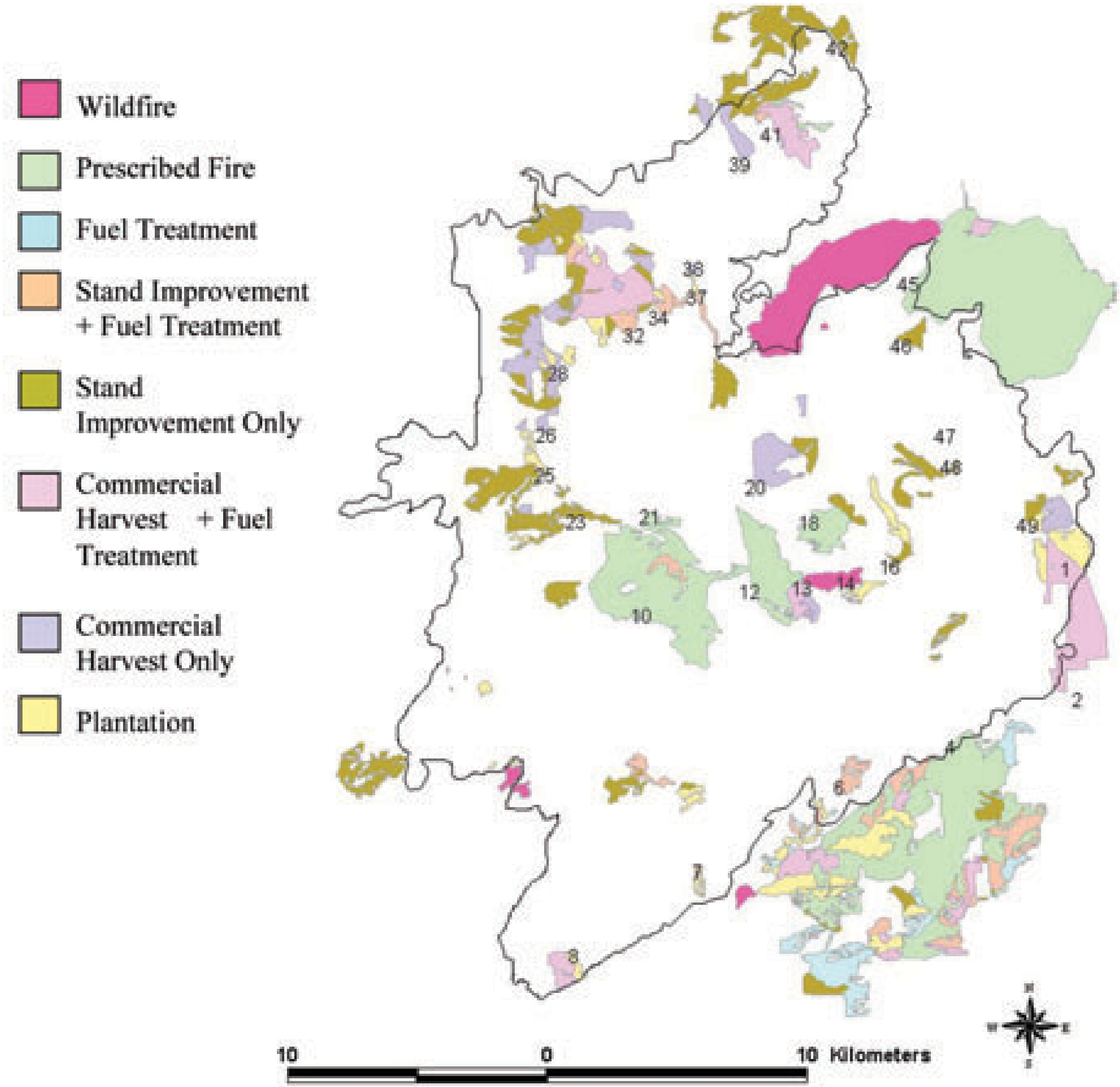

Figure 63—Approximate locations of helicopter photo points near fuel modified areas within the Hayman Fire.

Table 24—Distribution of fire severity classes and fuel modifications among windward (SW) and leeward (NE) aspects on slopes of less than 30 percent that burned in the Hayman fire on June 10.

Severity class	NE aspects	SW aspects
Unburned (%)	5	3
Low (%)	15	21
Moderate (%)	6	10
High (%)	74	66
Fuel Modification		
Yes	63	37
No	56	44

or only older modifications. This is significant because the high degree of continuity in age and patch structure of fuels and vegetation facilitates development of large fires that, in turn, limit the effectiveness of isolated treatments encountered by the large fire.

Introduction

Fuel treatments are distinguished from other land management activities by the intention to change fuels and potential fire behavior (Pyne 1984). Treatments can alter quantity, continuity, and compactness of surface fuels (for example, dead and downed woody material, grasses, shrugs, needle litter) and aerial fuels (trees and tree crowns, live and dead lower limbs). The prescriptions and techniques appropriate for accomplishing a treatment require understanding the fuel changes that result from different techniques and the fire behavior responses to fuel structure. Fuel treatments, like all vegetation changes, have temporary effects and require repeated measures, such as prescribed burning, to maintain desired fuel structure.

Clearly, many forest management activities have side effects that relate to fuels, but rarely can these activities be considered synonymous with fuel treatments. Commercial timber harvesting typically reduces the amount and continuity of aerial fuels but may increase surface fuels and surface fire intensities unless followed by slash removal (Agee 1997; van Wagtendonk 1996). Precommercial harvesting or thinning of only the smallest trees in a stand tends to decrease the vertical continuity of the forest by raising the crown base and separating the surface fuels from the aerial fuels. This can make ignition of the crown more difficult from a surface fire but may have little effect on surface fuels or on canopy cover. Prescribed fire reduces the quantity and continuity of surface fuels, increases fuel compactness, and may kill the lower limbs on the trees. These changes often decrease surface fire intensity and the vertical fuel continuity in the stand, making a crown fire less likely to start and crown damage less severe (Deeming 1990; Koehler 1993; Martin and others 1989; Helms 1979; Pollet and Omi 2002). Prescribed burning typically has little effect on the aerial fuels derived from the crowns of the largest trees.

This report summarizes postfire assessment of fire severity associated with many types of management activities. Some activities were designed as fuel treatments but most were implemented for other objectives. Fire effects must be interpreted in the context of the kind of activity, its likely effects on fuels, and the many unknowns with respect to the fire behavior and fuel conditions at the time the fire burned through a particular location.

Methods

The Hayman Fire encountered many types of fuel conditions. We classified these as natural disturbances (primarily wildfires), prescribed fires, surface fuel treatments, timber stand improvements, commercial timber harvests, and plantations. Each of these treatments or disturbances could be expected to alter different components of the overall wildland fuel complex. A total of 21,283 acres were found to have been affected by one or more management activities. This total contained the following categories:

- **Wildfires** (544 acres) temporarily reduce the quantity and continuity of surface and ladder fuels, and reduce the density canopy fuels by killing or consuming tree crowns. Consequently, potential surface and crown fire behavior is likely to be reduced after wildfires, until surface fuels accumulate and canopy fuels increase through regeneration and in-growth of trees. Fuel changes are spatially variable within the burned area.
- **Prescribed fires** (5,814 acres) have effects similar to those of a moderate wildfire. Ignition patterns and the weather and moisture conditions generally associated with prescribed burning tend to reduce canopy damage compared to wildfires. As a result, there may not be as much surface fuel consumption from prescribed fires as compared to wildfires. Crown density and continuity may not be affected but ladder fuels will often be reduced. Prescribed fire can be expected to moderate subsequent surface fire intensity and reduce the potential for crown fire initiation, but generally not to the extent expected in areas burned by wildfire.
- **Fuel treatments** (13 acres) refer to surface fuel modification for the purpose of mitigating wildfire potential by means other than prescribed fire. Some examples include lop and scatter, piling and burning, and mechanical or manual removal of surface fuels. The result is a rearrangement or reduction in surface fuels, which would be expected to reduce potential surface fire intensity. However, ladder fuels, crown bulk density, and crown base height are generally unaltered by these fuel modifications. Thus crown fire potential may not be as effectively reduced as by prescribed burning or wildfire.
- **Timber stand improvements** (7,670 acres) include precommercial thinning, removal of trees weakened by insects or disease, or weeding of undesirable species or individuals. These activities predominantly involve mechanical removal of understory trees, with minimal removal of overstory trees. Reduction in vertical fuel continuity, and to

a lesser extent horizontal canopy continuity, would be expected. However, the tree cutting produces additional surface fuels with increased exposure to solar radiation and winds, potentially resulting in increased surface fuel availability and surface fire intensity under wildfire conditions. These effects may be mitigated by subsequent treatment of the slash and preexisting surface fuels. Where this is the case, the combined reduction in surface and crown fuels would be expected to moderate potential wildfire behavior.

- **Commercial timber harvests** (5,629 acres) involve removal of trees that have merchantable value. Included are patch and stand clearcuts, shelterwood preparation and seed cuts, individual tree selection, and commercial thinning. These activities remove overstory trees, resulting in reduced crown bulk density. Depending on stand structure and the silvicultural prescription, commercial harvests may or may not affect small trees or crown base height. Harvesting residues (also called activity fuels) increase the amount of surface fuels that can be mitigated by subsequent surface fuel treatments like prescribed burning. Large changes in canopy structure increase the sun and wind exposure of surface fuels and potential surface fire behavior.
- **Plantations** (1,613 acres) are even-aged stands regenerated by direct seeding or planting. The surface and ground fuels depend on the method of site preparation used to regenerate the stand. The height to crown base and crown bulk density both depend on the species, age, and spacing of the plantation. In general, surface fire behavior would not be expected to be extreme in plantations. However, crown fire potential could be relatively high due to the low crowns and increased continuity of aerial fuels.

Explanation of every shift in the spread and behavior of the Hayman Fire as it entered each of these different types of fuel modification is beyond the scope of this report and would probably be impossible. However, systematic comparison of available documentation allowed us to make limited inferences regarding changes due to historic management activities and disturbances.

Determining the role of fuel modifications within the Hayman Fire relied on spatial analyses using Geographic Information System (GIS) software and databases provided by the Pike-San Isabel National Forest, supplemented by a helicopter survey of the fuel-modified areas. Approximate locations of where the photos were taken in relation to areas of fuels modification are shown in figure 63.

Spatial information provided by the Pike-San Isabel National Forest was used to assess the influence of prefire fuel modifications on the spread and severity of the Hayman Fire. Our assessment included qualitative evaluation of patterns in fire spread and severity in relation to fuel modifications, as well as quantitative analysis of the distribution of fire severity classes in fuel modified areas compared to that in unmodified areas. The information used in our assessments included a fire severity map (fig. 64) derived from satellite imagery, a map of fire progression (fig. 65), maps of previous fuel modifications, and a Digital Elevation Model that was used to derive aspects and steepness of slopes. While all these sources of information are prone to errors, they represent the best information currently available.

The fire severity map was produced by an interagency Burned Area Emergency Rehabilitation (BAER) team. BAER fire severity maps generally distinguish four classes of fire severity interpreted from satellite imagery: foliage consumed (high), foliage completely scorched (moderate), patchy foliage scorch, (low), foliage unscorched (unburned). While the “unburned” class indicates little or no canopy scorch, fire may have burned through the area as a low-intensity surface fire. Since our assessment relied heavily on the BAER fire severity map, we visited several locations representing the range of fire severities depicted on the map to verify its classification.

The fire severity map reflects fire effects primarily in terms of overstory tree mortality, and does not necessarily reflect changes in causative fire behavior that are potentially important to fire suppression or progress (for example ember production, fireline intensity, fire spread rate). Fire severity is the product of several interacting variables. These include fire intensity, vegetation sensitivity to scorch and consumption, and weather conditions that affect upward heat transfer, particularly temperature and windspeed. Further, fire intensity itself is the product of interactions among weather, topography, and fuels. Therefore, in our quantitative analysis we attempted to minimize the effects of factors other than vegetation conditions that may have influenced fire severity.

The influence of weather variations was addressed by restricting the quantitative analysis to a single burning period, the afternoon of June 9. This particular period was chosen because it appeared to be the most active in terms of fire growth, fire severity, and the number and variety of fuel-modified areas encountered. The area burned on the afternoon of June 9 is shown in relation to Hayman Fire severity and areas of fuel modification in figure 64.

Variations in topography were minimized in the analysis by focusing on only those areas of moderate slope (less than 30 percent), since this is where the

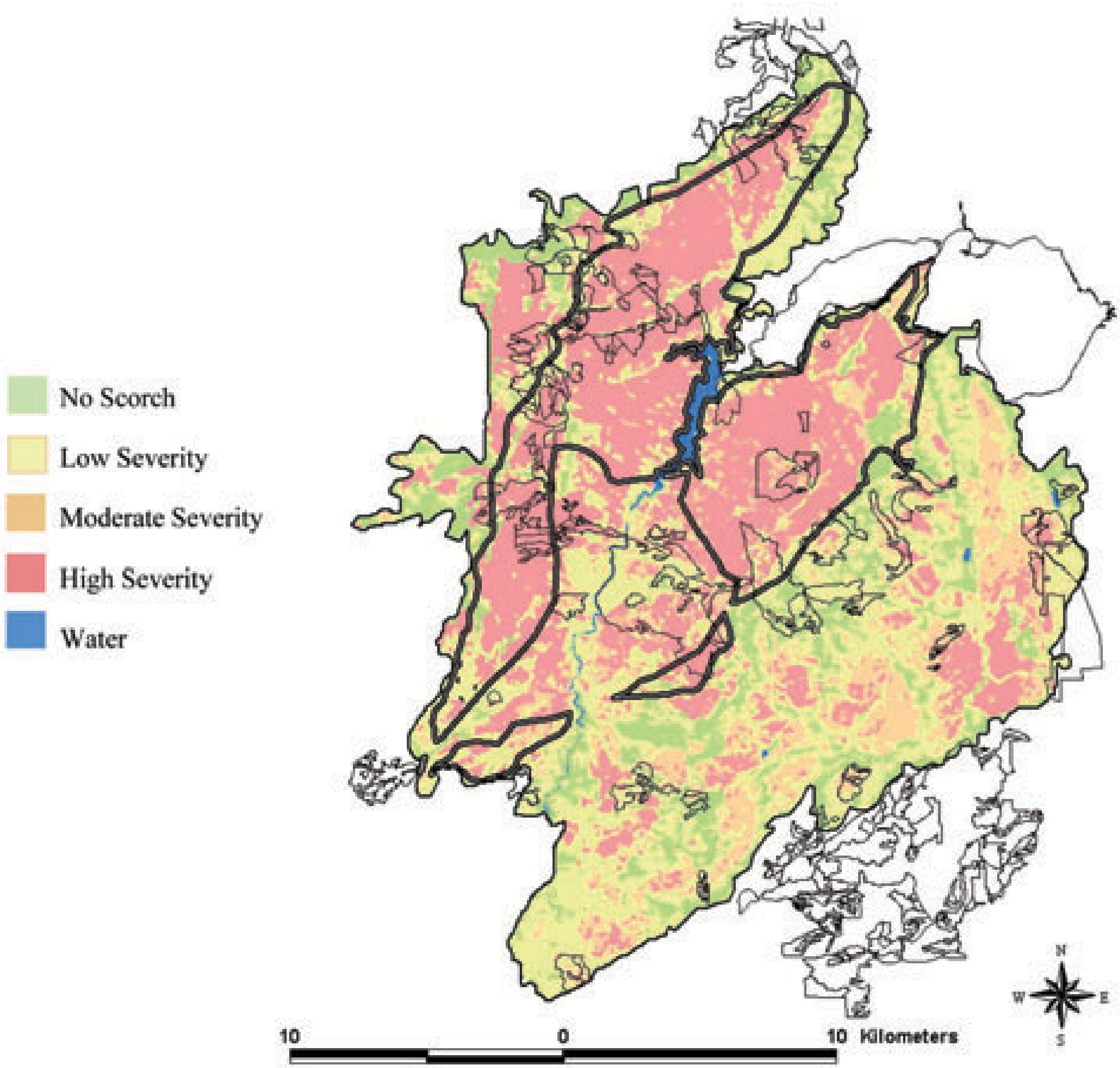

Figure 64—Fuel modifications in relation to Hayman Fire severity and area burned through June 9, 2002.

majority of fuel modifications were located (88 percent of the fuel modified areas affected on June 9 were on slopes of less than 30 percent). Since our analysis was restricted to moderate slopes, we assumed aspect had no effect on fire behavior and severity within the analyzed area. This assumption greatly simplified our analysis and was confirmed by comparison of fire severity in untreated areas of moderate slope on northeast versus southwest aspects (table 24).

Somewhat surprisingly, fire severity was slightly greater on the lee face (northeast aspects on June 9) of these moderate slopes. However, on steeper slopes we would expect greater fire intensity on the windward side. Further, aspects were similar among unmodified areas and areas that had fuel modifications, though northeast aspects were slightly more prevalent among the modified areas. Because northeast aspects experienced slightly greater fire severity in the areas we considered, our analysis could be considered a somewhat conservative assessment of the effects of fuel modifications under the hypothesis that they mitigate wildfire severity.

Results

Comparing the fire progression map with areas of fuel modifications reveals several striking patterns in the growth of the Hayman Fire (fig. 65). Most notable is the adjacency of much of the final fire perimeter with

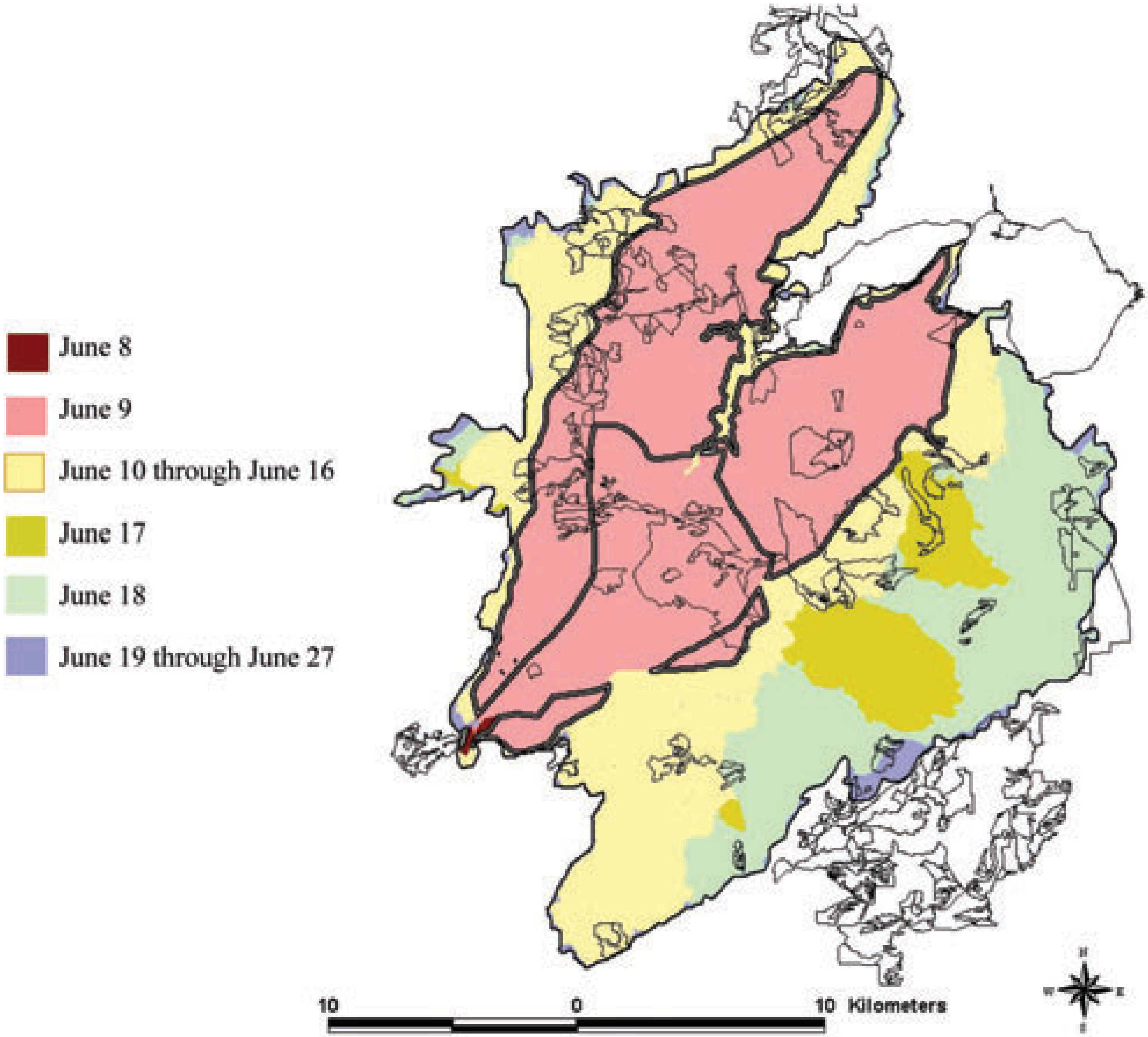

Figure 65—Hayman Fire progression in relation to areas of fuel modification.

the boundaries of fuel-modified areas, suggesting that they may have helped prevent further fire spread. On the other hand, equally striking is the June 9 run over 60,000 acres that included several areas of fuel modifications with little apparent effect on fire severity (fig. 64). This impression was confirmed by our analysis of the distribution of fire severity classes in the various types of fuel-modified areas that burned on the afternoon of June 9 (table 25). Field verification of the fire severity map used to conduct this analysis confirmed that it is generally accurate, though the moderate and high classes seem poorly distinguished (table 26), suggesting that they should probably be combined when evaluating the severity map or interpreting table 25.

The results of the quantitative assessment indicate that fuel modifications generally had little influence on the severity of the Hayman Fire during its most significant run on June 9. However, there was some variability among the different types of fuel modification, with prescribed fires and other surface fuel treatments that seemed to be most effective at changing fire severity and behavior. Also, there were several instances on moderate days (following June 9) where fuel modifications appear to have had a greater influence on fire spread and severity. The apparent effects

Table 25—Distribution of fire severity classes among fuel-modified areas on moderate slopes (less than 30 percent) that burned in the Hayman fire on June 9, 2002.

	Area (ac)	Unburned (%)	Low (%)	Moderate (%)	High (%)
Unmodified	22,546	4	18	8	70
			Recent Modifications (after 1990)		
Wildfires	12	0	0	25	75
Rx fires	719	6	20	11	63
Fuel treatments	0	NA	NA	NA	NA
Improvements + treatment	395	0	19	7	74
Improvements, no treatment	625	3	12	9	76
Harvest + treatment	1622	5	14	10	71
Harvest, no treatment	583	0	1	33	66
Plantation	136	0	8	5	87
			Older modifications (prior to 1990)		
Wildfires	Unknown	NA	NA	NA	NA
Rx fires	84	17	50	8	25
Fuel treatments	5	0	86	14	0
Improvements + treatment	0	NA	NA	NA	NA
Improvements, no treatment	1462	1	14	8	77
Harvest + treatment	3	0	16	9	75
Harvest, no treatment	948	3	27	2	68
Plantations	314	0	27	10	63

Table 26—Correspondence of fire severity classifications on the BAER map to our field assessments.

	Map classification			
Field classification	**High**	**Moderate**	**Low**	**Unburned**
High	4	7	1	0
Moderate	0	3	3	0
Low	0	1	10	1
Unburned	0	0	0	1

of each of the different types of fuel modification are discussed separately below.

Wildfires: The Hayman Fire burned over several recent wildfires (544 acres total), including 12 acres of the Schoonover fire on the afternoon of June 9. The Schoonover occurred two weeks prior to the Hayman Fire and is located west of point 45 on figure 63. The area burned over on June 9 was a spot fire separate from the main body of the Schoonover fire that had no effect on the severity of the Hayman (table 25). However, it is evident that the main body of the Schoonover fire altered the spread pattern of the Hayman Fire during its June 9 run (fig. 64). This took place along the eastern flank of the Schoonover Fire which burned as a surface fire resulting in little impact on the canopy. This area shows up as a green strip separating the Schoonover from the Hayman Fire (fig. 51). The Hayman encountered this strip on June 9 and only burned a short distance into it.

The Hayman Fire burned over two other recent wildfires, the 2002 Platte Springs and the 1998 Big Turkey fires (fig. 66). The Platte Springs fire is on the Southwest perimeter of the Hayman Fire in area where the fire did not burn very intensely. This wildfire was partially burned over with low severity by the Hayman Fire, but adjacent unmodified fuels also burned with low severity, so no effect was apparent. However, it is interesting the way the Hayman Fire seemed to burn around much of the Platte Springs fire having low severity effects.

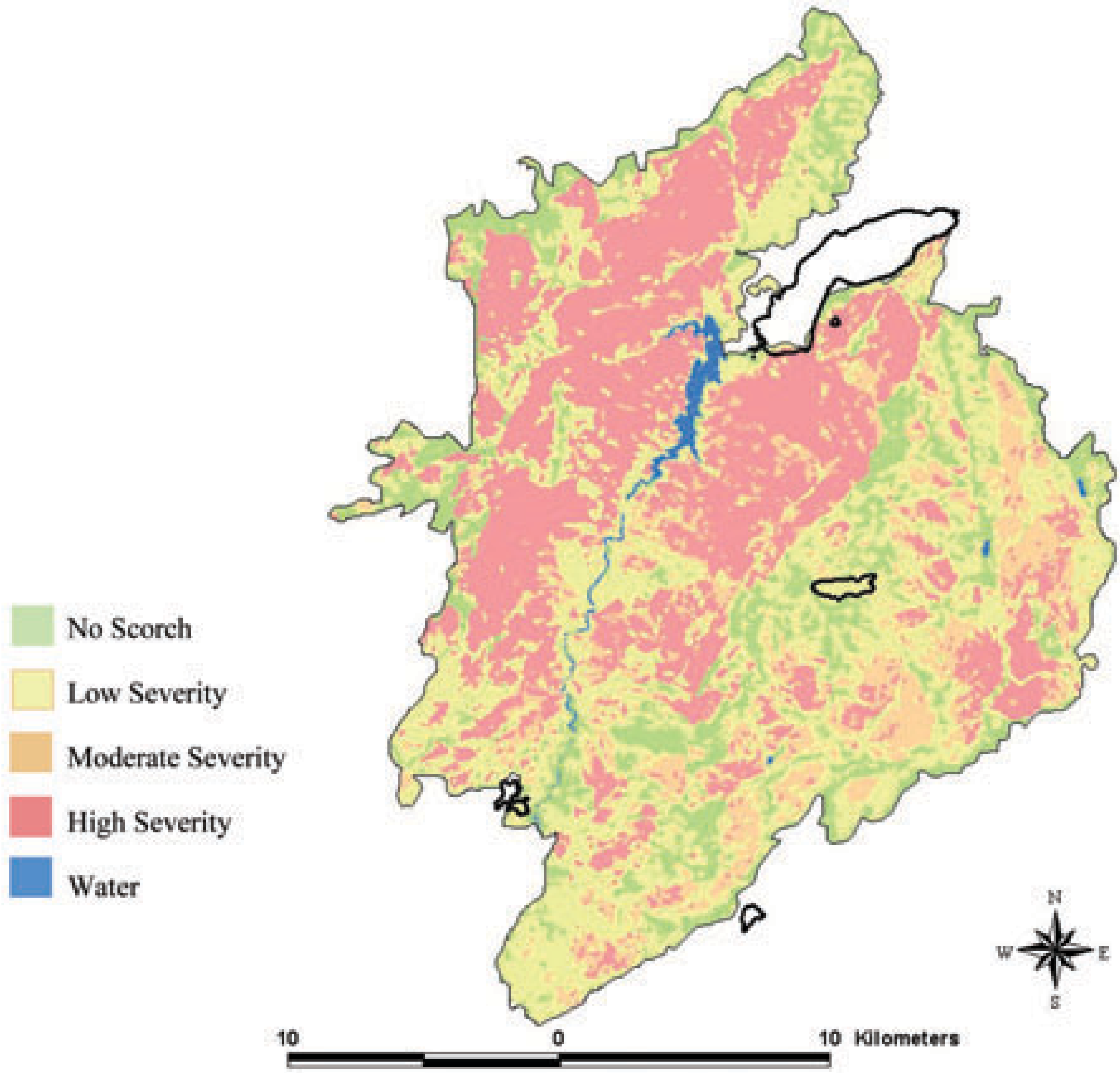

Figure 66—Recent wildfires in relation to the Hayman Fire perimeter and severity.

The area around the Big Turkey Fire (point 14 on fig. 63) burned over the several days between the large runs of June 9 and 17. Though there are patchy areas adjacent to this fire where the Hayman Fire crowned, from the air the Hayman appears not to have entered the Big Turkey Fire area (fig. 53, 54, 56b). Even more interesting is the apparent effect of the Big Turkey Fire on the pattern of fire spread the afternoon of June 17 (see Fire Chronology section, fig. 56). Winds from the northwest initiated runs on either side of the Big Turkey Fire, but not from within it. The older wildfire, in combination with the adjacent Turkey prescribed burns (1990, 1995) appears to have prevented the spread of fire out of that area along a 2-mile segment of the perimeter when extreme weather conditions returned.

We were aware of at least two older wildfires within the Hayman's perimeter, the Turkey Creek and Wildcat fires which both burned in 1963. Though we do not know their exact perimeters, approximate locations have been revealed by previous fire history studies. The Turkey Creek fire burned a small area in the lower Turkey Creek drainage (midway between points 20 and 21 on fig. 63) and appears to have considerably reduced overstory density. This area burned in the high intensity fire on June 9, but green trees in the area could be seen from the air (fig. 67). It should be noted that since we did not know the perimeter of this fire, it was considered unmodified fuel in the GIS analysis. Thus, the severity for unmodified fuels may be somewhat underestimated in table 25.

Figure 67—Photo of 1963 Turkey fire (between points 20 and 21 on fig. 63) showing green tree crowns following the Hayman Fire.

The Wildcat fire burned in the same area as the Northrup prescribed burn (between points 10 and 21 on fig. 63). This prescribed burn covered several thousand acres straddling the South Platte River (fig. 68). This Wildcat area was burned on the morning of June 9. Stocking of large conifer trees was low within most of the Wildcat burn area. Patches of conifers did survive here, but many were completely scorched and presumed killed. Pockets of aspen that sprouted after the 1963 fire also survived the Hayman Fire. Some forested areas immediately downwind of The Wildcat burn did not crown in the Hayman Fire, but complete crowning resumed just beyond during the June 9 run (fig. 69).

In addition to wildfires, the Hayman Fire burned over another type of natural fuel modification: an area affected by a spruce budworm outbreak. Most Douglas-fir in the area between points 47 and 48 on figure 63 were killed by spruce budworm in the early 1990s with subsequent mortality in remaining trees from Douglas-fir beetle. Surface fuel loads were not excessive, since most of the Douglas-fir snags remained standing. The only live trees remaining prior to the Hayman Fire were scattered ponderosa pine and the reduction in crown cover due to insect mortality seemed to affect fire behavior. The fire spread towards the southeast through this area during the relatively inactive period between the runs of June 9 and 17. The fire burned mostly as a surface fire on both sides of Westcreek, with small patches of crown fire activity. From the air the burn appeared less severe than in areas outside the budworm affected area (fig. 70).

Prescribed Fires: The Hayman Fire burned over 5251 acres of area that had been recently prescribed burned (fig. 71). Of this area, 719 acres were burned the afternoon of June 9 and included in our GIS analysis. Most of this area falls within the northern half of the 1990 Turkey prescribed burn (Turkey Rx1990) (point 12 on fig. 63). The results of the GIS analysis suggest that burn severity in this area was only slightly lower than adjacent areas with unmodified fuel on similar topography that burned in the same period (table 25). However, fire severity was patchier within Turkey Rx1990 than adjacent un-

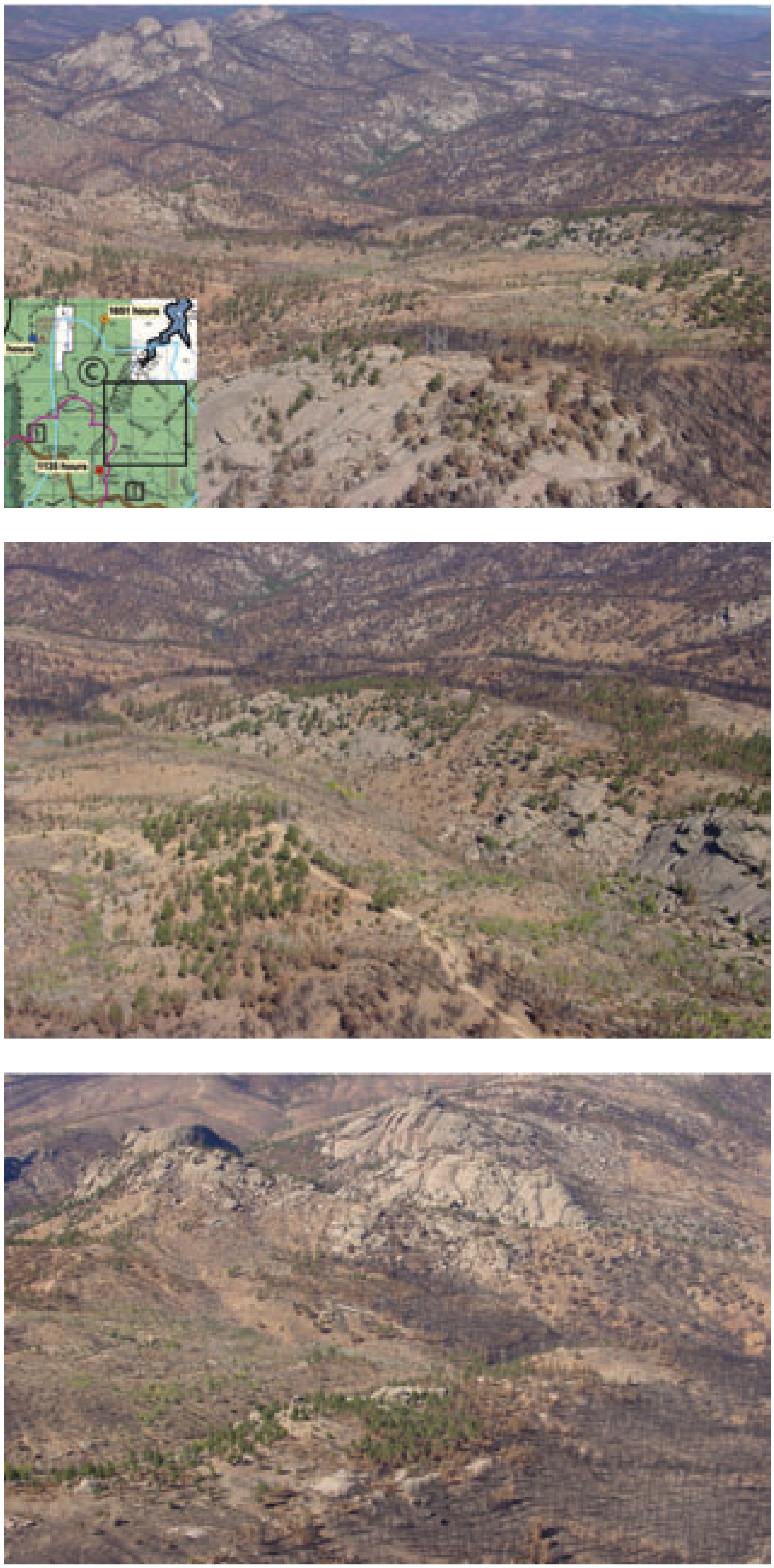

Figure 68—Photo point 10 showing surviving forest within Northrup 1992 prescribed burn from different angles.

Figure 69—Photo point 10 showing surviving forest within 1963 Wildcat wildfire from different angles.

Figure 70—Variable fire effects on the overstory in area of spruce budworm mortality. Hayman Fire burned through this area between June 10 and June 16.

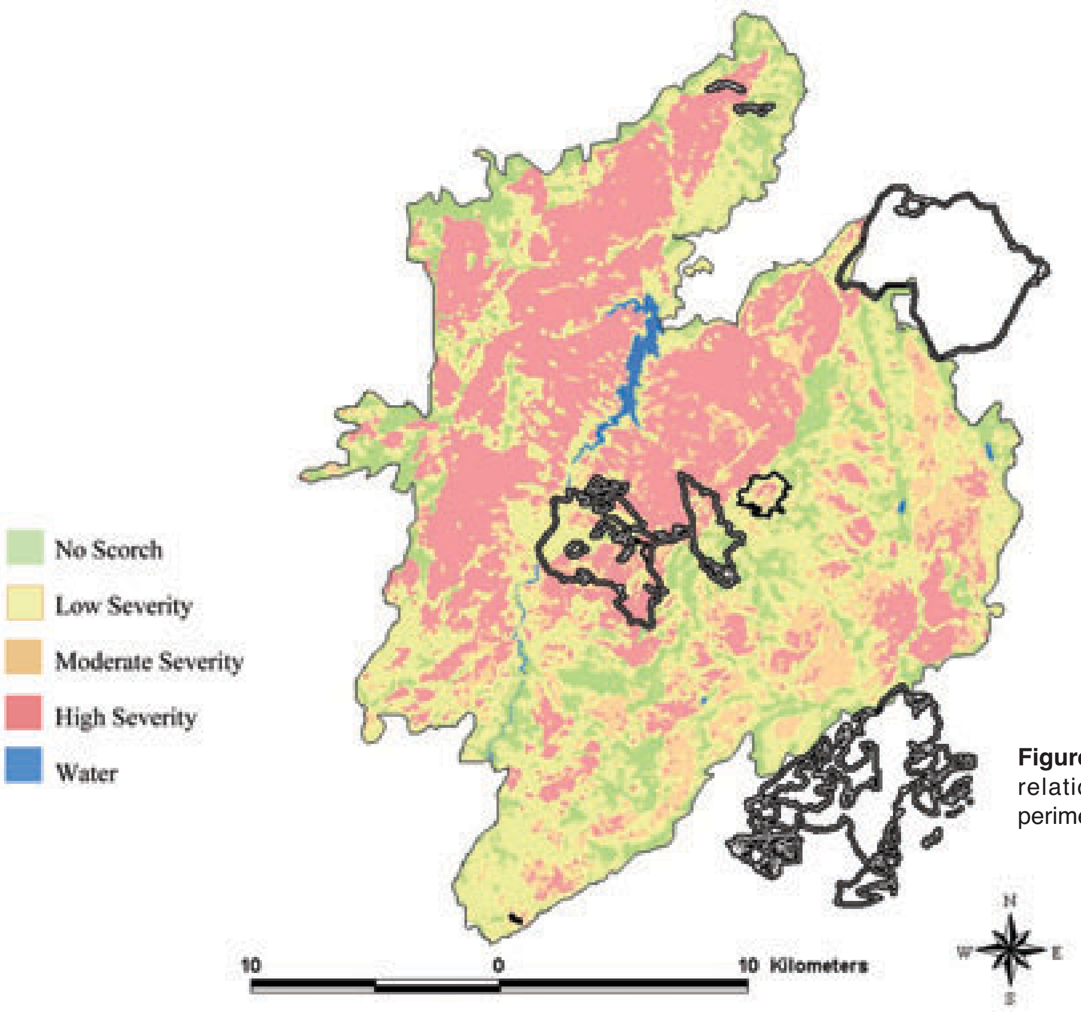

Figure 71—Prescribed burns in relation to the Hayman Fire perimeter and severity.

treated stands, having a greater proportion of low to moderately scorched trees (fig. 53, 72). Tree density was quite low in some parts of this area, perhaps due to past thinning activities; stumps are present in this area along the road into the south side of Cheesman Reservoir.

The southern half of Turkey Rx1990 is immediately adjacent to Turkey Rx1995, both of which burned over several days between the runs of June 9 and 17. The Hayman Fire burned quite moderately through these prescribed burn areas, but the evidence of treatment effectiveness is somewhat conflicting. While there are patches of apparent crown fire activity in adjacent unmodified fuels to the northeast, unmodified vegetation to the southwest appears to have been even less severely impacted than that within the prescribed burns. However, this area of low severity to the southwest may have benefited from a buffering effect provided by a strip of fuels treated by the Northrup Rx1992 burn. The unmodified fuels to the northeast of the Turkey Rx1990 burn had no such buffer and thus may have been more prone to crown fire initiation.

The run on the evening of June 9 also encountered the Brush Creek Rx1992 burn (northeast of point 41 on fig. 63). This prescribed burn followed commercial harvest in 1989. The severity of the Hayman Fire generally appears similar inside and immediately adjacent to these prescribe-burn units. But there are a few small patches of more moderately burned vegetation on the ridge immediately behind the northern section, suggesting a buffer effect that reduced fire intensity for a short distance behind the treatment. The effectiveness of this prescribed burn might have been greater and more apparent had it been wider. The run on the afternoon of June 9 also encountered the 1992 Brush Creek prescribed fire (northeast of point 41 on fig. 63). However, the severity of the Hayman Fire appears similar inside and immediately outside of this treatment area.

Three other recent prescribed burns were encountered by the Hayman Fire after June 9. These were Polhemus Rx2001, North Divide Rx1998, and Northrup Rx1992. The Hayman's June 9 run crossed Trout Creek and Highway 67 but stopped at the edge of the Polhemus burn (point 45 on fig. 63). On subsequent days the Hayman burned through an unburned notch between the Polhemus and the Schoonover Fires but made little progress into either (fig. 47, 48, 49, 50). From the air the Polhemus prescribed burn did not appear to change overstory forest density, but because of the 2002 drought there was little surface fuel of any kind within this area.

Figure 72—Photo point 12 and 13 facing northwest shows areas within the Turkey prescribed burn in 1990 and 1995.

The North Divide Rx1998 is at the southeast perimeter of the Hayman Fire and at first glance appears to have stopped its forward spread (point 4 on fig. 63). However, a field visit to this area made it apparent that the Hayman Fire stopped here because of the presence of the perennial Phantom Creek and associated beaver ponds. Though the Hayman Fire was crowning in several areas as it approached Phantom Creek (fig. 73), it is evident from the low-severity effects that the Hayman Fire was not able to cross the road and the creek directly (fig. 74). We could not evaluate, however, the possibility that the North Divide Rx1998 burn stopped the Hayman Fire by reducing the success of embers igniting spot fires.

Much of Northrup Rx1992 is in the same area as the 1963 Wildcat wildfire described above (between points 10 and 21 on fig. 63). While this area appears as a low severity patch within the matrix of general high severity from the June 9 run, this is most likely due to the extreme openness of the area rather than treatment effects of the prescribed fire. Nevertheless, in contrast to adjacent untreated areas, patches of sparse ponderosa pine did survive within the Northrup area prescribed burn unit (fig. 68). Also, as discussed above, this burn appears to have had a buffering effect on the adjoining a Turkey Rx1990 treatment area.

The Hayman Fire also burned over the Turkey Creek Rx1987 prescribed burn (563 acres). Of this total, 84 acres burned the afternoon of June 9 (point 18 on fig. 63) as the fire flanked to the east (fig. 65). This portion, along with adjacent untreated stands, appeared to have experienced lower severity overstory effects than surrounding areas burned that same day (table 25). Thus, it is difficult to attribute a possible reduction in severity within the prescribed burn solely to the treatment. By contrast, the interior of the Turkey Creek Rx1987 unit burned on June 10 showed apparently greater severity than surrounding unmodified fuels (fig. 53). Definitive reasons for this cannot be determined at this time, but burn coverage and fuel consumption levels in the original prescribed burn (Turkey Creek Rx1987) may have varied spatially, fuel changes over the 15 years since treatment may have recovered to essentially pretreatment levels, or more fuel may have been made available to the Hayman Fire because of tree mortality. Forest species composition may also be interacting with these factors in producing various fire effects. Forest type classifications for the Rx1987 burn unit (fig. 53) suggested that Douglas-fir was dominant compared in the interior and more severely burned areas compared to ponderosa pine around the outside edge.

Figure 73—Photo point 4 looking south over North Divide (1998) prescribed burn.

Figure 74—Photo point 4 looking at North Divide prescribed burn (1998) near Phantom Creek.

Fuel Treatments: A total of only 13 acres, in two separate units, were classified as fuel treatment with no prescribed burning. Both units occurred near the southeastern edge of the fire (south of point 6 on fig. 63) and burned on June 18. The first area treated since 1990 (8 acres) was classified as low severity, identical to surrounding stands, so there was no basis for assessing its effectiveness (fig. 75). The second area was 5 acres in size and treated before 1990. It burned with low intensity and was adjacent to untreated areas that burned with moderate and high intensity (table 25). Effectiveness of these treatments at reducing severity or changing fire behavior could not be determined conclusively due to of the small sizes of these areas and ambiguous contrast in severity compared to neighboring areas.

Timber Stand Improvements Followed by Activity Fuel Treatment: The Hayman Fire burned over 939 acres of timber stand improvements that were followed by treatment of the surface fuels produced by the management activities (fig. 76). About 395 of these acres burned on the afternoon of June 9. This included a fuel break along the road north of Cheesman Reservoir (point 37 on fig. 63) the Goose Creek sanitation harvest (point 32 on fig. 63) and release weeding treatment (point 34), and the Switchback dwarf mistletoe treatment. The GIS analysis indicates that collectively these activities did little to influence fire severity.

The Cheesman fuel break (point 37 on fig. 63) was accomplished in 2000. The prescription was a thinning from below that removed all but the largest trees in the stand. The harvest was accomplished by a feller-buncher with slash piled. Most of the slash piles were subsequently burned. The Hayman Fire killed or torched most of the trees along the ridge and in the fuel break (fig. 77). However, in a different section, trees along the Reservoir entrance road still supported green foliage (fig. 78). The latter effect is likely related to several factors including (1) the fire crossing this valley as a flanking fire rather than a heading fire, (2) the treatment location within the lower topographic position compared to surrounding ridges, (3) the lee-side blocking effect of Cheesman Reservoir that had been partially responsible for dividing the main head fire on June 9, and (4) the protection afforded by the Schoonover wildfire to the east that did not reburn in the Hayman Fire.

Several treatments occurred in the vicinity of the Goose Creek sanitation harvest and the nearby weeding treatment; these are discussed separately in sections below. Both the sanitation harvest and weeding

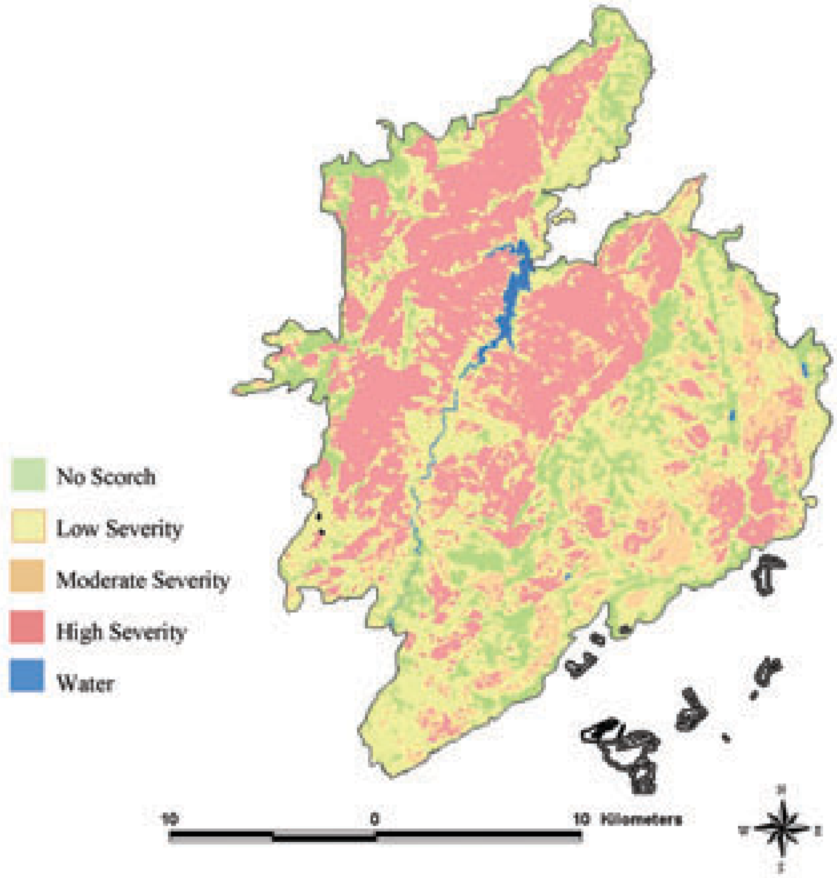

Figure 75—Fuel treatments (other than prescribed burns) in relation to the Hayman Fire perimeter and severity.

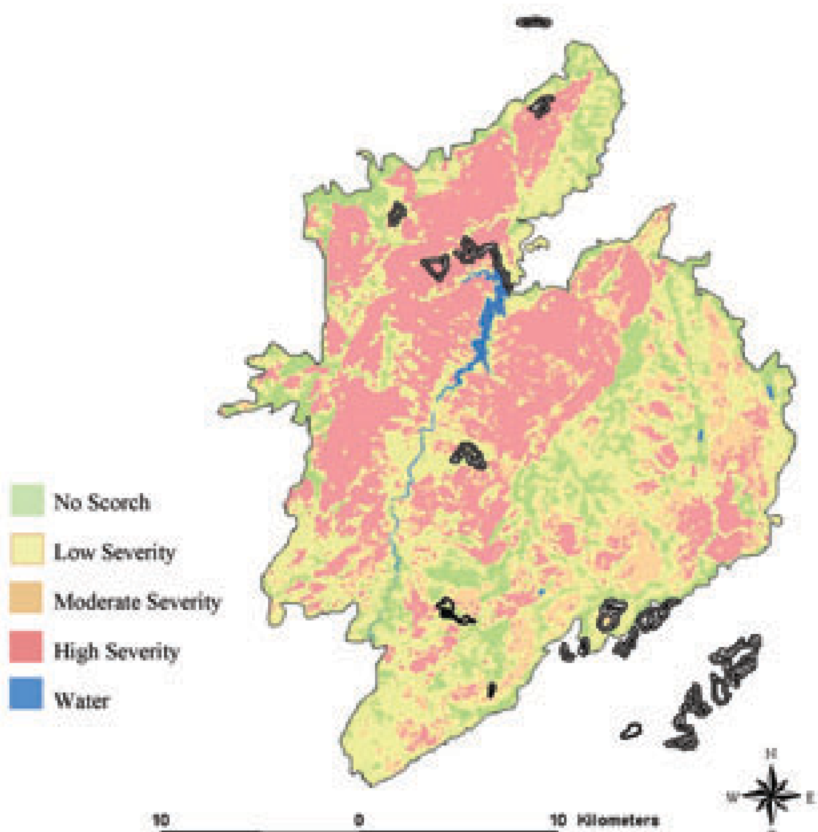

Figure 76—Timber stand improvements followed by activity fuel treatment in relation to the Hayman Fire perimeter and severity.

Figure 77—Photo point 37 looking west at Cheesman fuel break north of Cheesman Reservoir. All tree foliage was severely scorched although not consumed.

treatment were accomplished in the early 1990's and were followed by removal or burning of the resulting slash. Neither treatment had any discernible effect on the spread of the Hayman Fire on June 9 or the severity of overstory effects.

The Switchback mistletoe treatment was accomplished in 1998 with the slash piled and burned (northwest of point 32 on fig. 63). The treated areas exhibited low severity effects from the fire on June 9 as it flanked across this area. Most of the adjacent areas were also classified as having low severity effects, perhaps because they were within the Wigwam timber sale (discussed below). By contrast, areas south of the treatment were burned severely, possibly reflecting a treatment effect.

Several other areas receiving recent stand improvements followed by treatment of activity fuels burned in the Hayman Fire on subsequent days. A small area in the 1992 Northrup prescribed burn was pre-commercially thinned the year before (mid-way between point 10 and 21 on fig. 63). This area was burned by the Hayman Fire on the morning of June 9 and experienced lower severity than most of the adjacent fuels, though these had been modified by the Northrup prescribed burn and perhaps by the 1963 Wildcat fire as well.

An area of Christmas tree sales in 1992 and 1993 was followed by the Brush Creek prescribed fire in 1996 (north of point 41 on fig. 63). This area was burned by the Hayman Fire on June 10 and appears to have reduced burn severity. On the other hand, an area east of Signal Butte (point 6) was classified as having greater severity from the fire burning on June 18 than the surrounding unmodified stands despite a

Figure 78—Photo looking north at Cheesman Reservoir and thinning operation along southern edge.

sanitation harvest in 1995 to 1996 and slash removal (fig. 79). Two sanitation harvests were also done a few years prior to being burned by the North Divide prescribed fire adjacent to the southeast perimeter of the Hayman Fire, but as discussed above, it appears that Phantom Creek probably stopped the Hayman Fire unless spot fires were unable to initiate inside the North Divide treatment unit.

The Hayman Fire also burned over 153 acres of older modifications of this type, all after June 9. One area was pre-commercially thinned in 1984 with the slash piled and burned (point 7 on fig. 63). This area sustained low to moderate burn severity on June 18, but is adjacent to unmodified forest that was completely scorched or consumed (fig. 80). Another area received a weeding treatment in 1983 with slash piled and burned (northwest of point 7). This treatment unit burned in the Hayman Fire on June 11, also sustaining low severity and adjacent to areas with unmodified fuels that were burned more severely.

Timber Stand Improvements Without Treatment of Activity Fuels: The Hayman Fire burned over 1900 acres of recent timber stand improvements that had received no follow-up treatment of activity fuels (fig. 81). Of this area, 625 acres were affected on the afternoon of June 9 and included in our GIS analysis. Most of these modifications were part of the Goose Creek and Switchback activities described above. There is also an area of on the east side of Cheesman Reservoir where ladder fuels and trees less than 8 inches in diameter were removed in 2001 and 2002, but the slash had not yet been treated. Other areas include diseased tree removals in 1999 east of point 23 on figure 63 and a year 2000 weeding treatment southeast of point 25. The results of the GIS analysis suggest that these areas fared slightly worse than unmodified fuels that burned during the June 9 run (table 25).

Fire severity appears to have been reduced in the northern part of the Cheesman treatment (fig. 82) but this could also have been a result of its location on the downwind (lee-side) of the Reservoir which was protected from fire moving from the southwest. The southern half of this area was treated most recently and contained red slash that probably increased fire intensity. The 1998 Goosecreek weeding treatment at point

Figure 79—Area east of Signal Butte (photo point 6) with sanitation harvest and slash removal showed burned severely by the Hayman Fire on June 18.

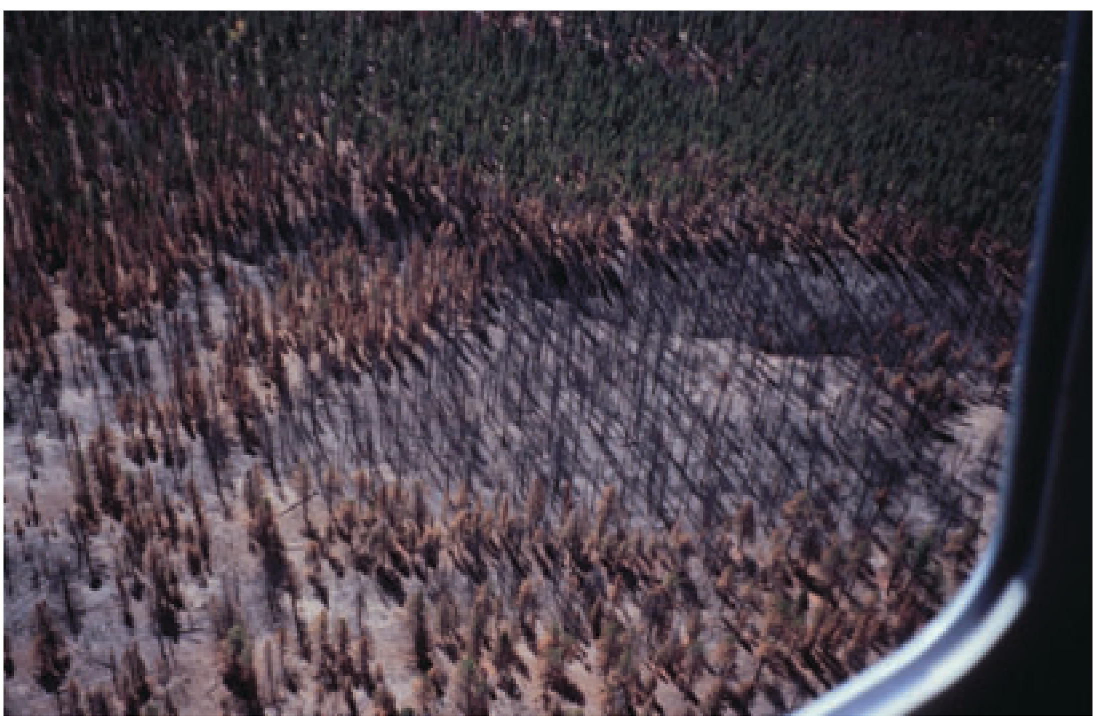

Figure 80—Photo point 7 showing area precommercially thinned in 1984.

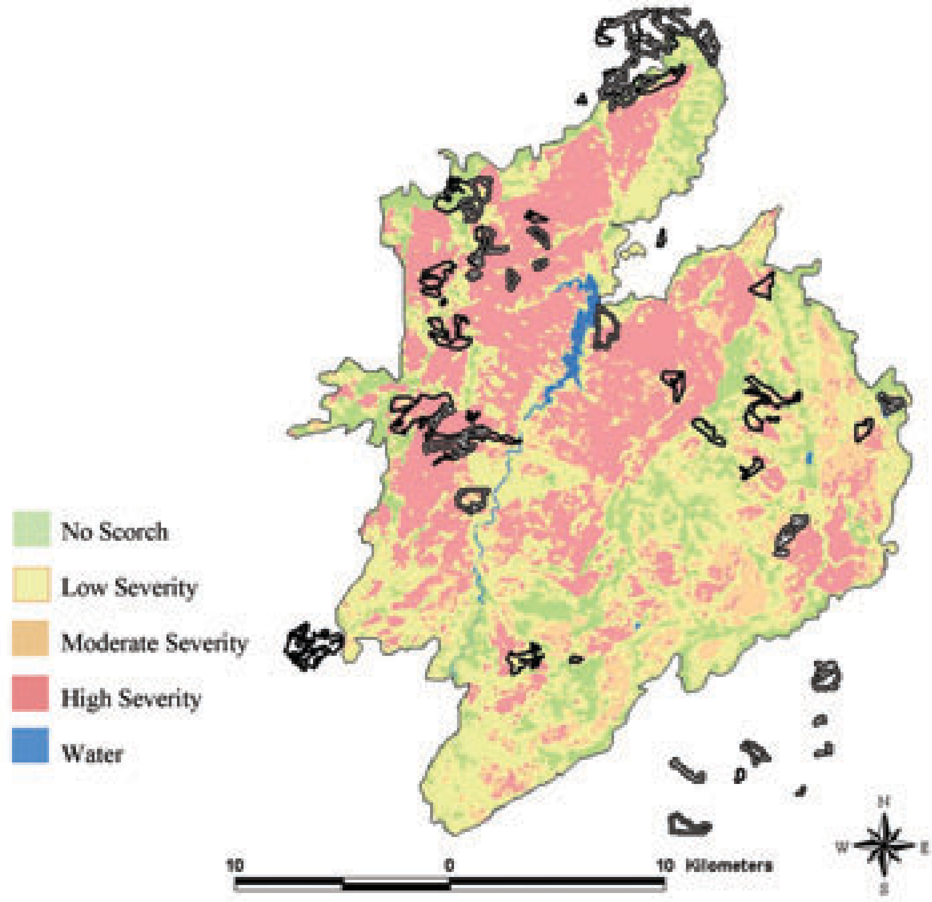

Figure 81—Timber stand improvements that received no subsequent treatment of activity fuels in relation to the Hayman Fire perimeter and severity.

Figure 82—North end of Cheesman Reservoir (southeast of photo point 37) showing thinning operation along the shoreline and lower severity, partly due to proximity to the Reservoir and lee-side protection from heading fire on June 9.

32 on figure 63 also appears to have moderated fire behavior, as does the 1998 Switchback mistletoe treatment northwest of point 33. However, the severely burned area ahead of this mistletoe treatment was modified by the Goose Creek commercial thin discussed in the next section.

Several similar fuel modifications outside of the area that burned on June 9 also appear to have affected fire behavior. An area where diseased trees were removed in 2000 was burned by the Hayman Fire on the morning of June 9 (due south of point 23 on fig. 63) and appears to have contributed to a reduction in fire severity. The parts of the Switchback mistletoe treatment that burned between June 10 and 12 experienced lower severity than adjacent unmodified fuels to the north and south. Particularly interesting is the adjacency of the northern tip of the Hayman perimeter to an area of release weedings (killing and removal of small trees) accomplished in 1991 (point 42), suggesting that these may have helped slow its forward spread. Also, another 1991 release weeding that burned on June 18 (southeast of point 16) had no apparent effect on the behavior of the Hayman Fire. An area treated to control the spread of mountain pine beetle that also burned on June 18 also had no discernible affect on fire severity (northeast of point 49).

The Hayman Fire also burned over 4,678 acres of older stand improvements that went without activity fuel treatment. The Hayman Fire encountered 1462 acres of these older fuel modifications on the afternoon of June 9 and the GIS analysis indicates that they also were affected somewhat more severely than unmodified fuels. Comparison of fire severity in these modifications to immediately adjacent unmodified fuels over the entire burned area does little to change this impression. Within the run on the afternoon of June 9 these areas include the Wigwam timber stand improvements of the 1960's (near points 25 and 28 on fig. 63), a 1985 stand improvement in the Goose Creek area, the 1981 Fourmile precommercial thin (between points 20 and 46), and a 1987 sanitation cut (point 46). Areas burned on subsequent days include the 1986 Twin Creek sanitation cut (northwest of point 28), the 1967 Thunder Butte stand improvement (east of point 48), the 1981 Thunder Butte precommercial thin (northeast of point 18), the 1981 Sheepnose precommercial thin (point 16), the 1986 Rainbow sanitation cut (point 49), and weeding treatments in the 1980's between points 7 and 10. None of these appear to have had any appreciable affect on fire behavior. However, the northernmost section of the Wigwam sale (northwest of point 32 near the Hayman perimeter) does appear to have lower burn severity than adjacent areas – a late 1980's commercial harvest to the south and a recent timber stand improvement to the east, neither of which had any subsequent activity fuel treatment.

Commercial Harvests Followed by Activity Fuel Treatment: The Hayman Fire burned over 2,477 acres of commercial harvests that were followed by treatment of the activity fuels, with 1,622 acres affected on the afternoon of June 9 (fig. 83). This area consists of the Goose Creek commercial thinning (northeast of point 32 on fig. 63), the Y sale commercial thinning (northeast of the Goose Creek sale), and the Brush Creek shelterwood seed cut (point 41). The GIS analysis suggests that fire severity in these areas was no different from that in modified fuels that also burned on the afternoon of June 9.

The Goose Creek sale occurred in 1985 with subsequent removal of trees with dwarf mistletoe in 1986 and 1993. Activity fuels were treated by removal and jackpot burning in 1993 and 1995 (burning isolated concentrations of large fuels). The area is very evident from the air and shows evidence of multiple treatments, which left even-aged stands of openly spaced trees in several different age classes prior to the Hayman Fire. The fire appeared to have burned through the entire area, killing most of the trees near County Road 211, which passes along a broad ridge through the area. Some trees were affected less severely on west and NE sides of the sale area (fig. 84) and on the lee side of ridges away from prevailing winds at the time of the June 9 run (fig. 85, foreground). However, this fuel modification does not appear to have slowed the overall progression of the Hayman Fire.

The Y sale occurred in 1981, followed by prescribed burn in 1982. The area was also treated for dwarf mistletoe in the late 1990's with slash removed or piled and burned. As with Goose Creek, the Hayman Fire affected this area severely.

The Brush Creek sale occurred in 1989 and was followed by prescribed burning in 1990. Although overstory density appeared to be low, the Hayman Fire burned over the entire area on June 9 with high severity. The only effect on fire behavior observable from the air was that some trees in more open areas were killed by crown scorch, rather than consumption (fig. 86), indicating intense surface fire rather than crown fire occurred there. Treatments of this type that burned on more moderate subsequent days may have been more successful in moderating fire behavior and consequent severity. The 1984 Turkey Rock commercial thin (point 13 on fig. 63) was subsequently treated by the Turkey prescribed burn in 1990 and was not affected severely by the Hayman Fire when it was burned over on June 11 and 12. However, neither were surrounding areas, though these had mostly been treated by the Turkey Rx1990 burn.

The 2002 Trout Creek timber sale on the Manitou Experimental Forest (point 1) showed significantly less overstory damage compared to untreated stands. This was a ponderosa pine restoration treatment that

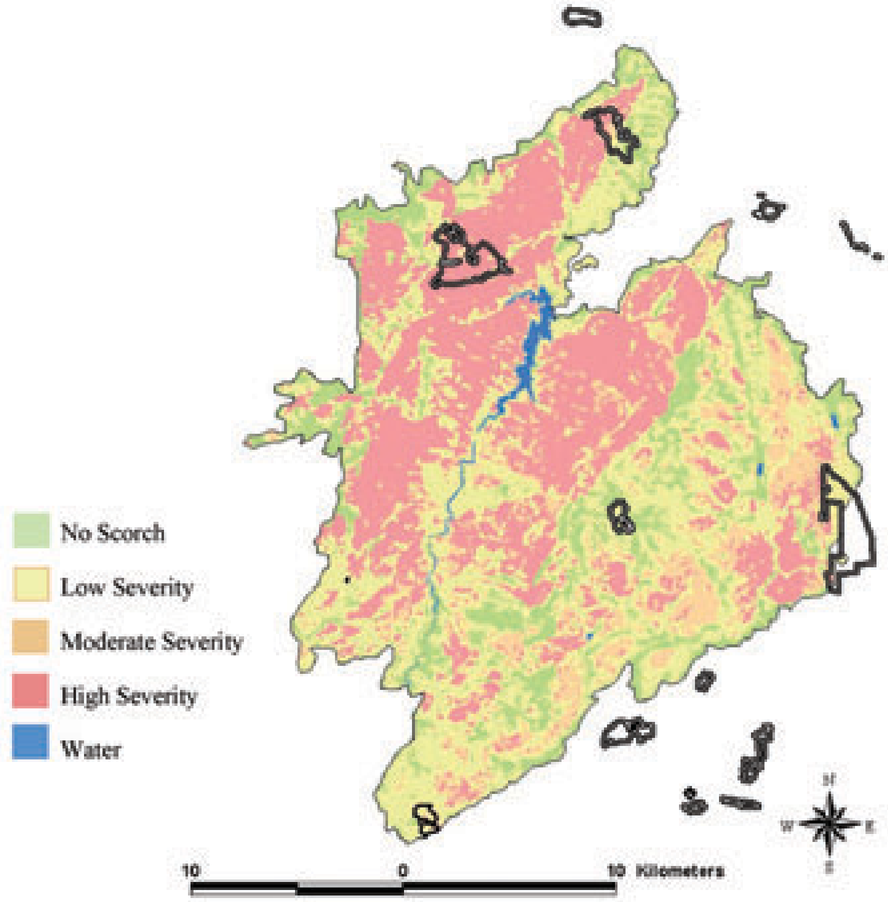

Figure 83—Commercial timber harvests followed by treatment of activity fuels in relation to the Hayman Fire perimeter and severity.

Figure 84—Photo points 30 and 31 showing Goose Creek timber sale area in foreground (1986-1993). Activity fuels were pile-burned in 1993-1995. The Hayman Fire burned here the afternoon of June 9 as a high intensity surface fire.

Figure 85—Photo points 34 and 35 showing Goose Creek timber sale area in foreground (1986-1993). Activity fuels were pile-burned in 1993-1995. The Hayman Fire burned here the afternoon of June 9 as a high intensity surface fire.

Figure 86—Photo points 39 and 40 showing the Brush Creek timber sale that was followed by prescribed burning. The Hayman Fire burned here the afternoon of June 9 in crownfire and high-intensity surface fire.

variously included commercial thinning, irregularly spaced individual tree selection, and complete overstory removal of mistletoe-infected trees. Slash had been piled but not yet burned when the Hayman Fire arrived on June 18. The fire resulted in lower severity to the overstory trees when it entered the sale area (fig. 87). Detailed information on this fuel modification and its effect on the Hayman Fire is presented in a separate section (below).

The fire encountered 240 acres of older commercial harvests where the slash was treated, with 3 acres affected on the afternoon of June 9. This was a small 1979 clearcut followed by piling and burning in 1980. It appears to have been burned more severely than adjacent unmodified fuels, though the GIS analysis indicates that it contains a distribution of severities that is similar to that of unmodified fuels over the entire area burned on the afternoon of June 9. The other older modification of this type was the Trail Creek shelterwood seed cut of 1988 with slash piled and burned. This area appears to have burned with similar severity as adjacent unmodified fuels (fig. 88).

Commercial Harvests Without Treatment of Activity Fuels: The Hayman Fire burned over 583 acres of commercial harvests that had no subsequent treatment of activity fuels, all on the afternoon of June 9 (fig. 89). This consisted entirely of the Sheepnose shelterwood seed cut in the year 2000, which was intended to be a ponderosa pine restoration treatment (point 20 on fig. 63). The treatment consisted of mechanically harvested smaller trees, leaving a scattered, open overstory. Trees were skidded to landings and processed, leaving large slash piles throughout the area, which had not yet been burned when the Hayman Fire arrived. Additional removal of submerchantable small stems had not been completed either. The GIS analysis indicates that this area had a higher proportion of moderate burn severity than unmodified fuels that burned during the run on the afternoon of June 9, but a lower proportion in the high and low severity classes. However, this area is especially striking when compared to adjacent unmodified fuels (fig. 90). Most trees within the Sheepnose area were killed by scorch rather than by consumption,

Figure 87—Trout Creek timber sale on the Manitou Experimental forest (photo points 1 and 2). This area was burned the afternoon of June 18.

Figure 88—Photo of the 1988 Trail Creek shelterwood seed cut of 1988 where slash was piled and burned. The area inside and outside of this unit did not experience severe effects from the Hayman Fire.

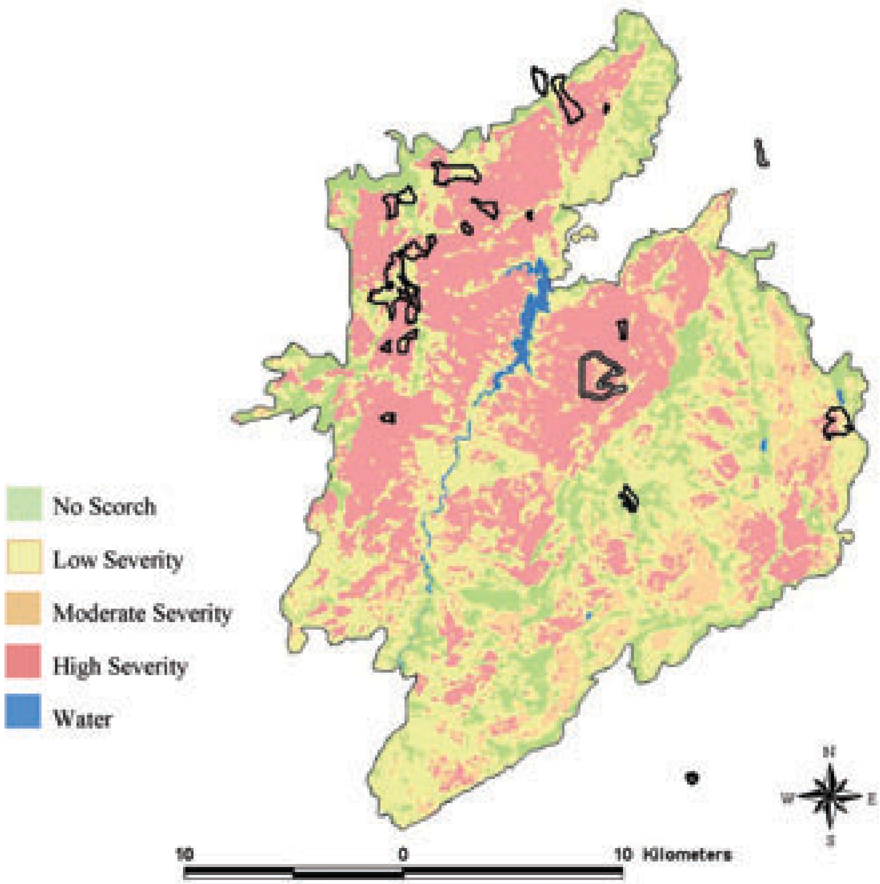

Figure 89—Commercial timber harvests that received no subsequent treatment of activity fuels in relation to the Hayman Fire perimeter and severity.

Figure 90—Photo of 2001 Sheepnose timber sale (photo points 19 and 20). Slash fuels were not removed prior to the Hayman Fire (June 9) which burned as an intense surface fire rather than a crown fire because of the treatment.

while tree crowns in adjacent areas on all sides were completely consumed. A few trees survived at the back of the treatment and protection appears to have been provided for a short distance behind the treatment as well (the road in the fig. 90 is the sale boundary).

The fire also burned over 2,329 acres of older fuel modifications of this type, with 948 acres affected on the afternoon of June 9. These areas include the 1989 Brush Creek clearcut (point 39 on fig. 63), the 1985 Cheesman commercial thin (point 38), the 1985 Cabin Creek clearcut (due west of point 38), the 1982 Webster commercial thin (northwest of Cabin Creek), the 1983 Wigwam commercial thin (southwest of Cabin Creek), the 1987 Flying G shelterwood seed cut (north of point 28), the 1982 Fruit commercial thin (southwest of the Flying G sale), the 1989 Sheep Rock commercial thin (point 28), the 1984 Molly Gulch commercial thin (point 26), the 1989 Wildcat commercial thin (west of point 23), and the 1987 Schoonover commercial thin (northeast of point 20). The GIS analysis indicates that collectively these modifications experienced slightly lower severity than unmodified fuels that burned in the same period. However, when compared to immediately adjacent fuels, the only areas that appear to have had an effect on fire severity are the Cheesman, Webster, Molly Gulch and Sheep Rock (fig. 91) commercial thinning.

Areas of this type that burned on subsequent days are mostly parts of the previously mentioned sales that burned on June 10 or June 11 with similar burn severity as in adjacent unmodified areas. However the 1982 Rainbow Falls shelterwood seed cut north of Manitou Experimental Forest (point 1 on fig. 63) burned on June 18 (fig. 92). The objective of this treatment was to initiate regeneration of a new stand of mixed Douglas-fir/ Ponderosa pine. Subsequent regeneration had created an open multistoried structure. The Hayman Fire burned through this area early on June 18th, when winds were out of the west. Most trees below the highway were killed, but trees in more open areas were scorched, not consumed (fig. 92). Fire intensity decreased to the east as it progressed through the area, eventually stopping near Rainbow Falls.

Trout Creek Timber Sale, Manitou Experimental Forest: This area lies between map points 1 and 2 (fig. 64) on the southeast perimeter of the Hayman Fire. The sale was being harvested at the time of the Hayman Fire and was about 80 percent complete. The objective was a ponderosa pine restoration treatment, which variously included commercial

Figure 91—Photo points 28 and 29 showing the 1989 Sheep Rock commercial thinning burned on June 9. Fire severity was somewhat more variable and moderate than surrounding untreated stands.

Figure 92—Photo of smoke direction oriented toward advancing column near Manitou Experimental Forest June 18.

thinning, irregularly spaced individual tree selection, and complete overstory removal of mistletoe infected trees. Residual stocking varied, but most stands had been thinned to less than 60 square feet of basal area per acre. Presale surface fuel loadings were 3.27 tons per acre within the sale area. Logging did not increase this, because all trees were skidded to landings for delimbing and processing. Harvesting was by mechanical feller-buncher with a landing-based processor, which resulted in all slash being deposited in large piles within the sale area.

On Tuesday, June 18, the fire crested the ridge west of Manitou. We believe that it burned across Highway 67 on the north end of the forest in late morning as a heading fire driven by a westerly wind. No one on the Manitou staff was present to witness it, as this is about 4 miles north of headquarters and crews had been pulled out of the area.

Later on Tuesday, June 18 at 1300 hours the fire crested the ridge directly west of Manitou Experimental Forest (MEF) headquarters. At this time, flame lengths on the ridge were greater than 150 feet (fig. 93). The fire then dropped down to the lower ridge, and the flames were no longer visible. Steve Tapia discussed the fire behavior on the burn as it came onto MEF with the Fire Behavior Analyst on the Incident Team. The analyst said two fire heads approached MEF: the fire was coming from the northwest out of Turkey Rock area, and the other from the southwest out of Trail Creek. The two heading fires merged, sucking the air in the area into the center behind where they met, consuming the fuel. As Steve and other firefighters watched at MEF Headquarters, there was a 20 mph wind into their faces, then when the flames dropped it became very still. After 10 minutes, a slight breeze from the east developed. The fire dropped from the crowns to the ground, about where harvesting had been completed in the Trout Creek Timber Sale west of MEF Headquarters (fig. 94). The thinning kept it on the ground moving very slowly except where it encountered piles of unskidded trees, where it flared up (fig. 95). The fire crept slowly enough that a dozer could be brought in to cut a line around the fire. This stopped the fire in MEF. This also enabled the fire crew to save Casey's lumber mill which was/is a huge potential fuel source.

About 1,000 acres of MEF were burned in the Hayman Fire. However, only about 100 acres burned as a crown fire that resulted in complete overstory mortality. This area was mostly on the northwest corner of the

Figure 93—Looking west toward fire and column advancing on Manitou Experimental Forest on June 18.

Figure 94—Photo point 1 showing the Rainbow Falls shelterwood seed cut north of Manitou Experimental Forest that suffered high severity the afternoon of June 18.

Figure 95—Mixed severity in Manitou Experimental Forest thinning plots. Areas with high severity still had fallen trees that had not been skidded yet.

Forest. Fire in this area burned seven replications of a ponderosa pine regeneration study under an open canopy structure. It also burned three replications of a ponderosa pine spacing study containing eight 10 ft. trees. Elsewhere, the fire burned through the Trout Creek Timber Sale as an underburn, consuming few large trees, but pruning lower branches and eliminating some seedlings and saplings (fig. 96). The change in fire severity experienced in the treated areas of MEF cannot be unequivocally be attributed solely to the altered stand structure because of the observed 180 degree shift in the wind that occurred immediately prior to fire encountering MEF. However, the absence of small understory trees undoubtedly limited the torching and crown damage that could have otherwise occurred under the moderate wind conditions.

Plantations: The Hayman Fire burned over 136 acres of recent plantations, all on the afternoon of June 9 (fig. 97). The GIS analysis indicates that these burned with greater severity than unmodified fuels affected during this burning period. The plantation north of point 34 in particular appears to have burned with greater severity than surrounding areas. The fire also burned over 1,477 acres of older plantations, with 314 acres affected on the afternoon of June 9. Not surprisingly, the GIS analysis indicates that these older plantation areas fared substantially better than the younger ones and even somewhat better than unmodified fuels that burned on June 9. Many of these older plantations seem to be burned less severely than surrounding areas, though they are mostly surrounded by other types of fuel modification, so it's difficult to attribute an effect directly to them. The 1986 plantation at point 28 on figure 63, for example is within the Sheep Rock commercial thin area (center of fig. 91). The fire burned into about a third of the plantation, which did appear to protect the forest on a southwest facing slope downwind of the plantation.

Older plantations that burned after June 9 generally do not appear to have had an appreciable affect on burn severity. However an older plantation that was thinned and cleaned in 1985 appears may have contributed to the effect of the Big Turkey wildfire in splitting the head of the June 17 run (point 14). This treatment also appeared to have influenced the spread of the Big Turkey Fire itself.

Figure 96—Underburn on June 18 of a thinned stand unit resulted in very little scorching even to small trees.

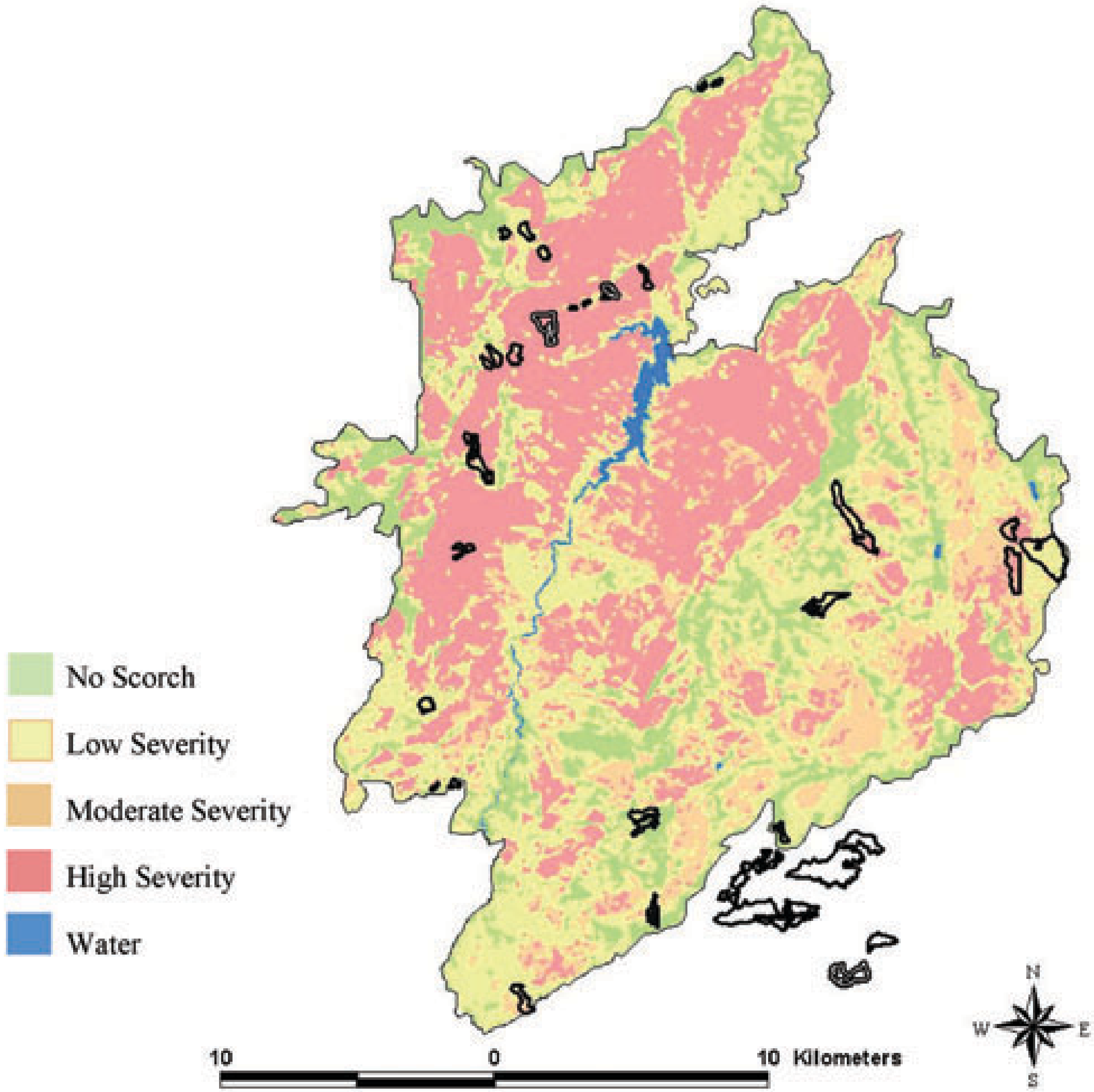

Figure 97—Forest plantations in relation to the Hayman Fire perimeter and severity

Part 4: Relation of Roads to Burn Severity

Charles W. McHugh and Mark A. Finney

Introduction

Effects of roads on fire behavior intensity and severity can be studied directly or indirectly. A direct study of road effects would include uses by fire suppression, burnout operations, and delay of fire progress at the roadside. Interpretations after the fire burns are easily confounded by the unknown nature of suppression activities and fire arrival time, and fire behavior. Indirect study of road effects is by association. We chose to perform only an indirect analysis given the uncertainties in road usage by suppression resources and the imprecision of the fire progression. Our methods relied on a calculation of road density across the area and examined the correlations or differences in fire behavior intensity and severity, biophysical settings, vegetation types, canopy cover, and fuel models. This offered a more comprehensive means of evaluating effects throughout a large fire area.

Methods

The methods used for this analysis relied on the transportation data and final fire perimeter provided by the Pike-San Isabel National Forest. Topographical data were developed from 10 m digital elevation model data developed by U.S. Geological Survey, EROS Data Center for large fire areas at a 10 m resolution (http://edc.usgs.gov/nedfire/). The original elevation data was resampled to a 30 m resolution, to better match the coarse resolution of the fuels and vegetation data for the analysis area. Burn severity information was from an analysis conducted by the National Park Service – U.S. Geological Survey, National Burn Severity Mapping Project (http://edc2.usgs.gov/fsp/severity/fire_main.asp). The Differenced Normalized Burn Ratio (DNBR) is a continuous variable indicative of the amount of change experienced across the area. We reclassified the DNBR values into five classes of severity: Unburned, areas of light overstory mortality, moderate overstory mortality, high overstory mortality, and complete overstory mortality.

The Pike-San Isabel National Forest transportation layer was used to determine miles of road per square mile within the Hayman Fire perimeter. The transportation layer contains information about the road network as well as forest recreational trails. Prior to analysis, those features designated as trails based on their Cartographic Feature File (CFF) codes were removed from this layer. The resulting road network was then clipped to the final fire perimeter. This information was then used to develop a road density map within the fire perimeter area.

Road density was calculated in ARCINFO using the LINEDENSITY function in GRID. This function calculates the density of linear features in a specified area, based on the length of the lines per unit of area. For this analysis, outputs were derived in miles of road per square mile of area.

Results

The Hayman Fire burned into a portion of the Lost Creek Wilderness Area; these acres were excluded from the road density analysis as no roads were identified within the wilderness area (fig. 98). A graphical analysis of road density versus elevation, and fire severity was conducted to search for correlations of biophysical settings and fire severity to road density.

The Hayman Fire burned a total 138,114 acres (216 square miles) of which 6,699 acres were in the Lost Creek Wilderness. 131,415 acres (205 square miles) were burned outside of the wilderness area. Approximately 426 miles of roads are within the fire perimeter and outside of wilderness (fig. 99). These roads vary from unimproved four-wheel-drive routes to secondary highways such as State Highway's 126 and 67. The road density within the fire perimeter ranged from a 0.0 miles per square mile to a high of 9.4 miles per square mile, the mean road density for the area was 1.8 miles per square mile (fig. 99). The highest concentrations of road density were located within or adjacent to developed areas within the fire perimeter.

Based on a graphical analysis we found no apparent correlation of road density to elevation (fig. 100). Similar results were found for fire severity (fig. 101).

Summary

Based on our indirect analysis and graphical interpretation we found no apparent correlation of road density to elevation (fig. 100). Similar results were found for fire severity (fig. 101). We reviewed daily unit logs for the fire and while mention of burnout operations conducted along roads were noted, they were not site specific enough to correlate to specific areas on the burn severity map. The road network offered several benefits during the course of the fire, including obviating use of helicopters for crew transport, providing adequate escape routes for crews, and under moderate weather conditions serving as control lines and as anchor points for line construction and burnout operations (Operations and Fire Behavior Narratives, Frye Type 1 Incident Management Team).

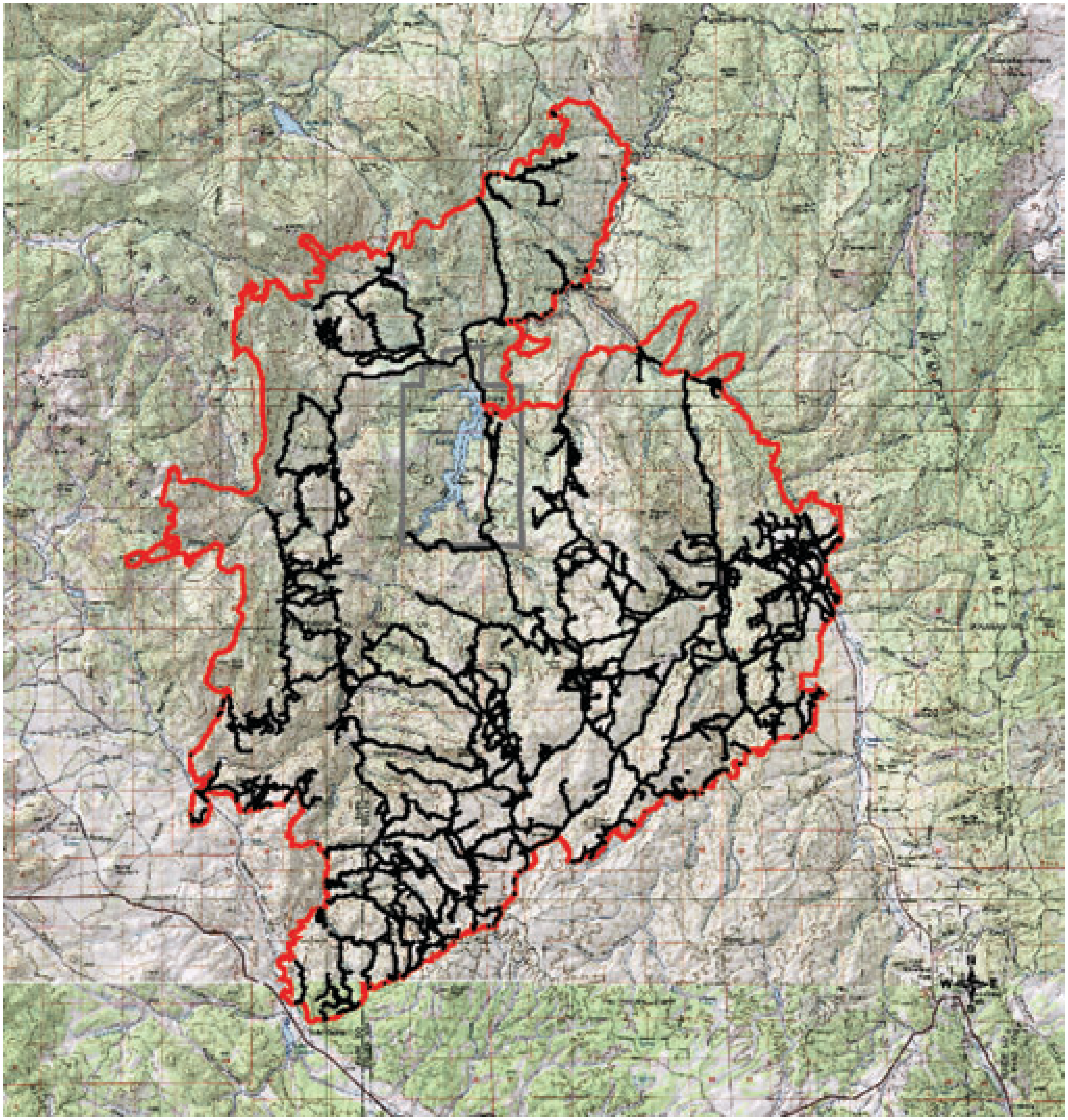

Figure 98—Road network within the Hayman Fire perimeter.

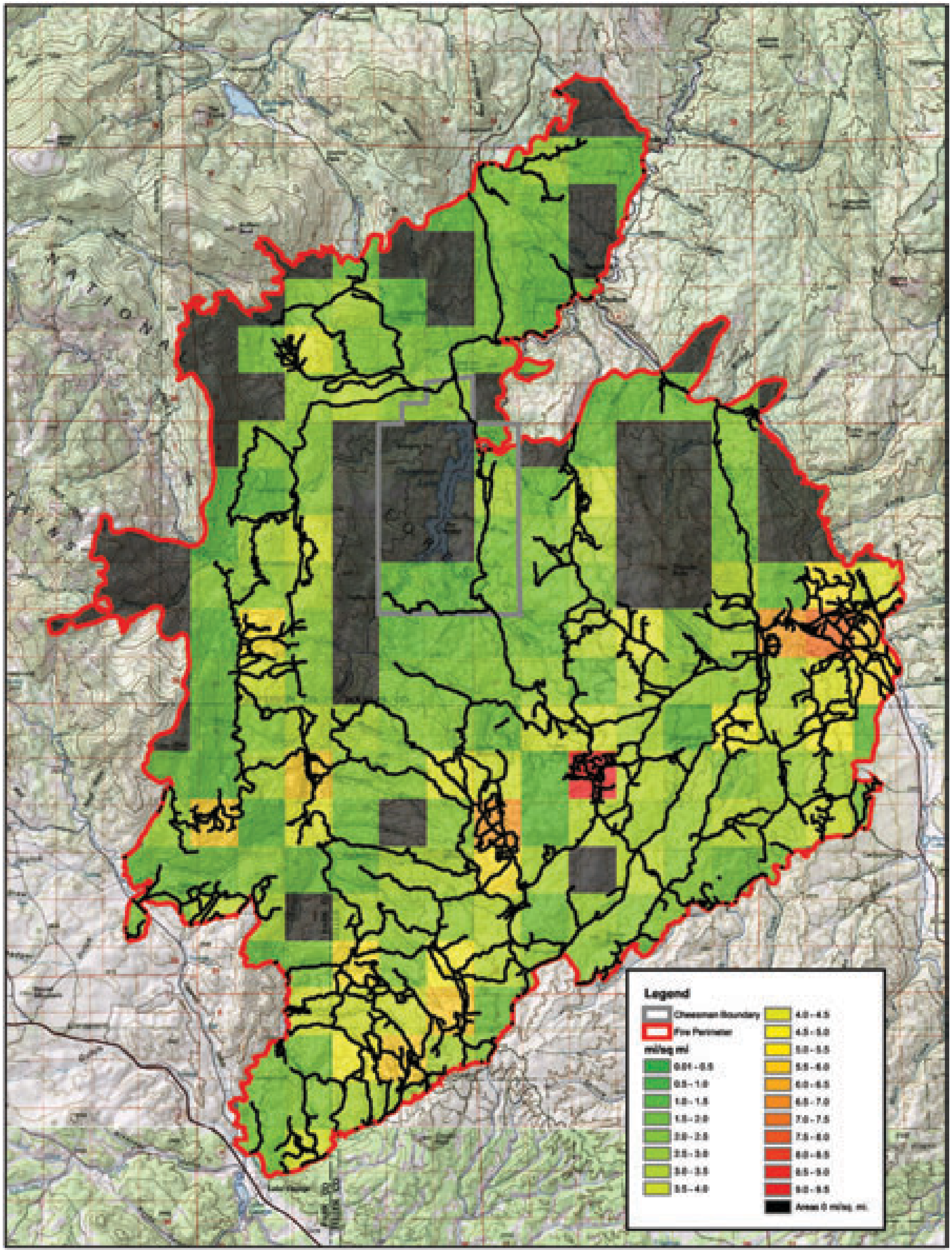

Figure 99—Road density (miles) summarized per 1 square mile.

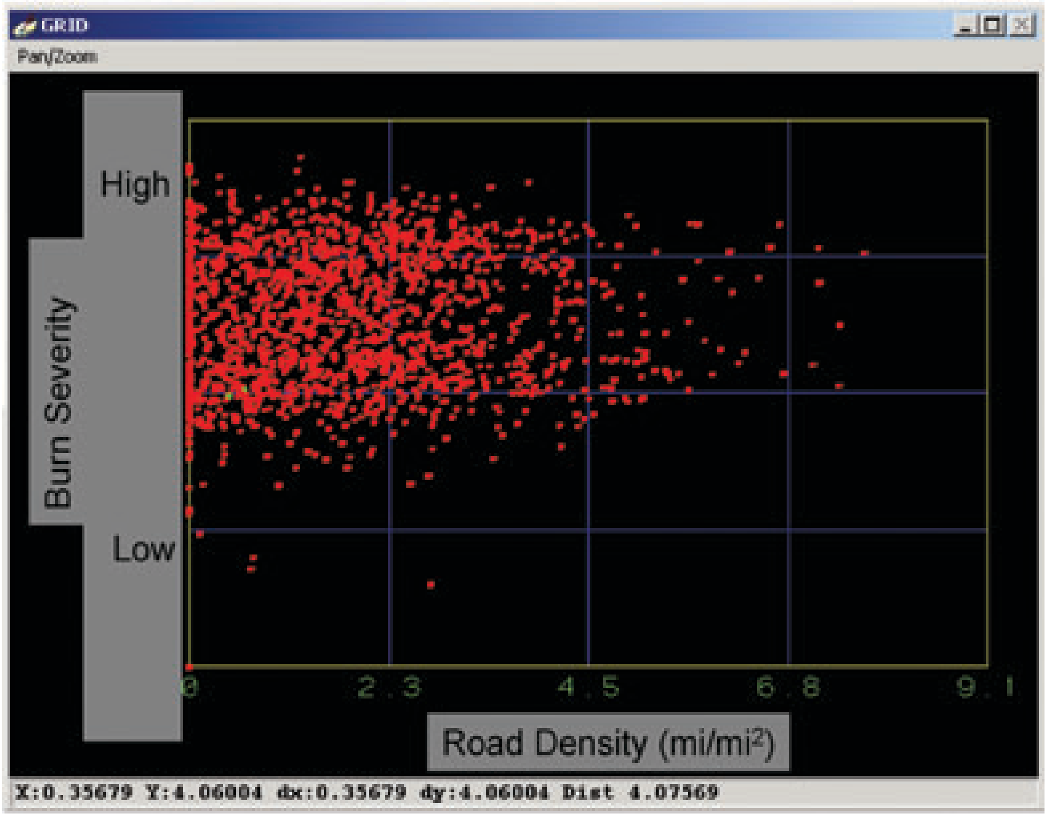

Figure 100—Plot of burn severity against road density suggests no relationship.

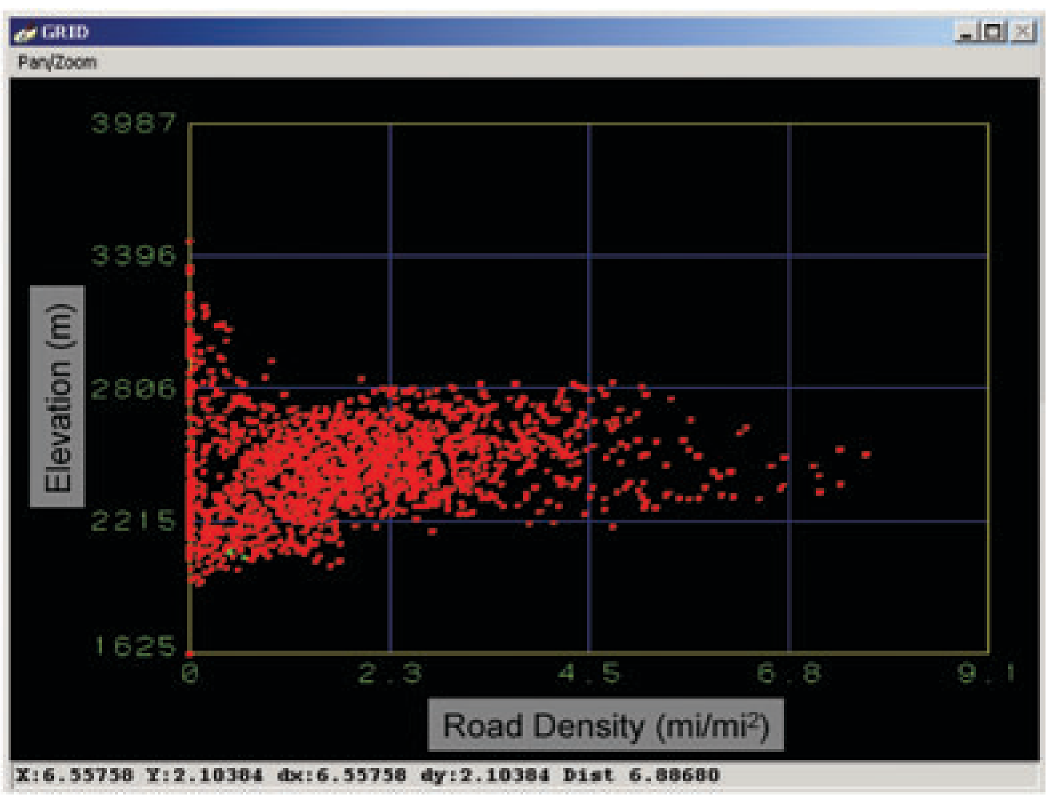

Figure 101—Plot of burn elevation against density suggests no relationship.

Part 5: Fire Suppression Activities

Charles W. McHugh, Paul Gleason

Introduction

The purpose of this report is to document the suppression actions taken during the Hayman Fire. The long duration of suppression activities (June 8 through July 18), and multiple incident management teams assigned to the fire, makes this a challenging task. Original records and reports produced independently by the various teams assigned to different portions of the Hayman Fire had different reference locations and time frames. Nevertheless, this report reviews the success of those crews in achieving their planned tactics but did not attempt to equate this performance to their overall effectiveness on suppressing the fire or in producing changes in fire growth and behavior.

Suppression actions taken on the Hayman Fire are outlined from a number of sources:

- Narratives from Fire Behavior, Operations, Air Operations, and Planning Sections from Martin's Type 1 Incident Management Team, Frye's Type 1 Incident Management Team, and Raley's Type 1 Incident Management Team.
- National Interagency Fire Center (NIFC) Situation Report Narratives.
- Review of daily Incident Action Plans (IAP's) prepared for the incident.
- Review of daily unit logs.
- Historical Incident ICS-209 Reports.

ICS 209 reports were filed for the Hayman Fire starting June 8, 2002, with the final report filed on August 11, 2002. Based on information contained in the Historical Incident ICS-209, the Hayman Fire was initially attacked on the afternoon of June 8, 2002, was declared 100 percent contained on the evening of July 2, 2002, and declared controlled on the evening of July 18, 2002.

Incident Management Teams (IMT) Assigned to the Hayman Fire

During the period of June 8, 2002, through August 11, 2002, that Incident Status Summary forms (ICS-209) were filed, five Type 1 Incident Management Teams, three Type 2 Incident Management Teams and one Type 3 Incident Management Team were assigned to the Hayman Fire (http://famweb.nwcg.gov/pls/hist_209/) (table 27).

Initially a local Type 3 team managed the fire and then transitioned to a Type 1 IMT (Martin) on June 10. Due to the complexity of the assignment, the potential number of structures threatened and numbers of evacuations, a second Type 1 IMT (Raley) was ordered on June 10 with the fire being split into Hayman North, under Raley's Team and Hayman South under Martin's team. Administration of the fire with two Type 1 IMT continued under various combinations (Martin - Hayman South/Raley - Hayman North [June 12 through 16]; Frye – Hayman South/Raley – Hayman North [June 17 through 25]). Frye's Type 1 IMT took sole control of the incident on June 26 through 28 followed by Lohrey's Type 1 team. Lohrey's Type 1 IMT administered the fire until July 3 at which time the fire transitioned to Type 2 Incident Management Teams Koehler and Sisk. On August 11 responsibility for management actions on the fire were assumed by the Burned Area and Emergency Rehabilitation (BAER) Team.

During the time period June 19 through 22, three Type 1 IMT (Frye, Raley, Vail) were assigned to the fire. Frye – Hayman South/Raley – Hayman North had operational control of the incident. Vail's Incident

Table 27—Incident Management Teams assigned to the Hayman Fire.

IMT Incident Commander	IMT type	Dates assigned	Number days assigned
Mike Hessler	3	6/8 – 6/9	2
Kim Martin	1	6/10 – 6/16	7
Ron Raley	1	6/12 – 6/25	14
Steve Frye	1	6/17 – 6/28	12
Scott Vail	1	6/19 – 6/22	4
Mike Lohrey	1	6/29 – 7/3	5
Tom Speaks	2	7/4 – 7/19	16
John Koehler	2	7/20 – 8/5	17
Mike Hessler	3	8/6	1
David Sisk	2	8/7 – 8/10	4

Management Team was assigned to work with local officials in the development of contingency and structural protection plans for potentially affected communities in El Paso County. Once the plan was completed Vail's team was released from the incident.

Personnel and Equipment

On June 16 approximately 2,564 people were identified as assigned to the Hayman Fire based on an analysis of the historical ICS-209 database (appendix E), and was the maximum number of people assigned to the Hayman Fire (fig. 102a). However, this number should be considered an approximate. First, and most importantly, data entered in the ICS-209 database were found to contain a number of irregularities, for example, numbers of crews were entered instead of numbers of persons. Secondly, only those resources with an "Official" Resource Order Number" are tracked, ignoring individuals working in support of the fire located offsite, such as Multi-Agency Coordinating Groups (MAC), Area Command teams, buying teams, air tanker pilots, air tanker base support personnel, and so forth.

On June 15 and 16 and again June 22 and 23, a total of 12 Type 1 handcrews (Hotshots) were assigned to the fire (fig. 102b). This was 19 percent of all available Type 1 crews during the period of June 12 to 25. The number of Type 2 handcrews assigned to the fire varied from 21 to 51 with the peak of 51 reached on June 22 (fig. 102b). Appendix E contains the entire dataset used in this analysis.

From June 14 through 22, the number of dozers assigned to the fire ranged from eight to 12, with the maximum number of dozers assigned to the fire occurring on June 19 (appendix E). The number of engines assigned to the fire ranged from 0 to 156 (fig. 103a), with the maximum number of engines assigned (156) occurring on June 21 (appendix E). Dozer numbers and number of engines by classification of their size or type were not identified in the ICS-209 database.

Air Resources

During the period of June 10 through 28, 2002, all air resources (fixed-wing and helicopters) dropped 4,669,108 gallons of water, 1,064,820 gallons of foam, and 552,032 gallons of retardant, transported 42,443 pounds of cargo, and flew 402 passengers on various missions. The combined flight hours for air tankers, helicopters, lead planes, and air attack was 1,512 hours, the vast majority of which were flown by helicopters.

Based on information contained in the Incident Action Plans (IAP) Air Operations Summary forms (ICS-220) for the Hayman Fire the number of air

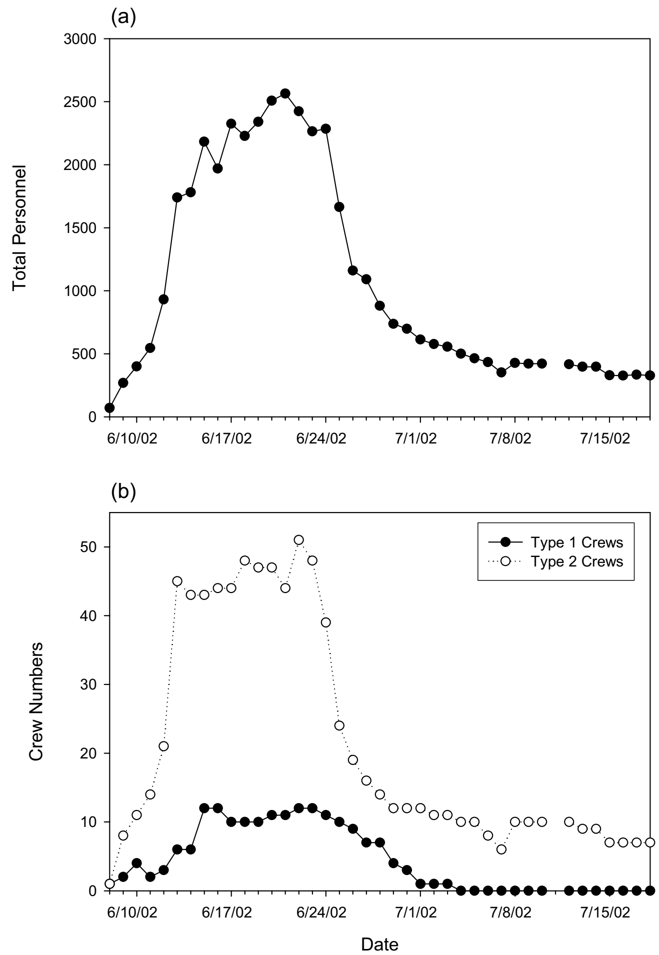

Figure 102—Total personnel (a) and numbers of Type 1 (Hotshot Crews) and Type 2 handcrews (b) on the Hayman Fire for the period of July 8 through July 18, 2002. Data are from historical ICS-209 database (appendix D). ICS-209 data were unavailable for July 11.

tankers available to the incident varied from four to six (appendix F). However, these resources were also available to be diverted to other fires and initial attack demands within the Rocky Mountain Geographic Area. On several occasions during the Hayman Fire air tankers were diverted to the Missionary Ridge Fire (06/09, 06/17, 06/18). On June 18, commercial contract air tankers were not available until the afternoon due to a mandatory stand-down following the crash of a C-130 air tanker on the Cannon Fire on the Humboldt Toyabee National Forest on June 17, 2002 (Paul Linse, personal communication). During this stand-down, Air National Guard Modular Airborne Firefighting Systems (MAFFS) were available for use.

One Single Engine Air Tanker (SEAT), four MAFFS, and a combination of other national commercial contract Type 1 and Type 2 Air Tankers were used during the Hayman Fire. Air tanker operations were conducted out of the JEFFCO Tanker base located 9 miles southwest of Denver, CO, and from Pueblo Memorial Airport, located 5 miles east of Pueblo, CO.

During the period June 10 to 28, air tankers (fixed-wing only) dropped a total of 373,836 gallons of retardant of which 113,000 gallons (30 percent) were dropped by MAFFS units (table 28). Flight hours of air tankers could only be determined for the Frye and Raley teams and do not include the hours of air tanker time for Martin's team. Of the total air tanker flight hours in table 28, 22 hours of flight time were by MAFFS units.

A single SEAT (Single Engine Air Tanker) was used on June 17 to make drops on the south zone of the Hayman Fire. This tanker dropped 13,000 gallons of retardant (3.5 percent) for 2.5 hours of flight time and was based out of the Pueblo Tanker Base. These figures are included in the totals in table 28.

The number of lead planes and air attack assigned to the fire varied, but during the heavy suppression period a minimum of one lead plane and two air attacks were available (appendix F). These aircraft accounted for 241 hours of flight time excluding the time which could not be determined for Martin's team (table 28).

During the period of June 8 to 28, 2002, for the Hayman Fire, Type 1, 2, and 3 helicopters were used to transport cargo and passengers, drop foam, water and retardant, and to conduct aerial reconnaissance, infrared mapping, and Global Positioning (GPS) mapping of fire perimeters (table 29). Use of helicopters for crew transport was not needed due to the extensive road network that provided adequate egress into the fire area. During the course of the fire, the maximum number of Type 1 helicopters assigned to the fire was 14 (appendix E). The maximum numbers of Type 2 and Type 3 helicopters assigned to the fire were three and five respectively (fig. 103b).

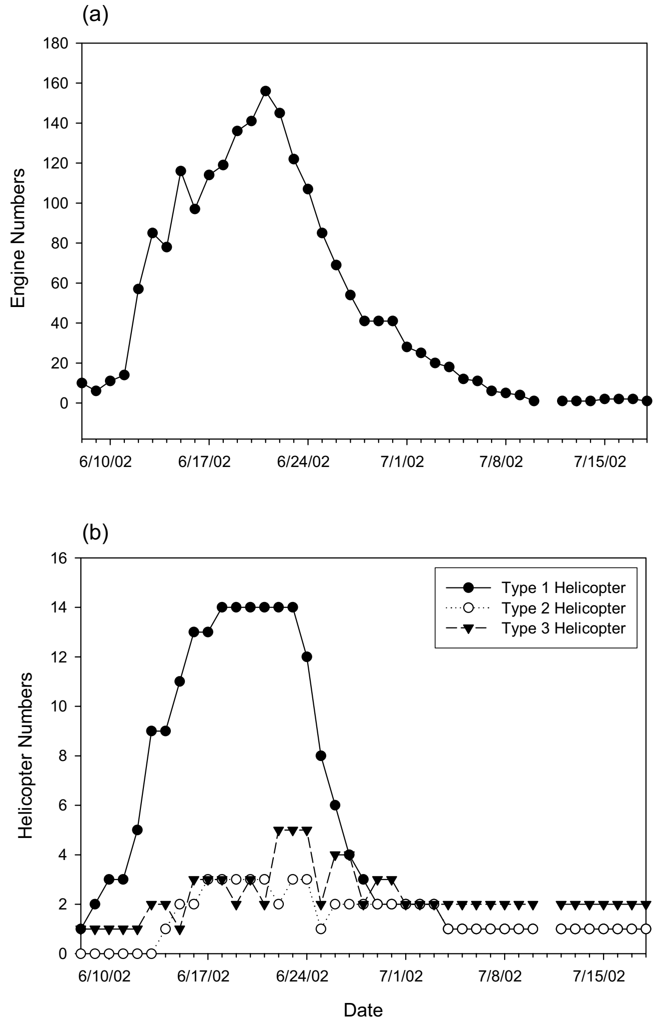

Figure 103—Number of engines (a) and numbers of helicopter by type (b) assigned to the Hayman Fire for the period of June 8 through July 18, 2002. Data are from historical ICS-209 database (appendix D). ICS-209 data were unavailable for July 11.

Table 28—Flight hours, retardant (gallons) for fixed-wing aircraft by Type 1 Incident Management Team for the period June 10 to June 28, 2002. Information for Initial Attack (IA) is not included in this table. Data are from the individual team's air operations narrative and supporting data.

Type 1 Incident Management Team	Air tanker flight hours	Retardant (gal)[1]	Lead planes/air attack (flight hours)
Martin (6/10-6/16)	**	194,650[2]	**
Frye (6/14-6/28)	64	144,086	132
Raley (6/12-6/25)	7	35,100[3]	109
Totals	71	373,836	241

[1] Includes retardant dropped by all fixed wing aircraft (SEAT, MAFFS, and other air tankers).
[2] MAFFS or SEATS were not used by this team.
[3] 100% of the retardant and flight hours were by MAFFS units.
** Information for this team was reported only as the total flight hours for all fixed wing aircraft (air tankers, lead planes, and air attack) and helicopter for a total of 171 hours.

Table 29—Flight hours, gallons of water, foam, and retardant, pounds of cargo and number of passengers transported, for helicopters by Type 1 Incident Management Team for the period June 10 to June 28, 2002. Information for Initial Attack (IA) is not included in this table. Data are from the individual team's air operations summary narrative and supporting data.

Type 1 Incident Management Team	Flight hours	Water (gal)	Foam (gal)	Retardant (gal)	Cargo (lb)	Passenger (number)
Martin (6/10-6/16)	**	903,047	0	0	3,685	87
Frye (6/14-6/28)	579	2,139,296	524,800	118,000	32,358	244
Raley (6/12-6/25)	450	1,626,765	540,020	60,196	6,400	71
Totals	1029	4,669,108	1,064,820	178,196	42,443	402

** Information for this team was reported only as the total flight hours for all fixed wing aircraft (air tankers, lead planes, and air attack) and helicopter for a total of 171 hours.

Helicopters accounted for the majority of flight time during the period analyzed (table 29). The ability to drop foam and retardant from helicopters became feasible after the establishment of a portable retardant base at Wellington Lake on June 21, located 8 miles northwest of Deckers. The limited number of passengers and transported cargo are due to the fact that crews did not require transport or support due to the road system in the fire area.

Initial and Extended Attack Actions

Saturday, June 8, 2002: Despite the fact that the fire was subjected to an extremely aggressive initial attack with four air tankers, a Type 1 heli-tanker, two Type 3 helicopters, seven engines, two water tenders, a Type 1 handcrew, two Type 2 handcrews, and two five-person handcrews, the weather and forest fuel conditions were beyond control (see appendix C and appendix D). On this day ambient air temperature was 85 °F, relative humidity was 5 percent, and wind speeds were sustained at about 15 mph and gusting to 36 mph out of the south-southwest. These conditions contributed to prolific spotting, both short and long range (see appendix A).

During this time, values at risk trigger points for evacuations based on current fire behavior and forecasted weather conditions were developed. Suppression actions were to keep the main fire to the west of State Highway 77 using crews and air support through flanking actions and establishing a defendable anchor point at the heel. Air tankers and helicopters were used to attack and control spotfires until the cessation of air operations at dark.

Sunday, June 9, 2002: Weather conditions the morning of June 9 were more severe than on the previous day. A National Weather Service Red Flag Warning was in place for high winds and low relative humidity, and by 0900 hours wind speeds were reported at 25 to 30 mph, and relative humidity was 5 percent. By 1330 winds gusted to 60 mph. Trigger points identified the previous day were being met quickly, and while anchoring at the back of the fire and holding the main fire were still being accomplished, firefighter and public safety, evacuations, and structure protection became the first priority.

By the end of the day evacuation orders were in place for over 600 homes for the following areas: Goose Creek, Molly Gulch, Lost Valley Ranch, Flying G Girl Scout Camp, Wildhorn Ranch, for homes along County Road 77, Y Camp, South Platte River, and Turkey Peak. It was anticipated that more than 3,700 homes could potentially be affected. On this day the local Type 3 Team started its transition with Martin's Type Incident Management Team (IMT).

Ron Hivzdak, Fire Behavior Analyst with Frye's Type 1 Incident Management Team noted that there were few treatments or natural fuel breaks to slow down the fire or to work from (appendix G). He noted that the recent prescribed fire, the Polhemus burn, conducted in the fall of 2001 and recent wildfire (Schoonover 2002) significantly slowed the fire spread of the northeast head of the fire (appendix G). Rich Hawkins, Planning Section Chief, Raley's Type 1 Incident Management Team, noted that a recent prescribed burn (Polhemus 2001) and a recent wildfire (Schoonover 2002) were effective in stopping the head of the fire and allowed them to concentrate their suppression efforts along the west flank of the fire in the North Hayman zone (personal communication, November 2002).

Martin's IMT Team Operations Section Narrative

The following excerpt is from the Incident Narrative prepared by Martin's Type 1 Incident Management Team and includes portions from the Incident summary, Planning and Operations Section narratives prepared and edited by Steve Raddatz, Planning

Section Chief, Martin's Type 1 Incident Management Team. This report was edited to retain comments only pertaining to suppression activities. In addition, acronyms, and jargon were defined when appropriate as well as minor spelling and grammar changes when needed.

Saturday, June 8, 2002: Martin's Team Type 1 Incident Management Team (IMT) received notification before 2200 hours that they were assigned to the Hayman Fire. At the time of the notice they were assigned to the Iron Mountain fire and had a scheduled debriefing for Saturday morning. The Hayman Fire at the time was being managed by the Jefferson County Type 3 IMT. Basic information indicated it was 60 acres in size with a 40 acre spot fire. The fire was burning in Ponderosa pine with ladder fuels.

Sunday, June 9, 2002: Members of Martin's IMT began to arrive at approximately 1400 hours and started to transition with the Type 3 team. An Agency Administrator's briefing with Martin's IMT was scheduled for 1800 hours at the Lake George community Center. This meeting eventually took place at 1920 hours. The fire at this time was driven by strong south-southwest winds and low relative humidity and spread quickly across a swath 19 miles long through forest fuels and urban interface. During the afternoon of June 9 the Type 3 Team in conjunction with the Park and Teller County Sheriff Department's focused on the evacuation of civilians. By late evening the fire was estimated to be between 50,000 to 60,000 acres.

During the Agency Administrator's briefing it was decided that under the current weather and fire behavior that the following strategy would be used: continue evacuations, suppression actions would be to establish a defendable and secure anchor at the heel with line construction proceeding north on the east and west flanks of the fire. In addition, a unified command would be established and due to the complexity of the incident a second Type 1 IMT would be ordered and the fire be split on a north south basis.

Monday, June 10, 2002: Martin's IMT assumed command of the incident at 0600. The initial strategy established the previous day was initiated. This strategy primarily focused on public safety through assisting and supervising in the development of a safe and organized evacuation of areas in immediate threat. Provide for firefighter safety and start with the basics; secure the heel of the fire then start flanking. This strategy was necessary due to a number of factors: extreme fire behavior, heavy fuel loading, difficult terrain, limited resources and limited access.

The fire involved urban interface, so major areas of concern were threats to additional structures outside the fire area, unburned fuels adjacent to structures and continued fire spread to the north-northeast. There were numerous local fire departments and agencies participating in the initial attack and extended attack, so the status of resources involved was uncertain.

During the operational period line construction and burn out of line was initiated in Divisions A, B, Z and Y (see fig.104 for approximate division locations). Some limited success occurred with the limited resources on hand and the shifting and at times gusty winds. In Division X the limited resources available only allowed for a defensive effort of preparing structures to make

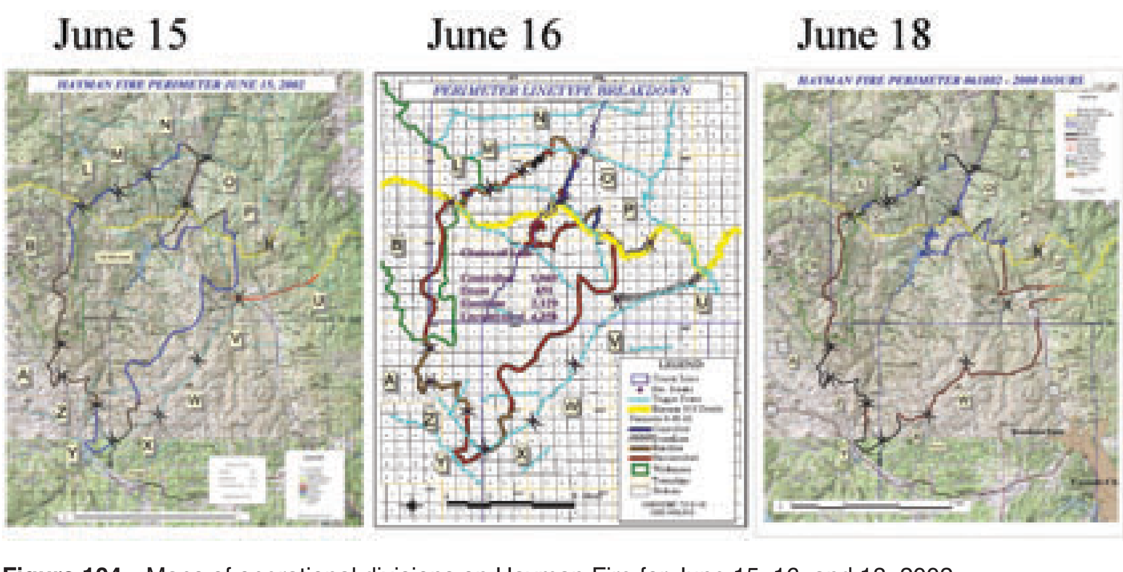

Figure 104—Maps of operational divisions on Hayman Fire for June 15, 16, and 18, 2002.

them more defendable. The fire made a major run to the north - northeast at about 1500 hours when winds picked up with gusts to 35mph. The fire grew to approximately 75,000 acres.

During this period, plans for evacuating a total of 6,000 homes and over 40,000 people were being implemented with evacuation centers being established at numerous locations in Park, Jefferson, and Douglas Counties (ICS-209, June 10, 2002).

Tuesday, June 11, 2002: Raley's Type 1 IMT arrives and begins to meet with members of Martin's IMT and Chesley's Area Command. The fire is divided into two sections, Hayman North with Raley's IMT assuming command, and Hayman South with Martin's IMT in command.

The primary objectives for the operational period were to start working toward containment keeping the fire north and east of County Road 77 and west of Highway 67 and the Manitou Experimental Forest. These objectives were met for the operational period. During the operational period Division A (see fig. 104 for approximate division locations) continued efforts to line the fire edge and burn out. Good progress was made. In Division B the effort focused on holding established line and assessing line location to tie into an anchor point in the wilderness. During the afternoon the wind picked up and changed direction for a while, so firefighters were able to hold established line but were unable to anchor into the wilderness. Division Z was successfully held by established line but was unable to connect to the Division Y line. Division Y was to hold established line and reassess line location to provide an anchor point for Divisions Z and X. Divisions Z and X to start line construction from where the line tied-in to anchors. Construction of line was started after a location was scouted, but afternoon winds pushed the fire across the line. In Division X primary efforts were confined to structure protection and preparation with some scouting for possible line location.

Personnel were assigned to work the fire during the night shift were limited to two Division Supervisors, a Type 2 crew and six engines. The primary mission was to patrol around structures in Divisions Z and Y. Emphasis was placed in areas where burnout operations had occurred around structures.

Wednesday, June 12, 2002: At 0600 Raley's IMT assumed command of Hayman North. For Hayman South, objectives for the day operational period were the same as for June 11 and were met. Good progress was made in Division A in patrolling line and the start of mop up 300 feet in from the line. Division B was to hold established line and locate line to construct to anchor in the wilderness (see fig. 104 for approximate division locations for June 12). They too, made good progress. The wind picked up in the afternoon and Division B had a spot fire outside the line and pulled off to a safety zone. The main objective for Division Z was to hold established line and provide protection to structures at Sportsman's Paradise. The division was successful in meeting this objective. In Division Y the main objective was to protect structures in Sportsman's Paradise and construct and hold line. The Division was partially successful. They protected the structures and held some line. The objective for division X was to protect structures around Cedar Mountain, Turkey Rock, and along Turkey Creek. The Division was successful in this effort. In Division W the main effort was to construct a dozer line from Highway 67, above West Creek, east to Long Hollow. The Division made good progress in this effort with about three-quarters of the line being completed.

The fire made a run in the afternoon around 1600 hours when the wind picked up from the east-northeast. The fire was active in the southeastern portion of the fire in the vicinity of Sportsman's Paradise. The day shift worked late protecting structures and burning around the structures. This operation was successful.

A night shift was established with two division supervisors, a Type 2 crew and six engines. The main actions for the operational period were to patrol around structures and assist with burn out operations in Division Y. This mission was successfully completed.

Thursday, June 13, 2002: The Team's general objectives were the same as on June 12. The main objective for Division B was to hold existing line and construct line into the wilderness. The personnel working in the division were successful in meeting these objectives. Fire activity in this area was relatively quiet. The main objective for Division A was to patrol and hold the line (see fig. 104 for approximate division locations for June 13). There was little fire activity on this division and the line was held. Division Z primary efforts were to hold established lines and protect structures. They continued efforts to anchor the line to Division Y, but had a short tough stretch to complete. In Division Y the main objective was to protect structures in Sportsman's Paradise and Tom's Ranch while continuing efforts to construct and hold line to the Division Y/Z break. The division was partially successful in protecting structures and in the construction and holding of some new line. The main objective in Division X was to protect structures in the Cedar Mountain area, Turkey Mountain subdivision and along Turkey Creek. The efforts in this division were successful. In Division W the main actions were to hold constructed line and scout line from Highway 67 to the west toward the end of Division X. These actions were successfully completed.

The main fire activity was on the southern portion of the fire above the ICP. The fire increased in activity at about 1400 as an east wind started picking up. At 1700 the wind shifted to the north-northeast gusting to 20 to 25 mph. The fire was moving toward George Lake and the ICP, so a dozer line was constructed and a burn out operation done. This action was successful.

A night shift was in place with the main goal to protect structures in Division Y and support a burn out operation. This effort was successful.

Friday, June 14, 2002: Frye's Type 1 IMT arrives and begins to meet with Area Command and with members of Martin's IMT. Transition of management of Hayman South is to begin on Saturday June 15 with Frye's team scheduled to assume command at 0600 hours on Sunday June 16.

Divisions B and A were in patrol status by air and one engine (see fig. 104 for approximate division locations for June 14). The efforts in Division Z were to hold established line, protect structures and begin mop up from 300 feet in from the line. Fire fighters were successful in meeting the division objectives. The main actions in Division Y were to protect structures in Sportsman's Paradise and Tom's Ranch, hold established line, and finish burn out of constructed line. The division was successful in meeting most of these objectives, but some line was left to burn out at the end of the operational period. Division X protected structures in the Indian Creek subdivision, scouted line locations and start constructing line. The Division was successful in all efforts, but there was still line to construct and hold. Division W's main objectives were to construct dozer line from Division V/W break west towards Division X, protect structures along Trail Creek and line all spots. The division made significant progress in this effort. In Division V the main efforts were to continue structure protection along Trail Creek and construct dozer line from an established anchor point from Division W/V break. The division was successful in this effort and made significant progress in constructing dozer line. The main efforts in Division U were structure protection in Trout Creek area and West Creek area and to construct dozer and hand line from Highway 67 to trail Creek. Line construction was successfully started, which was key to protecting the east flank from future wind events from the southwest.

The fire made no significant runs and acreage increase was primarily due to burn out operations to secure line. The Operation Section had no knowledge of additional structures lost.

A night shift was in place with the primary duty to patrol Divisions Z, Y, X and W to protect structures and hold the line. This effort was successful.

Saturday, June 15, 2002: The formal transition from Martin's Type 1 IMT to Frye's Type 1 IMT begins with incoming Section Chiefs and staffs formally meeting and shadowing their counterparts.

The general control objectives for the incident remained the same as June 14. Divisions A, Z, and Y were to patrol all line, continue working hot spots and mop up (fig. 104). Three crews were assigned to do this with most of the effort concentrated in Division Z where the most recent fire activity has occurred.

Division B was completely within the Lost Creek Wilderness and was unstaffed. Some line had been constructed in this Division from the B/A Division break north. No other actions were being taken in this division due to its low priority and the current prevailing winds and topography were limiting further spread to the west.

Actions on Division Y were focused on protecting structures, improving line, and completing burn out where necessary. Division Y aided Division X by sending resources to help with structure protection.

The southwest portion of Division X is indicated as contained with mop up actions continuing. The remaining half of this division is located in Crystal Creek and uncontained at this time. Objectives for Division X focused on structure protection in Indian Creek, construction of fire line (hand and dozer) to complete the line to Division W and burned out line when completed, and coordinate structure protection with Indian Creek Fire Protection District.

Division's U, V, and W are mostly uncontained with the fire edge in these divisions located in rugged, steep drainages. As such, indirect tactics were being utilized with burnout operations from existing roads and indirect line. Division W objectives were to prepare the road and line for burn out, provide for structure protection and conduct the burn out if weather allowed and all resources were in place. The main efforts in Division V were to construct dozer line from Lutheran Valley Ranch east to Thunder Butte, protect structures, line spots, and send engines assist Division W when burn out started. The main actions for Division U for the day were to continue line construction on the ridge and burn out if completed weather and resources allowing. A limited night shift was assigned to patrolling divisions Y/X and W/V.

High winds developed at approximately 1200 hours, wind gusts up to 40 mph associated with thunderstorms were experienced over the fire area.

Raley's IMT Team Operations Section Narrative

The following excerpt is from the Incident Narrative prepared by Raley's Type 1 Incident Management Team and includes portions from Incident summary, Planning and Operations Section narratives prepared and edited by Rich Hawkins, Planning Section Chief. Raley's IMT was responsible for the North zone of the Hayman Fire, hereafter referred to as North Hayman.

The original document was edited to include only information directly pertaining to suppression activities. In addition, acronyms, and jargon were defined when appropriate as well as minor spelling and grammar changes when needed.

Wednesday, June 12, 2002: The fire was officially split into two zones at 0600 hours on June 12 with CIIMT#5 assuming command of the northern portion of the Hayman Incident. The fire would now be managed as two connected incidents, North Hayman and South Hayman (fig. 104). An Incident Briefing was conducted with all of the firefighters being assigned to structure protection. These resources were all from local fire districts. As they day progressed 13 additional engines from other Western States arrived to join the structure protection effort. During the prior evening a cabin was lost at Trumbull, this was the first structure lost in the northern portion of the fire that was officially confirmed.

By the end of the operational period seven hand crews had either arrived or were reported to be arriving by 1000 hours the following morning.

The major issues on the Hayman North were evacuations and structure protection over a large geographic area located in Douglas and Jefferson Counties. In Douglas County alone, 19 neighborhoods had been evacuated. Evacuations were planned based on identifying physical lines on the map (trigger points). The fire reaching these predestined locations were intended to trigger a discussion between operational and law enforcement personnel regarding community evacuations. Each trigger point had a written list of communities affected to help guide the discussions and insure that all potential evacuations were considered in a timely manner.

At the Operational Briefing I discussed the requirements of the Thirtymile implementation plan (referring to the Thirtymile fire and firefighter fatalities in Washington State the year before). The "Pocket Guides" and the pocket cards were being made available by the Forest. Agency Representatives were asked to validate by written documentation that each of the respective resources were qualified for the position. All of the Local Engines that were "depicted" on the IAP were strictly use for their own structure protection responsibilities, with the following exception: Division N, Task Force 285 Team with E652, E635, E461, E458, E153, WT 175, WT 371. These resources will be issued ordered numbers and should be compensated for Wildland Firefighting. These departments were asked to ensure that they met the NWCG qualifications for wildland fires.

Thursday, June 13, 2002: The first handline was constructed on Hayman North but less that two miles was completed due to just a few handcrews arriving in time to go to the fireline.

Between 1400 and 1600 hours, the Incident Commander and Deputy met with Region 5 Fire Safety Officer Charlie Gripp to discuss implementation of the Thirtymile action items and implementation plan.

The total lack of any containment along the northern perimeter and record dryness in the vegetation resulted in a huge potential for major fire spread (fig. 104). The Incident Commander, the Jefferson County Sheriff, and the Douglas County Sheriff were unified in their message to public. There would be no reoccupation of evacuated communities until such time that CIIMT5 (Raley's IMT) determined there was no further threat to their communities.

At 2200 hours it was identified that there were problems with the Pike National Forest pocket cards related to the Thirtymile implementation plan. The Fire Behavior Analyst was directed to write a fire behavior prediction based on what was covered on the forest pocket card based on current fuel conditions.

Friday, June 14, 2002: There were now 600 firefighters assigned to the incident. Span of control has become an emerging issue on the divisions. Because resources that were ordered in strike team or task force configuration are being sent as single resources the span of control is being exceed in the individual divisions.

Type 1 Helicopters were used to check the fire's spread as there was now a considerable ground force constructing and holding hand line on the ground. Considerable hand line construction was in Divisions L, M, and P (see fig. 104 for locations of associated divisions). Division O running north and south along the South Platte River continued to back down the hill in an easterly direction.

At approximately 1200 hours, two Greyback Crews disengaged from their assignment due to the fire making a run up a knoll in division N. The Division Supervisor supervised the disengagement. The Safety Officer notified the Incident Commander and directed the Division Supervisor to document the disengagement in their unit logs.

The Fire Behavior Analyst completed his document regarding Pike National Forest fire behavior and fuel conditions. From that day forward, all Incident Briefings were conducting using this information. This provided the firefighters with far more information than any national forest pocket card provides.

Saturday, June 15, 2002: Personnel assigned to suppression action consisted of 750 people, including 31 handcrews. Haines Index was forecasted to reach 6 between 1000 and 1400.

Handcrews constructed line around the top of Division N (fig. 104) in an attempt to keep the fire out of Kelsey Creek. That portion of line was completed but there was still over a mile of open line between that point and the Division N/M boundary to the west. This was a major area of concern by the Operations Chiefs and the Incident Commander.

The actions of the Lone Peak and Vale Hotshot Crews in picking up two spotfires on the north side of Kelsey Creek in conjunction with air support from Type 1 Helicopters was a critical tactical accomplishment in the future containment of the North Hayman Incident.

The Fire Behavior Analysts (north and south) were tasked with providing a common approach to assessing fuels and fire behavior information. This ensured that the Thirtymile implementation plan was being met on both sides of the incident.

Sunday, June 16, 2002: Actions were delayed during the middle of the day due to unfavorable wind conditions and hazards to firefighters. At approximately 1400 hours, firefighters resumed line construction with the most important accomplishment being the completion of the fire line in Division N. Two Hotshot crews were utilized to complete the final section of line after all other firefighters on the top portion of the fire moved down the line towards Division M while the hotshots finished the line across Gunbarrel Creek and Saloon Gulch. Five Heavy Helicopters and several air tankers were utilized to support this operation.

Burnouts were accomplished along the South Platte River in Division O and spot fires occurred in Division P (fig. 104). Hand line construction was completed on the spot fires by 1200 hours and fire line was now complete in Division P.

While not officially contained, for the first time, a comfort level was developing that the fire would not spot across the South Platte River. This 3 mile long area in Division O on the west side of the river was a critical area for preventing the eastward spread of the fire into an area of heavy fuels and Tussock Moth mortality in the timber stands.

By evening, a spike camp had been set up at Dott Campground, adjacent to the community of Trumbull. Division N and M both had orderly disengagement.

Monday, June 17, 2002: Approximately 850 fire fighters including 32 hand crews were now assigned to the fire.

Martin's IMT had now been replaced by Steve Frye's IMT from the Northern Rockies on the South Hayman Incident and Frye's IMT took command of the southern portion at 0600 hours.

The weather and fire behavior forecast were a significant concern to the Operations Chiefs. Several spot fires and slopovers occurred and were picked up. By 1200 hours, the prediction of a Haines Index of 6 appeared to be realized as significant fire activity was realized. Throughout the afternoon all aircraft were utilized continuously to hold Divisions L, M, N, and portions of O (fig. 104). Division P was now cooling off and did not require air support.

At around 1300 hours the fire kicked up in Frye's division W and V and made a 9,000 to 12,000 acre run (fig. 104). Trigger Point 5B was activated and approximately 1,000 people were evacuated from the following Douglas County Communities: Highway 78 northwest to Westcreek, Painted Rocks Road, Quinlan Gulch Ridgewood, Road 339, Skyhigh Ranch, Hotel Gulch , and Road 791.

The fire spreading east in the South Hayman Incident was of great concern to CIIMT5 (Raley IMT) because of the potential for a future end run around the containment lines that were being held in the north.

CIIMT5 (Raley IMT) requested that the forest start considering suppression tactics for the Lost Creek Wilderness. The Incident Management Team specifically requested permission to use fire retardant in the wilderness.

New trigger points for evacuations were discussed at great length during the evening regarding potential evacuations. The formal decision regarding these was made the following morning.

Tuesday, June 18, 2002: The fire spread easterly across State Highway 67 along Divisions V and U (fig. 104) triggered the Contingency planning that was conducted for the community of Perry Park and Perry Park East. Perry Park, with approximately 593 residences identified as the area most at risk in the general vicinity of the Perry Park Ranch. Later in the evening this area was evacuated.

A structure protection branch director assessed the area and determined significant structure losses would occur in the case of crown fire and most of the community could be saved if the fire was on the ground when the fire arrived.

Potential lines of defense were identified to the west of the community utilizing old roads, potential dozer lines, hazard fuel removal, and possible hand line construction. The Branch Director requested resources to begin preparing the community for the arrival of the fire on the following shift.

The infrared film indicated a spot fire had become established in Division L overnight. Type 1 Helicopters and Type 1 Hotshots worked along this portion of the line throughout the day but were not able to contain the spot fire. This was a concern to the Operations Group as this was the only portion of the North Hayman Incident that was not contained. The fire was also active on the south side of Wigwam Creek in the South Hayman portion of the fire.

Divisions M, N, O, P (fig. 104) all held despite the wind pushing against the fire lines. Significant fire activity to the south would represent a continuing threat to Perry Park based on predicted fire behavior and weather.

A major factor the success of control efforts was the wind speed not reaching the predicted 28 mph wind speeds. Most of the area did not experience wind speeds over 10 mph. Relative humidity (RH) as low as 3 percent were encountered at several locations on the fire.

At 1700 hours, District Ranger Randy Higgenbotham was contacted concerning the team wanting to use retardant in the Lost Creek Wilderness. Randy advised the team that the Forest Leadership Team had discussed and approved this use of retardant.

Wednesday, June 19, 2002: The spot fire in Division L (fig. 105) in the Lost Creek Wilderness advanced upslope from Wigwam Creek northwesterly to the top of Buffalo Peak. This was the only portion of the Hayman North Incident that moved during the shift. The increase in acreage due to the spot in Division L was about 60 acres.

The expansion of the fire in the South Hayman Incident south of Rainbow Falls was a significant concern presenting an opportunity for the fire in the south to outflank containment lines in the north by spreading to the east and then the north.

Relative humidity rose from a low of 3 percent on the prior day to 15 to 20 percent during this shift. Unlike the prior evening, weather was very favorable with high humidity and slight rainfall over most of the incident. This rainfall afforded only a temporary halt to the fire considering that the 1000-hour fuels in the vicinity of the fire were at record dryness levels of just 3 percent.

The Operations Group began contingency planning for structure protection for communities that would be threatened if the fire made a major run to the east or northeast. New trigger points were established for future evacuations.

Thursday, June 20, 2002: Most of the fire area experienced 0.25 to 0.50 inch of rainfall and the fire moved little during this shift. A contingency plan was under development for dealing with the fire that had spread outside of Division L northwest to the Buffalo Peak area. Retardant and water drops were to be used to try and check the future fire spread as an assessment of the area by the Operations Chiefs indicated that the 10 standard orders and 18 situations could not be adhered to if we decided to directly attack the fire at Buffalo Peak.

Substantial progress was made as hand crews from Hayman North entered the Hayman South area at the Division U/P break. The crews were able to construct handline from the division break to Trout Creek in Division U (fig. 105).

Bear Team Leader, Greg Bevenger, met with the Deputy IC and was told the fire was still too hot for ground access by BAER Team members, but helicopter flights for aerial assessments would be considered, based on non-interference with fire suppression activities.

The most significant event of the day was the lifting of mandatory evacuations in the communities some distance to the north of the fire in Jefferson and Douglas Counties. This reduced the number of structures threatened by approximately 1,400 and approximately 3,000 people were able to return to their homes, Fern Creek was reoccupied.

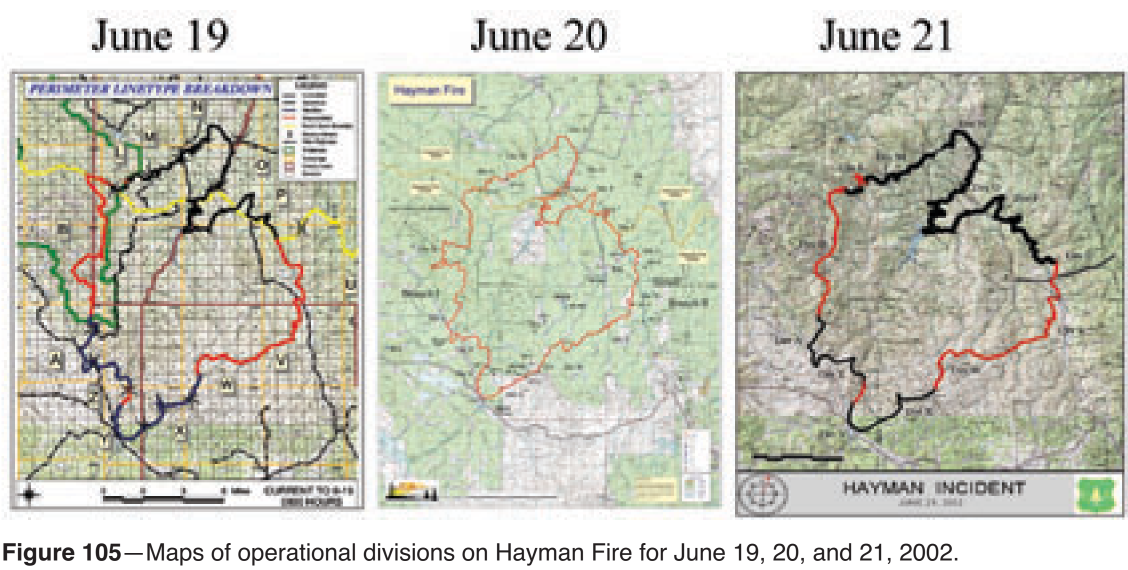

Figure 105—Maps of operational divisions on Hayman Fire for June 19, 20, and 21, 2002.

The following communities were reoccupied with it publicly stated that evacuations could occur again in the future

Douglas County

Sedalia	Indian Creek Ranch	Roxborough Park
Moon Ridge	Spruce Wood	Roxborough Village
Sprucewood	Pine Creek Road	Night Hawk
Sugar Creek Road		Scraggy View

Jefferson County

Buffalo Creek Mountain	Valley Acres	Buffalo Creek Park
Pine	Christmas Hill	Pine Grove
Cliffdale	Pine Valley North	Crossons
Riverview	Crystal Lake	South Platte
Dome Roick	Sphinx Lodge	Ferndale
Sphinx Park	Foxton	Longview
Indian Springs Village		

Friday, June 21, 2002: Fire activity was minimal on the North Hayman Incident. Light showers and high humidity assisted firefighters in preventing additional spread. Coordination between the two Incident Management Teams was excellent as a joint effort was made to complete a fireline on the east perimeter between Westcreek northerly to Trout Creek. By the end of the shift, most of the line was completed.

There had been many spot fires in the Long Hollow Creek drainage and the intelligence group was concerned there was still a significant chance of the fire spreading easterly towards Perry Park, which had been evacuated a few days prior.

A portable retardant plant was used for the first time in the vicinity of Wellington Lake, which allowed the firefighters to check the spread of the fire southwest of Buffalo Peak in the Lost Creek Wilderness.

Lightning adjacent to the northern portion of the Hayman perimeter resulted in one initial attack fire for 0.50 acre. Pike National Forest ground forces contained the fire after Type 1 Helicopters from the North Hayman suppressed the fire. As night fell a second lightning fire was located and was knocked down with a helicopter bucket drop by a pilot returning to base.

Two communities, Oxyoke and Fern Creek were reoccupied

Saturday, June 22, 2002: There was no movement of the fire on this date, and suppression rehabilitation and mop up operation continued. Some of the water bar work on cool divisions was nearing completion. Work assignments were now based in large part on the aerial GPS/IR Mapping Unit being provided on the North Hayman Incident by a private contractor.

The most significant event of the day was the work of the Vale, Alpine, and Lone Peak Hotshots, in completing a line up the northeast flank of the slopover on Buffalo Peak. The crews concurred with a prior decision by the Operations Chief and Safety Officer that the hazards associated with the southwest flank of the slopover and the spotfires above that were could not be mitigated.

Sunday, June 23, 2002: Reoccupation of all communities except Decker and Rainbow Falls had now occurred on the North Hayman. Less than 100 people remained in evacuation status associated with the northern end of the fire.

One issue surfaced regarding the reoccupation of communities and homes. The perception was that this opened the areas up to the public when in actuality the areas are still closed to the public due the danger associated with the fire fighting effort.

Mop up was now based on looking for hotspots with the infrared map from the helicopter mounted IR unit.

A decision was made to transition from two Type I IMT's to Frye's Incident Management Team, effective June 26 at 0600.

Monday, June 24, 2002: The infrared indicated that even the slopover on Buffalo Peak was cooling rapidly. This supported the plan to transition to a single Type 1 Incident Management Team.

One of the team's Logistics and Operations Section Chiefs attended a planning meeting at the South Hayman Incident Base to support Frye's IMT in developing an IAP for the entire incident for day shift on June 25. The plan was for Raley's IMT to continue managing the North Hayman until 0600 on June 26.

Frye's IMT Team Operations Section Narrative

The following excerpt is from the Incident Narrative prepared by Frye's Type 1 Incident Management Team and includes portions from Incident summary, Planning and Operations Section narratives prepared and edited by Jeff Scussel; Planning Section Chief and Rick Floch and Phil Perkins; Operations Section Chief. This report was edited to retain references only to suppression activities. In addition, acronyms, and jargon were defined when appropriate as well as minor spelling and grammar changes when needed.

Sunday, June 16, 2002: To facilitate proper span of control, the Operations Section divided the fire into two branches with Divisions B, A, Z and Y in Branch I and Divisions U, V, W, and X in Branch II (fig. 104). The focus of work this day was on completing the construction of indirect line in Branch II and completing burnout as weather conditions allowed. Continuing an anchor from drop point (DP) 4 in X was critical to the success of tying in these divisions. Conditions along Road 360 in W were favorable during the afternoon and that Division was successful in burning out along approximately half of its line. Division X finished preparation for the burnout but never had favorable conditions before the shift ended. Division V continued indirect line construction from the W/V break towards Highway 67 and managed to reach the Sheep Nose area of the division by the end of the shift. Some burnout was also done in the Turkey Rocks area. Division U anchored at the fire edge along the road into the Trout Creek subdivision and flanked the fire to the south up along the ridge between West Creek and Trout Creek. The fire did not spread appreciable on any division.

A structure protection group was also formed to coordinate the activities of several local Rural Fire Departments. Their work focused on performing structure protection measures mainly in the Indian Creek subdivision. Other work included mopping up around structures burned over in the Turkey Rocks area and other subdivisions nearby.

A nightshift was operated and their function was confined to the patrolling of subdivisions and areas that were burned out during the day. Higher relative humidity prevented effective burnout during the night.

Monday, June 17, 2002: On this day, the weather forecast predicted continued warming with the potential for increased west winds. Planned work included a continuation of burning out and further construction of indirect line (fig. 104).

Division W was unable to continue burnout where they left off the day before because of unfavorable winds. There was a need to widen the previous day's burnout but during the morning, this tactic was considered too dangerous considering the potential for west winds. In Division X, unfavorable winds prevented any burnout and direct line was constructed in an attempt to corral a series of burning spots on the south side of Crystal Creek. In Division V, burnout continued to the east of Turkey Rock and Division U improved their line on the ridge between West and Trout Creeks.

During the early afternoon, increasing west winds and single digit relative humidity caused a dramatic increase in fire activity. A large patch of unburned fuel northwest of Turkey Rock actively burned and, pushed by west winds, crossed the indirect dozer line and burned southeast across the Trail Creek Road in a large finger. At about this same time, another unburned patch of timber northeast of Sheep Nose burned southeast across dozer line and on across Trail Creek further to the northeast of the Turkey Rock finger. Crews pulled back into safety zones in Divisions V and W and toward the end of the day, took advantage of opportunities to mop up around and/or protect threatened structures. Division U was able to hold their ridgetop line but had some slopovers and spotting that they planned on picking up the following day.

Again personnel were assigned to a night shift but their efforts were focused on protecting structures in the West Creek area.

Tuesday, June 18, 2002: Weather predictions for this day were similar to the previous day and extreme fire behavior and fire spread were expected and predicted. Initial plans focused on flanking from the anchor on Division X toward Division W and holding the line that still remained in that division (fig. 104). Division V planned to continue mop up around the structures in West Creek and anchor in at the U/V break and flank the fire to the south. The two fingers of fire from yesterday became active in the late morning and soon burned together, creating a large convection column. This drew in air from all around, particularly from the southwest, which increased activity in Divisions X and W, causing unburned areas in Crystal Creek to burn toward the column, crossing the lines in X and in Division W.

Late in the day, the main fire stalled out on top of the ridge east of West Creek. A plan to burn out from this ridge was developed but before it could be implemented, winds again picked up and the fire burned down off the ridge to the east and crossed Highway 67. Division U was not able to hold the line on the ridge between West and Trout Creek and most of the area around the Westcreek subdivision burned at this time. The fire also crossed Highway 67 near Westcreek at this time. Crews pulled into safety zones as needed, but by the end of the day, were again working on structure protection and mop up as well as developing anchor points and gathering information for the following day's suppression activities.

Again, the night shift extended anchor points in Division V and X.

Wednesday, June 19, 2002: Work on this day focused on establishing and/or extending anchor points. Crews on the northeast edge of the fire were able to construct considerable line in Division U and V (fig. 105). Because of the size of Divisions W and V, a new Division E was inserted between them (fig. 105). The fire burned back onto itself for the most part, there was considerable fire activity along the southeast edge of the fire in Division's W, X and E. Crews in Division W pulled back to safety zones during midday. By the end of the day, Division E had tied in with V and was poised to move down into Manchester Creek on the southeast flank. Division W was burning out along some roads and mopping up spots. Division X was anchored and pushing toward W. Division U was flanking the south side of the fire from Highway 67 and again flanking the fire from the P/U Division break.

The night shift was able to complete line from an anchor point in Division X to the X/W Division break and mopped up in Division V.

Thursday, June 20 and Friday, June 21, 2002: A cooler and moister air mass moved in over the fire area. Thunderstorms occurred both afternoons and some rain fell on the fire. Lower temps and higher humidity allowed crews to construct direct fireline on the remaining parts of Divisions W, E, V and U. Again, because of the size of Division U and the rough terrain, a new Division T was inserted between P and U (fig. 105). Line was completed in all divisions on Friday and some burnout occurred in Division W to clean up some spots near Signal Butte. Night crews continued mopup in W and V.

Saturday, June 22, 2002: Crews continued to mop up and hold all lines (fig. 106). The two un-staffed Initial Attack fires were staffed with helitack and put out. A third Initial Attack fire was discovered on the west edge of the fire and staffed during the afternoon.

Rehabilitation on Division A was completed. Burnout in Division W along the dozer line southwest of Signal Butte was completed. In Divisions X, E, V, U, and T, mop up continued with considerable support from heavy helicopters. All lines held.

Sunday, June 23, 2002: Mop up continued on all active divisions. Rehabilitation in Division Z was completed. Homeowners were allowed back into the Tom's Ranch and Sportsman's Paradise subdivisions. The Trail Creek Road in Division W was snagged.

Monday, June 24, 2002: Rehabilitation in Division Y was completed. A tractor berm in Division A was smoothed-out with a dozer. The power company met with OPS and a schedule for assessing electrical repairs in the burned subdivisions was completed. Electrical power in the Tom's Ranch and Sportsman's Paradise subdivisions was repaired and turned back on.

References

Agee, J.K. 1997. The severe weather wildfire – too hot to handle? Northwest Sci. 71:153-156.

Agee, J.K., C.S. Wright, N. Williamson, and M.H. Huff. 2002. Foliar moisture content of Pacific Northwest vegetation and its relation to wildland fire behavior. For. Ecol. Mgt. 167:57-66.

Albini, F.A. 1979. Spot fire distance from burning trees – a predictive model. USDA For. Serv. Gen. Tech. Rep. INT-56.

Albini, F.A., and E.D. Reinhardt. 1995. Modeling the ignition and burning rate of large woody natural fuels. Intl. J. Wildl. Fire. 5(2):81-92.

Alexander, M.E., N.P. Cheney, and A.C.F. Trevitt. 1991. Tree-crown streets and wildfires in pine plantations of Australasia. In P.L. Andrews and D.F. Potts (eds). Proc. 11th Conf. On fire and forest meteorology. Soc. Am. For. P 167.

Anderson. H.E. 1968. Sundance Fire: An analysis of fire phenomena. USDA For. Serv. Res. Pap. INT-56.

Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. USDA For. Serv. Gen. Tech. Rep. INT-122.

Bartlette, R. A. (Hartford) and R.E. Burgan. 1998. Vegetation condition and fire occurrence: a remote sensing connection. P. 273-280 IN Proc. Fire Management Under Fire (Adapting to Change) 1994 Interior West Fire Council Meeting. Nov 1-4 1994 Coeur d'Alene, Idaho.

Bradshaw, L. and E. McCormick. 2000. FireFamily Plus user's guide, version 2.0. Gen. Tech. Rep. RMRS-GTR-67WWW. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Burgan, R.E. and R.A. Hartford. 1993. Monitoring vegetation greenness with satellite data. Gen. Tech. Rep. INT-297. Ogden, UT: U.S. Department of Agriculture, Forest Service. Intermountain Research Station. 13 p.

Burgan, R.E., R.A. Hartford, and J.C. Eidenshink. 1996. Using NDVI to assess departure from average greenness and its relation to fire business. Gen. Tech. Rep. INT-GTR-333. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

Byram, G.M. 1954. Atmospheric conditions related to blowup fires. USDA, Forest Service. Southeastern Forest Experiment Station. Station Paper 54. 30 p.

Byram, G.M. 1966. Scaling laws for modeling mass fires. Pyrodynamics 4:271-284.

Byram, G.M. and R.E. Martin. 1970. The modeling of fire whirlwinds. For. Sci. 16(4):386-399.

Catchpole, E.A., N.J. de Mestre, and A.M. Gill. 1982. Intensity of fire at its perimeter. Aust. For. Res. 12:47-54.

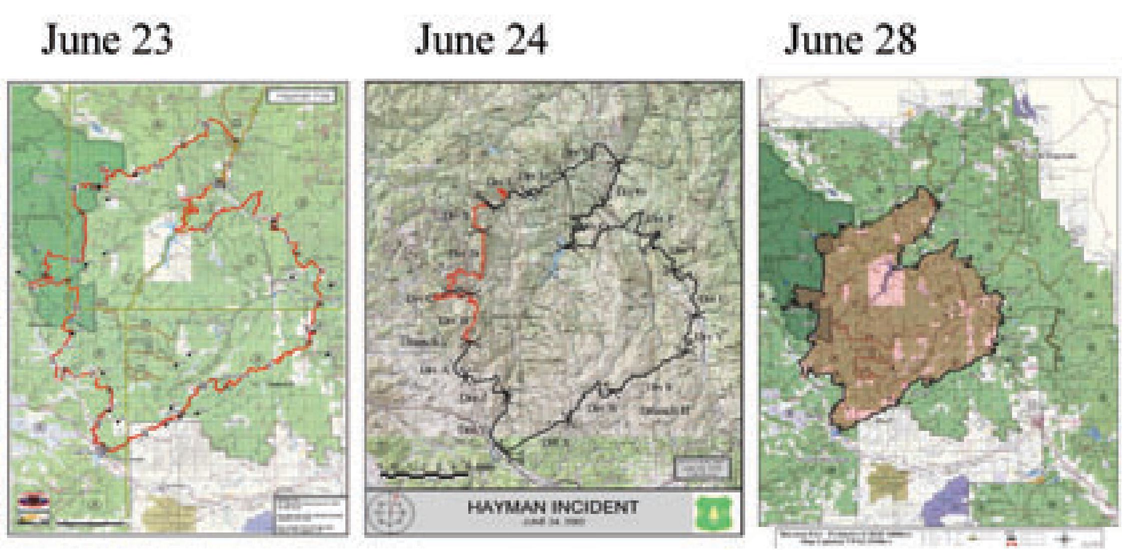

Figure 106—Maps of operational divisions on Hayman Fire for June 23, 24, and 28, 2002.

Countryman, C.M. 1964. Mass fires and fire behavior. USDA For. Serv. Res. Pap. PSW-19.

Deeming, J.E. 1990. Chapter 8: Effects of prescribed fire on wildfire occurrence and severity. IN: J.D. Walstad, S.R. Radosevich, and D.V. Sandberg (eds), Natural and prescribed fire in Pacific Northwest forests. OSU Univ. Press. Corvallis, OR. Pp 95-104.

Deeming, J.E., R.E. Burgan, and J.D. Cohen. 1977. The National Fire-Danger Rating System—1978. USDA For. Serv. Gen. Tech. Rep.INT-39. 57 p. Intermountain. For. And Range Exp. Stn., Ogden, Utah 84401.

Fendell, F.E. 1986. Crown Streets. Comb. Sci. and Tech. 45:311-315.

Finney, M.A. 1998. *FARSITE* Fire Area Simulator – Model development and evaluation. USDA For. Serv. Res. Pap. RMRS-RP-4.

Goward, S. N., B. Markam, D.G. Dye, W. Dulaney, and J. Yang. 1990. Normalized difference vegetation index measurements from the advanced very high resolution radiometer. Remote Sensing of the Environment. 34:257-277.

Haines, D.A. 1982. Horizontal roll vortices and crown fires. J. Appl. Meteor. 21:751-763.

Haines, D.A. 1998. A Lower Atmosphere Severity Index for Wildland Fire. National Weather Digest 13(2). 23-27.

Helms, J.A. 1979. Positive effects of prescribed burning on wildfire intensities. Fire Mgt. Notes 40(3):10-13.

Kaufmann, M.R.; Fornwalt, P.J.; Huckaby, L.S.; Stoker, J.M. 2001. Cheesman Lake – a historical ponderosa pine landscape guiding restoration in the South Platte watershed of the Colorado Front Range. In Vance, R. K., W. W. Covington, and C. B. Edminster (tech. coords.), Ponderosa pine ecosystems restoration and conservation: steps toward stewardship. U.S. Department of Agriculture Forest Service Rocky Mountain Research Station Proc. RMRS-P-22: 9-18.

Koehler, J.T. 1993. Prescribed burning: a wildfire prevention tool? Fire Management Notes, 53-54(4):9-13.

Martin, R.E., J.B. Kauffman, and J.D. Landsberg. 1989. Use of prescribed fire to reduce wildfire potential. IN: N.H. Berg (Tech. Coord). Proc. of the Symp. on Fire and Watershed Management. USDA For. Serv. Gen. Tech. Rep. PSW-109. Pp 17-22.

McRae, D.J. and B.J. Stocks. 1987. Large-scale convection burning in Ontario. Ninth Conf. on Fire and Forest Meteorology. Am. Met. Soc., Boston Mass. pp 23-30.

Palmer Wayne C. 1965. "Meteorological Drought", Research Paper No. 45., 58 pp. US Dept. of Commerce, Office of Climatology of the U.S. Weather Bureau.

Pollet, J. and P.N. Omi. 2002. Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. Intl. J. Wildl. Fire. 11(1):1-10.

Pyne, S.J. 1984. Introduction to wildland fire: Fire management in the United States. John Wiley and Sons, New York. 455 pages.

Richards, G.D., and R. Walberg. 1998. The computer simulation of crown fire streets. In III International Conference on Forest Fire Research and 14th conferences on Fire and Forest Meteorology. Pp 435-440. ADAI – Associacao para o Desenvolvimento da Aerodinamica Industrial. Caminho da Malvada, No 12., Apartado 10131-3030 Coimbra Portugal.

Rothermel, R.C. 1991. Predicting behavior and size of crown fires in the northern Rocky Mountains. USDA For. Serv. Res. Pap. INT-438.

Tucker, C. J. and B. J. Choudhury. 1987. Satellite remote sensing of drought conditions. Remote Sensing of the Environment. 23: 243-251.

Van Wagner, C.E. 1977. Conditions for the start and spread of a crown fire. Can. J. For. Res. 71(3):23-34.

Van Wagtendonk, J.W. 1996. Use of a deterministic fire growth model to test fuel treatments. In: Sierra Nevada Ecosystem Project: Final Report to Congress. Vol II. Assessments and Scientific Basis for Management Options. Univ. Cal. Davis, Centers for Water and Wildl. Resources, pp1155-1165.

Wade, D.D. and D.E. Ward. 1973. An analysis of the air force bomb range fire. USDA For. Serv. Res. Pap. SE-105. 38pp.

Werth, P and R. Ochoa. 1990. The Haines Index and Idaho Fire Growth. Fire Management Notes. 51(4): 9-13.

Werth and P, J. Werth. 1998. Haines Index Climatology for the Western United States. Fire Management Today. 58(3): 8-18.

Zimmerman, G.T., M. Hilbruner, P. Werth, T. Sexton, and R. Bartlette. 2000. Long-range fire assessments: procedures, products and applications. Pages 130-138 in Third Symposium on Fire and Forest Meteorology. 9-14 Jan. 2000, Long Beach, CA.. American Meteorological Society, Boston, MA.

Part 6: Daily Emissions

Wei Min Hao

Introduction

Biomass burning is a major source of many atmospheric trace gases and aerosol particles (Crutzen and Andreae 1990). These compounds and particulates affect public health, regional air quality, air chemistry, and global climate. It is difficult to assess quantitatively the impact wildfires have on the environment because of the uncertainty in determining the size of burned areas and the amount of emitted pollutants and greenhouse gases. However, they can be estimated using data gathered daily from burned areas by MODIS satellite, experimental results of aboveground biomass burning, and the emission factors of different compounds. This technique was used to estimate the daily emissions of carbon monoxide (CO) and particles less than 2.5 μm (PM2.5) from the Hayman Fire from June 9 to June 27, 2002, when approximately 138,000 acres were burned.

Figure 107 shows satellite (MODIS) images of the Hayman Fire on June 19, 2002. About 60,000 acres had been burned up to that day with ponderosa pine and Douglas-fir being the dominant vegetation burned. Figure 107a is a true color image, figure 107b is a false color image, and figure 107c shows the perimeter of the fire mapped by the Forest Service and the burned area detected by the satellite. The MODIS-derived burn area corresponds well with the active fire perimeter. The major discrepancies of the two maps are along the edge of the fire perimeter and are caused by the differences of the time of observation. The overpass time of the satellite was near noon, while the Forest Service aircraft estimated the fire size about 12 hours later.

Carbon Monoxide Concentrations

Carbon monoxide (CO) is a major compound produced by fires. The less efficient the combustion process is, the larger the amount of carbon monoxide emitted (Hao and others 1996). Carbon monoxide is a reliable tracer of biomass burning because CO is not very reactive photochemically, and CO concentrations are low in clean atmosphere. The MOPITT (Measurements of Pollution in the Troposphere) data for the Western United States on June 19, 2002, was retrieved from the Web site of NASA Earth Observing System (EOS) Data Gateway.

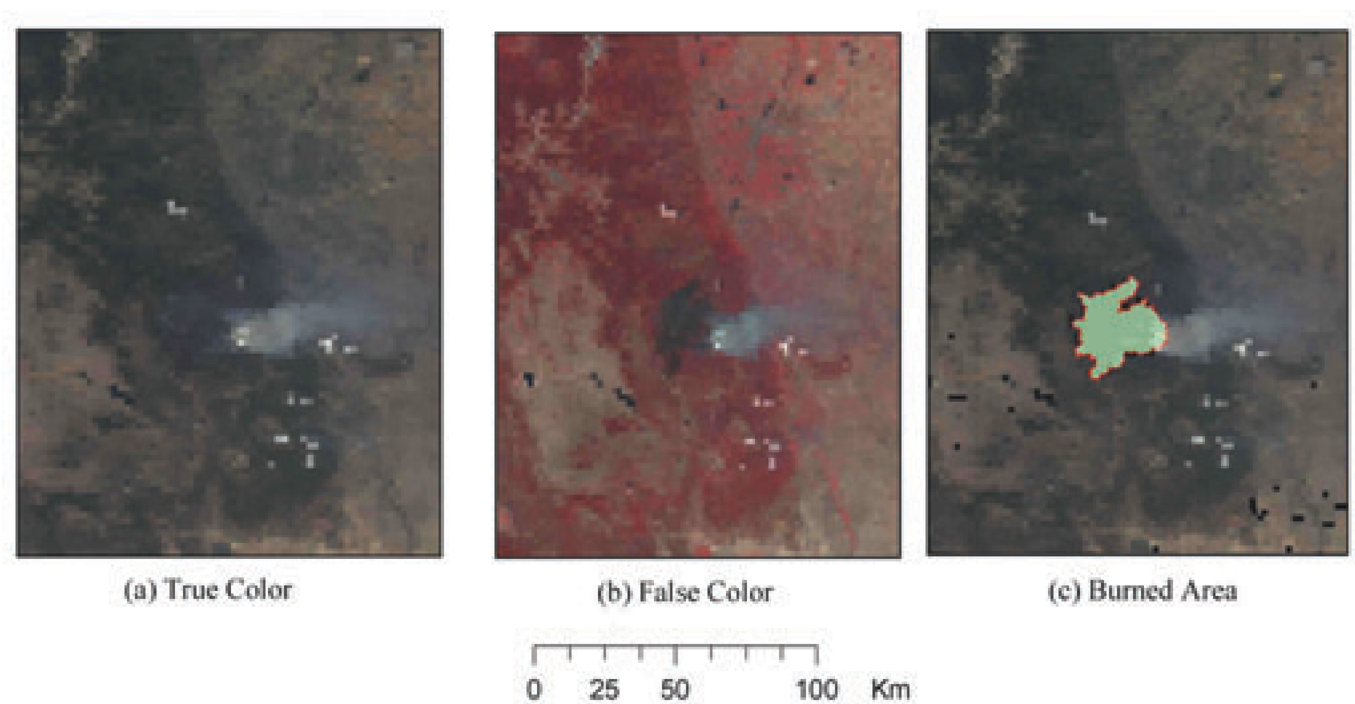

Figure 107—The satellite (Terra MODIS) images of the Hayman Fire in Colorado, on June 19, 2002: (a) visible band image; (b) near infrared band image; and (c) NIR band image with Forest Service burned area perimeter overlaid.

Figure 108 shows the CO concentrations at about 11,000 to 20,000 feet above sea level corresponding to approximately the height of the smoke plume. The missing CO concentrations in the MOPITT data set were interpolated, but CO concentrations were not interpolated over areas where data for the entire swath were missing. The spatial distribution of CO concentrations is similar to the plume pattern as shown in figure 107a. Carbon monoxide concentrations were above 150 parts per billion (ppb) in the center of the plume and dissipated to 100 to 125 ppb several miles downwind from the plume.

Daily Emissions

The amount of CO and PM2.5 (particles less than 2.5 μm), two major pollutants, emitted daily by the Hayman Fire were quantified. The burned areas used in the computation are based on MODIS images (fig. 107). Information on the amount of fuels burned, the combustion efficiency of each fuel type, and the emission factors of CO and PM2.5 was based on results of field experiments conducted by the Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT. The amount of CO and PM2.5 emitted daily is shown in figure 109. The majority of CO and PM2.5 was emitted during the period of June 9 through 13 and June 18 through 21 when most acres were burned. About 60 percent of the total emissions occurred during the first period, and about 31 percent occurred during the second period. Overall, approximately 2.3 x 10^5 tons of carbon monoxide and 2.9 x 10^4 tons of PM2.5 were emitted by the Hayman Fire. Approximately 4.3 x 10^4 tons of CO and 1.4 x 10^4 tons of PM2.5 were emitted by industrial sources in Colorado in 1999 (EPA 2003). Hence, the amount of CO emitted by the Hayman Fire is at least five times of the annual production of CO by industrial sources in Colorado. The amount of particles less than 2.5 μm emitted by the Hayman Fire is about twice of that produced by industries in Colorado.

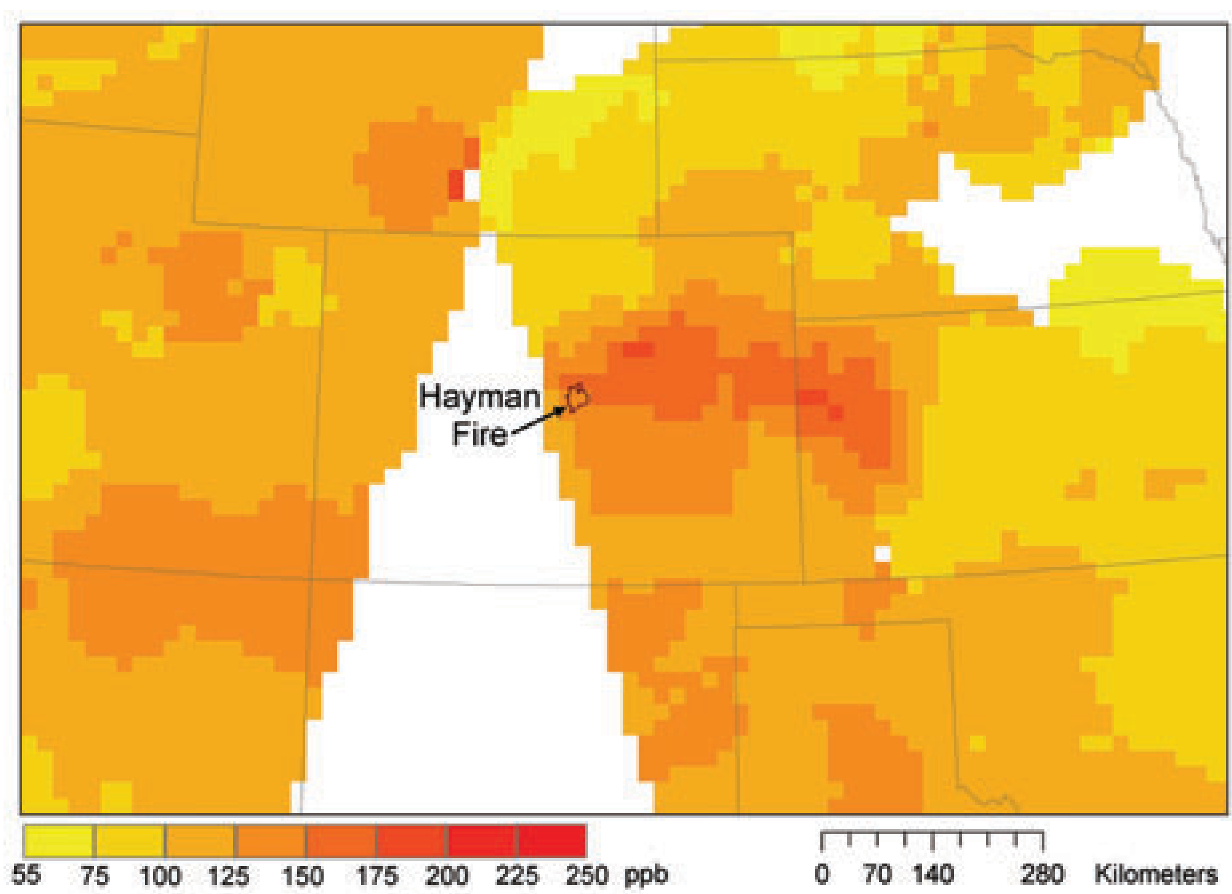

Figure 108—Carbon monoxide concentrations at about 11,000 to 20,000 feet above sea level corresponding to approximately the height of the smoke plume in the Central and Western United States on June 19, 2002.

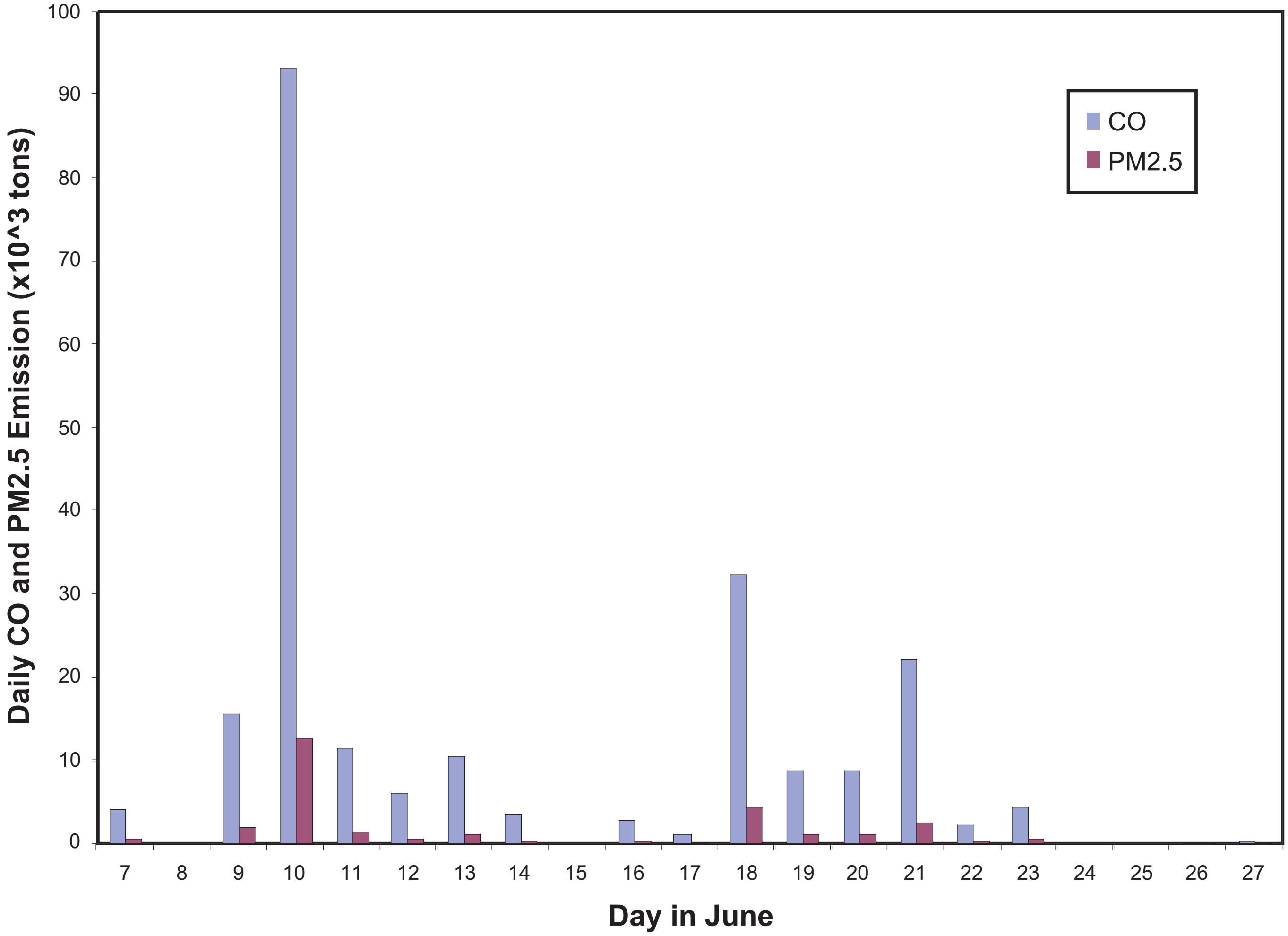

Figure 109—Daily emissions of CO and PM2.5 from the Hayman Fire from June 7 to June 27, 2002.

References

Crutzen, P.J.; Andreae, M.O. 1990. Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles. Science 250: 1669-1678.

Environmental Protection Agency (EPA). 2003. AirData: access to air pollution data. http://www.epa.gov/air/data.

Hao W.M.; Ward, D.E.; Olbu, G.; Baker, S.P. 1996. Emissions of CO_2, CO, and hydrocarbons from fires in diverse African savanna ecosystems. J Geophys Res 101:D19, 23577-23584.

Li R.-R.; Kaufman, Y.J.; Hao, W.M.; Salmon, J.M.; Nordgren, B.M. 2003. Remote sensing of burn scars using MODIS near-IR channels. IEEE Trans Geosci Remote Sens submitted.

Appendix A: Weather Data

Data from the Cheesman and Lake George NFDRS Stations are transmitted via satellite at 53 minutes after the hour. Averaged weather readings (temperature, humidity, wind speed, and direction) are for the 10 minutes prior to that (from 43 to 53 minutes after the hour). Wind gusts data are maximum values at any time during the hour, and rain is totaled for the hour. Dew points were computed from temperature and relative humidity. Table rows are displayed to the nearest hour in Mountain Daylight Time (MDT) for ease of reading.

Data from the Manitou Station were recorded on a data logger, and all values are hour averages. The wind sensor at Manitou is on a short mast. No wind gust information was recorded. Dew points were computed from temperature and relative humidity.

Hourly weather observations from Cheesman RAWS from June 8 to June 22.

				10-min avg. wind		Max gust during hour		
Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	Speed mph	Direct deg.	Speed mph	Direct deg.	Rain inches
0608 0000	59	37	44	10	42	23	46	
0608 0100	56	37	48	6	52	14	27	
0608 0200	52	36	55	1	45	12	58	
0608 0300	51	36	57	4	146	6	152	
0608 0400	49	36	61	1	33	6	175	
0608 0500	48	36	63	2	223	6	200	
0608 0600	48	36	62	2	217	6	177	
0608 0700	53	34	49	2	206	8	194	
0608 0800	64	31	29	2	292	5	178	
0608 0900	72	22	15	10	207	20	199	
0608 1000	77	16	10	12	210	21	228	
0608 1100	79	15	9	16	213	34	229	
0608 1200	82	12	7	17	238	37	197	
0608 1300	83	13	7	17	224	36	223	
0608 1400	86	11	6	16	235	34	196	
0608 1500	83	16	8	13	209	29	219	
0608 1600	84	13	7	14	217	30	215	
0608 1700	86	11	6	14	211	32	192	
0608 1800	82	9	6	17	191	36	220	
0608 1900	81	8	6	13	199	36	190	
0608 2000	80	10	7	13	196	34	188	
0608 2100	77	8	7	13	189	26	179	
0608 2200	76	11	8	10	203	23	164	
0608 2300	74	12	9	8	202	16	195	
0609 0000	72	13	10	7	209	15	205	
0609 0100	73	13	10	10	169	19	222	
0609 0200	72	15	11	6	172	24	217	
0609 0300	71	14	11	10	196	22	198	
0609 0400	69	14	12	7	127	14	183	
0609 0500	70	13	11	8	207	18	197	
0609 0600	69	14	12	9	183	22	183	
0609 0700	70	15	12	10	198	21	175	
0609 0800	73	13	10	13	203	23	194	
0609 0900	76	11	8	17	226	40	227	
0609 1000	75	10	8	24	245	51	198	
0609 1100	77	11	8	15	241	37	246	
0609 1200	77	11	8	15	237	29	203	
0609 1300	78	12	8	14	223	30	225	
0609 1400	79	10	7	10	224	33	219	
0609 1500	81	8	6	10	206	29	269	
0609 1600	85	7	5	16	224	29	233	
0609 1700	84	6	5	13	201	34	201	
0609 1800	84	10	6	15	233	44	229	

Hourly weather observations from Cheesman RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0609 1900	96	14	5	30	183	84	199	0.01
0609 2000	85	7	5	21	143	47	331	
0609 2100	81	4	5	17	146	37	131	
0609 2200	78	6	6	15	154	31	125	
0609 2300	76	4	6	16	153	28	156	
0610 0000	75	7	7	13	158	31	172	
0610 0100	73	8	8	14	157	27	173	
0610 0200	71	7	8	11	152	24	171	
0610 0300	70	3	7	11	151	18	163	
0610 0400	68	5	8	9	145	19	171	
0610 0500	65	5	9	11	142	19	171	
0610 0600	64	6	10	8	126	16	108	
0610 0700	65	7	10	7	129	15	132	
0610 0800	68	5	8	11	187	21	193	
0610 0900	72	1	6	11	173	23	177	
0610 1000	74	-1	5	13	164	24	184	
0610 1100	76	0	5	10	159	25	211	
0610 1200	77	1	5	14	250	24	236	
0610 1300	79	2	5	17	232	34	196	
0610 1400	69	25	19	18	34	34	272	
0610 1500	66	29	25	14	20	30	34	
0610 1600	66	26	22	12	31	27	48	
0610 1700	64	28	25	13	33	24	270	
0610 1800	62	30	30	11	32	23	33	
0610 1900	61	30	31	13	36	24	43	
0610 2000	60	30	32	8	41	20	42	
0610 2100	59	31	34	5	45	11	36	
0610 2200	58	31	35	5	46	10	53	
0610 2300	56	31	38	7	32	9	38	
0611 0000	53	31	42	3	42	8	51	
0611 0100	52	31	44	1	75	5	0	
0611 0200	50	32	49	1	304	2	263	
0611 0300	48	32	53	1	69	3	85	
0611 0400	47	32	55	2	155	3	174	
0611 0500	48	31	52	1	126	3	58	
0611 0600	46	32	57	1	35	4	52	
0611 0700	45	32	61	1	327	5	20	
0611 0800	47	34	60	1	202	3	306	
0611 0900	54	33	45	1	190	3	226	
0611 1000	61	33	35	5	31	11	34	
0611 1100	65	34	31	9	5	17	15	
0611 1200	70	35	27	10	12	22	33	
0611 1300	66	35	31	13	29	25	41	
0611 1400	69	35	29	11	12	22	13	
0611 1500	72	34	25	10	9	23	38	
0611 1600	72	32	23	10	25	22	27	
0611 1700	70	35	27	11	31	23	39	
0611 1800	69	36	30	10	26	20	22	
0611 1900	68	36	31	10	32	21	25	
0611 2000	66	37	34	8	35	18	41	
0611 2100	65	36	34	9	44	15	39	
0611 2200	63	36	36	5	50	13	38	
0611 2300	61	36	39	2	73	7	52	
0612 0000	58	36	43	0	231	4	63	
0612 0100	56	37	48	0	149	3	103	
0612 0200	57	37	47	3	164	6	144	

Hourly weather observations from Cheesman RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0612 0300	54	37	53	3	240	5	163	
0612 0400	51	38	60	1	267	3	176	
0612 0500	50	39	66	1	269	2	24	
0612 0600	46	39	76	2	166	5	33	
0612 0700	48	40	74	2	168	6	163	
0612 0800	55	38	53	0	227	1	155	
0612 0900	58	37	45	1	276	3	276	
0612 1000	64	37	37	4	354	7	19	
0612 1100	73	33	23	5	339	9	341	
0612 1200	77	11	8	8	219	15	227	
0612 1300	78	19	11	10	33	25	228	
0612 1400	75	31	20	11	40	25	38	
0612 1500	74	34	23	12	63	24	81	
0612 1600	74	32	21	8	61	21	31	
0612 1700	74	29	19	5	41	18	28	
0612 1800	75	35	23	7	31	16	16	
0612 1900	74	35	24	8	24	16	39	
0612 2000	70	36	29	9	47	19	43	
0612 2100	66	39	37	6	81	13	50	
0612 2200	63	40	43	0	197	8	81	
0612 2300	61	40	46	2	56	3	62	
0613 0000	59	40	49	2	103	4	49	
0613 0100	59	38	46	6	34	9	31	
0613 0200	57	24	28	14	32	24	51	
0613 0300	53	24	32	11	39	24	48	
0613 0400	51	25	36	6	55	17	45	
0613 0500	49	25	39	3	45	9	43	
0613 0600	47	27	45	1	235	6	29	
0613 0700	51	28	40	0	62	2	85	
0613 0800	56	29	35	2	264	3	14	
0613 0900	58	28	31	4	351	7	315	
0613 1000	61	28	28	10	19	15	286	
0613 1100	61	32	33	13	29	21	39	
0613 1200	62	35	36	14	22	25	38	
0613 1300	65	37	35	15	21	24	24	
0613 1400	66	36	33	15	16	27	26	
0613 1500	67	37	33	13	12	28	11	
0613 1600	65	35	33	12	17	24	11	
0613 1700	67	36	32	12	12	24	15	
0613 1800	64	36	35	10	39	24	32	
0613 1900	63	35	35	8	33	20	31	
0613 2000	61	35	37	8	28	14	31	
0613 2100	60	34	37	5	38	15	60	
0613 2200	59	31	35	7	30	14	35	
0613 2300	58	32	37	7	39	14	48	
0614 0000	55	31	40	6	32	16	67	
0614 0100	52	31	44	5	40	11	33	
0614 0200	52	31	45	7	53	12	32	
0614 0300	49	31	50	1	124	10	80	
0614 0400	48	32	53	2	105	4	114	
0614 0500	47	33	57	2	118	3	106	
0614 0600	45	32	61	1	249	4	128	
0614 0700	47	33	59	0	358	2	50	
0614 0800	53	33	46	2	13	3	315	
0614 0900	60	34	37	3	359	6	358	
0614 1000	64	36	35	12	176	20	211	

Hourly weather observations from Cheesman RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0614 1100	68	35	29	12	201	20	179	
0614 1200	74	30	20	8	105	22	179	
0614 1300	74	32	21	9	45	16	144	
0614 1400	70	36	29	12	52	22	16	
0614 1500	70	40	33	8	69	23	36	
0614 1600	71	37	29	8	42	13	38	
0614 1700	69	31	24	8	42	29	42	
0614 1800	74	29	19	3	202	14	61	
0614 1900	72	23	16	9	35	13	37	
0614 2000	69	27	21	7	37	12	318	
0614 2100	65	34	32	6	34	10	43	
0614 2200	61	40	45	7	122	13	124	
0614 2300	59	41	52	6	152	13	158	
0615 0000	58	40	51	5	119	12	151	
0615 0100	59	42	53	6	181	9	190	
0615 0200	59	42	53	7	142	15	166	
0615 0300	57	40	52	1	168	11	146	
0615 0400	55	42	61	1	145	5	161	
0615 0500	54	41	61	3	162	5	142	
0615 0600	51	39	64	1	87	8	136	
0615 0700	56	40	54	2	210	6	189	
0615 0800	64	41	43	1	203	3	27	
0615 0900	71	40	32	1	159	4	249	
0615 1000	74	34	23	4	161	8	201	
0615 1100	77	11	8	7	190	14	179	
0615 1200	67	21	17	19	32	36	43	
0615 1300	69	25	19	14	36	28	35	
0615 1400	68	33	27	17	41	30	46	
0615 1500	70	27	20	14	35	25	39	
0615 1600	69	24	18	11	30	23	26	
0615 1700	70	26	19	11	7	28	47	
0615 1800	70	28	21	9	35	20	54	
0615 1900	65	30	27	9	35	23	37	
0615 2000	63	33	32	7	53	21	38	
0615 2100	62	33	33	6	30	9	34	
0615 2200	60	32	34	4	207	12	42	
0615 2300	59	33	37	3	90	13	63	
0616 0000	58	33	39	4	123	6	122	
0616 0100	56	37	48	1	138	9	163	
0616 0200	53	42	67	4	138	5	108	
0616 0300	53	43	68	4	133	10	155	
0616 0400	53	42	67	7	163	13	188	
0616 0500	52	41	67	8	152	16	179	
0616 0600	52	41	65	4	148	12	147	
0616 0700	58	42	55	0	296	6	158	
0616 0800	61	39	44	3	212	8	205	
0616 0900	70	36	29	2	221	6	233	
0616 1000	76	33	21	3	255	6	207	
0616 1100	77	21	12	4	122	12	83	
0616 1200	74	28	18	14	18	22	233	
0616 1300	75	26	16	13	31	26	36	
0616 1400	75	27	17	10	25	21	51	
0616 1500	72	28	19	11	36	23	235	
0616 1600	72	29	20	16	35	26	47	
0616 1700	73	28	19	5	284	28	43	
0616 1800	72	28	19	8	17	16	18	

Hourly weather observations from Cheesman RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0616 1900	68	28	22	10	46	23	39	
0616 2000	69	27	21	4	116	14	28	
0616 2100	64	31	29	4	122	7	155	
0616 2200	61	31	32	3	28	7	127	
0616 2300	59	31	34	5	140	8	132	
0617 0000	59	31	34	5	145	7	161	
0617 0100	59	31	35	5	146	10	185	
0617 0200	60	32	34	8	149	13	157	
0617 0300	60	32	34	10	155	15	154	
0617 0400								
0617 0500								
0617 0600								
0617 0700	59	31	35	1	180	3	166	
0617 0800	66	31	27	2	208	5	188	
0617 0900	73	31	21	2	209	4	213	
0617 1000	81	27	14	2	194	7	300	
0617 1100	83	9	6	7	290	20	241	
0617 1200	82	5	5	12	251	26	289	
0617 1300	84	6	5	9	256	26	291	
0617 1400	83	5	5	7	30	27	249	
0617 1500	85	7	5	8	325	29	315	
0617 1600	85	7	5	10	337	19	13	
0617 1700	88	9	5	8	259	25	344	
0617 1800	88	9	5	6	246	22	251	
0617 1900	86	7	5	7	262	19	255	
0617 2000	83	5	5	7	295	21	269	
0617 2100	76	0	5	4	10	11	295	
0617 2200	73	-2	5	2	44	7	299	
0617 2300	72	-3	5	1	275	6	70	
0618 0000	67	1	7	2	164	3	254	
0618 0100	64	2	8	2	195	7	175	
0618 0200	61	4	10	2	167	5	220	
0618 0300	59	7	12	1	113	5	89	
0618 0400	57	5	12	1	209	6	197	
0618 0500	56	6	13	2	198	7	152	
0618 0600	54	7	15	1	127	5	156	
0618 0700	56	8	14	1	323	7	156	
0618 0800	64	6	10	2	208	6	207	
0618 0900	74	3	6	3	224	6	216	
0618 1000	81	4	5	9	220	15	218	
0618 1100	83	5	5	6	313	18	224	
0618 1200	84	6	5	15	259	33	259	
0618 1300	84	6	5	14	219	27	231	
0618 1400	87	8	5	10	237	28	235	
0618 1500	85	7	5	8	223	24	251	
0618 1600	87	8	5	16	237	32	186	
0618 1700	87	8	5	5	197	27	228	
0618 1800	88	9	5	13	269	27	243	
0618 1900	85	7	5	10	230	27	262	
0618 2000	83	5	5	12	180	21	163	
0618 2100	81	4	5	9	177	30	179	
0618 2200	78	2	5	4	134	18	179	
0618 2300	75	0	5	4	192	18	130	
0619 0000	73	5	7	2	126	11	120	
0619 0100	70	3	7	4	180	7	207	
0619 0200	67	6	9	3	170	7	179	

Hourly weather observations from Cheesman RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0619 0300	62	7	11	1	264	5	175	
0619 0400	59	7	12	3	199	7	179	
0619 0500	57	7	13	0	110	5	144	
0619 0600	55	7	14	0	166	4	138	
0619 0700	57	8	14	0	185	3	171	
0619 0800	60	7	12	1	268	4	128	
0619 0900	65	7	10	3	216	4	261	
0619 1000	75	10	8	2	248	4	28	
0619 1100	76	20	12	6	311	10	253	
0619 1200	80	16	9	8	26	14	10	
0619 1300	79	24	13	14	42	23	39	
0619 1400	80	27	14	12	61	27	66	
0619 1500	81	24	12	9	65	21	61	
0619 1600	79	24	13	11	40	23	51	
0619 1700	78	23	13	11	45	22	45	
0619 1800	76	27	16	10	25	20	20	
0619 1900	75	30	19	12	26	21	29	
0619 2000	73	31	21	6	36	23	26	
0619 2100	63	38	40	13	49	33	31	
0619 2200	60	41	49	9	36	22	38	
0619 2300	59	40	50	11	37	20	44	
0620 0000	58	41	53	8	25	22	39	
0620 0100	56	42	59	5	38	15	50	
0620 0200	55	44	67	3	173	13	57	
0620 0300	55	45	69	1	353	4	244	
0620 0400	55	45	68	1	286	2	173	
0620 0500	55	44	67	2	122	4	52	
0620 0600	56	42	60	2	176	5	173	
0620 0700	58	43	58	3	152	6	170	
0620 0800	61	42	50	7	168	12	193	
0620 0900	64	43	46	11	165	22	152	
0620 1000	65	41	42	14	179	24	200	
0620 1100	66	41	40	12	170	24	172	
0620 1200	68	41	37	14	184	26	156	
0620 1300	71	40	32	12	172	24	179	
0620 1400	76	38	25	10	215	23	220	
0620 1500	82	28	14	12	222	23	209	
0620 1600	79	20	11	11	236	31	229	
0620 1700	74	26	17	6	341	20	248	
0620 1800	65	39	38	8	58	34	291	
0620 1900	67	43	42	1	338	7	39	
0620 2000	67	37	33	2	164	4	124	
0620 2100	65	45	48	2	303	16	152	
0620 2200	60	46	59	7	38	13	46	
0620 2300	58	48	69	4	49	15	90	
0621 0000	59	45	60	7	46	11	43	
0621 0100	59	46	62	6	153	10	35	
0621 0200	60	40	47	2	130	28	257	
0621 0300	58	42	55	5	207	14	152	
0621 0400	59	38	45	3	201	14	198	
0621 0500	62	35	37	7	215	13	187	
0621 0600	64	34	33	7	222	15	192	
0621 0700	65	35	33	11	201	20	206	
0621 0800	68	36	31	5	131	24	199	
0621 0900	72	33	24	6	207	12	206	

Hourly weather observations from Cheesman RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0621 1000	74	34	23	10	223	18	210	
0621 1100	78	30	17	12	231	19	229	
0621 1200	82	24	12	8	271	18	221	
0621 1300	85	20	9	9	206	20	241	
0621 1400	88	19	8	3	332	18	221	
0621 1500	82	18	9	8	8	14	236	
0621 1600	79	22	12	5	24	17	205	
0621 1700								
0621 1800	77	30	18	11	91	21	105	
0621 1900	69	39	34	7	25	21	23	
0621 2000	68	42	39	9	34	13	38	
0621 2100	66	42	42	6	305	14	26	
0621 2200	58	45	63	6	200	25	275	
0621 2300	58	46	64	1	143	9	62	
0622 0000	56	46	68	1	211	9	179	
0622 0100	58	45	61	3	200	9	168	
0622 0200	57	45	65	3	178	7	172	
0622 0300	57	45	63	1	178	5	209	
0622 0400	60	42	51	4	159	12	167	
0622 0500	62	40	44	8	218	20	208	
0622 0600	63	39	41	13	222	25	221	
0622 0700	62	39	42	10	185	26	209	
0622 0800	63	41	44	4	127	11	203	
0622 0900	65	39	38	12	221	20	227	
0622 1000	70	38	31	19	218	32	210	
0622 1100	75	39	27	9	255	31	224	
0622 1200	79	32	18	13	229	27	252	
0622 1300	79	32	18	10	266	28	214	
0622 1400	79	31	17	12	223	27	237	
0622 1500	81	29	15	10	223	26	225	
0622 1600	83	31	15	9	212	25	245	
0622 1700	85	27	12	9	280	28	252	
0622 1800	84	26	12	12	221	32	224	
0622 1900	82	24	12	10	238	26	239	
0622 2000	81	22	11	7	212	17	217	
0622 2100	77	19	11	6	210	15	201	
0622 2200	74	20	13	6	189	9	198	
0622 2300	70	22	16	1	27	7	179	

Hourly weather observations from Lake George RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0608 0000	50	20	30	6	132	10	146	
0608 0100	48	22	35	4	124	7	136	
0608 0200	44	23	43	3	134	6	138	
0608 0300	41	27	57	3	140	7	137	
0608 0400	39	30	70	3	122	6	139	
0608 0500	36	30	78	3	141	5	138	
0608 0600	35	30	83	1	127	6	150	
0608 0700	37	32	83	0	140	6	168	
0608 0800	55	38	52	2	143	6	106	
0608 0900	73	36	26	1	80	5	137	
0608 1000	77	22	13	8	248	19	237	
0608 1100	80	21	11	10	243	28	214	
0608 1200	81	17	9	16	198	36	192	
0608 1300	81	19	10	13	218	32	221	
0608 1400	83	21	10	16	179	32	90	
0608 1500	82	20	10	14	195	33	176	
0608 1600	84	19	9	18	167	36	179	
0608 1700	84	16	8	17	177	36	212	
0608 1800	83	16	8	15	163	33	197	
0608 1900	81	17	9	18	161	33	174	
0608 2000	78	15	9	15	160	31	163	
0608 2100	74	16	11	12	156	24	98	
0608 2200	72	17	12	8	158	19	181	
0608 2300	66	16	14	2	149	13	164	
0609 0000	68	17	14	3	179	11	171	
0609 0100	69	18	14	8	152	16	177	
0609 0200	68	19	15	7	139	13	134	
0609 0300	67	18	15	5	150	14	181	
0609 0400	67	18	15	8	149	16	173	
0609 0500	66	19	16	8	156	15	160	
0609 0600	60	18	19	6	125	18	195	
0609 0700	60	21	22	5	140	12	120	
0609 0800	73	19	13	7	174	11	144	
0609 0900	74	16	11	17	179	38	189	
0609 1000	77	19	11	14	219	35	227	
0609 1100	79	18	10	10	242	32	185	
0609 1200	81	19	10	11	194	28	232	
0609 1300	82	18	9	10	238	26	229	
0609 1400	83	18	9	12	209	28	71	
0609 1500	85	14	7	14	169	28	179	
0609 1600	87	16	7	13	177	24	198	
0609 1700	86	18	8	10	199	27	175	
0609 1800	84	19	9	14	198	27	124	
0609 1900	82	15	8	16	193	32	178	
0609 2000	78	17	10	14	177	30	180	
0609 2100	73	15	11	11	170	24	180	
0609 2200	70	15	12	6	144	14	163	
0609 2300	68	15	13	5	141	13	156	
0610 0000	65	16	15	4	122	10	105	
0610 0100	65	16	15	4	158	11	132	
0610 0200	57	16	20	2	192	5	276	
0610 0300	52	16	24	0	140	4	178	
0610 0400	52	16	24	3	86	5	130	
0610 0500	47	15	27	1	221	5	119	
0610 0600	45	15	30	4	140	7	168	
0610 0700	48	17	29	2	106	5	241	

Hourly weather observations from Lake George RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0610 0800	69	16	13	2	94	5	75	
0610 0900	71	12	10	12	179	24	186	
0610 1000	73	13	10	11	183	24	189	
0610 1100	76	13	9	12	210	32	182	
0610 1200	77	14	9	9	222	31	186	
0610 1300	79	13	8	7	269	29	161	
0610 1400	79	18	10	15	169	32	183	
0610 1500	79	22	12	16	192	30	165	
0610 1600	78	25	14	17	151	32	168	
0610 1700	73	28	19	11	1	28	182	
0610 1800	63	32	31	14	23	31	17	
0610 1900	61	33	35	5	36	23	39	
0610 2000	59	33	38	5	23	15	33	
0610 2100	58	33	39	5	0	14	18	
0610 2200	57	33	40	2	348	9	39	
0610 2300	54	32	43	1	13	5	36	
0611 0000	49	31	50	0	45	5	22	
0611 0100	44	29	56	3	141	5	135	
0611 0200	41	29	62	3	133	4	130	
0611 0300	39	29	67	1	144	7	132	
0611 0400	36	28	72	2	133	6	125	
0611 0500	34	27	75	0	154	5	171	
0611 0600	32	27	81	1	154	2	154	
0611 0700	36	30	78	1	153	3	152	
0611 0800	52	34	50	1	143	5	134	
0611 0900	66	39	37	1	310	4	300	
0611 1000	71	29	21	4	139	13	140	
0611 1100	74	18	12	8	266	23	156	
0611 1200	76	16	10	10	203	21	229	
0611 1300	78	12	8	12	239	24	218	
0611 1400	80	10	7	12	287	26	308	
0611 1500	82	9	6	9	283	32	322	
0611 1600	83	13	7	13	312	25	301	
0611 1700	78	34	20	5	72	24	355	
0611 1800	72	33	24	9	5	19	10	
0611 1900	69	39	33	6	29	18	1	
0611 2000	66	40	38	8	13	16	0	
0611 2100	64	40	41	1	45	14	1	
0611 2200	61	39	44	0	0	4	26	
0611 2300	58	38	47	2	210	4	125	
0612 0000	53	46	78	2	310	7	119	
0612 0100	51	50	95	1	340	3	338	
0612 0200	47	46	95	0	340	2	340	
0612 0300	43	43	99	0	340	2	341	
0612 0400	41	41	100	1	129	5	128	
0612 0500	39	39	100	1	117	4	129	
0612 0600	37	37	100	2	118	3	117	
0612 0700	39	39	100	1	30	3	122	
0612 0800	50	39	67	0	336	4	348	
0612 0900	62	44	52	7	161	11	160	0.01
0612 1000	69	42	37	6	150	15	176	
0612 1100	73	15	11	8	231	31	276	
0612 1200	76	13	9	9	287	25	315	
0612 1300	78	9	7	9	285	23	277	
0612 1400	80	3	5	10	284	24	290	
0612 1500	82	0	4	10	269	24	268	

Hourly weather observations from Lake George RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0612 1600	75	37	25	8	46	24	343	
0612 1700	73	38	28	7	28	20	26	
0612 1800	73	35	25	6	7	15	119	
0612 1900	71	38	30	10	7	19	0	
0612 2000	68	40	36	6	90	19	17	
0612 2100	65	43	45	5	76	16	87	
0612 2200	62	43	49	1	160	11	65	
0612 2300	60	43	53	0	85	3	110	
0613 0000	57	41	56	1	135	4	142	
0613 0100	56	42	59	1	167	5	203	
0613 0200	58	36	43	8	22	18	22	
0613 0300	54	28	36	3	59	16	43	
0613 0400	49	27	42	2	15	14	44	
0613 0500	47	27	46	0	140	6	337	
0613 0600	42	27	54	0	140	2	140	
0613 0700	44	29	56	2	42	3	53	
0613 0800	52	30	42	4	131	7	134	
0613 0900	61	33	35	5	125	9	137	
0613 1000	69	30	23	7	190	16	186	
0613 1100	74	20	13	8	306	21	348	
0613 1200	73	24	16	9	1	19	19	
0613 1300	74	29	19	11	8	18	15	
0613 1400	74	34	23	8	27	23	18	
0613 1500	69	40	35	6	52	18	11	
0613 1600	70	41	35	8	24	23	16	
0613 1700	68	40	36	9	22	18	0	
0613 1800	66	40	39	5	95	16	0	
0613 1900	63	40	43	6	29	13	90	
0613 2000	60	40	47	3	82	11	108	
0613 2100	57	38	49	2	67	12	105	
0613 2200	56	39	53	4	90	8	91	
0613 2300	55	39	55	2	99	6	76	
0614 0000	54	36	51	3	39	11	24	
0614 0100								
0614 0200	50	34	54	1	1	11	30	
0614 0300	45	34	65	2	126	7	133	
0614 0400	42	33	70	3	131	5	131	
0614 0500	41	33	72	3	141	8	169	
0614 0600	41	33	73	1	214	5	164	
0614 0700	43	34	70	0	271	3	270	
0614 0800	52	36	55	4	157	9	135	
0614 0900	58	43	58	8	222	13	228	
0614 1000	63	42	46	6	196	14	206	
0614 1100	67	42	40	8	148	16	215	
0614 1200	71	43	36	9	137	20	171	
0614 1300	70	42	36	12	133	24	173	
0614 1400	71	42	35	13	163	28	186	
0614 1500	73	44	35	7	147	20	82	
0614 1600	70	44	39	7	128	19	178	
0614 1700	69	42	37	8	29	14	22	
0614 1800	67	43	41	6	127	16	42	
0614 1900	68	42	39	6	164	11	138	
0614 2000	66	39	37	2	127	10	162	
0614 2100	63	42	47	6	160	14	186	
0614 2200	60	41	50	5	137	15	177	
0614 2300	57	42	57	3	138	9	153	

Hourly weather observations from Lake George RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0615 0000	53	43	68	4	110	7	138	
0615 0100	50	42	75	3	133	7	128	
0615 0200	46	40	80	0	108	5	122	
0615 0300	44	40	85	1	137	5	173	
0615 0400	42	39	90	3	124	7	147	
0615 0500	40	38	93	2	134	6	128	
0615 0600	38	37	97	1	127	5	133	
0615 0700	41	40	98	0	126	6	139	
0615 0800	58	45	63	2	170	6	132	
0615 0900	67	44	44	5	143	8	125	
0615 1000	74	40	29	3	29	8	173	
0615 1100	77	32	19	3	112	8	343	
0615 1200	79	20	11	10	309	21	332	
0615 1300	72	28	19	4	247	31	22	
0615 1400	71	29	21	12	24	28	25	
0615 1500	70	35	27	10	22	26	33	
0615 1600	68	29	23	3	136	26	331	
0615 1700	70	29	22	6	26	14	36	
0615 1800	69	32	25	9	26	19	347	
0615 1900	66	31	27	6	28	19	37	
0615 2000	62	35	36	5	105	17	16	
0615 2100	60	37	42	2	53	12	102	
0615 2200	57	36	45	3	173	5	110	
0615 2300	56	37	49	6	147	9	146	
0616 0000	53	44	72	5	135	15	154	
0616 0100	51	45	79	4	137	10	108	
0616 0200	47	43	86	2	134	6	136	
0616 0300	45	43	92	2	122	4	126	
0616 0400	42	41	97	2	140	5	147	
0616 0500	40	40	99	1	165	6	194	
0616 0600	38	38	100	0	157	2	157	
0616 0700	42	42	100	1	229	3	155	
0616 0800	56	43	62	7	178	12	177	
0616 0900	62	44	51	5	140	13	249	
0616 1000	70	42	36	4	191	12	183	
0616 1100	74	30	20	7	319	18	308	
0616 1200	76	28	17	7	211	18	299	
0616 1300	77	21	12	5	295	16	342	
0616 1400	74	32	21	7	29	18	298	
0616 1500	78	34	20	6	110	18	21	
0616 1600	76	32	20	10	347	18	14	
0616 1700	69	35	28	8	8	21	16	
0616 1800	71	27	19	6	342	21	330	
0616 1900	69	31	24	3	24	19	21	
0616 2000	67	32	27	5	83	13	338	
0616 2100	61	35	38	2	98	9	128	
0616 2200	54	34	46	1	87	4	87	
0616 2300	49	32	52	2	284	5	196	
0617 0000	47	32	56	2	92	6	303	
0617 0100	44	33	64	1	111	3	137	
0617 0200	41	32	69	0	136	2	133	
0617 0300	39	32	75	3	130	5	143	
0617 0400								
0617 0500								
0617 0600								
0617 0700	38	33	81	3	131	5	127	

Hourly weather observations from Lake George RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0617 0800	55	36	49	1	281	5	134	
0617 0900	67	36	32	2	141	6	159	
0617 1000	74	32	21	4	141	10	135	
0617 1100	79	18	10	8	308	14	307	
0617 1200	81	17	9	10	309	25	307	
0617 1300	82	15	8	10	310	22	319	
0617 1400	82	12	7	5	347	21	211	
0617 1500	85	7	5	13	303	28	311	
0617 1600	83	9	6	7	260	26	258	
0617 1700	81	11	7	6	270	28	205	
0617 1800	80	13	8	8	228	57	269	
0617 1900	84	13	7	9	304	21	210	
0617 2000	80	10	7	7	317	17	261	
0617 2100	70	9	9	1	343	13	349	
0617 2200	61	12	14	0	0	2	343	
0617 2300	53	12	19	3	153	7	113	
0618 0000	49	12	22	4	142	7	147	
0618 0100	45	12	26	2	137	4	117	
0618 0200	41	10	28	1	106	6	117	
0618 0300	39	11	31	3	151	6	135	
0618 0400	37	11	34	2	72	6	128	
0618 0500	35	11	36	2	129	6	135	
0618 0600	32	10	40	1	135	3	124	
0618 0700	36	12	37	1	125	3	126	
0618 0800	55	16	21	1	137	4	145	
0618 0900	68	19	15	1	342	4	290	
0618 1000								
0618 1100	81	4	5	7	292	18	286	
0618 1200	84	6	5	7	236	16	231	
0618 1300	85	2	4	9	265	24	233	
0618 1400	88	4	4	6	295	24	342	
0618 1500	88	4	4	11	274	27	316	
0618 1600	89	5	4	10	248	25	307	
0618 1700	87	3	4	11	207	22	124	
0618 1800	85	2	4	12	151	37	186	
0618 1900	83	5	5	11	141	26	168	
0618 2000	79	2	5	9	163	23	154	
0618 2100	77	8	7	11	147	28	152	
0618 2200	70	9	9	6	146	17	171	
0618 2300	60	11	14	2	140	7	127	
0619 0000	54	13	19	3	122	7	218	
0619 0100	49	15	25	5	129	7	143	
0619 0200	46	15	28	1	119	7	113	
0619 0300	41	13	32	1	118	6	115	
0619 0400	38	13	35	0	117	2	117	
0619 0500	36	12	37	2	115	3	117	
0619 0600	34	12	40	0	150	3	111	
0619 0700	36	12	37	2	134	3	147	
0619 0800	47	16	29	0	250	5	127	
0619 0900	59	17	19	0	287	2	251	
0619 1000	73	15	11	2	321	3	302	
0619 1100	84	1	4	4	130	11	215	
0619 1200	85	2	4	7	227	17	232	
0619 1300	86	2	4	6	305	21	332	
0619 1400	88	4	4	7	223	18	269	
0619 1500	81	31	16	11	1	24	86	

Hourly weather observations from Lake George RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0619 1600	80	25	13	7	83	24	348	
0619 1700	78	30	17	8	30	18	15	
0619 1800	77	30	18	5	60	21	15	
0619 1900	74	34	23	6	0	22	56	
0619 2000	71	35	27	7	337	14	15	
0619 2100	69	39	33	6	116	15	105	
0619 2200	61	43	52	8	17	22	8	
0619 2300	57	43	59	8	358	17	37	
0620 0000	56	44	63	5	11	21	335	
0620 0100								
0620 0200	54	44	69	1	342	10	332	
0620 0300	53	44	71	3	349	8	27	
0620 0400	53	43	70	0	123	5	7	
0620 0500	54	44	68	3	349	5	343	
0620 0600	53	43	69	0	330	4	7	
0620 0700	55	44	67	1	125	4	99	
0620 0800	59	46	62	7	179	16	173	
0620 0900	60	46	60	12	167	21	167	
0620 1000	61	47	59	9	171	19	195	
0620 1100	61	46	58	14	170	21	170	
0620 1200	64	45	50	10	178	19	183	
0620 1300	68	45	43	12	186	20	179	
0620 1400	74	45	35	10	154	20	171	
0620 1500	78	44	30	10	162	22	143	
0620 1600	77	42	29	13	169	22	174	
0620 1700	75	46	36	17	143	28	203	
0620 1800	73	41	32	10	344	30	22	
0620 1900	73	41	31	2	46	10	336	
0620 2000	67	45	45	10	140	19	177	
0620 2100	66	46	48	4	161	21	160	
0620 2200	61	47	60	1	167	14	187	0.01
0620 2300	61	45	55	6	161	13	150	
0621 0000	59	42	54	1	98	7	148	
0621 0100	59	48	68	2	339	6	25	
0621 0200	56	45	66	3	350	14	1	
0621 0300	50	43	77	2	96	4	89	
0621 0400	46	41	82	2	127	5	140	
0621 0500	44	41	88	4	127	7	110	
0621 0600	43	40	90	1	36	11	137	
0621 0700	48	43	82	2	108	5	120	
0621 0800	56	44	64	4	146	7	146	
0621 0900	66	43	44	3	221	9	137	
0621 1000	72	41	32	6	250	15	220	
0621 1100	76	37	24	8	304	18	262	
0621 1200	81	37	21	5	168	16	260	
0621 1300	84	35	17	6	310	13	282	
0621 1400	83	31	15	7	164	15	241	
0621 1500	79	31	17	6	359	28	132	
0621 1600	76	37	24	4	106	15	269	0.02
0621 1700								
0621 1800	78	35	21	12	164	22	179	
0621 1900	73	35	25	12	111	29	133	
0621 2000	71	31	23	3	50	41	173	
0621 2100	68	38	33	4	295	12	341	
0621 2200	59	45	59	10	334	22	171	
0621 2300	55	48	76	5	328	20	324	

Hourly weather observations from Lake George RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	Dew point °F	RH %	10-min avg. wind Speed mph	10-min avg. wind Direct deg.	Max gust during hour Speed mph	Max gust during hour Direct deg.	Rain inches
0622 0000	53	47	81	0	330	8	339	
0622 0100	51	47	86	2	0	3	357	
0622 0200	50	47	89	3	139	5	146	
0622 0300	53	47	80	2	129	4	138	
0622 0400	52	47	84	3	146	8	121	
0622 0500	54	46	74	4	126	8	141	
0622 0600	52	47	82	3	139	5	146	
0622 0700	52	46	80	4	126	8	127	
0622 0800	58	46	65	4	136	6	140	
0622 0900	62	45	53	5	210	8	215	
0622 1000	71	43	37	6	207	15	165	
0622 1100	75	43	32	7	153	22	176	
0622 1200	77	34	21	16	197	29	187	
0622 1300	77	35	22	9	195	23	206	
0622 1400	78	36	22	6	254	21	169	
0622 1500	78	36	22	6	235	20	196	
0622 1600	82	36	19	9	211	21	115	
0622 1700	82	31	16	10	213	22	206	
0622 1800	83	32	16	10	214	23	202	
0622 1900	80	30	16	7	202	24	217	
0622 2000	76	27	16	7	51	19	38	
0622 2100	68	25	20	0	117	10	62	
0622 2200	62	27	26	2	113	5	105	
0622 2300	58	28	31	4	136	10	125	
0623 0000	54	28	36	356	145	0	7	

Hourly weather observations from Manitou Experimental Forest RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	RH %	Dew point °F	Hour averaged wind Speed mph	Hour averaged wind Direct Deg.	Hour rain Inch
0608 0100	41	72	32	4	171	
0608 0200	39	81	34	5	179	
0608 0300	40	83	35	4	169	
0608 0400	37	90	34	3	175	
0608 0500	34	93	32	2	147	
0608 0600	36	92	34	2	154	
0608 0700	54	56	38	5	169	
0608 0800	72	17	25	9	201	
0608 0900	75	15	23	10	210	
0608 1000	77	13	23	12	199	
0608 1100	79	12	22	15	209	
0608 1200	80	11	20	13	221	
0608 1300	82	11	21	14	199	
0608 1400	82	11	23	16	194	
0608 1500	82	11	23	15	197	
0608 1600	83	11	22	16	191	
0608 1700	83	10	21	16	198	
0608 1800	82	10	20	16	194	
0608 1900	79	11	20	13	187	
0608 2000	75	12	19	10	175	
0608 2100	72	13	19	7	159	
0608 2200	64	19	22	5	183	
0608 2300	58	25	22	4	147	
0608 2400	59	24	23	3	162	
0609 0100	57	27	23	7	178	

Hourly weather observations from Manitou Experimental Forest RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	RH %	Dew point °F	Hour averaged wind Speed mph	Hour averaged wind Direct Deg.	Hour rain Inch
0609 0200	54	30	24	7	179	
0609 0300	53	31	24	8	184	
0609 0400	51	33	23	6	176	
0609 0500	53	32	24	6	174	
0609 0600	58	28	25	5	168	
0609 0700	70	17	23	7	192	
0609 0800	74	13	21	14	215	
0609 0900	77	12	20	13	228	
0609 1000	79	11	20	15	228	
0609 1100	80	10	19	16	234	
0609 1200	81	10	21	14	224	
0609 1300	83	10	21	13	226	
0609 1400	84	9	20	12	215	
0609 1500	86	8	18	13	183	
0609 1600	85	9	20	13	187	
0609 1700	85	10	21	14	198	
0609 1800	82	11	23	15	191	
0609 1900	78	12	21	15	183	
0609 2000	75	13	20	11	175	
0609 2100	72	13	19	9	171	
0609 2200	68	15	19	7	178	
0609 2300	66	17	20	5	178	
0609 2400	59	24	22	4	166	
0610 0100	52	32	23	5	172	
0610 0200	48	38	24	6	174	
0610 0300	46	41	23	6	178	
0610 0400	42	48	24	6	177	
0610 0500	39	53	23	6	181	
0610 0600	44	43	23	5	168	
0610 0700	60	24	23	6	185	
0610 0800	71	13	17	11	192	
0610 0900	73	12	17	14	192	
0610 1000	75	11	17	13	205	
0610 1100	76	11	17	14	210	
0610 1200	77	13	22	13	182	
0610 1300	76	18	29	11	148	
0610 1400	77	19	32	11	151	
0610 1500	75	21	32	11	169	
0610 1600	67	30	34	7	354	
0610 1700	64	36	36	5	331	
0610 1800	61	40	37	7	344	
0610 1900	59	43	36	5	356	
0610 2000	57	45	36	4	4	
0610 2100	54	49	35	2	80	
0610 2200	48	59	35	2	159	
0610 2300	43	70	34	4	182	
0610 2400	41	72	33	3	170	
0611 0100	38	77	32	4	170	
0611 0200	40	74	32	4	152	
0611 0300	36	82	31	2	168	
0611 0400	34	87	30	3	185	
0611 0500	32	91	29	2	173	
0611 0600	34	89	31	2	166	
0611 0700	48	66	37	2	167	
0611 0800	60	46	39	4	8	
0611 0900	64	38	38	6	7	

Hourly weather observations from Manitou Experimental Forest RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	RH %	Dew point °F	Hour averaged wind Speed mph	Hour averaged wind Direct Deg.	Hour rain Inch
0611 1000	66	34	37	6	2	
0611 1100	70	31	38	6	77	
0611 1200	69	32	37	6	100	
0611 1300	70	29	37	6	84	
0611 1400	72	29	37	7	106	
0611 1500	71	28	36	7	123	
0611 1600	71	26	35	5	99	
0611 1700	71	28	36	5	10	
0611 1800	70	31	38	4	4	
0611 1900	67	36	40	5	13	
0611 2000	63	45	41	4	5	
0611 2100	59	54	42	2	24	
0611 2200	53	62	40	3	156	
0611 2300	51	66	40	2	160	
0611 2400	48	90	45	3	118	0.03
0612 0100	46	96	45	2	175	
0612 0200	43	98	42	3	184	
0612 0300	42	98	41	4	172	
0612 0400	39	99	39	3	161	0.01
0612 0500	37	99	37	2	172	
0612 0600	39	99	38	3	167	
0612 0700	48	93	46	1	337	
0612 0800	56	77	49	2	356	
0612 0900	64	49	44	3	171	
0612 1000	69	25	31	5	265	
0612 1100	72	17	25	6	262	
0612 1200	75	10	15	10	250	
0612 1300	75	19	30	10	155	
0612 1400	72	32	40	7	81	
0612 1500	71	32	39	5	88	
0612 1600	72	30	39	5	98	
0612 1700	74	28	39	5	69	
0612 1800	69	36	41	7	54	
0612 1900	66	44	44	4	48	
0612 2000	62	53	45	3	279	
0612 2100	56	64	44	2	155	
0612 2200	53	72	44	2	156	
0612 2300	51	75	44	2	168	
0612 2400	51	95	49	4	178	0.03
0613 0100	50	96	48	2	49	
0613 0200	43	93	41	3	141	
0613 0300	40	95	38	2	140	
0613 0400	38	96	37	2	153	
0613 0500	36	97	36	2	154	
0613 0600	37	96	36	3	172	
0613 0700	44	83	39	3	186	
0613 0800	53	57	38	3	232	
0613 0900	62	43	39	3	30	
0613 1000	66	36	38	7	12	
0613 1100	67	34	38	7	5	
0613 1200	67	39	42	8	25	
0613 1300	66	43	43	7	49	
0613 1400	64	46	43	8	37	
0613 1500	64	47	43	6	59	
0613 1600	63	47	43	8	33	
0613 1700	63	48	43	6	52	

Hourly weather observations from Manitou Experimental Forest RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	RH %	Dew point °F	Hour averaged wind Speed mph	Hour averaged wind Direct Deg.	Hour rain Inch
0613 1800	60	51	42	5	48	
0613 1900	59	51	41	4	45	
0613 2000	57	55	42	3	55	
0613 2100	54	63	42	2	159	
0613 2200	51	67	41	2	103	
0613 2300	51	58	37	3	213	
0613 2400	46	71	37	2	145	
0614 0100	43	78	36	2	135	
0614 0200	38	88	35	3	178	
0614 0300	36	92	34	3	178	
0614 0400	35	95	34	3	180	
0614 0500	36	94	34	1	224	
0614 0600	38	91	35	1	159	
0614 0700	47	76	40	2	159	
0614 0800	57	60	44	7	183	
0614 0900	61	50	42	10	206	
0614 1000	65	41	41	7	215	
0614 1100	69	34	39	9	197	
0614 1200	71	30	38	7	170	
0614 1300	66	46	45	6	105	
0614 1400	65	54	48	8	141	
0614 1500	67	51	49	9	188	
0614 1600	66	50	47	7	126	
0614 1700	66	47	45	7	168	
0614 1800	65	50	47	8	173	
0614 1900	64	54	47	6	189	
0614 2000	59	64	47	6	175	
0614 2100	57	64	45	7	184	
0614 2200	50	88	47	6	172	
0614 2300	47	94	46	4	167	
0614 2400	46	96	44	3	167	
0615 0100	44	97	43	3	170	
0615 0200	42	97	42	3	146	
0615 0300	41	98	41	3	146	
0615 0400	39	98	39	4	172	
0615 0500	40	98	40	7	173	
0615 0600	43	96	42	7	178	
0615 0700	53	84	48	6	183	
0615 0800	64	53	47	5	174	
0615 0900	71	32	40	5	183	
0615 1000	75	16	26	5	326	
0615 1100	72	20	29	10	356	
0615 1200	68	24	30	7	15	
0615 1300	69	29	35	12	6	
0615 1400	68	30	36	11	29	
0615 1500	69	26	33	9	15	
0615 1600	70	24	32	8	12	
0615 1700	68	28	34	10	11	
0615 1800	65	37	38	9	29	
0615 1900	62	43	39	7	36	
0615 2000	60	42	37	4	84	
0615 2100	58	48	39	4	316	
0615 2200	56	61	43	5	149	
0615 2300	52	78	46	4	153	
0615 2400	47	85	43	2	155	
0616 0100	44	92	42	4	169	

Hourly weather observations from Manitou Experimental Forest RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	RH %	Dew point °F	Hour averaged wind Speed mph	Hour averaged wind Direct Deg.	Hour rain Inch
0616 0200	43	94	41	3	169	
0616 0300	41	97	41	4	181	
0616 0400	41	98	40	3	173	
0616 0500	40	98	40	2	176	
0616 0600	42	98	42	4	163	
0616 0700	54	75	46	5	160	
0616 0800	61	55	45	6	157	
0616 0900	67	37	40	5	147	
0616 1000	71	27	35	6	63	
0616 1100	72	26	35	8	35	
0616 1200	72	26	36	10	23	
0616 1300	73	25	35	7	42	
0616 1400	71	26	35	7	38	
0616 1500	70	27	35	8	26	
0616 1600	71	25	33	8	44	
0616 1700	71	23	31	5	234	
0616 1800	69	26	33	7	32	
0616 1900	65	32	35	5	137	
0616 2000	60	44	38	4	169	
0616 2100	51	60	38	4	170	
0616 2200	47	68	37	4	174	
0616 2300	47	70	38	4	169	
0616 2400	45	71	37	4	169	
0617 0100	42	78	35	2	147	
0617 0200	38	84	34	2	145	
0617 0300	37	88	34	4	167	
0617 0400	36	89	34	4	166	
0617 0500	36	91	33	4	174	
0617 0600	38	87	35	4	178	
0617 0700	53	60	40	2	162	
0617 0800	68	31	36	5	163	
0617 0900	74	21	31	6	204	
0617 1000	77	15	26	5	22	
0617 1100	78	11	20	8	289	
0617 1200	81	10	19	9	282	
0617 1300	81	9	18	7	306	
0617 1400	78	10	16	4	319	
0617 1500	75	11	18	3	134	
0617 1600	74	12	19	3	136	
0617 1700	76	12	19	4	156	
0617 1800	77	11	19	3	121	
0617 1900	74	13	20	5	185	
0617 2000	68	18	23	3	144	
0617 2100	59	27	25	4	153	
0617 2200	54	35	27	4	161	
0617 2300	48	42	26	4	179	
0617 2400	47	41	24	4	175	
0618 0100	46	41	24	3	157	
0618 0200	43	46	24	4	165	
0618 0300	44	40	21	4	161	
0618 0400	39	52	23	5	179	
0618 0500	42	42	20	6	173	
0618 0600	44	37	20	4	150	
0618 0700	55	29	24	2	168	
0618 0800	70	19	25	2	349	

Hourly weather observations from Manitou Experimental Forest RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	RH %	Dew point °F	Hour averaged wind Speed mph	Hour averaged wind Direct Deg.	Hour rain Inch
0618 0900	78	9	15	5	297	
0618 1000	79	8	13	6	265	
0618 1100	78	8	12	9	234	
0618 1200	78	8	11	5	260	
0618 1300	80	7	11	6	170	
0618 1400	79	9	14	6	90	
0618 1500	78	9	16	5	54	
0618 1600	79	9	15	5	100	
0618 1700	78	9	14	6	151	
0618 1800	80	8	14	13	190	
0618 1900	78	9	15	9	178	
0618 2000	73	11	15	5	161	
0618 2100	63	15	15	3	156	
0618 2200	55	25	20	5	171	
0618 2300	51	29	21	4	160	
0618 2400	49	36	23	6	182	
0619 0100	49	38	24	6	179	
0619 0200	46	42	24	6	177	
0619 0300	41	49	24	5	177	
0619 0400	40	47	21	3	165	
0619 0500	36	57	22	5	175	
0619 0600	38	54	23	5	183	
0619 0700	46	43	25	4	180	
0619 0800	56	30	25	2	181	
0619 0900	69	19	25	2	50	
0619 1000	74	17	26	4	359	
0619 1100	79	12	22	5	3	
0619 1200	76	21	33	8	41	
0619 1300	77	21	34	10	32	
0619 1400	79	19	33	7	73	
0619 1500	78	19	32	7	36	
0619 1600	77	20	32	8	36	
0619 1700	77	21	34	9	28	
0619 1800	74	24	35	8	24	
0619 1900	72	29	38	7	26	
0619 2000	66	47	45	8	8	0.05
0619 2100	54	89	50	5	25	0.25
0619 2200	53	88	50	3	1	
0619 2300	51	94	50	2	124	
0619 2400	50	97	49	1	118	
0620 0100	49	99	48	3	176	
0620 0200	49	98	49	2	153	
0620 0300	50	97	49	3	169	
0620 0400	50	97	49	2	138	
0620 0500	49	97	49	1	87	
0620 0600	49	97	48	1	155	
0620 0700	56	81	50	5	175	
0620 0800	59	72	50	9	182	
0620 0900	61	65	49	8	171	
0620 1000	60	66	49	10	172	
0620 1100	63	57	48	10	197	
0620 1200	66	49	47	11	226	
0620 1300	72	42	47	7	176	
0620 1400	77	31	44	9	177	
0620 1500	76	37	48	14	184	
0620 1600	76	36	47	11	166	

Hourly weather observations from Manitou Experimental Forest RAWS from June 8 to June 22.

Mmdd hhmm (MDT)	Dry bulb °F	RH %	Dew point °F	Hour averaged wind Speed mph	Hour averaged wind Direct Deg.	Hour rain Inch
0620 1700	73	37	45	7	200	
0620 1800	71	31	39	6	29	
0620 1900	66	55	49	7	163	
0620 2000	63	63	50	3	169	
0620 2100	62	67	51	3	75	
0620 2200	61	70	51	3	115	
0620 2300	63	45	41	5	170	
0620 2400	58	57	43	3	157	
0621 0100	54	70	44	3	138	
0621 0200	50	75	43	5	169	
0621 0300	50	76	43	5	168	
0621 0400	48	83	43	4	176	
0621 0500	45	88	42	4	168	
0621 0600	47	83	42	4	152	
0621 0700	58	58	43	6	167	
0621 0800	65	44	42	7	166	
0621 0900	69	35	41	7	174	
0621 1000	74	27	38	7	224	
0621 1100	79	20	34	7	228	
0621 1200	81	16	30	5	247	
0621 1300	82	14	29	6	221	
0621 1400	79	20	35	5	108	
0621 1500	76	25	38	9	162	
0621 1600	78	24	38	8	151	
0621 1700	74	32	42	7	133	
0621 1800	70	40	45	6	146	
0621 1900	70	36	42	4	134	
0621 2000	66	45	45	4	16	
0621 2100	59	76	51	6	191	0.04
0621 2200	55	85	50	4	85	0.01
0621 2300	52	93	50	3	171	
0621 2400	50	94	49	3	160	
0622 0100	51	91	48	4	172	
0622 0200	52	86	48	5	161	
0622 0300	52	88	48	3	159	
0622 0400	51	91	48	3	175	
0622 0500	51	92	48	2	19	
0622 0600	51	86	47	3	146	
0622 0700	56	75	48	4	168	
0622 0800	61	58	47	5	175	
0622 0900	65	50	46	8	201	
0622 1000	72	34	42	11	225	
0622 1100	75	28	40	9	232	
0622 1200	75	23	35	10	227	
0622 1300	76	24	36	9	217	
0622 1400	78	23	37	10	206	
0622 1500	80	22	37	10	220	
0622 1600	79	20	35	10	216	
0622 1700	78	20	34	9	202	
0622 1800	80	18	32	10	213	
0622 1900	77	19	32	7	190	
0622 2000	66	32	35	3	138	
0622 2100	58	43	36	4	171	
0622 2200	54	51	36	4	144	
0622 2300	52	54	36	2	125	
0622 2400	50	62	37	4	153	

Haines Index computations from Denver Soundings, June 7 to July 7.

Hour (GMT)	Day GMT	700mb-500mb temp °C	Stability term	700 mb dew point depression °C	Moisture term	Haines Index
00Z	7-Jun-02	24.7	3	18	2	5
12Z	7-Jun-02	25.3	3	22	3	6
00Z	8-Jun-02	26.1	3	25	3	6
12Z	8-Jun-02	25.3	3	27	3	6
00Z	9-Jun-02	27.1	3	24	3	6
12Z	9-Jun-02	21.1	3	26	3	6
15Z	9-Jun-02	20.7	2	27	3	5
18Z	9-Jun-02	20.9	2	25	3	5
21Z	9-Jun-02	23.7	3	28	3	6
00Z	10-Jun-02	26.5	3	30	3	6
12Z	10-Jun-02	20.7	2	24	3	5
15Z	10-Jun-02	18.5	2	22	3	5
18Z	10-Jun-02	20.5	2	23	3	5
21Z	10-Jun-02	18.3	2	11	1	3
00Z	11-Jun-02	17.5	2	8	1	3
12Z	11-Jun-02	16.1	1	3.2	1	2
15Z	11-Jun-02	13.3	1	1.5	1	2
18Z	11-Jun-02	15.1	1	6	1	2
21Z	11-Jun-02	19.1	2	6	1	3
00Z	12-Jun-02	21.3	3	7	1	4
12Z	12-Jun-02	17.7	2	6	1	3
15Z	12-Jun-02	17.5	2	20	2	4
18Z	12-Jun-02	19.3	2	23	3	5
21Z	12-Jun-02	22.9	3	20	2	5
00Z	13-Jun-02	23.1	3	16	2	5
12Z	13-Jun-02	15.5	1	7	1	2
00Z	14-Jun-02	18.9	2	6	1	3
12Z	14-Jun-02	15.1	1	4.7	1	2
00Z	15-Jun-02	23.1	3	12	1	4
12Z	15-Jun-02	24.5	3	21	3	6
15Z	15-Jun-02	24.7	3	21	3	6
18Z	15-Jun-02	24.5	3	21	3	6
21Z	15-Jun-02	22.3	3	13	1	4
00Z	16-Jun-02	19.9	2	9	1	3
12Z	16-Jun-02	21.1	3	9	1	4
00Z	17-Jun-02	22.7	3	15	2	5
12Z	17-Jun-02	25.1	3	20	2	5
00Z	18-Jun-02	25.5	3	25	3	6
12Z	18-Jun-02	24.1	3	27	3	6
00Z	19-Jun-02	26.7	3	31	3	6
12Z	19-Jun-02	26.9	3	31	3	6
18Z	19-Jun-02	21.3	3	15	2	5
21Z	19-Jun-02	21.7	3	14	1	4
00Z	20-Jun-02	23.7	3	14	1	4
03Z	20-Jun-02	19.9	2	6	1	3
12Z	20-Jun-02	17.1	2	4.9	1	3
00Z	21-Jun-02	23.5	3	15	2	5
12Z	21-Jun-02	23.3	3	19	2	5
00Z	22-Jun-02	24.9	3	18	2	5
12Z	22-Jun-02	22.1	3	13	1	4
00Z	23-Jun-02	25.1	3	17	2	5
12Z	23-Jun-02	20.7	2	13	1	3
00Z	24-Jun-02	25.5	3	22	3	6
12Z	24-Jun-02	25.1	3	20	2	5
15Z	24-Jun-02	25.5	3	22	3	6
18Z	24-Jun-02	25.7	3	24	3	6
21Z	24-Jun-02	25.1	3	22	3	6

Haines Index computations from Denver Soundings, June 7 to July 7.

Hour (GMT)	Day GMT	700mb-500mb temp °C	Stability term	700 mb dew point depression °C	Moisture term	Haines Index
00Z	25-Jun-02	25.7	3	21	3	6
03Z	25-Jun-02	24.7	3	18	2	5
12Z	25-Jun-02	23.9	3	17	2	5
00Z	26-Jun-02	22.3	3	15	2	5
12Z	26-Jun-02	22.1	3	12	1	4
00Z	27-Jun-02	24.9	3	17	2	5
12Z	27-Jun-02	23.5	3	16	2	5
00Z	28-Jun-02	24.3	3	18	2	5
12Z	28-Jun-02	22.3	3	15	2	5
00Z	29-Jun-02	23.5	3	16	2	5
12Z	29-Jun-02	24.1	3	20	2	5
00Z	30-Jun-02	25.9	3	23	3	6
12Z	30-Jun-02	25.1	3	29	3	6
00Z	1-Jul-02	24.3	3	23	3	6
12Z	1-Jul-02	26.3	3	25	3	6
00Z	2-Jul-02	26.7	3	27	3	6
12Z	2-Jul-02	25.1	3	24	3	6
00Z	3-Jul-02	24.5	3	21	3	6
12Z	3-Jul-02	24.9	3	18	2	5
00Z	4-Jul-02	23.5	3	16	2	5
12Z	4-Jul-02	17.9	2	6	1	3
00Z	5-Jul-02	21.3	3	10	1	4
12Z	5-Jul-02	18.9	2	9	1	3
00Z	6-Jul-02	22.1	3	9	1	4
12Z	6-Jul-02	14.5	1	0.8	1	2
00Z	7-Jul-02	19.3	2	9	1	3
12Z	7-Jul-02	19.5	2	10	1	3
00Z	8-Jul-02	20.9	2	11	1	3
00Z	7-Jun-02	24.7	3	18	2	5
12Z	7-Jun-02	25.3	3	22	3	6

Appendix B: Fuels classification for fuel map (Kelly Close)

Reclassification of DOQs

The mosaic of DOQs was re-classified to represent standardized fuel types represented in the area, per the 13 stylized fuel models used for fire behavior modeling (Anderson 1982):

1 - Short Grass
2 - Grass with litter, understory (<30% overstory cover)
5 - Short brush
6 - Dormant brush
8 - Closed timber litter (lodgepole pine an aspen stands)
9 - Hardwood/long-needle pine litter (ponderosa pine stands, greater than 30 percent overstory cover)
10 - Timber (litter and understory)

The classification used, which provided reasonable results, was as follows:

DOQ values	Fuel Model
0 - 45	8
46 - 80	10
81 - 125	9
126 - 130	6
131 - 135	5
136 - 155	2
156 - 215	1
216 - 300	99 (barren, rock)

These classifications were developed by comparison with aerial photos, ground verification, and comparison with the vegetation data layer provided by the USDA Forest Service.

Adding Past Burns

There are burned areas from three major wildfires (Buffalo Creek, Hi Meadows, and Schoonover) and one prescribed burn (Polhemus) that changed the stand structure and fuel type over large areas. These necessarily needed to be accounted for in the fire spread simulations, so were incorporated into the FARSITE fuels layer. First, the area of these burns was clipped from the fuels layer into a separate layer. Then, the fuel types were reclassified to represent the effects of the burns on the fuel types now in the area. Time since the burns occurred was also factored into this, as the Buffalo Creek burn (1996) has much more grass and forb growth than the others.

Burn/Fire	Date	Burn type	Fuel re-classification
Buffalo Creek	May 1996	Stand replacement	1 to 1
			2 to 2
			5 to 5
			6 to 5
			8 to 99
			9 to 1
			10 to 99
Hi Meadow	June 2000	Stand replacement	1 to 1
			2 to 1
			5 to 99
			6 to 99
			8 to 99
			9 to 1
			10 to 99
Polhemus	Sept. 2001	Understory burn	1 to 1
			2 to 99
			5 to 2
			6 to 2
			8 to 99
			9 to 99
			10 to 2
			99 to 99
Schoonover	May 2002	Stand replacement	All to 99

This clipped/reclassified layer was then combined with the resampled fuels layer to provide a fuels layer with modifications within each burn.

The other factor affecting fire spread pertains to large bodies of water and large areas devoid of vegetation. These were derived from the vegetation layer provided by the USDA Forest Service. "WATER" was classified as fuel model 98, and "BARREN/OTHER" was classified as fuel model 99. This was then added to the fuels layer. The final layer accounted for previously burned areas, water, and rocky/barren areas.

Appendix C: Hayman Fire fact sheet from Ted Moore, Pike-San Isabelle National Forest fire management officer

Hayman Fire Fact Sheet

The Hayman Fire was reported on June 8, 2002, at 1655 hours, to the Pueblo Interagency Dispatch Center (PDC), Pueblo, Colorado, by USDA Forest Service, Pike National Forest employee, Terry Barton. The fire is currently under investigation and not all dispatch logs are available for public review.

1. Initially the fire was reported to be less than 1 acre, burning in ponderosa pine with a grass understory. The fire was burning on level ground in the South Fork of the Platte River drainage. The initial reported fire behavior was intermittent crowning and spotting, with 20-foot flame lengths. The weather conditions were reported to be winds from the S, SW at 15 to 20 miles per hour.
2. At 1700 hours Mike Hessler, the South Park Ranger District Fire Management Officer, radioed PDC and requested two Type I airtankers, the District's 5-person handcrew Squad 10, a Type III helicopter, engine 2431, and engine 941 to respond to the fire.
3. At 1706 hours Mike Hessler radioed PDC and confirmed the airtanker order, and ordered the Type 1 helitanker 707 that had been pre-positioned at Lake George. This helitanker, which holds 2,000 gallons of water in its belly tank, was on the fire scene dropping water within 20 minutes. The turn-around time for reloads from Lake George was 6 minutes a load. Mike Hessler also ordered Engines 1061 and 1071, and Pikes Peak Ranger District Squad 9 (a 5-person crew based at Woodland Park), to respond to the fire, with a 30-minute ETA.
4. At 1708 hours, the smokejumper ship at Fremont airport called. They were told by Pueblo Dispatch to stay on late and stage at the airport, for either a dispatch to Hayman Fire or to be held as a reserve for another initial attack, considering the increasing resource needs of the Hayman Fire.
5. At 1709 hours, Mike Hessler radioed Terry Barton, who was on the scene. Terry told Mike Hessler the fire was "no longer torching in the trees but creeping in the grass," which indicated that the fire might be burning at a lower intensity.
6. At 1713 hours Engine 1061 was on scene.
7. At 1714 hours the Lake George Fire Department was sending two wildland-fire- qualified engines and two wildland-fire-qualified water tenders to the Hayman Fire.
8. At 1718 hours Hayman air attack reported to PDC; his ETA was 19 minutes to the fire.
9. At 1728 hours Mike Hessler radioed PDC. He ordered two more airtankers and a hotshot crew that had been staged at Salida. Mike also asked about the status of four additional handcrews that had been planned to be pre-positioned at Woodland Park. Two of these crews had been diverted from Woodland Park that afternoon to go to the Coal Seam Fire near Glenwood Springs. Mike Hessler also ordered a law enforcement officer to conduct a fire investigation.
10. At 1745 hours Mike Hessler ordered a division group supervisor and a safety officer. There was already a Type II safety officer on scene that had been brought into the area days before to aid in initial and extended attack fires due to the extreme fire conditions.
11. At 1828 hours Mike Hessler ordered another division group supervisor, 2 additional Type II handcrews, a strike team leader with crews, and a task force leader. Mike also ordered a second Type III helicopter.
12. At 1831 hours Mike Hessler radioed dispatch and asked PDC to notify Park County Dispatch that the fire had spotted across and to the east of Highway 77.
13. At 1855 hours Park County Dispatch was again notified of houses at risk.
14. At 1930 hours Teller County Dispatch was notified and updated on the fire.
15. At 1934 hours Park County Dispatch was notified of one possible lost structure, (later determined to be a false report). At this time the fire was estimated to be 200 + acres.
16. At 2024 hours the Jefferson County Type III Incident Management Team (composed of wildland-fire-qualified technical specialists from Denver Metro Fire Departments and adjacent community fire departments) was requested to be at Lake George Work Center by 0600 on June 9 — until a Type I or Type II Incident Management Team could be mobilized. Joe Hartman's Regional Type II Incident Management Team was discussed, but they had been mobilized to the Coal Seam Fire earlier that evening. There were no other local Type I or Type II incident management teams in Forest Service Region 2.

17. Kim Martin's National Type I Incident Management Team was closing out the Iron Mountain Fire with the BLM at 1000 on June 9 in Canon City. Martin's team was ordered to be at Lake George by 1800 on June 9. The members of Martin's team trickled in throughout the late morning and early afternoon, and the team in-briefing was conducted by the Forest and State at 1900 on that day in Lake George Community Center. Martin's team was in place within 21 hours. There were no night operations so Martin agreed to begin managing the fire at 0600 on June 10.
18. At 2058 hours Teller County Dispatch was notified again of threats to structures. Teller County Sheriff's Dispatch was notified 3 or 4 times throughout the evening of June 8 and into the morning of June 9.
19. By 2230 hours the main fire to the west of Highway 77 was being managed with on-scene crews and engines. The new spot fires east of the highway were burning intensely on timbered slopes above two homes on the east side of the South Platte River The fires were now inaccessible to engines and crews.

Since 1831 hours there had been a dramatic increase in extreme fire activity. There were continued crown fire runs from the main fire; they ran of 5 to 15 acres at a time. With 15- to 25-mile-an-hour winds and a Haines Index of 6 (the worst conditions for a plume-dominated fire), torching trees were lofting fire brands up to 1 mile ahead of the main fire to the east northeast. By 2030 new spot fires to the east of Highway 77 had grown in size to 100 to 150 acres total. The intensity of the spot fires was high (estimated at 500 to 800 BTUs or greater); flame lengths were 3 to 7 feet on the ground and 40 to 50 feet or more when crowning; short- and long-range spotting continued to be a problem. The current strategy was to hold the main fire to the west of Highway 77 with engines, crews and air support. The strategy for the spot fires on the east of Highway 77 and on the east of the river was to use air support: the airtankers, the Type I helitanker, and the Type III helicopters with buckets would try to hold these spots until dark when air operations would shut down. Once the sun set no tactical operations using firefighters or mechanical fire equipment was possible because of rapid fire spread, high flame lengths, inaccessible terrain, spotting, and the unpredictable and volatile nature of the fire. Firefighter safety was a primary objective.

Fire weather and fire behavior were predicted to be the same or worse on June 9 and 10: red flag warnings, winds at 30 – 40 mph with gusts to 50+ mph, and Haines indices of 5 and 6. Weather conditions were predicted to be hot and dry, with continued high temperatures and very low relative humidity. With these forecasts, direct line construction was impossible as a safe tactic on June 9 and even on June 10.

The smoke column from running spot fires and residual burning in the main fire was laying low over the forest to the east and northeast. Air attack and lookouts could not see into or ahead of the spot fires nor see the current fire behavior of the spot fires. Without good intelligence on the status of these spot fires, Incident Commander Mike Hessler used firefighters to secure the main fire. This would maintain an anchor point to work the fire the next morning. Holding the south end of the fire would serve as a foundation for management teams to build on in the future, and reduce the probability of southern spread of the fire. During the late evening of June 8 and early morning of June 9, Mike Hessler, along with the South Park District Ranger and the Park County Sheriff, began identifying values at risk ahead of the fire with the forecasted conditions over the next few days. These individuals and the Jefferson County Type III Incident Management Team should be credited with devising a safe, thorough, and complete strategy for trigger points and evacuations considering these forecasted fire behavior and fire weather conditions.

No fire departments with qualified and trained wildfire firefighters were turned back during initial attack by Pueblo Dispatch or Mike Hessler. The Pueblo Dispatch Center does not dispatch volunteer and rural fire departments; the State of Colorado has not yet developed a system to list status of fire departments on a daily basis. Many times on fires, fire departments just show up; then we determine qualifications and need, and decide whether to use the resources or not. In the case of the Hayman Fire, the main fire was not fully accessible to be tactically worked by engines. Parts of the fire could be safely worked by engines, but handcrews and air support were needed to contain this fire. Any engines in addition to those already working the fire would have had to be staged or turned around. The engines on scene were worked efficiently, either on the fireline where access was available, or in protecting the two structures on the west side of the road and the two on the east side of the road.

During the first two plus hours of initial attack there were four air tankers, one Type I helitanker, two Type III helicopters with crews, Type I hotshot crew, two Type II handcrews, two 5-person handcrews, seven fire engines, two water tenders, and up to twelve miscellaneous fire overhead on scene – a total of 110 ground personnel, not counting aviators.

The Hayman Fire is a good example of a fire burning under the influence of all the extreme factors that affect fire behavior. Fuels were flashy, dry from a 3-year drought, and at all-time live and dead fuel moisture lows; fuels were abundant and continuous. Terrain was very steep once the fire crossed Highway 77 and the South Fork of the Platte River, and the terrain was on a west aspect (very dry), oriented to a south and southwest wind direction. The area was prime for the large fire event that occurred on June 8, 9 and 10. The homes in the area were in a poor position from a fire behavior standpoint and many were minimally defensible under these conditions.

Decision by South Park Ranger District Fire Management Officer Mike Hessler to use wildland-fire-trained and -qualified firefighters from the Forest and local cooperators, and to implement LCES, Thirty-mile Abatement Items and hazard/risk analysis mitigations played a critical role providing for firefighter and public safety in the initial attack and early extended attack on the Hayman Fire.

Throughout the course of the winter and early spring a fire danger assessment was conducted of precipitation and snowpack deficiencies. Precipitation and snowpack were 30 percent of normal. The ground fuels were very dry, as demonstrated by the lack of fuel moisture in live and dead vegetation, and extreme energy release components and burning indices. Early in March all indicators pointed to a severe fire season. On April 1 the Pike and San Isabel National Forest (PSICC) requested a substantial increase in severity funds to purposefully stage and preposition severity firefighting resources. The PSICC strategically staged additional severity crews, engines, and aircraft in areas of potentially high fire occurrence and high risks and hazards. On most days throughout this period the PSICC managed three to five 20-person crews deployed throughout the two forests. We had up to twelve extra engines from outside of the geographic area to bolster our fire resources; they were available not just for federal land fires but for our State and private partners. The PSICC used severity funds throughout the spring to stage a Type I airtanker at JEFFCO or Pueblo. This airtanker flew on many State and private fire; it was the first resource on many of these fires. On many days we had three to four helicopters staged throughout the PSICC for rapid initial attack. The BLM aided the Zone with staging smokejumpers at Fremont County Airport. The State had one single-engine airtanker based at the Pueblo Airtanker reload base to support the cause. On many days the PSICC staged up to three air attack ships and supervisors for multiple initial attacks. With these forces we managed initial attacks on federal lands and provided more support to fires on private lands than ever before. The Cascade Fire west of Colorado Springs was an example of quick and efficient initial attack. This was partly due to the airtankers at Pueblo, the helicopters staged throughout the Pike NF, the three 20-person handcrews on the Pike NF, and seven extra engines to support initial attack. The crews we had staged not only bolstered the Cascade Fire initial attack but also stayed for two days after initial attack and mopped up the fire for containment and control. The same applied earlier in the year to the Black Forest Fire north of Colorado Springs and the Spatz Fire near Monument. These are just a few incidences where all agencies worked together to preposition severity wildland-fire- qualfified resources in anticipation of an extreme fire season. If not for this foresight and strategic planning by all agencies, more catastrophic fire stories would have unfolded.

Communities and federal and state agencies associated with and affected by the Hayman Fire are thankful for the proactive planning and coordination of all of the fire services in this dispatch zone.

Ted Moore
Pike and San Isabel National Forests
Cimarron and Comanche National Grasslands
Fire Management Officer

Appendix D: Transcription of Pueblo Dispatch Log as included in fire behavior narrative by fire behavior analysts Greg Morris, Henry Goehle, Kelly Close, and Incident Meteorologists Makoto Moore Rob Crone

June 8

1658 Initial fire report. Fire origin is Located at T115N, R72W, Sec. 35; Tarryall, Rd. 77. It's currently less than one acre, and is torching.

1709 Fire is no longer torching, now creeping; in grass sheltered from wind (Mike Hessler, IC)

1714 On-scene size up: 3-4 acres / 40 acres. Wind S-SW, 15 mph with gusts to 26mph. Fire is burning in ponderosa pine. Flame lengths up to 20 ft., torching, intermittent crowning. Multiple spots to head and flanks.

1715 A second smoke is reported.

1723 2 Columns are visible from Divide, fairly close to each other.

1928 Retardant line in west flank tied to dirt road, not completely through. Crews working both flanks. Have picked up a _ acre spot east of Road 77, trying to get retardant on spot (Hessler).

1939 The spot east of Road 77 has grown to 3-4 acres (Hessler)

2059 May want to evacuate Wildcat Cyn., don't know where fire is headed by morning (Hessler)

2131 Not much [RH] recovery, will stay warm. Breezes may die down. Same for tomorrow. Cheeseman is at 7% (Eric, Denver Wx).

2220 Trying to get line tied in to Rd. 77 around original fire, not quite there. Spot is bigger than the main (original) fire. Fire estimated at 100 acres. Head of spot fire is 1 mi. past Tarryall Rd., on back side of Tappan Mtn.

2229 Martin's Team ETA 1800 6/9.

June 9

0016 Size-up of situation. Fire is on east side of 77, has gone about 3 miles. Not very wide. Presently several hundred acres. Line all around it on the west side. Will take work to hold it tomorrow. There is a second smaller spot fire on the east side of CR77. If weather continues tomorrow, fire could go to 3000-4000 acres (Hessler)

0730 Left flank of fire is down near a paved road. Legal is T115N, R72W, sec 24. Spot fire about 1/4 acre, active, within 100 yards of a cabin. Lat/Long 39:04.42, 105:23.96.

0754 Multiple evacuations in place, no WFSA yet.

0806 Fire is about 1000-1200 acres (Air Attack).

0854 RH 9%, winds gusting to 20 mp h. Advising to look at evacuating area up to 100,000 acres ahead of fire (Hessler).

1004 Active fire behavior.

1047 Smoke seen in Parker, CO. Running crownfire, up in the river. Tracking toward Cheeseman. No idea where head of fire is because of smoke.

1135 Fire has crossed the river, front is at Custer Cabins. Tracking up toward Cheeseman Reservoir.

1308 Fire has blown up. More air tankers requested.

1331 60 mph winds, spot fire flaring back up.

1334 Fire is 5000 acres, more active than Hi Meadows. Smoke is shooting into Denver.

1612 Fire has topped over the ridge, creeping down into the Thunder Butte drainage (Bill at Devil's Head).

1650 Flames on north Sheep Rock, moving around the mountain. Passed Turkey Creek. North end is on both sides of Cheeseman Reservoir.

1657 Fire boundaries - west on Sheep Rock, east on Thunder Butte, north at Cheeseman Reservoir.

1712 Four engines at Lost Valley Ranch are surrounded, fire all around them. They have a safe zone.

1841 Two heads on fire; right head is at T105 R70 Sec. 16.

2137 News is reporting column is 21,000 ft., producing thunder and lightning.

2217 Fire has crossed 126 (confirmed via recon from 6 mile hill).

2253 Fire not at Buffalo Creek. From Kelsey Creek overlook, fire is 1-1/2 miles past Trumbull, still making really good runs. Running parallel to Buffalo Creek.

2304 Head of fire is now about Bridge Crossing and Platter River (seen from Kelsey Creek Overlook).

Appendix E: Committed Resources

Committed Resources reported in the Historical Incident Status Summary (ICS-209) forms for the Hayman Fire for the period June 8, 2002 through August 11, 2002 (http://famweb.nwcg.gov/pls/his_209).

Date	Type 1 Crews	Type 2 Crews	Type 1 Helis	Type 2 Helis	Type 3 Helis	Engines	ST[1] Engines	Overhead	Dozers	Water-tenders	Camp Crews	Total Personnel
6/8/02	1	1	1	0	1	10	0	15	0	1	0	71
6/9/02	2	8	0	0	0	6	0	41	0	0	1	269
6/10/02	4	11	0	0	0	11	0	111	0	4	1	400
6/11/02	2	14	0	0	0	14	0	156	0	5	2	546
6/12/02	3	21	5	0	1	57	2	248	2	15	2	931
6/13/02	6	45	5	0	2	85	6	227	5	18	3	1740
6/14/02	6	43	9	2	2	78	2	375	8	14	7	1781
6/15/02	12	43	11	2	1	116	2	467	9	15	7	2183
6/16/02	12	44	11	2	3	97	0	415	9	13	7	1969
6/17/02	10	44	13	3	3	114	2	594	11	21	17	2325
6/18/02	10	48	14	3	3	119	0	648	11	13	8	2228
6/19/02	10	47	14	3	2	136	0	703	12	13	8	2340
6/20/02	11	47	14	3	2	141	0	761	10	13	8	2508
6/21/02	11	44	14	3	2	156	0	772	11	17	10	2564
6/22/02	12	51	14	2	5	145	0	691	9	21	10	2424
6/23/02	12	48	14	2	4	122	0	574	4	18	10	2264
6/24/02	11	39	13	2	4	107	0	591	3	15	7	2285
6/25/02	10	24	8	1	2	85	0	525	1	10	10	1664
6/26/02	9	19	6	2	4	69	0	392	2	4	6	1160
6/27/02	7	16	4	2	4	54	0	393	2	3	8	1091
6/28/02	7	14	3	2	2	41	0	341	1	3	4	881
6/29/02	4	12	2	2	3	41	0	267	1	3	4	738
6/30/02	3	12	2	2	3	41	0	247	1	3	4	698
7/1/02	1	12	2	2	2	28	0	223	1	13	5	613
7/2/02	1	11	2	2	2	25	0	214	1	11	5	577
7/3/02	1	11	2	2	2	20	0	194	1	11	5	556
7/4/02	0	10	1	1	2	18	0	184	2	8	4	501
7/5/02	0	10	1	1	2	12	0	170	2	7	5	464
7/6/02	0	8	1	1	2	11	0	182	2	7	6	434
7/7/02	0	6	1	1	2	6	0	159	4	7	2	352
7/8/02	0	10	1	1	2	5	0	148	3	5	5	427
7/9/02	0	10	1	1	2	4	0	152	4	6	5	421
7/10/02	0	10	1	1	2	1	0	163	4	4	5	422
7/11/02												
7/12/02	0	10	1	1	2	1	0	168	4	4	3	417
7/13/02	0	9	1	1	2	1	0	168	4	4	3	397
7/14/02	0	9	1	1	2	1	0	170	4	5	3	397
7/15/02	0	7	1	1	2	2	0	152	0	4	2	330
7/16/02	0	7	1	1	2	2	0	169	0	4	1	327
7/17/02	0	7	1	1	2	2	0	173	0	4	1	335
7/18/02	0	7	1	1	2	1	0	171	0	5	1	328
7/19/02	0	6	0	0	1	1	0	211	0	5	2	355
7/20/02	0	6	0	0	1	1	0	170	0	6	2	317
7/21/02	0	4	0	0	1	1	0	162	0	5	2	290
7/22/02	0	3	0	0	1	0	0	166	0	4	2	252
7/23/02	0	7	0	0	1	0	0	172	2	5	2	339
7/24/02	0	8	0	0	1	0	0	159	2	5	2	330
7/25/02	0	8	0	0	1	0	0	159	2	5	2	330
7/26/02	0	8	0	0	1	0	0	166	2	6	2	337
7/27/02	0	8	0	0	1	0	0	168	2	4	3	337
7/28/02	0	8	0	0	1	0	0	176	2	4	2	348
7/29/02	0	8	6	0	0	1	0	179	2	4	2	414
7/30/02	0	8	6	0	0	1	0	183	2	4	2	420
7/31/02	0	7	5	0	0	1	0	167	1	4	3	380
8/1/02	0	7	5	0	0	1	0	168	1	4	3	382
8/2/02	0	4	6	0	0	1	0	161	1	4	2	310
8/3/02												
8/4/02	0	6	0	0	0	0	0	142	0	0	2	264
8/5/02	0	6	0	0	0	0	0	139	0	0	2	243
8/6/02	0	4	0	0	0	0	0	134	0	4	2	234
8/7/02	0	6	0	0	0	0	0	151	2	4	2	186
8/8/02	0	6	0	0	0	0	0	130	1	4	2	222
8/9/02												
8/10/02												
8/11/02	0	6	0	0	0	0	0	0	0	0	0	120

[1] ST: Strike Team
Orange: Date in ICS-209 that fire was 100% contained.
Grey: ICS-209's were missing in the ICS-209 Historical Database.
Green: Date in ICS-209 that fire was controlled.

Appendix F: Data on Fixed Wing Aircraft

This appendix F contains data for numbers of fixed wing aircraft assigned to the Hayman Fire from June 9, 2002, through July 15, 2002. Information in this appendix was obtained from a review of the Air Operations Summary ICS Form 220 within the specific daily Incident Action Plan (IAP).

For June 9 through June 11 the fire was managed under one Incident Management Team.
From June 12 through June 24 the fire was zoned and split between two Type 1 Incident Management Teams.
From June 25 through July 15 the fire was managed under one Type 1 Incident Management Team.

From June 12 through 24, air tankers were a shared resource. As such, the number of air tankers represents the total number assigned for that day; for example on 6/12 only four air tankers total were assigned to the fire and on 6/18 only six air tankers were available.

From June 12 through 14 a total of two air attack were shared between the two zones after these dates separate air attacks were available for each zone. On June 12 and June 13 one of the two lead planes on the Hayman South Zone was shared with the Hayman North Zone.

For those dates identified as "No Data Available," photocopies of those respective dates IAP were not available or ICS-220 form was missing from the photocopy of the IAP used in this analysis.

	Hayman North			Hayman South		
Date	**Air tankers**	**Lead planes**	**Air attack**	**Air tankers**	**Lead planes**	**Air attack**
06/09		4	0	2		
06/10		4	2	2		
06/11		4	2	2		
06/12	4	0	2	4	2	2
06/13	4	0	2	4	2	2
06/14	4	1	2	4	2	2
06/15	6	1	2	4	2	2
06/16	6	1	2	4	2	2
06/17	6	1	2	No data available		
06/18	6	1	2	6	2	2
06/19	6	1	2	No data available		
06/20	6	1	2	6	2	2
06/21	No data available		6	2	2	
06/22	6	1	2	6	2	2
06/23	6	1	2	6	2	2
06/24	6	1	2	6	2	2
06/25		0	0	2		
06/26		0	0	3		
06/27		No data available				
06/28		0	0	3		
06/29		0	0	3		
06/30		0	0	0		
07/01		No data available				
07/02		0	0	1		
07/03		0	0	1		
07/04		0	0	0		
07/05		0	0	1		
07/06		0	0	1		
07/07		0	0	1		
07/08		0	0	1		
07/09		0	0	1		
07/10		No data available				
07/11		0	0	1		
07/12		0	0	1		
07/13		0	0	1		
07/14		0	0	0		

Appendix G: Fire Behavior Narrative Summary

Hayman Fire
June 24, 2002

The Hayman Fire began as a person caused fire that was detected on Saturday, June 8th, 2002 in the protection area of the Pike National Forest. The fire started on level ground in the valley of the South Fork of the Platte River drainage. It immediately displayed very active fire behavior and escaped initial attack efforts.

Following is a review of the fuels, weather, and topography and how these factors affected the fire behavior of the Hayman Fire.

Fuels

There was a variety of fuel types that the fire burned through, but primarily it burned in ponderosa pine fuels. There was some areas of short grass mixed among some areas of the pine. This is a very flashy fuel type which leads to rapid rates of spread and can easily outrun suppression crews. Abundant ladder fuels were present and led to abundant torching, crowning and spotting. These fuel types would model out as 9 and 1.

There were inclusions of mixed conifer timber that consisted of Douglas fir, lodgepole, and ponderosa pine at the lower elevations. These stands were primarily on the northerly aspects. At the higher elevations limber pine and bristlecone pine were present. These fuel types would model out as both 8 where ground fuels were light and 10 where downed fuels were heavy.

The ground fuels were very dry for all size classes. Smaller fuels (1, 10, and 100 hour) were in the 2-3% range, while the larger fuels (1000 hour) were in the 5-7% range in the lower elevations. These fuel moisture ranges are very dry for the time of year and elevation. Energy Release Component levels were above the 97th percentile. Live fuel moistures were also low for this time of year (85-95%).

There were very few natural fuel breaks for the fire to slow down or for the suppression crews to take advantage of. The Schoonover fire and the Polhemus prescribed burn did significantly slow the spread of the fire on the northeast head.

There was evidence of an older fire in the wilderness, approximately 40-50 years ago. Fire in this area basically stopped and went out on its own once the wind quit and humidity came up. There is also a lot of rocky ground in the wilderness that breaks up the continuity of the fuel, and fire eventually went out in most areas once the major run was over.

Weather

Many factors of weather played a part in the fire behavior of this fire. Precipitation amounts were well below normal. The area typically receives 7 inches of rain From January to June, whereas only 2.5 inches had fallen in that time period this year. There was also very little if any snowfall during the winter. This led to abnormally low 1000 hour fuel moistures. The low precipitation amounts also led to very dry live fuel moistures.

During the first two days of the fire temperatures were well above normal with temperatures in the 90's at the lower elevations and 80's at the higher elevations. Relative humidities were very low, with single digits common. Humidity recoveries were also very poor the first two nights, with recoveries only to the mid teens. When temperatures and humidities reach these levels, fine fuel moistures are extremely dry and flammable. Fires climb ladders more easily, resulting in torching and crowning. Spot fires start more readily with ignition potentials being very high.

Wind was also a strong factor that affected the fire. Strong southwesterly winds hit the fire on September June 8th, pushing the fire to the northeast during the day, and then making another push to the northeast the next day. Winds were reported at 30-40 mph with gusts to 50 mph at many weather stations. The Cheeseman RAWS showed a peak gust of 84 mph, but this was likely influenced by the fire front as it passed by.

Strong winds and low humidities again hit the fire area on June 17th and 18th. On June 17th the winds were out of the NW, probably influenced somewhat by the orientation of the drainages, and blew 15-20 with gusts to 30 mph. On the 18th, the winds blew from the southwest at approximately the same speed. Relative humidities dropped into the single digits both days, with poor humidity recoveries both nights as well.

On June 19th, the winds switched to the northeast but were not as strong. Relative humidities moderated into the low 20's. Fire remained active on the south end, but spread was slowed on the northeast side of the fire. The weather during the days between the two fronts and after the second front was relatively quiet. Humidities were above critical ranges and winds were mainly diurnal.

Some light precipitation did fall on the fire, but not enough to affect fuel moistures significantly. It did give the suppression crews enough of a break to at least get a foothold on some sections of the line.

Topography

Terrain on the fire varied from gentle to extremely steep (50-60%). The more gentle terrain allowed road access along much of the east flank. The fire started in gentle terrain that is exposed to strong prevailing southwest winds.

The South Fork of the Platte River drainage is oriented to a southwest wind. This drainage is a natural funnel with the high elevation Lost Creek Wilderness to the west and the Rampart Range to the east.

Most of the steeper terrain is in the wilderness on the west side and in the Trout Creek area to the Rampart Range on the east side. However, much of the S.F. Platte river drainage is dissected by smaller steep side drainages.

The terrain on the east flank of the fire was more gentle with rolling terrain. This feature did not provide any breaks to slow the wind down at all, no matter which direction it happened to be blowing. The fire on this plateau moved southeast, northeast, and south-southwest. The gentle terrain did proved good road access where crews were able to contain the fire once the winds died down and humidities rose. Another downside to the gentle terrain were all the homes that were in the area.

Summary

The Hayman fire is a good example of a fire burning under the influence of all the extreme factors that affect fire behavior. Fuels were flashy, abundant, and continuous. Terrain was very steep in places and oriented to the wind direction. The weather was unseasonable warm and dry and there was a wind event to push the fire. The area was prime for the large fire event that occurred on June 8th and 9th. The homes in the area were in a poor position from a fire behavior standpoint

The fire started on a gentle terrain in a ponderosa pine stand that had extremely dry fuels. It was easy for the fire to climb into the crowns on June 8th due to the warm temperatures, low humidities strong winds. The drought conditions led to low fuel moistures in the crowns. On June 9th the fire was pushed by strong winds that pushed the fire down the S.F. Platte River. The fire moved approximately 19 miles in an 8 hour period.

On June 17th, the fire spread in two heads from Turkey Rock and Shrewsbury Gulch. The fire spread southeast toward Woodland Park approximately 6 miles in 6 hours, with active crown fire and spotting up to _ mile. Many homes were burned during these runs.

On June 18th, a red flag warning was issued for strong southwest winds with low humidities. The two heads came together in a push to the northeast with the heads coming together on the ridge between West Creek and Highway 67. Once the interior between the two heads came together, the intensity was strong enough to overcome the wind and the power of the fire overcame the power of the wind, essentially slowing down the northeastward spread. Then when the energy from the interior burnout started to cool down, the power of the wind took over once again and started pushing the fire to the northeast. The fire crossed Highway 67 just north of the Rainbow Falls camp turnoff. It then proceeded to cross Trout Creek late in the day. Numerous houses burned this day as well. The fire in the wilderness was also active on the steep southerly aspects north of Hankins Gulch.

On June 19th, a frontal passage was forecast to bring northeast winds with slightly higher humidities early in the afternoon. The front did come as forecast and actually hit the east side of the fire around midmorning. By 1100 the winds were out of the east with humidities in the 20's on the east side of the fire, moderating fire activity. Crews were able to take advantage of the moderating conditions and use direct attack at the top of the slopovers east of Trail Creek. At the same time, humidities were down to 5% on the south side of the fire along with southwest winds, and fire the fire was very active with abundant torching and short crowning runs. As the front passed through the south part of the fire, it pushed the south end of the fire south across Trail Creek with spotting over Phantom Creek. Several houses burned during this run. The fire in the wilderness was very active as well, with a run in Hankins Gulch burning up over the top of South Tarryall Peak. It also burned out a bowl on the ridge south of Wigwam Creek.

Starting on June 20th, humidities again started moderating to the 20's and 30's early in the afternoons. Crews were able to utilize direct attack methods and contain the fire. A minor section of line utilized indirect attack to burn out an area that had numerous spotfires on a north slope. By June 24th, all containment lines were in on the non-wilderness portion and holding well. The lines were tested on June 23rd with hot dry winds from the southwest again, but everything held.

Most of the fire area burned very intense and clean with high mortality, especially in the ponderosa pine stands. Aspen stands and Douglas fir stands with brush in the understory burned on the drier aspects, but not as well on the northerly aspects

The effects of prescribed fire was evident when the fire burned into the Polhemus burn as the fire remained on the ground and burned slowly, even under dry, windy conditions. There was another prescribed burn in the Phantom Creek area that reduced the intensity of the fire as it burned through the stand, with only a low intensity ground fire going through the area.

One other factor that aided in the suppression of the fire was the access provided by the road system on the east side of the fire. Roads provided control lines as well as good escape routes for the crews.

While the drought and wind played a big part in the spread of this fire, it seems that the overriding factor that helped spread the fire was the low humidities. Once the humidity got below 12%, the fire became very active. When it got below 8%, it became explosive. Moderate burning conditions were experienced when the humidity was between 12-30%. Above 30% and the fire was not very active, even with moderate wind speeds.

Ron Hvizdak
Fire Behavior Analyst
Northern Rockies Incident Management Team

Ecological Effects of the Hayman Fire

Part 1: Historical (Pre-1860) and Current (1860 – 2002) Fire Regimes

William H. Romme, Thomas T. Veblen, Merrill R. Kaufmann, Rosemary Sherriff, and Claudia M. Regan

Introduction

To address historical and current fire regimes in the Hayman landscape, we first present the concepts of "historical range of variability" and "fire regime" to provide the necessary conceptual tools for evaluating fire occurrence, fire behavior, and fire effects. Next we summarize historical (pre-1860) fire frequency and fire effects for the major forest types of the Colorado Front Range, to illustrate and emphasize the key point that the ecological role of fire is dramatically different in the various forest types that are found in and around the area burned by the Hayman Fire. We consider the magnitude by which these different kinds of fire regimes in the Colorado Front Range have been altered (or not altered) by human actions, notably 20th century fire exclusion. Finally, we focus on the Hayman Fire itself, to evaluate the extent to which this large, severe fire can be regarded as either a "natural" or an "unprecedented" event in this ecosystem.

Because future Front Range fires will likely occur outside the Hayman area, and because one purpose of this report is to provide a scientific basis for developing fire management policy, we believe it is important to place our assessment of the Hayman Fire into a broader context. For this reason, we discuss the role of fire in some forest types that actually are uncommon within the Hayman Fire perimeter per se (for example, spruce-fir), recognizing that the next big Front Range fire may well occur in these other kinds of ecosystems. Moreover, an understanding of the fire ecology of other ecosystems adjacent to the Hayman area helps clarify some of the unique features of the Hayman landscape. Thus, our treatment moves from basic concepts of fire and landscape dynamics in general, to a description of broad fire and landscape patterns in the Colorado Front Range, to a specific analysis of fire and landscape history within the specific area where the Hayman Fire occurred.

"Historical Range of Variability" (HRV)

Modern concepts of resource management that emphasize maintenance of ecosystem integrity while also providing commodities and services to society are encompassed under "ecosystem management." Ecosystem management (Christensen and others 1996) has been defined as: "Management driven by explicit goals, executed by policies, protocols, and practices, and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem structure and function." An important component of the ecosystem management paradigm is explicit recognition of the dynamic character of ecosystems. Ecosystem management is not intended to provide maintenance of any status quo in ecosystem conditions but rather accepts that change is an inherent characteristic of ecosystems across both space and time.

For resource managers, it is important to know the range of critical ecological processes and conditions that have characterized particular ecosystems over specified time periods and under varying degrees of human influences (Christensen and others 1996). As applied to the management of forested ecosystems in the Western United States, an ecosystem management paradigm emphasizes knowledge of the range of ecosystem conditions prior to significant changes brought on by intensive Euro-American settlement and how these conditions have continued to change during the 20th century (Kaufmann and others 1994; Morgan and others 1994; Landres and others 1999; Swetnam and others 1999). The timing of major impact of Euro-American settlement on terrestrial ecosystems varies in the West from the middle 18th to early 20th centuries but generally begins in the latter half of the 19th century for most areas, including the Front Range of Colorado (but see part 5 of this report, "Historical Aquatic Systems"), where major impacts are described as early as the 1810s when beaver were extirpated. We refer to the range of ecological conditions and ecological processes (including disturbance processes such as fire) that characterized Front Range ecosystems for several centuries prior to significant impacts of Euro-American settlers as the ***historical range of variability*** or ***HRV***.

Understanding of natural variability in ecosystem conditions and processes provides operational flexibility for management actions and protocols (Landres and others 1999). Incorporating historical ecosystem patterns into management goals provides a strategy for dealing with sustainability of diverse and often unknown species requirements. Managing within the natural bounds of site variability and history, as well as maintaining major historical patterns and processes of ecosystems, is also probably easier and less expensive to achieve than trying to manage outside of constraints imposed by driving factors of the system (Landres and others 1999). Historical patterns of ecosystem conditions provide what may be the only viable model for how ecosystems have evolved and perpetuated themselves in the absence of significant human effects. Although anthropogenic climate change may alter ecosystems, natural climatic variation also has resulted in relatively rapid ecological changes in the past. In the absence of clear knowledge that historical ecosystem function is no longer an appropriate model, using the historical condition as a guide for evaluating current ecosystem conditions is warranted

Throughout this report, we compare ecological conditions in the aftermath of the Hayman Fire not only to conditions that existed just prior to the fire, but also to the natural range of conditions that characterized this ecosystem for hundreds of years prior to the arrival of Euro-American settlers. It becomes apparent that not all conditions just prior to the fire were "natural" or even desirable from an ecological standpoint. The HRV concept is most valuable when used as a reference against which to compare current conditions or trends. Where current ecosystem properties or trajectories are not much different from what would be expected under the historical disturbance regime, then the system probably is functioning normally, and ecological restoration is not needed. However, if current ecological conditions are dramatically different from historical patterns and trends, then careful assessment of the changes is warranted, and restoration of some or all of the historical ecosystem components and processes should be considered.

Historical Range of Variability in Fire Regimes of the Colorado Front Range

A "fire regime" is a summary description of the salient characteristics of fire occurrence and effects within a specified area (table 1). One of the most important aspects of a fire regime is the fire "severity" or impact of the fire on organisms and abiotic components of the ecosystem. The term "fire severity" is used with many different meanings, however (table 2), so we are careful in this report to define what we mean by fire severity. Fire regimes varied greatly throughout the Front Range during the historical period, as a result of underlying variation in vegetation characteristics and local climate (Agee 1998). Both vegetation and climate vary along gradients in elevation and topography (fig. 1).

As elevation increases, precipitation generally increases and temperatures decrease. This pattern is complicated by topography and soils, however, and the elevational zones in figure 1 depict only general trends. At any given elevation, the north-facing slopes tend to be cooler and moister than the south-facing slopes because the sun strikes south-facing slopes more directly. Fine-textured soils (derived, for example, from sedimentary rocks) generally retain more moisture than coarse-textured soils (derived, for example, from the granitic rocks that are prevalent in the Hayman area). Thus, vegetation zones extend to somewhat

Table 1—Components of a fire regime.

Component	Definition
Fire frequency	Number of fires occurring within a specified area during a specified time period, for example, number of fires in the Pike – San Isabel National Forest per year
Fire size or fire extent	The size (hectares) of an individual fire, or the statistical distribution of individual fire sizes, or the total area burned by all fires within a specified time period, for example, total hectares within the Pike – San Isabel National Forest that burned in 2002
Fire interval (or fire recurrence interval)	The number of years between successive fires, either within a specified landscape or at any single point within the landscape
Fire season	The time of year at which fires occur, for example, spring and fall fires, when most plants are semi-dormant and relatively less vulnerable to fire injury, or summer fires when most plants are metabolically active and relatively more vulnerable to fire injury
Fire intensity	Amount of heat energy released during a fire … rarely measured directly, but sometimes inferred indirectly from *fire severity*
Fire severity	Fire effects on organisms and the physical environment (see table 2)

Table 2—Commonly used synonyms and definitions of the concept "fire severity." The meanings differ depending on whether the focus is on fire effects on the forest canopy and understory or on the soil and soil surface. Note that the definitions may be inconsistent, for example, a *high*-severity fire from the perspective of the forest canopy may be *low*-severity from the soil perspective. However, high-severity effects on soils are almost always accompanied by high-severity effects on the canopy. The definitions used in the BAER process (burned area emergency rehabilitation) also are included.

Term	Definitions
Effects on the forest canopy and understory vegetation	**High severity** = **Lethal** = **Stand-replacing** … the fire kills all or most canopy and understory trees, and initiates a succession process that involves recruitment of a new cohort of canopy trees **Low-severity** = **Non-lethal** = **Non-stand-replacing** … the fire kills only a few or none of the canopy trees, but may kill many of the understory trees, and does not result in recruitment of a new canopy cohort but creates or maintains an open, low-density forest structure **Mixed-severity** = **Intermediate severity** … used in two different ways: *Within-stand* – the fire kills an intermediate number of canopy trees (less than high-severity but more than low-severity), and may or may not lead to recruitment of a new canopy cohort *Among-stand* – the fire burns at high severity in some stands but at low or intermediate severity in others, creating a mosaic of heterogeneous fire severity across the landscape
Effects on the soil and soil organisms	**High severity** … the fire consumes all or nearly all organic matter on the soil surface, as well as soil organic matter in the upper soil layer, and kills all or nearly of the plant structures (for example, roots and rhizomes) in the upper soil layer … results in possible water repellency and slow vegetative recovery **Low-severity** … the fire consumes little or no organic matter on the soil surface or in the upper soil layer, and kills few or no below-ground plant parts … results in limited or no water repellency, and to rapid vegetative recovery via re-sprouting
Definitions used by BAER	**High-severity** … areas of crown fire, i.e., leaves and small twigs consumed by the fire … always stand-replacing **Moderate-severity** … areas where the forest canopy was scorched by an intense surface fire, but the leaves and twigs were not consumed by the fire … may be stand-replacing or not, depending on how many canopy trees survive the scorching **Low-severity** … areas where the fire burned on the surface at such low intensity that little or no crown scorching occurred (may include small areas that did not burn at all) … never or rarely stand-replacing

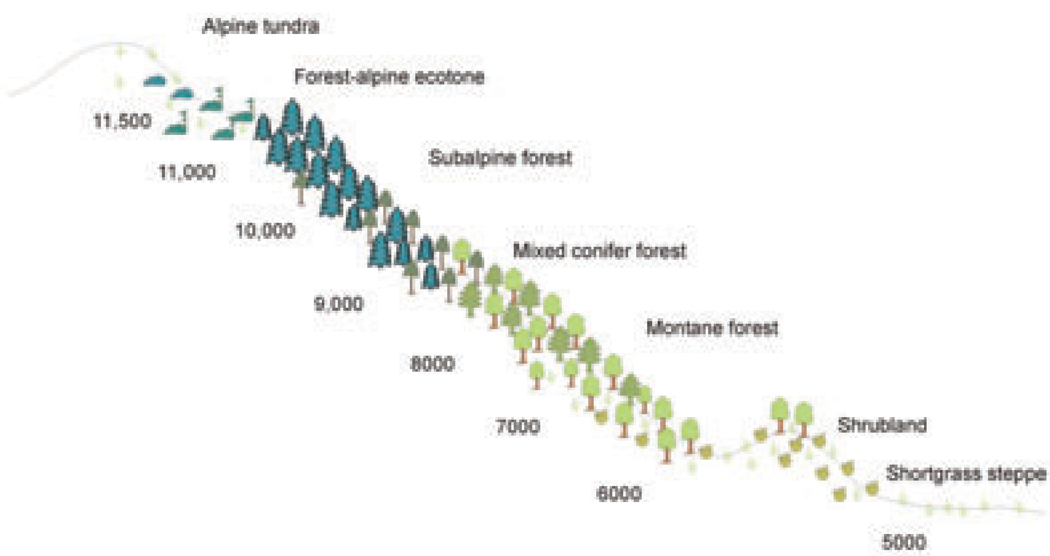

Figure 1—Major forest zones in the Colorado Front Range (provided by Laurie Huckaby).

higher elevations on south-facing slopes or where soils are coarse textured and extend to lower elevations on north-facing slopes or where soils are fine textured (Peet 1981).

Where the Great Plains meet the foothills of the Front Range (approximately 5,500 feet), the arid short-grass steppe gives way to dense shrublands of mountain-mahogany (*Cercocarpus montanus*) and other shrub species, intermixed with open forests of ponderosa pine (*Pinus ponderosa*). The open ponderosa pine forests are referred to as the "lower montane" zone, and they grow in the driest sites capable of supporting trees. Ponderosa pine becomes denser with increasing elevation, until in the "montane" zone (approximately 6,500 to 8,000 feet) it can form closed forests if undisturbed for long periods. Douglas-fir (*Pseudotsuga menziesii*) also grows with ponderosa pine in the montane zone. Douglas-fir tends to be more abundant on relatively cool, moist sites (for example, north-facing slopes and higher elevations), whereas ponderosa pine tends to be more abundant on relatively warm, dry sites (for example, south-facing slopes and lower elevations) within this broad vegetation zone. In the "mixed conifer" zone (approximately 8,000 to 8,500 feet), higher precipitation allows ponderosa pine and Douglas-fir to form dense stands in which both species codominate, along with a variable mixture of other tree species including aspen (*Populus tremuloides*), lodgepole pine (*Pinus contorta* var. *latifolia*), and limber pine (*Pinus flexilis*). Ponderosa pine and Douglas-fir drop out as one reaches the cool, wet "subalpine forest" zone (approximately 8,500 to 11,000 feet), and forests become dominated by a variable mixture of lodgepole pine, aspen, subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and limber pine. Above 11,000 to 11,500 feet, the growing season is too short for trees, and the vegetation is alpine tundra.

Within this framework of natural variation in vegetation and climate, we can recognize three general kinds of fire regime in the Front Range (table 3). We must emphasize that the distribution patterns described in table 3 are necessarily general and qualitative, and that many local exceptions are to be expected. Nevertheless, these three kinds of fire regimes provide a basic ecological context for evaluating fire occurrence and fire effects throughout the Front Range – including the Hayman Fire. All three fire regimes are powerfully influenced by weather and climate. Fuels conditions also are important in the frequent, low-severity, and mixed fire regimes, but are of far less importance in infrequent, high-severity fire regimes where weather conditions conducive to extensive fire occur only rarely (table 3 and below). Similarly, the importance of ignition frequency and ignition source (for example, by Native American peoples) varies greatly with elevation and geographic location (Baker 2002). We discuss changes in stand and landscape structure during the past 150 years in Front Range forests, and, later in this part 1, we discuss how these changes may influence fuels and fire behavior.

We cannot overemphasize the importance of these fundamental differences in natural fire regimes along an elevational gradient from lower montane to subalpine zones, not only in the Front Range but throughout the Rocky Mountain region of southern Wyoming and Colorado (Romme and Knight 1981; Peet 1988; Brown and others 1999; Veblen and others 2000, Kipfmueller and Baker 2000). Although fire ecologists have long recognized that fire regimes vary with elevation, topography, vegetation type, and geographic region (for example, Swetnam and Baisan 1996; Agee 1998; Heyerdahl and others 2001; Brown and Shepperd 2001; Allen and others 2002; Schmidt and others 2002), many recent policy statements portray all Western forests as a single, homogeneous entity (for example, President Bush's "healthy forests initiative" of 2002).

Infrequent High-Severity Fire Regimes – Continuous canopy fuels of dense Engelmann spruce, subalpine fir, and lodgepole pine forests, growing in cool, moist environments, permit widespread stand-replacing crown fires or severe surface fires – but only during conditions of low fuel moisture, low relative humidity, high temperatures, and winds. These kinds of weather conditions occur only a few times in several decades in the subalpine zone, and consequently most ignitions extinguish naturally without spreading. Low decomposition rates in the subalpine zone cause accumulation of fuels during the long intervals between fires and, therefore, intense fire behavior when extremely dry weather conditions eventually coincide with ignition (Clagg 1975; Romme and Knight 1981). Thus, subalpine forests generally are characterized by *infrequent, high-severity fires* (table 3).

For spruce-fir and lodgepole pine forests in the subalpine zone of northern Colorado and adjacent areas in the Rockies, stand-replacing fires are well documented as the kind of fires that have the greatest impacts on forest structure. In areas of continuous forest in the subalpine zone, vast areas have burned in single stand-replacing events as indicated by extensive even-aged tree populations (Whipple and Dix 1979; Romme and Knight 1981; Veblen 1986; Aplet and others 1988; Parker and Parker 1994; Sibold 2001; Kulakowski and Veblen 2002). Figure 2 depicts a portion of the area that burned in the extensive fires of 1851 – a regional drought year similar to 2002, in which fires occurred in almost every mountain range in Colorado, New Mexico, and Arizona. Large, high-severity fires in subalpine forests represent an infrequent but entirely normal event in subalpine forests. In contrast, low-severity surface fires in the subalpine

Table 3—Three general types of fire regimes in the Colorado Front Range. See table 2 for definitions of fire severity, and see the text for explanations and important caveats.

Type of regime	General characteristics	Major controlling variables	Distribution
Infrequent, High-Severity Fire Regimes	Fires recur within any stand at long intervals (100 to 500+ years), burning at high severity in the canopy and understory, and at variable severity to the soil	**Weather** and **Climate** are the primary controllers (most ignitions extinguish by themselves because of wet conditions; extensive fires occur only in very dry summers); variability in fuels usually has little influence on fire frequency, extent, or severity)	This type predominates at higher elevations (lodgepole pine and spruce-fir forests in the **subalpine zone**) in the Front Range and throughout the Rocky Mountains
Frequent, Low-Severity Fire Regimes	Fires recur within any stand at relatively short intervals (5 to 50 years), burning at low severity in the canopy and soil, and variable severity in the understory	**Weather** (fires occur during dry periods), **Climate** (extensive fires tend to occur in dry years that follow 1-3 wet years), and **Fuels** (fuels gradually accumulate during the intervals between successive fires)	Within the Colorado Front Range, this type apparently is restricted to ponderosa pine forests in the **lower montane zone** … it is more widespread in ponderosa pine forests in Arizona, New Mexico, and southern Colorado
Mixed Fire Regimes	These fire regimes are intermediate between the Frequent, Low-Severity and the Infrequent, High-Severity Fire Regimes … fires occur at variable intervals (10 to greater than 100 years), and burn at variable severity (patches of high severity intermingled with patches of low or intermediate severity)	**Weather**, **Climate**, and **Fuels** all influence fire frequency, extent, and severity, in complex ways that are not well understood, with enormous variability over time and space	This type predominates at middle elevations (ponderosa pine and Douglas-fir forests in the **montane zone**) in the Front Range and probably also characterizes middle elevations throughout much of the Rocky Mountains and Southwest

zone are relatively restricted in extent and probably have less ecological importance than the stand-replacing fires (Veblen 2000; Sibold 2001; Kulakowski 2002; Sherriff and others 2001; Kipfmueller and Baker 2000). In some of the driest sites at high elevations, where limber pine is the dominant tree species, fire-scarred trees are sometimes common, indicating a local history of surface fires (Sibold 2001). Overall, however, spruce-fir forests growing on cool, moist sites at high elevations commonly exhibit long fire intervals of more than 400 years between extensive crown fires (Romme and Knight 1981; Veblen and others 1994; Sibold 2001; Kulakowski 2002).

Frequent Low-Severity Fire Regimes – Fires in open ponderosa pine woodlands of the lower montane zone, where grass and other herbaceous fuel types are well developed, tend to be surface fires of relatively low intensity and high frequency. Weather conditions that dry fuels sufficiently for fire spread are more common at lower elevations and result in widespread fires during dry years (Veblen and others 2000). Thus, lower montane ponderosa pine forests generally were characterized by *frequent, low-severity fires* prior to the mid-1800s (table 3). This historical fire regime along the lower forest ecotone in the Colorado Front Range is similar in some respects to the historical fire regime of Southwestern ponderosa pine forests, for example, in northern Arizona (Covington and Moore 1994; Fule and others 1997; Veblen and others 2000; Brown and Shepperd 2001). Fires were less frequent in this habitat in the Front Range than in most Southwest sites, but ecological effects were similar in the sense that surface fires were sufficiently frequent to prevent open woodlands from developing into dense stands. Because many resource managers believe that ponderosa pine forests in the Front Range had historic fire regimes similar to the frequent, low-severity fire regime of many Southwest ponderosa pine forests, it is important to estimate how applicable the low-severity

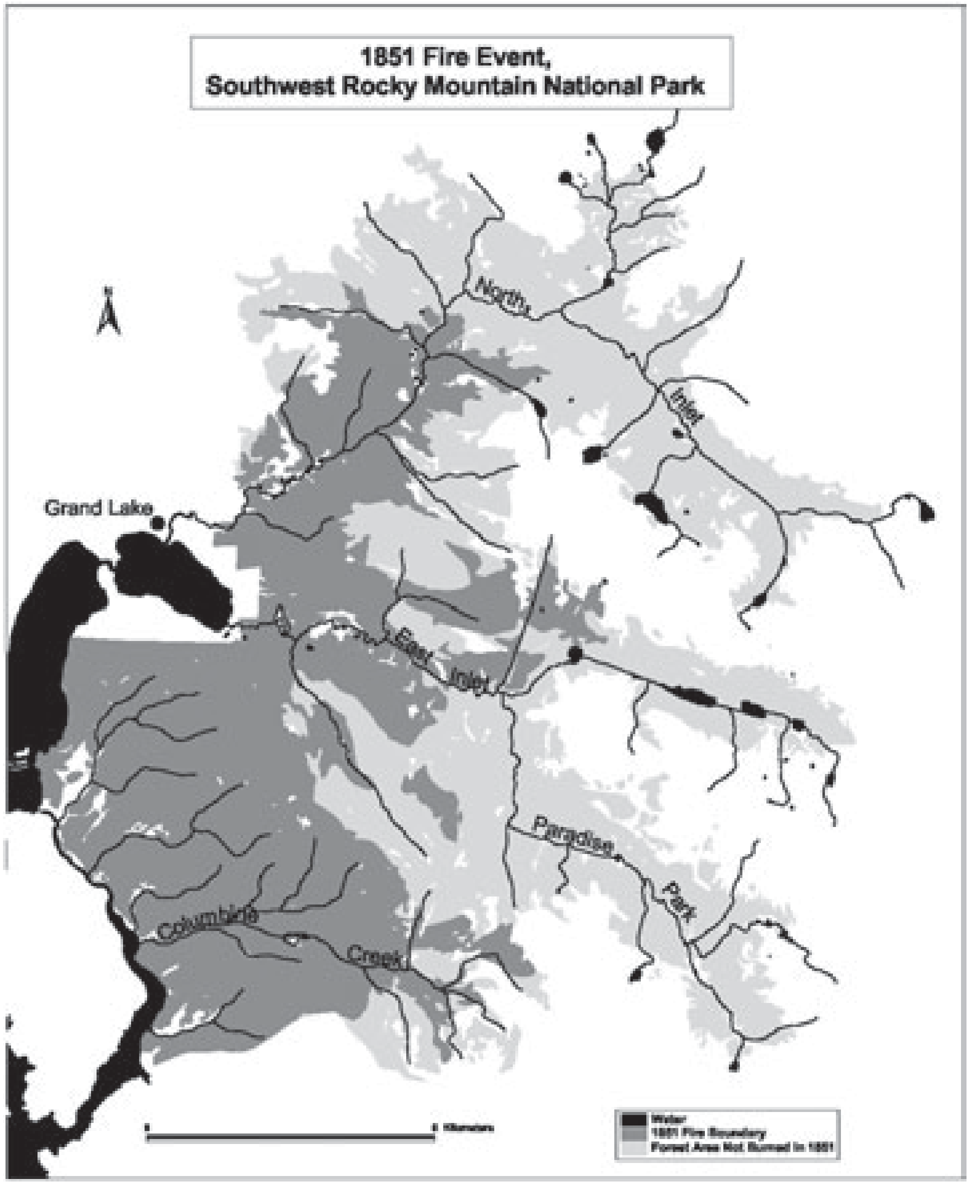

Figure 2—Map showing the extent of burning in 1851 in the southwestern sector of present-day Rocky Mountain National Park. The 1851 fire burned approximately 5,200 ha in the 11,000 ha area sampled for fire history. Fire extent was reconstructed from approximately 1,000 tree ages and 150 fire-scar wedges and field observations in all vegetation patches greater than 8 ha in the Park's GIS vegetation layer as described in Sibold (2001). Data are from J. Sibold and T. Veblen, unpublished.

fire regime is to ponderosa pine forests throughout their elevational distribution in the Front Range.

In the northern Front Range a study is currently under way that maps historic fire regimes in the ponderosa pine zone based on empirical models derived from 54 fire history sample sites (approximately 100 ha each) that relate fire regime type to environmental site conditions. The focus of the study is on discrimination of areas of relatively frequent fires (that is, return intervals to the same approximately 100 ha stand of 5 to 50 years) as opposed to infrequent fires (return intervals of many decades or even a century or more). Each of the 54 fire history sample sites was classified as having a fire frequency type of high, moderate, or low; the former approximates the Frequent-Low-Severity regime, and the latter two correspond to Mixed Fire Regimes in table 3. Environmental conditions at each site were classified in terms of the mean elevation, slope steepness, aspect, proximity to grassland, distance to ravine and the associated fire frequency type (high, moderate, and low fire frequency). Logistic regression and decision tree classification were used to model the relationship between each fire frequency regime type and the predictor environmental variables. These empirical models were developed for all cover types in the Arapaho-Roosevelt National Forest (ARNF) on the eastern slope of the Front Range that include ponderosa pine in a 71,224 ha study area. Using the ARNF Integrated Resource Inventory (IRI), the cover types and percent areas included were: ponderosa pine (29 percent), ponderosa pine-Douglas fir (25 percent), Douglas fir-ponderosa pine (10 percent), and mixed conifer (36 percent). In the mixed conifer type, ponderosa pine was the dominant species in 57 percent of the area. Thus, in the area of analysis ponderosa pine was dominant over 75 percent of the area.

Both the logistic regression and decision tree classification techniques indicate that lower elevations are more favorable to high fire frequency than higher elevation areas, and both models consistently predict the same low elevation areas as having high fire frequency regimes. According to these models, less than 17 to 18 percent of the ARNF ponderosa pine forests (where ponderosa is either the dominant species or a subdominant but significant component of the stand) would have had high fire frequency regimes. Conversely, 62 to 74 percent of the ponderosa pine study area would have had low fire frequency regimes (three or fewer fires between 1750 and 1915). The areas with reconstructed high fire frequencies are clearly limited by elevation. Elevation may be a proxy for other factors such as proximity to grasslands, given that the lowest elevations are adjacent to the plains-grassland ecotone, where the highest fire frequency sites occur. The low fire frequency sites tend to occur on more mesic north-facing aspects farther from ravines and on steep slopes.

This study is based on empirical fire history data from the northern Front Range where topographic and other differences may have resulted in a somewhat different historic fire regime than in the ponderosa pine zone of the southern Front Range. Given that caveat, the percentage area of estimated fire regime type for the ponderosa pine zone cannot be directly extrapolated outside of the area of study in the northern Front Range. However, this study in the northern Front Range clearly documents the following points: (1) The total amount of area now dominated by ponderosa pine that supported a frequent low-severity fire regime in the northern Front Range was relatively small and generally restricted to the lowest elevations along the mountain front. (2) Even within the cover type mapped as "ponderosa pine," where stands are often monospecific, approximately half of the area was not characterized by a frequent low-severity fire regime. Although this study is still in progress, these initial findings for the northern Front Range indicate that presence of a ponderosa pine cover type does *not* necessarily indicate a history of formerly frequent surface fires.

Mixed-Severity Fire Regimes – Most of the ponderosa pine and Douglas-fir forests within the montane and mixed conifer zones of the Colorado Front Range were characterized by a ***mixed-severity fire regime***. This is a complex fire regime that contains elements of both the frequent low-severity and the infrequent high-severity types (Agee 1998). Neither the Southwestern ponderosa pine model developed for northern Arizona (Covington and Moore 1994; Fule and others 1997) nor the boreal/subalpine forest model (for example, Johnson 1992; Veblen and others 2000) is appropriate in itself to describe this mixed-severity fire regime. Mixed-severity fire regimes in general are perhaps the most complex and poorly characterized of all historical fire regimes in Western North America, but they were widespread historically and were distinct from other types of fire regimes (Agee 1998).

Mixed-severity fire regimes in forests of ponderosa pine and Douglas-fir in the Colorado Front Range can be characterized as follows (from Brown and others 1999; Kaufmann and others 2000a,b, 2001; Veblen and others 2000; Ehle and Baker in press): Fires recurred at highly variable intervals, ranging from a decade to a century, and varied in size from very small (less than 1 ha) to very large (tens of thousands of hectares). Within the perimeter of any individual fire were areas where all of the canopy trees were killed, areas where many but not all of the trees were killed, areas with little or no canopy mortality, and unburned patches. These mortality patterns were produced by a mix of active crown fire, passive crown fire, severe surface fire that scorched tree crowns, and low-intensity underburning that did not scorch tree crowns. Proportions of total burned area in each of these categories of fire severity varied greatly among individual fire events. The largest, most severe fires tended to occur in extremely dry years, especially dry years following one to three wet years. Some large fires burned over a period of several months, dying down during moist days but flaring up again on dry windy days. However, not every watershed necessarily burned in every dry year, because of random variation in locations of ignitions as well as local variation in weather, disturbance history, and fuels characteristics.

We have good empirical evidence for both the stand-replacing and non-stand-replacing components of this mixed fire regime in Front Range forests of ponderosa pine and Douglas-fir. For example, centuries-old ponderosa pine trees with multiple fire scars, as well as all-aged structure in extant stands, testify to recurrent low-severity surface fires (for example, Rowdabaugh 1978; Skinner and Laven 1983; Goldblum and Veblen 1992; Brown and others 1999; Kaufmann and others 2000a,b; Donnegan 2000; Veblen and others 2000; Huckaby and others 2001; Brown and Shepperd 2001). In addition, around the year1900, photos of severely burned areas and young regenerating forests, as well as current even-aged stand structures, document the occurrence of stand-replacing fire (Veblen and Lorenz 1986, 1991; Hadley and Veblen 1993; Brown and others 1999; Kaufmann and others 2000a,b; Ehle and Baker in press).

Climatic Variation: a Key Influence on Front Range Fire Regimes – At an interannual scale, synchronous occurrence of fire-scar dates from sample sites separated by tens or hundreds of miles is strong evidence that regional climate is influencing fire regimes. For the area from southern Wyoming to southern Colorado, widespread burning in 1880 was recorded in early, albeit fragmentary, documentary sources (Jack 1900; Plummer 1912; Ingwall 1923), as well as in tree-ring studies of fire history (see Skinner and Laven 1983; Zimmerman and Laven 1984; Goldblum and Veblen 1992; Kipfmueller and Baker 2000; Veblen and others 2000; Brown and others 1999). Other individual years that recorded fire scars at disjunct locations over this large area include 1654, 1684, 1809, 1813, 1842, 1851,1859 to 1860, 1871 to 1872, 1879 to 1880, and 1893 to 1894 (Kipfmueller and Baker 2000; Alington 1998; Brown and others 1999; Veblen and others 2000; Donnegan 2000; Sherriff and others 2001; Sibold 2001). Such synchrony of fire years suggests that at a regional scale extreme weather increases fire hazard over extensive areas from southern Wyoming to southern Colorado. Indeed, tree rings sampled at numerous sites in northern Colorado (Cook and others 1998; Veblen and others 2000) indicate that all of the major fire years listed above correspond with significant drought during the year of the fire and/or the year immediately preceding the fire year. Over the period from 1800 to 1900, reconstruction of the Palmer Drought Severity Index indicates that the three driest years were 1842, 1851, and 1880 (Cook and others 1998), which were years of widespread burning in the Front Range (see fig. 2). The tree-ring record of drought and fire occurrence indicates that over the past several hundred years, fire years of similar extent to the year 2002 have occurred numerous times.

A comparison of fire occurrence and climatic variation from 1600 to the present, based on tree-ring records collected from ponderosa pine and associated conifers, indicates that fire is strongly associated with interannual climatic variation in the montane zone of the northern Colorado Front Range (Veblen and others 2000). Warmer and drier spring-summer seasons, indicated in instrumental climatic records (1873 to 1995) and in tree-ring proxy records of climate (1600 to 1983), are strongly associated with years of widespread fire. Years of widespread fire in the ponderosa pine cover type also tend to be preceded by 2 to 4 years of wetter than average spring conditions. Thus, years of widespread fire tend to occur during dry years closely following years of above average moisture that increase the production of fine fuels (Veblen and others 2000). Alternation of wet and dry periods lasting 1 year to a few years is conducive to the occurrence of large fires and is strongly linked to El Niño-Southern Oscillation (ENSO) events. The warm (El Niño) phase of ENSO is associated with greater moisture availability during spring, resulting in abundant production of flammable herbaceous material that burns in a subsequent dry year. Conversely, dry springs associated with La Niña events were followed by more widespread fire during the same year (Veblen and others 2000). There is a highly similar pattern of ENSO influences on fire occurrence in Pike National Forest (Donnegan 2000). A similar pattern of ENSO and fire for Arizona and New Mexico (Swetnam and Betancourt 1992, 1998) indicates a regionally extensive association of fire and ENSO activity in the Southern Rocky Mountains. Because regional weather patterns are driven by other circulation features in addition to ENSO, which has only a relatively weak influence on the Front Range (Woodhouse 1993), not all major fire years are directly linked with ENSO events. Nevertheless, many of the years of most widespread fire in the past are associated with ENSO events.

The period from about 1780 to 1830 was a time of reduced ENSO activity, which is manifested as reduced year-to-year variability in tree-ring widths in the Southwest (Sweetnam and Betancourt 1998) and the Colorado Front Range (Donnegan 2000; Veblen and Kitzberger 2002). During this interval, the difference between El Niño and La Niña extremes may have been damped or such events may have occurred less frequently. In the Colorado Front Range this time period of reduced alternation of wet and dry periods coincides with reduced fire occurrence in the montane zone (Veblen and others 2000; Donnegan 2000; Donnegan and others 2001; Brown and others 1999). Fewer or less extreme ENSO-related cycles of wet, fuel-producing El Niño events closely followed by dry La Niña events may explain this period of reduced fire occurrence. In contrast, the second half of the 19th century was a time of increased ENSO activity (Michaelsen and Thompson 1992), and in the Colorado Front Range, of increased variability of tree-ring widths and of fire occurrence. Based on tree-ring evidence from sites widely dispersed in the Front Range, after 1840 there is a gradual increase in the variability of tree-ring widths in the late 1800s (Donnegan 2000; Donnegan and others 2001; Veblen and Kitzberger in 2002). Increased variability in tree-ring widths may indicate greater ENSO variability at that time and in conjunction with increased ignitions by humans (see below) probably accounts for the increase in fire occurrence during the latter half of the 19th century. The mid- and late-19th century was also characterized by numerous years of severe drought (Cook and others 1998), whether related to ENSO activity or not, and widespread fires are recorded by fire scars in the Front Range during this period.

The increase in fire occurrence during the second half of the 19th century, associated with climatic variation, is evident in both montane and subalpine forests of the Front Range. However, there are important differences between the montane and subalpine zone in the sensitivity of fire to climatic variation. In montane forests of ponderosa pine, years of widespread fire generally are dry years that follow years of above-average moisture availability with a lag of 2 to 4 years (Veblen and others 2000). In contrast, at high elevations major fire years are dependent only on severe drought and do not require prior periods of fuel-enhancing increased moisture availability (Sherriff and others 2001).

Changes in Fire Regimes of the Front Range During the Past 150 Years

A key question underlying much of the current debate on fire management policy has to do with the extent to which the large, severe fires of 2000 and 2002 should be attributed to unnatural fuels build up during the 20th century period of fire exclusion. The answer is different for different forest types, different geographic regions, and different historical fire regimes. Therefore, in this section we assess the magnitude and significance of changes in fire *frequency* (number of fires per year in a region, or interval between successive fires in a single forest stand) and fire *severity* (table 1) for each of the three historical fire regimes described above for the Colorado Front Range (table 3).

Tree-ring records document a pattern of reduced fire frequency (table 1) during the 20th century in the lower to middle-elevation forests of the Front Range and nearby areas (Rowdabaugh 1978; Laven and others 1980; Skinner and Laven 1983; Goldblum and Veblen 1992; Alington 1998; Brown and others 1999; Veblen and others 2000). The modern fire exclusion period began in the early 1900s as a result of two key changes: suppression of lightning-ignited fires and cessation of widespread burning by humans (intentional as well as accidental ignitions by early settlers and Native Americans). Reductions in herbaceous fuels due to heavy grazing in the late 19th and early 20th centuries also contributed to the decline in fire frequency near the turn of the century, which in many studies predates effective fire-suppression technology by one or several decades (Veblen 2000).

The magnitude and significance of the 20th century decline in fire frequency varies significantly with forest type and elevation. In general, the impact of 20th century fire exclusion on fire frequency has been greatest at the lowest elevations in open forests dominated by ponderosa pine. In these ecosystems, where fires formerly were frequent but generally of low severity, 80-plus years of fire exclusion during the 20th century generally has permitted a buildup of woody fuels, which in turn may lead to greater severity in today's fires. However, the importance of 20th century fire exclusion in altering fuel conditions and fire severity becomes progressively less with increasing elevation, because natural fire intervals generally increase with elevation. Twentieth-century fire exclusion generally has had the least impact in subalpine forests dominated by spruce, fir, lodgepole pine, and limber pine. In mid-elevation forests with a large component of ponderosa pine (including forests codominated by Douglas-fir), the reduction in fire frequency also is more pronounced at lower elevations than at higher elevations (Veblen and others 2000). Consequently, changes in fuels conditions as a result of fire exclusion are likely to be greatest at the lowest elevations, where historical fire regimes were dominated by frequent low-severity fires, and least at the highest elevations, within infrequent high-severity fire regimes.

Although frequent low-severity fire regimes at the lowest elevations in the Front Range clearly have been altered by 20th century fire exclusion, it is questionable whether fire exclusion really has changed the fire regime of subalpine forests in the Front Range in any ecologically significant way. It is true that numerous small fires have been suppressed in the last century. However, these fires likely would have remained relatively small even without fire suppression because large subalpine fires occur only under severe fire weather conditions – conditions in which fires generally cannot be suppressed even with modern firefighting technology. Fires igniting at lower elevations probably burned into high-elevation forests in the past, and such fires have now been largely eliminated; however, just like locally ignited fires, fires spreading into the subalpine zone from below would be unlikely to cover much area except under severe fire weather conditions – conditions that occur rarely in this moist, high-elevation environment (Sheriff and others 2001; Sibold 2001). A large part of the spruce-fir cover type in the Front Range has not been significantly affected by fire for more than 400 years (Sibold 2001; Kulakowski 2002). Consequently, even if fire suppression were effective, there has not been a long enough period of fire exclusion to move the fire regime far outside of its historical range of variability. Moreover, periods of 80 to well over 100 years of no widespread (that is, more than 100 ha) fires in study areas of 4,000 ha or more are typical of the pre-1900 historical fire regimes of the spruce-fir cover type of the Front Range (Sibold 2001; Kulakowski 2002). Given these naturally long intervals between widespread fires in spruce-fir forests, the paucity of high-elevation fires since the onset of fire exclusion around 1910 is not outside the historical range of variability for this cover type.

Fire severity in subalpine forests also does not appear to have been altered significantly by 20th century fire exclusion because these forests are naturally characterized by infrequent but high-severity, stand-replacing fires occurring under severe fire weather conditions. For example, the severe fires that occurred in 2002 in spruce-fir forests in the Park Range, on the White River Plateau, and in the San Juan Mountains of Colorado probably were well within the historical range of variability for fire severity and fire size in these ecosystems. Indeed, it is important to stress that severe and widespread fires are a natural feature of lodgepole pine and spruce-fir forests of the Colorado Front Range and elsewhere in the Southern Rocky Mountains. Thus, the premise that fire exclusion has created unnatural fuel buildup in spruce-fir forests of the Front Range is *not* supported.

We can make a reasonable generalization that 20th century fire exclusion has significantly altered the frequent low-severity fire regimes at the lowest elevations but has not significantly altered the infrequent high-severity fire regimes at the highest elevations in the Front Range; however, no such simple interpretation is possible for the mixed-severity fire regimes of middle elevations. Given the inherent complexity and variability of mixed-severity fire regimes, we need more detailed, site-specific analyses to assess the impact of fire exclusion on fire frequency and severity. The Hayman Fire occurred within a landscape that historically was dominated by a mixed-severity fire regime, so with the conceptual background just developed, we now take a close look at the fire history and recent fire effects in the landscape where the 2002 Hayman Fire occurred.

Historical Fire Regimes and 20th Century Changes in the Hayman Area

Most of the Hayman Fire burned in montane ponderosa pine/Douglas-fir forest, with a small amount of mixed conifer forest on Thunder Butte and some subalpine forest in the Lost Creek Wilderness Area. Thus, the Hayman Fire occurred within an area where the historical range of variability was characterized primarily by a mixed fire regime (table 3). The other two types of historical fire regimes described in table 3 (frequent, low-severity fires and infrequent, high-severity fires) probably are *not* well represented in the Hayman Fire perimeter, though they characterize some small areas within the Hayman burn. However, these other types of fire regimes cover extensive portions of the Front Range, and one or both of them likely would have been major components of the burned ecosystem had the fire occurred just a few miles farther north in the Front Range or had it burned farther to the east.

Human impacts and land use patterns in the Hayman Fire area are similar to those in the ponderosa pine/Douglas-fir vegetation zone throughout much of the Colorado Front Range. Sources of information include fire history studies at Cheesman Lake (described below); fire history at other South Platte watershed locations (Donnegan and others 2001; Huckaby and others unpublished data); the Jack (1900) report on forest resources; a historical summary of human activities in the South Platte watershed (Pike National Forest historical review); General Land Office field notes recorded during the 1870s and 1880s (USGS, Lakewood, CO); and fire histories and assessments of historical human impacts in other Front Range locations (Veblen and Lorenz 1991; Veblen and others 2000; Brown and Shepperd 2001). As with nearly the entire Front Range montane zone, fire exclusion has affected the Hayman area and the surrounding South Platte watershed, beginning with the effects of logging and grazing in the 19th century and continuing with fire suppression policies during the 20th century. Grazing continues in limited areas, but most grazing allotments ended in the mid-1900s. Logging also tapered off during the 20th century and has been limited during the last few decades. Changes in stand structure and landscape structure of Front Range forests during the past 150 years are discussed in more detail in the next part of this chapter.

Historical and Recent Fire Frequency in the Hayman Area

We have detailed information on pre-1900 fire regimes in the 35-km^2 Cheesman Lake landscape and an adjacent study area along Turkey Creek in the Pike National Forest, both of which lie largely within the perimeter of the Hayman Fire (fig. 3). Both areas are dominated by ponderosa pine/Douglas-fir forest and probably are representative of much of the area burned in the Hayman Fire. The Cheesman landscape, owned by Denver Water, had never been logged, and grazing had not occurred since 1905 (Kaufmann and others 2000a,b). Thus, the Cheesman studies done prior to the Hayman Fire provide exceptional insight into historical fire regimes and other factors affecting historical landscape conditions in the Hayman Fire area. Fire history was studied at more than 150 sites in the Cheesman and Turkey Creek landscape. The earliest fire scars observed were formed in 1197, and coarse woody debris over 1,000 years old was found (Brown

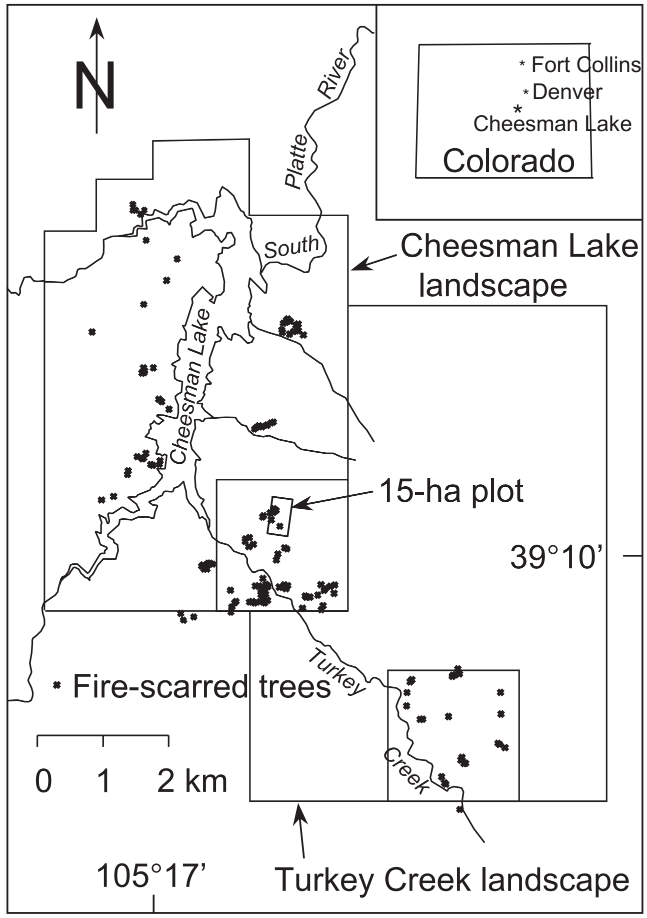

Figure 3—Map of Cheesman Lake and adjacent area in Turkey Creek (taken from Kaufmann and others 2000a).

and others 1999). Ages of live trees dating to the late 1300s were measured (Huckaby and others 2001).

During the six centuries prior to 1880, for which good fire history records were available from fire scars, fire intervals at Cheesman Lake varied from relatively frequent fires to moderate fire intervals to one long interval (fig. 4). During the 1300s and 1400s, the mean fire interval in an old-tree cluster near the south end of the Cheesman landscape was 16.8 years (Brown and others 1999). From about 1500 to the late 1800s, a series of widespread fires (5 km^2 or larger) occurred with longer intervening periods, each burning portions of the Cheesman landscape (Brown and others 1999). These fires occurred in 1534, 1587, 1631, 1696, 1723, 1775, 1820, 1851, and 1880. When the Cheesman fire history data for this period were analyzed for individual 0.5 to 2.0 km^2 portions of the landscape, the mean fire interval was 50 years (Kaufmann and others 2001). A limited number of fires in intervening years scarred one to several trees. It is unknown how many such fires occurred without scarring trees, or how large such fires might have been, but tree age data (below) suggest that the effects of these fires on the forest structure were relatively minor.

Since 1880, only one fire is known to have killed trees in the overstory – a 25 to 40 ha fire in the dry summer of 1963. In addition, a Cheesman caretaker reported an unsuppressed low-intensity fire during the summer in the early 1950s, burning in the northwest portion of the Cheesman landscape, but apparently this fire had limited effect on the overstory. The complete absence of large fires during the 20^{th} century was primarily the result of fire suppression: in recent years, 10 to 12 ignitions were suppressed annually, some under dry weather conditions that could have supported a moderate to large fire (Bill Newbury, personal communication). Had there been no fire suppression, it is likely that at least one extensive fire

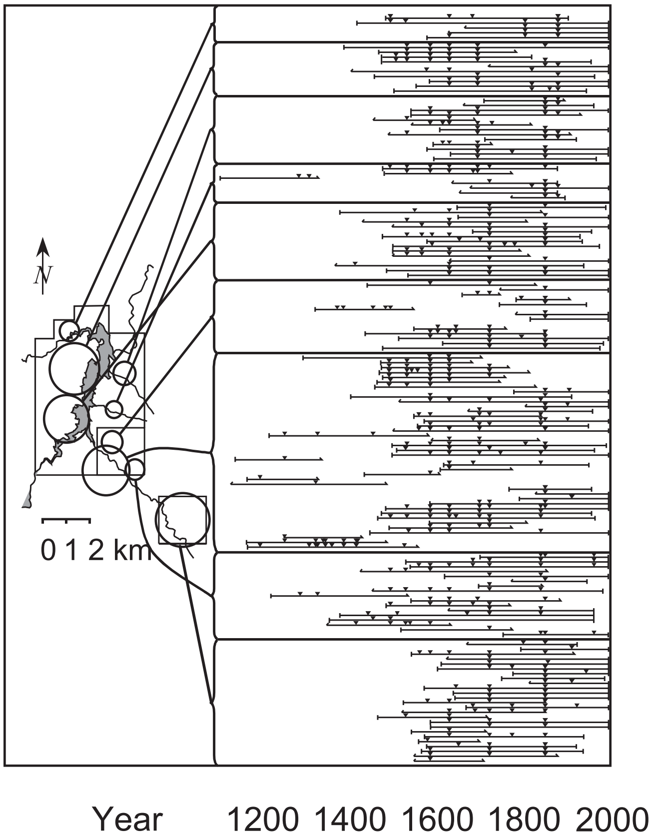

Figure 4—Cheesman Lake fire history (taken from Kaufmann and others 2000b).

would have affected this area during the 20th century (in 1963), and possibly two or more extensive fires would have occurred (for example, the questionable 1950s fire, and possibly others that were suppressed). Thus, there seems little question that fire exclusion affected the 20th century fire history of the Cheesman landscape; however, the number of fires effectively excluded in this area probably was far fewer than the number of fires excluded in some other ponderosa pine ecosystems, for example, in northern Arizona.

The long period of no fires or only minor fires ended abruptly with the 2002 Hayman Fire, which burned as an active crown fire over nearly all of the 35-km^2 Cheesman Lake landscape. Prior to the Hayman Fire, the most recent widespread fires had occurred in 1851 in the southern portion of the landscape and in 1880 in the northern portion (Brown and others 1999). The intervals between these historical fires and the 2002 fire were 151 and 122 years respectively – substantially longer than the average 50-year interval between large fires during the pre-1900 period.

Historical and Recent Fire Sizes

The spatial extent of the larger historical fires at Cheesman cannot be determined, because locations of fire scars extended to the edge of the sampled area. Nonetheless, it is clear that several fires exceeded 5 km^2, some exceeded 10 km^2, and at least one (1631) burned in all areas sampled (nearly 40 km^2; Brown and others 1999).

The Hayman Fire was large (550 km^2) but probably not unprecedented in the fire history of the Colorado Front Range where disjunct fire history samples show fire occurrence in the same year over similar extents of the montane zone of ponderosa pine-dominated forests (Veblen and others 2000). Several of the fire years at the Cheesman Lake study area also were prominent throughout the Front Range and Western United States, including 1631 and 1851 (fig. 2), indicating extensive, landscape-scale fires. Thus, the Hayman Fire probably was not unusually large in comparison with large historical fires. However, the patterns of fire severity within the overall perimeter of the Hayman Fire were unlike the patterns in pre-1900 fires within the Cheesman study area.

Historical and Recent Patterns of Fire Severity

Tree age data can indicate the severity of past fires. Where extant trees predate a known fire, it is clear that the fire was not completely stand-replacing. However, where all trees postdate a past fire, it is likely that the fire had killed all trees existing at that site (Kaufmann and others 2000a,b). Pre-1900 fires at Cheesman were stand-replacing in places but burned through the forest floor without causing significant tree mortality in other places, demonstrating that this ecosystem was characterized by a mixed-severity fire regime (table 3).

For the period of more frequent fires in the 1300s and 1400s, tree age data are too limited to evaluate fire severity, but it is likely that these fires, recurring at relatively short intervals, were predominantly low-intensity surface fires that left behind many surviving trees in the overstory. During the period from 1500 to 1880, however, extensive tree age data from more than 200 randomly sampled forested patches (Huckaby and others 2001; unpublished data of M. R. Kaufmann), coupled with the spatial heterogeneity of the landscape, indicate clearly that fires during this period were mixed in severity, having both a lethal component that created openings and a nonlethal component that left many surviving trees (Kaufmann and others 2000a,b; 2001). The 1851 fire created treeless openings in the forest that were still present in 2002. Old dead trees found on the ground in those openings were charred by fire, and dating of the outermost tree ring indicated that they had been killed in the 1851 fire. In some places within the 1851 burn area, patches of trees all postdated the1851 fire, indicating they had germinated after the fire killed the canopy that was present at that time. But in other patches, some extant trees predated 1851, indicating that the fire was not lethal to all trees in those locations.

In the Cheesman study area, the largest persistent opening created by past fires was no more than about 1 to 1.5 km^2, and the greatest distance to 300 to 400 year old trees was no more than 500 to 600 m (unpublished data of Kaufmann, Huckaby, Stoker, and Fornwalt). The tree age data indicate that on average, less than 20 percent of each fire was stand-replacing, and that stand replacement occurred as small patches dispersed in the fire area.

In the 2002 Hayman Fire, severity also varied spatially, but the patterns were dramatically different from the patterns created by historical fires in the Cheesman study area. Roughly half of the total Hayman Fire area (28,000 ha) burned at a severity great enough to kill all trees either by crown fire or lethal scorching of tree crowns. In other portions of the Hayman Fire, severity was low and overstory mortality was limited, and some areas within the fire perimeter did not burn at all. Nevertheless, both the total acreage and relative proportion of the Hayman Fire that produced lethal effects on the forest canopy far exceeded anything documented historically in the Cheesman landscape. During the five centuries for which we have historical fire data for the 35-km^2 Cheesman landscape, the largest area of complete mortality was no more than 1 to 1.5 km^2. In the Hayman Fire, however, most of this 35- km^2 area burned severely in just 1 day. Almost no trees survived within this exceptionally large patch of severe fire, and only small, widely spaced patches of surviving forest now remain.

Historical and recent Fire seasonality

Most large historical fires scarred numerous individual trees in different portions of their annual ring growth that represent different portions of the growing season or the spring/fall dormant period (Brown and others 1999). This indicates that large historical fires typically burned over an extended period, perhaps several weeks or even months, creeping slowly or residing in logs or litter most of the time, but increasing in intensity for brief periods during which trees were killed. In dramatic contrast to the pattern exhibited by historical fires, the major high severity portion of the Hayman Fire burned in a single day – an event of a spatial and temporal scale unprecedented in the fire history at Cheesman Lake.

Conclusions: Was the Hayman Fire a "Natural" Ecological Event?

Comparing the 2002 Hayman Fire with the historical fire record developed in the Cheesman Lake study area and elsewhere in the Front Range, we conclude that there is no simple answer to the question whether the Hayman Fire was a "natural" or unprecedented fire event in the ecological history of this region. We do conclude that the size of the Hayman Fire – that is, the total area burned – was not unusual either for the Cheesman landscape or for the Front Range in general. Many historical fires that occurred during extremely dry summers (for example, in 1851) appear to have been as large as the Hayman Fire or even larger. The fact that portions of the Hayman Fire were high-severity and stand-replacing also was not unusual for the Cheesman landscape or the Front Range; many pre-1900 fires contained a significant stand-replacing component wherever historical fire regimes were of either the infrequent high-severity or the mixed-severity type.

However, two features of the Hayman Fire are unprecedented in the historical record of the Cheesman area. First is the size and homogeneity of the patches of high-severity, stand-replacing fire in 2002. None of the fires documented from the early 1300s through 1880 created such a large contiguous patch of severe stand-replacing fire as was created on June 9, 2002. Second is the seasonality of fire: large fires before 1880 usually burned for several weeks or months, encompassing a wide range of weather conditions and fire behavior; whereas nearly half of the area burned in 2002 was burned in a single day of extreme fire weather, and the entire Hayman area burned in a period of only 3 weeks during early summer.

Placing the Hayman Fire into the context of the entire Front Range, the size of the severely burned patch created on June 9 is less unusual. Indeed, large, contiguous patches of stand-replacing fire are typical of subalpine forests characterized by an infrequent high-severity fire regime. However, the Hayman Fire was not in the subalpine zone; it was in the middle-elevation zone where a mixed-severity fire regime prevailed historically. Given the great variability of this type of fire regime, it is possible that similarly large patches of stand-replacing fire have occurred in other portions of the Front Range montane zone in the last several centuries. We have no direct evidence of such a large severe patch elsewhere in the Front Range montane zone, but neither has such a patch been explicitly searched for. Therefore, all that we can definitively conclude about patch sizes is that such a large patch of severe stand-replacing fire is unprecedented in the past 700 years within the 35-km^2 Cheesman landscape that is situated near the center of the Hayman Fire.

Acknowledgments

We thank Paula Fornwalt, Jason Stoker, and Laurie Huckaby for their contributions to the Cheesman Lake research, and Natasha Kotliar for discussions about fire ecology in Front Range forests. Greg Aplet, Bill Baker, Marcia Patton-Mallory, Wayne Shepperd, and Tom Swetnam provided helpful reviews of early drafts. This work was supported by the USDA Forest Service, Rocky Mountain Research Station.

References

Agee, J. K. 1998. The landscape ecology of western forest fire regimes. Northwest Science 72 (special issue):24-34.

Alington, K. 1998. Fire history and landscape pattern in the Sangre de Cristo mountains, Colorado. Ph.D. Dissertation, Colorado State University, Fort Collins, Colorado.

Allen, C. D., M. Savage, D. A. Falk, K. F. Suckling, T. W. Swetnam, T. Schulke, P. B. Stacey, P. Morgan, M. Hoffman, and J. T. Klingel. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: a broad perspective. Ecological Applications 12:1418-1433.

Aplet, G.H., R.D. Laven, and F.W. Smith. 1988. Patterns of community dynamics in Colorado Engelmann spruce and subalpine fir forests. Ecology 69:312-319.

Baker, W.L. 2002. Indians and fire in the Rocky Mountains: the wilderness hypothesis revisited. Pages 41-76 in: Vale, T.R. (editor), Fire, native peoples, and the natural landscape. Island Press.

Brown, P.M., M.R. Kaufmann, and W.D. Shepperd. 1999. Long-term, landscape patterns of past fire events in a montane ponderosa pine forest of central Colorado. Landscape Ecology 14:513-532.

Brown, P.M., and W.D. Shepperd. 2001. Fire history and fire climatology along a 5^0 gradient in latitude in Colorado and Wyoming, USA. Paleobotanist 50:133-140.

Christensen, N.L., A.M. Bartuska, J.H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J.F. Franklin, J.A. MacMahon, R.F. Noss, D.J. Parsons, C.H. Peterson, M.G. Turner, and R.G. Woodmansee. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. Ecological Applications 6:665-691.

Clagg, H.B. 1975. Fire ecology in high-elevation forests in Colorado. Masters Thesis, Colorado State University, Fort Collins, Colorado.

Cook, E.R., D.M. Meko, D.W. Stahle, and M.K. 1998. Reconstruction of past drought across the coterminous United States from a network of climatically-sensitive tree-ring data. Available online at

Covington, W. W., and M. M. Moore. 1994. Southwestern ponderosa forest structure: changes since Euro-American settlement. Journal of Forestry 92:39-47.

Donnegan, J. 2000. Climatic and human influences on fire regimes in Pike National Forest. Ph.D. Dissertation, University of Colorado, Boulder, Colorado.

Donnegan, J., T.T. Veblen, and J.S. Sibold. 2001. Climatic and human influences on fire history in Pike National Forest, central Colorado. Canadian Journal of Forest Research 31: 1526-1539.

Ehle, D. S., and W. L. Baker. In press. Disturbance and stand dynamics in ponderosa pine forests in Rocky Mountain National Park, USA. Ecological Monographs.

Fulé, P.Z., W.W. Covington, and M.M. Moore. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecological Applications 7:895-908.

Goldblum, D. and T.T. Veblen. 1992. Fire history of a ponderosa pine/Douglas-fir forest in the Colorado Front Range. Physical Geography 13:133-148.

Hadley, K.S. and T.T. Veblen. 1993. Stand response to western spruce budworm and Douglas-fir bark beetle outbreaks, Colorado Front Range. Canadian Journal of Forest Research 23:479-491.

Heyerdahl, E. K., L. B. Brubaker, and J. K. Agee. 2001. Spatial controls of historical fire regimes: a multiscale example from the Interior West, USA. Ecology 82:660-678.

Huckaby, L. S., M. R. Kaufmann, J. M. Stoker, and P. J. Fornwalt. 2001. Landscape patterns of montane forest age structure relative to fire history at Cheesman Lake in the Colorado Front Range. In Vance, R. K., W. W. Covington, and C. B. Edminster (tech. coords.), Ponderosa pine ecosystems restoration and conservation: steps toward stewardship. U.S. Department of Agriculture Forest Service Rocky Mountain Research Station Proc. RMRS-P-22: 19-27.

Ingwall, H. 1923. History: Pike National Forest. USDA Forest Service, Historic Report of the Recreation Assistant, Pueblo, Colorado.

Jack, J.G. 1900. Pikes Peak, Plum Creek, and South Platte Reserves. Twentieth annual report of the United States Geological Survey to the Secretary of the Interior, 1898-1899. United States Government Printing Office, Washington, D.C.

Johnson, E. A. 1992. Fire and vegetation dynamics: Studies from the North American boreal forest. Cambridge Studies in Ecology, Cambridge University Press.

Kaufmann, M. R., P. J. Fornwalt, L. S. Huckaby, and J. M. Stoker. 2001. Cheesman Lake – a historical ponderosa pine landscape guiding restoration in the South Platte watershed of the Colorado Front Range. In Vance, R. K., W. W. Covington, and C. B. Edminster (tech. coords.), Ponderosa pine ecosystems restoration and conservation: steps toward stewardship. U.S. Department of Agriculture Forest Service Rocky Mountain Research Station Proc. RMRS-P-22: 9-18.

Kaufmann, M.R., R.T. Graham, D.A. Boyce, Jr., W.H. Moir, L. Perry, R.T. Reynolds, R.L. Bassett, P. Mehlhop, C.B. Edminster, W.M. Block and P.S. Corn. 1994. An ecological basis for ecosystem management. USDA Forest Service, General Technical Report RM-246.

Kaufmann, M. R., L. Huckaby, and P. Gleason. 2000b. Ponderosa pine in the Colorado Front Range: long historical fire and tree recruitment intervals and a case for landscape heterogeneity. Proc. Joint Fire Sci. Conf. and Workshop, Boise, ID, Vol. 1, pp. 153-160.

Kaufmann, M.R., C.M. Regan, and P.M. Brown. 2000a. Heterogeneity in ponderosa pine/Douglas-fir forests: Age and size structure in unlogged and logged landscapes of central Colorado. Canadian Journal of Forest Research. 30:698-711.

Kipfmueller, K.F. and W.L. Baker. 2000. A fire history of a subalpine forest in southeastern Wyoming, USA. Journal of Biogeography 27:71-85.

Kulakowski, D. 2002. Interactions among natural disturbances in subalpine forests in northwestern Colorado. Ph.D. dissertation, University of Colorado, Boulder, CO.

Kulakowski, D. and T.T. Veblen. 2002. Influences of fire history and topography on the pattern of a severe blowdown in a subalpine forest in northwestern Colorado. Journal of Ecology 90: 806-819.

Landres, P., P. Morgan, and F. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9:1179-1188.

Laven, R.D., P.N. Omi, J.G. Wyant and A.S. Pinkerton. 1980. Interpretation of fire scar data from a ponderosa pine ecosystem in the Central Rocky Mountains, Colorado. USDA Forest Service, General Technical Report RM-81.

Michaelsen, J. and L.G. Thompson. 1992. A comparison of proxy records of El Niño/Southern Oscillation. Pages 323-346 *in* H.F. Diaz and V. Markgraf, editors, El Niño: historical and paleoclimatic aspects of the Southern Oscillation. Cambridge University Press, Cambridge.

Morgan, P., G.H. Aplet, J.B. Haufler, H.C. Humphries, M.M. Moore and W.D. Wilson. 1994. Historical range of variability: a useful tool for evaluating ecosystem change. Journal of Sustainable Forestry 2:87-111.

Parker, A.J. and K.C. Parker. 1994. Structural variability of mature lodgepole pine stands on gently sloping terrain in Taylor Park Basin, Colorado. Canadian Journal of Forest Research 24:2020-2029.

Peet, R. K. 1981. Forest vegetation of the Colorado Front Range: composition and dynamics. Vegetatio 45:3-75.

Peet, R.K. 1988. Forests of the Rocky Mountains. Pages 64-101 *in* M. G. Barbour and W.D. Billings, editors, North American terrestrial vegetation. Cambridge University Press, New York, New York.

Plummer, F.G. 1912. Forest fires: their causes, extent and effects, with a summary of recorded destruction and loss. USDA Forest Service, Bulletin 117.

Romme, W.H. and D.H. Knight. 1981. Fire frequency and subalpine forest succession along a topographic gradient in Wyoming. Ecology 62:319-326.

Rowdabaugh, K.M. 1978. The role of fire in the ponderosa pine-mixed conifer ecosystems. Ph.D. Dissertation, Colorado State University, Fort Collins, Colorado.

Schmidt, K.M., J.P. Menakis, C.C. Hardy, W.J. Hann, and D.L. Bunnell. 2002. Development of coarse-scale spatial data for wildland fire and fuel management. USDA Forest Service General Technical Report RMRS-GTR-87.

Sherriff, R. 2000. Fire history at high elevation in the Colorado Front Range. Masters thesis, University of Colorado, Boulder, CO.

Sherriff, R., T.T. Veblen, and J.S. Sibold. 2001. Fire history in high elevation subalpine forests in the Colorado Front Range. Ecoscience 8:369-380.

Sibold, J. 2001. The forest fire regime of an upper montane and subalpine forest, Wild Basin, Rocky Mountain National Park. Masters Thesis, University of Colorado, Boulder, CO.

Skinner, T.V. and R.D. Laven. 1983. A fire history of the Longs Peak region of Rocky Mountain National Park. Pages 71-74 *in* Proceedings of the seventh conference on fire and forest meteorology, April 25-28. American Meteorological Society, Boston, Massachusetts.

Swetnam, T.W., C.D. Allen, and J.L. Betancourt. 1999. Applied historical ecology: Using the past to manage for the future. Ecological Applications 9:1189-1206.

Swetnam, T. W., and C. H. Baisan. 1996. Historical fire regime patterns in the southwestern United States since AD 1700. Pages 11-32 in Allen, C. D. (technical editor). Fire effects in southwestern forests: proceedings of the second La Mesa fire symposium, Los Alamos, 1994. USDA Forest Service General Technical Report RM-GTR-286.

Swetnam, T.W. and J.L. Betancourt. 1992. Temporal patterns of El Niño/Southern Oscillation - wildfire teleconnections in the southwestern United States. Pages 259-270 *in* H.F. Diaz and V. Markgraf, editors, El Niño: historical and paleoclimatic aspects of the Southern Oscillation.

Swetnam, T.W. and J.L. Betancourt. 1998. Mesoscale disturbance and ecological response to decadal variability in the American Southwest. Journal of Climate 11:3128-3147.

Veblen, T. T. 2000. Disturbance patterns in Southern Rocky Mountain forests. Pages 31-54 in: Knight, R.L., F.W. Smith, S.W., Buskirk, W.H., Romme, and W.L. Baker (editors), Forest fragmentation in the southern Rocky Mountains. University Press of Colorado, Boulder, Colorado, USA.

Veblen, T.T., K.S. Hadley, E.M. Nel, T. Kitzberger, M.S. Reid, and R. Villalba. 1994. Disturbance regime and disturbance interactions in a Rocky Mountain subalpine forest. Journal of Ecology 82:125-135.

Veblen, T.T. and T. Kitzberger. 2002. Inter-hemispheric comparison of fire history: The Colorado Front Range, U.S.A. and the Northern Patagonian Andes, Argentina. Plant Ecology, in press.

Veblen, T.T., T. Kitzberger and J. Donnegan. 2000. Climatic and human influences on fire regimes in ponderosa pine forests in the Colorado Front Range. Ecological Applications 10:1178-1195.

Veblen, T.T. and D.C. Lorenz. 1986. Anthropogenic disturbance and recovery patterns in montane forests, Colorado Front Range. Physical Geography 7:1-24.

Veblen, T.T. and D.C. Lorenz. 1991. The Colorado Front Range: a century of ecological change. University of Utah Press, Salt Lake City, Utah.

Whipple, S.A., and R.L. Dix. 1979. Age structure and successional dynamics of a Colorado subalpine forest. American Midland Naturalist 101:142-158.

Woolsey, T. S. Jr. 1911. Western yellow pine in Arizona and New Mexico. U. S. Department of Agriculture Forest Service Bulletin 101. 64 p.

Woodhouse, C.A. 1993. Tree-growth response to ENSO events in the central Colorado Front Range. Physical Geography 14:417-435.

Zimmerman, G.T. and R.D. Laven. 1984. Ecological implications of dwarf mistletoe and fire in lodgepole pine forests. Pages 123-131 *in* G.G. Hawksworth and R.F. Scharpf, editors, Proceedings of the symposium on the biology of dwarf mistletoes. USDA Forest Service, General Technical Report RM-111.

Part 2: Historical (Pre-1860) and Current (1860-2002) Forest and Landscape Structure

William H. Romme, Merrill Kaufmann, Thomas T. Veblen, Rosemary Sherriff, and Claudia Regan

Introduction

The term "landscape structure" refers to the configuration of vegetation and other land features over a large land area (usually an extent of many square kilometers). A landscape can be regarded as a mosaic composed of patches of different kinds— for example, different forest types, landforms, or human-built structures such as roads. The scientific discipline of landscape ecology is concerned with quantitatively describing the features of landscape mosaics, including, for example, the variety of patch types, the sizes and shapes of patches, and how different patch types are juxtaposed (Forman 1995). Landscape ecology also is concerned with understanding how the structure of a landscape influences its function – for example, what kind of habitat it provides for various plant and animal species, or how water and nutrients or pollutants move from place to place (Turner and others 2001). Another critical aspect of landscape structure is how it influences the spread of disturbances – including fire.

We address this question about historical and recent landscape structure in the area burned by the Hayman Fire in two parts. First, to put the Hayman Fire of 2002 into context, we characterize the historical range of variability (HRV – see the part 1 in this chapter) in landscape structure of the major forest zones of the Colorado Front Range, and compare these reference conditions with current landscape structure. This comparison of current to reference conditions permits an assessment of the magnitude, causes, and significance of changes that have occurred in the last century, and identifies generally where in the Front Range the changes have been great or small. We then focus on the Hayman area itself, to identify the nature, magnitude, and significance of 20th century landscape changes within the area where the 2002 fire occurred. We begin with a general assessment of the Front Range as a whole before treating the Hayman area in detail for two reasons: first, the general overview provides a context for understanding the unique features of the Hayman landscape, and second, future Front Range fires are likely to occur in other forest zones that are not well represented in the Hayman area per se.

Historical Range of Variability and 20th Century Changes in Landscape Structure of the Colorado Front Range

Historical landscape structure varied substantially among the major forest zones in the Front Range, and the nature and magnitude of changes during the 20th century also vary greatly. Four general causes for changes in landscape mosaics during the last century include fire exclusion, logging, exurban development (dispersed, low-density housing), and climatic variability. The relative importance of each of these four factors is different among the various forest zones of the Colorado Front Range, and explicit recognition of these fundamental differences among forest types is critical if we are to accurately assess the causes of the wildfire hazards that we face in our contemporary mountain landscapes. Therefore, we characterize landscape structure separately for each forest zone in the sections below. See table 4 for a general summary of these changes and mechanisms, and also see part 1 of this chapter for descriptions of each forest zone and its historical fire regime.

The Subalpine Zone – As described in part 1 of this chapter, the historical fire regime in subalpine spruce-fir and lodgepole pine forests of the Front Range and nearby areas was characterized by infrequent but large, high-severity fires. The result was a landscape mosaic composed of large patches of even-aged forests developing through natural succession after fire. The locations and ages of patches fluctuated over the centuries as stands became older and as new fires burned through the patch mosaic created by earlier fires (Romme 1982; Kipfmueller and Baker 2000; Sibold 2001; Kulakowski and Veblen 2002). In high-elevation wilderness areas and other portions of the Front Range where logging and development have not occurred, this fundamental landscape mosaic is still much in evidence. Because fire frequency and severity in these forest types are controlled mainly by climate and weather, rather than by fuels conditions, and because fires naturally occurred at long intervals even before the 20th century (see part 1 in this chapter), the fire exclusion practices of the last century probably have had only a modest impact on subalpine landscape mosaics.

However, spruce-fir and lodgepole pine forests in some areas have been altered by logging, including both selective cutting during the late 19th century and commercial clearcut logging during the mid-20th century. Logging probably has reduced the extent of older stands compared to what existed before the late 1800s, but the magnitude of this reduction is unknown. Logging of large old lodgepole pine probably accounts in

Table 4—General summary of the major changes in landscape patterns within forested portions of the Colorado Front Range during the past 150 years. Local exceptions are to be expected in every zone. See text for details and caveats.

Zone	Historical landscapes	Current landscapes
Subalpine zone	Pattern: Large patches of even-aged forest. Mechanism: Infrequent, high-severity fires followed by forest succession … fires occurred only in dry years and were little influenced by variation in fuel conditions.	Pattern: Unchanged from the historical pattern, except where logging and exurban development have created new kinds of forest patches. Mechanism: Fire regimes have changed little if at all, but new kinds of disturbance (human induced) have been introduced.
Lower montane zone	Pattern: Open ponderosa pine forests intermingling with dense ponderosa pine patches, openings, and shrublands Mechanism: Dry site conditions and relatively frequent, low-severity fires, maintained open pine forests in most of the area, but patches of high-severity fire also produced openings and patches of dense forest or shrubland.	Pattern: Generally more homogeneous landscape mosaics containing greater proportions of dense forest than occurred historically … extensive road systems and exurban development in many areas. Mechanism: 20th century fire exclusion, plus late 19th and early 20th century grazing, logging, and climatic conditions (all conducive to tree growth and survival).
Montane zone (including the Hayman landscape)	Pattern: Heterogeneous patch mosaics, containing variably-sized patches of even-aged forest resulting from high-severity fires, interspersed with relatively open, multiaged forests maintained by periodic low-severity fire … forests dominated by ponderosa pine except on moist sites (such as north-facing slopes and higher elevations) where Douglas-fir co-dominated. Mechanism: A complex, mixed fire regime, including significant components of high-severity as well as low-severity fire, plus variation over time in fire extent and severity.	Pattern: More homogeneous patch mosaics than were prevalent historically (at least in some areas, but not in all), consisting of large patches of dense forest and small patches of open forest. … Douglas-fir dominates or codominates on moist sites, as well as other sites where it was historically uncommon or absent … extensive road systems and exurban development in some areas. Mechanism: A complex mix of 20th century fire exclusion, coupled with late 19th century logging, late 19th and early 20th century grazing, and in some areas late 19th century burning (resulting in synchronous forest succession over large areas), and 20th century climatic conditions (conducive to tree growth and survival) … relative importance of each varies across the Front Range.

large part for the scarcity of stands older than 200 years in USDA Forest Service data-bases. Increased burning during the late 19th century (see part 1 in this chapter) also appears to have increased the abundance of 100 to140 year old stands in the Araphaho–Roosevelt National Forest. The net effect may be a more homogeneous age and size structure than existed before the late 1880s. In general, however, changes in the fire regime and in overall landscape structure, especially as they relate to wildfire hazard, are less significant in the subalpine zone than in any of the other forest zones of the Front Range.

The Lower Montane Zone – During the pre-1860 reference period, ponderosa pine forests near the lower forest/grassland ecotone apparently were predominantly low-density stands with well developed herbaceous or shrub strata. This open forest structure resulted in part from the low precipitation at the foot of the mountains but also was maintained by periodic low-severity fires (see part 1 of this chapter) that killed many of the tree seedlings that became established in openings between canopy trees. This interpretation is supported by fire history data (that is, fire scars indicating composite fire intervals less than 20 years), tree age data, and historical photographs (Veblen and Lorenz 1991; Sherriff and Veblen in prep.). The total area of open ponderosa pine forest maintained by periodic low-severity fire was relatively small. For example, for the portion of the northern Front Range in Arapaho-Roosevelt National Forest modeling of fire regimes in relation to environmental factors indicates that less than 20 percent of the ponderosa pine zone fits a model of model of moderately frequent, low-severity surface fires (Sherriff and Veblen in prep.; and see part 1 of this chapter).

Fire exclusion in the 20th century has allowed tree seedlings to survive, which has led to denser stands throughout much of the lower montane zone in the Front Range. However, fire exclusion probably is not the only mechanism that has promoted greater tree densities in the lower montane zone during the last century (Mast and others 1998). Studies of grazed and ungrazed ponderosa pine forests in Utah and Washington suggest that livestock grazing since the late 19th century also may have promoted increases in tree establishment by reducing competition from herbaceous plants and creating patches of mineral soil, and extensive grazing did occur in the Front Range during this period. Logging also can disturb the soil and create ideal seed-beds for establishment of conifer seedlings, and logging was intense in these accessible low-elevation forests in the late 19th century. Finally, the climate of the Front Range in the early 20th century was relatively moist and conducive to tree establishment and survival. However, studies of tree age structures in relation to climatic variability and local patterns in grazing and logging have not yet been able to confirm clear patterns of past tree establishment in relation to climatic variation or other causal factors (Mast and others 1998). More research is needed to tease out the relative importance of late19th century burning, 20th century fire exclusion, logging, grazing, and climate in producing the dense forests that characterize much of the ponderosa pine zone today.

Although the mechanisms are not yet fully understood, it is clear that many of the formerly open ponderosa pine forests along the base of the Front Range have developed a very different stand structure during the 20th century. Many stands now have higher total tree densities, fewer large trees and snags, and more homogeneous tree age and size distributions than existed between 1700 and 1900 (Veblen and Lorenz 1986, 1991; Kaufmann and others 2000). These areas now are generally more vulnerable to high-severity fire than they were during the reference period, and probably also are more susceptible to some pathogens. This change in forest and landscape structure constitutes a serious wildfire hazard, especially because of the great amount of exurban development that has occurred in the lower montane zone of the Front Range.

The Montane Zone – Historical photographs and stand structural data (on abundance of young stems) clearly indicate that many or most of the forests of ponderosa pine and Douglas-fir at middle elevations in the Colorado Front Range have increased in tree density during the past approximately 100 years. This generalization applies to areas that today are nearly pure stands of ponderosa pine as well as to mixtures of ponderosa pine with Douglas fir. Several ecological mechanisms and interactions have contributed to this increase in tree density, and the relative importance of each mechanism may be different in any specific area of the Front Range.

Twentieth century fire exclusion clearly is one important mechanism that has contributed to increased tree densities in the montane zone of the Front Range. Many photographs of this region from the late 1800s and early 1900s show low-density ponderosa pine stands and visual evidence of recent fire occurrence (Veblen and Lorenz 1991; Kaufmann and others 2001), and certainly many fires have been excluded during the last century that might have burned large areas if left unsuppressed (for example, in 1963 in the Cheesman landscape; see part 1 in this chapter). The moist climatic conditions of the early 20th century and of the decades of the 1970s and 1980s also were favorable for tree establishment, which may have been enhanced also by the effects of grazing. Prescribed fires in the 1980s and 1990s killed many of the trees that had established in the 1960s and 1970s, but these fires were of limited extent and did not affect landscape patterns. If more extensive fires had occurred during the 20th century, it is likely that many more young trees would have been killed throughout much of the montane landscape, and overall forest densities would not be as high as they now are.

However, other mechanisms also have clearly contributed to increasing forest density during the 20th century. Douglas-fir forests and mixed ponderosa pine/Douglas-fir forests were dramatically transformed in many parts of the Front Range by logging in the late 19th and 20th centuries. These forests today tend to have high tree densities but few old trees or snags and are generally less diverse in size and age structure than what we believe were the conditions before 1860. Naturally increasing stand density associated with forest regeneration after widespread 19th century fires (see part 1 in this chapter) also has contributed to the young, even-aged structure seen today in many ponderosa pine and Douglas-fir stands (Veblen and Lorenz 1986; Ehle and Baker in press). The extensive burning and logging of Douglas-fir forests during the latter half of the 19th century resulted in synchronized regeneration over large areas of the montane zone. The combination of these two early Euro-American settlement activities has produced what appear to be unusually homogeneous tree age and size structures across much of the mid-elevation portion of the Front Range.

Although we do not yet fully understand the relative contributions of 20th century fire exclusion and recovery from late 19th century logging and burning in creating the dense forests that characterize much of the montane zone today, most would agree that the diversity of stand structures at a landscape scale generally has been reduced in comparison with the pre-1860 reference period. Based on tree ages obtained from the relatively small area that escaped logging and recent burning, we know that the pre-1860 landscape included even-aged patches of trees resulting from previous stand-replacing fires, as well as patches of all-aged forest in which fires had repeatedly burned with lower severity (Veblen and Lorenz 1986; Kaufmann and others 2000; Ehle and Baker in press). The availability of spatially explicit data on past forest structures is insufficient to allow quantitative estimates of past vegetation structures for the montane zone as a whole. However, it is known that areas of meadow and relatively open, fire-maintained woodlands were juxtaposed with areas of dense ponderosa pine and Douglas-fir forest – a complex mosaic maintained in part by the complex mixed-severity fire regime that characterized this zone (see part 1 of this chapter). The increasing homogeneity of landscape structure in the montane zone during the last century, as a result of multiple and interacting ecological factors, probably has increased the chances of large, severe fires in Douglas-fir and mixed ponderosa pine/ Douglas-fir forests of the Colorado Front Range. In addition, extensive outbreaks of mountain pine beetle (*Dendroctonus ponderosae*) and other native tree-killing insects have occurred periodically, most recently in the late 1970s and early 1980s, creating snags and dead woody fuels that further contribute to potential fire severity.

One additional significant impact on the landscape mosaics of the montane zone of northern Colorado is exurban development (Theobald 2000). The proliferation of homes and roads in some areas during the last half-century has been dramatic. The major effect of new roads and homes on the landscape mosaic has been to fragment the forests; that is, to create potentially smaller patches than characterized the pre-1900 landscape. Another effect of exurban development in the montane zone, of course, has been to put a great many people and homes into an environment that is naturally characterized by periodic fires, including high-severity fires.

Historical Range of Variability and 20th Century Changes in Landscape Structure Within the Hayman Fire Area

Most of the forest area burned in the 2002 Hayman Fire was ponderosa pine and Douglas-fir forest, which was characterized historically by a mixed-severity fire regime (see part 1 of this chapter). The landscape mosaic during the reference period in the area of the Hayman Fire and surrounding areas in the South Platte watershed included patches of even-aged forest developing after stand-replacing fires, as well as patches of multiaged forest affected by periodic low-severity fires, and small tree-less openings that resulted from locally severe fire events followed by poor tree regeneration (Brown and others 1999).

Fire exclusion within the South Platte Watershed began with the effects of logging and grazing in the late 19th century and continued with the addition of active fire suppression during the 20th century. Grazing was probably never as intense in this area as in other parts of the West because of limited understory production. Grazing continues in limited areas, but most grazing allotments ended during the middle of the 20th century. Logging tapered off during the 20th century and has been limited during the last few decades.

Historical documents from the Pike National Forest indicate that logging progressed up the South Platte watershed during the 1870s to 1890s, reaching the east boundary of the Cheesman landscape by around 1895 (Jack 1900; De Lay 1989). Tree age data near the Cheesman landscape (Turkey Creek study area just southeast of the Cheesman boundary) indicate that large numbers of trees became established during the 1890s (Kaufmann and others 2000), apparently in response to the opening of the canopy and the localized disturbance of the soil associated with logging. Grazing also may have favored high seedling survival after logging by reducing competition prior to active fire suppression, and favorable climatic conditions during the early 20th century also may have enhanced survival of the young trees that established during this time. The importance of these two mechanisms is still not certain, but fire suppression also clearly contributed to tree survival. Regardless of the exact ecological mechanisms, it is well documented that the late 19th century and early 20th century was a time when great numbers of ponderosa pine and other tree species became established in the Hayman Fire area, as well as throughout the montane zone of the Colorado Front Range and elsewhere in the West.

Our most detailed information on historical landscape structure in the area of the Hayman Fire comes from research within the 35-km2 Cheesman Lake property owned by the Denver Water Board (Brown and others 1999; Kaufmann and others 2000, 2001; Huckaby and others 2001; Fornwalt and others 2002; Kaufmann and others 2003). Logging in the Cheesman landscape actually was limited to a few small areas near several old cabin sites, and grazing was excluded by a six-strand fence completed in 1905, coinciding with completion of the dam. Nonetheless, tree densities increased within the Cheesman landscape during the 20th century, just as in surrounding areas where logging and grazing impacts were much greater. Douglas-fir, a fire-sensitive species, showed an especially striking increase in density (Kaufmann and others 2000). Indeed, forest densities were nearly as high at the end of the 20th century in the unlogged and ungrazed Cheesman landscape as they were in the nearby Turkey Creek area, which was intensively logged and grazed. Thus, fire suppression apparently is the primary reason for increasing tree densities during the past 100 years in the Cheesman area (Kaufmann and others 2001; Fornwalt and others 2002).

Canopy cover (percent of ground beneath tree crowns) was estimated for the Cheesman Lake and Turkey Creek landscapes using 1:6000 color infrared aerial photographs taken in 1996 (fig. 5). These estimates indicate that 45 percent of the Cheesman landscape and 53 percent of the Turkey Creek study area had canopy cover of 35 percent or higher in 1996. This level of canopy cover is adequate to support active crown fires (fires that spread both on the ground and in the canopy) under typical wildfire conditions. Canopy cover in the Cheesman landscape in 1900 then was reconstructed, using the Forest Vegetation Simulator (FVS) program, to assess how forest density had increased during a century of fire suppression. The 1900 canopy cover reconstructions were confirmed with historical photographs in the Denver Water archives. These studies indicated that 93 percent of the Cheesman landscape in 1900 had a canopy cover of 30 percent or less, and only 7 percent was dense enough to support a crown fire (fig. 5). If the landscape mosaic that existed in 1900 also was generally typical of earlier times in the reference period (which presumably it was, given the fire history of the area), then this reconstruction suggests that historical forests, influenced by mixed severity fire behavior patterns, were generally more open and less prone to large-scale crown fires than current forests.

Thus, the historical Cheesman landscape was dominated by open stands of ponderosa pine with lesser amounts of Douglas-fir (primarily on north slopes), and forests were interspersed with openings created by high-severity fires. Even at higher elevations, where remnant ponderosa pine trees now exist within dense stands of fire-sensitive species such as Douglas-fir, fire evidently occurred with enough frequency in the past to limit competition from the less fire-resistant tree species. Many formerly pure ponderosa pine stands in and around the Cheesman landscape now have been replaced with ponderosa pine/Douglas-fir forests or mixtures with other species

Conclusions: Changes in Front Range Forests and Wildfire Hazards

An extensively large area in the Colorado Front Range is included within the "Red Zone," identified by the Colorado State Forest Service as a region where the risk of substantial loss of property and even human life to wildfire is very high (Sampson and others 2000). The "Red Zone" encompasses portions of all the major forest zones in the Front Range, from the lower montane to the subalpine (see part 1 of this chapter). However, the reasons for high fire hazard are not the same in all places (table 5). In lodgepole pine and spruce-fir forests of the subalpine zone, recent large severe fires are *not* an artifact of abnormal fuel build-up during 20th century fire exclusion. The high fuel loads that characterize most subalpine forests are the normal result of high forest productivity and long intervals between disturbances; fires only occur during periods of extremely dry weather when variation in fuel characteristics has less influence on fire behavior and intensity than the effects of wind and low humidity. In contrast, the extent of dense ponderosa pine forests in the lower montane zone probably has increased substantially during the last century as a result of fire exclusion and other human activities. Frequent, low-severity fires formerly maintained open forest structure and reduced potential for severe fire behavior in these areas along the base of the Front Range, whereas today we have many unusually dense stands that can support unusually severe fires relative to the reference period. One factor is consistent across all forest zones: a major reason for serious damage and loss in recent and future wildfires is the presence of extensive exurban development and other vulnerable developments such as water storage facilities within ecosystems where fire has always been an important and recurring ecological process.

The relative importance of natural fire hazards vsersus augmented hazards resulting from past and current human actions (such as fire suppression) is much less clear in the extensive montane zone at middle elevations in the Colorado Front Range. This zone was characterized historically by a mixed-severity fire regime, which included significant components of high-severity as well as low-severity fire, and by a heterogeneous landscape mosaic, including dense stands as well as more open stands. The extent to which 20th century fire exclusion has altered this fundamental fire regime and the resultant landscape mosaic throughout the Front Range is uncertain. Moreover, the magnitude of change probably is different in different parts of the montane zone. New research is needed to better understand the spatial variability in historical and contemporary disturbance regimes and landscape dynamics throughout the Front Range.

With respect to the Hayman Fire that occurred in the southern portion of the Front Range in 2002, it is clear that the contemporary forest and landscape structure contributed to the size and severity of the fire. The relatively homogeneous forest structure of the contemporary landscape provided continuous fuels which facilitated fire spread in the Hayman and other recent fires in the montane zone of the Front Range. Under severe fire weather conditions, today's forests of ponderosa pine and Douglas-fir often do not

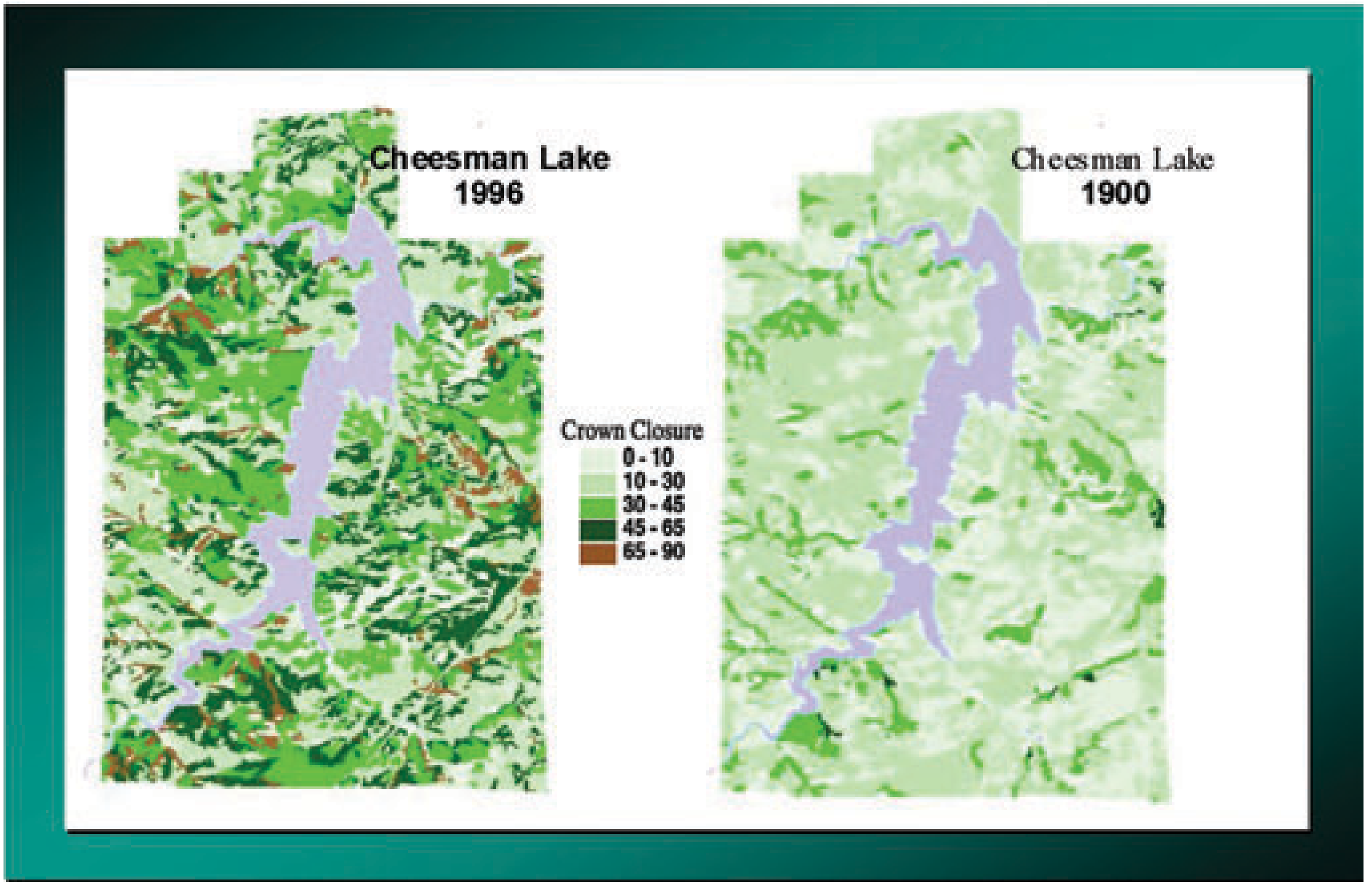

Figure 5. Recent and historical crown closure in the Cheesman Lake landscape (taken from Kaufmann and others 2001; also see Kaufmann and others 2003).

Table 5—General reasons for high wildfire hazard in the major forest zones of the Colorado Front Range. Local exceptions are to be expected in every zone; see text for details and caveats.

	Relative importance of factors contributing to current high wildfire hazard		
Forest zone	**Exurban development**	**20th century fire exclusion**	**Other late 19th and 20th centuries land uses (for example, logging and grazing)**
Subalpine	High	Low	Low
Lower montane	High	High	High
Montane	High	Moderate or variable	Moderate or variable

burn with the predominantly mixed-severity fire behavior that characterized historical fires in the Cheesman landscape, but tend to burn instead with predominantly intense fire behavior – much like that expected in higher-elevation lodgepole pine or spruce-fir forest (see part 1 of this chapter). This is evidenced by a series of fires since 1989 in the montane zone of the Front Range – Black Tiger, Buffalo Creek, Bobcat Gulch, Hi Meadows, Schoonover, and Hayman (see the chapter on fire behavior in this publication). Each of these recent fires had crown fire components that burned rapidly and with limited or no survival of trees over large areas, in contrast to historically more mixed fire behavior patterns reconstructed for the Cheesman landscape. As noted in part 1 of this chapter, the patch of severely burned forest created on June 9 was larger than in any fire in the Cheesman landscape from the early 1300s through 1880.

However, the extreme fire weather on June 9 also was an important contributing factor to the size and severity of the Hayman Fire, and other recent Front Range fires burned under extreme fire weather conditions as well. We need new research to better understand the relative importance of weather and fuels in controlling the behavior and impact of large fires in coniferous forests. Given the inherent complexity and variability of the mixed-severity fire regime that characterizes the montane zone, it is possible that large, severe fires comparable to the Hayman Fire did occur in Front Range forests of ponderosa pine and Douglas-fir during the pre-1860 reference period. For example, Elliott and Parker (2001) found geomorphic evidence for three severe, watershed-scale fire events that resulted in significant flooding and sedimentation – natural events that may have been similar to the severe sedimentation event that occurred after the severe 1996 Buffalo Creek Fire in the same area. The recurrence interval between these extreme events was long – 900 to 1,000 years — indicating that if fires like Hayman occurred in the Front Range montane zone during the pre-1860 reference period, they probably did not occur often in any particular watershed. However, no systematic search has been conducted for similar evidence of large severe fires in other watersheds during the historical period, so we cannot make any reliable inferences about the frequency or spatial pattern of such events.

What we can say with confidence is that the forests of the Cheesman study area and surrounding portions of the South Platte watershed were denser and more homogeneous in 2002 than they had been in the late 1800s, and that this landscape structure contributed to the severity of the Hayman Fire. Major uncertainties revolve around longer term variability of the landscape mosaic and the occurrence of extreme fire events in montane forests of the Front Range.

Acknowledgments

We thank Paula Fornwalt, Jason Stoker, and Laurie Huckaby for their contributions to the Cheesman Lake research, and Natasha Kotliar for discussions about fire effects in Front Range forests. Greg Aplet, Bill Baker, Marcia Patton-Mallory, Wayne Shepperd, and Tom Swetnam provided helpful reviews of early drafts. This work was supported by the USDA Forest Service, Rocky Mountain Research Station.

References

Brown, P. M., M. R. Kaufmann, and W. D. Shepperd. 1999. Long-term, landscape patterns of past fire events in a montane ponderosa pine forest of central Colorado. Landscape Ecology 14: 513-532.

Covington, W. W., and M. M. Moore. 1994. Southwestern ponderosa forest structure – changes since Euro-American settlement. Journal of Forestry 92: 39-47.

De Lay, T. J. 1989. The history of the South Platte Ranger District. USDA Forest Service, Pike National Forest, South Platte Ranger District. 108 p.

Ehle, D. S., and W. L. Baker. In press. Disturbance and stand dynamics in ponderosa pine forests in Rocky Mountain National Park, USA. Ecological Monographs.

Elliott, J. G., and R. S. Parker. 2001. Developing a post-fire flood chronology and recurrence probability from alluvial stratigraphy in the Buffalo Creek watershed, Colorado, USA. Hydrological Processes 15:3039-3051.

Forman, R. T. T. 1995. Land mosaics: the ecology of landscapes and regions. Cambridge University Press. 632 p

Fornwalt, P. J., M. R. Kaufmann, J. M Stoker, and L. S. Huckaby. 2002. Using the Forest Vegetation Simulator to reconstruct historical stand conditions in the Colorado Front Range. Crookston, N. L., and Havis, R. N. compilers. Second Forest Vegetation Simulator Conference; February 12-14, 2002, Fort Collins, CO. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Proc. RMRS-P-25, pp. 108-115.

Huckaby, L. S., M. R. Kaufmann, J. M. Stoker, and P. J. Fornwalt. 2001. Landscape patterns of montane forest age structure relative to fire history at Cheesman Lake in the Colorado Front Range. In Vance, R. K., W. W. Covington, and C. B. Edminster (tech. coords.), Ponderosa pine ecosystems restoration and conservation: steps toward stewardship. U.S. Department of Agriculture Forest Service Rocky Mountain Research Station Proc. RMRS-P-22: 19-27.

Jack, J. G. 1900. Pikes Peak, Plum Creek, and South Platte Reserves. Part V, Forest Reserves, 20th Annual Report, U.S. Geological Survey, 1898-99. Government Printing Office, Washington, DC. p. 39-115.

Kaufmann, M. R., P. J. Fornwalt, L. S. Huckaby, and J. M. Stoker. 2001. Cheesman Lake – a historical ponderosa pine landscape guiding restoration in the South Platte watershed of the Colorado Front Range. In Vance, R. K., W. W. Covington, and C. B. Edminster (tech. coords.), Ponderosa pine ecosystems restoration and conservation: steps toward stewardship. U.S. Department of Agriculture Forest Service Rocky Mountain Research Station Proc. RMRS-P-22: 9-18.

Kaufmann, M. R., C. M. Regan, and P. M. Brown. 2000. Heterogeneity in ponderosa pine/Douglas-fir forests: age and size structure in unlogged and logged landscapes of central Colorado. Canadian Journal of Forest Research 30: 98-711.

Kaufmann, M.R., L.S. Huckaby, P.J. Fornwalt, J.M. Stoker, and W.H. Romme. 2003. Using tree recruitment patterns and fire history to fund restoration of an unlogged ponderosa pine / Douglas-fir landscape in the southern Rocky Mountains after a century of fire suppression. Forestry 76:231-241.

Kipfmueller, K.F. and W.L. Baker. 2000. A fire history of a subalpine forest in southeastern Wyoming, USA. Journal of Biogeography 27:71-85.

Kulakowski, D. and T.T. Veblen. 2002. Influences of fire history and topography on the pattern of a severe blowdown in a subalpine forest in northwestern Colorado. Journal of Ecology 90: 806-819.

Mast, J.N., T.T. Veblen and Y.B. Linhart. 1998. Disturbance and climatic influences on age structure of ponderosa pine at the pine/grassland ecotone, Colorado Front Range. Journal of Biogeography 25:743-767.

Romme, W.H. 1982. Fire and landscape diversity in Yellowstone National Park. Ecological Monographs 52:199-221.

Sampson, R. N., R. D. Atkinson, and J. W. Lewis (editors). 2000. Mapping wildfire hazards and risks. The Haworth Press, Inc., New York [co-published as Journal of Sustainable Forestry, Volume 11, Numbers 1,2, 2000].

Sibold, J. 2001. The forest fire regime of an upper montane and subalpine forest, Wild Basin, Rocky Mountain National Park. Masters Thesis, University of Colorado, Boulder, CO.

Theobald, D. M. 2000. Fragmentation by inholdings and exurban development. Pages 155-174 in: Knight, R.L., F.W. Smith, S.W., Buskirk, W.H., Romme, and W.L. Baker (editors), Forest fragmentation in the southern Rocky Mountains. University Press of Colorado, Boulder, Colorado, USA.

Turner, M. G., R. H. Gardner, and R. V. O'Neill. 2001. Landscape ecology in theory and practice. Springer-Verlag, New York. 401 p.

Veblen, T.T. and D.C. Lorenz. 1986. Anthropogenic disturbance and recovery patterns in montane forests, Colorado Front Range. Physical Geography 7:1-24.

Veblen, T.T. and D.C. Lorenz. 1991. The Colorado Front Range: a century of ecological change. University of Utah Press, Salt Lake City, Utah.

Part 3: Soil Properties, Erosion, and Implications for Rehabilitation and Aquatic Ecosystems

Jan E. Cipra, Eugene F. Kelly, Lee MacDonald, and John Norman

Introduction

This team was asked to address three questions regarding soil properties, erosion and sedimentation, and how aquatic and terrestrial ecosystems have responded or could respond to various land management options. We have used soil survey maps, burn severity maps, and digital elevation model (DEM) maps as primary map data. We used our own field measurements and observations coupled with previous research and professional judgment in addressing these questions.

Question 1: What was the historic range of variability (pre-1860) in the frequency, extent, and locations of mudflows and other erosion/sedimentation events (related to fire or other processes); how did the frequency, extent, and locations of erosion/sedimentation events in the recent period (1860 to 2002) compare with historic conditions; and how are events in the near future (next approximately 5 years) likely to compare with the historic range of variability?

Question 2: Where were key soil properties altered by the fire (including such things as organic matter content, water repellency, and productivity); and how long are these changes likely to persist?

Question 3: Where are fire-induced changes in soil properties likely to adversely affect recovery of aquatic and terrestrial ecosystems (over the short and long term) if no postfire rehabilitation is attempted; where are soil rehabilitation efforts likely to improve recovery of aquatic and terrestrial ecosystems; and where is soil rehabilitation unlikely to improve recovery of aquatic and terrestrial ecosystems?

Historical Analysis

The degree of soil development and movement of soil materials is dependent upon the climate, parent material, time, vegetation, and the intensity and size of disturbances. Human disturbances of the landscape during the past 100 years has significantly altered biotic factors and disturbance factors. Consequently, soil development and soil movement may have been much different, spatially and temporally, in the recent period (1860 to 2002) than during the thousands of years before humans became a component of the landscape. The imbalance between soil development processes and disturbances that degrade or dampen soil development may potentially have long-term effects on the health and integrity of the landscape.

Wind and water erosion on agricultural and nonagricultural lands removes 4 billion tons of soil annually in the United States (Brown and Wolf 1984). Two thirds of this amount is moved by water and one-third by wind. In forested areas erosion can occur by a wide variety of processes, including soil creep, dry ravel, mass movements including slumps and slides from slope failure, and biogenic transport (for example, animal burrowing or tree throw). In most undisturbed forests erosion rates and sediment yields are typically low (Dunne and Leopold 1978). Unpaved roads, rural and urban development, and forest management activities will usually increase erosion rates, but the net effect on waterways and aquatic habitat is highly variable. Because most forested areas in the Colorado Front Range (and to a degree in the Hayman Fire area as well) have sandy and gravelly soils with high infiltration rates and hence little overland flow, much of the sediment eroded from a site may not make it to the stream. In such cases, an increase in erosion may have relatively little adverse effect on stream channel morphology and aquatic ecosystems. On the other hand, erosion is likely to remove much litter and some of the surface mineral soil layer. Both of these are sources of onsite nutrients and organic matter, in which case loss by erosion will have a direct, adverse effect on site productivity. Drainage from roads and developed areas often flows directly into the stream network, and the increase in runoff and/or sediment can adversely affect downstream resources and aquatic ecosystems.

Pre-1860 – The historic range of variability for pre-1860 disturbance patterns has not been well documented. Potential sources of information for reconstructing landscape patterns and processes are early journals and more formal land survey records. Land survey records were made as early as the mid 1700s for Eastern portions of the United States, but not until the latter 1800s for portions of the Western United States. These land survey records can be examined for evidence of historical disturbance as the surveyors kept detailed journals on forest cover type, local topography, soil conditions, and other landscape features. This information can be used to infer the "presettlement" condition. Alterations to this presettlement condition may then be recorded as lands were resurveyed. The strengths of this technique are that (1) it is often geo-referenced, and (2) in many cases it reveals the presettlement condition and how disturbance (natural and human) had altered the landscape. However, its limitations are that (1) the presettlement reference condition represents a point in time, and (2) it is not able to establish conditions and processes existing prior to that point in time. This method is also limited by the landscape interpretation made by the surveyor (as surveyors changed, so did the interpretation quality). The quality of interpretations is especially important in this case because the information is not quantitative. In this evaluation of the Hayman Fire we did not directly use any information from early journals or land survey records.

However, descriptions and documentation of soil erosion in the vicinity of the Hayman Fire as early as the 1880s do exist, and are discussed in the next section "1860 to 2002." From these sources, we might surmise that, prior to 1860, soil erosion was much less severe than in later periods as activities such as logging, mining, and grazing increased. It is likely that in the past, soil erosion patterns varied temporally and spatially and were correlated to long-term climate and to significant events such as 50, 100, and 500-year storms.

The key controlling processes that contribute to soil erosion and mass movement of soils in the assessment area are the effects of water movement and wind transport of materials. Both of these weathering agents transport sediment and are highly dependent on local climatic variability, local topography, ground cover, and geologic substrate (parent material).

Mass movement of soil material is characterized by the presence of debris/mud flows within an area and is generally considered to be episodic and is likely driven by large storm events. Slope failures resulting in slumps of slides may occur after severe burns on slopes that would otherwise be stabilized by the presence of forest vegetation. One factor involved in postfire slope failure is the increasing buildup of water in the soil in the absence of vegetation, which increases soil weight and downward forces on the slope. After slope failure, the disturbed area is subject to further erosion by rainfall and snowmelt.

Erosion by water has specific mechanisms that tend to degrade the system over large spatial and long temporal scales. For example, the impact of raindrops erodes soil by first detaching the soil and destroying aggregates, making the soil more susceptible to movement. The force of the splash will then initiate overland sheet erosion that combines to form rills. As rills concentrate and erosive power increases, gullies or channels exhibiting downward cutting are formed that are capable of delivering large volumes of sediment-laden water to wetlands and waterways.

The specific mechanisms for wind erosion involve the processes of detachment and transportation. The initial detachment of soil particles from granules or clods results from the lifting power of the wind. Whereas silt-sized particles become airborne and can be transported long distances, medium-sized particles (0.05 to 0.5mm) bounce along the soil surface dislodging other particles as they move.

Morris and Moses (1987) documented soil movement following forest fires for five ponderosa pine forested catchments along the Colorado Front Range. They found that the sediment flux rates following forest fires was elevated by three orders of magnitude in comparison to control catchments of undisturbed forest. They suggested that the two most significant variables controlling sedimentation were (1) the fire-induced formation of a water repellent layer in the soil and (2) the tendency for surface debris to become detachment limited. They concluded that forest fire disturbances might account for a large portion of the long-term sediment yield from Front Range hill slopes. Given the extreme weather events common to the Colorado Front Range, we can hypothesize that the erosion events that are occurring since the Hayman Fire might have occurred prior to settlement, and may be within the range of historic variability.

1860 to 2002 – Several excellent sources document soil erosion in the vicinity of the Hayman Fire and on the Pike National Forest, beginning as early as the 1880s. The Forest Service photographic archives in Pueblo, CO, contain photographs of the Pike National Forest as early as 1920, often commenting on the soil erosion effects shown. A caption on one photo makes reference to natural regeneration after an 1880s fire. Some of the history of the Pike National Forest since its formation in 1907 is detailed on the Forest Service Web page, "...the story behind the Pike National Forest" by Vance and Vance (World Wide Web address fs.fed.us/r2/psicc/pp/history.htm [2003]). It documents some of the disturbance history of the Forest and what the erosional responses to fire, logging, mining, and grazing have been. Even earlier, Jack (1899) reported descriptions of soil erosion in some of the watersheds in what is now the Pike National Forest. He included both maps and photographs of observed erosion. Connaughton (1938) reported "excessive erosion" due to overgrazing by domestic livestock as well as erosion resulting from wildfire. Elliott and Parker (2001) discuss the long-term effects of soil erosion following fire.

The United States Geological Survey (USGS) initiated erosion and deposition studies in the Buffalo Creek watershed immediately following the 1996 Buffalo Creek Fire. They measured hydrological and erosional responses of severely burned hillslopes by monitoring runoff, rill erosion, and interrill erosion, as well as measuring postfire sedimentation (Moody and Martin 2001a). Coupled with other related studies (Martin and Moody 2001a,b; Moody and Martin 2001a,b,c; Moody 2001) these extensive measurements provide an excellent understanding of postfire erosion, deposition, runoff, and fire-induced changes in soil properties and behavior. Some of these studies are especially relevant because they were conducted on the Buffalo Creek Fire, which occurred in the same general geologic terrain as the Hayman Fire. It is not unreasonable to expect some similar postfire behaviors in the two areas.

Figure 6 is a burn severity map of the Hayman Fire area with the topographic map background and five observation points in the northern part of the burn north and west of the town of Deckers and in the Saloon Gulch area. (These same five observation points are plotted on most of the other maps as well). Areas shown as *high severity* burn are of primary concern in this analysis, as related to (1) potential erosion and sedimentation, (2) where key soil properties were altered, and (3) where fire-induced soil changes will adversely affect recovery of aquatic and terrestrial ecosystems.

Figure 7 is a map of soil surface textures in the burn area. It is interesting to note that much of the area in the western part is mapped as weathered or unweathered bedrock and that in the eastern part there is a large extent of soils that are not sandy and/or gravelly; specifically, soils with clay loam surface textures. Many of the conclusions in this report are based on the fact that forest soils in the Front Range are dominantly coarse textured. Most of the clay loams were not in the severely burned areas, and from figure 8, are not as steep in general as soils to the west.

Key soil properties used from the soil map were (1) surface/subsurface texture, (2) mineral soil organic matter content (OM, SOM, or SOC), (3) soil depth to bedrock, (4) presence/absence of bedrock outcrop at the surface, and (5) slope. Slope information is also available in a different format and in greater detail as a DEM. The soil survey maps had limited information on surface litter.

Figure 9 shows the intersection of high SOM (greater than 3 percent of the mineral soil) with high burn severity (shown in orange). The spatial extent of this intersection is similar to the high burn severity extent, an indication that most of the high severity burn area had high SOM, although there were a few areas that did not. We believe that most of this common area had a significant amount of litter on the surface of the mineral soil prior to the burn. Field observations verified nearly total destruction of the litter layer in high severity burn areas, as was expected. In part 1 in this report, the effect of high severity burn on soil is described as the fire consuming all or nearly all organic matter on the soil surface (the terminology "organic matter on the soil surface" refers to what we call "surface litter" in this report), as well as soil organic matter in the upper soil layer, and killing all of nearly all of the plant structures (such as roots and rhizomes) in the upper soil layers, resulting in possible water repellency and slow vegetative recovery.

The areas shown in orange on this map (fig. 9) likely had the most surface litter and SOM in the mineral soil surface layer in the burned area prior to the burn, and likewise had the least after the burn. There has been a considerable loss of nutrients and productivity in these areas, resulting from the fire.

Figure 8 is a three-dimensional rendering of the Hayman Fire DEM, draped with a 15-m resolution Landsat panchromatic image and the high severity burn/high SOM intersection extent (in yellow). In this view of the area from a south-southwest perspective, it appears that some of the high SOM/high severity burn occurred on the steeper slopes, which would be more prone to soil erosion than would more gentle slopes (all other factors being equal). It could prove useful to do additional evaluations of these areas; however, within the scope of this study we were unable to make any field observations in this vicinity.

A slope stability analysis model was developed to identify areas of potential slope failure, slumping, or sliding, which could contribute to mudflows, soil erosion, and sedimentation. Slope stability is dependent on many factors that balance resisting forces and driving forces. The ratio between resisting forces and driving forces, the factor of safety, is useful to quantitatively evaluate a slope's willingness to remain stable (Ritter and others 2002). The factor of safety utilizes soil cohesion, soil weight, soil depth, soil pore pressure, and slope angle in calculating the risk of slope failure. The resisting forces incorporate soil cohesion, soil pore pressure, soil depth, soil weight, and slope angle. Driving forces include soil depth, soil weight, and slope angle. Factor of safety values are centered around 1, with 1 being the slope stability threshold. Values greater than 1 indicate the slope is instable, whereas, values less than 1 indicate the slope is in equilibrium. In the Hayman Fire area the loss of vegetation will result in increased soil moisture content, which increases pore pressure within the soil profile, which decreases the factor of safety.

Figure 10 is the output map from the slope stability model analysis. Only the areas shown in red fall below the critical threshold, and they also correspond to the steepest slopes in the burn area. Conclusions from this analysis are that, given the input parameters we used, slope failure does not appear to be a major concern in the Hayman Fire area. To have more confidence in the model rendering of the "risk areas" in the western part, additional fieldwork would be necessary to validate the input parameters used.

High severity wildfires represent one of the greatest potential threats to site productivity, soil resources, and aquatic ecosystems in the Colorado Front Range. In the Buffalo Creek Fire of May 18, 1996, approximately 7,500 acres were mapped in the BAER report (Bruggink and others 1998) as high intensity burn. In the first few months after the fire, and the following summer, a series of storms impacted the area. These caused a great deal of erosion and sedimentation, with

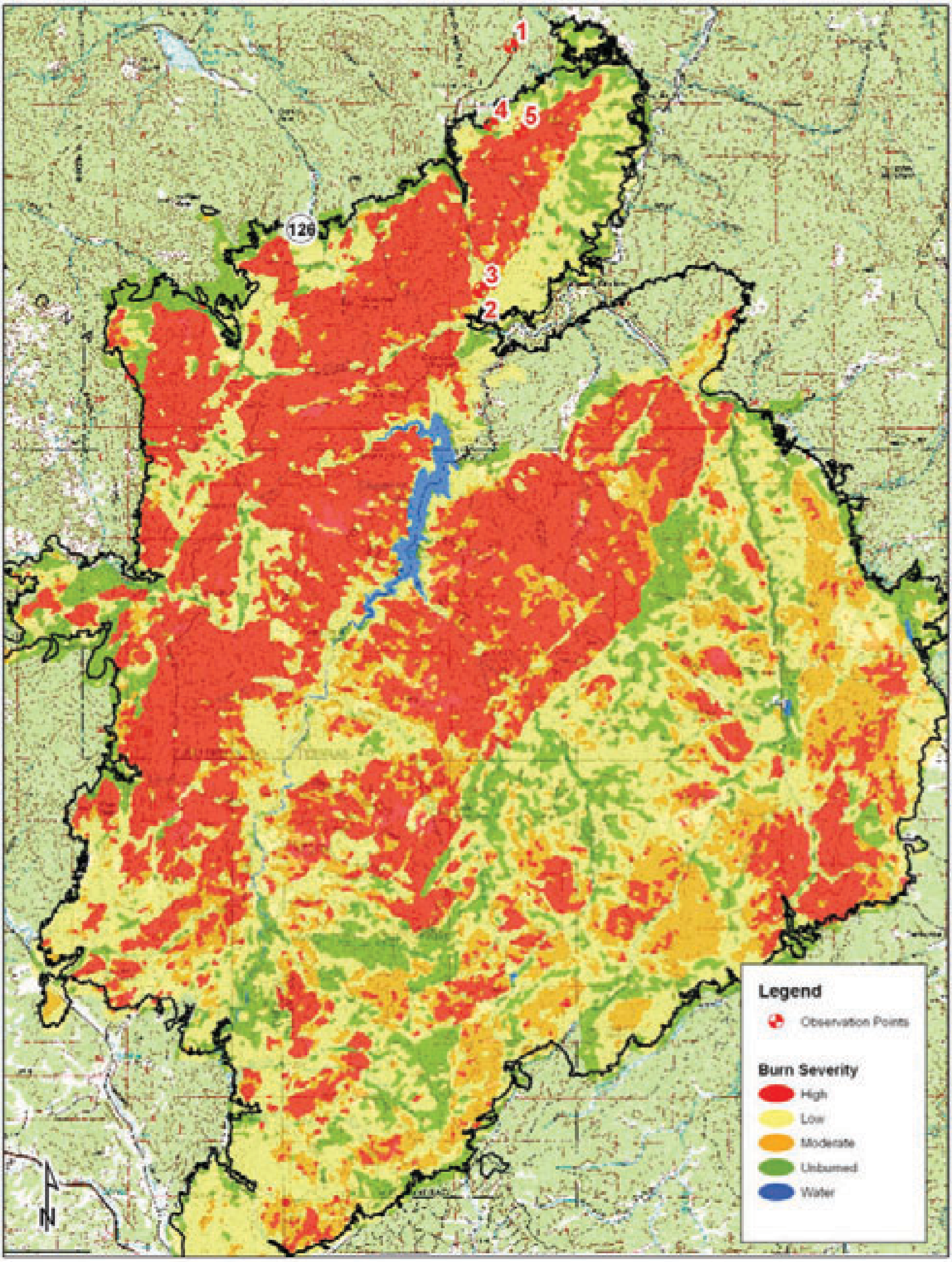

Figure 6—Burn severity map of Hayman Fire.

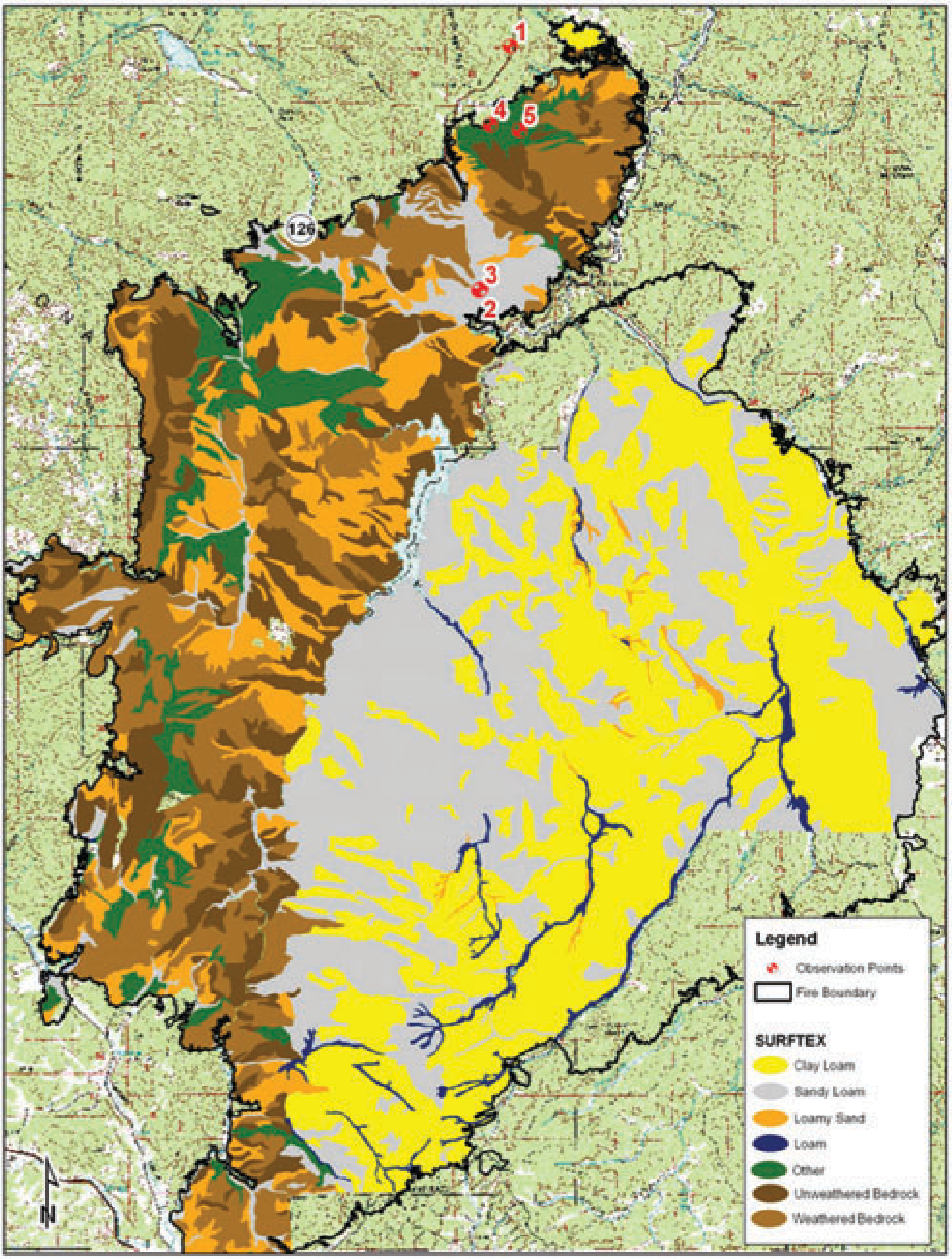

Figure 7—Soils map of Hayman Fire.

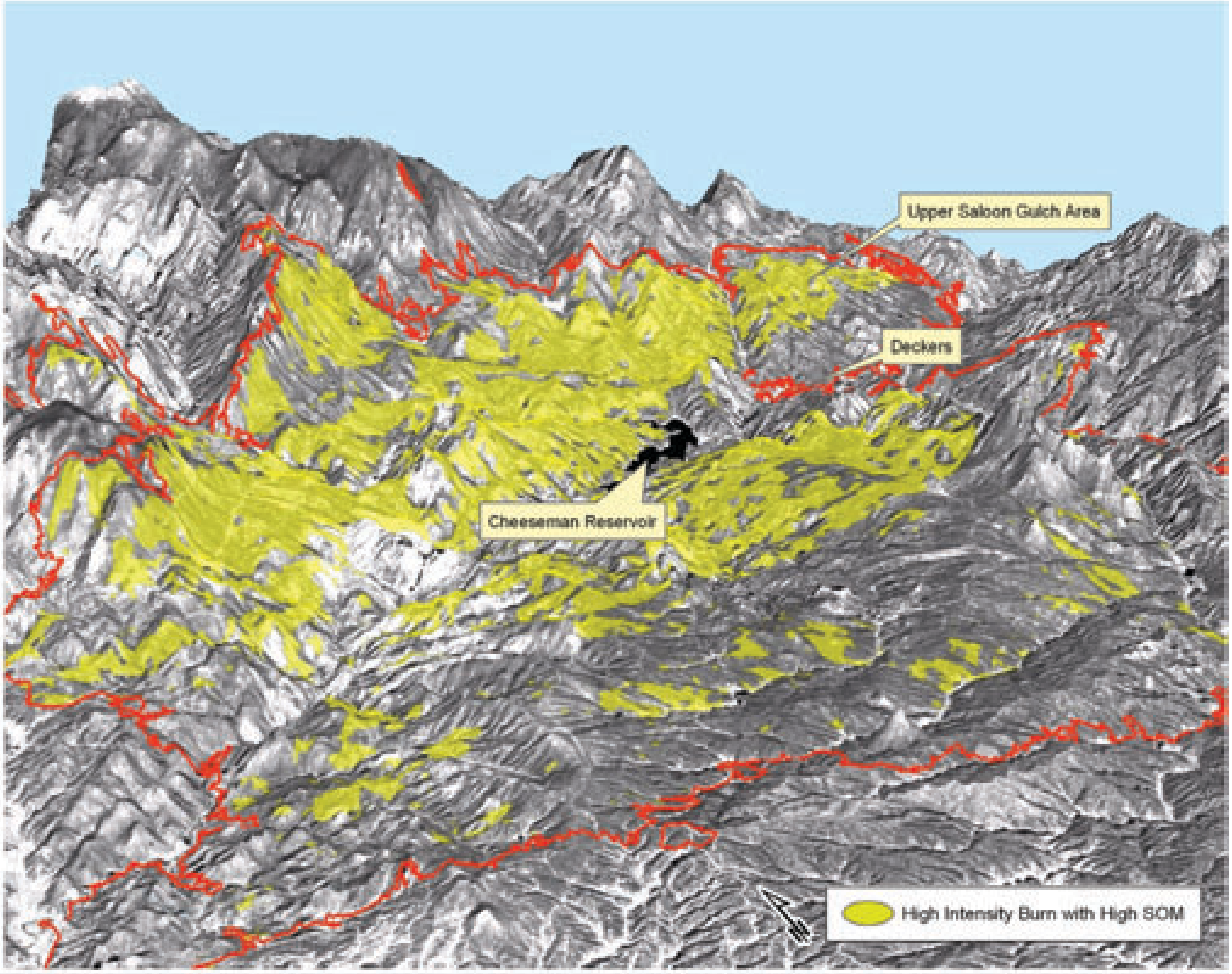

Figure 8—Digital Elevation Model (DEM) of Hayman Fire area draped with burn severity and soil organic matter (SOM).

sediment filling and destroying catchment structures and washing away 90 percent of the seed from aerial reseeding efforts, in addition to other erosion and sedimentation damage. Loss of storage capacity in downstream reservoirs, coupled with impaired water quality for Denver's water supply, resulted in large monetary losses. These conditions combined to produce what is quite likely a worst-case scenario of postfire erosion in the Pikes Peak batholith, which also underlies most of the area burned by the Hayman Fire.

Figures 11 and 12 depict the Upper Saloon Gulch area, where multiyear sedimentation studies were conducted both before and after the Hayman Fire. Figure11 shows the intersection of high SOM with high burn severity, and figure 12 depicts surface SOM levels in the area prior to the burn. Field assessments here confirmed that in high severity fire areas, all surface litter and the organic matter (SOM) in the upper few centimeters of the mineral soil has been destroyed by the fire. In addition, postfire erosion has removed some of the mineral soil (primarily topsoil). Most of the published and unpublished observations that we are aware of, as well as our field measurements and those of other scientists and forest managers, indicate that high severity fires do in fact usually destroy both above and below ground organic material in similar situations.

On the other hand, the threat of erosion from *low severity* fires – either prescribed or wild – is relatively small, as by definition these fires do not completely consume the surface litter layer (and therefore do not

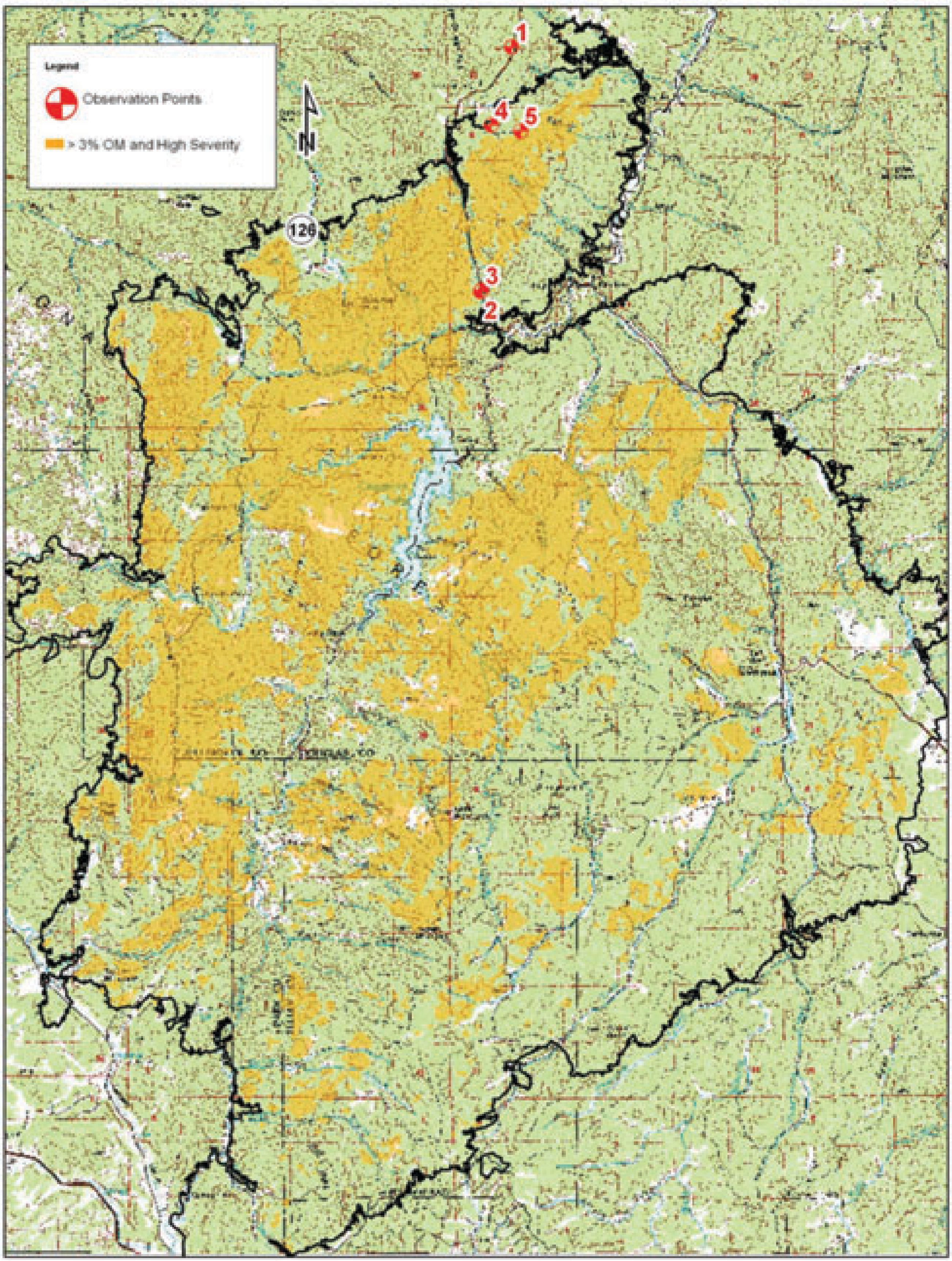

Figure 9—Extent of intersection of high burn severity and high soil organic matter.

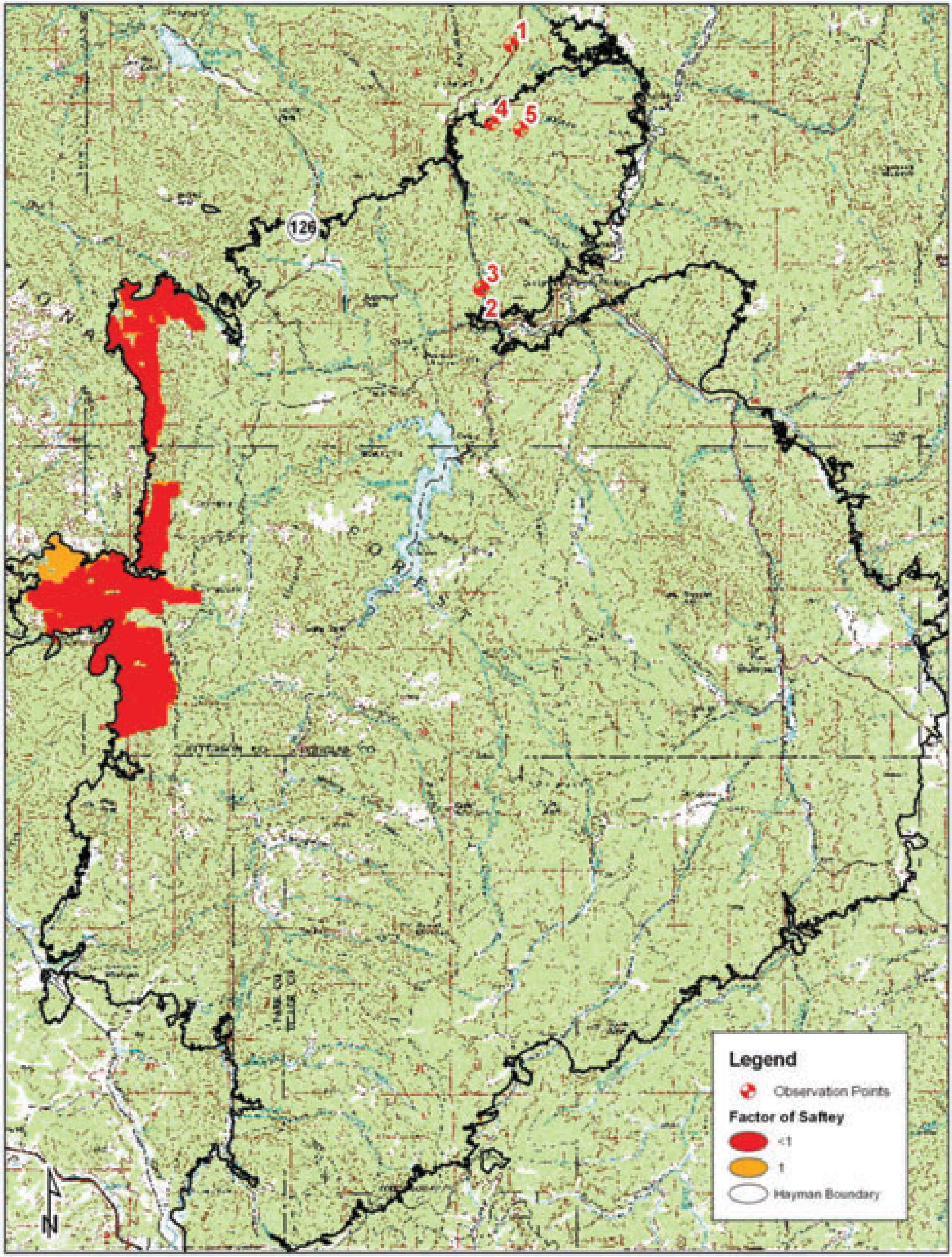

Figure 10—Map output from the slope stability model analysis. Areas shown in red fall below the threshold value of 1.

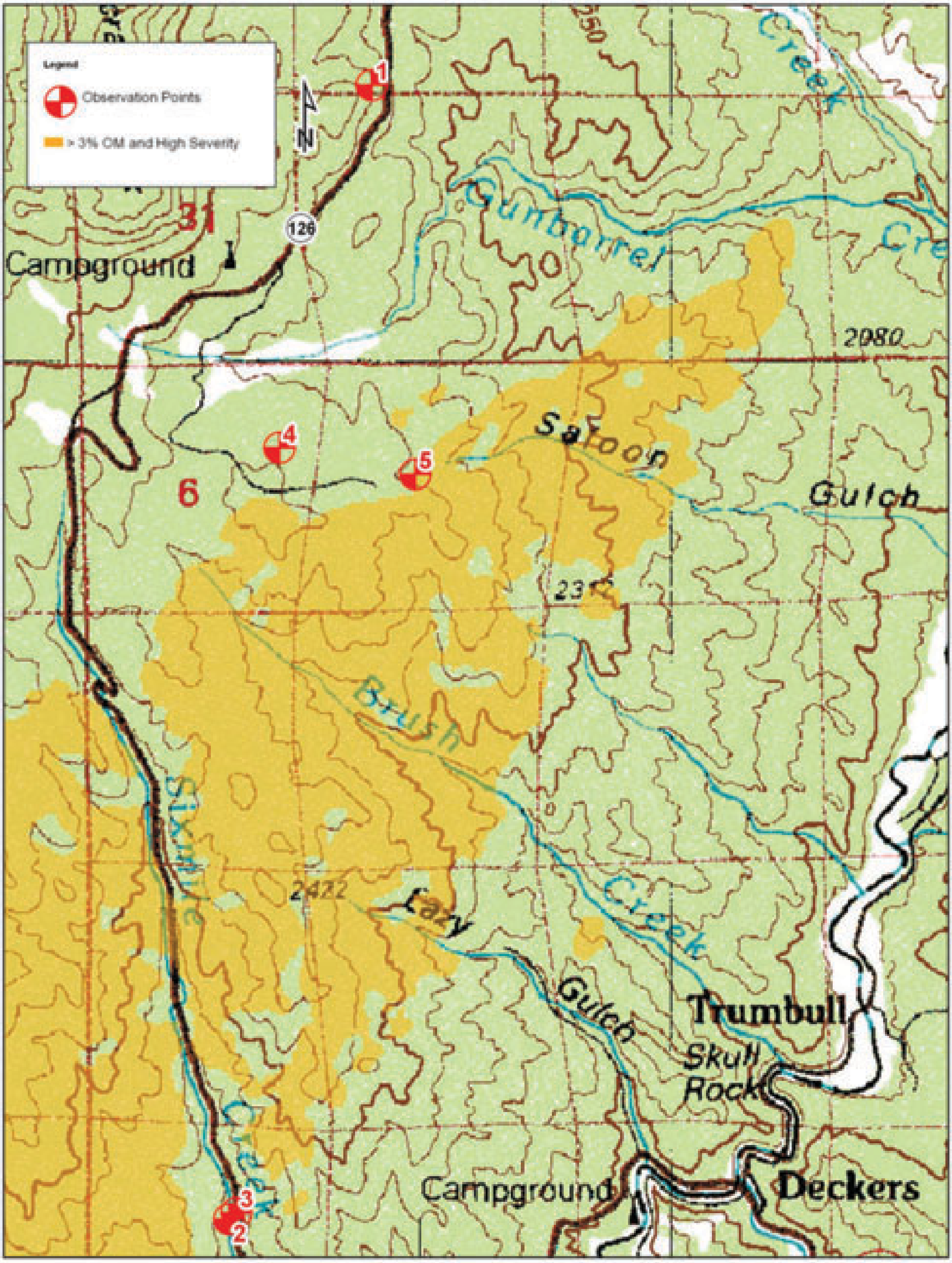

Figure 11—Intersect of soil organic matter and severity.

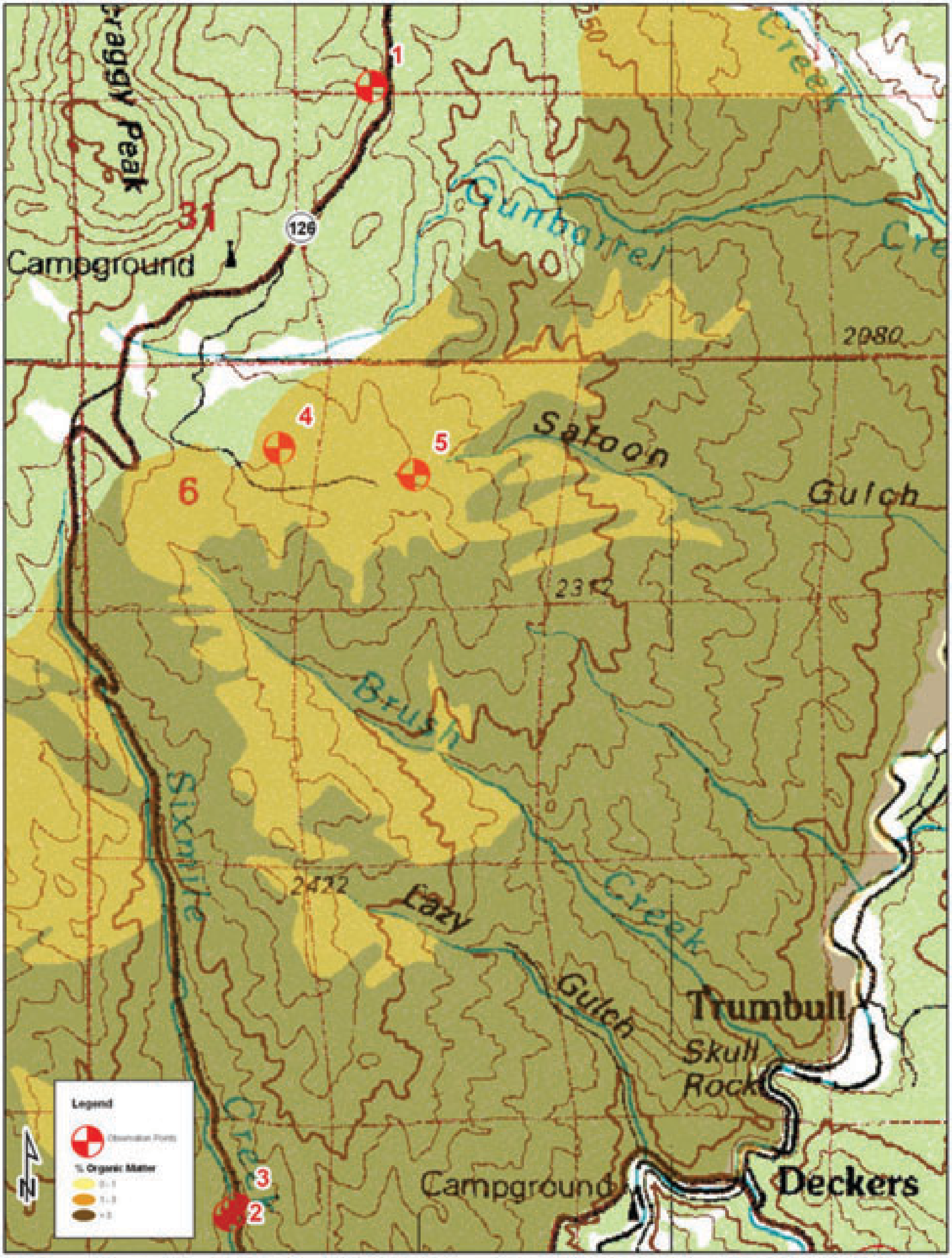

Figure 12—Soil organic matter in Saloon Gulch area.

consume the organic matter and nutrients in the surface mineral soil either). Areas burned at low severity are often found in a complex mosaic with unburned areas, reducing the overall litter and topsoil loss from these areas.

Similarly, areas burned at *moderate severity* may pose a lesser, shorter term threat than high severity burn areas to terrestrial and aquatic resources, as the mineral soils in these areas are not visibly altered and recovery is relatively rapid (Benavides-Solorio 2003). In the Hayman Fire moderate intensity burn areas, much of the litter layer has been burned but some still remains, and vegetation understory recovery is expected to be relatively rapid, thus protecting the soil from erosion and restoring soil fertility.

Most available literature suggests that high-severity wildfires can increase postfire erosion rates by one or more orders of magnitude. This increase in erosion has been documented in pine forests in South Africa (Scott 1993), eucalyptus forests in Australia (Prosser and Williams 1998), chaparral in the Southwestern United States (Laird and Harvey 1986; Rice 1974), coniferous forests in Yellowstone National Park and central Washington (Helvey 1980; Meyer and others 1995), and ponderosa pine in the Colorado Front Range (Morris and Moses 1987). Recent sediment yield studies in Colorado Front Range forests (Benavides-Solorio 2003; Moody and Martin 2001a) reported more than seven times as much sediment from plots that were severely burned compared to plots that were moderately burned. The precise causes of the observed increases are generally not well documented. Contributing processes include the pulverization of the soil due to the burning of the soil organic matter and accompanying breakdown of soil aggregates, increased rain splash due to the loss of the protective litter layer, destruction of the microbial crust, soil sealing, increased dry ravel, and development of a less permeable hydrophobic layer 1 to10 cm below the surface. Many of these processes interact to change the hydrologic regime from little or no surface runoff in the unburned condition to large amounts of overland flow from moderate to high intensity rainfall events.

Sediment deposition occurs when there is a reduction in transport capacity, and this adversely affects most of the designated beneficial uses of water, including reservoir storage, fish habitat, and domestic water supply. This sequence of wildfire, increased runoff, erosion, and downstream sedimentation is of great concern because past land management practices have created excessive fuel loadings in many areas of the Western United States. The Hayman Fire is simply one of the most recent and dramatic examples of erosion and sediment deposition affecting the soil and water resources of the Front Range.

Evidence also suggests, in contrast to severe wildfires, low (and even moderate) severity fires generally do not result in a corresponding increase in runoff and erosion (Robichaud and Waldrop 1994; Benavides-Solorio 2003). Certainly, runoff and erosion from moderate severity burn areas are expected to be significantly less than from high severity burn areas. Thus, if the threat of severe wildfires was reduced through fuel modifications, then most likely the associated risks of flooding, erosion, and downstream sedimentation would also be reduced. The identification of areas with the highest erosion and sedimentation hazards on both landscapes and sites could display and quantify the potential benefits from reducing the risk of severe wildfires. Limited data from an ongoing study indicate that forest thinning is unlikely to cause substantial increases in runoff and erosion (Libahova and MacDonald 2003).

Two other important factors responsible for accelerated erosion following forest fire are the loss of canopy and ground cover (especially forest floor litter) and the increased probability of soil water repellency, especially in sandy soils under coniferous forest cover (Morris and Moses 1987).

The National Forestry Manual published by the USDA Natural Resource Conservation Service (NRCS) in 1997 employs the K factor (representing soil erodibility) from RUSLE and breaks out four slope categories that are combined to develop a soil rating for potential erosion hazard. The guidelines in this manual are useful because of the standardized national application, the availability of data, and the functionality to be manipulated within a GIS framework and on a watershed basis. (The K factor is the soil's inherent susceptibility to erosion and is closely related to infiltration capacity and structural stability; which factors are in turn influenced by surface soil texture, surface organic matter content, permeability, and other variables specific to soil type.) K factor values typically range from near zero to 0.6, with low values representing low soil erodibility and high values reflect high erodibility. However, we did not apply the RUSLE model to the Hayman Fire because there is a lack of field data at this time to supply input parameters and calibration of the model.

To obtain field data for immediate assessment and as input to empirical erosion hazard models, recent research has been conducted in northern Colorado Front Range forests (Rough and others 2003; Kunze and Stednick 2003; Benavides-Solorio 2003; Hughes and others 2003; Libohova and MacDonald 2003; Pietraszek and MacDonald 2003). Initial findings indicate that *percent cover* and *rainfall erosivity* are two important controlling variables, which in one study explained nearly two-thirds of the observed variability in hillslope-scale erosion rates from both prescribed and wild fires

(Benavides-Solorio 2003). Soil texture was only a minor factor, probably due to the fact that most forest soils in the study areas (and many Front Range forests as well) are at least 60 percent sand and less than 10 percent clay. Many soil textures in the Hayman Fire fall within this range, with some areas in the southeast portion of the burn being less sandy. There are not yet enough hillslope-scale erosion data collected to know whether the existing empirical models can be directly applied to predict soil losses and sediment deposition with a high degree of accuracy.

The USDA Forest Service Watershed Conservation Practices Handbook (FSH 2509.25) establishes standards and design criteria intended to protect soil (soil productivity and sediment control), aquatic (hydrologic function and water quality), and riparian system functions on National Forest lands. Soil quality has been defined as "the capacity of a specific soil to function, within natural or altered land use boundaries, to sustain or improve plant and animal productivity, water, air quality, and human health and habitation" (National Cooperative Soil Survey Soil Quality Committee 1995). Soil health is defined as "the condition of the soil with reference to its inherent quality and ability to perform vital ecosystem functions." Those vital functions are to: (1) sustain biological activity, diversity, and productivity; (2) partition water, energy, and solute flow; (3) restore and cycle nutrients and other materials; (4) filter, buffer, immobilize, and detoxify organic and inorganic materials; and (5) support structures and protect archeological treasures.

Removal or reduction in surface vegetation cover and formation of less permeable soils can lead to increased surface runoff and overland flow that acts as a force to cause the detachment and transport of sediment. These sediment-laden flows may then induce sheet wash, rill, and gully erosion, and cause mass movements such as debris torrents and flows. As mass movements travel through the channel network, they can cause intense bank scour and erosion, which increases the volume of sediment delivered to downstream areas. Ultimately, the increased surface flow relative to infiltration and subsurface flow can result in downstream flooding and damage to life and property.

Reduction in soil organic matter increases the susceptibility of soil to surface sealing and compaction. The resulting decrease in infiltration will increase overland flow that can lead to rill and gully erosion.

Impact of the Hayman Fire on Key Soil Properties

Changes in soil properties due to fire in the Hayman Fire area were estimated from detailed studies conducted on other recent fires in the Colorado Front Range (Huffman and others 2001) and a limited amount of data from the adjacent Schoonover Fire. Areas severely burned were expected to have a complete loss of the protective litter layer and a loss of the organic matter in the top few centimeters (that is, 0 to 3 cm). Also in these areas a relatively strong water repellent layer may extend from a few centimeters below the mineral soil surface to as much as 10 cm below the surface. This water repellent layer has been observed in the adjacent Schoonover Fire by the critical surface tension test as used by Huffman and others (2001), and it can also be inferred by the large amounts of surface runoff and erosion generated by summer rainfall events after the Hayman Fire. Extensive rilling has been observed on various sites in the northern portion of the Hayman Fire, while prefire observations showed no evidence of rilling in some of the same areas (for example, in the Upper Saloon Gulch area).

Similar effects can be expected in the areas with moderate burn severity, although in these areas the loss of surface organic matter may not be as complete as in the areas with high burn severity. Data from other fires suggest that a fire-induced water repellent layer burned moderately (severity) will be similar in depth and magnitude to those areas burned at high severity (Huffman and others 2001). In contrast, areas burned at low severity will still retain some of the surface litter and most, if not all, of the organic matter in the top few centimeters of the soil. The water repellent layer will be too weak and discontinuous to substantially affect runoff and erosion rates at the hillslope of small catchment scale.

The water repellent layer can be expected to persist for up to 1 to 2 years (Huffman and others 2001). Over the winter this layer is not expected to cause an increase in runoff rates, as the combination of low intensity rainfall events and snowmelt will cause this water repellent layer to wet. Once the soils are wet, the soils cease to be water repellent until they are dry. Preliminary data from the Bobcat Fire in the northern Colorado Front Range suggests that the soil water repellency is largely eliminated at soil moisture contents ranging from about 12 percent in areas burned at low severity to as much as 25 to 30 percent in areas burned at high severity (MacDonald and Huffman, in prep.). The water repellent layer was again be expressed in the summer of 2003 when the soils were dry. By the summer of 2004 the water repellent layer should be substantially weakened and have much less impact on runoff and erosion rates than it did immediately after the fire.

Other Impacts of Fire-Induced Soil Changes in the Hayman Fire

In mid-2001 a project was initiated to evaluate the effects of a proposed thinning project on runoff, erosion, water quality, and channel morphology. Sediment fences were established on 20 swales ranging in size from 0.1 to 1 ha. During the latter half of 2001 and through the winter of 2001 to 2002 no mineral sediment was collected in any of the sediment fences. The Hayman Fire burned all of these sites at severely, and the percent bare soil and ash increased from a mean of 12 to 93 percent (fig. 13). Soil water repellency was measured using the critical surface tension (CST) test (Huffman and others 2001). In this test drops of pure water are placed on the surface, and if these do not infiltrate within 5 seconds, drops with successively higher concentrations of ethanol are applied. Because ethanol reduces the surface tension, the first solution that readily infiltrates into the soil is considered the critical surface tension. Previous work has shown that the CST test is both faster and less variable than the more common water drop penetration test (Huffman and others 2001). Data from sites burned at high severity and nearby unburned sites show that the Hayman Fire increased the strength of soil water repellency from the soil surface to a depth of approximately 6 cm (fig. 14). The loss of soil cover, when combined with the development of a water repellent

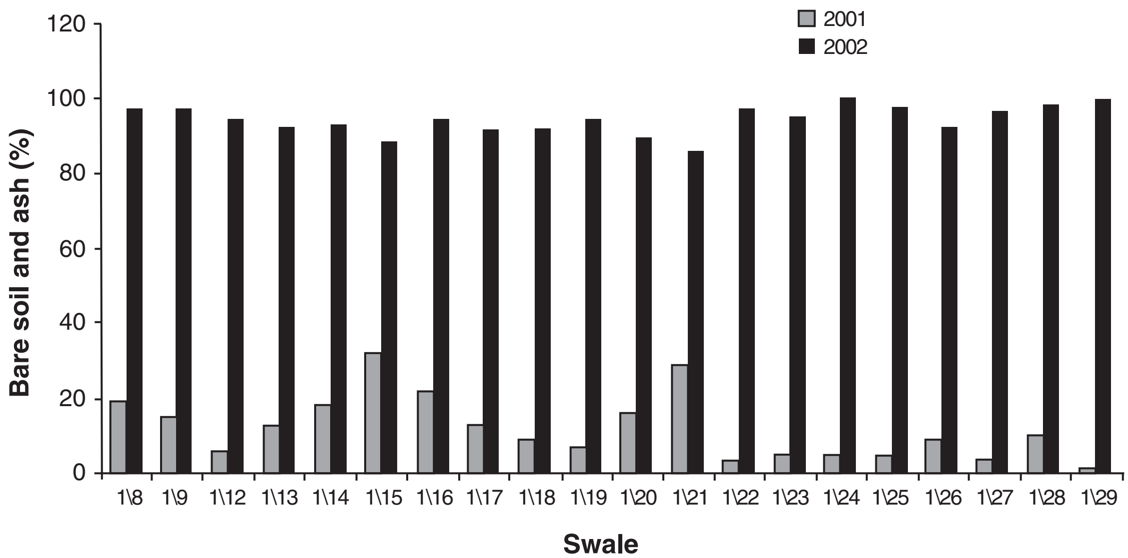

Figure 13—Percent bare soil and ash on 20 swales in Upper Saloon Gulch in October 2001 and in July 2002 after the Hayman Fire.

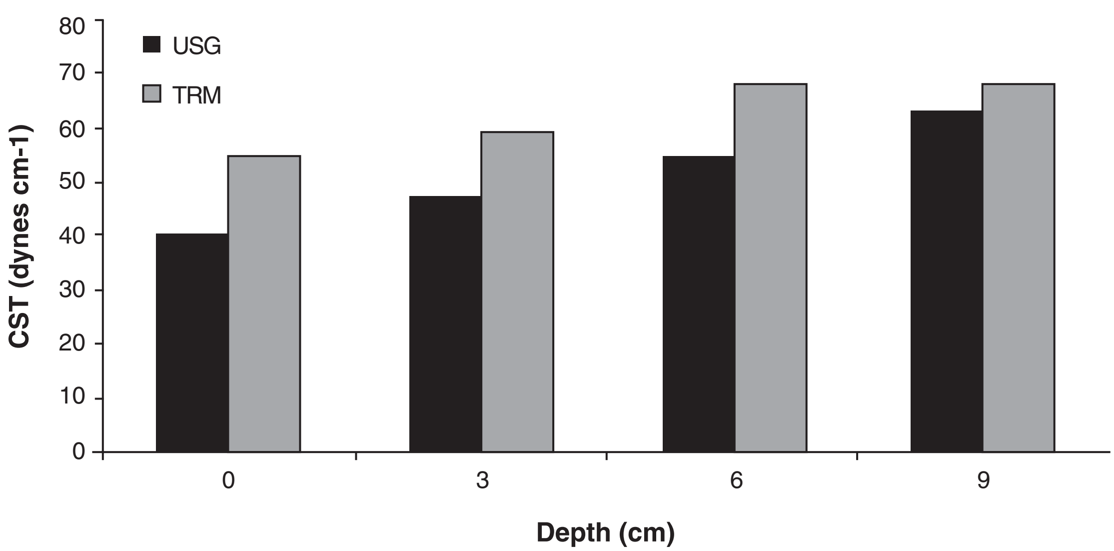

Figure 14—Mean soil water repellency in the burned swales in Upper Saloon Gulch (USG) in July 2002 after the Hayman Fire compared to unburned areas in Trumble Creek (TRM). Lower values indicate stronger soil water repellency.

layer, greatly increases the potential soil erosion rates. We observed an average erosion rate of approximately 0.6 kg/m2 (nearly 3 tons/acre) on our 20 study plots from a single storm of 11 mm of rain in 45 minutes (fig. 15). The limited amount of data collected in summer 2001—prior to the fire—strongly indicate that this storm would not have generated any measurable surface runoff or erosion. High runoff and erosion rates were observed from other convective rain storms, but the total erosion rate after the Hayman Fire was relatively low because the rainfall in June, July, and August was less than 50 percent of the long-term average (fig. 16). Most of the rainfall in September fell at low intensities (less than 10 mm per hour) and therefore did not generate as much erosion as the convective storms in July.

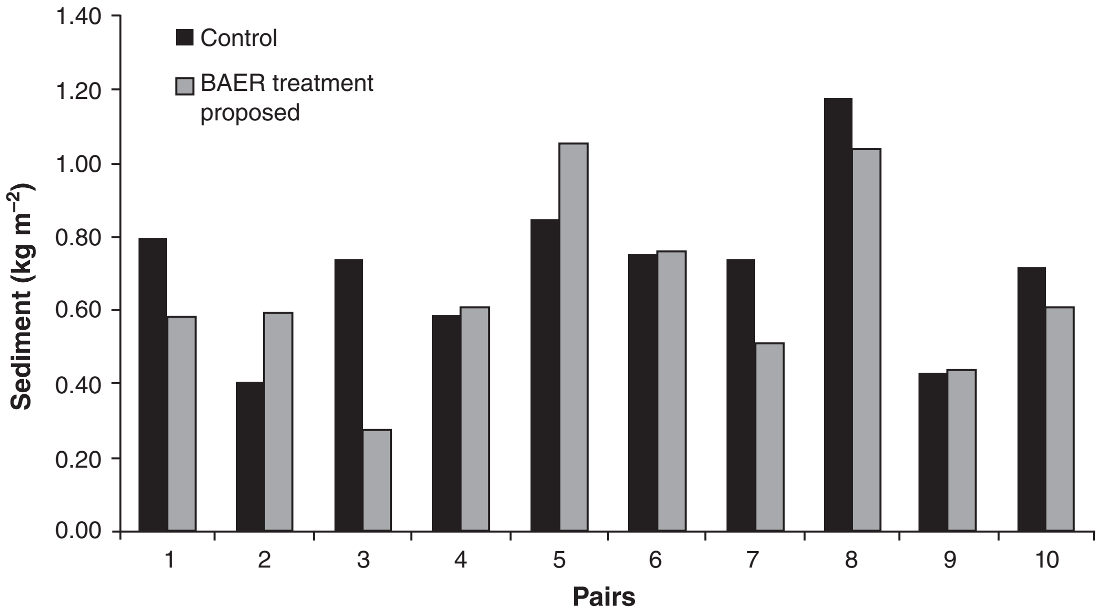

Figure 15—Sediment production from 10 pairs of swales in Upper Saloon Gulch from an 11 mm rainstorm. One swale of each pair was designed to be a control for a burned area emergency rehabilitation treatment (BAER). A rainstorm occurred before the treatments could be applied.

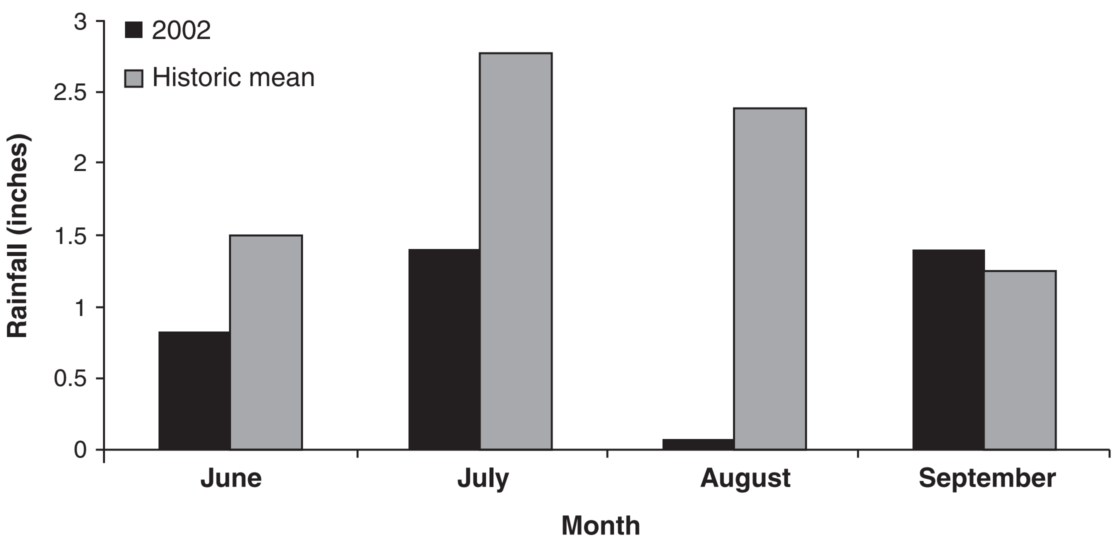

Figure 16—Monthly rainfall at Cheesman Reservoir for June-September 2002 versus the long-term mean.

Relatively little erosion occurred over the winter, and this is probably due to two reasons. First, the water repellent layer had wetted up, and at higher soil moisture contents (for example, greater than about 20 to 30 percent) the soil is no longer water repellent. Second, the rate of snowmelt is much less than the rainfall rate from summer convective storms, so the snowmelt all infiltrates into the soil instead of generating infiltration-excess overland flow.

Percent cover was remeasured in April 2003 and showing that there has been little reduction in the amount of bare soil since late summer 2002. The lack of cover indicates that the areas burned at high severity are still at high risk for high runoff and erosion rates from convective rainstorms in summer 2003. In contrast, nearby sites that were subjected to thinning show only a small increase in the amount of bare soil, and we therefore expect little or no increase in sediment yields from these sites.

Other recent studies have shown that soil erosion rates are strongly correlated with the proportion of the soil surface covered by organic materials (Benavides-Solorio 2003; Wagenbrenner 2003; Wagenbrenner and MacDonald, in prep.; Pietraszek and others 2003). Sites burned with high severity typically have less than 10 to 15 percent cover in the first summer after burning, and similar values have been measured at numerous sites in the northern part of the Hayman Fire. Percent cover increases over time, but in the absence of any rehabilitation treatments, the percent cover was expected to be low (such as less than 30 percent) in summer 2003, the year after the fire, especially given a continuing drought in Colorado. Erosion rates in the second summer may be nearly as high as in the first summer after burning, although the values will be highly dependent on the magnitude and intensity of the summer thunderstorms. The greatest reduction in erosion rates occur as the percent cover increases from about 30 to 70 percent. Data from other sites suggest that erosion rates should substantially decline by the third summer after burning, and approach background levels within 4 to 5 years. Erosion from winter storms is expected to be minimal, as much of the precipitation falls as snow, and rainfall intensities are much lower than for the convective thunderstorms that are characteristic of the summer season.

Areas burned with moderate severity typically have slightly more soil cover in the first year after burning, and they recover more rapidly (Hughes and others 2003). Erosion rates from areas burned at moderate severity have only 15 to 20 percent of the erosion rates from areas burned with high severity. Areas burned with low severity have much more cover, and in the first summer after burning the surface erosion rates from low-severity areas will be only 3 to 8 percent of the erosion rates from areas burned at high severity.

Data from the Bobcat Fire showed that mulching was the only treatment that consistently and significantly reduced erosion rates. In the second summer contour-felling did significantly reduce erosion in some areas (J. Wagenbrenner, USDA Forest Service, personal communication 2002). The primary reason for the immediate effectiveness of the mulch treatment is that it immediately increased the percent cover, compared to gradual increase in percent cover from growing vegetation. Data from a single small rainstorm on the Hayman Fire also suggest that mulching was effective in reducing soil erosion, but the results might be quite different if the study areas are subjected to a much larger storm. In general, rehabilitation treatments are going to be most effective in the small storms and have progressively less effect on reducing runoff and erosion rates with increasing storm size. The other treatment that immediately increases surface cover is hydromulching. Unfortunately this treatment was only installed on our study sites in the Hayman Fire in mid-September 2002, so we have no data yet on its effectiveness. Qualitative observations indicate that some hydromulched areas already have experienced considerable rilling, while in other areas rilling has not occurred, and the hydromulch is still largely intact.

The scarification and seeding treatment applied on the Hayman Fire is likely to be the least effective, as both the mechanical and hand scarification is too shallow to break up the hydrophobic layer, and the seeding has not yet had an effect on soil cover. Erosion data from one storm over four small catchments suggest no difference in sediment production rates between untreated sites and adjacent sites subjected to scarification and seeding. Qualitative observations from the Hi Meadows Fire suggest that scarification facilitated seed germination, but in this case a series of small rainstorms allowed the seed to germinate. The Hayman Fire generally did not receive as much postfire rainfall, and this may explain why the scarification treatments and seeding treatment have not appeared to result in much vegetative cover.

In conclusion, the areas burned at high severity are of greatest concern due to lack of cover and the development of a water repellent layer a few centimeters below the soil surface. Treatments that immediately increase the percent cover are most likely to reduce erosion rates, but these treatments will be progressively less effective with increasing rainfall intensities. Areas burned at moderate severity are also of concern, particularly in the first 1 to 2 years after burning. Erosion rates can be expected to return to near-background levels after 4 to 5 years when the percent cover has increased to at least 60 to 70 percent. Recovery of the stream channels is likely to be much slower, as the headwater channels are incising, and many downstream channels are being buried by large amounts of fine sediment.

References

Benavides-Solorio, J. D. D. 2003. Post-fire runoff and erosion at the plot and hillslope scale, Colorado Front Range. Ph. D. Dissertation, Colorado State University.

Booker, F.A. 1998. Landscape and management response to wildfires in California. M.S. thesis, Department of Geology and Geophysics, University of California, Berkeley, CA. 436 pp.

Brown, L.R., and E.C. Wolf. 1984. Soil Erosion: Quiet Crisis in the World Economy, World-watch Paper 60.

Bruggink, J., D.Bohon, C. Clapsaddle, D. Lovato, and J. Hill. 1998. Buffalo Creek Burned Area Emergency Rehabilitation Final Report: U.S. Department of Agriculture, Forest Service. 22 pp.

Bunte, K., and L.H. MacDonald, in press. Scale considerations and the detectability of sedimentary cumulative watershed effects. Technical Bulletin, National Council for Air and Stream Improvement, New York, N.Y. 300 pp.

Connaughton, C.A. 1938. Erosion on the National Forests of Colorado, Eastern Wyoming and Western South Dakota: Rocky Mountain Forest and Range Experiment Station, United States Department of Agriculture Forest Service, 68 pp.

Elliott, J.G., and R.S. Parker, 2001. Developing a post-fire flood chronology and recurrence probability from alluvial stratigraphy in the Buffalo Creek watershed, Colorado, USA, Hydrological Processes 15:3039-3051.

Helvey, J.D. 1980. Effects of a north central Washington wildfire on runoff and sediment production. Water Resour. Bull. 16(4):627-634.

Hughes, D.H., J.D.D. Benevides-Solorio, and L.H. MacDonald. 2003. Use of a rainfall simulator to assess controls on post-fire runoff and sediment production, Colorado Front Range. In J.A. Ramirez (ed.), Proceedings of AGU Hydrology Days 2003, Colorado State University, Ft. Collins CO, Mar 31 – April 2, 2003.

Jack, J.G. 1899. Pikes Peak, Plum Creek and South Platte reserves, Twentieth Annual Report of the U.S. Geological Survey, Part V - Forest Reserves: Washington, Government Printing Office. pp 39-115.

Kunze, M.D., and J.D. Stednick. 2003. Streamflow and sediment yield following the 2000 Bobcat Fire, Colorado Front Range. In J.A. Ramirez (ed.), Proceedings of AGU Hydrology Days 2003, Colorado State University, Ft. Collins CO, Mar 31 – April 2, 2003.

Laird, J.R., and M.D. Harvey. 1986. Complex response of a chaparral drainage basin to fire. In R.F. Hadley (ed.), Drainage Basin Sediment Delivery, Int. Assoc. of Hydro. Sci. Publ. no. 159, pp. 165-183.

Libohova, Z., and L.H. MacDonald. 2003. Effects of the Hayman Fire and thinning on sediment production rates, channel morphology, and water quality. 2003. In J.A. Ramirez (ed.), Proceedings of AGU Hydrology Days 2003, Colorado State University, Ft. Collins CO, Mar 31 – April 2, 2003.

MacDonald, L.H., R. Sampson, D. Brady, L. Juarros, and D. Martin. in press. Predicting post-fire erosion and sedimentation risk on a landscape scale: a case study from Colorado. J. of Sustainable Forestry.

Martin, D.A.. and J.A. Moody. 2001a. Comparison of soil infiltration rates in burned and unburned mountainous watersheds. Hydrological Processes 15:2981-2993.

Martin, D.A.. and J.A. Moody. 2001b. The flux and particle size distribution of sediment collected in hillslope traps after a Colorado wildfire. *In* Proceedings of the Seventh Federal Interagency Sedimentation Conference. Reno, Nevada. III-40 - III-47.

Meyer, G.A., S.G. Wells, and A.J.T. Jull. 1995. Fire and alluvial chronology in Yellowstone National Park: climatic and intrinsic controls on Holocene geomorphic processes. Geolog. Soc. Am.Bull. 107:1211-1230.

Montgomery, D.R., and J.M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geolog. Soc. Am. Bull. 109(5):596-611.

Moody, J.A., 2001. Sediment transport regimes after a wildfire in steep mountainous terrain. *In* Proceedings of the Seventh Federal Interagency Sedimentation Conference. Reno, Nevada. X-41 – X-48.

Moody, J.A. and D.A. Martin. 2001a. Hydrologic and sedimentologic response of two burned watersheds in Colorado. U.S. Geological Survey Water-Resources Investigations Report, WRIR 01-4122. 142 pp.

Moody, J.A. and D.A. Martin. 2001b. Initial hydrologic and geomorphic response following a wildfire in the Colorado Front Range. Earth Surface Processes and Landforms 26:1049-1070.

Moody, J.A. and D.A. Martin. 2001c. Post-fire, rainfall intensity – peak discharge relations for three mountainous watersheds in the western USA. Hydrological Processes 15:2981-2003.

Morris, S.E., and T.A. Moses. 1987. Forest fire and the natural soil erosion regime in the Colorado Front Range. Annals of the Assoc. of Amer. Geog. 77(2):245-254.

Pietraszek, J.H., and L.H. MacDonald. 2003. Use of a rainfall simulator to assess controls on post-fire runoff and sediment production, Colorado Front Range. In J.A. Ramirez (ed.), Proceedings of AGU Hydrology Days 2003, Colorado State University, Ft. Collins CO, Mar 31 – April 2, 2003.

Prosser, I.P, and L. Williams. 1998. The effect of wildfire on runoff end erosion in native Eucalypt forest. Hydro. Proc. 12:251 -265.

Quinn, P.F., K.J. Beven, and R. Lamb. 1995. The In(a/tanB) index: how to calculate it and how to use it within the TOPMODEL framework. Hydro. Proc. 9: 161-182.

Renard, K.G., G.R. Foster, G.A. Weesis, D.K. McCool, and D.C. Yoder. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Dept. of Agriculture, Agriculture Handbook No. 703, Washington, D.C. 404 pp.

Rice, R.M. 1974. The hydrology of chaparral watersheds. In Proceedings of Symposium on Living with the Chaparral, Riverside, CA, pp. 27-33.

Ritter, D.F., R.C. Kochel, and J.R. Miller. 2002. Process Geomorphology. 4^{th} ed.; McGraw Hill, New York, NY.

Robichaud, P.R., and T.A. Waldrop. 1994. A comparison of surface runoff and sediment yields from low- and high-intensity prescribed burns. Water Resour. Bull. 30(1):27-34.

Rosgen, D.L., 1994. A classification of natural rivers. Catena 22(3):169-199.

Rough, D.T.M., L.H. MacDonald, and J.W. Wagenbrenner. 2003. Effectiveness of BAER treatments in the Bobcat, Hayman, and Schoonover Fires. In J.A. Ramirez (ed.), Proceedings of AGU Hydrology Days 2003, Colorado State University, Ft. Collins CO, Mar 31 – April 2, 2003.

Scott, D.F.. 1993. The hydrological effects of fire in South African mountain catchments. J. of Hydro. 150:409-432.

Wagenbrenner, J.W. 2003. Effectiveness of Burned Area Emergency Rehabilitation treatments, Colorado Front Range. M. S. Thesis, Colorado State University.

Part 4: Forest Succession

William H. Romme, Claudia M. Regan, Merrill R. Kaufmann, Laurie Huckaby, and Thomas T. Veblen

Introduction

The ecosystems within the area that burned in the Hayman Fire have a long history of fire (see part 1 of this chapter). It follows, therefore, that all of the native species and populations in this area probably have one or more mechanisms for enduring fire or becoming reestablished after fire and that no native species is likely to become extinct as a result of the direct effects of the Hayman Fire. It also follows that active rehabilitation is not required for all of the burned area. In fact, much or even most of the area is likely to recover normally without intervention, and in some areas our well-intentioned rehabilitation efforts actually could interfere with natural recovery processes.

Despite the general expectation just stated, ecosystem recovery and native species persistence is likely to be problematic within certain portions of the Hayman burn area. In other parts of the burned area, postfire trajectories may lead to ecological conditions different from what existed just before the Hayman Fire, but nevertheless within the historical range of variability for this ecosystem. Therefore, in addressing this question, we describe three potential postfire trends in vegetation development, and indicate generally where in the Hayman landscape each trend is likely to be manifest. The three trends are (1) development of vegetation structure, composition, and function *similar* to what existed just before the Hayman Fire, (2) development of vegetation that is different from prefire conditions but *within* the historical range of variability, and (3) development of vegetation that is different from prefire conditions and also is *dissimilar* to or at *extremes* of the historical range of variability for this ecosystem. Vegetation structure refers to overall physiognomy, for example, dense forest, open forest, shrubland, or grassland. Composition refers to the species present and the relative abundance of each species. Function refers to ecosystem processes of energy flow, material cycling, disturbances, and others. Our predictions are summarized generally in table 6.

Development of Vegetation Structure Similar to the Prefire Condition

In much of the Hayman Fire area we can expect either a rapid or gradual return to prefire conditions, even without postfire remediation or rehabilitation. In fact, some remediation techniques, such as planting of nonnative grasses, actually may retard the natural course of postfire succession (Robichaud and others 2000). The most rapid return to prefire conditions is predicted where sprouting species predominated before the fire (for example, aspen and meadows) or where tree canopy mortality was low (for example, ponderosa pine forests that burned at low severity). A slower, but nevertheless normal, postfire succession is predicted in lodgepole pine and spruce-fir forests that comprise a small portion of the burned Hayman landscape.

Sprouting Species – Where the vegetation is dominated by sprouting species, a rapid return to prefire conditions is generally expected (fig. 17, 18). Although the fire kills all or most of the aboveground portions of the plants, belowground structures such as rhizomes, roots, and root collars survive the fire because of the insulating properties of soil. After fire, the dormant buds in these belowground structures are no longer suppressed by the aerial portions of the plant, and the buds respond by producing fast-growing new shoots (Miller 2000). In many places, perhaps even most places, sprouting by belowground survivors is responsible for the earliest and most rapid recovery of aboveground plant cover and biomass after fire (Turner and others 1997; Floyd and others 2000).

Some of the major sprouting species in the Hayman area include: trees – quaking aspen (*Populous tremuloides*), several species of willow (*Salix* spp.), cottonwood (*Populus angustifolia*, some *P. deltoides*); and shrubs – mountain-mahogany (*Cercocarpus montanus*), wax currant (*Ribes cereum*), cliffrose (*Jamesia americana*), kinnikinnik (*Arctostaphylos uva-ursi*), wild rose (*Rosa* spp.), and yucca (*Yucca glauca*). In addition to these important trees and shrubs, many – perhaps most – of the native herbaceous species are capable of resprouting after disturbance. These include herbs of the forest floor, for example, Geranium (*Geranium caespitosum*), dogbane (*Apocynum androsaemifolium*), some asters (*Aster* spp.), gayfeather (*Liatris punctata*), which is the obligate flower of the endanged Pawnee montane skipper, as well as the grasses blue gramma (*Bouteloua gracilis*) and Ross sedge (*Carex rossii*).

Riparian areas usually have large numbers of sprouting herbs and shrubs, and consequently riparian areas often recover aboveground cover and biomass more rapidly than surrounding upland areas following a severe fire that kills much or all of the aboveground plant parts. Rapid recovery of prefire vegetation structure may be disrupted in some places by chronic, heavy browsing on aspen, cottonwood, and other species, by either native or domestic ungulates, for example, elk or cattle. Although severe browsing effects are well documented in some parts of the Rocky Mountains

Table 6—Expected trajectories of postfire vegetation development in the Hayman burn area. "HRV" refers to the historical range of variability (see part 1 in this chapter). Data on extent are from the BAER report on the Hayman burn.

Development of vegetation structure similar to prefire condition:			
Aspen forests and shrublands of oak, mountain-mahogany, and others	Extent: 1.8 percent of the Hayman area.	Trajectory: Reestablishment of dense stands over the next 20 to 50 years.	Mechanism: Aspen and the shrub species re-sprout vigorously from surviving below-ground plant structures and grow rapidly, naturally reestablishing dense stands similar to the stands that burned in 2002 … *except* in areas where chronic heavy browsing suppresses plant growth.
Meadows and grasslands	Extent: 0.6 percent of the Hayman area.	Trajectory: Reestablishment of herbaceous cover within the next 2 to 10 years.	Mechanism: Native herbs resprout vigorously from surviving belowground plant structures, and new seedlings become established, resulting in rapid recovery of prefire cover and biomass … *except* in areas where chronic heavy grazing suppresses plant growth.
Lodgepole pine and spruce-fir forests	Extent: 1.0 percent of the Hayman area.	Trajectory: Reestablishment of dense stands over the next century.	Mechanism: Serotinous cones in lodgepole pine and canopy seed banks in spruce and fir provide onsite seed source for rapid establishment of new trees that naturally grow into dense stands similar to the stands that burned in 2002.
Ponderosa pine and Douglas-fir forests: where fire severity was "low" on the BAER map	Extent: 32.8 percent of these two forest types; 29.4 percent of the Hayman area.	Trajectory: Maintenance of current forest structure.	Mechanism: Canopy mortality varied from almost none to moderate where fire severity was mapped as "low"; consequently, most such stands remain as dense or nearly as dense as in 2002 … herbaceous plants will be more productive over the next several years, and crown fire potential may be reduced.
Development of vegetation structure different from prefire condition, but within HRV:			
Ponderosa pine and Douglas-fir forests: where fire severity was "moderate" on the BAER map … and invasive species are few	Extent: 16.0 percent of these two forest types; 14.3 percent of the Hayman area.	Trajectory: Development of moderately open to moderately dense forests over the next century … increased herb cover next several years.	Mechanism: Canopy mortality varied from moderate to nearly 100 percent where fire severity was mapped as "moderate"; a new cohort of trees may become established within a few years where tree crowns were not severely damaged, but very slowly where seed mortality was high … woody fuels were reduced and herbaceous plants will be more productive over the next several years.
Ponderosa pine and Douglas-fir forests: *small* patches where fire severity was "high" on the BAER map … and invasive species are few	See footnote[1]	Trajectory: Development of open forests or non-forest over the next century … increased herb cover next 1 to 2 decades.	Mechanism: Canopy mortality was nearly 100 percent where fire severity was mapped as "high"; canopy seed banks were severely damaged, and reforestation will occur slowly as seeds blow in from outside (or are planted); some persistent openings will be formed, similar to openings created after large historical fires (such as in 1851) … woody fuels were reduced and herbaceous plants will be more productive over the next several years.

(con.)

Table 6—(Con.)

Development of vegetation structure different from prefire condition, and dissimilar to or at extremes of HRV:			
Ponderosa pine and Douglas-fir forests: *very large* patches where fire severity was "high" on the BAER map … and invasive species are few	See footnote below[1]	Trajectory: Development of very open forests or non-forest over the next century … increased herb cover next 1 to 2 decades.	Mechanism: Basically the same as in small patches of high-severity fire (described above) *except* that some of the large patches of severely burned forest created by the Hayman Fire are substantially larger than in any historically documented fire … consequently, the persistent treeless openings resulting from the 2002 fire may be far larger than any such openings during the historical period… woody fuels were reduced and herbaceous plants will be more productive over the next several years in large patches as in small patches.
Any vegetation type where invasive nonnative species become established in high densities	Extent: The specific areas of nonnative invasion are not yet determined.	Trajectory: Long-term or permanent dominance by nonnative species.	Mechanism: Some nonnative species can aggressively out-compete the native species, ultimately displacing the native species, dominating a site for long periods, and altering or eliminating the normal course of postfire succession … all vegetation types are vulnerable, but the most vulnerable areas are (1) severely burned, (2) close to nonnative seed sources, or (3) in poor ecological condition before the fire (for example, compacted soil or excessive grazing).

[1]Extent: 37.1 percent of these two forest types and 33.2 percent of the Hayman area were classed as "high severity." However, the distribution of patch sizes within the "high-severity" category on the BAER maps has not yet been developed. Therefore, we cannot identify at this time the actual extent of burned ponderosa pine and Douglas-fir forests that fit the categories "different from prefire vegetation but within HRV" and "different from prefire conditions and dissimilar to or at extremes of HRV."

Figure 17—Root sprouts of aspen in the Hayman Fire area in September 2002. (Photo by W. H. Romme)

(Romme and others 2001), the extent to which browsing will interfere with normal vegetation recovery in the Hayman area is unknown. Similarly, chronic heavy grazing of meadows and grasslands may inhibit the rapid postfire recovery that we predict in this kind of vegetation.

Lodgepole Pine and Spruce-Fir Forests – Although they occupy only a small portion of the area burned in the Hayman Fire, lodgepole pine forests are widespread in areas nearby and will likely be affected more extensively by future fires in the Front Range. Lodgepole pine forests are expected to recover rapidly, even after high-severity fire (see the definitions of fire severity in table 2, part 1 in this chapter). Although lodgepole pine is incapable of sprouting, this species tends to have a large canopy seed bank that provides ample seed to restock the stand after fire. Many lodgepole pine trees have serotinous cones, which remain closed at maturity and do not release their seed until subjected to a heat shock – as occurs in a fire. The closed, serotinous cones may afford some small degree of protection to the seeds encased within, but the most important effect of serotiny probably is that many years of seed production are stored in the canopy, ready to be released en mass by the effects of the fire. A fire that consumes most of the forest floor creates an ideal seed bed for lodgepole pine, the canopy seed bank provides abundant seed, and the result is often an exceptionally dense stand of lodgepole pine seedlings that become established within the first few years after fire (Muir and Lotan 1985; Tinker and others 1994; Turner and others 1997). Because most of the lodgepole pine forests that burned in the Hayman Fire probably were greater than 100 years old, it will be many decades before the new lodgepole pine forests exactly resemble the forests that burned. Nevertheless, the new postfire stands are on a natural successional trajectory leading to stands much like those that burned in 2002. Spruce and fir often grow in association with lodgepole pine. Although these species do not have serotinous cones like the lodgepole pine, they do generate after fire from seed stored in canopy seed banks and from unburned areas nearby. Reforestation is often slower in spruce and fir than in lodgepole pine, but burned spruce-fir stands in the Hayman area also are likely to follow a normal postfire successional trajectory (Veblen 1986; Turner and others 1997).

Figure 18—Rapid recovery of herbaceous vegetation in a riparian area. The Hayman Fire consumed nearly all of the aboveground biomass of the herbaceous plants in this scene, but roots and other belowground structures survived the fire and sprouted vigorously in late July 2002. (Photo by Laurie Huckaby)

Ponderosa Pine and Douglas-Fir Forests in Low-Severity Burns – We also can expect a rapid return to prefire conditions in ponderosa pine and Douglas-fir forests that burned at low severity (Arno 2000). These conifer species are not capable of resprouting; if fire kills the aboveground portions of the tree, the entire tree is dead. However, in most places where the fire burned at low intensity through the forest floor, few or none of the mature trees were killed (fig. 19a). Some small trees may have been killed, but the density of canopy trees remains about what it was before the fire, and the canopy's general dominance over the understory (that is, its ability to capture most of the available light, water, and nutrients) is unaffected. Even though the herbaceous plants will likely exhibit a brief episode of increased productivity because of the temporary flush of nutrients released by the fire, and even though the fire consumed some of the woody material on the forest floor, these effects on the understory and forest floor are relatively transient (lasting a few years at most).

Although we predict a rapid return to prefire conditions for most characteristics of the stand, it is important to point out that low-intensity surface fires can have some persistent and important effects on stand structure and function if they scorch and kill the lower branches of the canopy trees. Because the scorched branches will gradually fall and not be replaced (the trees put their energy into the well-illuminated upper branches), the effect of the fire will be to raise the height of the lower canopy, thereby increasing the distance between surface fuels and canopy fuels, and thus reducing the probability that a future fire will ignite the canopy (Lynch and others 2000).

Development of Vegetation Structure Different From Prefire Conditions, But Within the Historical Range of Variability

The Hayman landscape has a long history of fire and a dynamic forest mosaic. Ponderosa pine and Douglas-fir forests that burned at moderate severity or in small patches of high-severity in 2002 are predicted to be significantly different from their prefire state for several decades after the Hayman Fire. However, even though different, these forests should not be regarded as abnormal or degraded because historical fires produced similar forest structures. The ponderosa pine and Douglas-fir forests that burned at moderate severity or in small patches of high-severity in 2002 are predicted to exhibit a trajectory of natural reforestation over the next several decades. In most of these areas, planting or other forms of postfire remediation probably are not needed and could even inhibit the natural course of succession.

Ponderosa Pine and Douglas-Fir Forests in Moderate-Severity Burns – We use the term "moderate severity' in the context of the BAER maps produced immediately after the fire, that is, the term refers to areas where the fire scorched but did not consume the forest canopy. This fire severity category actually encompasses a wide range of overstory mortality. Some of the scorched trees will not suffer permanent injury: they will shed the injured leaves and produce a set of new leaves over the next 1 to 3 years. Other scorched trees are already dead. Where a substantial portion of the canopy has been killed in these "moderate severity" burns, say 25 to 75 percent of the canopy trees, we can expect establishment of a new cohort of ponderosa pine seedlings over the next several years. The major seed source will be seeds that survived the fire in the canopy seed bank, plus some seeds that blow in from unburned areas nearby or are planted as part of the fire rehabilitation process. The density of this postfire cohort probably will vary greatly from place to place, depending on (1) local numbers of viable seed that survived the fire or are produced soon after, (2) local soil and environmental conditions, including erosion, hydrophobicity, and herbivory, (3) degree of local competition from native or planted herbaceous plants, and (4) weather conditions during the next several years. Seed survival in the canopy, and postfire soil and environmental conditions, are strongly dependent on local fire severity and vary greatly from place to place. Herbaceous plants, notably some native grass species (for example, *Calamagrostis rubescens*), have been shown to suppress conifer seedlings. Some of the grasses that have been planted to retard erosion, if they persist more than a year or two, may potentially inhibit conifer seedling establishment and growth (Robichaud and others 2000). Weather is a critical, and highly unpredictable, factor in this set of conditions influencing the density of postfire ponderosa pine regeneration. If the next few years are moist and cool, then seedling survival will likely be high, but if the warm, dry conditions of the years 2001 and 2002 continue, seedling survival will be low in many places. All of the reasoning just presented assumes that these burned areas are not invaded extensively by nonnative plant species, which could result in a novel postfire successional trajectory unprecedented in the historical range of variability (see below).

The upshot is that we cannot predict with any precision the postfire tree densities likely to develop in areas that burned at "moderate severity." However, the probable range of postfire seedling densities and the high degree of variability in local density probably are typical of responses to historical fires. Thus, even if some of the exceptionally dense ponderosa pine forests that burned in 2002 come back as less dense or even open stands, this pattern will not be abnormal. In fact, the exceptionally high density of many ponderosa pine stands in 2002 was probably not typical of the historical period, and the effect of the Hayman Fire may be to move some of these stands onto a developmental trajectory that will result in forest structure more like historical conditions. Monitoring and research are needed over the next several years to critically test and refine the predictions that we offer here.

Ponderosa Pine and Douglas-Fir Forests in Small Patches of High-Severity Burns – "High-severity" burned areas on the BAER map are places where the fire consumed the foliage of the canopy, and we can assume that essentially all of the pine and Douglas-fir trees in these areas are dead (fig. 19b). By burning in the crowns of the trees, the fire also probably killed most of the canopy seed bank, which is generally the most important seed source for postfire reestablishment of these species. Consequently, tree seedlings are likely to be sparse in the areas where the canopy was killed and consumed by high-intensity fire. Where this occurs in relatively small patches, the treeless openings that result actually will be a normal component of this landscape (assuming that these openings are not invaded by nonnative plant species – see below). Historical fires produced similar persistent openings, for example, in 1851, especially on dry, south-facing slopes (Brown and others 1999). Nonforest patches and patches of low-density forest were important components of the historical landscape that have gradually disappeared over the last century (see part 2 of this chapter). Consequently, even though the forests that develop after the Hayman Fire in many places will be substantially different from the forests that burned (that is, far less dense or even nonforest), these open areas actually will contribute to the diversity of the Hayman landscape, as well as an overall landscape structure that more closely resembles historical conditions (Kaufmann and others 2000, 2001).

Development of Vegetation Structure Different From Prefire Condition, and Dissimilar to or at Extremes of HRV

In some portions of the Hayman Fire, we predict postfire vegetation responses that are do not resemble the responses to historical fires. These areas include extremely large patches of severe crown fire, where tree seed sources may be inadequate to reestablish forest cover, and places where invasive nonnative species displace the native flora. It is in these areas where well-conceived postfire remediation efforts may enhance the development of more normal postfire successional trajectories.

Figure 19—Ponderosa pine forests that burned at (a) low and (b) high severity in the Hayman Fire, as they appeared in September 2002. (Photos by W. H. Romme)

Ponderosa Pine and Douglas-Fir Forests in Large Patches of High-Severity Burn – Some of the patches of high-severity burn, where the fire consumed the canopy foliage and seed banks (see above), were substantially large – notably the immense area that burned during the spectacular fire run of approximately 60,000 acres on June 9, 2002. As explained above, natural conifer regeneration is likely to be limited in this area because of high seed mortality within the burned area and long distances to seed sources outside the burned area. In one sense, the patches of low-density forest or even nonforest that will develop in these areas are normal because historical fires produced low-density stands and persistent openings. However, the patches of this kind that were produced by historical fires on the Cheesman landscape were relatively small, on the order of less than 1 ha to a few hundred hectares at most (Kaufmann and others 2000, 2001). In contrast, the patch created by the June 9 run probably is an order of magnitude larger than anything produced in historical burns. Because of this striking difference in scale, we regard postfire development within the large patches of high-severity burn in 2002 to be an extreme condition for the Hayman ecosystem. It is important to note, however, that this conclusion would not necessarily apply following large and severe fires elsewhere in the Colorado Front Range. Similarly large, severely burned patches clearly would be a normal component of fires during exceptionally dry years in subalpine forests (see part 1 in this chapter). Moreover, fire history studies conducted farther north in the Front Range (for example, in Rocky Mountain National Park) suggest that large, severe fires were a part of the historical fire regime even in some ponderosa pine and Douglas-fir forests (Ehle and Baker in press). Although the research at Cheesman Lake clearly shows that the large patch of high-severity burn produced on June 9 was unprecedented during the past 700 years in this particular location, additional research is needed to determine the extent to which such extreme fire effects would be regarded as normal or abnormal in other parts of the Front Range montane zone.

Any Vegetation Type Where Invasive, Nonnative Species Become Dominant – As explained elsewhere in this report, invasive, nonnative plant species pose a serious threat to ecosystem integrity in many places throughout the Rocky Mountains and the world (D'Antonio 2000). These invasive plants can displace the natives by directly outcompeting them, or by changing fundamental ecosystem processes such as nutrient cycling and disturbance frequencies. Unfortunately, the environment created by fire – especially by high-severity fire – is generally suitable for the establishment of invasive plant species that thrive in an environment of high light intensity and high nutrient availability (Hobbes and Huennecke 1992). In some places, these invaders are transient and have no long-lasting impact on development of the vegetation after fire, especially in the long term (50 to 100 years). In other places, however, the invaders persist indefinitely and may even dominate postfire plant communities for many decades. This latter kind of situation clearly is outside the historical range of variability for Front Range ecosystems. At this time we cannot predict with certainty where invasive nonnative species will cause significant departures from natural postfire trajectories in the Hayman burn area. Generally, though, we predict that the most serious problems are likely to be seen in places that were (1) severely burned, (2) in proximity to seed sources of invasive nonnative species, for example, roads and other disturbed lands, and (3) in poor ecological condition before the Hayman Fire, for example, as a result of excessive grazing or soil compaction. The burned areas being seeded for erosion control also may be at higher risk of invasion by nonnative species because of impurities that exist in even the best commercial seed mixes. Even where the applied seed mixes are not contaminated with weed seeds, if the planted cultivars persist more than a year or so they may interfere with reestablishment of the native plant community. Careful and extensive monitoring should be conducted over the next several years to test the predictions stated above and to detect problem areas early so that remediation can be attempted.

Acknowledgments

We thank Paula Fornwalt, Jason Stoker, and Laurie Huckaby for their contributions to the Cheesman Lake research, and Natasha Kotliar for discussions about fire ecology in Front Range forests. Greg Aplet, Bill Baker, Marcia Patton-Mallory, Wayne Shepperd, and Tom Swetnam provided helpful reviews of early drafts. This work was supported by the USDA Forest Service, Rocky Mountain Research Station.

References

Arno, S. F. 2000. Chapter 5: Fire in western forest ecosystems. Pages 97-120 in: Brown, J. K, and J. K. Smith (editors), Wildland fire in ecosystems: effects of fire on flora. USDA Forest Service General Technical Report RMRS-GTR-42 volume 2 (http://www.fs.fed.us/rm/pubs/rmrs_gtr42_2.html)

Brown, P. M., M. R. Kaufmann, and W. D. Shepperd. 1999. Long-term, landscape patterns of past fire events in a montane ponderosa pine forest of central Colorado. Landscape Ecology 14:513-532.

D'Antonio, C. M. 2000. Fire, plant invasions and global change. Pages 65-93 in: Mooney, H., and R. Hobbs (editors), Invasive species in a changing world. Island Press.

Ehle, D. S., and W. L. Baker. In press. Disturbance and stand dynamics in ponderosa pine forests in Rocky Mountain National Park, USA. Ecological Monographs.

Floyd, M. L., W. H. Romme, and D. Hanna. 2000. Fire history and vegetation pattern in Mesa Verde National Park. Ecological Applications 10:1666-1680.

Hobbes, R. J., and L. F. Huenneke. 1992. Disturbance, diversity, and invasion: implications for conservation. Conservation Biology 6:324-337.

Kaufmann, M. R., L. Huckaby, and P. Gleason. 2000. Ponderosa pine in the Colorado Front Range: long historical fire and tree recruitment intervals and a case for landscape heterogeneity. Proc. Joint Fire Sci. Conf. and Workshop, Boise, ID, Vol. 1, pp. 153-160.

Kaufmann, M. R., P. J. Fornwalt, L. S. Huckaby, and J. M. Stoker. 2001. Cheesman Lake – a historical ponderosa pine landscape guiding restoration in the South Platte watershed of the Colorado Front Range. In Vance, R. K., W. W. Covington, and C. B. Edminster (tech. coords.), Ponderosa pine ecosystems restoration and conservation: steps toward stewardship. U.S. Department of Agriculture Forest Service Rocky Mountain Research Station Proc. RMRS-P-22: 9-18.

Lynch, D.L., W.H. Romme, and M. L. Floyd. 2000. Forest restoration in southwestern ponderosa pine. Journal of Forestry 98:17-24.

Miller, M. 2000. Chapter 2: Fire autecology. Pages 9-34 in: Brown, J. K, and J. K. Smith (editors), Wildland fire in ecosystems: effects of fire on flora. USDA Forest Service General Technical Report RMRS-GTR-42 volume 2 (http://www.fs.fed.us/rm/pubs/rmrs_gtr42_2.html)

Muir, P. S., and J. E. Lotan. 1985. Disturbance history and seotiny of *Pinus contorta* in western Montana. Ecology 66:1658-1668.

Robichaud, P. R., J. L. Beyers, and D. G. Neary. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. USDA Forest Service General Technical Report RMRS-GTR-63.

Romme, W. H., L. Floyd-Hanna, D. D. Hanna, and E. Bartlett. 2001. Aspen's ecological role in the West. Pages 243-259 in: Shepperd, W. D., D. Binkley, D. L. Bartos, T. J.

Stohlgren, and L. G. Eskew (compilers), Sustaining aspen in western landscapes: symposium proceedings; 13-15 June 2000; Grand Junction, CO. USDA Forest Service, Rocky Mountain Research Station, Proceedings RMRS-P-18.

Tinker, D.B., W.H. Romme, W.W. Hargrove, R.H. Gardner, and M.G. Turner. 1994. Landscape-scale heterogeneity in lodgepole pine serotiny. Canadian Journal of Forest Research 24:897-903.

Turner, M. G., W. H. Romme, R. H. Gardner, and W. W. Hargrove. 1997. Effects of fire size and pattern on early succession in Yellowstone National Park. Ecological Monographs 67:411-433.

Veblen, T.T. 1986. Age and size structure of subalpine forests in the Colorado Front Range. Bulletin of the Torrey Botanical Club 113: 225-240.

Part 5: Historical Aquatic Systems

Lynn M. Decker, Jeffrey L. Kershner, and David Winters

> *The rivers of the Front Range are dammed and diverted to provide water to the surrounding regions, and they are constricted by roads and railroads, stocked with fish, polluted by mining wastes and urban runoff. Yet many of the people who visit the Front Range for short periods perceive the landscape to be a nearly pristine wilderness because they are unaware of the historical impacts of human activities.* (Wohl 2001)

Anthropogenic Changes to the Hayman Area

Although there is little historical information on the aquatic ecosystems within the perimeter of the Hayman Fire, we have developed a probable description of them based on available sources as well as from literature and reports on other Colorado Front Range systems, particularly the recent scholarly work of Wohl (2001).

Three recent periods of anthropogenic change (including early Native American influence) influence the current structure and function of the aquatic ecosystems in the area of the 2002 Hayman Fire: (1) prior to 1811 before beaver trapping began; (2) between 1811 and 1859 during which the beaver were essentially removed through extensive trapping for the fur trade; and (3) from 1859 to 2002 during which more extensive and complex changes occurred in the aquatic system. The cumulative result of almost 200 years of change is an aquatic and riparian environment that was already substantially and probably irreversibly different in physical and biological structure and function prior to the 2002 Hayman Fire.

Pre-1811 – Before 1811 the effects of humans would have been relatively subtle in this naturally dynamic system as the influences of native inhabitants were thought to be small (Kaufmann and others 2000, 2001; Huckaby and others 2001). The geology, topography, and climate within the Hayman Fire area probably had the most influence on the processes and structure of the aquatic and riparian systems. The dominant geology of noncalcareous granite that forms relatively unconsolidated and highly erodible soils contributes to naturally high erosion rates. The steep canyons and a local climate that is influenced considerably by storm events in the late spring through early fall months exacerbate erosion potential. While early inhabitants may have altered the frequency of forest fires in the basins along the Front Range, the effects of these alterations on aquatic ecosystems and biota were probably small and localized. Influxes of sediment and wood would have entered the streams and rivers following natural fires, windstorms, or floods (Benda and others 2003).

These sediment and wood inputs would have enhanced the development of fans, terraces, wide floodplains, and side channels throughout the system, creating highly complex habitats in some areas. In addition, woody vegetation regeneration would have begun shortly after sediment deposition on floodplains and gravel bars. As a consequence of this disturbance, watersheds throughout the South Platte River drainage probably existed in a mosaic of conditions prior to Euro-American settlement.

Key disturbance processes affecting aquatic ecosystems before 1811 were most likely those common to other Front Range systems: floods, debris flows, and avalanches at higher elevations, drought, wind, and fire. The floods in this area primarily result from snowmelt or rainfall. Snowmelt floods occurred in late spring and early summer and generally lasted less than a month. Monsoon storms in July and August produced floods lasting 3 or 4 days (Wohl 2001). Windstorms probably occurred periodically in these areas as well, contributing wood to channels and affecting water, sediment, and nutrient storage and routing. Where fires exhibited high severity, but infrequent return intervals, there were probably pulses of debris and sediment associated with flood flows. It is likely that where fire severity was low, these effects were moderated both temporally and spatially.

Beaver also could have been considered a key biological disturbance process. Beaver were thought to be well distributed across the Front Range and would have had a significant effect on the structure and functioning of these streams and rivers (Wohl 2001). On streams with suitable habitat, beaver density might have averaged two or three colonies (six to 40 animals) per half mile (Wohl 2001). Suitable habitat for beavers include streams or rivers with constant or nearly constant flow, in valley bottoms on the order of 150 feet wide, channel gradients of less than 15 percent and near aspen or willow (Wohl 2001). We analyzed stream gradient in the Hayman Fire area and found that 84 percent of the stream miles had gradient less than 14 percent, and within this, 26 percent of the area was aspen dominated and an additional 19 percent was riparian shrub dominated (before the fire). While we are not proposing that the historic distribution of suitable beaver habitat was 45 percent of the area, there is good reason to believe that beaver were historically well distributed in the area. Beaver presence and activity probably would have resulted in a more enhanced braiding of stream channels in low gradient sections and more wetland habitat than are present today. Beyond the direct result of beaver on the structure of the perennial streams and rivers, a significant beaver presence would have resulted in riparian areas that were probably lush and moist in the broad valley bottoms and not as prone to severe fires except during longer periods of extreme drought. If these riparian areas did burn, they most likely did so in a patchy pattern (Arno and Allison–Bunnell 2002; Dwire and Kauffman 2003). Smaller, steeper, and drier drainages probably burned more often and more similarly to the adjacent hillslopes. The nature of the riparian development in the broad valley bottoms would have buffered downstream disturbance effects. Overall, these disturbances were likely to have been patchily distributed in time and space and describe the "natural variability."

Beaver have a significant effect on processes and functions in aquatic and riparian systems (Naiman and others 1988; Wohl 2001). Fine sediment from hillslope disturbance is generally trapped behind beaver dams. In general, stream reaches downstream of beaver ponds have been found to contain 50 to 75 percent fewer suspended solids than equivalent reaches without beaver ponds (Wohl 2001). Where beaver were present, they significantly altered the longitudinal profile of the streams, decreasing channel gradient, resulting in a stream with a more stepped profile. The presence of the beaver in large numbers would also have significant effects on the quantity and quality of water. Beaver impoundments locally elevate both surface and subsurface water levels. The increased water storage capacity within the system moderates the stream flow during high and low flows. This can bolster the growth of streamside vegetation, which further reduces flow and traps more sediment, allowing further expansion of the riparian environment. This riparian expansion would also enhance the lateral buffering of the streams from hillslope inputs. These streams would have been cool, clear, and well-oxygenated. Beaver ponds would have contributed to more moderated stream temperatures by keeping them generally cooler in the summer and more insolated in the winter (because of the increased stream depth and riparian canopy cover), but locally the increased surface area of the ponds can also increase stream heating.

The riparian environment would have included small, forested draws to narrow confined canyons with little or no riparian vegetation, to the broader valley bottoms with meadows and hardwoods. Their development and sustainability to a large extent was dependent on their relationship to surface and subsurface water as well as a function of topography, aspect, and channel gradient. It is probably safe to say that the riparian environment was much more extensive, diverse, and productive than it is today both longitudinally and laterally. These riparian areas would have provided a mosaic of habitats for both aquatic and terrestrial native plants and animals.

Beaver activity resulted in areas of impounded water between faster flowing sections of stream, increasing both the aquatic and riparian habitat diversity. The channels were probably well supplied with wood and nutrients, increasing habitat complexity. This environment probably supported a diverse macroinvertebrate community and substantial fish populations. By historical accounts, the native fish community of the South Platte River tributaries in the area of the fire consisted of greenback cutthroat trout (*Onchorhynchus clarki stomias*), longnose sucker (*Catostomus catostomus*), longnose dace (*Rhinichthys cataractae*), and white sucker (*Catostomus commersoni*) (Li 1968). The two sucker species and the dace could be considered habitat generalists and were probably widely distributed except in the smaller high-elevation streams. The greenback cutthroat trout is native to both the mountain and foothill waters of the South Platte River Basin. These fishes were broadly distributed in the basin and were known to make extensive migrations to spawn, rear, and overwinter (Young and others 2002; Behnke 2002). Overall, the aquatic biota were likely to have inhabited a system that was more diverse, more complex, and more productive. Populations of fishes were more connected between basins and able to recolonize areas following disturbances.

1811 to 1859 –

> *But it was not until the coming of the beaver trappers in the early decades of the nineteenth century that the activities of humans began to alter these systems substantially.* (Wohl 2001)

Significant changes occurred to Front Range systems between 1811 and 1859. By the 1840s beaver had been trapped to near extinction, reducing the number of functioning beaver dams and significantly altering the stream and riparian environments where beaver had been present (Wohl 2001). Channels probably experienced significant reorganization. Without the beaver to maintain the dams, the pools created by the dams presumably would have been compromised by high flows within the first decade. The sediment released would probably have been transported downstream, filling pools and reducing the overall habitat capacity for fishes both in the short and long term. Channels probably became laterally unstable, and channel bank stability would have been reduced as the water table associated with the pools dropped, killing some of the riparian vegetation.

The streams likely entered into a period of scouring and filling before they stabilized into a substantially different system, one with higher sediment loads and wider, shallower, less diverse channels. Removal of beaver dams probably resulted in lower base flows. Water tables were probably substantially lowered, and water retention in the system lessened. Changes in water quantity most likely resulted in increases in summer water temperature, changes in nutrient storage, and routing.

As the water table was lowered, there was likely a change in the riparian community structure from water-associated plant communities to drier site vegetation. The result would most likely have been changes in both the longitudinal and lateral extent of the riparian environment and altered energy and material flow in the river system. As the riparian area changed, the results would have been manifested as simplified channels, constricted riparian environments, and less storage of sediment, water, and nutrients. Increases in sediment in a geology that has naturally high erosion rates would have filled pools, creating less diverse and productive habitat for fishes and macroinvertebrates, and would have smothered plants and abraded surfaces. The final result, when viewed at the broad scale, was probably some change in the distribution and abundance of native fishes within the system, but the system was still well connected both laterally and longitudinally, and most major processes and functions were still intact allowing for potential recovery.

1859 to 2002 – The channel changes due to the removal of the beaver were significant but probably exacerbated by changes in land use that began with the mining in the 1860s. Both gold and silver were discovered in 1859, resulting in the influx of thousands of people over the next three decades into the Front Range. Following the miners, others usually arrived to provide support services and built infrastructure and railroads. Settlement of the early migrants and then their communities more often than not occurred along the rivers and streams beginning in the 1860s. The local landscape was changed as forests were harvested for the building of houses and homesteads, were burned, roads and trails were built, and streams were diverted for human uses. The miners diverted streams and used water in mining activities, changing the structure and functioning of the systems onsite and downstream. In addition, mining activities often included the use of mercury, cyanide, and other toxic chemicals, and these were commonly disposed of in or near the streams and rivers. The actual extent of these activities in the Hayman fire area is not known, but both the South Platte River and Tarryall Creek were active mining areas.

A variety of other human activities most certainly have affected the streams and riparian areas within the fire area. In addition to the fire history (part 1 of this chapter), both livestock grazing and timber harvesting were widespread throughout the area at the turn of the 20th century. Connaughton (1938) documented excessive erosion along the streams in the South Fork of the South Platte River and noted that the area was "cutover very heavily" before the creation of the National Forest. He also documented excessive erosion in Trail Creek due to timber cutting, a burned area and excessive grazing up until 1934. In Tarryall Creek, he noted excessive erosion and also that the area was heavily grazed by cattle. The reported levels of livestock grazing likely significantly influenced both riparian vegetation and stream bank integrity. Livestock grazing is limited in the area now, primarily because of forage limitations (David Winters personal observation). Where timber cutting was heavy or in riparian areas, the amount and timing of woody debris inputs in streams have been affected. The consequences are most likely similar to those described in other areas, a reduction in the number of pools, decreased pool volume, and a decline in habitat diversity and complexity. The overall and lasting result of all of these activities is a significant change in the landscape setting and a simplification of the form and function of the stream and riparian environments.

When the majority of the mining and related activities ceased in the early to mid-1900s, vegetation began to return to the valley bottoms and logged slopes began to revegetate, but changes to channels, water routing, and other impacts to aquatic and riparian systems were well established. Roads continued to be built to support the various activities of the developing Front Range and eventually in support of managing the National Forests.

In the Hayman Fire area there are currently more than 250 miles of identified roads, with an average density of more than 1 mile of identified road per square mile. More than half of these road miles are within the influence zones of streams and compromise the functioning of the riparian system. There are several other negative consequences of the extensive road development. Where roads cross the streams, culverts often create migration barriers to aquatic species and additional sources of sediment. Streams have also been confined and banks stabilized to protect roads, resulting in reduced connectivity to floodplains and habitat simplification. In addition to existing roads, off-highway vehicle (OHV) use has increased dramatically along the Front Range (David Winters personal observation). Trails created by these vehicles have similar direct and indirect influences to riparian and aquatic systems as formal road systems and often more because proper maintenance is rarely done. The overall result was a drainage system that retained less of its historical function, resulting in fragmented, often isolated populations of aquatic organisms. These influences dramatically limited the ability of fish and other aquatic biota to recolonize after disturbance.

In addition, rivers and streams within the area have been dammed, diverted, and augmented for agricultural and municipal purposes. Dams and river regulation have reduced the environmental variability downstream of the reservoirs. Several impoundments exist within the Hayman Fire area, the largest being Cheesman Reservoir. Cheesman Dam was completed in 1905, resulting in major permanent physical disruption of the system. This has also resulted in an economically valuable tailwater fishery for introduced trout species below Cheesman Dam.

Native greenback cutthroat trout that historically inhabited the region approached extinction by 1937 because of extensive overharvest, the widespread stocking of nonnative brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), and other subspecies of cutthroat trout (*Oncorhynchus clarki*), and habitat alteration (Wiltzius 1985; Young and others 2002). The introductions of nonnatives and other subspecies of cutthroat trout were believed to have caused the final elimination of greenback cutthroat trout from nearly all of their historical range (Young and others 2002). While greenback cutthroat trout are believed extirpated from the streams within the Hayman Fire area, a small population exists in the portion of Wigwam Creek upstream of the Lost Creek Wilderness Area boundary and beyond the area affected by the Hayman Fire.

At the time of the Hayman Fire, the fish fauna in the area consisted of three native species, longnose dace, longnose sucker, and white sucker; and four nonnative trout species, brook trout, brown trout, rainbow trout, and nonindigenous cutthroat trout. The highest quality fishery for these introduced trout was in the South Platte River where flows are regulated, although good recreational fisheries for introduced trout also existed on smaller streams in the area. Whirling disease, introduced to United States waters from Europe, affects native and nonnative trout populations in Colorado and is present in the introduced trout species in the basin. Whirling disease is spread by fish stocking as well as by movement of infected gear and equipment between waters. It is more likely to expand its distribution within basins if water temperatures increase.

In summary, the watersheds within the Hayman Fire area just prior to the fire were a mosaic of conditions that ranged from functioning systems that exhibited higher integrity, to highly altered, fragmented, and poorly functioning systems. Although beaver returned to the system, they are not abundant and population expansion is often in conflict with humans (along the Front Range beaver are estimated to be at approximately one-tenth of their historic population). Prior to Euro-American influence, fire and other disturbances were patchy in time and space, resulting in complex, heterogeneous ecosystems; in contrast, the current system is fragmented and relatively homogenous as a result of almost 200 years of human influence. Nevertheless, aquatic ecosystems are a critical component of the Hayman landscape and the fisheries for nonnative trout are highly valued by visitors. Rehabilitation and restoration efforts in terrestrial and aquatic habitats will need to be adapted to the variety of human influences on key biological and physical processes that affected their condition even before the 2002 Hayman Fire.

References

Arno, S.F; Allison-Bunnell, S. 2002. Flames in our forest: disaster or renewal? Island Press, Washington, D.C.

Benda, L.; Miller, D.; Bigelow, P.; Andras, K. 2003. Effects of post-wildfire erosion on channel environments, Boise River, Idaho. Forest Ecology and Management. Vol. 178:105-119.

Connaughton, C.A. 1938. Erosion on the National Forests of Colorado, eastern Wyoming and western South Dakota. Rocky Mountain Forest and Range Experiment Station

Dwire, K.A; Kauffman, J.B. 2003.Fire and riparian ecosystems in landscapes of the western USA. Forest Ecology and Management. Vol. 178: 61-74

Huckaby, L. S., M. R. Kaufmann, J. M. Stoker, and P. J. Fornwalt. 2001. Landscape patterns of montane forest age structure relative to fire history at Cheesman Lake in the Colorado Front Range. In Vance, R. K., W. W. Covington, and C. B. Edminster (tech. coords.), Ponderosa pine ecosystems restoration and conservation: steps toward stewardship. U.S. Department of Agriculture Forest Service Rocky Mountain Research Station Proc. RMRS-P-22: 19-27.

Kaufmann, M. R., P. J. Fornwalt, L. S. Huckaby, and J. M. Stoker. 2001. Cheesman Lake – a historical ponderosa pine landscape guiding restoration in the South Platte watershed of the Colorado Front Range. In Vance, R. K., W. W. Covington, and C. B. Edminster (tech. coords.), Ponderosa pine ecosystems restoration and conservation: steps toward stewardship. U.S. Department of Agriculture Forest Service Rocky Mountain Research Station Proc. RMRS-P-22: 9-18.

Kaufmann, M. R., L. Huckaby, and P. Gleason. 2000. Ponderosa pine in the Colorado Front Range: long historical fire and tree recruitment intervals and a case for landscape heterogeneity. Proc. Joint Fire Sci. Conf. and Workshop, Boise, ID, Vol. 1, pp. 153-160.

Li, H.W. 1968. Fishes of the South Platte River Basin. Unpublished M.S. Thesis, Colorado State University, Fort Collins, Colorado. 67 pp.

Naiman, R.J., Johnson, C.A. and Kelly, J. 1988. Alteration of North American streams by beaver. Bioscience 38:753-761.

Wiltzius, W. J. 1985. Fish culture and stocking in Colorado, 1872-1978. Colorado Division of Wildlife, Division Report No. 12

Wohl, E. E. 2001. Virtual Rivers: Lessons from the Mountain Rivers of the Colorado Front Range. Yale University Press, New Haven & London.

Young, M. K.; Harig, A.L.; Rosenlund, B.; Kennedy, C. 2002. Recovery history of greenback cutthroat trout: population characteristics, hatchery involvement, and bibliography. Version 1.0. Gen. Tech. Rep. RMRS-GTR-88WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Part 6: Fire-Induced Changes in Aquatic Ecosystems

Jeffrey L. Kershner, Lee MacDonald, Lynn M. Decker, David Winters, and Zamir Libohova

The aquatic ecosystems within the Hayman fire area represent a highly altered landscape that has been influenced by a variety of activities including mining, vegetation management, road building, urbanization, recreation and water development. Consequently, the expression of aquatic community structure has been significantly altered from the conditions found during European exploration and settlement in the late 1700s and early 1800s.

Introduction

The watersheds within the Hayman Fire area represent a mosaic of ephemeral, intermittent, and perennial streams of various sizes. Given the intensity of the fire, the effects on these streams will often vary from mild to severe. For example, the vegetation along streams in the upper Wigwam Creek drainage was almost completely removed by the intense fire that moved through the upper watershed, while vegetation along other streams was minimally affected (fig. 20; table 7). The severity of the fire in the surrounding watershed will generally dictate the initial response of the stream. Recovery of the stream/riparian interface generally parallels forest recovery (Minshall and others 1989).

The effects of wildfires on streams are generally viewed as "pulse" disturbances (Detenbeck and others 1992) that may be initially severe but are generally short lived. In some cases, sediment accumulations in downstream areas and incision in upstream areas may take decades or longer to recover to prefire conditions. Full recovery of aquatic communities is often dependent on the presence of intact communities that are adjacent to burned areas and the lack of additional disturbances that either retard recovery or pose additional stresses to the system. In the case of the Hayman Fire, human-caused chronic disturbances are present from roads, vegetation management, recreation, and urbanization. The full expression of recovery may be inhibited or truncated by these additional disturbances.

Aquatic Ecosystems Within the Hayman Fire: Prefire and Immediate Postfire Response

The response of aquatic ecosystems during and after a fire can be highly variable and depends on factors such as fire severity, magnitude of storm and snowmelt events relative to normal flow regimes, burned area relative to the watershed area, stream size, stream type, and the ecosystem of interest. The immediate effects of light to moderate fire severities were generally minimal. In these areas runoff and erosion rates may increase, but the increases will not be nearly as large as in severely burned areas, and rates rapidly return to prefire values. In the case of the Hayman Fire, the initial recovery of the riparian zones may have been slowed by the exceptionally dry conditions experienced after the fire. Many of the streams in the northern part of the fire are spring-fed, and the drought apparently caused a reduction or cessation of flow in many areas. Because of the dry conditions, the loss of the forest and riparian vegetation is unlikely to have affected stream flow in the first few months after the fire.

In areas that were severely burned there was almost a complete removal of the streamside vegetation as well as the loss of the duff and litter layer on the adjacent hill slopes. Other studies in the Colorado Front Range have shown that runoff and erosion rates can increase by several orders of magnitude in areas burned at high severity. We were fortunate that a

Table 7—Burn severity for upslope and riparian areas for seven subwatersheds in the Hayman Fire area.

Burn Class	Turkey Creek	Trout Creek	Tarryall Creek	Upper S. Platte R.	Goose Creek	Wigwam Creek	West Creek	Total
	Percent							
Upslope								
Unburned	14.90	17.78	4.84	23.74	14.62	19.31	21.08	17.77
Low	33.32	33.48	46.33	51.17	23.15	19.15	50.14	36.80
Moderate	20.14	36.55	17.18	14.09	5.92	3.73	3.78	12.42
High	31.64	12.18	31.65	11.01	56.32	57.82	25.00	33.01
								Riparian
Riparian								
Unburned	1.98	24.83	12.32	15.22	27.60	10.11	29.56	6.86
Low	2.00	37.82	55.60	53.15	26.89	28.21	28.13	12.24
Moderate	93.94	25.84	7.86	23.18	3.09	6.52	17.22	73.74
High	2.08	11.51	24.22	8.45	42.42	55.16	15.09	17.17

Figure 20—Riparian areas along streams within the fire area were differentially affected by the fire. Note presence of ash and fine sediment in picture on the left and minimal effects to riparian community on the right.

series of study sites had been established in the northern part of the Hayman Fire in summer 2001 to determine the effects of a proposed thinning project. These included the establishment of sediment fences on 12 pairs of swales ranging in size from 0.1 to 1 ha, the installation of 76-cm H-flumes on the 3.4km^2 Saloon Gulch and the 6.2km^2 Brush Creek watersheds, and the assessment of channel characteristics immediately upstream of each flume. Grab water samples were collected on eight occasions between August 2001 and April 2002, before the Hayman Fire.

Prior to the fire, most of the swales had no distinct channel, and there was no measurable erosion in any of the swales from mid-2001 to the time of the Hayman Fire. At the watershed scale, the estimated bankfull channels were less than 1 m wide and only a few centimeters deep (table 8). The channels were relatively stable and well vegetated. The grab water samples had total suspended sediment (TSS) concentrations of less than 10 mg/L, and low concentrations of nutrients and metals (table 9).

Although there were few rainfall events after the fire, they caused dramatic changes in the swales, channels, and water quality, as nearly all of the swales and most of the watersheds above the flumes had been severely burned. By mid-July we had reestablished the sediment fences that had been burned by the Hayman Fire. On 21 July 2002 a rainstorm of only 19 mm resulted in an average sediment yield from the 20 swales of 0.6 kgm^{-2}. Each of the swales had developed an extensive rill network and a clearly incised channel as a result of this event (fig. 21). Permanent cross-sections established in six swales indicated that the newly formed channels were up to 45 cm wide and 15 cm deep.

At the watershed scale, the effects of a 19-mm storm on July 7 were remarkable. The flume in Upper Saloon Gulch, together with its 3-m approach section, was completely buried by the sediment eroded off of the hillsides and out of the headwater channels. A comparison of the prefire and postfire cross-sections shows that over 1 m of sediment was deposited (fig. 22). At the mouth of the Saloon Gulch watershed, a large alluvial fan has been deposited. This fan extends into the channel of the South Platte River, and the erosion of the distal edge of this fan is introducing substantial amounts of fine sediment into the South Platte River.

At Brush Creek the rebars marking the channel cross-section were destroyed by the July 7 storm, but figure 23 shows the relative change in channel dimen-

Table 8—Channel characteristics in Saloon Gulch and Brush Creek in summer 2001.

Channel characteristics	Site: Saloon Gulch	Site: Brush Creek
Drainage area (km^2)	3.4	6.2
Date of survey (dd/mm/yr)	01/11/01	06/08/01
Active channel width (m)	0.64	0.4
Bankfull channel width (m)	0.76	0.67
Bankfull depth (m)	0.08	0.12
Discharge on survey date (l/s)	0.3	1.1
D50 (mm)	7	12
D84 (mm)	13	33
Percent fines <8 mm	62	35
Percent eroding banks	4	13

Table 9—Mean values for selected water quality parameters in Saloon Gulch and Brush Creek prior to and after the Hayman fire.

	Site			
	Saloon Gulch		Brush Creek	
Water quality parameters	Prefire	Postfire	Prefire	Postfire
Number of samples	8	1	8	6
Discharge ($l\ s^{-1}$)	0.2	0.6	1.3	11.9
pH	8	8	8	8
Conductivity (uS)	180	400	170	290
K ($mg\ l^{-1}$)	2.9	6.7	2.8	4.7
Mg ($mg\ l^{-1}$)	4.3	11.6	4.3	7.9
Ca ($mg\ l^{-1}$)	24.9	59.6	21.1	41.8
Cl ($mg\ l^{-1}$)	1.8	2.5	2.2	2.3
NO_3 ($mg\ l^{-1}$)	0.5	0.2	0.1	0.3
Total suspended sediment ($mg\ l^{-1}$)	10	35	16	4600
Turbidity (ntu)	5	17	10	62
Sum of Anions ($meq\ l^{-1}$)	1900	4500	1700	3100
Sum of Cations ($meq\ l^{-1}$)	1900	4400	1700	3100

sions. The high water mark at Brush Creek was clearly distinguishable by the deposition of ash, and this indicated that the peak flow depth was close to 2 m. The flume itself was filled with fine sediment, woody debris, and boulders up to 50 cm in diameter. The particle-size distribution after this event showed a much greater preponderance of fine sediment, as the percent of the channel bed smaller than 8 mm in diameter increased from 35 to 70 percent (fig. 24a,b). The observed changes in the bed material at Brush Creek can be expected to sharply reduce macroinvertebrate density and diversity in the short term.

Results from a limited number of grab samples taken after the fire show a sharp increase in the mean TSS concentrations in Brush Creek from 16 to 4600 mg l^{-1}, and from 10 to 35 mg l^{-1} in Saloon Gulch (table 9). There also were substantial increases in the concentrations of potassium, magnesium, calcium, chloride, and nitrate. Overall, the sum of anions and cations approximately doubled as a result of the Hayman Fire. In contrast to the other parameters, there was no significant change in pH.

General observations indicate that each storm event after the fire caused extensive erosion, with large amounts of sediment being deposited on the roads. New alluvial fans developed at the mouth of many headwater channels. Large amounts of ash and sediment were deposited in other streams, and in some cases these deposits filled beaver ponds.

These data and observations show that even small convective storms can generate large amounts of runoff and erosion in severely burned areas. Incision will occur in headwater areas and deposition in downstream

Figure 21—Rills and incised channels in a study swale in Upper Saloon Gulch after the fire.

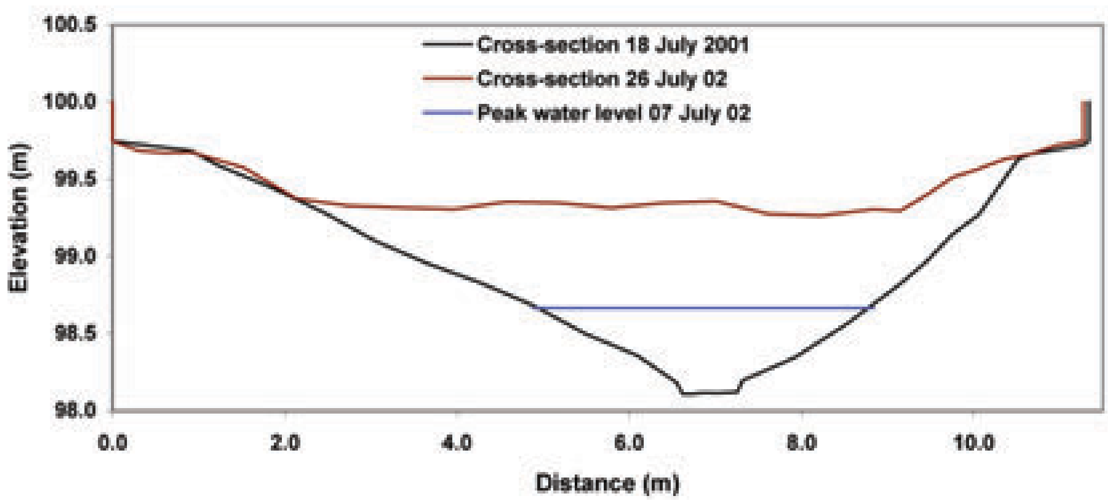

Figure 22—Cross–section of the channel in Saloon Gulch immediately upstream from the flume prior to the fire in summer 2001 and in July 2002 after the fire and a 19-mm storm event.

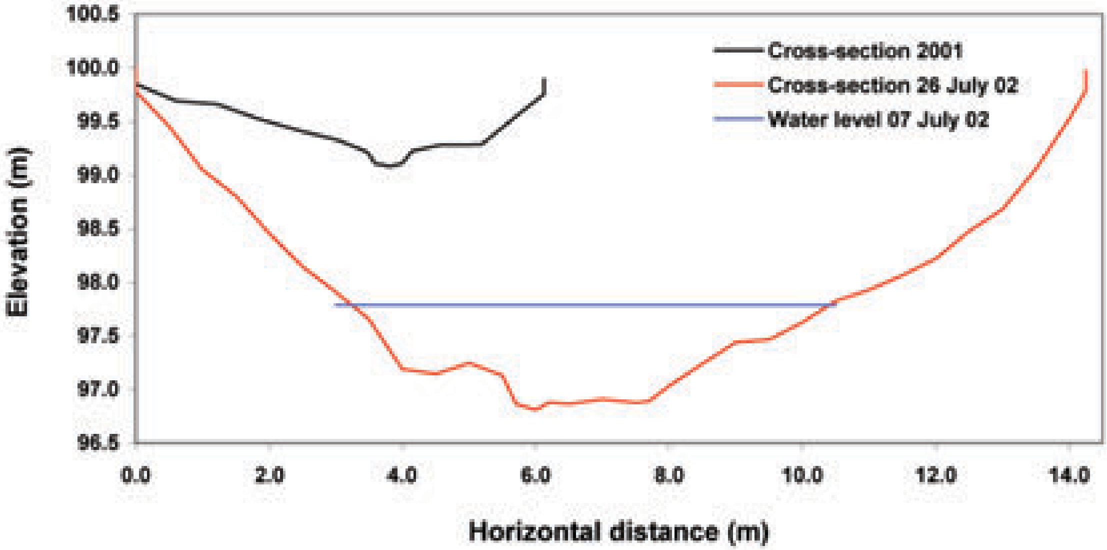

Figure 23—Channel cross-section in Brush Creek immediately upstream of the flume prior to the fire in summer 2001 and in July 2002 after the fire and a 14-mm storm event. The two cross-sections are each plotted relative to different benchmarks as the rebar established in 2001 were lost.

areas. Much larger effects can be expected from larger magnitude storm events, such as those that occurred after the 1996 Buffalo Creek Fire. Recovery in these aquatic ecosystems may be slow, as decades or longer may be needed to remove the sediment that is being deposited in lower gradient areas. Recovery of the incised rills and headwater channels should be relatively rapid once vegetation or organic debris protects the banks and slows the flow velocities. In contrast, the more deeply incised channels may require several decades before they fill in and recover to prefire conditions.

Small perennial streams that drained intensively burned watersheds most likely received inputs of nutrients from both ash and smoke during the fire (Spencer and Hauer 1991). We observed a coating of ash and burned needles over the stream bottom in many of the sections of stream during our field visit, as well as recent input of limbs and larger woody debris. Pulsed inputs of nutrients most likely resulted in elevated levels of phosphorus and nitrogen in the short-term, but these inputs may have returned to prefire levels within weeks after the fire. Pulsed inputs and elevated levels of nutrients will occur in the short-term during precipitation events and spring runoff.

Benthic macro-invertebrate communities were differentially affected in the fire area to a degree that depended on the severity within the immediate watershed and at the local site scale (authors' personal observation). Short-term effects during the fire may have included local extirpations or a catastrophic drift response where stream temperatures or water chemistry may have reached sublethal to lethal levels (Spencer and others 2003; Minshall and others 1989; Minshall 2003). Most likely, local populations may have been partially extirpated but maintained numbers of more tolerant organisms. We observed late instar mayflies (*Ephemeroptera*), stoneflies (*Plecoptera*), and other organisms patchily distributed where larger substrates were available in severe burn areas.

Immediate postfire response of the invertebrate community was also affected by the amount of sediment and debris transported into small streams from surface ravel and during initial runoff events. Stream channel sedimentation was occurring in many of the streams that we visited (fig. 25). Previous studies documented a decline in both diversity and biomass in some streams affected by fires where channel sedimentation has occurred (Minshall and others 1995, 2001; Rinne 1996). Local effects related to sedimentation appeared to be highly variable. Where large woody debris was present in sufficient quantity or there were beaver dams present to trap sediment, it appeared that stream substrate immediately downstream was much more heterogeneous.

A variety of short-term responses have been noted for fish communities affected by wildfire. Local extirpation of fishes has been noted where fire severity was high, potentially caused by lethal increases in water temperature and short-term changes in water quality that may have created unfavorable conditions for fish (Spencer and others 2003). Fish mortality may also be the result of poorly placed fire retardant that enters

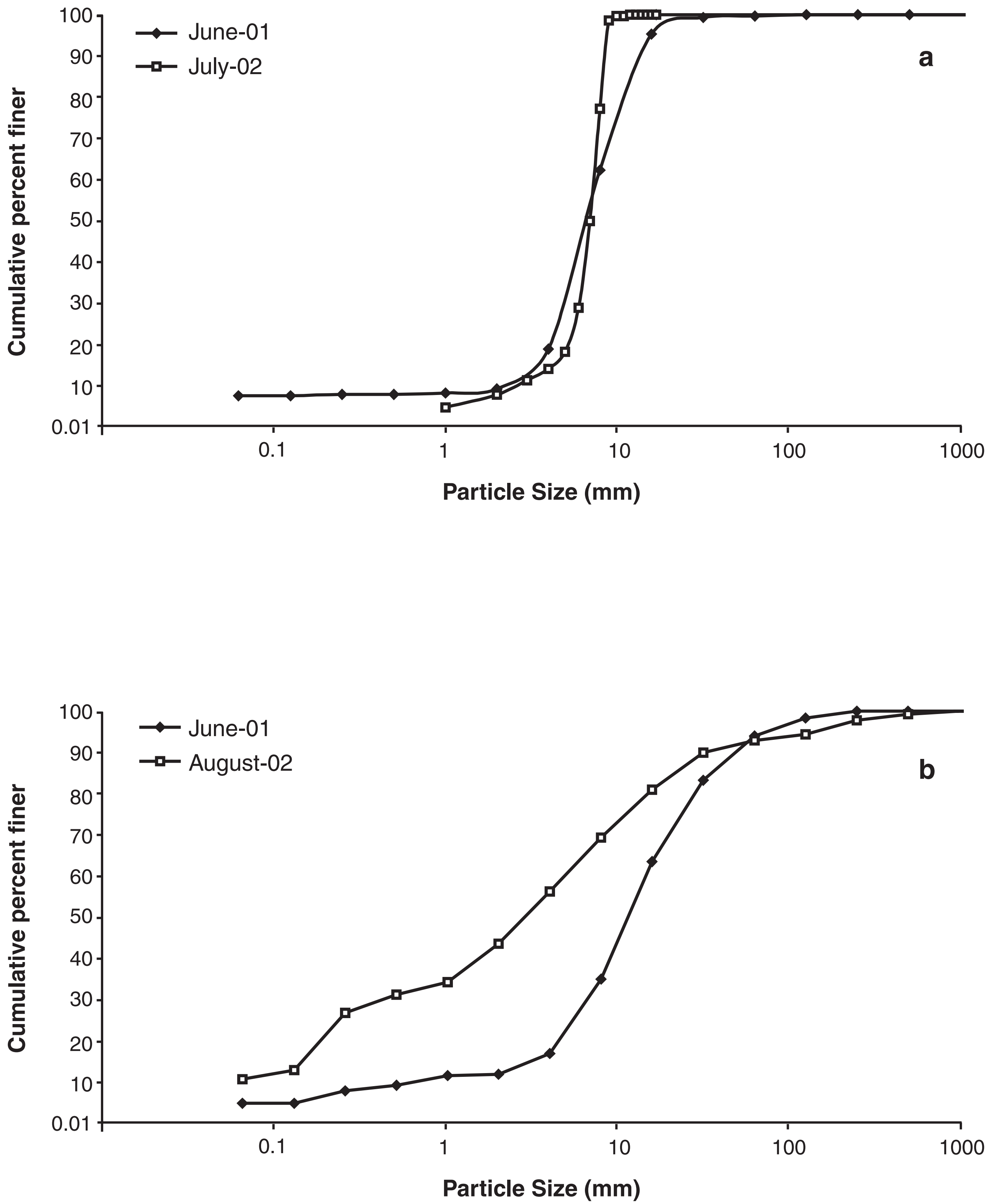

Figure 24—Size distribution of the bed material before and after the Hayman Fire in (a) Saloon Gulch and (b) Brush Creek.

the water during suppression (Minshall and others 1989).

The impact of these effects is often dependent on the availability of refugia in proximity to the affected area (Gresswell 1999). Short-term refugia may exist at small scales. For example, cool ground water sources may provide refugia at the scale of individual pools. In other cases, fish may be dependent on neighboring stream reaches or streams outside of the most impacted affected streams for temporary habitat. This presupposes that fish will be able to freely move within and among watershed.

Observations within the Hayman Fire area indicated that localized fish kills did occur in some of the more severely affected burn areas. Direct fire-related mortality was observed in Wigwam Creek (Denny Bohon, South Platte District Biologist, personal observation). We are unsure of the extent and the severity of the mortality. Certainly in cases where high fire intensity has severely affected water temperature, large-scale mortality can occur and cause significant population losses (Rinne 1996).

Fish mortality occurred within the fire area after the first rains carried debris flows into some of the larger streams and reservoirs. Fish mortality was observed in Cheesman Reservoir by employees of the Denver Water Board after rains carried ash and sediment into the reservoir. Fish mortality also occurred in off-channel rearing ponds located at the confluence of Wigwam Creek and the South Platte River (Pete Gallagher, Fisheries Technician, Pike National Forest, personal communication). These events are generally localized because large amounts of water from multiple watersheds provide some buffering capacity in these larger systems (Gresswell 1999; Minshall 2003).

Figure 25—Sedimentation of stream bed as a result of surface ravel and coarse-grained sediment inputs from ephemeral tributaries. Woody debris has trapped sediment in the area directly upstream.

Aquatic Ecosystems Within the Hayman Fire: Immediate Postfire Response to 5-Year Period

The speed and trajectory of aquatic ecosystem recovery within the Hayman Fire area will be affected by a variety of factors. The recovery of the hill slope and riparian vegetation will influence how quickly the aquatic environments recover. Clearly, the areas that were less severely burned will most likely recover to prefire conditions most rapidly. Recovery of the severely burned watersheds will be most dependent on riparian recovery, the juxtaposition to high quality habitats that can provide sources for recolonization, and the mitigation of additional chronic disturbances.

In general, the 5-year period after a major wildfire is one of transition in aquatic ecosystems. Stream nutrient levels and suspended sediment increase within the first year postfire and gradually decline within the first 5 years (Spencer and others 2003; Minshall and others 1989) (fig. 26). The trajectory and the speed of this response are often dependent on the presence of major debris flows and/or catastrophic floods. For example, Buffalo Creek experienced a major flood and debris flow following the 1996 Buffalo Fire. Debris terraces are still present in much of lower Buffalo Creek, but the stream has continued to cut through those terraces and establish a new channel in the floodplain. The initial pulse of sediment appears to be moving through the system, and a much more heterogeneous particle size distribution is apparent (fig. 27). The aggrading channels will take much longer to recover, as there has to be sufficient flow to scour out the channels without any substantial inputs of sediment. Depending on the sequence of future storm events, this could take anywhere from decades to centuries.

Increased solar inputs from the opened canopy, combined with increased nutrient levels, often result in an increase in primary production and a shift in the aquatic invertebrate community from organisms that process leaf litter and debris to organisms that can scrape and graze attached algae from the substrate (Minshall 2003; Gresswell 1999). The extent of this phenomenon will be dependent on the recovery of riparian vegetation and the extent that the canopy closes over the stream. For example, small streams within the Buffalo Fire area have developed an almost closed canopy of early successional vegetation in some areas. In areas where little vegetation is present, temperature increases will be dependent on water

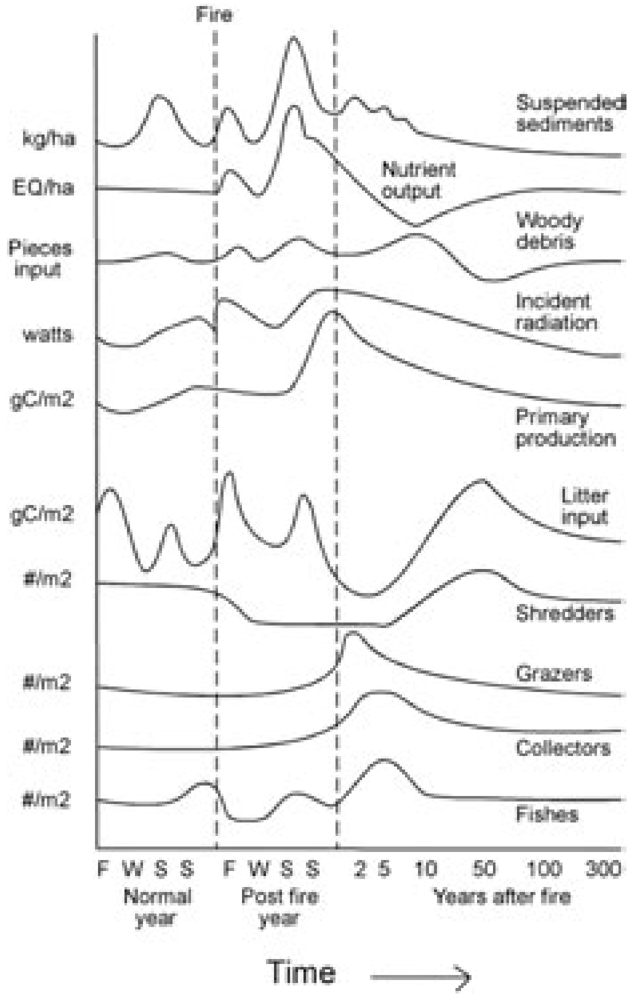

Figure 26—A generalized temporal sequence of selected events in response of aquatic ecosystems to fire (from Minshall and others 1989; Gresswell 1999). Note the short-term inputs of sediment and nutrients that may occur in the first few years after a fire. Most other major fire-related disturbances to streams, such as debris flows or flooding, typically occur within the first few years after a fire.

quantity available and the recovery of riparian vegetation. Short-term increases in temperature are more likely to occur in smaller, perennial streams.

Other inputs from the riparian area show a variety of responses. Inputs of leaf and needle litter may decline within the first 5 years if the canopy and surrounding riparian vegetation has been completely burned or removed. Large wood inputs often increase in the short-term as a result of windthrow but generally remain stable during the first decade or more (fig. 26). Long-term replacement of large wood is affected by the rate of forest succession. Recruitment from the dead standing wood in the riparian areas within the fire will be critical to maintain instream large wood in the near future.

Fish populations have generally shown a positive response during the initial 5-year period postwildfire where populations exhibit good connectivity with key refugia throughout the watershed (Minshall and others 1989; Gresswell 1999). Fish will generally reinvade fire-affected areas rapidly where movement is not limited by barriers created by poorly designed road crossings/culverts, diversions, or dams. These new colonists generally come from areas upstream of the affected area, from surrounding watersheds and from mainstem rivers where migration is not limited. Fish population recovery generally tracks the increase in primary and secondary production that occurs in the early postfire period. Where sediment is continually delivered into the mainstem and reservoirs of the South Platte, there could be short-term negative effects on fish and macroinvertebrate communities.

Postfire fish population surveys in the South Platte River indicate that the short-term consequences to populations varied in severity, depending on the location (Steve Puttman, Fisheries Biologist, Colorado Division of Wildlife Resources, unpublished data). For example, fall population estimates in the lower Cheesman Canyon indicated that the numbers of rainbow and brown trout were consistent with estimates from surveys conducted from 1998 to 2001 (table 10). Population estimates conducted at a site above Decker's Bridge show no clear trend, although the number of rainbow trout in this section declined from the 2001 survey (table 11). However, these numbers are still higher than numbers reported from 1996

Figure 27—Buffalo Creek 6 years after a severe wildfire and catastrophic debris flow. The initial inputs of wood and debris have been transported downstream. Debris accumulations may still be observed at the mouth of Buffalo Creek. Substrate within this stream reach represents a heterogeneous mix of particle sizes. Road location was returned to the floodplain where potential for stream interaction is high. Note that debris accumulations and scour lines are still present in the trees to the right of the stream.

to 2000. Brown trout numbers and density increased slightly while biomass declined to the lowest level during the survey period. Numbers of brown trout equal to or less than 35 cm/ha declined from 2001(highest reported during the survey period) but were higher than all but 2 other years during the 23-year survey history.

Brown trout and rainbow trout populations were also surveyed below Decker's Bridge, approximately 0.5 km downstream of the confluence with Horse Creek. This station was affected by flash flood inputs from both Wigwam Creek and Horse Creek after the Hayman Fire. Brown trout population numbers, density, and biomass declined dramatically in the fall of 2002 compared to 2001 and are at or near all-time lows for the period of study (table 12). Rainbow trout population parameters were also near all-time record low levels in the fall of 2002; however, those statistics have been hovering at that level since the mid-1990s, due in large part to the effects of whirling disease. It will be important to document the duration and magnitude of this response to predict the long-term effects on the blue ribbon trout fishery.

The postfire response of aquatic ecosystems during the first 5 years will be a resorting and renewal of the stream environment. The disturbance resulting from the fire will be followed by an initial response period that can be highly variable but generally moving in a predictable path (fig. 26). Recovery can be hindered by other pulsed or more chronic disturbances. For example, chronic fine sediment inputs from roads, ditches, and fill slopes can retard the ability of streams to sort this sediment and restore habitat. Poorly designed culverts that impede passage of all life stages of fish may slow or even prevent the recolonization of some stream sections. Native fishes such as longnose dace and suckers may require different passage requirements than do salmonids.

It is somewhat misleading to put the short-term condition and recovery of the aquatic environments of the Hayman Fire in the context of historic range of variability. Certainly, the aquatic ecosystems within the fire area can be characterized as a distribution of conditions that probably represented a broad array of habitat conditions from poor to excellent. These conditions were historically present in a mosaic across the

Table 10—South Platte River trout population (N), density (N/Ha), biomass (Kg/Ha), and abundance of trout ≥35 cm (N/Ha) at the lower Cheesman Canyon monitoring site (1979 to 2002).

	Brown trout				Rainbow trout			
Year[a]	N	N/Ha[b]	Kg/Ha	N/Ha ≥35 cm	N	N/Ha[b]	Kg/Ha	N/Ha ≥35 cm
F1979	327	791 (±29)	192	84	512	1238 (±60)	401	342
S1980	329	795 (±130)	176	79	514	1243 (±72)	422	404
F1980	333	805 (±22)	165	44	384	929 (±27)	336	355
S1981	259	766 (±27)	170	52	496	1467 (±33)	566	673
F1981	221	534 (±53)	135	62	264	638 (±85)	259	394
S1982	305	738 (±48)	164	34	344	832 (±46)	344	526
F1982	231	559 (±58)	121	33	232	561 (±77)	234	384
F1983	427	1032 (±41)	244	99	570	1378 (±31)	359	476
F1984	261	631 (±82)	168	61	373	802 (±85)	322	381
F1985	186	449 (±29)	120	83	247	597 (±12)	262	474
F1986	251	607 (±75)	143	69	262	634 (±80)	315	463
F1987	258	822 (±76)	186	47	230	735 (±108)	320	436
F1989	463	896 (±23)	204	108	384	743 (±15)	280	362
F1990	716	1435 (±36)	292	120	538	1078 (±18)	376	391
F1991	445	860 (±27)	216	83	238	461 (±17)	191	194
F1993	396	766 (±29)	200	110	199	385 (±14)	184	248
F1994	323	735 (±34)	210	121	176	400 (±14)	240	358
F1995	286	802 (±36)	219	192	121	339 (±20)	201	283
F1996	276	583(±45)	201	245	101	212(±18)	137	183
F1997	335	639 (±17)	218	285	182	348 (±15)	150	181
F1998	249	476 (±41)	169	253	103	198 (±23)	108	126
F1999	374	724 (±29)	254	336	104	202 (±6)	125	158
F2000	331	633(±19)	221	281	85	162(±8)	102	55
F2001	290	554(±13)	174	236	101	193(±10)	119	153
F2002	340	650(± 16)	209	262	117	224 (± 15)	105	123

[a] F prefex preceding the year denotes fall sample; S denotes a spring sample.

Table 11—South Platte River trout population (N), density (N/Ha), biomass (Kg/Ha), and abundance of trout ≥35 cm (N/Ha) at the above Deckers Bridge monitoring site (1979 -2002).[a]

	Brown trout				Rainbow trout			
Year	N	N/Ha[c]	Kg/Ha	N/Ha ≥35 cm	N	N/Ha[c]	Kg/Ha	N/Ha ≥35 cm
F1979[b]	416	1097 (±179)	141	14	140	369 (±53)	61	0
S1980	409	1079 (±34)	137	0	58	152 (±18)	28	7
F1980	545	1318 (±293)	164	5	130	314 (±203)	44	11
S1981	303	733 (±41)	103	7	37	89 (±10)	15	13
F1981	396	957 (±421)	185	46	88	213 (±324)	40	7
S1982	205	496 (±48)	77	4	17	41 (±5)	6	0
F1982	696	1683 (±210)	190	8	117	285 (±36)	32	8
F1983	973	2352 (±48)	270	20	313	757 (±19)	106	23
F1984	393	951 (±82)	145	3	132	319 (±15)	77	34
F1985	405	979 (±29)	158	3	244	590 (±10)	173	81
F1986	487	1179 (±34)	202	8	199	482 (±10)	165	156
F1987	641	2049 (±42)	306	14	224	716 (±80)	188	128
F1989	959	2140 (±16)	328	36	379	847 (±2)	238	193
F1990	1092	2643 (±58)	460	56	310	751 (±15)	247	199
F1991	1204	2686 (±49)	407	63	242	539 (±7)	171	145
F1993	806	1798 (±31)	398	37	162	361 (±9)	156	184
F1994	520	1325 (±23)	266	55	66	167 (±3)	89	126
F1995	419	934 (±85)	199	99	52	117 (±7)	58	80
F1996	334	745(±66)	130	82	23	50(± 3)	20	30
F1997	274	605 (±19)	179	169	35	76 (±22)	19	20
F1998	285	631 (±11)	167	48	21	46 (±3)	7	6
F1999	391	873 (±105)	208	129	22	49(±12)	29	33
F2000	239	533(± 31)	176	59	22	50(±2)	28	14
F2001	204	456(±6)	161	185	67	149(±22)	59	83
F2002	224	500 (± 3)	122	112	36	79 (± 3)	28	23

[a] An 8 trout/day bag limit was in effect on this section up through December 1982. Catch and release on all rainbow trout and a 2 trout ≥16 inches bag limit on brown trout with fly and lure only terminal tackle in effect in 1983.
[b] F prefix preceding the year denotes fall sample; S denotes a spring sample.
[c] 95% confidence limits in parentheses

Table 12—South Platte River trout population (N), density (N/Ha), biomass (Kg/Ha), and abundance of trout ≥35 cm (N/Ha) at the below Deckers Bridge monitoring site (1982 -2002).[a]

	Brown trout				Rainbow trout			
Year	N	N/Ha[c]	Kg/Ha	N/Ha ≥35 cm	N	N/Ha[c]	Kg/Ha	N/Ha ≥35 cm
F1982[b]	810	2,588 (±208)	295	?	189	604 (±214)	72.4	?
F1983	942	3,010 (±60)	380	?	302	963 (±49)	120	?
F1984	407	1,300 (±35)	199	10	196	626 (±32)	111	11
F1985	339	1,083 (±32)	209	7	160	511 (±16)	122	20
F1986	406	958 (±30)	189	10	174	410 (±23)	116	67
F1987	621	1,984 (±48)	248	11	278	889 (±32)	146	33
F1989	650	1,533 (±10)	272	29	488	1,150 (±13)	268	122
F1990	884	1,789 (±18)	326	72	477	966 (±6)	252	146
F1991	1,071	2,167 (±37)	332	42	391	791 (±24)	193	110
F1993	776	1,570 (±26)	343	28	182	368 (±11)	143	45
F1994	No sampling conducted at this station in the fall of 1994							
F1995	182	708 (±14)	185	58	112	435 (±10)	250	149
F1996	456	1,262 (±57)	274	36	56	154 (±4)	73	36
F1997	386	1,070 (±34)	306	107	74	206 (±25)	70	32
F1998	249	476 (±41)	169	102	104	198 (±21)	108	51
F1999	641	1,297 (± 20)	266	49	77	155 (±10)	52.2	16
F2000	482	976 (±16)	303	67	80	163 (±2)	69.7	28
F2001	404	817 (±18)	276	106	88	178 (±25)	60.6	29
F2002	244	494 (±8)	138	52	85	171 (±5)	56.5	23

[a] An 8 trout/day bag limit was in effect on this section up through December 1982. Catch and release on all rainbow trout and a 2 brown trout ≥16 inches bag limit with fly and lure only terminal tackle went into effect beginning in 1983.
[b] F prefix preceding the year denotes fall sample.
[c] 95% confidence limits in parentheses

landscape where some watersheds were intact while others may have been recovering as a result of a variety of natural disturbances (Reeves and others 1995). High quality habitat most likely was available throughout other areas of the watershed while streams and watersheds recovered from disturbance.

The current situation is somewhat different. The full expression of habitat capability has been compromised in many areas as a result of disturbances that do not allow for the full range of recovery. Management emphasis areas that include water withdrawals and urbanization are unlikely to ever reach historic levels of habitat capability. Roads that are within the historic floodplain of streams or limit the ability of streams to interact with the floodplain also limit the full expression of habitat conditions. The removal of beaver and beaver dams in streams may also inhibit full habitat recovery. In these areas, aquatic ecosystems are unlikely to ever recover to historic conditions unless there is a change in management emphasis. There are curious exceptions. Stream habitat capability within the North Fork and mainstem of the South Platte River is sustained at artificially high levels by the interbasin transfer of water and resulting increase in base flows.

Recovery of the riparian and aquatic ecosystems within the Hayman Fire area has already begun. The recovery of aquatic ecosystems may be influenced by large storm events. Large storms can generate high flows that cause channel incision in headwaters and the deposition of large quantities of fine sediment in lower gradient reaches. Where additional anthropogenic disturbance has not inhibited or truncated ecosystem processes, recovery should proceed along the trajectory we have outlined. In areas that have been influenced by chronic, human-caused disturbances, aquatic ecosystems will not fully recover to their historic potential. Postfire studies are urgently needed to identify the rate and direction of recovery of a range of ecological conditions within the Hayman Fire watersheds. In addition, few studies have documented the rate and extent of channel incision and deposition within streams affected by wildfires. We were fortunate in having some prefire data, and these have provided a relatively unique opportunity to track changes over time, relate these changes to specific storm events, develop a process-based understanding and then use this understanding to predict the physical rate of recovery.

Rehabilitation is often suggested as a means to accelerate the recovery of streams and riparian systems. Rehabilitation efforts could potentially accelerate the recovery of the headwater channels. The basic approach would be to slow the flow of water and facilitate sediment deposition by structural (for example, small check dams) or bio-engineering techniques (planting vegetation). The latter will only be successful in those streams with perennial flow or shallow groundwater, but the problem is that many of the incising streams are much farther up in the watersheds where flow is typically ephemeral.

In contrast, rehabilitation of the aggrading perennial streams downstream from the fire is impractical or difficult at best. The large volume of sediment in the system, poor access in many areas, and the logistical difficulty of removing spoil material would make this operation extremely difficult and costly. Efforts to accelerate the recovery of the hillslopes may help by reducing the future inputs of sediment, but so much sediment has already been mobilized, or is poised to move into the downstream areas, that relatively little can be done to stop the problem.

Given the limited number of postfire studies, this opportunity to understand the response of streams and riparian areas to wildfire should not be wasted. It is important to understand the range of responses of the postfire aquatic ecosystem in a variety of disturbance regimes (Bisson and others 2003). Well designed monitoring studies that track the biological, chemical, and physical aspects will provide useful information on the rate and trajectory of recovery.

The speed and trajectory of postfire recovery will be influenced by the amount and location of anthropogenic disturbances. While it is unrealistic to completely eliminate all of these disturbances within the fire area, there may be opportunities to restore a full range of processes in some watersheds. A watershed or landscape analysis that links fire-related disturbance with existing disturbances should be completed as quickly as possible. By linking this analysis to current restoration efforts, it should be possible to identify restoration opportunities through additional postfire rehabilitation efforts, as well as removing or modifying roads, campgrounds, and other stressors that will hinder or preclude the recovery of riparian and aquatic ecosystems.

References

Benda, L.; Miller, D.; Bigelow, P.; Andras, K. (in prep) Fires, erosion, and floods: The role of disturbance in forest ecosystems.

Bisson, P.A.; Rieman, B.R.; Luce, C.; Hessburg, P.F.; Lee, D.C.; Kershner, J.L.; Reeves, G.H. 2003. Fire and Aquatic Ecosystems: Current Knowledge and Key Questions. Forest Ecology and Management.

Detenbeck N.E; DeVore, P.W.; Niemi G.J.; Lima, A. 1992. Recovery of temperate-stream fish communities from disturbance: A review of case studies and synthesis of theory. Environmental Management 16:33-53.

Gresswell, R. E. 1999. Fire and Aquatic Ecosystems in Forested Biomes of North America. Transactions of the American fisheries society 128:193-221.

Minshall, G.W.; Brock, J.T.; Andrews, D.A.; Robinson, C.T. 2001. Water quality substratum and biotic responses of five central Idaho (USA) streams during the first year following the Mortar Creek fire. International Journal Wildland Fire 10:185-199.

Minshall, G.W. 2003. Community/food web responses of stream macroinvertebrates to fire. Submitted to Forest Ecology and Management.

Minshall, G.W.; Brock, J.T.; Varley, J.D. 1989. Wildfires and Yellowstone's stream ecosystems. BioScience 39: 707-715.

Minshall, G.W.; Robinson, C.T.; Lawrence, D.E. 1997. Postfire responses of lotic ecosystems in Yellowstone National Park, U.S.A. Can. J. Fish. Aquat. Sci. 54: 2509-2525.

Minshall, G.W.; Robinson, C.T.; Royer, T.V.; Rushforth, S.R. 1995. Benthic community structure in two adjacent streams in Yellowstone National Park five years after the 1988 wildfires. Great Basin Naturalist 55:193-200.

Reeves, G.H.; Benda, L.E.; Burnett, K.M.; Bisson, P.A.; Sedell, J.R., 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. In: Nielsen, J. (Ed.), Evolution and the Aquatic Ecosystem. Amer. Fisheries Soc. Symp. 17, Bethesda, MD, pp. 334-349.

Rinne, J.N. 1996. Short-term effects of wildfire on fishes and aquatic macroinvertebrates in the Southwestern United States. North American Journal of Fisheries Management 16: 653-658.

Spencer, C.N.; Hauer, F.R.; Gabel, K.O. 2003. Wildfire effects on nutrient dynamics and stream food webs in Glacier National Park, USA. Submitted to For. Ecol. Manage.

Spencer, C.N.; Hauer, F.R. 1991. Phosphorus and nitrogen dynamics in streams during a wildfire. Journal of the North American Benthological Society 10: 24-30.

Stohlgren, T. J. 2000. Current Stresses to Rocky Mountain Ecosystems. USGS Report

Wiltzius, W. J. 1985. Fish culture and stocking in Colorado, 1872-1978. Colorado Division of Wildlife, Division Report No. 12

Wohl, E. E. 2001. Virtual Rivers: Lessons from the Mountain Rivers of the Colorado Front Range. Yale University Press, New Haven & London.

Young, M. K.; Harig, A.L.; Rosenlund, B.; Kennedy, C. 2002. Recovery history of greenback. RMRS-GTR-88WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Part 7: Key Invasive Nonnative Plants

Geneva Chong, Tom Stohlgren, Catherine Crosier, Sara Simonson, Greg Newman, and Eric Petterson

Introduction

Invasive, nonnative plant species pose one of the greatest potential threats to long-term ecosystem integrity in the area burned by the 2002 Hayman Fire. In other ecosystems, nonnative invaders have been shown to cause decline of native plant species and pollinators, as well as adverse changes in fire regimes, nutrient cycling, and hydrology. Thus, invasive, nonnative species may be responsible for some of the most serious ecological impacts and the greatest long-term costs (for example, for mitigation) associated with the Hayman Fire. Early detection and subsequent monitoring will be essential for the most cost-effective control and the subsequent reduction of negative effects.

Hobbs and Huenneke (1992), in a review paper, found that disturbances outside of the historic range of variability (that is, more or less disturbance than a system evolved with) led to increased invasibility with examples from grasslands, shrublands, and woodlands (see part 1 in this chapter for a discussion of historic disturbance regimes in the Hayman area). D'Antonio and Vitousek (1992) linked invasive grasses to altered fire cycles, which led to ecosystem deterioration in places where the grasses supported much more frequent fires than had formerly occurred during the evolutionary history of the native biota (for example, *Bromus tectorum*, cheatgrass, in the Great Basin). Many researchers have found that areas rich in native species are highly vulnerable to invasion by nonnative species (for example, Levine and D'Antonio 1999; Stohlgren and others 1999). Perhaps of most concern for the Hayman burn area, studies repeatedly find that riparian systems (for example, Planty-Tabacchi and others 1996; Stohlgren and others 1998; Levine 2000) and roads and trails (for example, Tyser and Worley 1992; Greenburg and others 1997) are particularly vulnerable to invasion. Current research is focusing on predicting where nonnative species are likely to establish based on patterns of native species richness and spatial variables (for example, slope, aspect, elevation, soil type, position relative to drainage or road, and so forth) so that resource managers can prioritize and direct control efforts (for example, Chong and others 2001; Schnase and others 2002). These applied, predictive models require extensive species and plot data as well as remotely sensed data.

Nonnative Plants of the Hayman Area

Recognizing the importance of managing the nonnative plant species that appear after fires, the Pike National Forest has developed a prioritized list of nonnative plant species within the Hayman Fire area (table 13; D. Bohon personal communication). The highest priority species include: (1) those that are a priority for elimination (*Hieracium aurantiacum*, orange hawkweed, and *Centaurea maculosa*, spotted knapweed); (2) those that are already dominating some areas (*Linaria vulgaris*, yellow toadflax; *Cirsium arvense*, Canada thistle; and *Euphorbia esula*, leafy spurge) to the localized exclusion of native plant species; and (3) one that is currently found along roads and trails (*Centaurea diffusa*, diffuse knapweed). Following the fire, the Priority 1 species (species that are known to occur or are likely to occur) were surveyed (Petterson, unpublished data) but, because of the lateness of the growing season and the overall dry conditions, additional field work will likely be required for the data to be considered complete for the areas surveyed.

Cheatgrass (*Bromus tectorum*) is considered a Priority 2 species because it is a noxious weed on the Colorado State list, but it was not abundant before the burn (table 14). Data on cheatgrass were collected by the contractor, but future monitoring of cheatgrass is important because of its widespread introduction through straw mulch and the subsequent possibility of cheatgrass gaining dominance after the fire. Data resulting from the contract will provide useful input for future monitoring and modeling efforts (for example, to estimate where nonnative species are likely to occur in the future and so direct monitoring and control). Initial maps from the fall 2002 data show nonnative species concentrated along roads and drainages (fig. 28, 29).

In plots established within the Hayman burn perimeter before the 2002 fire, we documented 17 nonnative plant species, six of which are considered noxious in Colorado (table 14; unpublished data from Fornwalt and others 2002). In addition, Dalmation toadflax (*Linaria genistifolia* ssp. *dalmatica*) is known to occur on some State trust lands 7 km east of Cheesman Reservoir within the Hayman burn area (L. Routten, personal communication). Species seeded intentionally (or unintentionally, in the form of contaminated seed lots or hay bales) for rehabilitation include nonnatives and potentially, invasives (table 15).

Short-Term Expectations

Areas most vulnerable to nonnative plant invasion are generally those areas that are most favorable for native plant species recovery (Stohlgren and others

Table 13—Nonnative plant species prioritized by the Pike National Forest (D. Bohon, personal communication). Priority 1 species are known or likely to occur within the Hayman burn area. Priority 2 species were not common before the 2002 fire, but they are likely to become more common.

Rank	Scientific and common names
Priority 1 species	
Known to occur:	*Hieracium aurantiacum*, orange hawkweed
	Centaurea maculosa, spotted knapweed*
	Linaria vulgaris, yellow toadflax*
	Euphorbia esula, leafy spurge*
	Centaurea diffusa, diffuse knapweed*
	Cirsium arvense, Canada thistle*
Likely to occur:	*Cardaria draba*, hoary cress*
	Centaurea repens, Russian knapweed*
	Chrysanthemum leucanthemum, oxeye daisy*
	Cirsium vulgare, bull thistle*
	Clematis orientalis, Chinese clematis
	Cynoglossum officinale, houndstoungue*
	Hesperis matronalis, Dame's rocket*
	Hyoscyamus niger, black henbane
	Lepidium latifolium, perennial pepperweed*
	Linaria dalmatica, dalmation toadflax*
	Lythrum salicaria, purple loosestrife*
	Onopordum acanthium, scotch thistle*
	Salsola collina/iberica, Russian thistle*
Not expected, but possible:	
	All species included on the State's Noxious Weed List, Part 2.00C
Priority 2 species	*Bromus tectorum*, cheatgrass*

*Species on the Colorado Noxious Weed List were "identified by individual counties as problem weeds in the county's area or have been recommended for management through public testimony." (http://www.ag.state.co.us/DPI/rules/noxious.html)

Table 14—Nonnative plant species encountered on plots (N = 96) within the Hayman Burn perimeter (sampled before the burn).

Scientific and common names	Frequency
Bromus briziformis, rattlesnake brome	7
Bromus inermis, smooth brome	25
Bromus tectorum, cheatgrass*	1
Carduus nutans, musk thistle*	3
Cerastium fontanum, common chickweed	1
Chenopodium album, lamsquarters	NA
Cirsium arvense, canadian thistle*	25
Crepis capillaris, smooth hawksbeard	2
Festuca ovina, sheep fescue	28
Kochia scoparia, common kochia*	9
Lactuca serriola, prickly lettuce	2
Linaria vulgaris, yellow toadflax*	42
Poa annua, annual bluegrass	4
Poa pratensis, Kentucky bluegrass	NA
Thlaspi arvense, pennycress	NA
Tragopogon dubius, yellow salsify	34
Verbascum thapsus, common mullein*	80

*Species on the Colorado Noxious Weed List were "identified by individual counties as problem weeds in the county's area or have been recommended for management through public testimony." (http://www.ag.state.co.us/DPI/rules/noxious.html)

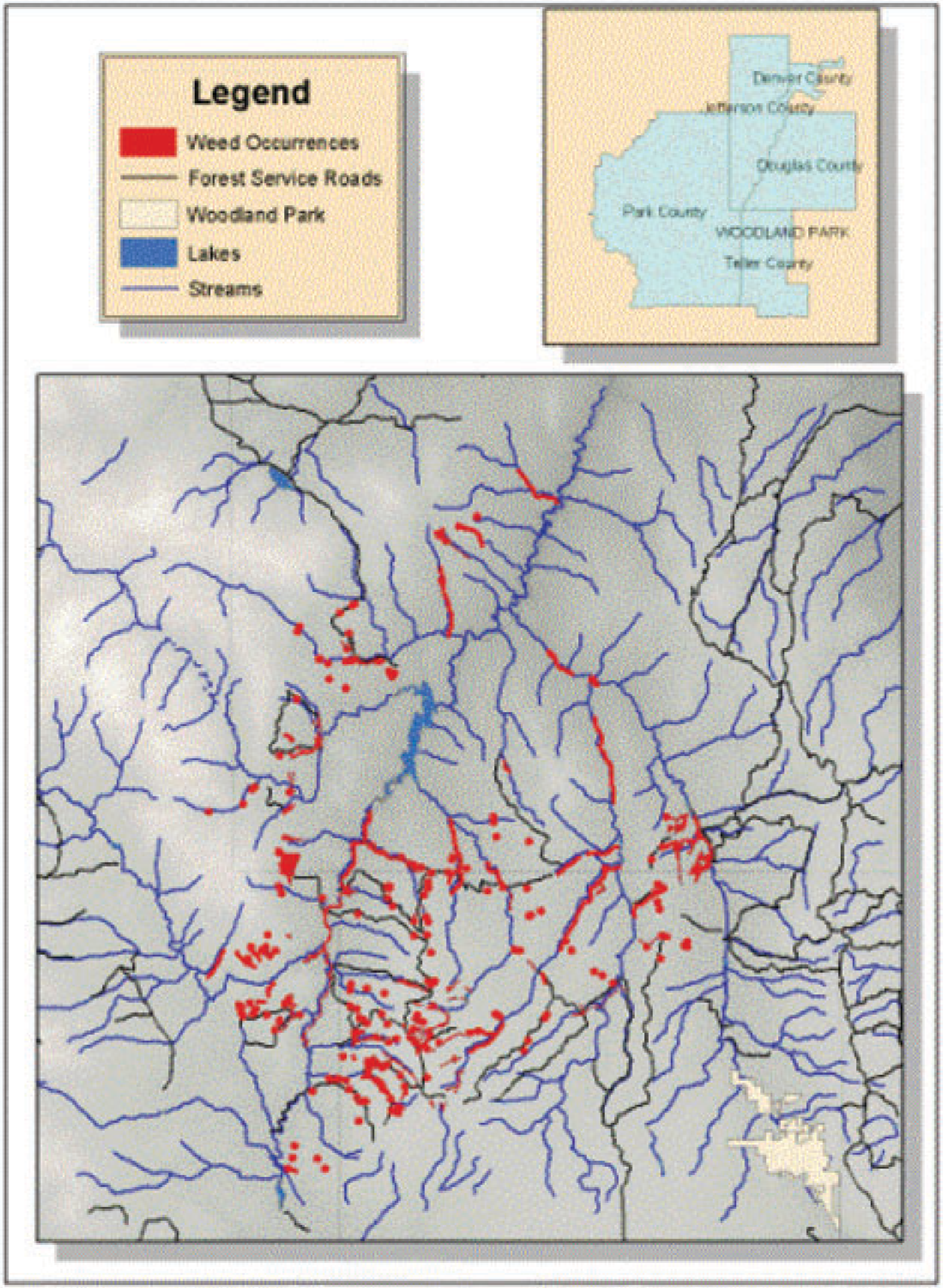

Figure 28—All nonnative plant species found within the Hayman Fire area.

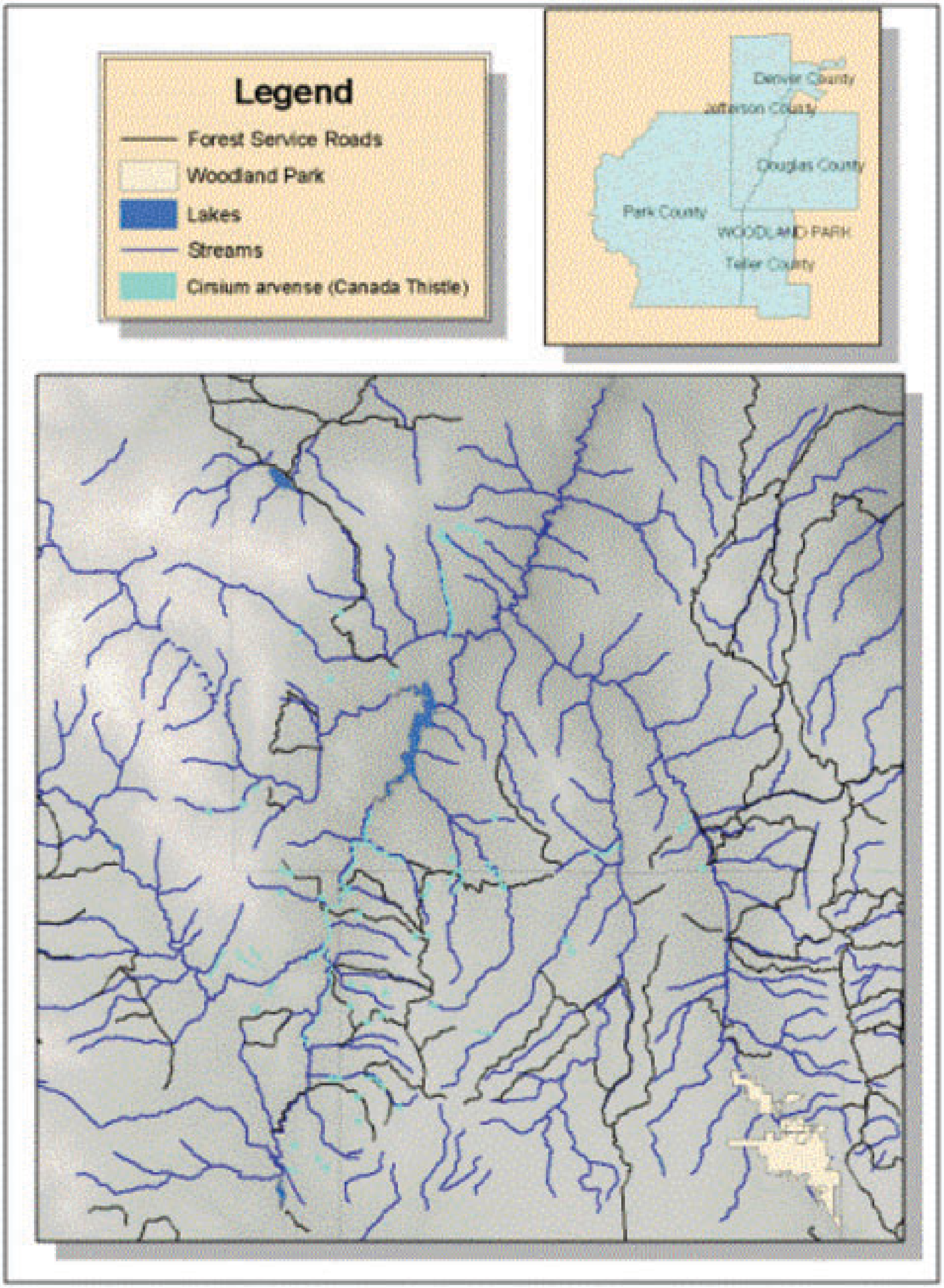

Figure 29—All occurrences of Canada thistle (*Cirsium arvense*) found within the Hayman Fire area.

Table 15—Information on species seeded on the Hayman burn area. All information from Denny Bohon, personal communication October 9, 2002, Pike National Forest, South Platte Ranger District.

Hand scarified and seeded area: 13,800 acres. Aerial seeding used the same mix.

Approximately 2,026,000 lb of seed were applied.

Seed was purchased from three vendors:
The majority of the seed came from Sharp Brothers Seed Company: (http://www.sharpbro.com/)
A small amount of seed came from Arkansas Valley Seed Solutions: (http://www.seedsolutions.com/Wildfire_Reseeding_Options.cfm)
And a small amount of seed came from Star Seed:
(http://www.starseed1.com/)

Mix:
70% barley (*Hordeum vulgare*)
30% triticale: (*Triticosecale rimpaui* Wittm.) [cross: *Triticum aestivum* _ *Secale cereale*](some white oats in early mixes: *Avena* sp.)

Two species need mention as possible future concerns. Straw bales were found contaminated with cheatgrass (*Bromus tectorum*), one of the species on the State noxious weed list. Although cheatgrass is not currently a Priority 1, nonnative species in the Hayman Burn area, it should continue to be included in future monitoring efforts because of its invasive and ecosystem-altering potential. Based on seed purity tests conducted by the Forest Service, approximately 6 lb of wild oats (*Avena fatua*) could have been seeded. Future monitoring of wild oats is important because this invasive annual does well along roads and on disturbed areas and, once established, can be difficult to eliminate because the seeds can remain dormant in the soil for up to 10 years (Whitson and others 1996).

1998, 1999, 2002) – areas with relatively high light, moisture, and soil nutrient availability. Over the short term (next approximately 5 years), riparian areas are likely to be the most vulnerable to invasion. Many of the invasive, nonnative plant species (for example, Canada thistle, fig. 29) were already concentrated in riparian areas and along roads, which are often located along streams (fig. 28. 29). Postfire flooding will provide disturbance as well as deliver seed to riparian areas, and additional disturbance may result from hazard tree removal and road and trail rehabilitation. Proximity to roads and trails may also provide avenues for introduction of other nonnative species.

The areas next most vulnerable to invasion are the staging areas for the rehabilitation effort. There were five staging areas for the straw bales, and these should be monitored over time to provide early warning of what nonnative species were present in the mulch. Roads, trails, areas that received ground-disturbing treatments (for example, ATV traffic, hazard tree removal, straw bale placement), and areas that received other potentially contaminating treatments (for example, seeding, straw mulching) complete the list of priority areas at risk for nonnative species establishment or invasion. Interacting factors in all cases include proximity to roads, staging grounds, and riparian/drainage areas, burn severity, and prefire disturbance (for example, logging, fuel treatments, grazing, and so forth).

Areas that experienced prefire disturbances, such as those mentioned above, may be at increased risk for nonnative invasion following wildfire because those areas may already have nonnative species present in their seed banks as was found in ponderosa pine forests in northern Arizona (J.E. Korb, personal communication). Areas that experienced higher burn severities may also be at increased risk for nonnative species establishment if, for example, the native seed bank is effectively destroyed and the majority of seeds available postfire are nonnative (for example, seeded intentionally or unintentionally). Higher burn severities also deplete mychorrhizae fungal propagules that may be required for native species establishment (Korb and others 2003). All of these scenarios may be expressed in the short term, but their effects are expected to continue into the long term as nonnatives continue to occupy sites and contribute to seed banks.

Long-Term Expectations

Over a longer term (approximately 50 to 100 years), without control measures, nonnative plant species would be expected to persist or dominate in relatively more mesic areas, open-canopy areas, and along disturbance corridors such as roads (fig. 28). In many cases, the areas where nonnative species persist are also the areas that contain the most native species such as along streams (Stohlgren and others 1998, 2001). Smaller patches of nonnative plants may be expected to persist but not dominate less favorable sites (drier, farther from roads, trails, and riparian areas) and thus provide additional, dispersed seed sources that could be expected to aid in the establishment of new patches of invasive species following future fires, treefall events, or other disturbances. Areas that experienced high burn severity and areas that had prefire disturbances that introduced nonnative species could also continue to maintain populations of nonnative species. Many of the areas at especially high risk may be predicted using spatial models that incorporate GIS maps (for example, roads, trails, drainages, burn severity, and prefire activities) and point/plot field data.

Conclusion

Decisions can be informed by knowing what kind of weed expansion to anticipate following the passage of time, future fires, droughts, wet periods, or other disturbances, given current locations and types of nonnative and native species. Moreover, effective inventory and monitoring combined with spatial data analysis can provide specific predictions with stated levels of accuracy as to the amount and location of nonnative as well as native species (Chong and others 2001; Schnase and others 2002). Data collected during the summer of 2003 for a Federal interagency Joint Fire Science Program project examining the interactions between fuels, wildfire, and nonnative plants will contribute directly to future spatial modeling capabilities (Omi and others 2000).

References

Chong, G.W., R.M. Reich, M.A. Kalkhan, and T.J. Stohlgren. 2001. New approaches for sampling and modeling native and exotic plant species richness. Western North American Naturalist 61:328-335.

D'Antonio, C.M and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Review of Ecology and Systematics 23:63-87.

Fornwalt, P.J., M.R. Kaufmann, L.S. Huckaby, J.M. Stoker, and T.J. Stohlgren. 2002. Nonnative plant invasions in managed and protected ponderosa pine/ Douglas-fir forests of the Colorado Front Range. Forest Ecology and Management (in press).

Grace, J.B., M. Smith, S.L. Grace, S. Collins, and T.J. Stohlgren. 2001. Interactions between fire and invasive plants in temperate grasslands in North America. Pages 40-65. In K. Galley and T. Wilson (Eds.), Fire Conference 2000: The First National Congress on Fire, Ecology, Prevention and Management. Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species. Tall Timbers Research Station, Miscellaneous Publication No. 11.

Greenburg, C.H., S.H. Crownover, and D.R. Gordon. 1997. Roadside soils: a corridor for invasion of xeric scrub by nonindigenous plants. Natural Areas Journal 17:99-109.

Hobbs, R.J. and L.F. Huenneke. 1992. Disturbance, diversity, and invasion: implications for conservation. Conservation Biology 6:324-337.

Korb, J.E., N.C. Johnson, and W.W. Covington. 2003. Arbuscular mycorrhizal propagule densities respond rapidly to ponderosa pine restoration treatments. Journal of Applied Ecology 40:101-110.

Levine, J.M. 2000. Species diversity and biological invasions: relating local process to community pattern. Science 288:852-854.

Levine, J.M. and C. D'Antonio. 1999. Elton revisited: a review of evidence linking diversity and invisibility. Oikos 87:15-26.

Omi, P., E.J. Martinson, M.A. Kalkhan, and G.W. Chong. 2000. Spatial interactions among fuels, wildfire, and invasive plants. Proposal funded by the Joint Fire Science Program RFP 2000-1, Tasks 2 and 3.

Planty-Tabacchi, A.-M., E. Tabacchi, R.J. Naiman, C. DeFerrari, and H. Decamps. 1996. Invasibility of species-rich communities in riparian zones. Conservation Biology 10:598-607.

Schnase, J., T.J. Stohlgren, and J. A. Smith 2002. The national invasive species forecasting system: A strategic NASA/USGS Partnership to manage Biological Invasions. Earth Observation Magazine 11:46-49.

Stohlgren, T.J., D. Binkley, G.W. Chong, M.A. Kalkhan, L.D. Schell, K.A. Bull, Y. Otsuki, G. Newman, M. Bashkin, and Y. Son. 1999. Exotic plant species invade hot spots of native plant diversity. Ecological Monographs 69: 25-46.

Stohlgren, T.J., K.A. Bull, Y. Otsuki, C.A. Villa, and M. Lee. 1998. Riparian zones as havens for exotic plant species in the central grasslands. Plant Ecology 138:113-125.

Stohlgren, T.J., G. W. Chong, L.D. Schell, K.A. Rimar, Y. Otsuki, M. Lee, M.A. Kalkhan, and C.A. Villa. 2002. Assessing vulnerability to invasion by nonnative plant species at multiple scales. Environmental Management 29:566-577.

Stohlgren, T.J., Y. Otsuki, C. Villa, M. Lee, and J. Belnap. 2001. Patterns of plant invasions: a case example in native species hotspots and rare habitats. Biological Invasions 3:37-50.

Tyser, R.W. and C.A. Worley. 1992. Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana (U.S.A.). Conservation Biology 6:253-262.

Whitson, T.D., L.C. Burrill, S.A. Dewey, D.W. Cudney, B.E. Nelson, R.D. Lee, and R. Parker. 1996. Weeds of the West, 5th Edition. Pioneer of Jackson Hole, Jackson, Wyoming. 630 pp.

Part 8: Effects on Species of Concern

Natasha B. Kotliar, Sara Simonson, Geneva Chong, and Dave Theobald

Temporal and Spatial Scales for Evaluating Fire Effects

Conclusions about the effects of fire on species of concern will depend on the temporal and spatial scales of analysis. Populations of some species may decline in abundance immediately postfire due to alteration or destruction of habitat, but over larger spatial and temporal scales, fire contributes to a shifting mosaic of habitat conditions across the landscape. Whether or not a fire results in persistent and significant population changes depends on a number of factors including fire size and severity, dispersal capabilities and other life history traits, availability of refugia within or outside the burn, postfire successional pathways. Thus, fire effects should be considered across a range of temporal and spatial scales.

Assessment of fire effects must be made within the context of the natural disturbance regime of a system. The historic fire regime for this area can be characterized as mixed-severity (Brown and others 1999; Veblen and others 2000), which includes both understory and crown fires. Local factors such as elevation, topography, and aspect affect the frequency to which the system experiences understory, mixed-severity, or large crown fire events (part 1, this chapter). Reference conditions for evaluating fire effects in montane forests of the Colorado Front Range, therefore, are dynamic forests composed of patches that vary with time since disturbance and severity. Yet, fire effects on wildlife are typically evaluated by simply comparing recently burned and unburned forests (Kotliar and others 2002).

To evaluate the effects of the Hayman Fire on species of concern, we consider both short- (less than 10 years) and long-term (greater than 50 to 100 years) postfire time frames. Likewise, we consider spatial scales that range from habitat patches within the 56,000-ha Hayman Fire perimeter to ponderosa pine landscapes that encompass the Pike National Forest. We also evaluate fire effects within the framework of a mixed-severity fire regime.

Although most fire experts agree that mixed-severity fires (including small crown fires) characterize the system, the historical occurrence of large crown fires remains equivocal and controversial. At the Hayman burn, a severe fire burned approximately half of the area (hereafter called the "severe fire"), whereas a mixed-severity fire burned the remaining area (hereafter called the "mixed-severity fire"). Within the severe, tree mortality is high, although live trees remain in isolated patches that escaped severe fire. These remnant patches are important seed sources and may serve as animal refugia. In addition, plants are rapidly resprouting in many areas, whereas bare mineral soil is all that remains elsewhere (Kotliar, personal observation). In the area burned by mixed-severity fire, there is variation among patches in tree mortality, resulting in a heterogeneous mixture of live and dead trees. Because of the differences in burn severity, and consequently landscape structure (for example, size of high-severity patches, distance to unburned forest), we consider the effects of these two fire "landscapes" (that is, severe versus mixed-serverity) on species of concern separately.

Effects on Species of Concern

Species of concern, for this discussion, are those Federally listed, or proposed, as endangered or threatened, and species designated as sensitive by Region 2 of the USDA Forest Service (table 16). Evaluating the effects of the Hayman Fire on species of concern is a difficult undertaking for several reasons. First, information on the effects of fire is quite limited for most species. Second, a number of factors can alter how species respond to burns including burn severity, as well as the spatial heterogeneity of burn-severity patterns, time since fire, cover type, context, postfire rehabilitation, and prefire management (Kotliar and others 2002). Other factors may compound or overshadow the effects of fire, such as the severe drought in 2002, disease outbreaks, or previous habitat losses caused by human activities. Finally, the magnitude of fire effects on species of concern will depend, in part, on the proportion of the species' range and total population that occurs within the burned area.

Here, we evaluate the effects of the Hayman Fire on species listed as sensitive by the Pike National Forest (Ryke and Madsen 2002). None of the Federally listed endangered species occurring on the Pike are known to occur within the Hayman Fire perimeter, but six Federally listed threatened species (Canada lynx, bald eagle, Mexican spotted owl, Preble's meadow jumping mouse, Pawnee montane skipper, Ute ladies'-tresses orchid) have occurrences or potential habitat within the burn (see table 16 for a list of scientific names). In addition, there are a number of amphibians, birds, fishes, invertebrates, mammals, and plants listed as Forest Sensitive Species or Management Indicator Species. Of the total 59 species of concern, we eliminated 26 species that are known not to occur in the burn area (table 17). We determined that several species (Canada lynx, boreal owl, golden-crowned kinglet, wolverine, marten, dwarf shrew), which are primarily associated with higher elevation lodgepole pine or spruce/fire forests, had minimal potential habitat (less than 2 percent of burn area) within the burn

Table 16—Species of Concern occurring or potentially occurring on the Hayman burn (Ryke and Madsen 2002).

A. Vertebrate Species associated with wetland habitats

Species	Scientific name	Occurrence category[1]	Status[2]	Habitat types[3]
Northern leopard frog	*Rana pipiens*	Occurs	S	RSS, WET, AQ
Tiger salamander	*Ambystoma tigrinum preblii*	Occurs	S	RSS, WET, AQ
Osprey	*Pandion haliaetus*	Occurs	S	RSS,
Bald Eagle	*Haliaeetus leucocephalus*	Occurs	T	RSS
Common loon	*Gavia immer*	Occurs	S	RSS, AQ
Fox sparrow	*Passerella iliaca*	Occurs	S	RIP
Preble's meadow jumping mouse	*Zapus hudsonius preblei*	Occurs	T, PCH	MG, RSS, RIP
Lewis' s woodpecker	*Melanerpes lewis*	Occurs	S	RIP

B. Vertebrate and Invertebrate Species Associated with montane forested habitats

Species	Scientific name	Occurrence category	Status	Habitat types
Mexican spotted owl	*Strix occidentalis lucinda*	Occurs	T, CH	PJ, MC, RO
Northern goshawk	*Accipiter gentilis*	Occurs	S	PP, MC, AS, LPP, SF
Flammulated owl	*Otus flammeolus*	Occurs	S	PP, MC, AS
Three-toed woodpecker	*Picoides tridactylus*	Occurs	S	MC, LPP, SF
Pygmy nuthatch	*Sitta pygmaea*	Occurs	S	PP, AS
Olive-sided flycatcher	*Contopus cooperi*	Occurs	S	MC, SF
Pawnee montane skipper	*Hesperia leonardus montana*	Occurs	T	PP, MC, MG
Townsend's big-eared bat	*Corynorhinus townsendii*	Occurs	S	RO, PP, MC, MS, PJ
Fringed-tailed bat	*Myotis thysanodes*	Occurs	S	RO, PP, MS, PJ, MC

C. Vertebrate Species associated with subalpine and alpine habitats

Species	Scientific name	Occurrence category	Status	Habitat types
Boreal toad	*Bufo boreas*	No Known Populations	S, C	RSS, AQ, WET, SF
Boreal owl	*Aegolius funereus*	No Known Populations	S	LPP, SF
Golden crowned kinglet	*Regulus satrapa*	Subalpine	S	MC, SF
Marten	*Martes americana*	Subalpine	S	MC, LPP, SF, AL
Lynx	*Lynx rufus*	Subalpine	T	LPP, SF, AL, RO
Wolverine	*Gulo gulo*	Subalpine	S	LPP, SF, AL
Dwarf shrew	*Sorex palustris*	Subalpine	S	SF, AL, MG, RO, MS, WET, MC

D. Plant species of concern

Species	Scientific name	Occurrence category	Status	Habitat types
Ute ladies'-tresses orchid	*Spiranthes diluvialis*	Habitat occurs	T	RSS, RIP
Narrow-leaved moonwort	*Botrychium lineare*	Habitat occurs	S, C	MG, RSS
Reflected moonwort	*Botrychium echo*	Habitat occurs	S	MG, RO
Pale moonwort	*Botrychium pallidum*	Habitat occurs	S	MG
Livid sedge	*Carex livida*	Habitat occurs	S	WET
Smith's whitlow grass	*Draba smithii*	Habitat occurs	S	RO
Altai cottongrass	*Eriophorum altaicum* var. *neogaeum*	Habitat occurs	S	WET
Colorado tansy-aster	*Machaeranthera coloradoensis*	Habitat occurs	S	AL, MG, RO
White adder's-mouth orchid	*Malaxis brachyopoda*	Habitat occurs	S	RSS, RIP
Weber's monkey-flower	*Mimulus gemmiparus*	Occurs	S	SF, AS, RIP
Greenland primrose	*Primula egaliksensis*	Habitat occurs	S	RSS, WET
Rocky Mtn. Cinquefoil	*Potentilla rupincola*	Habitat occurs	S	PP, RO
Porter feathergrass	*Ptilagrostis mongholica* ssp. *porteri*	Habitat occurs	S	WET
Northern blackberry	*Rubus arcticus* ssp. *acaulis*	Habitat occurs	S	RSS, WET
Rolland's bulrush	*Scirpus rollandii*	Habitat occurs	S	WET
Great-spurred violet	*Viola selkirkii*	Habitat occurs	S	AS, MC, RIP

[1]For species potentially occurring within the Hayman burn, we determined whether it: Occurs = known to occur; Habitat Occurs = potential habitat occurs; No Known Populations = no known current or historic populations; Subalpine = minimal area in this cover type occurred within the Hayman burn, consequently the species is expected to have limited occurrence.

[2]Conservation Status: E: Federally listed as Endangered; T: Federally listed as Threatened; P: Federally proposed for listing; C: Federal candidate for listing; CH: Federally designated Critical Habitat; PCH: Federally proposed Critical Habitat; S: Forest Service Sensitive Species.

[3]Habitat classifications from Ryke and Marsden (2002): AL = alpine; AQ = riparian/aquatic; AS = aspen; LPP = lodgepole pine; PJ = pinyon/juniper; PP = ponderosa pine; RO = Rock, cliff, caves, canyon, mine; MC = mixed conifer; MG = mountain meadows; MS = shrublands; SF = spruce/fir; WET = riparian/wetlands.

Table 17—Species of Concern for the Pike National Forest which do not occur within the Hayman burn.

Species	Scientific name	Status[1]	Habitat[2]
Purple martin	*Progne subis*	S	AS
Mountain plover	*Charadrius montanus*	P	MG
Harlequin duck	*Histrionicus histrionicus*	S	RSS, AQ
American bittern	*Botaurus lentiginosus*	S	RSS, WET
White-faced ibis	*Plegadis chihi*	S	RSS, WET
Black tern	*Chlidonias niger*	S	RIP, WET
Whooping crane	*Grus americana*	E	RSS
Sandhill crane	*Grus canadensis*	S	WET, RSS, RIP
Western snowy plover	*Charadrius alexandrinus*	S	RSS
Black swift	*Cypseloides niger*	S	AQ,RO
Greenback cutthroat trout	*Salmo clarki macdonaldi*	T	AQ
Southern red-belly dace	*Phoxinus eos*	S	AQ
Plain's topminnow	*Fundulus sciadicus*	S	AQ
Arkansas darter	*Etheostoma cragini*	S	AQ
Uncompahgre fritillary butterfly	*Boloria acrocnema*	E	AL
Rocky Mountain capshell snail	*Acroloxus coloradensis*	S	AQ
Hog-nose skunk	*Conepatus mesoleucus*	S	MS, PJ, RO
Ringtail cat	*Bassariscus astutus*	S	MS, PJ, RO, RIP
Penland alpine fen mustard	*Eutrema penlandii*	T	AL, WET, RSS
Sea pink	*Armeria maritime* var. *siberica*	S	AL
Leadville milk-vetch	*Astragalus molybdenus*	S	AL
Smooth rockcress	*Braya glabella* ssp. *glabella*	S	AL
Hall fescue	*Festuca hallii*	S	AL, MG
Globe gilia	*Ipomopsis globularis*	S	AL
Woolly willow	*Salix lanata* ssp. *calcicola*	S	AL, RSS
Myrtle-leaf willow	*Salix myrtillifolia*	S	WET

[1]Conservation Status: E: Federally listed as Endangered; T: Federally listed as Threatened; P: Federally proposed for listing; C: Federal candidate for listing; CH: Federally designated Critical Habitat; PCH: Federally proposed Critical Habitat; S: Forest Service Sensitive Species.

[2]Habitat classifications from Ryke and Marsden (2002): AL = alpine; AQ = riparian/aquatic; AS = aspen; LPP = lodgepole pine; PJ = pinyon/juniper; PP = ponderosa pine; RO = Rock, cliff, caves, canyon, mine; MC = mixed conifer; MG = mountain meadows; MS = shrublands; SF = spruce/fir; WET = riparian/wetlands.

perimeter (table 16c). We evaluated the potential effects of the Hayman Fire for remaining 17 vertebrate species of concern (table 16a,b). We also briefly evaluate the effects on plant species of concern (table 16d).

For each species we assessed the expected numerical response immediately postfire (that is, increase, decrease, remain the same, unable to determine) based on potential postfire conditions that could result in population changes. If data on fire effects were unavailable, we used life history attributes and interviewed experts to assess potential fire effects. Specifically, we asked the following questions:

1. Are the direct or indirect effects of the fire likely to alter habitat quality or availability: (a) in short or long time frames, and (b) in mixed-severity or crown fire?
2. How important is the population at Hayman to the long-term health of the species?
3. How severe are the threats to long-term viability of the species?
4. What other factors (for example, drought, habitat fragmentation) might influence the magnitude of fire effects?

Preferred habitat types are listed for all species of concern (table 16). We grouped these into several larger categories: wetlands (including riparian and adjacent aquatic habitats), shrublands (primarily mountain mahogany), and forested (primarily ponderosa pine, Douglas-fir, aspen). For each of these cover types, we discuss the potential structural changes that may occur postfire, and discuss the implications for species inhabiting these areas. Because shrublands composed a relatively small proportion of the burn and were not a primary habitat for any species of concern, we only briefly discuss this cover type. Aquatic species are addressed elsewhere in this chapter. In addition, we provide indepth assessments for several species of concern: Mexican spotted owl, Pawnee montane skipper, Preble's meadow jumping mouse, three-toed woodpecker, and blanket flower/Colorado fire moth. These species were selected because they are species of high concern on the Pike National Forest and/or represent a broad spectrum of expected responses to burns.

Potential habitat maps are available for the skipper, jumping mouse, and Mexican spotted owl. We used two burn severity maps to analyze the burn severity patterns of potential habitat maps of these species: the Normalized Burn Severity (NBR) technique (Miller and Yool 2002) and the Burned Area Emergency Rehabilitation (BAER) map (fig. 30-32). We use the NBR map because it detects greater heterogeneity and was not limited to the four burn-severity classes as defined in the BAER maps. We include BAER maps for comparison because of the pervasive use elsewhere in this document.

Wetlands:

Amphibians – Three amphibian species of concern are associated with wetland habitats (table 16a). Boreal toads have no known recent or historical occurrences within the burn perimeter and are typically found at higher elevations (table 16c; Loeffler 2001). Thus, we will restrict our discussion to northern leopard frogs and tiger salamanders. No published information on the effects of fire on these amphibians in the Rocky Mountains is available, although limited information is available for other regions. Direct mortality of amphibians was probably limited because drought conditions prevalent at the time of the Hayman Fire had likely caused the amphibians to seek water or underground refuges (for example, in rodent burrows; Pilliod and others 2003). In general, such refugia are presumed to afford protection from direct morality from fire (Russell and others 1999).

Indirect effects on amphibians, such as postfire erosion and flooding, may create, alter suitability, or destroy breeding sites (Pilliod and others 2003; see part 6 of this chapter). Fire can alter temperature profiles and hydroperiods, sedimentation and nutrient loads, and availability of duff, litter, and woody debris used for refugia (Pilliod and others 2003). The effects will vary with fire conditions, such as burn severity and seasonality of fire (Russell and others 1999; Pilliod and others 2003). It has been suggested that the negative effects of fire on amphibian populations may be lower in ponds, the primary breeding sites for northern leopard frogs and tiger salamanders (Hammerson 1999), compared to streams (Pilliod and others 2003). There is limited evidence that tiger salamanders may tolerate or prefer frequent fire; in a study in Florida, tiger salamanders were captured more frequently in stands of longleaf and shortleaf pine forests that burned annually compared to unburned stands (Russell and others 1999). Because many negative effects of fire are short-term, initial postfire mortality could be offset by the creation or maintenance of required habitat conditions by fire (Russell and others 1999).

Breeding sites in the drought-prone climate of Colorado are naturally dynamic as are amphibian populations (Hammerson 1999). Indeed, the 2002 drought may have diminished breeding opportunities and may have had greater effects on amphibian populations than did the Hayman Fire. Because of the natural dynamics of amphibian populations and habitats, the potential for both positive and negative effects on these amphibians, and the limited importance of the Hayman area to the survival of these species overall, we expect that neither northern leopard frog or tiger salamander will suffer significant population declines in a result of the Hayman Fire.

Birds – Three species of concern (bald eagle, osprey, common loon) are found in association with Cheesman Reservoir. Direct effects of the fire on bald eagles are limited to the potential loss of a winter roost site, which was located in the area burned by severity. This roost has been used by approximately 20 to 40 bald eagles, a relatively small proportion of its overall population. Most of the trees in the roost were scorched but many trees retained their needles during the winter 2002 to 2003; at least 24 eagles were observed roosting in scorched trees the first winter postfire (E. Odell, personal communication). The degree to which the winter roosts offer thermal protection is unclear, and whether the eagles will continue to use the roost, switch to nearby live trees at Cheesman Reservoir, or abandon the site once the needles drop from the roost trees remains to be seen. Prior to the Hayman Fire, eagles had not been observed foraging at Cheesman Reservoir and instead appear to rely on nearby reservoirs outside the burn perimeter for fishing sites (E. Odell, personal observation). Indirect effects of fire on the other two piscivorous bird species include potential fish die-offs due to postfire erosion and degradation of water quality. In the short-term, the reduction of the prey base may cause the osprey and migrating loons to abandon the site. Whether the local populations decline or shift to another area cannot be predicted. However, this artificial lake is not critical to any of these avian species, and any local changes associated with the fire are expected to have limited effect on the overall populations, although local population changes may be observed in the short term.

Several avian species of concern are associated with riparian areas (fox sparrow, and Lewis's woodpecker, which is also associated with older burns). Often, riparian areas escape burning or have lower burn severity than adjacent uplands. Indeed, burn severity was lower in many riparian corridors within the crown

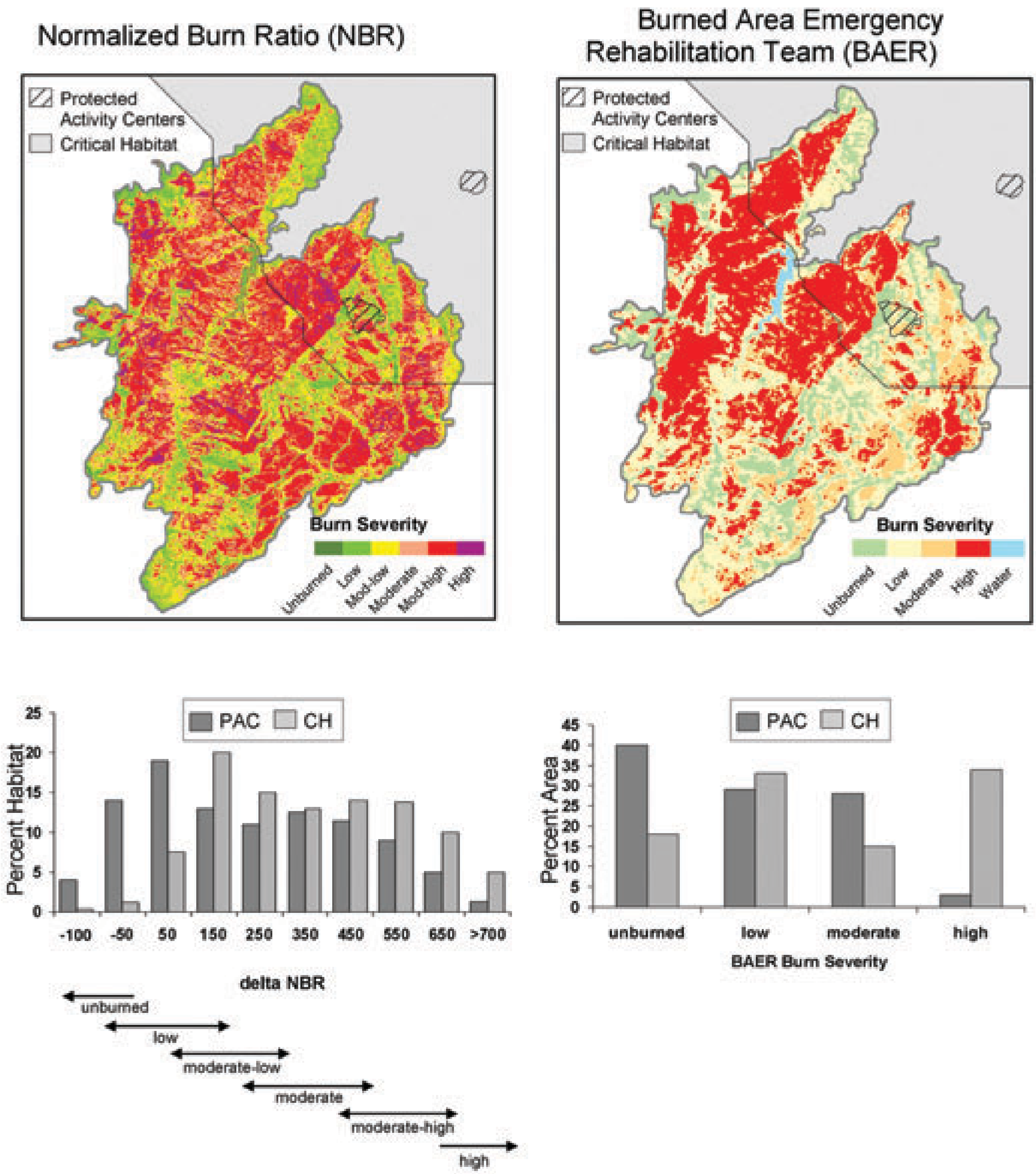

Figure 30—Burn severity patterns in Mexican Spotted Owl Protected Activity Centers (PAC) and Critical Habitat (CH). Normalized Burn Ratio (NBR) is an index of burn severity; low delta NBR scores indicate lower severity than high delta NBR scores.

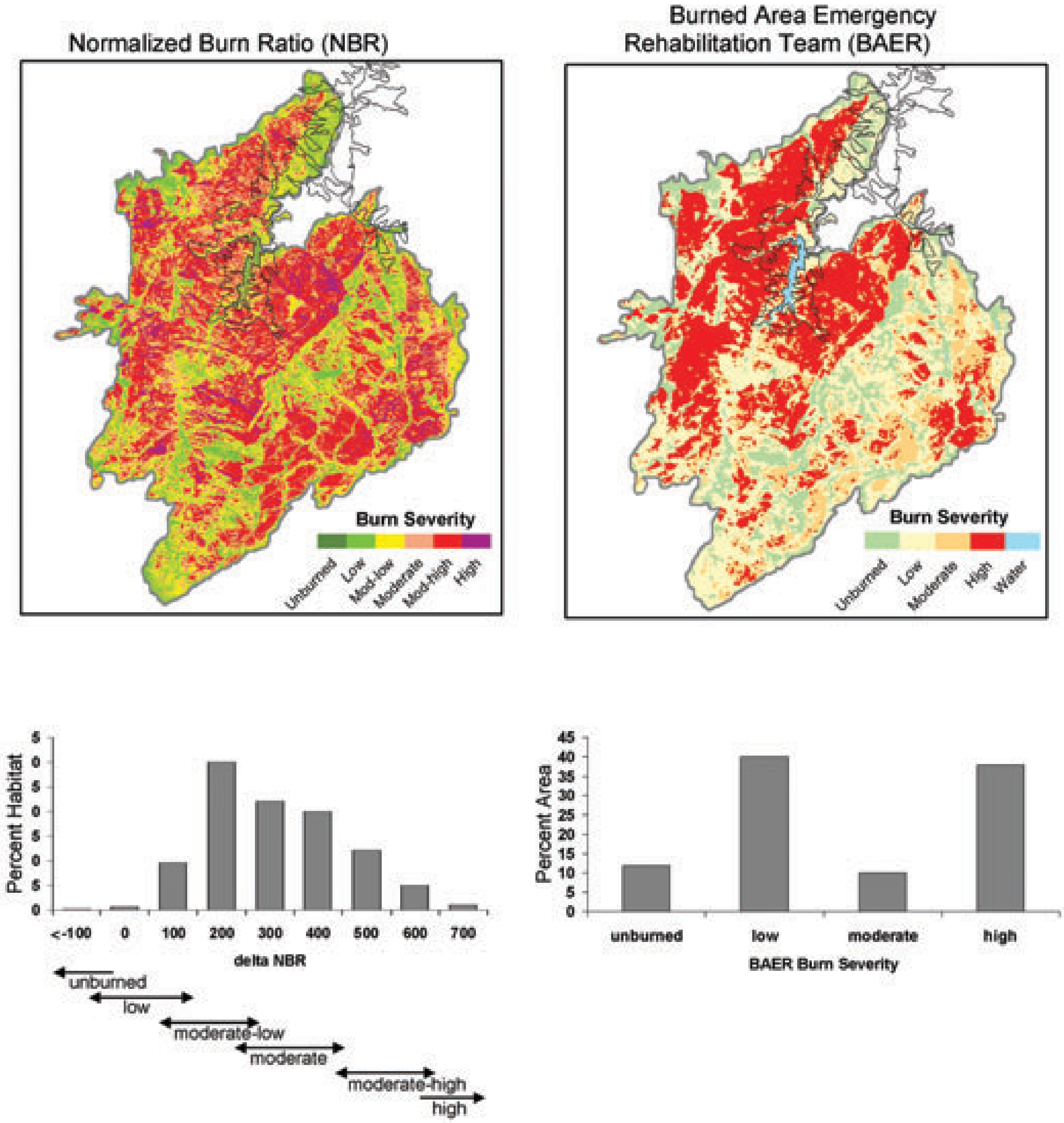

Figure 31—Burn severity patterns in Pawnee Montane Skipper Potential Critical Habitat. Normalized Burn Ratio (NBR) is an index of burn severity; low delta NBR scores indicate lower severity than high delta NBR scores.

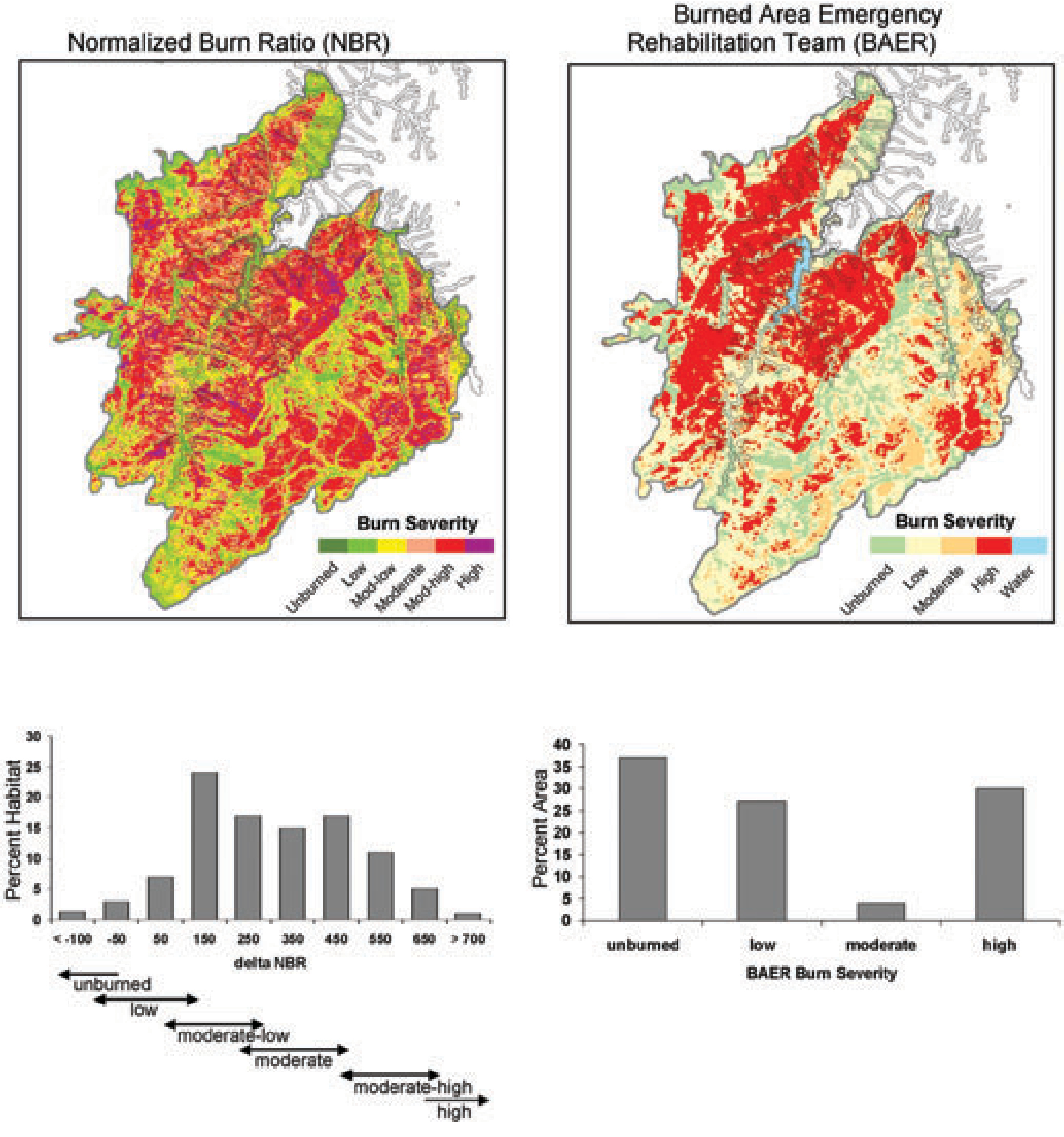

Figure 32—Burn severity patterns in Preble's Meadow Jumping Mouse Potential Critical Habitat. Normalized Burn Ratio (NBR) is an index of burn severity; low delta NBR scores indicate lower severity than high delta NBR scores.

compared to adjacent uplands. Although during severe drought, wetlands may burn (often severely) if moisture levels are reduced, riparian vegetation (for example, willows, aspen) resprouts readily after fire or following siltation from postfire erosion. Fire can also have positive effects on these species of concern. By decreasing canopy closure, severe fires may have increased habitat suitability for fox sparrows, which prefer open shrublands. Lewis's woodpeckers are associated with forested riparian areas but also use older burns (Kotliar and others 2002); fire may have diminished habitat availability in the short term, but as snags fall and the forest opens up, and as riparian forests resprout, potential habitat availability will increase. Because fox sparrows and Lewis's woodpeckers are fairly common and widespread, populations of both species should be able to withstand, and will likely benefit, from such habitat dynamics.

Mammals – Only one mammalian species of concern, the Preble's meadow jumping mouse, is associated with wetland (riparian) systems. This species is discussed below.

Plants – The majority of plant species of concern that are present or potentially occuring within the Hayman and Schoonover Fires, occur in conjunction with wet or riparian areas (table 16d). Because nonnative plant species are likely to respond favorably to the postfire environment (Grace and others 2001), especially in more mesic habitats (Stohlgren and others 1998, 1999, 2002), nonnative plant species over the short and long term may be expected to have negative effects on the native plant species of concern. Initial inventory and subsequent monitoring of vegetation in areas at high risk for nonnative plant species invasion and resulting negative impacts on species of concern, are needed to provide information for control of nonnatives.

Shrublands:

The primary shrublands that burned in the Hayman Fire were generally small pockets of mountain shrub communities that frequently occur in small forest openings or on south-facing slopes. The dominant species is typically mountain mahogany, but wax current and gambel oak are also present. Most of these shrub species are expected to resprout following fire. In addition, aspen sprouts (when small) are often used by many vertebrate species common to shrub systems. Because mule deer use shrublands for forage, there are some concerns about how the decrease in forage availability may affect the local populations, and how changes in forage may interact with wildlife diseases (for example, chronic wasting disease). However, resprouting shrubs and aspen, which are not protected by older woody growth (burned by fire), may potentially increase forage availability. Although the mule deer is a game species and is not listed as a species of concern, biologists on the Pike National Forest expressed concern about their status (D. Bohon, personal communication). Even in high-severity burns, we expect that the shrubland community will recover to prefire conditions relatively rapidly and may even be enhanced in some areas due to removal of the overstory.

Forests:

The dominant tree species burned in the Hayman Fire are ponderosa pine and Douglas-fir. Aspen and small areas of subalpine forests (lodgepole pine, spruce/fir) also burned. Two of the threatened species we are considering as part of this review, Mexican spotted owl and Pawnee montane skipper (see below), occur in forested habitats.

Birds – Several avian species of concern (northern goshawk, flammulated owl, and pygmy nuthatch) prefer mature or old-growth forests. Large crown fires may reduce habitat quality and availability for these species in the short term but enhance habitat quality in the long term by increasing landscape heterogeneity in the Pike. Goshawks have been observed in severe burns, and their prey includes woodpeckers, which are common in early postfire forests (N. Kotliar, P. Kennedy, personal observation). However, it is unclear how readily goshawks will use severely burned forest compared to old-growth forests (Kennedy, personal communication). Goshawk habitat quality may be enhanced, both short-term and long-term, by mixed-severity burns that can increase forest heterogeneity (Reynolds and others 1992). Flammulated owls prefer open montane forests, often with a dense understory, and require snags or dead limbs for nesting (McCallum 1994). Mixed-severity burns may enhance flammulated owl habitat by creating forest openings and snags, whereas large severe fires may diminish habitat quality in the short term, except, perhaps, along burn edges. Pygmy nuthatches are largely restricted to ponderosa pine forests across much of their range (Andrews and Righter 1992). They usually avoid severely burned forests but are common in understory burns (Kotliar and others 2002). Thus, habitat availability and quality may decrease locally for the nuthatches in severely burned areas, but such dynamics are not expected to have long-term negative effects given this species' dependency on forest types that burn regularly. Because all three species are fairly common and widespread, we do not expect any short-term declines in populations that may occur as a result of the Hayman Fire to negatively impact these species in the long term.

Three-toed woodpeckers (see expanded discussion below), olive-sided flycatchers, and Lewis's woodpeckers all readily use postfire forests (Kotliar and others 2002). Olive-sided flycatchers are common in burned forests, particularly at the interface between live trees and snags (Kotliar and others 2002). Thus, we expect their greatest use will be in the mixed-severity burns and along burn edges and unburned remnants of large severely burned areas. Lewis's woodpecker is an aerial forager, and appears to prefer older (for example, 10 years postfire) burns that still have high densities of snags but also include forest openings used for foraging (Kotliar and others 2002). Thus, we predict short-term local increases in habitat availability for these species as a result of the Hayman Fire.

Mammals – Two sensitive bat species may have been affected by fire. Maternal colonies of Townsend's big-eared bat are located in caves and abandoned mines, which may also function as a refuge during the fire. The fringed-tailed bat uses snags for maternal colonies, and thus, there may have been direct mortality to young if the mothers were unable to move their young (T. O'Shea, personal communication). Other than direct mortality, it is unclear whether the fire will enhance or degrade habitat quality and likely will depend primarily on the response of aerial insects to postfire changes. In addition, the availability of numerous snags for maternal colonies may benefit the fringed-tailed bat.

Focal Species of Concern

Mexican Spotted Owl – One known nest location for the Mexican spotted owl was located within the mixed-severity portion of the Hayman burn (fig. 30). Mexican spotted owls have been detected at approximately 20 sites in Colorado, including one other known nesting pair on the Pike National Forest. This represents a small proportion of the estimated 1,000 to 3,000 birds occurring in the United States (S. Hedwall, personal communication). However, spotted owl surveys in Colorado have been limited, and both the Colorado and U.S. population of Mexican spotted owls are deemed unreliable (S. Hedwall, personal communication). The short-term effects of fire on Mexican spotted owls are unclear (Jenness 2002), but mixed-severity fire is expected to enhance habitat quality by creating forest openings, snags for roost sites, and coarse woody debris that can enhance prey habitat (Bond and others 2002; Jenness 2002). Furthermore, low- or moderate-severity fires can decrease the threat of subsequent crown fires (Jenness 2002), which could potentially have negative effects on spotted owls.

Because of the minimal number of owls known to occur on the Pike and the potential for positive effects of mixed-severity burns on habitat quality, we do not expect the Hayman burn to have significant negative effects on this species. However, the cumulative effects of recent large crown fires across the range of the Mexican spotted owl need to be evaluated.

Pawnee Montane Skipper – A member of the *Hesperidae* butterfly family, the Pawnee montane skipper is Federally listed as a threatened species. The skipper is restricted to approximately 9,000 ha within a 38 mi^2 portion of the South Platte River Drainage on the Pike (Keenan and others 1986; Earth Resources Technology 1986). Mixed-severity fires from the Hayman and Schoonover Fires covered approximately 4,000 ha of skipper habitat, which constitutes 40 percent of the skipper's entire range (Ryke and Madsen 2002). Another 10 percent of the skipper's range was burned recently by the Buffalo Creek and Hi Meadow Fires. Because approximately 50 percent of the skipper's habitat burned in recent years, and because of the skipper's limited distribution, the status of the skipper population is of particular concern.

Burn-severity patterns of skipper habitat within the Hayman burn perimeter differed among NBR and BAER maps. NBR burn severity maps indicated that 76 percent of skipper habitat occurred in low- to moderate-severity burn patches. The remaining habitat was located along the perimeter of high severity burns area (fig. 31a). BAER burn severity maps indicated greater burn severity in potential skipper habitat; 48 percent of the potential habitat within the burn perimeter burned sufficiently to cause high tree mortality, whereas the remaining 51 percent was classified as either low-severity or unburned remnant patches (fig. 31b).

Because much of the skipper population was either in the larval or pupal stages during the Hayman Fire, direct mortality from the fire may have been high due to limited mobility. However, skipper populations are characterized by extreme fluctuation, in part because of the current drought. Thus, the low numbers of skippers observed in 2002 surveys may also reflect drought conditions, presumably due to limited availability of adult host plants (L. Ellwood, personal communication). Recovery of populations postfire depends on the species' ability to gain access to suitable postfire habitats and rebuild numbers from survivors or colonizers (Swengel 2001). Past studies suggest that skippers may take several years to recolonize an area following fire, severe disturbance, and regeneration (Ryke and Madsen 2002).

The effects of the Hayman Fire on skipper habitat quality and availability are expected to vary based on the severity of fire, the response of hosts plants to burn severity, and suitability of postfire vegetation. The Pawnee montane skipper occurs in open ponderosa pine woodlands on moderately steep slopes. Blue grama grass (*Buteloua gracillis*), the larval food plant, and *Liatris punctata*, the primary nectar plant, are critical components of skipper habitat. Blue grama typically resprouts from rhizomes across a range of burn severities, provided moisture is available and nonnative plant species invasions do not interfere with recovery (see Wasser 1982; see also http://www.fs.fed.us/database/feis/plants/graminoid/bougra/fire_effects.html). *Liatris* appears to require openings created by disturbances such as fire but apparently does not tolerate continuous disturbance (USFWS 1998) and may make take several years to recolonize high-severity burns. Based on fire research in mixed-grass prairies, postfire soil moisture is a major factor in determining the effects of fire; drought can slow or alter *Liatris* response to a fire (see http://www.fs.fed.us/database/feis/plants/forb/liapun/fire_effects.html). Thus, if there were higher than average precipitation received in 2003, it would have facilitated host plant recovery; however, Colorado continued its drought into that year.

Skipper habitat quality may either be enhanced or diminished depending on the effects of burn severity on forest structure. Skippers appear to prefer small forest openings and avoid large openings (USFWS 1998). Much of the skipper habitat within the Hayman burn was characterized as moderate severity, which can enhance skipper habitat by creating forest openings. In contrast, large treeless areas created by severe fires may diminish habitat quality in the short term. The size of forest openings may also be increased by postfire tree mortality resulting from outbreaks of bark and woodboring beetles. The effects of fire on the understory structure may likewise affect habitat suitability. Skippers are uncommon in pine woodlands where tall shrubs or young conifers dominate the understory (Keenan and others 1986; Earth Resources Technology 1986). They also avoid north-facing Douglas-fir stands where neither *Liatris* or blue grama are uncommon (USFWS 1998). Thus, fire exclusion, which can lead to greater density of understory trees and shrubs, can thereby diminish habitat quality and availability (USFWS 1998). In contrast, moderate-severity burns that kill understory but not overstory trees can enhance skipper habitat suitability. By contributing to landscape heterogeneity and dynamics as well as reducing future risk of severe crown fire, the Hayman burn may have many positive effects on skipper habitat in the long term.

Postfire management and resulting vegetation characteristics also influence habitat quality. During seeding and/or mulching of burned areas, efforts were made to minimize disturbance or unintentional introduction of nonnative plants that could affect recolonization/resprouting of host plants (D. Bohon, personal communication). However, research and monitoring are needed to determine the effects of postfire treatments on natural regeneration in skipper habitats.

It is unclear whether the potential long-term effects of drought and fire will compound other threats to the population. Human activities and development (for example, livestock grazing, logging, housing, roads, reservoirs, recreational access) in the Platte River Canyon have decreased former skipper range and modified its habitat. Invasion of noxious weeds that may compete with blue grama and *Liatris*, are a serious threat to the skipper (USFWS 1998). Long-term monitoring of the skipper populations is necessary to determine if any mitigation of postfire effects is warranted.

Preble's Meadow Jumping Mouse – Montane populations of the Preble's meadow jumping mouse are poorly studied (Meany 2000), but recent surveys located the mouse along the South Platte River and its tributaries (Schorr 1999; Meany 2001). Preble's meadow jumping mouse habitat has been characterized as "well-developed plains riparian vegetation with relatively undisturbed grassland and a water source in close proximity" (Armstrong and others 1997). Almost 6,000 ha of stream segments identified as potential critical habitat occurred within the perimeter of the Hayman Fire (fig. 32). Both NBR and BAER maps indicated that 66 percent of the habitat burned under low to moderate severity, with the remaining 34 percent burned with high severity (fig. 32).

In riparian areas, higher fuel moisture and the ability of dominant riparian species to resprout, can moderate fire effects compared to upland areas. For much of the potential critical habitat this appears to be the case. However, under severe drought, riparian areas can burn severely, as occurred along several portions of the habitat; in many high-severity patches, riparian vegetation apparently burned in continuous blocks along with surrounding trees and upland areas; thus, direct fire mortality may have been high in these areas if the mouse was unable to find refuge underground. However, most of the potential critical habitat that burned under high severity is in proximity to low- or moderate-severity patches that may serve as potential recolonization sources (fig. 32). There are some concerns that postfire erosion could alter mouse habitat further (L. Ellwood, personal communication), but it is difficult to predict the short- and long-term effects of erosion on Preble's meadow jumping mouse populations. Additional information is needed to assess the effects of fire, climate variability, and invasive plant species on these montane populations. Given the limited amount of potential mouse habitat that burned, the heterogeneity of the burn within its habitat, and the ability of riparian vegetation to resprout following disturbance, the effects of the Hayman Fire on these populations will likely be relatively short lived.

Three-Toed Woodpecker – Three-toed woodpeckers are uncommon and difficult to monitor, so population levels and trends are poorly quantified (Leonard 2001). Three-toed woodpeckers rapidly colonize severely burned forests in response to outbreaks of bark and woodboring beetles that feed on dead and dying trees (Kotliar and others 2002). Postfire insect outbreaks are short lived, and three-toed woodpeckers are usually rare in burns older than 5 years. Because the woodpeckers are generally uncommon outside areas of insect outbreaks, the availability of mixed-severity and severe burns may represent critical habitat needs; it has been suggested that three-toed woodpecker populations fluctuate with fluctuating availability of burns and other extensive insect outbreaks (Crist 2000). Thus, severe burns represent potentially critical, but ephemeral, habitat for this species (Kotliar and others 2002). Recent nearby fires (Hi Meadow, Buffalo Creek) may have increased the local woodpecker populations available to colonize the Hayman burn; at least 30 adult three-toed woodpeckers were observed in 2003 (Kotliar, personal observation). In turn, the Hayman Fire will likely result in an increase in local populations of three-toed woodpeckers.

Blanketflower and Colorado Fire Moth – The blanketflower (*Gaillardia aristata* Pursh) is found in open, sunny areas, such as hillsides, meadows, and clearings in woods from mesas into the foothills (Guennel 1995; Weber 1976). Research indicates that blanketflower may respond favorably to fire, thereby creating habitat patches for *Schinia masoni* (referred to as Colorado Firemoth; B. Byers, personal communication). Both larvae and adults of *Schinia masoni* depend on blanketflower for food. The reliance of the moth on blanketflower is manifest in the adult moth's cryptic coloring; their head and thorax blend with the yellow ray flowers and their crimson wings match the color of disc flowers (Ferner 1981).

Blanket flower is often a pioneer species that can become established following disturbances such as fire (Cox and Klett 1984). Seeds remain viable in the soil for 2 years (Hotes 1918) and may germinate after burning (Cox and Klett 1984). It also quickly resprouts from rhizomes if the stem is removed (Iles and Agnew 1993). Blanketflower competes well under moisture stress but not under low light conditions present in closed-canopy forests (Hotes 1918; Coupland and Brayshaw 1953; Budd 1979). Thus, blanketflower life history facilitates a positive response to mixed-severity burns and crown fire as long as seed sources or rhizomes are present. Consequently, increased habitat for the Colorado fire moth may occur following the Hayman Fire, provided the moth is able to recolonize burned areas from the surrounding landscape. Burns and other disturbances that cause increases in blanketflower may be essential for the long-term survival of the moth.

Postfire Management

A number of management activities designed to mitigate fire effects and remove dead trees are under way or proposed. The potential ecological effects of such activities have been addressed elsewhere (Robichaud and others, this volume). Here, we briefly discuss the potential implications of postfire management for species of concern.

Rehabilitation activities are primarily designed to reduce erosion in high severity-burn areas; however, the effectiveness or ecological effects have been poorly studied (Robichaud and others, this volume). Species of concern associated with wetland habitats may be negatively affected by erosion-control materials. Soil scarification, used to break up hydrophobic soils, could potentially increase rather than decrease erosion if assumptions about the prevalence and persistence of hydrophobicity are incorrect (D. Martin, personal communication). Materials used to control erosion (straw mulch, hydromulch, seeds) may collect in riparian and wetland areas following rain events. Such negative effects can be magnified by the undetected presence of invasive exotics within seed mixes. Once established, invasive exotics are difficult to eradicate and may compete with native plants, such as host plats for lepidopteran species of concern. Likewise, competition from seeing may inhibit ponderosa pine regeneration because seedlings require bare mineral soil for germination. Consequently, rehabilitation activities could alter the timing or direction of postfire successional trajectories and increase the time necessary for populations to return to prefire levels; this could diminish the ability of a local population to rebound after fire and may especially pose problems for species with restricted or limited populations.

Salvage logging can have serious implications for three-toed woodpeckers, which rarely use burned forests that are partially logged (Kotliar and others 2002). Salvage logging can reduce inputs of coarse woody debris that can provide important refugia for prey species for several species of concern. Disturbance from salvage logging operations may damage resprouting plants and potentially delay or alter postfire recovery. Likewise, disturbance from hazard tree removal along roads may have the greatest effects on riparian areas by potentially increasing erosion. Hazard tree removal includes live trees (75 percent crown scorch) that either may survive or may persist long enough to provide seed sources or refugia, which becomes increasingly important as tree mortality and distance to live trees increases. The potential negative ecological effects of rehabilitation and salvage logging have been poorly studied and thus not adequately considered when evaluating postfire management activities.

Critical Ecological Elements

There are a number of important elements created by fire that can be harmed by postfire management activities. High densities of dead and dying trees are critical resources for insects and woodpeckers. Isolated live trees are important seed sources and refugia. Likewise, remnant patches of unburned or lightly burned areas supporting a diverse understory of native plants may be important habitat refugia for species of special concern and may provide critical seed sources for recovery of burned and or disturbed areas. Bare mineral soil is necessary for germination of ponderosa pine seedlings, and blanketflower may respond favorably to the disturbance caused by fire. Only the full spectrum of burn-severity patterns present in mixed-severity burns can provide all these essential ecological elements.

In addition, dynamic landscapes are important to the health of ponderosa pine systems. Native vegetation in heterogeneous arrangements, as would have been present during pre-European settlement fire regimes, is essential to the natural recovery of wildlife populations. Nonnative plant species are a serious threat to the recovery of native vegetation, especially in mesic and riparian areas, which also tend to support the greatest variety of native species and species of concern. In particular, native host plants required by moths and butterflies may be displaced by seeding and via competition from invasive exotics. Thus, rehabilitation and other human activities that alter species composition and natural postfire recovery processes, can diminish the positive effects of fire and magnify the negative effects.

Conclusions

The effects of the Hayman Fire are expected to vary based on the patterns of fire severity. In general, the mixed-severity burn in the Hayman Fire will enhance habitat availability for several species of concern in the short term. Although it is possible that several species of concern may decline initially postfire, our review suggests that few, if any, species of concern will suffer long-term negative effects from the mixed-severity burn. Because of the lack of specific information on population changes resulting from fire, and the variation in fire effects (for example, burn severity), such a conclusion must be considered preliminary for many species. Postfire monitoring is necessary to test this prediction, and further research is desperately needed to improve our understanding of the effects of fire on many species of concern. However, given the importance of a mixed-severity fire regime to the health of ponderosa pine and Douglas-fir forests, it is unlikely that many of the 59 species listed as sensitive on the Pike will suffer long-lasting negative impacts of the fire, whereas several species of concern will benefit from the fire.

Concern remains for the Pawnee montane skipper because it is restricted to specialized habitat within a limited area. Further research is needed to quantify burn-severity patterns in the 40 percent of the skipper habitat that burned, and to determine how the species responds (positively and negatively) to burn-severity patterns in conjunction with drought conditions. Although drought is a common occurrence along the Colorado Front Range, rangewide monitoring is necessary to fully quantify the effects of the fire and drought in the context of changing land use and other threats to skipper habitat.

Although we expect that the mixed-severity burn will generally have positive long-term effects for most species, and forest health overall, the Hayman Fire occurred across a landscape that has been altered in numerous ways by human activities. The removal of beaver, roads, fire suppression, postfire rehabilitation, grazing, and habitat fragmentation can alter the structure and functioning of systems. Consequently, there may be interactions between the Hayman Fire and the altered landscape that could lead to greater effects on species of concern than that caused by historic fires. On the other hand, the Hayman Fire may help restore system structure and function by increasing landscape heterogeneity and contributing to system dynamics.

Acknowledgments

Denny Bohon, Nancy Ryke, Mike Elson, Steve Tapia, and Becky Parmenter (USDA Forest Service); Erin Muths, Tom O'Shea (U.S. Geological Survey); Leslie Ellwood, Shaula Hedland (U.S. Fish and Wildlife Service); Michael Menefee (Colorado Natural Heritage Program); Eric Odell (Colorado Division of Wildlife); and Pat Kennedy (Oregon State University) provided valuable discussions and expert opinions on the effects of fire on species of concern. We also thank Diana Tomback for her comments on the manuscript.

References

Andrews, R. and R. Righter. 1992. Colorado birds. Denver Museum of Natural History. Denver, CO, 442 pp.

Armstrong, D., M. Bakeman, N. Clippinger, A. Deans, M. Margulies, C. Meany, C. Miller, M. O'Shea-Stone, T. Ryon, and M. Sanders. 1997. Edited by Mark Bakeman. Report on habitat findings of the Preble's meadow jumping mouse. For the U.S. Fish and Wildlife Service and Colorado Division of Wildlife. 91pp.

Bond, M.L., R.J. Gutierrez, A.B. Franklin, W.S. LaHaye, C.A. May, and M.E. Seamans. 2002. Short-term effects of wildfires on spotted wol survival, site fidelity, mate fidelity, and reproductive success. Wildlife Society Bulletin 30:1022-1028.

Brown, P.M., M.R. Kaufman, and W.D. Sheppard. 1999. Long-term, landscape patterns of past-fire events in a montane ponderosa pine forest of central Colorado. Landscape Ecology 14: 513-532.

Budd, A.C. 1979. Budd's Flora of the Canadian Prairie Provinces. Revised and enlarged by J. Looman. 1987. Agric. Canada Pub. Ottawa, ON.

Coupland, R.T. and T.C. Brayshaw. 1953. The fescue grassland in Saskatchewan. Ecology 34:386-405.

Cox, R.A. and J.E. Klett. 1984. Seed germination requirements of native Colorado plants for use in the landscape. Plant Prop. 30:6-10.

Cryan, P.M., M.A. Bogan, and G.M. Yanega. 2001. Roosting habits of four bat species in the Black Hills of South Dakota. Acta Chiropterologica 3: 43-52.

Earth Resources and Technology (ERT Company). 1986. Pawnee montane skipper field studies. Unpublished report to the Denver Water Department, Denver, Colorado. 40pp.

Ferner, J.W. 1981. A cryptic moth, Schinia masoni, on Gaillardia aristata in Colorado. Southwest Natur. 26:88-90.

Grace, J.B., M. Smith, S.L. Grace, S. Collins, and T.J. Stohlgren. 2001. Interactions between fire and invasive plants in temperate grasslands in North America. Pages 40-65. In K. Galley and T. Wilson (Eds.), Fire Conference 2000: The First National Congress on Fire, Ecology, Prevention and Management. Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species. Tall Timbers Research Station, Miscellaneous Publication No. 11.

Guennel, G.K. 1995. Guide to Colorado Wildflowers: Mountains. Westcliffe Publishers, Inc., Engelwood, CO.

Hammerson, G.A. 1999. Amphibians and reptiles in Colorado. 2nd edition. University Press of Colorado, Niwot, CO.

Hotes, A.C. 1918. Commercial plant propagation. A.T. Delamare Co., Inc. New York, NY.

Iles, J.K. and N.H. Agnew. 1993. Response of five container grown herbaceous perennial species to laboratory freezing. HortTechnol. 3:192-194.

Jenness, J. 2002. The effects of fire on Mexican Spotted Owls in Arizona and New Mexico. Unpublished Ph.D. Dissertation. Northern Arizona University, Flagstaff, AZ.

Keenan, L.C., R.E. Stanford, S.L. Ellis, and B. Drummond. 1986. Status report on: Pawnee montane skipper. Report to the Denver Water Department, Denver, Colorado. 49pp.

Kotliar, N.B., S. Hejl, R.L. Hutto, V.A. Saab, C.P. Melcher, and M.E. McFadzen. 2002. Effects of fire and postfire salvage logging on avian communities in conifer-dominated forests of the western United States. Studies in Avian Biology 25:49-64.

Leonard, D.L., Jr. 2001. Three-toed Woodpecker (Picoides tridactylus). *In* The Birds of North America, No. 93 (A. Poole and F. Gill, eds.). Philadelphia: The Academy of Natural Sciences,: Washington, D.C.: The American Ornithologists' Union.

Loeffler, C. 2001. Report on the status and conservation of the boreal toad (Bufo boreas boreas) in the southern Rocky Mountains. Colorado Division of Wildlife, Denver, CO.

McCallum, D.A. 1994. Flammulated Owl (Otus flammeolus). *In* The Birds of North America, No. 93 (A. Poole and F. Gill, eds.). Philadelphia: The Academy of Natural Sciences, Washington, D.C.: The American Ornithologists' Union.

Meany, C. 2000. Survey for Preble's Meadow jumping mice, Wigwam Campground, Jefferson County. For the Pike National Forest, South Platte Ranger District, Morrison, Colorado.

Meany, C. 2001. Survey for Preble's Meadow jumping mice, Trout Creek, Jefferson County. For the Pike National Forest, South Platte Ranger District, Morrison, Colorado.

Miller, J. D .and S. R. Yool. 2002. Mapping forest postfire canopy consumption in several overstory types using multi-temporal Landsat TM and ETM data. Remote Sensing of Environment 82:481-496.

Philliod, D. S., R. B. Bury, E. J. Hyde, C. A. Pearl, and P. S. Corn. 2003. Fire and amphibians in North America. Forest Ecology and Management 178: 163-181.

Pierson, E.., M.C.Wackenhut, J.. Altenbach, P. Bradley, P.all, D.. Genter, C.. Harris, B.L. Keller, B. Lengus, L. Lewis, B. Luce, K.. Navo, J. M. Perkins, S. Smith, and L. Welch. 1999. Species conservation assessment and strategy for Townsend's big-eared bat (Corynorhinus townsednii townsendii and Corynorhinus townsendii pallescens). Idaho Conservation Effort, Idaho Department of Fish and Game, Boise, ID.

Reynolds, R.T., R. T. Graham, M.H. Reiser, R.L. Bassett, P.L. Kennedy, D.A. Boyce, Jr., G. Goodwin, R. Smith, and E.L. Fisher. 1992. Management recommendations for the northern goshawk in the southwestern United States. USDA Forest Service, GTR Rm-217.

Russell, K. R., D. H. Van Lear, and D. C. Guynn, Jr. 1999. Prescribed fire effects on herpetofauna: review and management implications. Wildlife Society Bulletin 27:374-384.

Ryke, N., and B. Madsen. 2002. Biological Evaluation/Assessment For Threatened, Endangered and Sensitive Species: Hayman and Schoonover Fires - Hazard Tree Removal. Pike National Forest: South Park, Pikes Peak and South Platte Ranger Districts

Ryke, N. D. Winters, L. McMartin, S. Vest, B. Masinton. 1994. Threatened, endangered, and sensitive species of the Pike and San Isabel National Forests and Comanchi and Cimmarron National Grasslands.

Schorr, R. 1999. Small mammal surveys on Pike National Forest. Douglas County, Colorado. Trout Creek, South Platte River and Indian Creek. For the Pike National Forest, South Platte Ranger District, Morrison, Colorado.

Stohlgren, T.J., D. Binkley, G.W. Chong, M.A. Kalkhan, L.D. Schell, K.A. Bull, Y. Otsuki, G. Newman, M. Bashkin, and Y. Son. 1999. Exotic plant species invade hot spots of native plant diversity. Ecological Monographs 69: 25-46.

Stohlgren, T.J., K.A. Bull, Y. Otsuki, C.A. Villa, and M. Lee. 1998. Riparian zones as havens for exotic plant species in the central grasslands. Plant Ecology 138:113-125.

Stohlgren, T.J., G. W. Chong, L.D. Schell, K.A. Rimar, Y. Otsuki, M. Lee, M.A. Kalkhan, and C.A. Villa. 2002. Assessing vulnerability to invasion by nonnative plant species at multiple scales. Environmental Management 29:566-577.

Swengel, A.B. 2001. A literature review of insect responses to fire, compared to other conservation managements of open habitat. Biodiversity and Conservation 10 (7): 1141-1169.

U.S. Fish and Wildlife Service (USFWS) 1998. Pawnee montane skipper butterfly (Hesperia leonardus montana) recovery plan. Denver, Colorado. 16 pages http://ecos.fws.gov/recovery_plan/pdf_files/1998/980921.pdf

Veblen, T. T., T. Kitzberger, and J. Donnegan. 2000. Climatic and human influences on fire regimes in ponderosa pine forests in the Colorado front range. Ecological Applications 10: 1178-1195.

Wasser, C. H. 1982. Ecology and culture of selected species useful in revegetating disturbed lands in the West. FWS/OBS-82/56. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services, Western Energy and Land Use Team. 347 p. Available from NTIS, Springfield, VA 22161; PB-83-167023.

Weber, W.A. 1976. Rocky Mountain Flora. Colorado Associated University Press, Boulder, CO.

Home Destruction Within the Hayman Fire Perimeter

Jack Cohen and Rick Stratton

Introduction

The Hayman Fire report on home destruction examines the following four questions:

1. How many homes were destroyed out of the total number of homes within the Hayman Fire perimeter?
2. What was the relative wildland fire intensity associated with the destroyed homes?
3. What was the categorical cause of home ignition suggested by the associated wildland fire intensity adjacent to the home site?
4. Did community covenants and/or county regulations exist that suggest differences in the potential for home destruction?

An onsite assessment at each destroyed home provided the principal information needed to address these questions. In addition, documentation and photographs during the fire, postfire aerial reconnaissance, and meetings and discussions with Federal and county personnel and local area residents contributed important information. Although we only specifically assessed the homes destroyed, surviving homes were considered when possible. Onsite assessments occurred 3 months after the Hayman Fire, at a time when much of the specific evidence describing the nature of home destruction and survival was lost. Discussions with fire personnel and residents indicate that most homes were not actively protected when the Hayman Fire burned the residential areas.

Number of Destroyed Homes

The Hayman Fire resulted in the destruction of 132 homes (that is, homes on permanent foundations, modular homes, and mobile homes—both primary and secondary). Some 794 homes existed within what is now the final perimeter of the Hayman Fire. Thus, 662 homes were not destroyed. The Hayman Fire resulted in about 17 percent destruction of the total homes within the fire area (table 1).

Table 1—The number of homes destroyed and remaining during the Hayman Fire, 2002. Information is based on county records and onsite assessments.

County	Destroyed	Remaining	Total
Douglas	45	232	277
Jefferson	1	~160	161
Park	4	144	148
Teller	82	126	208
Total	**132**	**662**	**794**

Fire Intensity

A wide array of wildland fire intensities were evidenced with respect to home destruction and survivability. Figure 1 shows the range of wildland fire intensities associated with homes destroyed and a similar range with those that survived.

Research (Cohen 2000) has shown that the characteristics of the home in relation to its immediate

Figure 1—A 2x2 matrix of home destruction associated with the nearby wildland fire intensity. Expectations correspond to fire intensities, for example, home survival is expected if low fire intensities occur (lower right cell) and unexpected if the home is destroyed (lower left cell).

surroundings (within 100 to 200 feet) principally determine home ignitions during intense wildland fires. This area that includes the home characteristics and its immediate surroundings is called the *home ignition zone*. Figure 1 shows expected cases and unexpected cases based on an association of fire intensities and the resulting home destruction or survival. The home ignition zone provides the means for understanding the unexpected situations—homes destroyed associated with low fire intensity and surviving homes associated with high intensities. The wildland fire intensity in the general area does not necessarily cause home destruction or survival. This distinguishes the difference between the exposures (flames and firebrands) produced by the surrounding wildland fire from the actual potential for home destruction (home ignition zone) given those exposures. Recognizing that the home ignition zone principally determines home ignition potential provides an important context for interpreting the home destruction information. The home ignition zone implies that the issue of home destruction can be considered in a home site-specific context rather than in the general context of the Hayman Fire.

Causes of Destruction

Seventy homes were destroyed in association with the occurrence of torching or crown fire in the home ignition zone. Sixty-two homes were destroyed by surface fire and/or firebrand(s). The homes destroyed correspond to the two left cases in figure 1. A destroyed home was counted in the high intensity fire category if any high intensity burning occurred in the area surrounding the home. Significant site disturbance in the time lapsed between the fire occurrence and our assessment prohibited any further analysis as to whether these high intensities could have directly caused home ignition. That is, loss of evidence and the limited time for assessment disallowed a postburn analysis of the home ignition zone.

Covenants and Local Regulations

Significant patterns of destruction were not observed. This can likely be attributed to the wide variety of home types, designs, and building materials, the scattering of destroyed homes, the significant number of surviving homes within the fire perimeter, and the wide range of fire intensities associated with home destruction. Teller and Park County did not have any regulations in place. In 1994 Douglas County adopted an amended version of NFPA 299 (1991) as an appendix to the Uniform Building Code as well as some minimum rural water storage requirements for developments. All new developments and building permits after the adoption date are subject to these regulations. Likewise, Jefferson County required defensible space permits on habitable space greater than 400 ft^2 in 1996, but because of little new construction, few—if any—homes fall into this category in the fire area.

Home Destruction Chronology

The following timeline is based on the fire chronology presented in the fire behavior section but focuses on the progression of the fire in relation to homes destroyed (fig. 2). The exact time individual homes were destroyed is largely unknown. Furthermore, the progression of the fire may not coincide with the actual date a home burned. This is largely a function of an estimate of the fire's perimeter at a specific time and unburned areas within the perimeter that can later burn.

Most of the destroyed homes occurred in the eastern portions of the Hayman Fire area. The major fire runs on June 9 and 10, 2002, resulted in 36 homes destroyed. The major eastward fire spread a week later on June 17 and 18 produced the greater proportion of destroyed homes (87 homes).

June 8, 2002: No homes destroyed. Fire size: 280 acres.

June 9: Sustained, prefrontal southwest winds with wind speeds near 20 mph, with gusts exceeding 30 mph, pushed the fire northeast and into the Nine-J road area (County Road 59) at approximately 1800 hours; six homes were destroyed. In the evening, the fire approached State Highway 67 and burned two homes, the Horse Creek CafÈ and Saloon, and a summer home in Lazy Gulch (near Deckers) (approximately 2300 hours). Fire size: 60,133 acres.

Teller Co.	Douglas Co.	Jefferson Co.	Park Co.
0	9	1	0

Homes destroyed: 10 Cumulative: 10

June 10: With the arrival of the cold front (approximately 1400 hours), the southwest-southeast winds shifted, and the southeast flank spread into Lutheran Valley. Various bunk houses and outbuildings of the Lutheran Valley Retreat (LVR) were destroyed, as well as several summer homes in the adjoining area. Fire size: 81,463 acres.

Teller Co.	Douglas Co.	Jefferson Co.	Park Co.
26	0	0	0

Homes destroyed: 26 Cumulative: 36

June 11: Cold front winds from the north persisted and pushed the fire into the Beaver Creek drainage, burning three homes (south of Forest Road 220/897). Fire size: 82,000-96,000 acres.

Teller Co.	Douglas Co.	Jefferson Co.	Park Co.
3	0	0	0

Homes destroyed: 3 Cumulative: 39

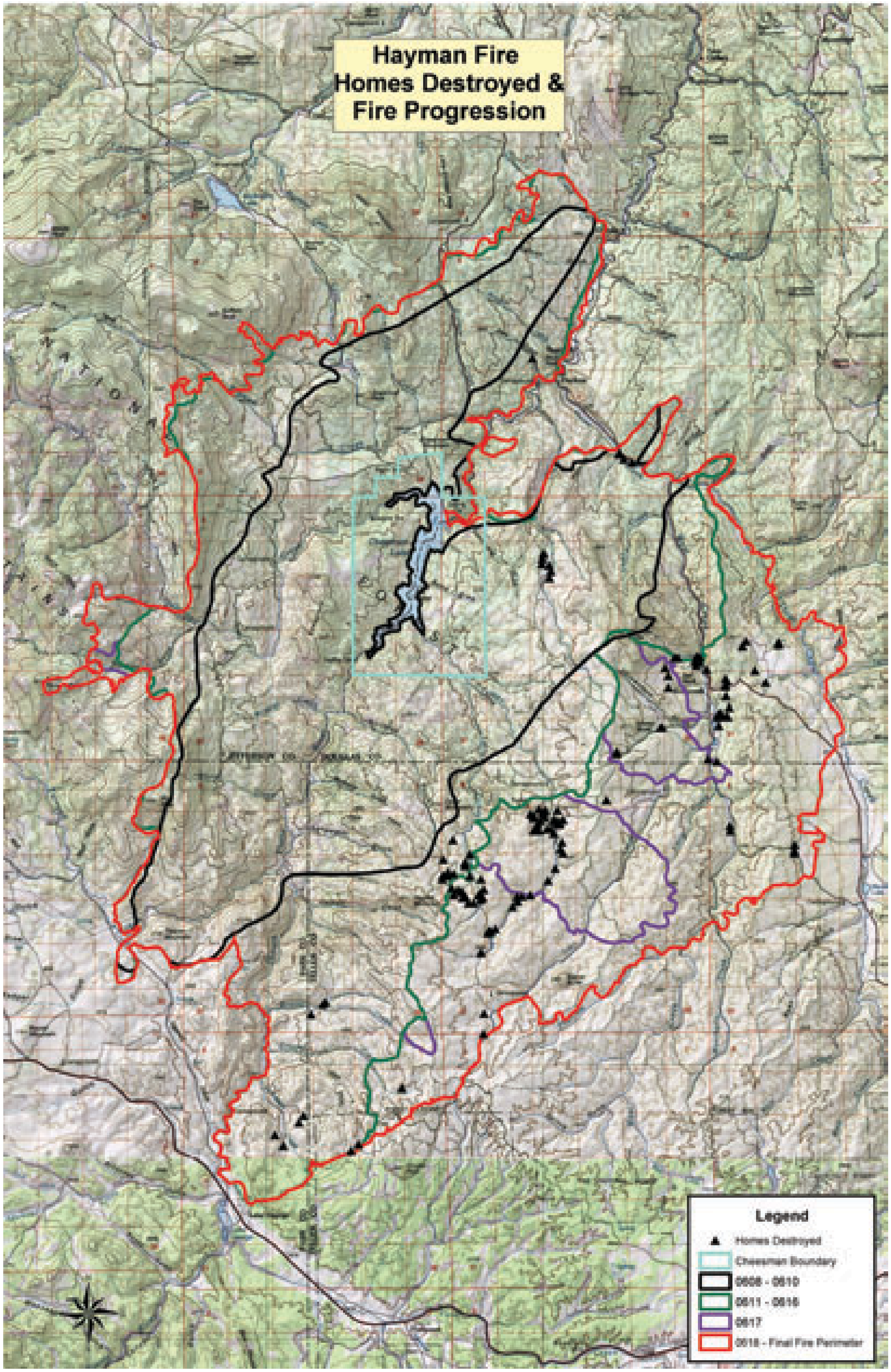

Figure 2—Locations of destroyed homes in relation to the Hayman Fire progression. The lines correspond to the estimated position of the perimeters at the end of June 10, 16, 17, and the final fire perimeter.

June 12 through 13: Frontal winds continued to advance the fire southeast into Crystal Creek on June 12 and Vermillion Creek (Tom's Ranch or Forest Road 200)/Indian Creek (north of Lake George) on June 13, destroying six homes.
Fire size: 97,000 acres.

Teller Co.	2	Douglas Co.	0	Jefferson Co.	0	Park Co.	4

Homes destroyed: 6 Cumulative: 45

June 14 through 16: No homes destroyed.
Fire size: 99,590 acres.

June 17: Weather conditions of the previous 6 days changed at about noon. Winds shifted and increased from the west-northwest, pushing the eastern flank of the fire into Turkey Rock Ranch, Thunder Butte subdivision, Bell Rock, and Stump Road (County Rd. 68).

Teller Co.	30	Douglas Co.	16	Jefferson Co.	0	Park Co.	0

Homes destroyed: 46 Cumulative: 91
Fire size: 109,609 acres.

June 18: Weather experienced on June 17 persisted; the entire southeast, east, and northeast flanks spread into Trout Creek Ranch, Wildhorn Ranch, West Creek Lakes, and the Painted Rock area (County Road 78).

Teller Co.	21	Douglas Co.	20	Jefferson Co.	0	Park Co.	0

Homes destroyed: 41 Cumulative: 132
Fire size: 135,174 acres.

June 19 through 28: No homes destroyed.
Fire size (final): 138,114 acres.

Assessment Methods

A qualitative, onsite assessment was done at each home destroyed by the Hayman Fire. The main objectives of the assessment were to (1) locate and record the GPS coordinates of each destroyed home, (2) determine for the general area and for each destroyed home the associated wildland fire intensity, and (3) determine the likely categorical cause of ignition (surface fire/firebrand or torching/crown fire). Each destroyed home site was photographically documented, and general area photographs were taken from an aerial survey. County assessors provided locations of recorded burned homes. Discussions with local area residents also aided in locating destroyed homes. We visited 132 homes over 2 weeks; approximately 800 photos were taken.

The field assessments for each destroyed home occurred the middle of September 2002, about 3 months after the homes burned. Site disturbance during that period (for example, home debris removal, tree removal, rebuilding activities) eliminated much of the evidence important for highly reliable determinations of the categorical ignition cause. The occurrence of high intensity burning adjacent to a home site does not necessarily cause direct home ignition (fig. 1, upper right cell), and this can usually be determined immediately after the fire. For this assessment, the lack of adequate evidence and the assessment's time constraints dictated our assumption that any high intensity burning adjacent to the home site categorically designated the cause to be tree torching/crown fire.

The assessment process was as follows:

- Record the address, local area map designation, and GPS location.
- When possible, note the dominant vegetation, canopy cover, surface fuel, aspect, and slope.
- Categorically estimate the general area intensity (GAI). (This indicates the potential firebrand exposure to the home ignition zone without significant flame heating.)
- Categorically estimate the site-specific intensity (SSI). (This indicates the potential exposure to direct flame heating.)
- Categorically designate the probable ignition source of the home (for example, surface/firebrand or tree torching/crown fire).
- Record if there was unburned fuel in the immediate home area as well as unburned homes in the general vicinity (within approximately 0.25 mile).
- Take digital photographs of the site from the four cardinal directions, as well as any other points of particular interest (such as the likely path of the fire, unconsumed fuel, unburned homes).

Specific Area Assessment

The 132 homes burned on the Hayman Fire were clustered into groups based on location and time of destruction. Eight assessment groups were delineated (fig. 3) and are listed below in relative order of occurrence (table 2). Each of the assessment groups is specifically examined. The destroyed homes are displayed on maps delineating fire severity. Corresponding photos provide a clearer understanding of the nonuniform burn patterns associated with homes destroyed and those that survived. The photos show burned homes as well as unburned homes in the same area. Many of the photos show trees with dead needles remaining that were unconsumed during the fire. This indicates that the intensities at those locations were not sufficient to initiate combustion in tree canopies.

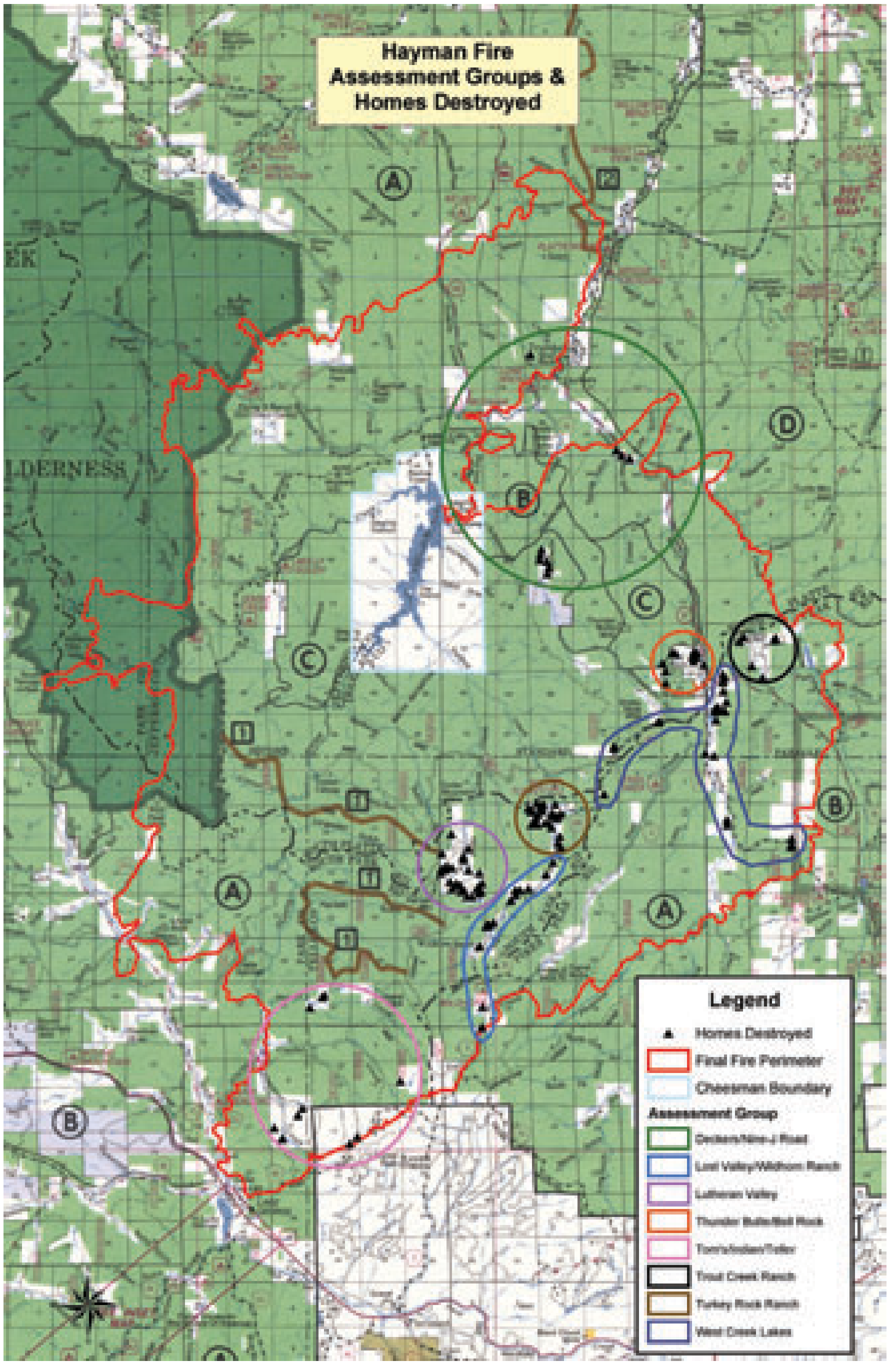

Figure 3—The 132 destroyed homes were clustered into eight assessment groups according to area proximity and the fire progression.

Table 2—Assessment groups based on relative order of destruction during the Hayman Fire.

	Homes destroyed
Deckers/Nine-J Rd.	10
Lutheran Valley	26
Tom's Ranch/Indian Creek/West Teller Co.	12
Thunder Butte Subdivision/Bell Rock	11
Turkey Rock Ranch	28
Lost Valley/Wildhorn Ranch	14
West Creek Lakes/Stump Rd./County Rd. 78	25
Trout Creek Ranch	6

Deckers/Nine-J Road

This assessment group consists of home(s) northwest and southeast of Deckers and the Nine-J Road area (County Road 59) (fig. 4). One summer cabin was destroyed in Lazy Gulch (Jefferson County), just northwest of Deckers along State Highway 126 (fig. 5, 6). Three additional structures—two primary residence and the Horse Creek Cafe and Saloon (fig. 7)—were destroyed southeast of Deckers (State Highway 67). General area intensity (GAI) was high, where as the site-specific intensity (SSI) was moderate to low in Lazy Gulch and high to moderate along State Highway 67. In the Nine-J Road area, six homes were destroyed; GAI and SSI were high (fig. 8).

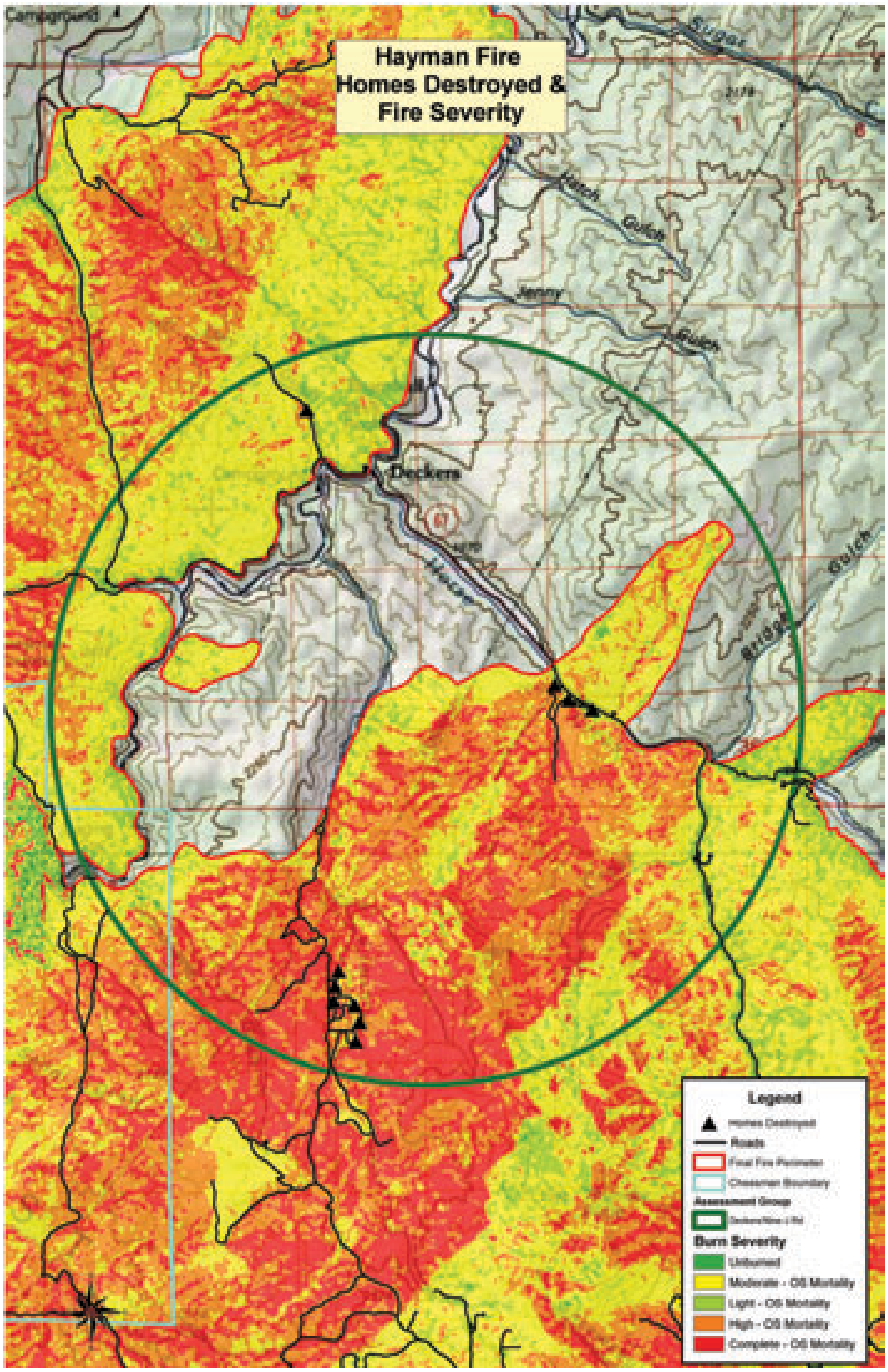

Figure 4—The Deckers/Nine-J Road assessment group with the associated fire severity.

Figure 5—Aerial view looking north at Lazy Gulch (State Highway 67, northwest of Deckers). The circle indicates where the summer home was destroyed. Note the unburned homes below the circle.

Figure 6—Site view of the summer home destroyed in Lazy Gulch (State Highway 67, northwest of Deckers). The remaining needle kill indicates a surface fire next to the home without tree torching and crowning.

Figure 7—The destroyed remains of the Horse Creek Cafe and Saloon on State Highway 67, southeast of Deckers. Note the unburned vegetation. (Photo by R. Moraga)

Figure 8—Aerial view looking to the south-southwest of Nine-J Road (County Road 59). Circled areas indicate where a home was destroyed. Note the unburned home with the green roof.

Lutheran Valley

Twenty-six homes were destroyed in Lutheran Valley Ranch (fig. 9, 10) as well as several outbuildings and bunkhouses at the Lutheran Valley Retreat. To the northeast the GAI was moderate to high and the SSI was moderate to low (fig. 11); all other areas experienced high GAI and high to moderate SSI (fig. 12).

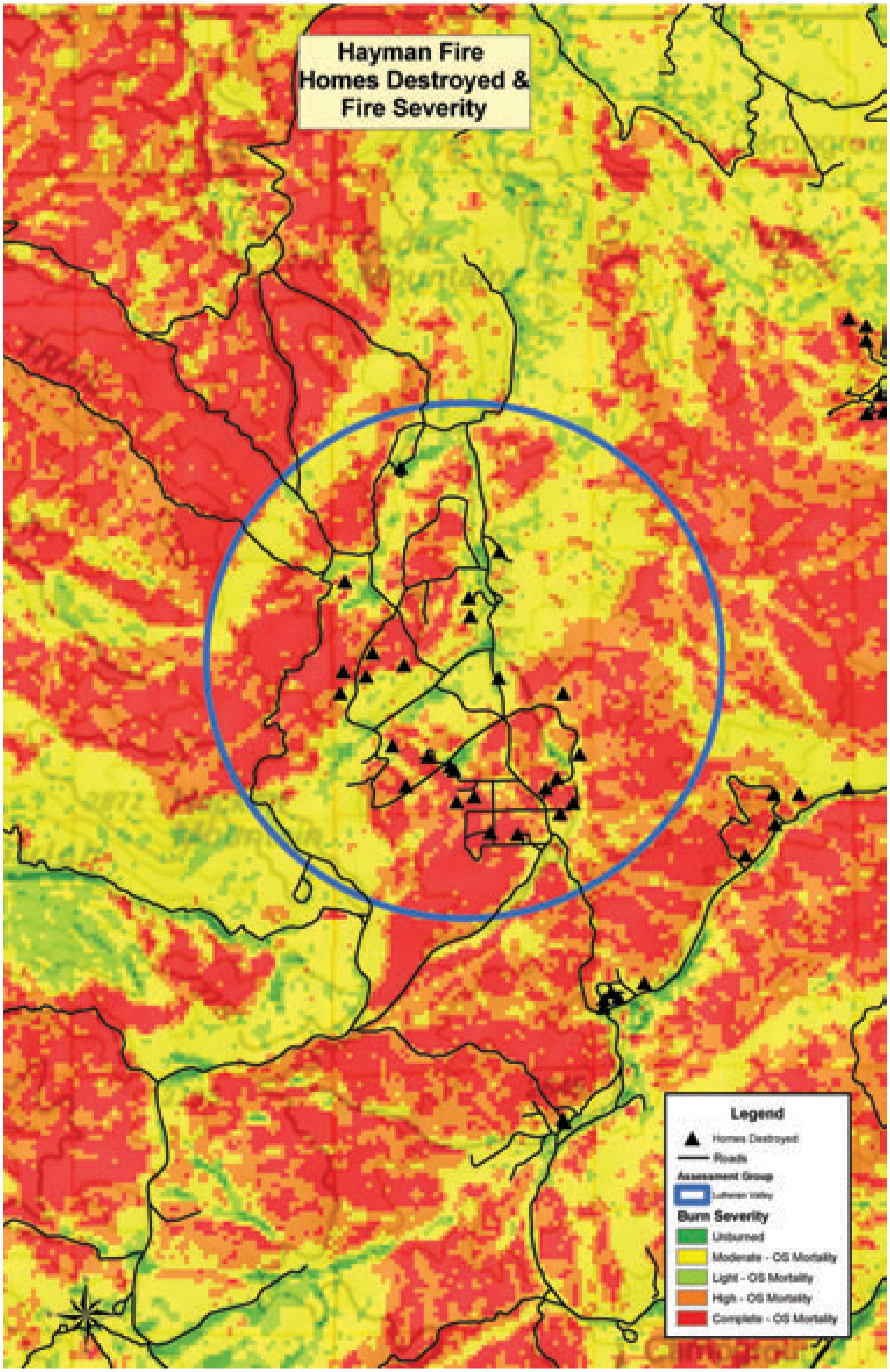

Figure 9—Lutheran Valley Ranch assessment group with the associated fire severity.

Figure 10—Aerial photograph of Lutheran Valley Ranch. (Photo produced by Jim Ellenwood)

Figure 11—Home destroyed in Lutheran Valley Ranch; ignition cause was designated as surface fire and/or firebrand.

Figure 12—Another example home destroyed in Lutheran Valley Ranch. The ignition cause was designated as torching/crown fire.

Tom's Ranch/Indian Creek/West Teller County

Twelve homes were destroyed in the southern end of the fire perimeter (fig. 13). Homes in Tom's Ranch (Forest Road 200) experienced a range of intensities (both GAI and SSI) (fig. 14, 15). The GAI of the Indian Creek area was moderate and the SSI was moderate to low. Homes in west Teller County experienced high to moderate GAI and moderate to high SSI.

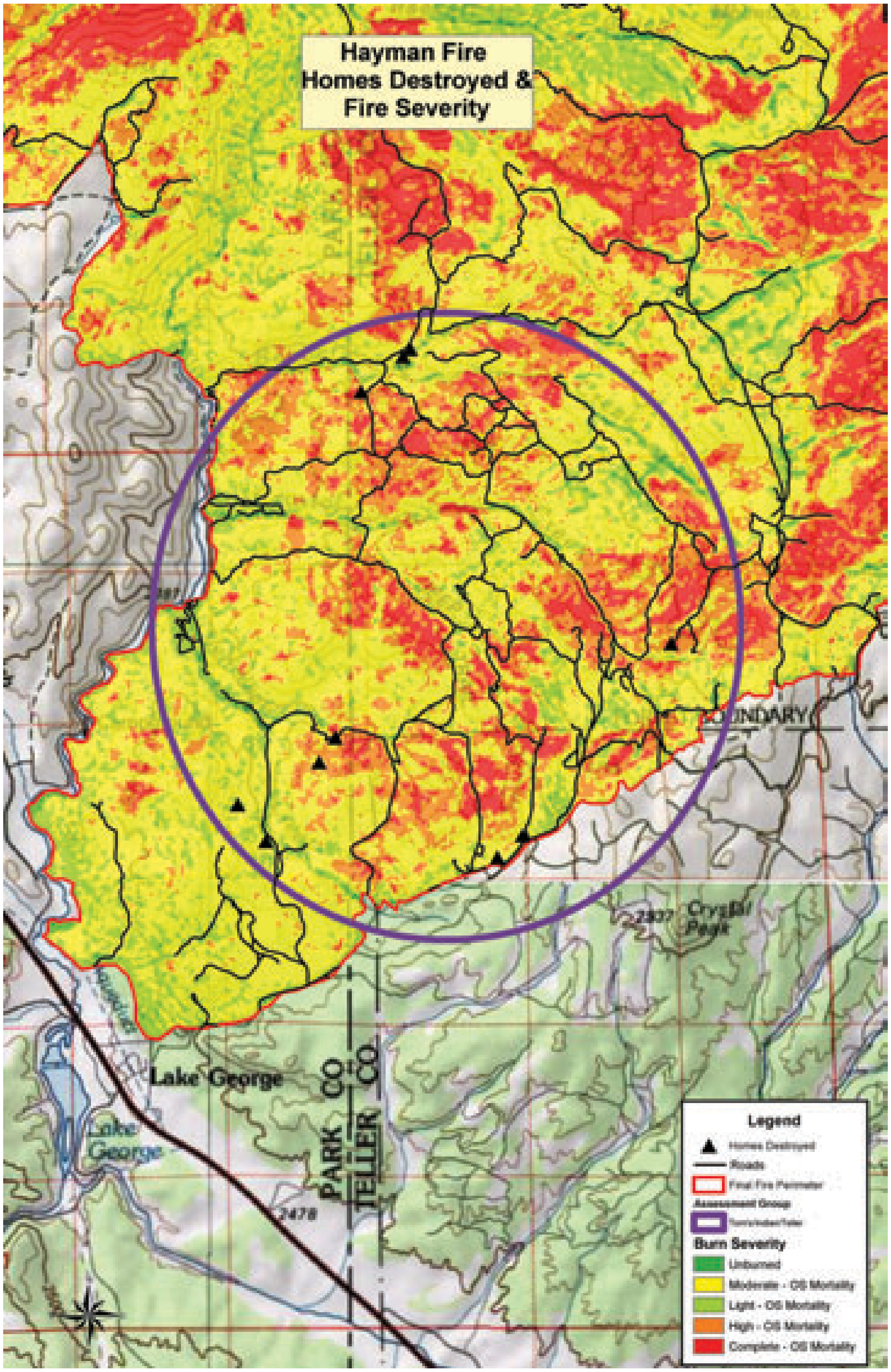

Figure 13—The Tom's Ranch/Indian Creek/West Teller County assessment group with the associated fire severity.

Figure 14—Home site where a structure was destroyed in Tom's Ranch (Forest Road 200). The ignition cause was designated as surface fire and/or firebrand.

Figure 15—Home destroyed in Tom's Ranch (Forest Road 200); ignition cause was designated as torching/crown fire. Note the unburned tree canopies scattered throughout the area.

Thunder Butte Subdivision/Bell Rock

This assessment group consists of seven homes in Thunder Butte Subdivision, one home on the east side of State Highway 67, and three homes south and west of Bell Rock along Bell Rock Road (fig. 16). The GAI was high and the SSI was high to moderate in the Thunder Butte area (fig. 17, 18). The GAI was high to moderate and the SSI was moderate to low in the Bell Rock Area (fig. 19).

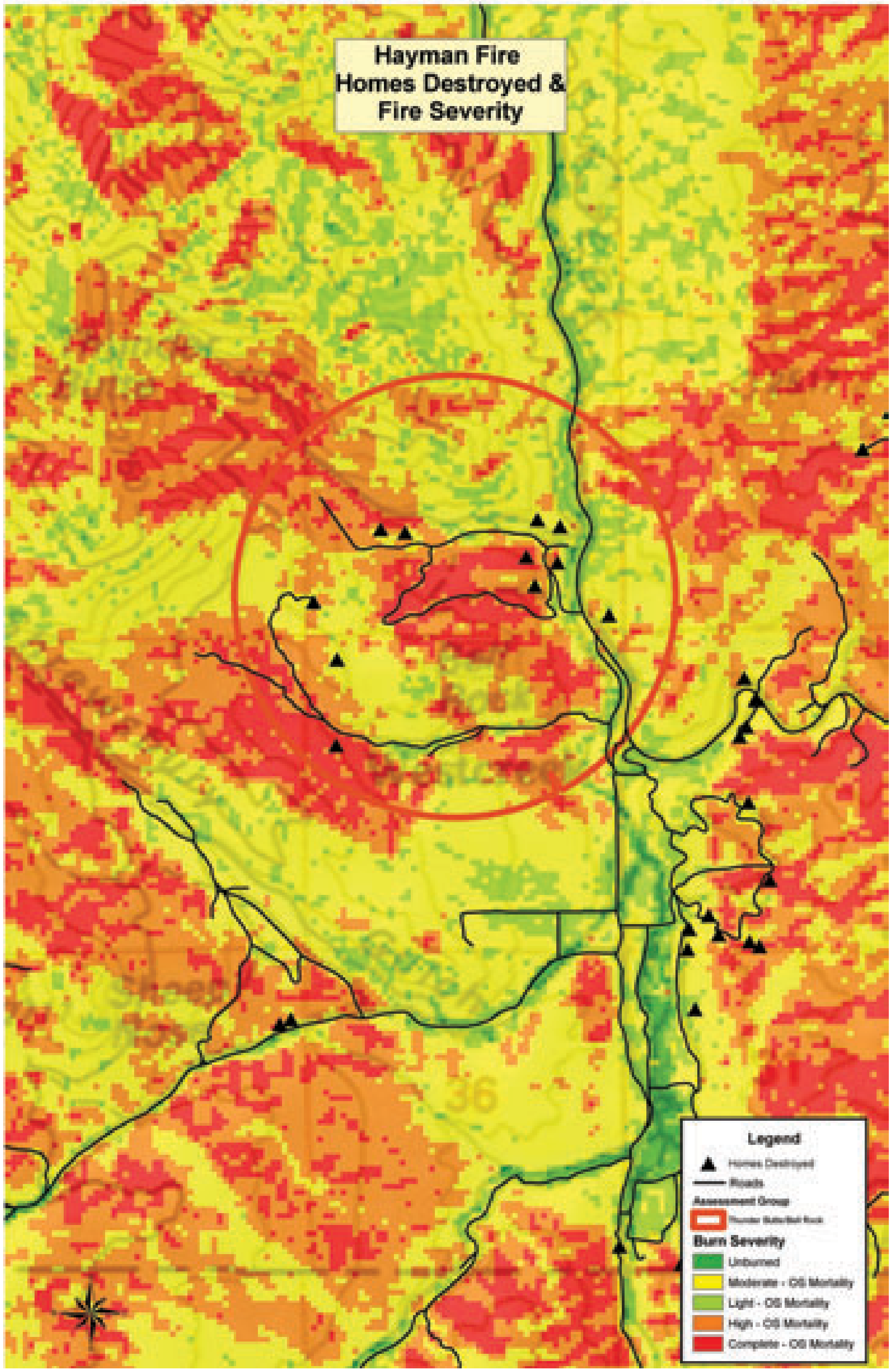

Figure 16—Thunder Butte Subdivision/Bell Rock assessment group with the associated fire severity.

Figure 17—Aerial photograph looking west through the Thunder Butte Subdivision with Bell Rock (top left) and the east face of the Thunder Butte bowl (top right).

Figure 18—Destroyed home in the Thunder Butte Subdivision designated as torching/crown fire cause. The garage is in the foreground and the home is in the background. The trees in the immediate vicinity were severely burned by the structure fire.

Figure 19—This home, southwest of Bell Rock, was designated as destroyed by surface fire and/or firebrand. (Photograph by Jeff DePooter)

Turkey Rock Ranch

Twenty-eight homes in Turkey Rock Ranch were destroyed (fig. 20, 21). Homes on the north and east side of the subdivision experienced moderate to low GAI and SSI (fig. 22); however, the GAI on the south and west sides were high with the SSI high to moderate (fig. 23).

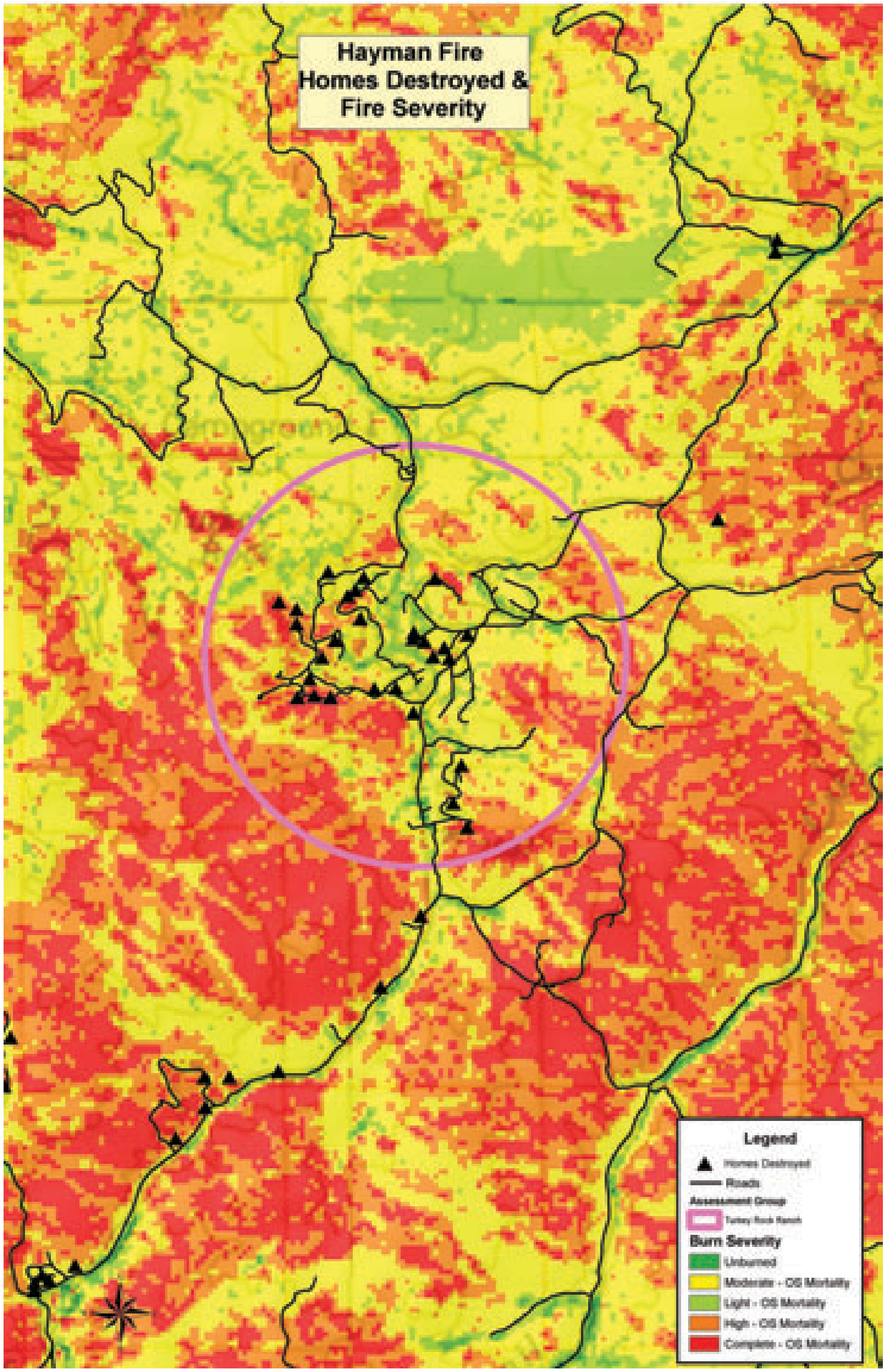

Figure 20—The Turkey Rock Ranch assessment group with the associated fire severity.

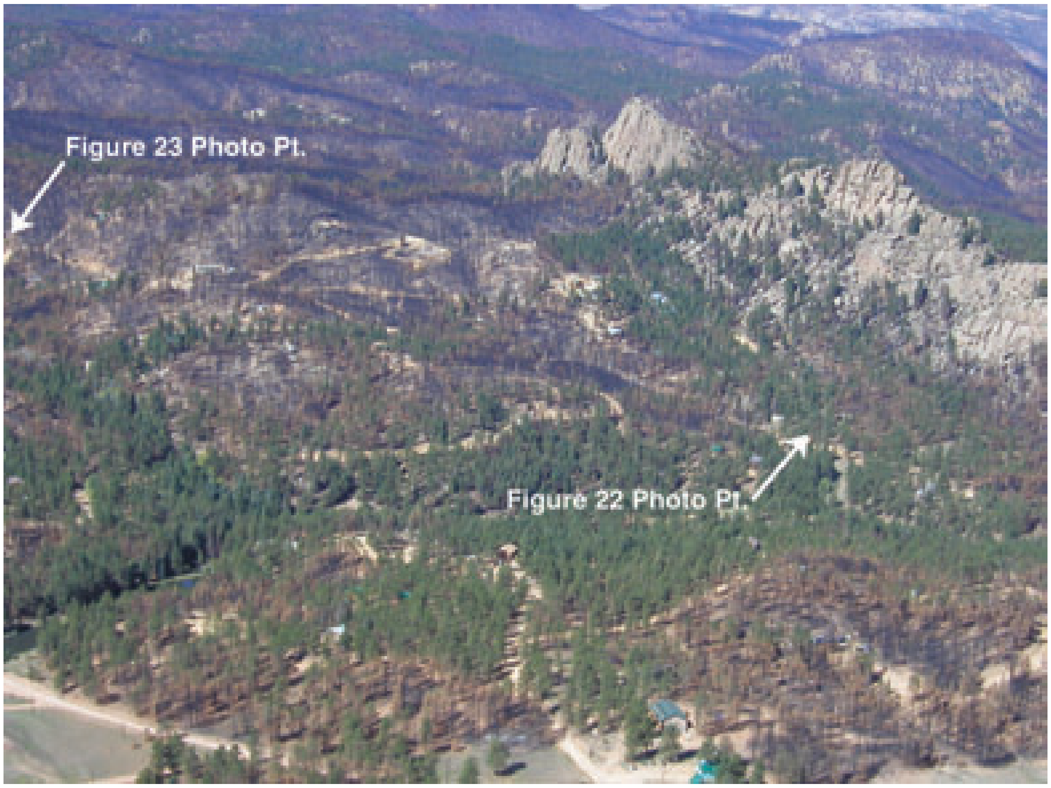

Figure 21—Aerial photograph showing the Turkey Rock Ranch area looking west-northwest. Note the unburned homes scattered throughout the lower two-thirds of the photo.

Figure 22—Home in Turkey Rock Ranch designated as destroyed by surface fire and/or firebrand.

Figure 23—This home in Turkey Rock Ranch was designated as destroyed by torching/crown fire.

Lost Valley/Wildhorn Ranch

This assessment group consists of the homes along Lost Valley Ranch Road (County Road 33), Wildhorn Ranch Subdivision, and the Wildhorn Lodge (fig. 24). The GAI and the SSI in Lost Valley was high to moderate (fig. 25). The Wildhorn Ranch Subdivision (fig. 26) and Wildhorn Lodge (fig. 27) experienced high GAI and high to moderate SSI.

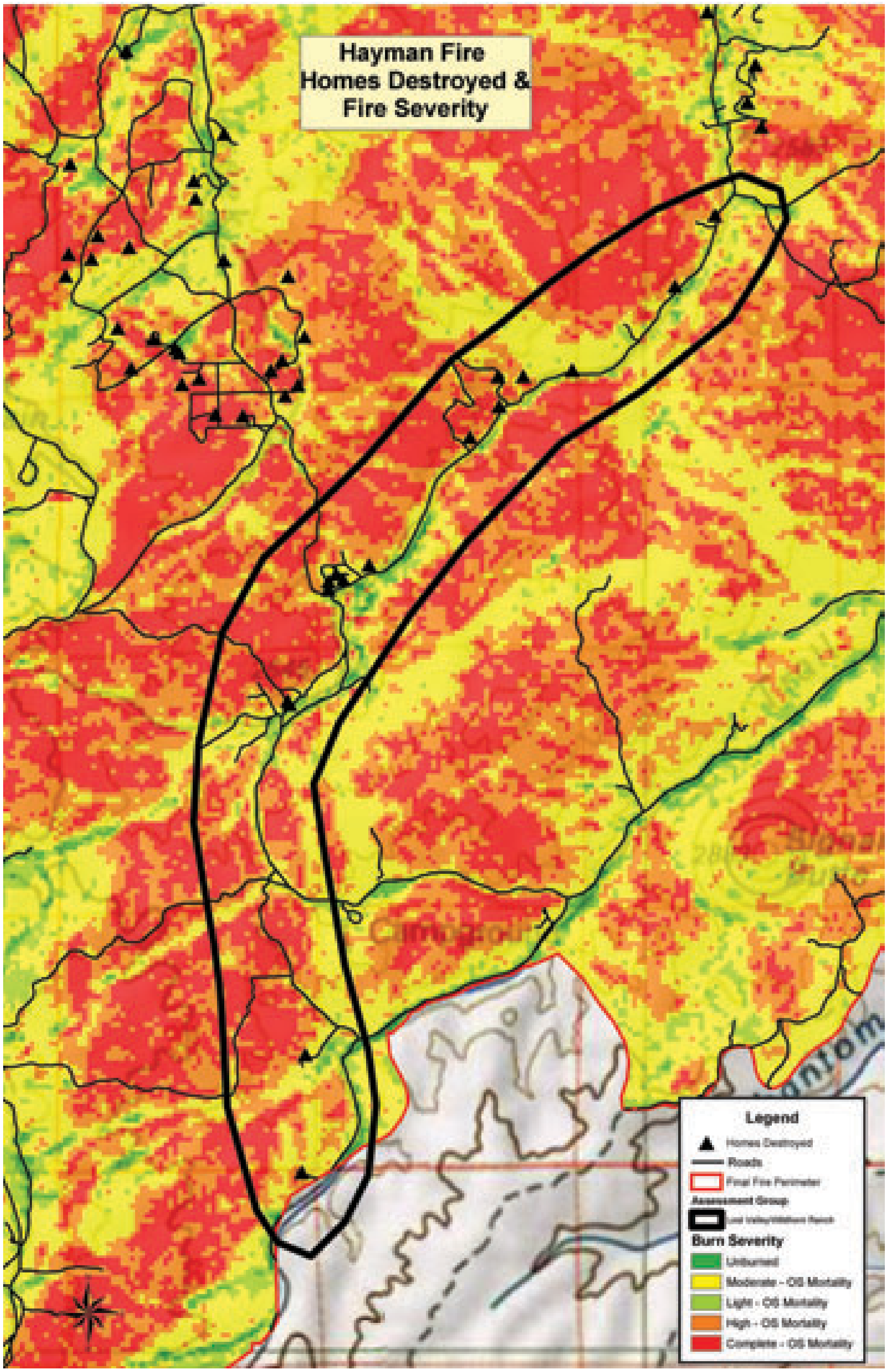

Figure 24—The Lost Valley/Wildhorn Ranch assessment group displayed in association with the fire severity.

Figure 25—Aerial photograph of a home in Lost Valley Ranch designated as destroyed by torching/crown fire. Note the unburned vegetation immediately adjacent to the home on the right as well as other unburned vegetation.

Figure 26—Aerial photograph looking southwest at the Wildhorn Ranch Subdivision.

Figure 27—This aerial photo shows the Wildhorn Lodge and guest home. These structures were designated as destroyed by torching/crown fire.

West Creek Lakes/Stump Road/County Road 78

This assessment group consists of homes along County Road 78, including the Painted Rocks area, three homes along State Highway 67, homes along Stump Road (County Road 68), and the West Creek Lakes community (fig. 28). Homes along County Road 78 (fig. 29, 30) and State Highway 67 (fig. 31) experienced high GAI but moderate and low SSI. The four homes along Stump Road experienced high to moderate GAI and SSI (fig. 32). Homes in West Creek Lakes experienced high to moderate GAI and moderate to low SSI (fig. 33 through 35).

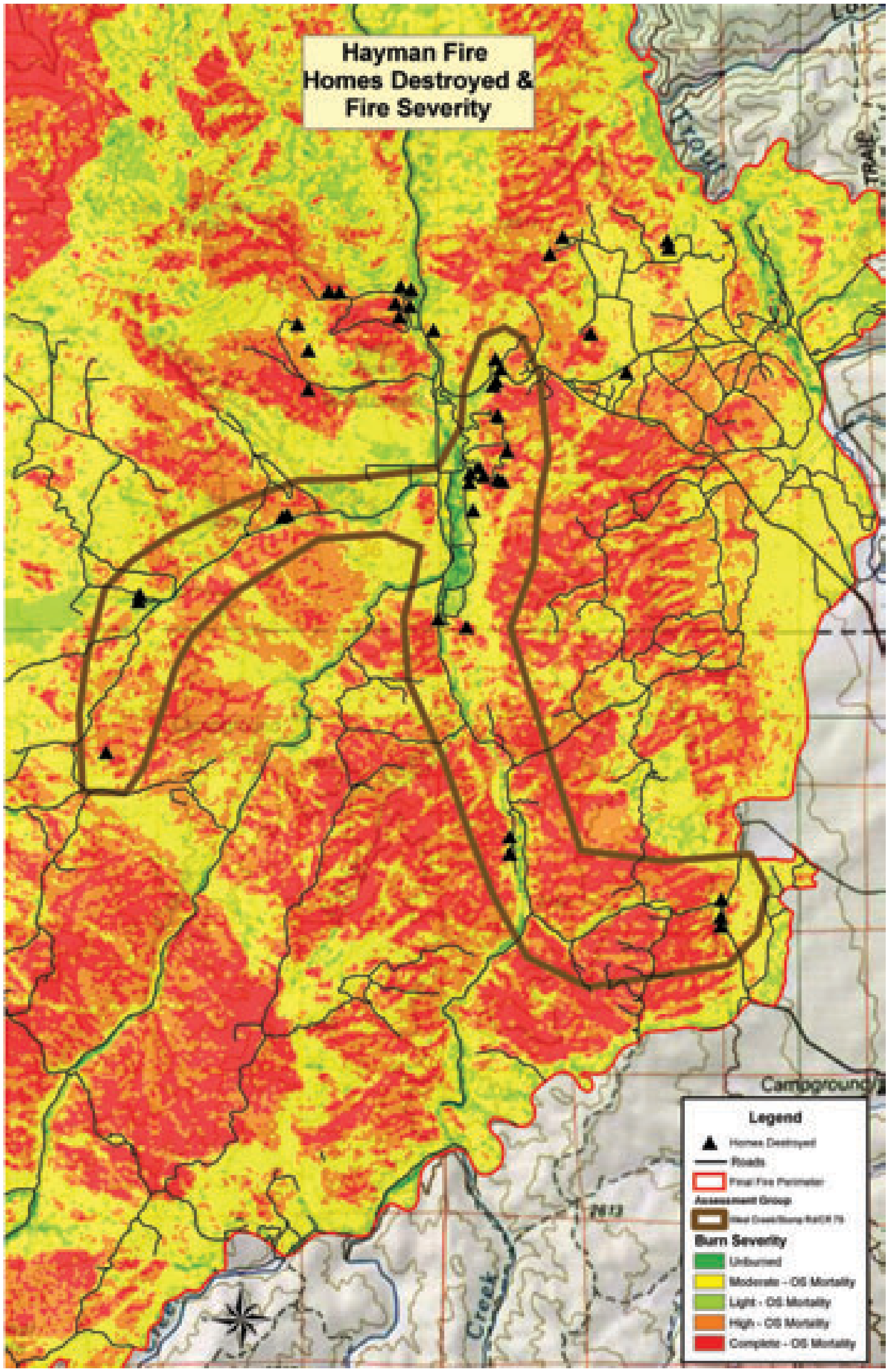

Figure 28—The West Creek Lakes assessment group displayed in association with the fire severity.

Figure 29—Aerial photograph looking west-southwest showing a home destroyed along County Road 78. The ignition cause was designated as torching/crown fire.

Figure 30—Aerial photograph showing two homes (circled areas) destroyed along County Road 78 (Painted Rocks area). The ignition cause was designated as surface fire and/or firebrand.

Figure 31—This view looking to the south shows a destroyed home along State Highway 67. Although the crown fire crested the ridge, the home is surrounded by unconsumed vegetation (albeit killed), indicating that the crown fire did not directly ignite this home.

Figure 32—The homes in this scene (circled) along County Road 68 (Stump Road) were designated as destroyed by torching/crown fire. The home farthest away in the view is being rebuilt.

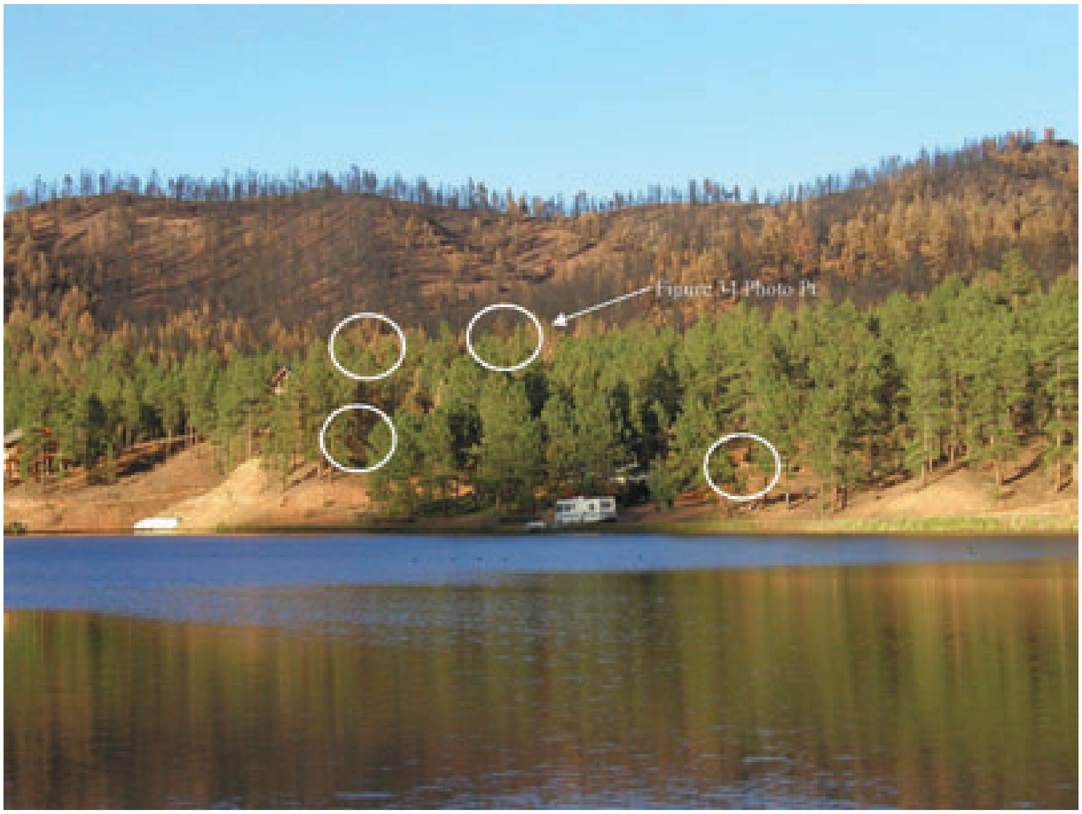

Figure 33—This view looking east in West Creek Lakes shows homes (circled) destroyed by surface fire and/or firebrands.

Figure 34—Surface fire and/or firebrands destroyed this home in West Creek Lakes.

Figure 35—This home in West Creek Lakes was designated as destroyed by torching/crown fire.

Trout Creek Ranch

Six homes were burned in the Trout Creek Ranch area (fig. 36). All but one of the homes were on cul-de-sacs and experienced moderate to high GAI and high to moderate SSI (fig. 37, 38). The one exception was a home on Trout Creek that experienced moderate to low GAI and SSI (fig. 39).

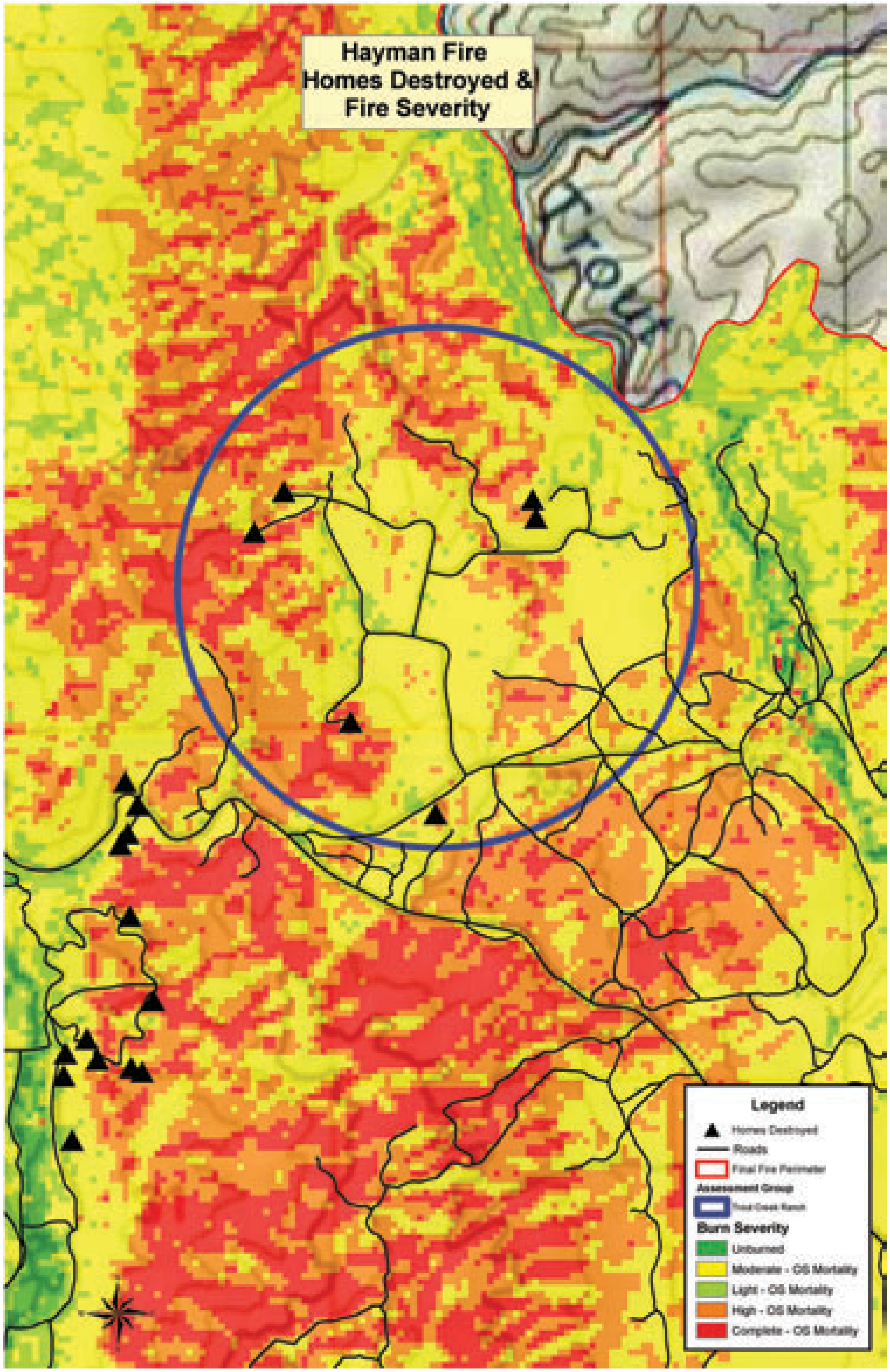

Figure 36—Trout Creek Ranch assessment group displayed in associated with the fire severity.

Figure 37—View of the west side of Trout Creek Ranch looking northwest toward two homes destroyed on a cul-de-sac.

Figure 38—These homes on the east side of Trout Creek Ranch were designated as destroyed by torching/crown fire.

Figure 39—This home, on the south side of Trout Creek Ranch, was designated as destroyed by surface fire and/or firebrand.

References

Cohen, Jack D. 2000. Preventing disaster: home ignitability in the wildland-urban interface. Journal of Forestry 98(3): 15-21.

National Fire Protection Agency (NFPA). 1991. *Protection of Life and Property from Wildfire*. NFPA 299.

Postfire Rehabilitation of the Hayman Fire

Peter Robichaud, Lee MacDonald, Jeff Freeouf, Dan Neary, Deborah Martin, Louise Ashmun

Introduction

Our team was asked to analyze and comment on the existing knowledge and science related to postfire rehabilitation treatments, with particular emphasis on the known effectiveness of these treatments. The general effects of fire on Western forested landscapes are well documented (Agee 1993; DeBano and others 1998; Kozlowski and Ahlgren 1974) and have been thoroughly discussed in other chapters of this report. However, postfire erosion and rehabilitation treatment effectiveness have not been studied extensively.

The first part of this chapter describes the postfire conditions, as identified by the Burned Area Emergency Rehabilitation (BAER) team, and the subsequent BAER team recommendations for rehabilitation treatment. The next sections describe the different treatments, where they were applied on the Hayman Fire burn area, and the current knowledge of treatment effectiveness. The recommendations for monitoring treatment effectiveness will answer the specific question, "What types of monitoring protocol and reports should Forest Service and other jurisdictions put in place to continue to learn from this fire?" and outline a general process for monitoring postfire rehabilitation efforts. This is followed by a description of the sites currently established within the Hayman Fire burned area to evaluate the effectiveness of various rehabilitation treatments. The need to establish control sites (burned but not treated) to provide a basis for comparison and monitor natural recovery is also discussed. The final section identifies the knowledge gaps that need to be addressed to guide the selection of postfire rehabilitation treatments on future fires in the Colorado Front Range and similar environments.

BAER Team Report of Postfire Conditions and Predictions for the Hayman Fire Area

The Burned Area Report filed by the BAER team describes the hydrologic and soil conditions in the Hayman Fire area as well as the predicted increase in runoff, erosion, and sedimentation. The predictions were then evaluated in combination with both the onsite and downstream values at risk to determine the selection and placement of emergency rehabilitation treatments (USDA Forest Service 2002). The BAER team used data from nearby fires, erosion prediction tools, and professional judgment to make these predictions and recommendations.

Burn Severity

The BAER team burn severity map was derived from a Spot 4 satellite image and is based primarily on overstory tree mortality (fig. 1). However, burn severity is the result of several interacting variables that are reflected to varying degrees in the overstory tree mortality. Hungerford (1996), building on earlier work by Ryan and Noste (1983), developed a general burn severity classification based on the postfire appearance of litter and soil (table 1). In the Hayman Fire area, there are many areas where the ground conditions reflect moderate burn severity in Hungerford's scheme while the overstory, with all the twigs and needles consumed, reflects a high severity burn. This is less problematic than it might first appear, as the lack of needlecast indicates: (a) minimal protection of soil particles to detachment by rainsplash and overland flow; (b) no needles to moderate surface soil temperatures and facilitate soil moisture storage (which may lead to longer revegetation recovery times); and (c) no needles to immediately add organic matter. The lack of needles, combined with a thin but strong water repellent surface layer, will likely lead to rapid runoff and substantial soil erosion during intense storms.

The BAER team did considerable ground truthing to compare ground cover and soil conditions with canopy conditions before deciding that the satellite burn severity map, while based on overstory effects, is roughly aligned with the expected hydrologic and erosion response. Given the lack of time and resources to develop more detailed or direct evaluation of soil conditions, the burn severity map created from satellite data is a

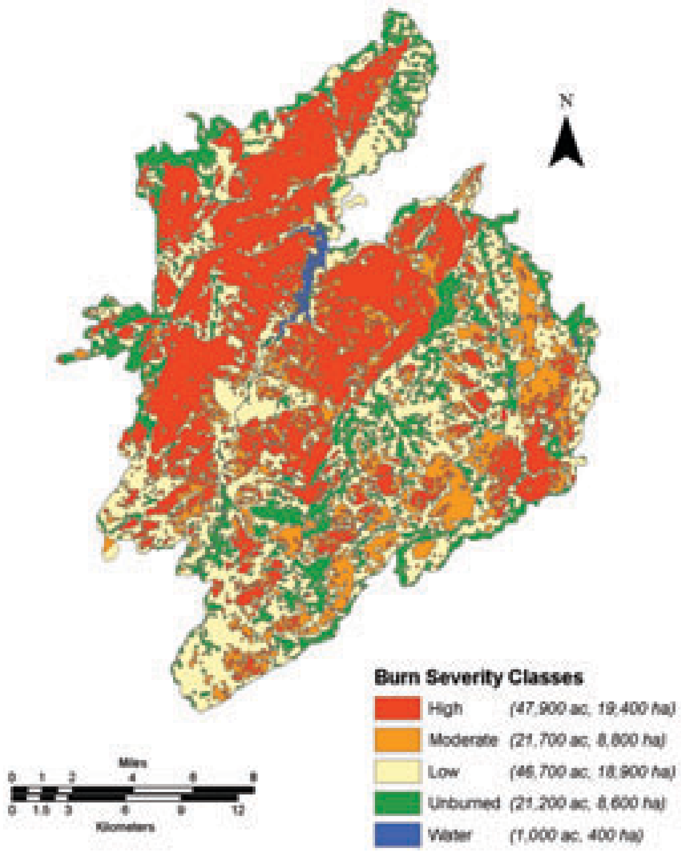

Figure 1—The burn severity map of the Hayman Fire area as developed by the BAER Team.

reasonable tool for evaluating postfire conditions, predictive modeling, and recommending rehabilitation treatments (fig. 1). From this image, the BAER team classified approximately 48,000 acres (35 percent) as high severity, 22,000 acres (16 percent) as moderate severity, 47,000 acres (34 percent) as low severity, and 21,000 (15 percent) as unburned. The team also decided that moderate severity burn areas would respond to future rain events in much the same way as high severity burn areas; consequently, 50 percent of the moderate severity burn areas were considered for postfire rehabilitation treatment.

Hydrology

Soils, vegetation, and litter are critical to the functioning of hydrologic processes. Forested watersheds with good hydrologic conditions (greater than 75 percent of the ground covered with vegetation and litter) sustain stream baseflow conditions for much or all of the year and produce little sediment. Under these conditions 2 percent or less of the rainfall becomes surface runoff, and erosion is low (Bailey and Copeland 1961). Fire can destroy the accumulated forest floor layer and vegetation and greatly alter infiltration rates by exposing soils to raindrop impact and creating water repellent conditions (DeBano and others 1998). Severe fires may create poor hydrologic conditions (less than 10 percent of the ground surface covered with plants and litter); surface runoff can increase over 70 percent; and erosion can increase by three orders of magnitude (DeBano and others 1998). Poor hydrologic conditions are likely to occur in any area with high, or in some cases moderate, burn severity. Given that 35 percent of the Hayman Fire area was classified high burn severity and another 16 percent was classified moderate burn severity, poor hydrological conditions can exist in approximately half of the burned area.

In the Intermountain West, high-intensity, short-duration rainfall is relatively common (Farmer and Fletcher 1972). After fires such storms have been shown to generate high stream peakflows and high erosion rates (DeBano and others 1998; Neary and others 1999; Moody and Martin 2001a). Thirty-minute rainfall intensities (I_{30}) greater than 0.4 inches per hour (10 mm per hour) exceeded the average infiltration rate and caused surface runoff after the Buffalo Creek Fire (Moody and Martin 2001a) and the Bobcat

Table 1—Burn severity classification based on postfire appearances of litter and soil and soil temperature profiles (Hungerford 1996; DeBano and others 1998).

	Burn severity		
Soil and litter parameter	**Low**	**Moderate**	**High**
Litter	Scorched, charred, consumed	Consumed	Consumed
Duff	Intact, surface char	Deep char, consumed	Consumed
Woody Debris - Small	Partly consumed, charred	Consumed	Consumed
Woody Debris - Logs	Charred	Charred	Consumed, deep char
Ash Color	Black	Light colored	Reddish orange
Mineral Soil	Not changed	Not changed	Altered structure, porosity, etc
Soil Temp. at 0.4 in (1 cm)	<120 °F (<50 °C)	210-390 °F (100-200 °C)	>480 °F (>250 °C)
Soil Organism Lethal Temp.	To 0.4 in (1 cm)	To 2 in (5 cm)	To 6 in (16 cm)

Fire (Kunze 2003) in the Colorado Front Range. The loss of ground cover, combined with water repellent soils, will cause flood peaks to arrive faster, rise to higher levels, and entrain significantly greater amounts of bedload and suspended sediments. The thunderstorms that produce these rainfall intensities may be quite limited in extent but can produce profound localized flooding effects (Moody and Martin 2001a, Kunze 2003). Observations to date indicate that flood peakflows after fires in the Western United States can range up to three orders of magnitude greater than prewildfire conditions (table 2). As a result of the Hayman Fire, peak flows within the watersheds covered by the burned area are expected to occur more rapidly and be much greater than prefire magnitudes, but specific amounts are difficult to predict and will vary with the magnitude and season of the individual storm event.

Runoff Modeling

The BAER team predicted runoff volumes by applying the National Resource Conservation Service (NRCS) curve number model to a design storm. The resulting runoff depths were converted to runoff by using the triangular unit hydrograph model on each watershed. This approach did not involve any channel routing (Hawkins and Greenberg 1990).

Design Storm and Runoff Predictions—The design storm selected to evaluate prefire and postfire runoff was the 25-year, 1-hour storm over an area of 5.0 mi^2 (13 km^2). The predicted precipitation for this event is 1.0 inch (25 mm) in 1 hour. The distribution of rainfall intensities over the 1-hour period (33 percent of the rain falls in the first 5 minutes with declining intensity for the rest of the hour) was based on local information of short duration rainfall relations (Arkell and Richards 1986). This results in a design storm that looks like a typical summer thunderstorm for the Hayman region (fig. 2).

The runoff WILDCAT4 model (Hawkins and Greenberg 1990) was used by the BAER team to estimate pre- and postfire runoff hydrographs from 84 watersheds (average size 3 mi^2, 7.8 km^2). The assumed curve numbers to predict runoff volumes for various watershed conditions were: rock = 90, unburned = 80, low severity = 85, and moderate and high severity = 95 (Kuyumjian and others 2002).

The models were applied to the 84 watersheds, and substantial increases in peak flow events were predicted for those watersheds where a high percentage of the area was burned at moderate to high severity. The average prefire predicted peak flow was 75 cfs mi^{-2} (0.8 $m^3 s^{-1} km^{-2}$) and the predicted postfire peak flow was 290 cfs mi^{-2} (3.1 $m^3 s^{-1} km^{-2}$). The distribution of postfire predicted peak flows shows half of the watersheds falling between 100 to 300 cfs mi^{-2} (1.1 to 3.3 $m^3 s^{-1} km^{-2}$). Thirty-one of the 84 watersheds were above this range with predicted peak flows from 10 watersheds exceeding 500 cfs mi^{-2} (5.4 $m^3 s^{-1} km^{-2}$) and three of these exceeding 600 cfs mi^{-2} (6.5 $m^3 s^{-1} km^{-2}$) (fig. 3). Average predicted peak flows were nearly 300 cfs mi^{-2} (3.3 $m^3 s^{-1} km^{-2}$) for three main areas of the fire: (1) upstream of Cheesman Reservoir, (2) downstream of Cheesman on the west side of the South Platte River, and (3) downstream of Cheesman on the east side of the South Platte River (fig. 4 and table 3) (Kuyumjian and others 2002).

Model Validation—The design storm for the Hayman Fire has an I_{30} of 1.7 inch per hour (43 mm per hour), which is similar to the higher intensities recorded by Moody and Martin (2001a) after the Buffalo Creek Fire. An I_{30} of 2.0 inch per hour (50 mm per hour) yielded 480 cfs mi^{-2} (5.2 $m^3 s^{-1} km^{-2}$) and an I_{30} of

Table 2—Peakflow responses to wildfires in conifer forest habitats. The areas most similar to the Hayman Fire area are indicated in bold print (after Robichaud and others 2000).

Location	Treatment	Peakflow increase factor	Reference
Ponderosa pine, AZ	Wildfire	+5 Summer +15 Summer +10 Fall +0 Winter	Rich 1962
Ponderosa pine, AZ	Wildfire	+96	Campbell and others 1977
Ponderosa pine, AZ	Wildfire, Moderate Wildfire, Severe	+23 +406	DeBano and others 1996
Ponderosa pine, NM	Wildfire	+160	Bolin and Ward 1987
Mixed Conifer, AZ	Wildfire	+7	Neary and Gottfried 2001
Mixed Conifer, CO	**Wildfire**	**+140**	**Moody and Martin 2001**
Mixed Conifer, CO	**Wildfire**	**+10**	**Kunze 2003**

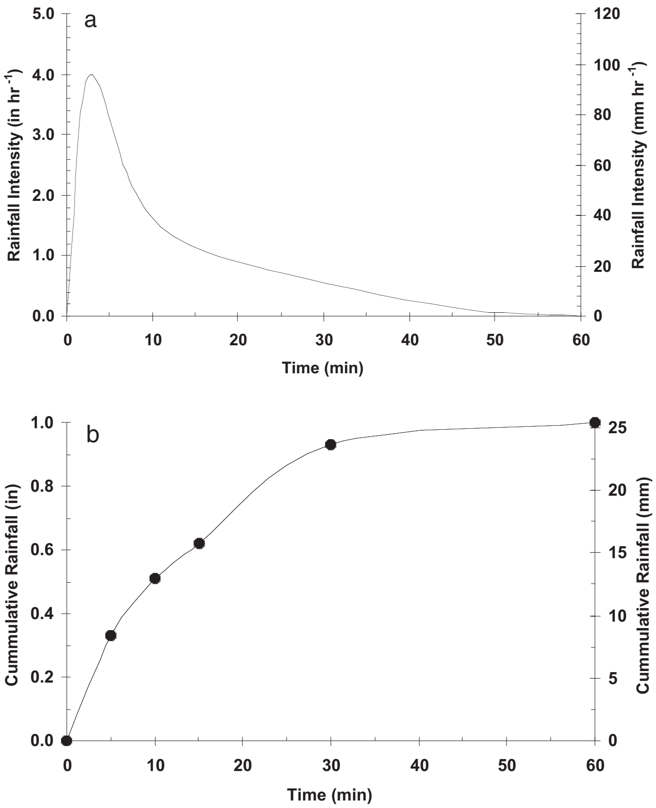

Figure 2—In order to model typical convective storm events and predict subsequent runoff, the BAER Team used NOAA Atlas #2 and rainfall data to develop the design storm of 1.0 inch (25 mm) in 1 hour. (a) Design storm intensity over time. (b) Cumulative rainfall over one hour. [Note: 33 percent of the total rain falls in the first 5 minutes and over 90 percent falls in the first 30 minutes]

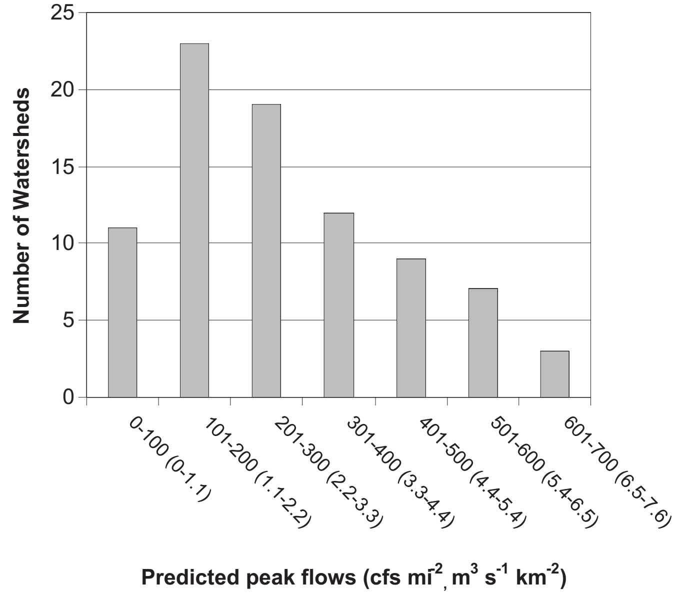

Figure 3—Distribution of predicted peak flows for the 84 watersheds within the Hayman Fire area for a design storm of 1.0 inch (25 mm) in 1 hour.

1.8 inch per hour (45 mm per hour) yielded 300 cfs mi^{-2} (3.2 m^3 s^{-1} km^{-2}) 2 years after the fire (Moody and Martin 2001a). The WILDCAT4 model used in the Hayman Fire area predicted unit area flows that are consistent with measured precipitation events and the resulting runoffs from the Buffalo Creek Fire (Kuyumjian and others 2002).

Soils

The landforms of the Hayman Fire area are dominantly steep mountain slope lands (15 to 80 percent) in highly dissected V-shaped valleys. Douglas fir (*Pseudotsuga menziesii*)/mountain muhly (*Muhlenbergia montana*) and ponderosa pine (*Pinus ponderosa*)/slimstem muhly (*Muhlenbergia filiformis*) are the dominant vegetation types. The parent material on the Hayman Fire area is Pikes Peak granite, which

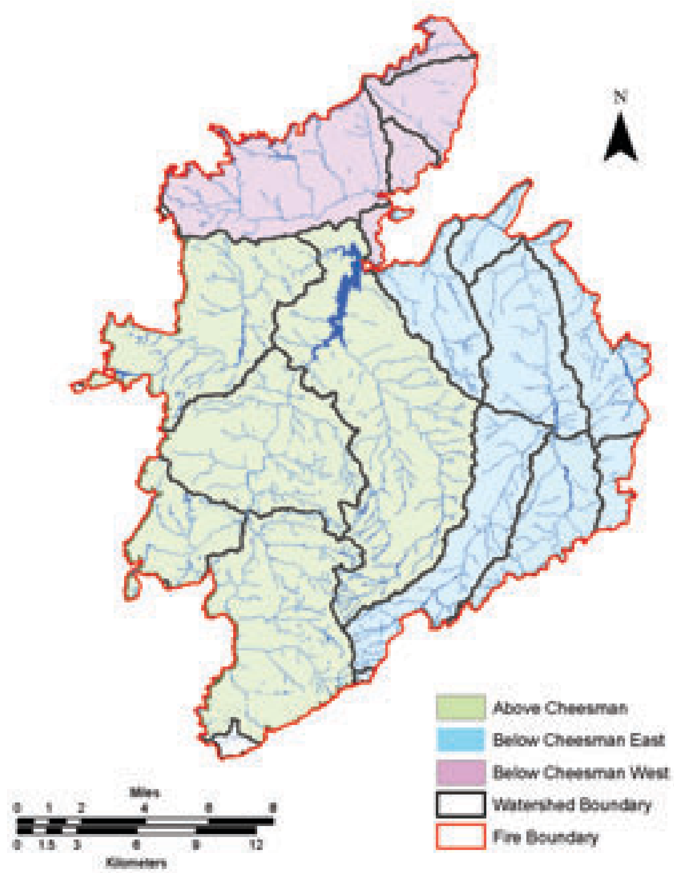

Figure 4—The three general areas used by the BAER team to determine potential postfire runoff and sediment delivery.

Table 3—Average predicted postfire peakflows from a design storm of 1.0 inch (25 mm) in 1 hour as modeled by the Hayman Fire BAER Team.

General area description	Average watershed size[a]		Average predicted peakflow	
	mi^2	*km*^{2}	*cfs mi*$^{-2}$	*m*^{3}*s*$^{-1}$ *km*$^{-2}$
Above Cheesman Reservoir	3.2	(8.3)	290	(3.2)
Below Cheesman Reservoir (West)	3.1	(8.1)	292	(3.2)
Below Cheesman Reservoir (East)	2.4	(6.2)	297	(3.2)

[a] Average size of modeled watershed within the selected area.

weathers to fine gravel and coarse sand in the soil profile. The coarse-textured parent material provides a moderately acidic substrate for soil development. The soils developed from Pikes Peak granite are highly susceptible to erosion, sheetwash, rilling and gullying (John 2002).

The soils in the area consist predominantly of two soil series, Sphinx and Legault. Rock outcrops (15 percent of the total area) dominate in some areas, and alluvial soils are found in most valley bottoms. The Sphinx soils are coarse-textured, shallow and somewhat excessively drained. The surface layer is gravelly coarse sandy loam. Permeability is rapid, and the available water capacity is low. Runoff is moderate to rapid, and the hazard of water erosion is moderate to severe depending on slope. The Legault soils are dark grayish brown, very gravelly coarse sandy loam. It is found on north-facing aspects and at higher elevations. Permeability is moderately rapid, and the available water capacity is very low. Runoff is rapid, and the hazard of erosion is moderate to severe depending on slope (John 2002).

Erosion

Nearly all fires increase sediment yield, but wildfires in steep terrain produce the greatest amounts (12 to 165 t ac^{-1}, 28 to 370 Mg ha^{-1}) (table 4). Postfire channel incision and gully formation can be important sources of sediment in the Colorado Front Range (Moody and Martin 2001a). Field studies initiated after the Hayman Fire are showing that the increase in surface runoff has led to channel initiation in formerly unchannelled swales as well as incision and gullying in existing channels (Libohova and MacDonald 2003). Hence, a full evaluation of the effects of wildfires on erosion rates includes an assessment of both hillslope erosion rates and changes in the extent and size of the stream channel network. The data and models needed to predict channel incision and erosion are not currently available, so this component was not

Table 4—First-year sediment losses after wildfires in conifer forest habitats (after Robichaud and others 2000).

Location	Treatment	Sediment loss		Reference
		t ac^{-1}	*Mg ha*$^{-1}$	
Ponderosa Pine, AZ	Control	0.001	0.003	Campbell and others 1977
	Wildfire	0.6	1.3	
Ponderosa Pine, AZ	Wildfire, Low	0.001	0.003	DeBano and others 1996
	Wildfire, Moderate	0.009	0.02	
	Wildfire, Severe	0.7	1.6	
Mixed Conifer, AZ	Control	<0.0004	<0.001	Hendricks and Johnson 1944
	Wildfire, 43% Slope	32	72	
	Wildfire, 66% Slope	90	200	
	Wildfire, 78% Slope	165	370	
P. pine/Doug. fir, ID	Wildfire	4	9	Noble and Lundeen 1971
P. pine/Doug. fir, ID	Clearcut and Wildfire	92	210	Megahan and Molitor 1975
P. pine/Doug. fir, OR	Wildfire, 20 % Slope	0.5	1.1	Robichaud and Brown 1999
	Wildfire, 30 % Slope	1.0	2.2	
	Wildfire, 60 % Slope	1.1	2.5	
Ponderosa Pine, CO	Wildfire, 25 to 43 % Slope	3 to 4	8 to 10	Benavides-Solorio 2003

included in the postfire predictions from the BAER team.

Hillside erosion rates are also difficult to predict with accuracy. Studies and observations indicate that high severity fires in the Colorado Front Range can greatly increase runoff and erosion rates (Morris and Moses 1987; Moody and Martin 2001a; Benavides-Solorio 2003). However, these rates are highly variable. Soil erosion after prescribed burns has been shown to vary from under 0.4 to 2.6 t ac^{-1} yr^{-1} (1 to 6 Mg ha^{-1} yr^{-1}), and in wildfires from 0.2 to over 49 t ac^{-1} yr^{-1} (0.4 to over 110 Mg ha^{-1} yr^{-1}) (Megahan and Molitor 1975; Noble and Lundeen 1971; Robichaud and Brown 2000) (table 4). There are few data available describing the controlling factors that account for the magnitude of runoff and erosion increases, or the rate at which the elevated processes recover to background levels, although this situation is beginning to change (Benavides-Solorio and MacDonald 2001; Benavides-Solorio 2003).

Existing data and observations indicate that erosion on burned areas typically declines in subsequent years. After a wildfire in eastern Oregon, Robichaud and Brown (2000) reported first-year erosion rates of 0.5 to 1.1 t ac^{-1} (1.1 to 2.5 Mg ha^{-1}), decreasing by an order of magnitude in the second year, and to no sediment by the fourth year. Erosion rates from high severity sites in the Buffalo Creek Fire declined to background levels within 3 years (Moody and Martin 2001b). Benavides-Solorio (2003) indicates erosion rates on the Colorado Front Range should recover in 4 to 6 years. To help limit damage to soil and watershed resources, postfire rehabilitation treatments that reduce erosion in the first years are important.

Given the uncertainties in predicting postfire erosion, the BAER team used erosion data from the nearby Turkey Creek and Buffalo Creek Fires to estimate the postfire erosion rate for the areas burned at moderate and high severity. The Water Erosion Prediction Project (WEPP) model, as modified for disturbed forest land (Elliot and others 2001), was used to predict the erosion rates for the low severity and unburned areas. Field assessments were used to verify the conditions and assumptions used in the modeling. The resulting predicted first year erosion rates for each burn severity class is shown in table 5. The estimated first year erosion rate by the BAER team for the Hayman Fire area is 43 t ac^{-1} (96 Mg ha^{-1}), based on a weighted average of the erosion rates by severity class and acreage in each group (John 2002).

Water Quality and Sedimentation

The South Platte River flows from southwest to the northeast through the interior of the Hayman Fire burn area. Eleven sixth-level watersheds were affected by the fire (fig. 4). The typical drainage area of a sixth-level stream is 10,000 to 30,000 acres (4,000 to 12,000 ha) and these include perennial tributaries such as Brush Creek, Fourmile Creek, Goose Creek, Horse Creek, Saloon Creek, Turkey Creek, West Creek, and Wigwam Creek. Cheesman Reservoir is a major impoundment on the South Platte River near the center of the burn. Strontia Springs Reservoir is another impoundment on the South Platte River downstream of the burned area. The Denver Water Board owns and operates these reservoirs as water supply facilities for the Denver metropolitan area. Approximately 44 percent of the burned area drains into the South Platte River downstream of Cheesman Reservoir, while roughly 56 percent of the burned area drains directly into Cheesman Reservoir or the South Platte River upstream of the reservoir.

During postfire storm events in August and September 2002, organic carbon, ash, and sediment increases occurred within several smaller drainage basins as well as within the South Platte River above and below Cheesman Reservoir. The first postfire storms mobilized sediment, which will continue to be mobilized with successive events.

The sediment delivery potential in the Hayman Fire area is based on postfire monitoring of the Buffalo Fire (Moody and Martin 2001a), which demonstrated that approximately 15 ac-ft (24,000 yd^3, 18,500 m^3) of sediment was delivered to Strontia Springs Reservoir for each square mile of burned area over the 5 years following the fire. This value—15 ac-ft mi^{-2} (24,000 yd^3 mi^{-2}or 71,000 m^3 km^{-2}) over the 5-year recovery

Table 5—Predicted first-year erosion rates by burn severity class as determined by the Hayman Fire BAER team.

Burn severity	Area			Erosion rate	
	acres	*ha*	*percent*	*tons/acre^{-1}*	*Mg/ha^{-1}*
Unburned	21,200	(8,600)	15	0.5	(1.1)
Low	46,700	(18,900)	34	22	(50)
Moderate	21,700	(8,800)	16	70	(160)
High	47,900	(19,400)	35	70	(160)

period—provides an upper bound for sediment export because Buffalo Creek runoff and sediment transport were influenced by an extreme precipitation event immediately after the fire. Given the Hayman Fire area of approximately 137,600 acres (215 mi^2 or 560 km^2) the potential upper bound of sediment volume delivered to streams may be as great as 3,500 ac-ft (5.6 million yd^3, 4.3 million m^3) over the 5-year recovery period (USDA Forest Service 2002).

The sediment delivery potential was estimated for the three main areas of the burn: (1) the area upstream of Cheesman Reservoir dam; (2) the watershed area downstream of Cheesman on the west side of the South Platte River; and (3) the watershed area downstream of Cheesman on the east side of the South Platte River (table 6 and fig. 4). Assuming a 5-year sediment yield of 15 ac-ft mi^{-2} (24,000 yd^3 mi^{-2}, 71,000 m^3 km^{-2}), approximately 1,500 ac-ft (2.4 million yd^3, 1.8 million m^3) of sediment could enter the South Platte River below Cheesman Reservoir over the 5 years. Potentially, 1,950 ac-ft (3.1 million yd^3, 2.4 million m^3) of sediment could enter the South Platte River and Cheesman Reservoir above the dam during the 5-year recovery period (USDA Forest Service 2002).

Cheesman Reservoir does not appear to be at risk to filling in with sediment. The maximum expected sediment delivery to Cheesman Reservoir over the first 5 years following the fire is 1,950 ac-ft (3.1 million yd^3 or 2.4 million m^3). Since the storage capacity of Cheesman Reservoir is approximately 79,800 ac-ft (130 million yd^3, 98 million m^3), the sediment delivered as the result of the Hayman Fire should be less than 3 percent of the reservoir storage capacity.

The storage capacity of Strontia Springs Reservoir is about 7,600 acre-ft (12.3 million yd^3 or 9.4 million m^3). A maximum of about 1,500 acre-ft (2.5 million yd^3, 1.9 million m^3) of sediment could enter the South Platte River below Cheesman; however, only a portion of that is expected to be routed directly to Strontia Springs Reservoir. The South Platte River flows for approximately 20 to 25 miles (32 to 40 km) from Cheesman Reservoir downstream to Strontia Springs, and it is a relatively low gradient meandering stream with a fair amount of in-channel and near-channel sediment storage capacity. This section of the river should reduce the amount of sediment that is delivered to Strontia Springs Reservoir. However, other large fires (Buffalo Creek, 1996; Hi Meadow Fire, 2000; Schoonover, 2002) have occurred in this drainage over the last 6 years, contributing significant sediment to this reservoir. Strontia Springs Reservoir was being dredged because of excess sedimentation when the Hayman Fire occurred (USDA Forest Service 2002).

Risk Assessment

The values at risk as identified by the BAER Team include the following:

Increased Flood Flows—Stream flows will increase after the fire due to a combination of the loss of ground cover, decreased infiltration, a reduction in evapotranspiration, reduced water storage within the soil, and snowmelt modification. Moderate to high severity burn areas in high precipitation zones will produce the largest increases in runoff. The increased risk of flash flood flows will diminish the safety of recreational travel and camping. An increase in flood flows may temporarily prevent access to private property and recreational opportunities.

Ponds/Dams—Several private ponds exist in the West Creek and Trout Creek drainages. Both in-channel and within floodplain ponds exist. Postfire flows may be a combination of water and debris in which jams form and break, causing surges or slugs of material down the stream channels filling ponds and threatening earthen dams.

Debris Flow Potential—Increased stream flows may be combined with debris flows of floatable and transportable material. Recent experiences from the Cerro Grande, East Fork Bitterroot, Clover-Mist, and

Table 6—Potential sediment delivery to streams as modeled by the Hayman Fire BAER team for a 5 year recovery period.

General area description	Area[a]		Potential sediment delivery to streams[b]	
	acre ha	*mi^2 km^2*	*acre-feet (5 year)$^{-1}$*	*m^3 (5 yr)$^{-1}$*
Above Cheeseman Reservoir	83,000 (34,600)	130 (340)	1,950	(2,400,000)
Below Cheesman Reservoir (west)	21,700 (8,800)	34 (90)	510	(600,000)
Below Cheesman Reservoir (east)	43,700 (17,700)	68 (180)	1,020	(1,300,000)

[a] Approximate area, includes some unburned area outside of fire perimeter.
[b] Based on postfire monitoring of the Buffalo Creek Fire (Moody and Martin 2001) . The potential rate of 15 ac-ft mi^{-2} (7,100 m^3 km^{-2}) during the 5-year recovery period includes storms of higher intensity than the design storm.

Buffalo Creek Fires demonstrate that debris flows have greater potential of occurrence after high severity burns. Debris flows may impact road crossings, private property, and channel stability.

Water Quality—Trout Creek and the South Platte River above Cheesman Reservoir are on the 1998 Colorado 303(d) list for sediment. Section 303(d) of the Clean Water Act requires that States or the EPA set total maximum daily load (TMDL) for water bodies that fail to comply with the standards. A TMDL stipulates how much of a particular pollutant a water body may receive and still conform to water quality standards (Colorado WQCD 2002). Goose Creek, Horse Creek, Taryall Creek, and Trail Creek are on the 1998 Colorado Monitoring and Evaluation (M&E) list for sediment. The M&E list is intended to identify and track water bodies for which there is some evidence of nonattainment of water quality standards, but for which there is not adequate documentation to support inclusion on the 303(d) list (Colorado WQCD 2002).

The South Platte River is the conveyance system for the public water supply of the Metropolitan Denver area. There are also domestic wells within and around the burned area that may be impacted. In addition, reduced water quality within the burned area and downstream will affect esthetics and recreational use.

Threats to Aquatic Life—Ash, sediment, and other water quality factors may impact aquatic resources. The South Platte River is a significant and popular sport fishery.

BAER Team Treatment Objectives

The BAER Team delineated specific treatments and application locations (USDA Forest Service 2002). The BAER Team report included the following treatment objectives:

- Reduce erosion by providing ground cover and increase infiltration by scarifying the soil surface. Seeding done at appropriate locations and application methods will also increase ground cover.
- Reduce impacts to the Denver water supply reservoirs and the water quality-listed streams.
- Protect targeted structures that are downslope from National Forest burned acreage.
- Protect roads and crossings from flood flows.
- Spot-treat noxious weeds within the fire area to reduce the threat of significant expansion and invasion of noxious weed species.
- Straw bale placement to divert anticipated storm flows away from two sensitive heritage sites.
- Monitor erosion and sediment delivery in treated areas to evaluate success of BAER treatments.

BAER Team Treatment Recommendations

The BAER team recommended a variety of emergency rehabilitation treatments based on the estimated runoff and erosion rates as well as the risks summarized above. Included in the BAER team recommendations is the area of each treatment (fig. 5). The large-scale logistics of emergency rehabilitation treatment application means that adjustments must accommodate unforeseen circumstances during the application process. The Hayman Fire was no exception, as the recommended treatment areas and associated costs changed throughout the application process (table 7). Rationales for the changes from the original BAER treatment plan were delineated in the revised Burned Area Report submitted on August 21, 2002. These explanations are summarized, in italics, at the end of the treatment descriptions that follow (USDA Forest Service 2002).

The final figures for 2002 indicate that approximately $16.5 million were spent to treat 45,500 acres (nearly 45 percent) of the 100,000 acres of National Forest land that burned (table 7). Approximately $2.5 million to $5 million are allocated for 2003 to complete these rehabilitation treatments. Unless otherwise noted, treatment figures refer to National Forest land only and do not include any treatment on the 16,300 acres of private and State owned land that burned (fig. 5).

Land Treatments—

- *Ground-based hydromulching with seed* (fig. 6), for 1,500 acres (600 ha). Truck-mounted hydromulching was done from existing roads within high severity burn areas. Treatment occurred within 300 feet (90 m) either side of 25 miles (40 km) of road. Ground-cover amounts were 2000 lb per acre (2.24 Mg per ha). Seed mix and seed application rate were as described in table 8.
- *Aerial hydromulching with seed* (fig. 7, 8, 9), for 1,500 acres (600 ha). Aerial hydromulching was done on high severity burn areas draining to the South Platte River below Cheesman dam that could not be reached by existing roads. The focus was on ridge-tops and upper one-third of 20 to 60 percent slopes. Application rate was 2,000 lb per acre (2.24 Mg per ha), and the mulch and tackifier was suitable for 20 to 60 percent slopes. Seed mix and seed application rate were as described in table 8.
- *Aerial dry mulching with seed* (fig. 10, 11), for 7,700 acres (3,100 ha). Aerial dry mulching with

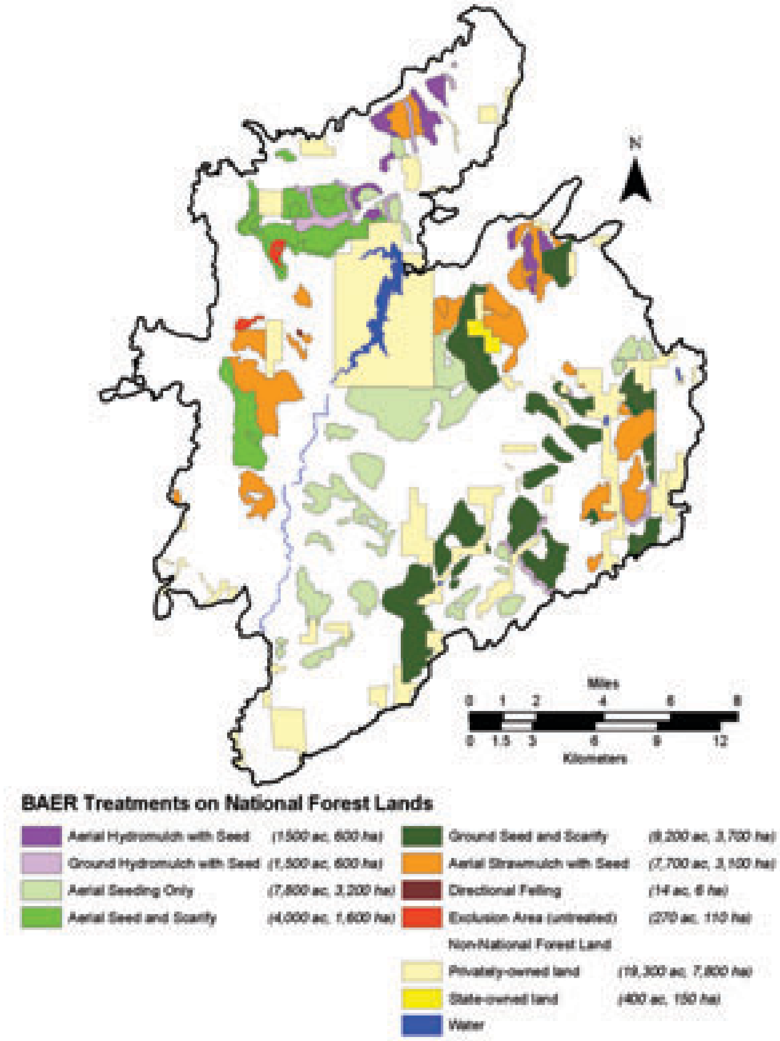

Figure 5—Hayman postfire rehabilitation treatment map for National Forest lands.

seed was applied to high severity fire areas above Cheesman dam that cannot be reached by existing roads. Focus was on ridge-tops and the upper one-third of the slopes. Application rate was 2,000 lb per acre (2.24 Mg per ha). Seed mix and seed application rate were as described in table 8. *A total 4,000 acres of treatments originally intended for the more costly aerial hydromulching were changed to the dry mulching treatment. The cost savings provided for an additional 5,500 acres of dry mulch treatment on high severity burn areas. The contract was terminated for convenience to the government prior to the contract completion.*

- *Mechanical scarification by all terrain vehicles (ATV), with seed* (fig. 12), for 9,200 acres (3,700 ha). Scarification and seeding occurred on selected high severity-burn areas on slopes less than 20 percent. Areas were treated with a chain-link harrow with 4 inches (10 cm) teeth pulled behind an ATV on the contour to break up the water repellent soil layer and thereby increase infiltration rates. Seed mix and seed application rates were as described in table 8. *Part of the acreage initially identified for ATV scarification was found to be too steep and dissected for safe operation.*
- *Hand scarification with seed* (fig. 13), for 4,000 acres (1,600 ha). Hand scarification and seeding was done on selected high severity burn areas where slopes were too steep (greater than 20 percent) for ATVs. The treatment was done using hand-rakes (McLeods) followed by aerial or hand seeding. Seed mix and seed application rate were as described in table 8. *These acres were initially*

Table 7—Postfire emergency rehabilitation treatment costs for the Hayman Fire in 2002. Note the changes in treatment acreages from the initial assessment to the actual acreages treated. An additional $3 to 5 million will be spent in 2003 to complete the BAER treatment application.

	National Forest System lands					
Land treatments	**Units**	**Unit cost**	**Recommended units**		**Actual units treated**	**Treatment cost**
		$	*#* July 5, 2002	*#* August 7, 2002	*#*	*$*
Road Hydromulching	Acres	950	1,500	1,500	1,500	1,400,000
Aerial Hydromulching	Acres	3,000	5,500	1,500	1,500	4,500,000
Aerial Dry Mulching	Acres	728	4,500	15,000	7,700	5,610,000
Mechanical Scarification	Acres	50	15,000	13,000	9,200	460,000
Hand Scarification	Acres	240	None	4,000	4000	960,000
Aerial Seeding	Acres	18	None	19,000	19,300	350,000
Seed	Pound	0.29			2,000,000	580,000
Colorado Cares	Project	1	1	1	1	16,500
Heritage Site Protection	Sites	670	2	2	2	1,300
Noxious Weed Treatments	Acres	100	210	370	370	37,000
NFS-Above Private Land Treatments	Sites	NA	6	6	6	12,000
Flood Warning Signs	Project				1	2,600
					Subtotal	$14,000,000
Road and trail treatments						
Maintenance and Closures	Total				1	190,000
					Subtotal	$190,000
BAER evaluation						
Team Costs and Helicopter Time	Total				1	136,000
					Subtotal	$136,000
Monitoring						
Noxious Weed Monitoring	Project				1	25,000
					Subtotal	$25,000
Other						
Implementation Overhead Team	day	24,000	45		86	2,100,000
					Subtotal	$2,100,000
					TOTAL	$16,500,000

Figure 6—Ground-based application of hydromulch.

Table 8—Seed mix used for aerial seeding, aerial hydromulch and ground hydromulch applications after the Hayman Fire.

Annual seed mix	Mix amount	Broadcast rate		Seeds	
	percent	*lbs ac^{-1}*	*kg ha^{-1}*	*# ft^{-2}*	*# m^{-2}*
Barley (*Hordeum vulgare*)	70	70	(80)	26	(280)
Triticale (*xTriticosecale rimpaui*)	30				

Figure 7—Aerial hydromulch staging area.

Figure 9—Aerial application of hydromulch.

Figure 8—Helicopter with tanks for hydromulch slurry.

Figure 10—Aerial dry mulch staging area. Straw bales on cargo nets ready for helicopter transport.

Figure 11—Aerial dry mulch being applied.

designated for mechanical scarification using ATV's pulling harrows; however, safety issues for the ATV's made hand scarification a better a option.

- *Seeding* for 25,000 acres (10,000 ha). Seeding was done on all areas that received scarification or mulch treatments. To ensure the quality of seed used in this rehabilitation effort, the Forest Service obtained all of the seed and made sure that the seed had been tested for noxious weed content and inert matter within the past 120 days. All seed was certified noxious weed-free mixes of 70 percent barley (*Hordeum vulgare*) and 30 percent triticale (*xTriticosecale rimpaui*) seed, nonpersistent annual grasses. *Aerial seeding was not initially planned. However, seeding was added shortly after the initial assessment and fixed wing aircraft were used to seed areas not seeded by hand or in conjunction with hydromulch applications. Approximately 5,300 acres (2,100 ha) that were scarified were aerial seeded to expedite completion of that treatment. Another 14,000 acres (5,700 ha) were seeded with the intent of being aerially straw mulched afterward. Because the aerial straw mulch contract was terminated prior to completion, approximately 7,800 acres (3,200 ha) were aerial seeded without any other treatment.*

Figure 12—Mechanical scarification with an ATV pulling a chain harrow.

- *"Colorado Cares Day" scarification, seeding and mulching* (fig. 13), for 125 acres (50 ha). On "Colorado Cares Day" (August 8, 2002) a variety of treatments were installed to utilize the services of 1,000 volunteers. These treatments included scari-

Figure 13—Volunteers using hand rakes and whirlybird seed spreaders to scarify and seed severely burned soils during the *Colorado Cares* event.

fication with McLeods, seeding with whirly-bird spreaders, and hand mulching.

- *Spot treatment of at-risk heritage sites.* Two heritage sites are at risk from high runoff flows and erosion. Strategically placed straw bales with rebar anchoring were placed to divert anticipated flood flows away from the sites.
- *Noxious weed spot-treatment and biologic control*, for 370 acres (1,500 ha). Herbicide spot treatments were applied to known weed infestations. Targeted sites posed a threat for the establishment, seed set and expansion into vulnerable fire areas and into uninfested areas directly outside of the burn. All treatments complied with the Pike and San Isabel National Forest Noxious Weed Environmental Assessment application guidelines.
- *Treatments on burned National Forest lands located above private land.* There is a considerable amount of private land within the Hayman Fire area (fig. 5). In many locations, moderate or high severity burned National Forest property is directly upslope of private homes. Six sites were treated with sandbag berm deflectors and directional felling in addition to the land treatments that occurred farther upslope.
- *Flood warning signs / system.* Three Remote Automated Weather Stations (RAWS) were installed to assist the National Weather Service in flood forecasting. In addition, 25 "Flash Flood Warning" signs were installed at key locations throughout the fire area, primarily at ingress points into the burn area.
- *Non-National Forest Land Treatments.* The BAER Team recommended no channel treatments. However, the Denver Water Board (DWB) installed straw bale check dams in tributaries above Cheesman Reservoir (fig. 14), a 25 by 100 foot (7.6 by 30 m) sediment basin on Goose Creek, and placed log sediment traps in other major gulches and drainages. The DWB also applied a polyacrylamide (PAM) as a soil binding agent on nearly 900 acres (360 ha).

Road and Trail Treatments –

- *Road maintenance,* for120 miles (190 km). In anticipation of flood flows from the burn area, road maintenance was implemented to ensure safe travel and reduce sediment sources. This included culvert and ditch cleaning, road grading, installation of rolling dips and armored grade dips, placement of rip rap and concrete barriers to protect road edges, and installation of silt lag dams and trash racks in drainages threatening road stability. Storm patrols will drive forest roads during or immediately following storm events to check culvert plugging or other drainage problems and thereby direct future road maintenance efforts.
- *Road closures*. Temporary road closures were necessary due to safety concerns (hazard trees, boulders rolling from steep burned slopes, and aerial rehabilitation treatment applications), possible road washouts and flash floods, and to aid in the rehabilitation of burned lands by simply reducing use. Closure methods included gates, large waterbars, boulders, and signs. Portable barricades will be used for rapid closure of open roads when warranted due to storms and flooding.

Effectiveness of Postfire Rehabilitation Treatments

The effectiveness of postfire rehabilitation treatments was recently reviewed by Robichaud and others (2000). Many of the different hillslope, channel, and road treatments recommended by Burned Area Emergency Rehabilitation (BAER) teams have not been extensively studied; however, some qualitative monitoring has occurred on various treatments. Overall, relatively little information has been published on most postfire emergency rehabilitation treatments (MacDonald 1988; Robichaud and others 2000).

Hillslope Treatments

Hillslope treatments such as mulches, contour-felled logs, and seeding are intended to reduce surface runoff and keep soil in place. These treatments are regarded

Figure 14—Straw bale check dams on Denver Water Board property within the Hayman Fire area.

as a first line of defense against postfire erosion and unwanted sediment deposition. However, the effectiveness of any hillslope rehabilitation treatment depend on the actual rainfall amounts and intensities—especially in the first years after the fire. Recent effectiveness monitoring on the Bobcat Fire in the northern Colorado Front Range showed that dry mulch, seeding, and contour log erosion barriers did not significantly reduce sediment yields in the first summer after the fire. This lack of effectiveness can be attributed to the intense rain event that overwhelmed all the treatment efforts. Some treatments did reduce sediment yields in the second year after burning, when rainfall was spread over several smaller events (Wagenbrenner 2003).

Mulch—Mulch is used to cover soil, thereby reducing rain impact, overland flow, and soil erosion. It is often used in conjunction with grass seeding to provide ground cover in critical areas. Mulch protects the soil from rainsplash, increases infiltration, and improves soil moisture retention thereby benefiting seeded grasses. Straw mulch has been shown to reduce erosion rates after wildfires by 50 to 94 percent (Bautista and others 1996; Faust 1998; Dean 2001; Wagenbrenner 2003).

Straw mulch was shown to be effective in a comparative study done for two monsoon seasons after the 2000 Cerro Grande Fire on the Bandolier National Monument and the Santa Fe National Forest in New Mexico (Dean 2001). Sediment from hillslope plots was compared using silt fence sediment traps (after Robichaud and Brown 2002). Although precipitation during the 2 study years was below normal, the plots treated with aerial seed and straw mulch yielded 70 percent less sediment than the no-treatment plots in the first year and 95 percent less in the second year. Ground cover transects showed that aerial seeding without added straw mulch provided no appreciable increase in ground cover relative to untreated plots. (Dean 2001). In the second year after the Bobcat Fire, Wagenbrenner (2003) reported sediment yields from mulched hillslope sites were significantly less than the sediment yields from untreated slopes and the slopes that were seeded without mulch.

Mulch is generally believed to be most effective on gentle and moderate slopes and in areas where high winds are not likely to occur. Wind either blows the mulch offsite or piles it so deeply that seed germination is inhibited. On steeper slopes, overland flow is more likely to wash the mulch downslope (Wagenbrenner 2003). Punching it into the soil, use of a tackifier or felling small trees across the mulch may increase on-site retention. The postfire dry mulching that was done after the Hayman Fire occurred on slopes ranging from 20 to 60 percent. With the exception of ridge tops, wind is not expected to be a significant issue; however, there is some chance that high intensity rain events might move some of this mulch downslope.

Mulch is frequently applied to improve the germination of seeded grasses. In the past, seed germination from grain or hay mulch was regarded as a bonus because this added cover to the site; however, the use of straw from pasture may introduce nonnative seed species that can persist and compete with the reestablishment of native vegetation. National Forests now seek "weed-free" mulch such as rice or wheat straw, but this is not always available in the locations and quantities needed. This problem was encountered during the rehabilitation efforts on the Hayman Fire. Although certified "weed-free" straw was used on the Hayman, cheat grass (*Bromus tectorium*) seed was found in some of the straw brought in for use in rehabilitation treatments. Straw and hay products may contain cheat grass and still meet Colorado weed-free standards. In addition to the introduction of nonnative species, there is concern that thick mulch may inhibit native herb and shrub germination. Shrub seedlings were found to be more abundant at the edge of mulch piles, where the material was less than 1 inch (2.5 cm) deep (Robichaud and others 2000).

Due to the cost and logistics of mulching, it is usually used when there are high downstream risks, such as above or below roads, above streams, or below ridge tops. Although mulch can be transported and distributed by helicopter, it is applied most easily where road access is available because bales must be trucked in. The use of helicopters to spread mulch is relatively new in postfire emergency rehabilitation and these were used to apply mulch on 7,700 acres (3,100 ha) after the Hayman Fire (table 7). Preliminary ground cover estimates on these areas showed approximately 70 percent ground cover immediately after application. The mulch thickness was not measured, but qualitative observations indicated that the straw bales broke apart as they fell from the cargo net and spread farther upon impact, resulting in a fairly even distribution of straw mulch over the ground surface.

Hydromulch—There are numerous fiber mulches, soil stabilizers, or combinations of material (tackifier, polymers, seeds, and so forth) that, when mixed with water and applied to the soil surface, form a matrix that help reduce erosion and foster plant growth. Hydromulch is most commonly applied on road cut and fill slopes, construction sites, and other disturbed areas with truck-mounted equipment. Several State transportation departments have tested the effectiveness of various hydromulch products on road cuts and fills. For unburned soils, an application of 3,500 lb per acre (3.9 Mg per ha) of hydromulch reduced erosion by 97 percent compared to bare soil under laboratory rainfall simulators (SDSU 2002).

The hydromulches applied after the Hayman Fire consisted of wood fibers, tackifers, soil binders, viscosity stabilizers, and water. Truck-mounted sprayers applied hydromulch on 1,500 acres (600 ha) along existing forest roads. Due to limitations in the spray equipment, treatment was limited to 200 feet (60 m) on either side of the road. When applied by helicopter, hydromulching is an expensive rehabilitation treatment. After the Hayman Fire, 1,500 acres (600 ha) of aerial hydromulching was applied to steep, inaccessible areas that drain directly to the South Platte River. Although the effectiveness of this treatment is expected to be high, there are no postfire effectiveness data available at this time.

Scarification—Scarification is a mechanical soil treatment aimed at improving infiltration rates in water repellent soils. Scarification may physically break up the water repellent layer, increase the macroporosity of the surface soil, and add roughness, thus increasing the infiltration rate. Hand rakes (McLeods) are commonly used in inaccessible, moderate slope terrain, whereas all-terrain vehicles (ATV) and tractors pulling harrows have been used on gentle slopes to break up the water repellent soil layers. The scarification depths using hand tools are generally 0.5 to 1.5 inch (1.3 to 3.8 cm) whereas machine pulled harrows or rippers can be 1 to 12 inches (2.5 to 30 cm) deep. Water repellent layers may be shallow (0.5 inch, 1.3 cm) and/or deep (6 inch, 15 cm). Therefore, for this treatment to be effective the depth of the water repellent layer must first be evaluated so that proper equipment can be used to break up that layer.

Scarification has been viewed as an effective treatment for roads, firebreaks, and trails, but less effective on hillslopes (Robichaud and others 2000). In the BAER team evaluation of the Hayman Fire, shallow water repellent conditions were observed. Thus, hand rakes and ATV pulled chain harrows (4 inch, 10 cm long harrow teeth) were used to scarify approximately 13,200 acres (5,300 ha).

Seeding—Historically, the most common BAER practice has been broadcast seeding of grasses, usually from aircraft. In the Hayman Fire 25,000 acres (10,100 ha) of National Forest land received aerial or hand seeding. Approximately 60 percent of the seeded acreage was also treated with mulch or scarification. The DWB aerial seeded 7,000 acres (2,800 ha) of their lands. Rapid vegetation establishment has been regarded as the most cost-effective method to promote water infiltration and reduce hillslope erosion (Miles and others 1989; Noble 1965; Rice and others 1965). Much of the research has focused on the effects of seeding on vegetative cover and the regeneration of native species rather than on infiltration and erosion. The studies reviewed by Robichaud and others (2000) used a wide variety of grass species, seed mixes, and application rates, and the data suggest that seeding does not assure higher plant cover during the critical first year after burning. Better cover and thereby better erosion control can be expected in the second and subsequent years. After the Bobcat Fire in the Colorado Front Range, Wagenbrenner (2003) found that seeding had no significant effect on sediment yields at the hillslope scale in either the first or second years. In addition, seeding had no significant effect on percent of vegetative cover compared to untreated areas (Wagenbrenner 2003).

Contour-Felled Logs—This treatment involves felling logs on burned-over hillsides and laying them on the ground along the slope contour. The contour-felled logs are intended to provide a mechanical barrier to overland flow, promote infiltration, and thereby reduce sediment movement. These barriers can also trap sediment, although this is not their primary intent. The logs need to be staked in place and the gaps between the logs and soil surface filled to prevent underflow (Robichaud and others 2000). Some recent installations have included the construction of soil berms at the end of the logs to increase their storage capacities. Although contour-felled logs had limited use on National Forest lands for the Hayman Fire rehabilitation, they were installed extensively on private lands within the burned area.

Dean (2001) found that plots treated with contour-felled logs as well as aerial seed and straw mulch yielded 77 percent less sediment in the first year and 96 percent in the second year; however, these results were not significantly different from the straw mulch with seed treatment alone. Recent postfire rehabilitation monitoring efforts for six paired watersheds have indicated that contour-felled logs can be effective for low to moderate rainfall intensity storm events. However, during high intensity rainfall events their effectiveness is greatly reduced. The effectiveness of contour-felled logs decreases over time. Once the sediment storage area behind the log is filled the barrier can no longer trap sediment that is moving downslope (Robichaud 2000; Wagenbrenner 2003).

Polyacrylamide (PAM)—PAM is a synthetic polymer that aids in aggregation of fine soil particles, which can reduce the erosion induced by flowing water. During the past few decades PAM has been used to reduce erosion in low-flow irrigation ditches, settle heavy metals in mine reclamation efforts, and increase sludge density in water treatment plants. More recently, PAM products have been introduced to hydraulic mulch/seed mixes to help bind soil particles. These products have been used on road cuts and fills and disturbed areas to stabilize soils and reduce erosion prior to revegetation.

The effectiveness of PAM for treatment of burned areas has not been tested. A single test using simulated rainfall on a severely burned plot in the northern Colorado Front Range found that sediment production from a plot treated with PAM initially had a much lower sediment yield than an untreated plot. However, sediment yield from the plot treated with PAM began to progressively increase after about 30 minutes, while the sediment yields from the untreated plot remained relatively constant until the end of the simulated rainfall (MacDonald, personal communication 2003). Although these preliminary results suggest some initial erosion-reduction benefit, the high variability in soil conditions in burned areas means that there may not be simple answers to the usefulness and potential effectiveness of PAM applications.

Channel Treatments

Channel treatments are designed for use in ephemeral or small-order channels to prevent or reduce flooding and debris torrents further downstream. Some in-channel structures slow water flow and allow sediment to settle out; the sediment is released gradually as the structure decays. Much less information is available on channel treatments after wildfire than on hillslope treatments (Robichaud and others 2000).

Straw Bale Check Dams—The DWB used 29,000 straw bales construct check dams in the swales and small tributaries that drain directly into Cheesman Reservoir. These structures were not used on National Forest lands; however, they have been installed and evaluated after other fires. These studies indicate that straw bale check dams are effective if they do not fail (Miles and others 1989; Fites-Kaufman 1993; Collins and Johnston 1995; Niehoff 1995). Failures due to blowouts, piping between bales, or undercutting were commonly reported. Blowouts are particularly common for straw bale check dams put into deeply incised or steeply sloped streams and after large storm events. High postfire erosion means sediment can quickly fill the area behind straw bale check dams, making them ineffective and susceptible to failure.

Goldman and others (1986) found that straw bales usually last less than 3 months and recommended that they only be used when flows are less than 11 cfs (0.3 $m^3 s^{-1}$). The bales also should be removed when the accumulated sediment exceeds one-half of the check dam height. More damage can result from failed barriers than if no barrier were installed (Goldman and others 1986). Denver Water Board maintenance of their straw bale check dams in the Hayman Fire area has included the use of small equipment to clean out accumulated sediment after storms and some reinforcement and extension of compromised structures.

Road Treatments

Generally, forest road structures are not directly damaged by fire but the consequences of fire (increased peak flows, movements of material downslope, sedimentation, etc.) can dramatically affect roads. Since it is impossible to design and build all stream crossings to withstand extreme storm flows, Best and others (1995) recommended increasing crossing capacity to minimize the consequences of culvert exceedence as the best approach for forest road stream crossings. Consequently, BAER road treatments include practices aimed at increasing the capabilities of roads and road structures to handle larger amounts of runoff and sediment (Robichaud and others 2000). The road treatments recommended by the Hayman Fire BAER team included outsloping, ditch and culvert cleaning, armored stream crossings, and rolling dips as well as riprap and concrete barriers for road edge protection. Trash racks and storm patrols try to prevent culverts from becoming blocked with organic debris, which could result in road failure that would increase downstream flood or sediment damage. Comprehensive discussions of road-related treatments and their effectiveness can be found in Packer and Christensen (1977), Goldman and others (1986), Burroughs and King (1989), and Copstead (1997).

Monitoring Postfire Rehabilitation Treatments

Monitoring the effectiveness of postfire rehabilitation treatments is important to determine if the treatments are functioning as desired and to compare the benefits of various treatments. Monitoring also is essential in determining the conditions under which different treatments are effective and thereby the limitations of each treatment. Both implementation and effectiveness monitoring need to occur. This section outlines a process for monitoring postfire rehabilitation as well as postfire rehabilitation monitoring efforts on the Hayman Fire.

Implementation Monitoring

Implementation monitoring ensures that postfire rehabilitation treatments are installed as designed for maximum effectiveness. To be effective, implementation monitoring has to be conducted as the individual actions are being completed. Close ties between the installation activity and the monitoring are critical for two reasons: (1) problems can be addressed while the fire crews, contractors, and other personnel are still on site; and (2) design problems may be readily identified, and modifications made in order to adjust the treatments being applied elsewhere. In the case of dry mulching, project inspectors check the application rate and coverage area as well as ensuring that straw quality, seed content, and preparation specifications are met.

During the installation of postfire rehabilitation treatments, logistical difficulties are usually encountered and these frequently require revisions to the recommended treatments. The preceding section described some of the adjustments made on the Hayman Fire during the implementation process. For example, the acreage to be treated by aerial hydromulch (with seed) was reduced and replaced by aerial dry mulch (with seed) treatment. Subsequently the acreage to be treated with aerial dry mulch was reduced and replaced by aerial seeding alone (no mulching or scarification). Changes in treatment implementation plans are common. Documentation and explanation of these changes may be useful for future rehabilitation efforts.

Effectiveness Monitoring

A major limitation to the design of postfire rehabilitation treatments is the lack of information on their effectiveness (Robichaud and others 2000). The paucity of data on the effectiveness of different BAER treatments means that funds are being spent with little surety of the potential benefits. As wildfires will continue to occur, there will be a continuing need to minimize postfire erosion rates and protect downstream resources, BAER treatments are almost certain to be applied after future wildfires. Hence, effectiveness monitoring must be conducted on current and future fires, as this information is necessary to determine: (1) the relative effectiveness of the different BAER treatments to achieve specified objectives, such as reduction in postfire runoff and erosion rates; (2) the change in treatment effectiveness over time; (3) the variation in treatment effectiveness over a range of storm events; (4) the relative treatment effectiveness for different watershed conditions, such as topography, geology, soils, vegetation, and so forth; and (5) an estimated cost-benefit analysis for the different treatments. Quantitative data from these monitoring efforts will not only guide future responses to postfire rehabilitation but also can be used to build and refine predictive models.

Robichaud and others (2000) examined 157 postfire monitoring reports generated between 1967 and 1998. They found that these monitoring reports varied widely in content. Only 55 of 157 (35 percent) reports contained quantitative data. The other 65 percent contained qualitative assessment of treatment success, such as trip reports or photos. The variation in the type of assessment made it difficult to tabulate and compare the results from different postfire rehabilitation efforts.

If effectiveness monitoring were required whenever significant BAER treatments were installed, the resulting data would facilitate comparisons between treatments and an assessment of the factors and conditions that limit treatment effectiveness. The large spatial and temporal variability in postfire runoff and erosion processes implies that effectiveness monitoring has to be replicated within and between areas. The collection of such data would provide better guidance for future management decisions, and allow a more rigorous assessment of the benefits that might be obtained from a given treatment. Recent changes in Federal land management agency policies allow up to 10 percent of BAER funds to be used for monitoring, so there is no fundamental reason why implementation and effectiveness monitoring should not be conducted after any wildfire that receives BAER treatments.

Monitoring as Part of the BAER Team Report— An important step for improving postfire rehabilitation treatment monitoring is to include implementation monitoring and the general outline for an effectiveness monitoring program as a required component of all BAER reports that recommend rehabilitation treatments. Given the time and logistical constraints on the BAER team, they cannot be expected to develop the details of a monitoring program. However, the monitoring section can outline the primary monitoring goals, how these goals might be achieved, provide an estimated budget, and indicate whether the monitoring can be conducted in-house or should be contracted out.

Generally, the design of an effectiveness monitoring program requires individuals with some knowledge of statistics and field measurement techniques. If expertise is not available locally, it may be advantageous to contact Forest Service researchers, universities, or similar agencies. An approximate budget is needed so that funds can be immediately made available for monitoring, as the installation of monitoring sites should occur simultaneously with the installation of the BAER treatments. The development of partnerships on a case-by-case basis means that flexibility is needed in how monitoring dollars provided through the BAER process can be spent.

Effectiveness monitoring needs to be done as quickly as possible, as the first storms typically pose the greatest risk to downstream resources, and we have few data on the immediate effectiveness of BAER treatments. In addition, effectiveness monitoring requires quantifiable data collection and a multiyear commitment (for example monitoring protocol, see Robichaud and Brown 2002). For monitoring projects to be successful, timely data collection, analyses, and reporting are needed (MacDonald 1994).

Untreated Areas Needed for Comparison—To evaluate the effectiveness of postfire rehabilitation treatment(s), untreated areas must be available for comparison. Burned but untreated areas provide a control, or baseline, from which effectiveness can be measured. These areas can be used to assess both short- and long-term effectiveness of treatments as well as ecosystem response to the fire. The untreated areas must be comparable to areas designated for treatment. A small number of untreated areas can serve as the controls for a much larger number of different treatments, as long as the controls have a similar mean and range of conditions as the various treated areas.

Open Monitoring Program—The monitoring program must be transparent and the results reported at regular intervals. Much of the controversy over postfire treatments is due to the lack of hard data on the effectiveness of different treatments. The development and regular reporting of results from monitoring programs are needed to guide future management actions. Regular reports of monitoring data will show that the Forest Service and other management agencies are actively evaluating the effects of their actions. An open and transparent presentation of the monitoring results also allows concerned agencies and individuals to make their own judgments based on data. By collecting and reporting monitoring data, the current debate over land management actions will be placed on a more objective basis, and this has the potential to reduce the stridency of this debate.

Current Monitoring in the Hayman Fire Area—As previously discussed, the Forest Service actively monitored the implementation of rehabilitation treatments after the Hayman Fire. Daily briefings allowed for immediate response to circumstances encountered during installation of the treatments. For example, the locations of some treatment polygons were changed when, upon inspection, burn severity was found to be less than indicated by the burn severity map. In addition, daily decisions were required to effectively deploy the materials, equipment, and labor required to install the different rehabilitation treatments. Implementation monitoring by seven to 10 project inspectors occurred while the treatment contractors were working onsite and lasted approximately 60 days.

Immediately after fire suppression activities ended, hillslope treatment effectiveness monitoring was being established by Robichaud (USDA Forest Service, Rocky Mountain Research Station, Moscow, ID) and MacDonald (Colorado State University, Fort Collins, CO). The BAER team has decided that the effectiveness monitoring data from these sites would meet the needs established by the current BAER program and will support these efforts rather than developing an independent program. In addition, the location and size of burned but untreated "exclusion" areas (300 acres, 120 ha) were established during the reconnaissance of the effectiveness monitoring sites (fig. 5).

Robichaud (unpublished study plan 2002) established six small watershed monitoring sites (10 acres, 4 ha) within high burn severity areas of the Hayman Fire Area. Four of the six small watersheds have been or will be treated with (1) aerial hydromulching, (2) aerial dry mulch, (3) contour-felled logs, and (4) salvaged logged. Salvage logging is not a postfire rehabilitation treatment, but it is included in this monitoring effort to evaluate its effect on runoff and erosion. Two of the sites have been left untreated as controls. Each site has a sediment trap and weir constructed at the outlet of the watershed. A complete weather station and four tipping bucket rain gauges are also installed onsite. After each storm event, the sediment will be collected, measured, and analyzed so that the treated and nontreated watersheds can be compared. These sites will be monitored for 5 years. In addition, 32 rill study plots (300 ft^2, 27 m^2) with silt fence sediment traps (Robichaud and Brown 2002) have been established to compare treatments. Eight plots of each treatment—straw mulch, wood straw mulch (new product), hand scarification, and untreated controls—are in place and being monitored.

MacDonald (unpublished study plan 2002) is also monitoring sites within the Hayman Fire area. At the watershed scale, 2.5 foot (0.75 m) H-flumes have been established in Saloon Gulch (840 acres, 340 ha) and Brush Creek (1,500 acres, 620 ha) where pre- and postfire data have been collected. At the hillslope scale, 20 paired swales (one control and one treated) have been established in Upper Saloon gulch and the adjacent Schoonover Fire. Swales range from 0.1 to 2.5 acres (0.06 to 1 ha) in size and have silt fence sediment traps. Three to six pairs of swales are being used to evaluate the following treatments: (1) ground-based dry mulch, (2) ground-based hydromulching, (3) hand scarification with seeding, and (4) wet PAM application. Four other swales in Upper Saloon gulch are being used to monitor sediment production rates from areas treated by aerial hydromulch. The sediment in each swale is being regularly collected, measured, and analyzed. Six tipping bucket rain gauges have been installed, and sediment production rates will be related to storm magnitudes and intensities.

The Pike-San Isabel National Forest South Platte Ranger District has begun sampling suspended sediment and nutrients in seven drainages within the Hayman Fire area. The USGS has also begun sampling nutrients, metals, dissolved organic carbon (DOC), and suspended sediment on Fourmile Creek, which drains a burned watershed, and Pine Creek, which drains an unburned watershed adjacent to the Hayman Fire area. Sampling for both studies will be done on a monthly basis and during some storm events from April through November 2003. These drainages have mixed burn severities and some have been treated with a variety of treatments. The main objective of these studies is to compare water quality parameters between drainages (Entwistle, personal communication 2003; Martin, personal communication 2003).

Key Information Needs

Emergency watershed rehabilitation efforts are designed to protect resources at risk while minimizing expenditures on measures that may be ineffective or adversely impact burned watersheds. Deficiencies in the information available to the Hayman BAER team have been identified. In most cases these deficiencies apply to other burned areas as well as the Hayman Fire and include:

- Knowledge of return intervals for short-duration, high-intensity thunderstorms and how storm magnitudes vary with increasing aerial extent.
- The relation between rainfall, runoff, and erosion from the burned area. This is needed for accurate predictions of downstream flooding and sedimentation, and indications of how this relation may change over time.
- Burn severity maps that accurately depict fire effects on soil properties such as erodibility and soil water repellency.
- Knowledge of the effectiveness of BAER treatments for given storm types, ecosystems, and geographic locations.

Summary

Burned watersheds respond to rainfall faster than unburned watersheds. Although flash flooding, erosion, and the mobilization of large amounts of bedload and suspended sediments are commonly observed and have been documented in the literature, we have limited knowledge and ability to predict this response, especially for short-duration high-intensity storms. We also have little data on the effectiveness rehabilitation treatments to reduce runoff and erosion rates. This is particularly true for the newer treatments used on the Hayman Fire area such as hydromulch, aerial dry mulch, and scarification. Active monitoring projects have been established in the Hayman Fire area; however, treatment effectiveness results will not be available for several years. Monitoring needs to be an integral part of the postfire emergency rehabilitation treatment process and maintained until recovery approaches prefire conditions for the parameters of interest.

Acknowledgments

The authors thank Greg Bevenger (Shoshone National Forest), Steve Johnson (Kootenai National Forest), Ken Kanaan (Pike and San Isabel National Forest), and Pete Wohlgemuth (Pacific Southwest Research Station) for their careful review and significant contributions to this chapter.

References

Agee, J. K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, DC. 493 p.

Arkell, R. E.; Richards, F. 1986. Short duration rainfall relations for the Western United States, Conference on climate and water management—a critical era and conference on the human consequences of 1985's climate. 1986 August 4-7; Asheville, NC.

Bailey, Reed W.; Copeland, Otis L. 1961. Vegetation and engineering structures in flood and erosion control. In: Proceedings, 13th Congress, 1961 Sept.; Vienna, Austria. International Union of Forest Research Organization Paper 11-1. 23 p.

Bautista, S.; Bellot, J.; Vallejo, V. R. 1996. Mulching treatment for postfire soil conservation in a semiarid ecosystem. Arid Soil Research and Rehabilitation 10: 235-242.

Benavides-Solorio, J. D.; MacDonald, L. H. 2001. Post-fire runoff and erosion from simulated rainfall on small plots, Colorado Front Range. In: Anderson, M.G.; Peters, N.E.; Walling, D. (eds) Hydrological Processes 15 (15): 2931-2952.

Benavides-Solorio, J. D. 2003. Post-fire runoff and erosion at the plot and hillslope scale, Colorado Front Range. Fort Collins, CO: Colorado State University. 218 p. Thesis.

Best, D. W.; Kelsey, D. K.; Hagans, D. K.; Alpert, M. 1995. Role of fluvial hillslope erosion and road construction in the sediment budget of Garret Creek, Humboldt County, California. In: Nolan, K. M.; Kelsey, H. M.; Marron, D. C. (eds.) Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin, Northwestern California. Professional Paper 1454. Washington, DC: U.S. Geological Survey: M1-M9.

Bolin, S. B.; Ward, T. J. 1987. Recovery of a New Mexico drainage basin from a forest fire. In: Swanson, R. H.; Bernier, P. Y.; Woodard, P. D., ed., Proceedings: Vancouver symposium; 1987 August; Vancouver, British Columbia, Canada; Forest Hydrology and Watershed Management, IAHS; 167: 191-198.

Burroughs, Jr., Edward R.; King, John G. 1989. Reduction in soil erosion of forest roads. Gen. Tech. Rep. INT-264. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 21 p.

Campbell, R. E.; Baker, M. B., Jr.; Ffolliott, P. F. 1977. Wildfire effects on a ponderosa pine ecosystem: an Arizona case study. Res. Pap. RM-191. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 p.

Collins, L. M.; Johnston, C. E. 1995. Effectiveness of straw bale dams for erosion control in the Oakland Hills following the fire of 1991. In: J.E. Keeley and T. Scott (eds.). Brushfires in California wildlands: ecology and resource management. Fairfield, WA: International Association of Wildland Fire: 171-183.

Colorado Water Quality Control Division (WQCD). 2002. Total maximum daily load assessment upper South Platte River, segment 1A, sediment. Douglas, Jefferson, Park and Teller counties, CO. Report on file. Denver, CO: Department of Public Health and Enviornment. 28 p.

Copstead, R. 1997. The water/road interaction technology series: an introduction. No.9777 1805-SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology Center. 4 p.

Dean, A. E. 2001. Evaluating effectiveness of watershed conservation treatments applied after the Cerro Grande Fire, Los Alamos, New Mexico. M.S. Thesis. University of Arizonia: Tucson, AZ: 116 p.

DeBano, L. F.; Ffolliott, P. F.; Baker, M. B. Jr. 1996. Fire severity effects on water resources. In: Ffolliott, P. F.; DeBano, L. F.; Baker, M. B. Jr.; Gottfried, G. J.; Solis-Garza, G.; Edminster,C. B.; Neary, D. G.; Allen, L. S.; Hamre, R. H. (tech. coords.). Effects of fire on Madrean province ecosystems - A symposium proceedings. Gen. Tech. Rep. RM-289. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 77-84.

DeBano, L. F.; Neary, D. G.; Ffolliott, P. F. 1998. Fires's effects on ecosystems. New York: John Wiley & Sons. 333 p.

Elliot, W. J.; Hall, D. E.; Graves, S. R. 2001. Forest Service WEPP Forest Service interfaces for the Water Erosion Prediction Project computer model, Moscow, ID: U.S. Department of Agriculture, Forest Service, [Online]. Available: http://forest.moscowfsl.wsu.edu/fswepp/ [2002, July]

Entwistle, D. C. 2003. [Personal communication]. April 30. Morrison, CO: Pike-San Isabel National Forest and Cimarron Comanche National Grasslands, South Platte Ranger District, USDA Forest Service.

Farmer, Eugene E.; Fletcher, Joel E. 1972. Some intra-storm characteristics of high-intensity rainfall burst. In: Distribution of Precipitation in Mountainous areas, Geilo Symposium, Norway; 1972 July 31-August 5; Geneva, Switzerland: World Meteorological Organization; 2: 525-531.

Faust, Robert. 1998. Lesson plan: Fork fire soil loss validation monitoring. Unit VIII, Long term recovery and monitoring. In: Burned area emergency rehabilitation (BAER) techniques, 1998. San Francisco, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. (course notebook).

Fites-Kaufman, Russell.1993. Survey of check dams in the Cleveland Fire Area. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Eldorado National Forest, CA. 3 p.

Goldman, S. J.; Jackson, K.; Bursztynsky, T. A. 1986. Erosion and sediment control handbook. San Francisco, CA: McGraw-Hill. 360 p.

Hawkins, R. H.; Greenberg, R. J. 1990. Wildcat4 Flow Model. [This edition further enhances Moore's version] School of Renewable Natural Resources, University of Arizona, Tucson, AZ. BLM contact: Dan Muller, Denver, CO. Kozlowski, T. T.; Ahlgren, C. E. eds.1974. Fire and ecosystems. New York: Academic Press. 542 p.

Hendricks, B. A.; Johnson, J. M. 1944. Effects of fire on steep mountain slopes in central Arizona. Journal of Forestry. 42: 568-571.

Hungerford, R. D. 1996. Soils- fire in ecosystem management notes: unit II-I. Marana, AZ: U.S. Department of Agriculture, Forest Service, National Advanced Resource Technology Center.

John, T. J. 2002. Soil report for Hayman Fire Burned Area. Prepared for: U.S. Department of Agriculture, Forest Service, 2002. Hayman Fire—burned area report. (Hayman Fire 2500-8, original 7/5/02, revised 8/21/02) Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Pike and San Isabel National Forest, Pueblo, CO. 9 p.

Kozlowski, T. T.; Ahlgren, C. E., eds.1974. Fire and ecosystems. New York: Academic Press. 542 p.

Kunze, M. D. 2003. Streamflow and sediment yield following the 2000 Bobcat Fire, Colorado Front Range, Fort Collins, CO: Colorado State University. 81 p. Thesis.

Kuyumjian, G. A.; Meador, K. L.; Higginson, B.; Brobst, R. B.; Entwistle, D. C. 2002. Hayman Fire PSICC June 2002 hydrology report. Prepared for: U.S. Department of Agriculture, Forest Service, 2002. Hayman Fire—burned area report. (Hayman Fire 2500-8, original 7/5/02, revised 8/21/02) Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Pike and San Isabel National Forest, Pueblo, CO, 8 p.

MacDonald, L.H. 2003. [Personal communication]. October 20. Fort Collins, CO: Colorado State University, Department of Earth Resources.

MacDonald, L. H. 1994. Developing a monitoring project, Journal of Soil and Water Conservation, 4a(3): 221-227.

MacDonald, L. H. 1988. Rehabilitation and recovery following wildfires: a synthesis, Proceedings of symposium on fire and watershed management; 1988 October 26-28; Sacramento, CA. Gen. Tech. Rep. PSW-109. Berkley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 141-144.

Martin, D. A. 2003. [Personal communication]. April 30. Boulder, CO: US Geological Survey, Water Resources Division, National Research Program.

Megahan, Walter F.; Molitor, Delbert C. 1975. Erosion effects of wildfire and logging in Idaho. In: Watershed management symposium: 1975 August; Logan, UT: American Society of Civil Engineers Irrigation and Drainage Division: 423-444.

Miles, Scott R.; Haskins, Donald M.; Ranken, Darrel W. 1989. Emergency burn rehabilitation: cost, risk, and effectiveness. In: Berg, Neil H., technical coordinator. Proceedings of the symposium on fire and watershed management, 1988 October 26-28; Sacramento, CA. General Technical Report PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 97-102.

Moody, J. A.; Martin, D. A. 2001a. Hydrologic and sedimentologic response of two burned watersheds in Colorado, U.S. Geological Survey Water Resources Investigation Report 01-4122, Denver, CO.

Moody, John A.; Moody, Deborah A. 2001b. Initial hydrologic and geomorphic response following a wildfire in the Colorado Front Range, Earth Surface Processes and Landforms 26:1049-1070.

Morris, S. E.; Moses, T. A. 1987. Forest fire and the natural soil erosion regime in the Colorado front range, Annals of the Association of American Geographers, 77(2): 245-254.

Neary, D. G.; Gottfried, G. J. 2001. Post-wildfire peak flood flows: Causes and effects. In: Proceedings Society of American Foresters 2000 National Convention; 2000 November 16-20; Washington, DC, Society of American Foresters, Bethesda, MD: 459-463.

Neary, D. G.; Klopatek, C. C.; DeBano, F. F.; Ffolliott, P. F. 1999. Fire effects on belowground sustainability: a review and synthesis. Forest Ecology and Management 122: 51-71.

Niehoff, Jerry. 1995. Mary-mix monitoring trip. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Idaho Panhandle National Forest, ID. 3 p.

Noble, Edward L. 1965. Sediment reduction through watershed rehabilitation. In: Proceedings of the federal inter-agency sedimentation conference 1963. Washington, DC: U.S. Department of Agriculture, Miscellaneous Publication 970: 114-123.

Noble, Edward L.; Lundeen, Lloyd. 1971. Analysis of rehabilitation treatment alternatives for sediment control. In: Symposium on forest land uses and stream environment, 1971 October 19-21; Corvallis, OR. Oregon State University, School of Forestry and Department of Fisheries and Wildlife, Continuing Education Publications: 86-96.

Packer, P. E.; Christensen, G. F. 1977. Guides for controlling sediment from secondary logging roads. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, and Missoula MT: U.S. Department of Agriculture, Forest Service, Northern Region. 42 p.

Rice, R. M.; Crouse, R. P.; Corbett, E. S. 1965. Emergency measures to control erosion after a fire on the San Dimas Experimental Forest. In: Proceedings of the federal inter-agency sedimentation conference 1963; Washington, DC: U.S. Department of Agriculture, Miscellaneous Publication 970:123-130.

Rich, L. R. 1962. Erosion and sediment movement following a wildfire in a ponderosa pine forest of central Arizona. Res. Note 76. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 p.

Rinne, J. N. 1996. Short-term effects of wildfire on fishes and aquatic macroinvertebrates in the southwestern United States. North American Journal of Fisheries Management 16: 653-658.

Robichaud, P. R. 2000. Fire and erosion: evaluating the effectiveness of a post-fire rehabilitation treatment, contoured-felled logs. Proceedings, Watershed management & operations management conference; 2000 June 20-24; Fort Collins, CO. Reston, VA: American Society of Civil Engineers, c2000.

Robichaud, P. R.; Beyers, J. L.; Neary, D. G. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. Gen. Tech. Rep. RMRS-GTR-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.

Robichaud, P. R.; Brown, R. E. 2000 (revised) [original publication, 1999]. What happened after the smoke cleared: onsite erosion rates after a wildfire in eastern Oregon. In: Olsen, D. S.; Potyondy, J. P. (eds.), Proceedings, Wildland Hydrology Conference, 1999 June; Bozeman, MT. Hernon,VA: American Water Resource Association: 419-426.

Robichaud, Pete R.; Brown, Robert E. 2002. Silt fences: An economical technique for measuring hillslope soil erosion. Gen. Tech. Rep. RMRS-GTR-94. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 24 p.

Ryan, K. C.; Noste, N. V., 1983. Evaluating prescribed fires. In: Lotan, J. E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R. W., tech. coords. Proceedings, symposium and workshop on wilderness fire. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 230-238.

San Diego State University. 2002. Results from a study of Canadian Forest Products Ltd. EcoAegis^{TM}: Runoff characteristics and sediment retention under simulated rainfall conditions. Prepared for: Canadian Forest Products Ltd; Project Reference No. 2001-02-CAN. San Diego, CA: San Diego State University/Soil Erosion Research Laboratory. 21 p.

U.S. Department of Agriculture, Forest Service, 2002. Hayman Fire—burned area report. (Hayman Fire 2500-8, original 7/5/02, revised 8/21/02) Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Pike and San Isabel National Forest, Pueblo, CO. 12 p.

Wagenbrenner, J. W. 2003. Effectiveness of burned area emergency rehabilitation treatments, Colorado Front Range. Fort Collins, CO: Colorado State University. 193 p. Thesis.

Social and Economic Issues of the Hayman Fire

Brian Kent, Krista Gebert, Sarah McCaffrey, Wade Martin, David Calkin, Ervin Schuster, Ingrid Martin, Holly Wise Bender, Greg Alward, Yoshitaka Kumagai, Patricia J. Cohn, Matt Carroll, Dan Williams, Carol Ekarius

Introduction

On June 26, 2002, U.S. Representative Mark Udall wrote the US Forest Service Chief, requesting that the Forest Service conduct an analysis of the Hayman Fire. In response to the Congressman's letter, five teams were established in August, 2002 to analyze various aspects of the Hayman Fire experience. This report describes the Hayman Fire analysis work conducted by the social/economic team and presents our findings.

When a fire the size and intensity of the Hayman Fire occurs largely in an urban/wildland area as highly developed as the Colorado Front Range, the social and economic effects or consequences will be extensive, complex, and long lasting. Any attempt to comprehensively catalog these impacts will be difficult, in part because it has never been attempted, especially for a fire as large and complex as the Hayman. Typically, social and economic or human dimensions consequences of wildfires have not received the attention that ecological issues have (Ffolliett, 1988; McIver and Starr, 2000), especially on the part of the Federal agencies directly involved with firefighting, such as the USDA Forest Service and the USDI Bureau of Land Management. As an example, Butry and others (2001) note that they are unaware of the existence of any "organization in the United States that systematically and empirically quantifies economic impacts of wildfires." The situation is perhaps even worse for the assessment of wildfire-related social impacts, with research having been limited to such key areas as public health and safety impacts, and social and community impacts (Machlis and others 2002). In fact, an understanding of the nature of these impacts is only now beginning to appear in the relevant literature.

Historically, wildfires, especially in the Western United States, typically burned in areas of low or nonexistent human habitation, with the result of minimal impacts on social or economic systems. For fires such as these, the importance of human dimensions issues was and is relatively low. As human populations in the West have grown; as the popularity of living in the wildland-urban interface has increased; and as the frequency and magnitude of wildfires has increased, especially in lower elevation Ponderosa pine and mixed conifer forests because of significant fuel buildups and extreme drought, more wildfires are causing significant damage and disruption to both social and economic systems. This trend ensures that the interplay between wildland fire management and human dimensions issues takes on far greater importance than it did historically. As pointed out in (Machlis and others 2002):

> The *human dimension* of Federal wildland fire management – the relationship of people and wildland fire in America – is an important and driving force in how Federal agencies respond to wildland fire, now and in the future. In many ways, it is *the* critical element, for the management of wildland fire is very much the management of people, communities, and organizations. From the fire prevention behaviors of local residents, to the safety of fire crews, to the economic impacts and ecological benefits of wildland fire, fire management has social, economic, and cultural consequences. Hence there is a need for accurate and comprehensive understanding of the human dimensions of wildland fire.

The Hayman Fire certainly is a first-class example of large, severe fire that had and will continue to have significant impacts on social and economic systems. It directly impacted four Counties: Park, Jefferson, Douglas, and Teller. Some of the immediate impacts that are relatively easy to tally up include the destruction of 132 residences, one commercial building, and 466 outbuildings; estimated suppression costs of $39,100,000; and numerous resources threatened including communities, subdivisions, isolated homes, gas transmission lines, electrical facilities and lines, timber, the major watershed for Denver County and recreation areas (from the Hayman Fire Web site: http://wildfires.nwcg.gov/colorado/hayman/index.shtml.) Other impacts will be much more difficult to estimate or, in many cases, to predict with great confidence, for they will make themselves felt over the next several years. Examples include; reduced property values and property tax revenues (The Jefferson County assessor's office is reducing values by 50 percent for burned acreages and up to 100 percent for burned structures *Rocky Mountain News*, September 18, 2002); lost sales tax and business revenues from causes such as reduced tourism; damage to the health of individuals and resultant costs, such as doctor and medical expenses; lost productivity – by evacuees, suppression volunteers and others; increased water treatment costs, both in terms of water quality and quantity issues; and nonmarket costs – including, aesthetics, habitat damage, reduced or lost recreation use, and reduced access. As a simple example of one of these questions, what will be the resultant damage to the blue ribbon trout fishery on the South Platte River and what will be the cost of this damage? Clearly, fully characterizing all of the monetary and nonmonetary impacts from the Hayman Fire especially in advance of when they occur will be difficult.

It is generally acknowledged that wildland ecosystems are complex and that there is much about the ways in which they function that humans do not understand. Perhaps less frequently recognized is the fact that human social and economic systems are also complex and in most cases, not fully understood. In terms of impacts from wildland fire, it may be easier to characterize ecological consequences than to characterize social/economic ones. In both cases some impacts such as those arising from the actual destruction by fire are relatively easy to determine. However, for social/economic systems, many other impacts are less obvious. In addition, simply identifying all of the components of social/economic systems that are impacted can be quite difficult. For example, in the case of the Hayman Fire, local and County governments in the four Counties directly affected were clearly impacted, as were residents in these areas. Beyond this, who else was affected and how?

As a closeout to this introduction, our team would like to point out that compared to other natural and human-caused environmental disasters such as hurricanes and floods, there is little social information and completed research results regarding wildland fire. In addition, social scientific data on the specific area impacted by the Hayman Fire is especially sparse. So when asked what we already know, what we are already doing, or what needs to be done it is hard to be specific. Organizations need to invest more in this area of research. For example, two of our team members have been working on a framework for monitoring the social/community impacts and recovery efforts associated with fires that took place in Forest Service Regions 1 and 4, but thus far have had little opportunity to test and refine this model. There is an urgent need and a real opportunity to learn how communities handle/react to a large wildfire. While work in other natural hazards can point to a variety of demographic and personal factors that are likely influential in understanding the social impacts of fire, it is important to establish information specifically related to wildfire.

We begin by looking at a preliminary formulation of a possible framework for organizing our thoughts about a social/economic analysis of the effects of a large-scale wildfire. We then describe four question areas that are considered in developing this analysis. We look briefly at the geographic scope of a social/economic analysis of the Hayman Fire. Next, we report on our findings for social and economic effects of the Hayman Fire. Then we turn our attention to a determination of what those individuals who live with the Hayman Fire and its aftermath every day have seen and learned. Next, we present some preliminary considerations pertaining to designs of social and economic monitoring systems for communities impacted by wildfire. We close with some conclusions and a review of key findings.

A Study Framework for Examining the Social/Economic Effects of the Hayman Fire

Our first step in trying to answer the above questions involved the definition of a study framework that facilitates identification of both Hayman Fire social/economic impacts and the individuals and organizations that were impacted. As an example of such a framework relating to social issues, Carroll and others (2000) conducted a social assessment for three Oregon communities that were impacted by wildfires on the Wenatchee National Forest in 1994. The primary purpose of their assessment was to determine the public's interest in fire recovery management on the Wenatchee in response to the 1994 fires. The framework they developed comprises five categories of people or organizations: (1) political coalitions such as those representing environmentalism and multiple use interests, (2) stakeholder groups such as civic leaders and residents directly effected by the fire, (3) residency tenure distinctions, or long timers and newcomers, (4) geographic divisions, or in town and up the valley, and (5) ethnic communities, or Latinos and non-Latinos. This framework of categories and descriptors was used to organize the data collected during interviews and also to help in understanding the data.

Butry and others (2001) modeled and analyzed the economic impacts of 6 weeks of large catastrophic wildfires that took place in northeastern Florida in 1998. Their framework consisted of seven categories of costs and losses: (1) presuppression costs, (2) suppression costs, (3) disaster relief expenditures, (4) timber losses, (5) property damage, (6) tourism-related losses, and (7) human health effects. As they note, this list is by no means complete, "as other potential costs and losses may exist (for example, lost wages, decreased quality of life, higher long-run fire expenditures, landscape rehabilitation, environmental degredation)."

Clearly, a social/economic framework designed for looking at most or all of the social/economic effects of the Hayman Fire would be considerably more complex than either of these examples. In addition, a complete analysis of all the social/economic consequences of the fire would require substantial resources and several years to complete because of the time needed for all impacts to play out. However, due to the need to complete this analysis by March 2003, the scope of this analysis is both broader in focus and shallower in depth than the example studies. It is broader in that it looks at other issues (although by no means all possible issues) in addition to fire recovery and economic costs, and it is shallower in that none of these issues are examined in as much detail as were the impacts/issues addressed in the example studies.

Our social/economic team explored possible designs for a framework to use for this analysis. We wanted a framework that would help us identify the key social and economic factors to consider in designing our analysis. In addition, we felt this exercise would assist in organizing our thinking. The first framework we considered involved the identification of four dimensions (when, who, what, and where), and a set of parameters associated with each dimension (table 1). The first dimension – when impacts occurred or will occur – breaks the overall timeline into three periods, before, during and after the fire. The second dimension – who was impacted – much like the Wenatchee study, divides people into categories: individuals, nongovernment organizations, governments, and markets. The third dimension or what is impacted includes money, attitudes and behaviors. Finally, the fourth dimension – where the impacts are felt – includes neighborhoods, communities, Counties, multicounty areas, States, and the Nation. In this model or framework each unique combination of dimension and associated parameter is a component of the entire picture of social/economic impacts arising from the Hayman Fire and therefore is a candidate for analysis.

Table 1—Four dimensional (when, who, what, and where) framework for Hayman Fire Social/Economic Review.

Dimension	Parameter
1) When	Before the fire During the fire After the fire
2) Who	Individuals Non-governmental organizations Governments Markets
3) What	Money Attitudes Behaviors
4) Where	Neighborhoods Communities Counties Multi-county areas States Nation

This framework clearly could be developed further, for example, by recognizing that there is some overlap across dimensions; that is, some organizations (say, volunteer fire departments) might fall into the who, the where, and the what dimensions. However, the simple version in table 1 already suggests more analysis possibilities than we had either time or funding to carry out. Therefore, we needed to refine the list of possible analysis topics into a manageable set, and we did this by translating the dimensions and parameters in the above framework into a series of four question areas. The criteria we used were the importance of the questions within in each question area, and the ease with which we could collect and interpret relevant data, where possible, taking advantage of work conducted as part of other ongoing and related projects.

Question Areas Identified by the Social/Economic Analysis Team

Our analysis addresses portions of four broad question areas that the team identified based on the framework in table 1. We do not provide full answers to all aspects of these question areas – they are all many faceted and complex. The four areas are:

1. How do we begin to get a handle on the various economic effects (both during and after the fire) associated with the Hayman Fire? Specific examples include:

- How were money and other resources utilized in fire suppression and postfire rehabilitation (BAER) and in the initial responses to the fire by communities? How do these costs compare to historic costs for other fires? Are they reasonable when factoring in the values of property etc damaged or destroyed, other values (for example, water quality), and in relation to the costs of prevention of postfiredamage including erosion?
- What impacts to society were caused by the fire (for example, tourism including hunting/fishing, other economic impacts, aesthetics, and so forth)?
- What values may be assigned to things that are at-risk due to postfire erosion, including soils, water quality, and so forth?
- What impacts pertaining to businesses and governments were caused by the fire (for example, property, business revenues, income taxes, sales taxes, property taxes, and so forth)?
- What is the value of lost human productivity and human health costs resulting from the fire?
- What are the equity considerations (who paid vs. benefited and individuals versus organizations) as a result of the fire?

2. How have stakeholder positions toward fuel treatments been influenced by the fire; in other words, what were they prefire and during the fire, and what are they now? How do stakeholders partition blame for the fire among various possible organizations, climatic conditions, and so forth? How do we work to collectively make progress on implementing fuels management treatments to reduce the risk of another Hayman Fire along the Colorado Front range in the future?

3. What have individuals, organizations, and communities learned from the Hayman Fire experience, what changes have they adopted, and how sustainable are these adoptions? How has the collaborative HayRAC project worked to facilitate the beginning of recovery for affected communities? What needs for additional education remain; for example, what does the general public need to know about forest management? How do we capitalize on the “teachable moment” that will exist only for a short while to get important lessons across? Is there a need to educate many on a wide variety of issues relating to natural resource management/wildfires? How do we institutionalize memories of lessons learned from the Hayman incident, especially in the face of a rapidly changing/growing population? In other words, how do we enhance community preparedness for future wildland fires?

4. How would we design and implement a long-term social and economic monitoring protocol for community impacts, recovery/rehabilitation needs, and risk preparedness following the Hayman Fire? What pieces of such a plan could be put into place in the near future?

Geographic Scale of the Analysis

In thinking about the area directly affected by a wildfire it is natural to think first about the area burned. Certainly, many of the most significant impacts are found only here. In the social/economic arena the most obvious example is structures/homes damaged or destroyed. However, as we have suggested above, social/economic effects of a fire such as the Hayman, reach far beyond the burn area. Figure 1 provides a partial picture by illustrating the four Counties within which the fire occurred. This fire

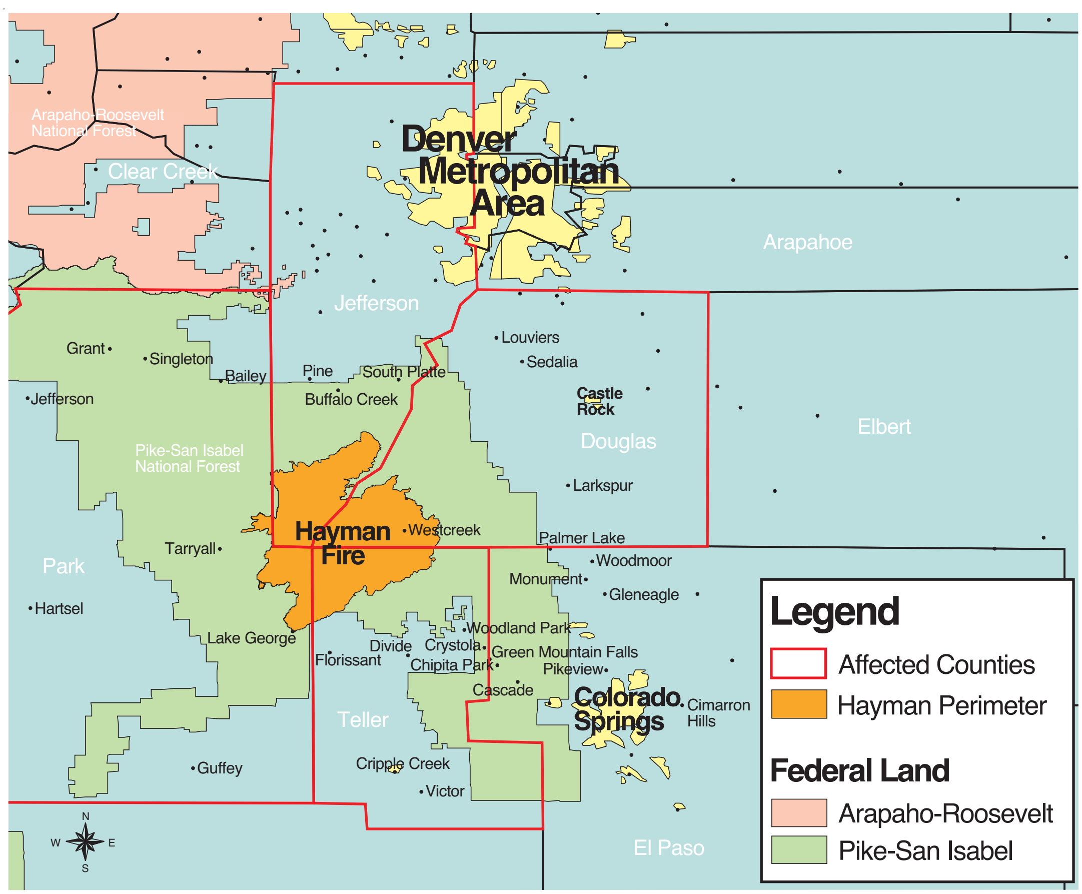

Figure 1—Map of the area influenced by the Hayman Fire from a social and economic perspective.

event has and will continue to make itself felt by virtually all social/economic systems in these Counties. Figure 1 also includes the Denver and Colorado Springs Metropolitan Areas as well as the area and communities in between. It is safe to say that many of these communities and their residents will also feel impacts from the fire, although perhaps not to the extent that residents of Park, Jefferson, Teller and Douglas Counties do.

As an example of the impacts on a community in the area, during the fire, consider the following. The city of Colorado Springs is the population and media center for southern Colorado. Although the fire did not reach the city, it directly impacted the city's emergency response resources and media. During the fire, the city committed operational and nonoperational resources to the effort. A task force of city engines was placed at the Rainbow Falls subdivision, and brush patrols were put in service along the shared boundary between the city and the Pike-San Isabel National Forest. The indirect impacts on the city included the threat to values at risk including water sources, communication sites and nonoperational resources. On June 19, Area Command tasked the Hayman East Type I Team (Vail, CO) with the production of a structure protection plan for El Paso County. (Information for this example was adapted from a letter from the Colorado Springs Fire Department, to RMRS Station Director Marsha Patton-Mallory, February 20, 2003.)

It is also safe to say that fire effects will stretch beyond the area shown in figure 1. As an example, there may be residents of other States who might have had a second or mountain home damaged or destroyed by the fire. Another example involves an individual or family that always vacationed in the area of the fire but no longer wishes to do so because of the loss of scenic beauty or some special favorite place.

Selected Economic Aspects of the Hayman Fire

The Hayman Fire was the largest recorded fire in Colorado's history, burning 138,114 acres in the four Counties of Douglas, Teller, Park, and Jefferson, with estimated suppression costs of over $42 million. Burned Area Emergency Rehabilitation (BAER) on Federal lands, including erosion control, noxious weed control, seeding, and so on, is expected to cost $24 million, with longer term restoration and rehabilitation projects estimated to cost another $37 million. Other related expenditures, such as rehabilitation on State and private land, water treatment, and evacuation costs add up to another $14 million. These costs, however, may be only a small part of the total cost of the fire. During the 41 days it took to control the fire, 600 structures burned, including 132 residences. The magnitude of other, less visible, effects is more difficult to assess. Water quality, erosion, tourism, property values, business revenues, income taxes, property taxes, and lost productivity are but some of the other values affected by the fire.

Though it is not really possible to assess the "total" economic cost of the Hayman Fire, or any large fire for that matter, it is important to be aware of the range of economic consequences associated with large wildfires. Another section in this case study entitled "A Framework for Anticipating and Understanding Economic Concerns Associated with Catastrophic Events Such as the Hayman Fire," presents an outline of the types of economic concerns that may be raised due to such an event. We have done our best to address many of these issues. Due to the limited time available to review the economic aspects of the Hayman Fire, however, it was not possible to complete such an indepth analysis. Instead, we tried to measure some of the more direct aspects, such as actual suppression and BAER expenditures, property losses, and changes in economic activity and resource values such as recreation visitation. Even these aspects have been difficult to assess within such a short period following the fire. For example, the most obvious economic aspect, the actual cost of suppression, may not be known for some time. On large fires, it is often 1 to 2 years before all of the actual expenditures are entered into the various agencies' accounting systems and all final accounting adjustments are made.

Methodology

Assessing selected economic aspects of an event such as the Hayman Fire can be a time-consuming and complex process. Analyses often take place several years after the event has occurred due to the time lag between the event and the availability of related economic data. Due to the timeframe for completion of this study, we restricted our analysis to those aspects for which we could collect adequate data in the time allotted. We collected information on the effect of the fire in four general areas: suppression and rehabilitation related expenditures, regional economic activity, property-related losses, and resource/output values.

Suppression and Rehabilitation Expenditures

We sought to answer two questions in this analysis: (1) how were money and other resources utilized in the Hayman Fire for suppression and postfire rehabilitation and (2) how do these costs compare to historic costs for other fires. To answer these questions we looked at expenditures on the Hayman Fire from five perspectives: (1) fire suppression expenditures as detailed in the financial system, (2) rehabilitation and restoration expenditures (both expended and planned), (3) daily expenditures (for both suppression and BAER), (4) other fire-related expenditures, and (5) comparison of expenditures on the Hayman compared to other historic fires in the same geographic area or of the same size. All monetary units were expressed in terms of constant 2002 dollars, based on the Gross Domestic Product Implicit Price Deflator.

Hayman Suppression Expenditures: Financial System: Expenditures associated with a specific wildfire correspond to different phases of firefighting and postfire activities. The action taken by those first to arrive at a fire is entitled initial attack. Initial attack is carried out when a fire is still small and limited firefighting resources are needed. If a fire (or "incident") is not contained/controlled by initial attack forces within a reasonable period and more resources are needed, the second phase, extended attack, is entered. Extended attack generally involves fires less than 100 acres, when the incident is expected to be controlled within 24 hours (NWCG 1998). For both initial and extended attack, actual expenditures for individual fires are almost impossible to ascertain from the Forest Service's financial system. Fires less than 100 acres (termed ABC fires) are generally charged to a forest's generic, ABC miscellaneous P-code (accounting codes used to track fire-related expenses are entitled P-codes since they consist of a "P" followed by five numbers). One ABC miscellaneous P-code may have hundreds of small fires charged to it; therefore, under the current system there is no way to match the actual expenditures from the financial system with individual fires.

Due to the inability to ascertain initial and extended attack expenditures for the Hayman Fire directly from the financial system, we obtained estimates of these expenditures from the Incident Cost Accounting and Reporting System (ICARS), a software application that can be used on incidents to track resources and expenditures (ICARS 2002a). From the ICARS database for the Hayman Fire (ICARS 2002b), we obtained an estimate of daily expenditures by P-code, including estimated charges to the ABC miscellaneous P-code. However, because of the rapid progression of the fire, the line between initial and extended attack and expansion to a larger firefighting force is unclear in the ICARS data. There was $9 million worth of expenditures in ICARS that were not assigned a P-code of any kind. We approximated the amount spent on initial and extended attack by counting the first day of these uncoded expenditures as initial and extended attack activities, as well as counting the charges to the miscellaneous ABC P-code.

Once it is determined that a fire will not be contained within the first operational period, the transition is made to a larger, more complex firefighting force. When this happens, a fire is assigned its own unique P-code to track fire-related expenditures. Therefore, once it was determined that the Hayman Fire would pass the extended-attack phase, which actually happened the first day of the fire, it was assigned a unique P-code, thereby enabling detailed expenditure information to be obtained from the Forest Service's financial system. In fact, the Hayman Fire was actually assigned three unique P-codes during the course of the fire. The initial P-code was established the first day when it was determined that the fire would pass the initial/extended attack phase. On June 9, it was decided that because of the fire complexity, the fire would be split into two parts, on a north/south basis, and a second incident management team would be ordered. On June 11, the actual split was made and the second P-code for the North Hayman was assigned (the first unique P-code established June 8 was designated for the South Hayman). Starting on June 18, the fire made a run toward the eastside of the fire perimeter, jumping over Highway 67 in some places. The concern was that the fire might continue to move east, or even southeast toward the development of Woodland Park. At this time a third incident management team was assigned, as well as a third P-code, for what was now designated the East Hayman (Moore, personal communication).

In addition to Forest Service expenditures, we also collected expenditure information for the other agencies involved in fighting the Hayman Fire. All five Federal agencies with firefighting capabilities and responsibilities (USDA Forest Service, USDI Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service, and National Park Service) contributed resources to fighting the Hayman Fire. Inquiries were sent to each of these agencies to obtain detailed fire suppression expenditure information from their financial systems. We also attempted to obtain expenditure information from the State of Colorado and the Counties involved in fighting the Hayman. However, we were unable to get anything other than a lump-sum figure of what the State and Counties spent; detailed information on the types of expenditures was unavailable at the time of this report.

Hayman Rehabilitation and Restoration Expenditures: In addition to expenditures spent fighting a fire, money is also spent after a fire for rehabilitation and restoration. BAER treatments, such as mulching, log erosion barriers, and seeding or scarification, are conducted within a short period after the fire (up to a year) to prevent erosion and control noxious weeds. Forest Service BAER expenditures associated with a given fire are given their own accounting code, consisting of the same five numbers as the P-code assigned to the fire, preceded by an "H" instead of a "P". We obtained detailed BAER expenditure information for the Hayman Fire directly from the Forest Service's financial system. We also obtained BAER expenditures from the other involved Federal agencies as well as the Natural Resource Conservation Service (NRCS) and Denver Water. The NRCS provides grants to conduct rehabilitation on State, County, and private lands. These are matching grants, with the NRCS providing 75 percent of the project funding and the landowner providing the remaining 25 percent. Personnel from Denver Water provided data on rehabilitation efforts on lands within the Denver municipal water system.

In addition to BAER treatments, other longer term (1 to 5 years) restoration and rehabilitation projects are also carried out by the Forest Service to mitigate the effects of a fire. These projects include restoring trails, campsites, and watersheds. Information on these longerterm projects was obtained directly from the Pike-San Isabel National Forest.

Daily Suppression and BAER Expenditures on the Hayman: ICARS: Using the ICARS database for the Hayman Fire, we estimated daily expenditures for both fire suppression and BAER by resource type. We aggregated these data into seven resource categories: (1) aircraft – air tankers, helicopters, lead planes, and so forth, (2) crews – the actual hand crews fighting the fire, (3) camp support – resources to support activity at the camp such as vehicles, camp crews, facilities, and caterers, (4) direct personnel – Incident Command staff as well as any individual that has direct duties on or around the fire line, (5) indirect personnel – personnel other than direct personnel, (6) equipment – dozers, engines, water tenders, and so forth, and (7) supplies. These daily data were available from the start of the fire on June 8, 2002 to August 3, 2002, the last entry in the database. Consequently, daily estimates of suppression expenditures were available for the entirety of the suppression effort, but BAER expenditure estimates are not complete. Additionally, ICARS data were available for the South Hayman only; information on the North Hayman and the East Hayman are missing.

Other Expenditure Data: Data on FEMA reimbursements to Counties for roadblocks, traffic control, evacuations, and other nonsuppression fire expenditures associated with the Hayman were provided by the Colorado Department of Forestry. Red Cross expenditures for disaster relief on the Hayman Fire were calculated by Dennis Lynch, Forest Science, Colorado State University. The Red Cross provided Dr. Lynch with a consolidated cost for disaster relief for catastrophic fires in Colorado in 2002. He obtained information on the fires that were not evacuated and subtracted the acres burned on these fires from the total acres burned in Colorado in 2002. He divided the remaining acres (for evacuated fires) into the consolidated costs to calculate a cost per acre. He then used this cost per acre to arrive at an estimate of the amount spent by Red Cross on the Hayman Fire.

Historical Comparisons: Finally, to put the Hayman Fire into historic context, we needed historical data on fire expenditures and fire occurrence. Data on actual Forest Service expenditures (suppression and BAER) were obtained from Forest Service accounting systems (Central Accounting Data Inquiry—CADI (pre-fiscal year (FY) 2000) and Foundation Financial Information System—FFIS (FY 2000 and beyond)). Fire occurrence information such as acres burned was obtained from the National Interagency Fire Management Integrated Database (NIFMID).

Regional Economic Activity

The goal of our inquiry into regional economic aspects of the Hayman Fire was simple: we sought to describe historical economic activity in a multicounty impact area, by semidetailed industrial classification, and how that activity level changed during the fire and the months immediately thereafter. To accomplish this, we: (1) identified appropriate geographical impact areas; (2) identified economic activities and industrial sectors of concern; (3) specified an analytical procedure, complete with appropriate statistical tests; and (4) collected data needed to implement the analytical procedure.

Geographical Impact Areas: The Hayman Fire took place in central Colorado, and its extent touched on four Counties: Douglas, Jefferson, Park, and Teller. We term these Counties the Primary Impact Area, but clearly there are other geographical perspectives that should be addressed. For instance, there is an issue of displaced economic activity. Economic activity lost by a County in the Primary Impact Area might be gained by an adjacent County. We addressed this issue with a Secondary Impact Area consisting of the 13 Counties bordering the Primary Impact Area. This area includes Adams, Arapaho, Boulder, Broomfield, Chaffee, Clear Creek, Denver, Elbert, El Paso, Fremont, Gilpin Lake, and Summit Counties. Because of the dominating role of Denver County, we assessed the Secondary Impact Area with and without Denver County. Finally, because of the statewide notoriety of the Hayman Fire and concern over its effect on the entire state, our third geographical impact area was the entire State of Colorado.

Economic Activities: There are numerous ways of describing the economy of an area. At the national level, measures derived from income and national product are common, such as national income and gross national product. Our analytical needs, however, required us to use measures of economic activity that were available: (1) for detailed industrial sectors, (2) by month, (3) for an extended period of time, and (4) at the County level. Those requirements excluded nearly all measures of economic activity. In the end, we selected three measures: wages (including salaries), employment, and retail sales. Data on wages along with employment are the basic data from which national income accounts derive. These data stem from ES-202 reports filed by employers as part of the Federal unemployment insurance process. Quarterly reports, containing monthly employment and wage information, are filed with the Colorado Department of Labor. These records do not cover the entire spectrum of economic activity because not all sectors and employers are liable for unemployment insurance payments. Importantly, employers with few employees and sole proprietorships do not file reports. Data on retail sales are collected by the Colorado Department of Revenue for purpose of calculating sales tax liability.

Economic Sectors: An economy is divided into numerous sectors, such as manufacturing, construction, and retail sales. There exist two taxonomies by which industrial sectors and related information are organized. Prior to 2000, the Standard Industrial Classification system (OMB 1987) was used throughout the United States. As a result of considerations prompted by the North American Free Trade Act, the North American Industrial Classification System was adopted for use in the United States, effective in 2000 (USDC-BOC 2003). Both systems are hierarchical, but the crosswalk between them is less than perfect. These industrial classification systems are important to our research because firms providing information on economic activity are classified under the hierarchical system, and economic information is aggregated and disaggregated according to the prescribed taxonomy. Although our time series data reflect both classification systems (SIC for 1999-2000 and NAICS for 2001-2002), we defined sectors according to the Standard Industrial Code. For purposes of our research, we chose to focus on entire economies of impact areas (that is, all industrial sectors) and on featured sectors. The sectors we chose to feature were the sectors thought to be most reflective of tourism and potentially most affected by the Hayman Fire. We chose to feature the Lodging sector (all SIC 70's, includes hotels, rooming houses, camps, and other lodging places), the Eating and Drinking sector (all SIC 58's), and the Recreation sector (all SIC 799's, including miscellaneous amusement and recreation services, such as physical fitness facilities, public golf courses, sports and recreational clubs, boat and canoe rental, hunting guides, and so forth).

Analytical Procedures and Tests: In a test-tube world, we would determine the effect of the Hayman Fire on regional economic activity by running the economy without the fire and rerunning it with the fire, the difference being the effect of the fire. In essence, we attempted to analytically model that difference. The first step was to develop statistical models describing the prefire economic activity situation. We collected monthly data (by economic activity, economic sector, and geographical area) from January 1999 through September 2002 (the most recent quarterly data then available). These data constituted the dependent variables ("Y").

Selection of independent variables was influenced by several considerations. Specifically, we wanted to model economic activity in the impact areas while accounting for: (1) national economy, (2) regional trends, (3) recent activity, (4) seasonal trends, and (5) the 9/11/2001 event. The general approach to independent variables was used consistently in all models with the intent of promoting statistical estimation efficiency and comparability of results:

USPCDPI	=	United States Per Capita Disposable Personal Inc…accounts for trends in the national economy.
Colorado "Y"	=	Equivalent economic activity for larger without impact area…accounts for statewide trends in economic activity.
"Y" lagged	=	Economic activity for the impact area lagged one month …accounts for linkage between past and present activity.
Dummy variables	=	June, July, August, December…accounts for seasonal differentials.
Dummy variable	=	9/11 …accounts for change differential in economic activity.

For example, we built a statistical model to estimate lodging sector employment in the Primary Impact Area that used: (1) USPCDPI; (2) lodging sector employment in Colorado, excluding the Primary Impact Area; (3) lodging sector employment in the Primary Impact Area the previous month; and (4) five dummy variables to account for 9/11 and seasonal variation. All monetary units were expressed in terms of constant 2002 dollars, based on the Gross Domestic Product Implicit Price Deflator.

Using the variable configuration just described, we built 88 multiple linear regression models, one for every relevant combination of economic activity, industrial sector, and geographical area. These prefire models were based on data from January 1999 through

May 2002. We used all coefficients from these prefire models to estimate levels of economic activity for the fire months (June and July) and the postfire months (August and September). These estimates represented what could be expected to happen to regional economic activity without the Hayman Fire. We also had available the actual levels of economic activity, with the Hayman Fire. The deviation between the estimated level of economic activity (from the prefire models) and the actual level represented changes in economic activity occurring during the summer of CY 2002. We used the standard error of the estimate from the prefire models to establish 95 percent confidence intervals around deviations from the June to September estimates of economic activity. We noted whenever actual economic activity exceeded the bounds of the upper or lower confidence interval for the deviations.

Data Sources: Data needed to perform analyses of regional economic activity came from three sources. Data on United States per capita disposable personal income and the GDP implicit price deflator were developed by the USDC-Bureau of Economic Analysis (USDC-BEA 2003). Data on retail sales (CDR 2003) were provided by the Office of Tax Analysis, Colorado Department of Revenue (Donna Stepan). Data on salary, wages, and employment (CDL 2003) were provided by the Colorado Department of Labor (Bill Harris) through the Colorado Demographer's Office (Cindy DeGroen), as facilitated by the Forest Service's Inventory and Monitoring Institute (Susan Winter). Wage, salary, and employment data result from a mandatory, quarterly report. Final, third-quarter data were not available for the study, but the Colorado Department of Labor provided preliminary data.

Property-Related Losses

We contacted the County assessors in Douglas, Teller, Park, and Jefferson Counties and requested data on real property-related losses associated with the Hayman Fire. Each assessor's office provided estimates of total real property loss, assessed value of the property loss, and the effects of the loss in property value on County tax receipts. We also contacted the Rocky Mountain Insurance Information Association for data on insured property losses derived from a survey of major insurance companies. The Small Business Administration provided information relating to long-term, low-interest loans for uninsured property and business losses and the Federal Emergency Management Agency (FEMA) provided information on grants issued to individuals with specified losses associated with the Hayman Fire. A number of power lines were destroyed due to the Hayman Fire and Excel Power and Intermountain Rural Electric Association provided data on the value of these lost power lines.

Resource Outputs and Values

Resource outputs and values were divided into the effects of the Hayman Fire on: (1) tourism and recreation and (2) other resource outputs and values. Tourism and recreation information includes recent trend data for developed recreation sites, outfitters and guides, and campsite cancellations, as well as anecdotal information of individual tourism-related losses. Other resource outputs and values pertained to Forest Service resource losses, including timber, forage, water storage, fisheries and wildlife, and recreation.

Tourism and Recreation: Data for developed recreation sites (fee day use areas and campgrounds) came from reports provided by the two concessionaires that manage developed areas within the three affected Ranger Districts of the Pike-San Isabel National Forest (Pikes Peak, South Platte, and South Park Ranger Districts). The Rocky Mountain Recreation Company manages recreation sites within the Pikes Peak and the South Platte Ranger Districts, while Canyon Enterprises Inc. manages sites within the South Park Ranger District. Monthly visitation data were obtained for January 2000 through December 2002.

We also explored the effects of the Hayman Fire on visitation to several developed recreation sites outside the Pike-San Isabel National Forest but near the fire perimeter. All sites reviewed remained open throughout the Hayman Fire event. Monthly visitation data were obtained for January 2000 through December 2002 for Florissant Fossil Beds National Monument, Pikes Peak Cog Railway and Toll Highway, and Eleven-Mile State Park.

Actual use data for outfitters and guides with permits to operate on the three affected districts of the Pike-San Isabel were obtained from actual use reports and the Special Use Database System. These data are maintained at the individual Ranger Districts and are measured in terms of annual National Forest Service client days for 2000, 2001, and 2002.

Changes in dispersed recreation visitation patterns due to the Hayman Fire could not be identified. However, the National Visitor Use Monitoring Results (NVUMR) conducted on the Pike-San Isabel National Forest in 2001 provides reference visitation data for total visitation and wilderness visitation. Additionally, recent research into the effects of forest fires on dispersed recreation behavior was reviewed.

It is difficult to determine if individuals who had planned to visit areas closed due to the fire made alternative recreation plans, and where they went instead of the Pike-San Isabel National Forest. We explored the effects of the closure order on individuals who made reservations through Reserve America, a nationwide system that allows users to make reservations for Forest Service and other Federal land campgrounds. All individual cancellations associated with the Hayman Fire closure were noted, as well as if subsequent reservation to an alternative campground within the system was made, and if so, the location of the subsequent reservation. Additionally, a survey question contained within the 2001 NVUMR report asked individuals what substitute behavior they would have participated in if the recreation area where they were interviewed had been closed.

Anecdotal information relating to financial losses associated with the Hayman Fire was obtained from telephone interviews with representatives from the Girl Scouts of America and the Lost Valley Guest Ranch. These organizations were identified as having been significantly impacted by the Hayman Fire.

Other Resources: Resource value losses to the Forest Service in terms of mature timber, forage, water storage, fisheries and wildlife, and recreation were estimated within the Wildland Fire Situation Analysis (WFSA) system by Ted Moore, Fire Management Officer, Pike and San Isabel National Forest. In discussion with Ted Moore, it was determined that the valuation of timber-related losses within WFSA was inadequate for our purposes; therefore, we estimated timber value losses by combining reports from the National Fire Management Analysis System (NFMAS) and fire intensity maps of the Hayman Fire event. The NFMAS system identifies estimated timber value loss by fire intensity level for the six forest management zones on the Pike-San Isabel National Forest that burned during the Hayman Fire. These results were overlaid with fire intensity maps to determine total timber value losses. The analysis using WFSA and NFMAS data provides a coarse overview of general long-term resource losses to the Pike-San Isabel National Forest. Information on specific short-term losses to the recreation and timber programs were provided by Lance Tyler, Recreation Program Manager, Pike-San Isabel National Forest, and Gary Roper, Timber Program Manager, Pike-San Isabel National Forest.

Results

The results that follow give an overview of some of the economic consequences of a fire as large and severe as the Hayman occurring in such proximity to populated areas. We have, in no way, attempted to measure the "total" economic consequences of this fire. Given the timeframe of this study, we restricted our analysis to those aspects for which we could collect adequate data in the time allotted. We collected information on the effect of the fire in four general areas: (1) suppression and rehabilitation related expenditures, (2) regional economic activity, (3) property-related losses, and (4) resource/output values. However, even in these four areas, the picture is somewhat incomplete. For instance, the cost of rehabilitation may not be known for years. Additionally, data on regional economic activity was available only through September of 2002; therefore, we were unable to conduct a long-term "after the fire" analysis. Any downturns, or upturns, in the economy could not be followed forward in time from the fire to see how the economy adjusted.

Suppression and Rehabilitation Costs: Before concentrating on the details of suppression and rehabilitation expenditures for the Hayman Fire, it might be helpful to step back and assess these expenditures in a broader context. Figure 2 shows fire suppression expenditures (2002$) by the Forest Service's Rocky Mountain Region (Region 2) from FY 1970 to 2002. It also shows the amount of money spent by all Forest Service firefighting organizations to suppress fires occurring in Region 2's geographic area (Colorado, Nebraska, Kansas, and parts of South Dakota and Wyoming) since 1995. Forest Service regional expenditures for fires can be thought of in two ways: (1) expenditures by the organizational unit known as a region (such as Region 2), which consist of expenditures for firefighting resources employed by that region regardless of where those resources are sent (within that region or to another region) or (2) expenditures on fires occurring within the region's geographical bounds regardless of who is sending and paying for the firefighting resources.

As can be seen, FY 2002 was an extremely expensive fire season for Region 2. Over the last three decades, Region 2's annual fire suppression expenditures averaged $8 million (not counting FY 2002). Before FY 2000, only 2 years—FY 1988 and FY 1996—saw expenditures as high as $20 million. Concentrating on the period from FY 1995 to 2001, for which we have data on both suppression expenditures *by* Region 2 (the organization) and *in* Region 2 (the geographic area), annual fire suppression expenditures by Region 2 averaged $14.5 million and Forest Service suppression expenditures for fighting fires in Region 2 averaged $16 million. FY 2002 was a record-breaking year. Expenditures spent fighting fires in Region 2 totaled $182 million, more than four times the amount spent in FY 2000, the next most expensive year. Although the $38 million in Forest Service expenditures accounted for only about 20 percent of this total, it is obvious that the Hayman Fire was expensive. More money was spent on suppressing the Hayman Fire than the total, yearly, suppression expenditures either by Region 2 or in Region 2 in any year except FY 2000 or FY 2002.

FY 2002 was also an extraordinarily expensive year for BAER (fig. 3) primarily due to the Hayman Fire. Previous to FY 1996, BAER expenditures by Region 2 averaged $140,000 per year (2002$). Starting in FY

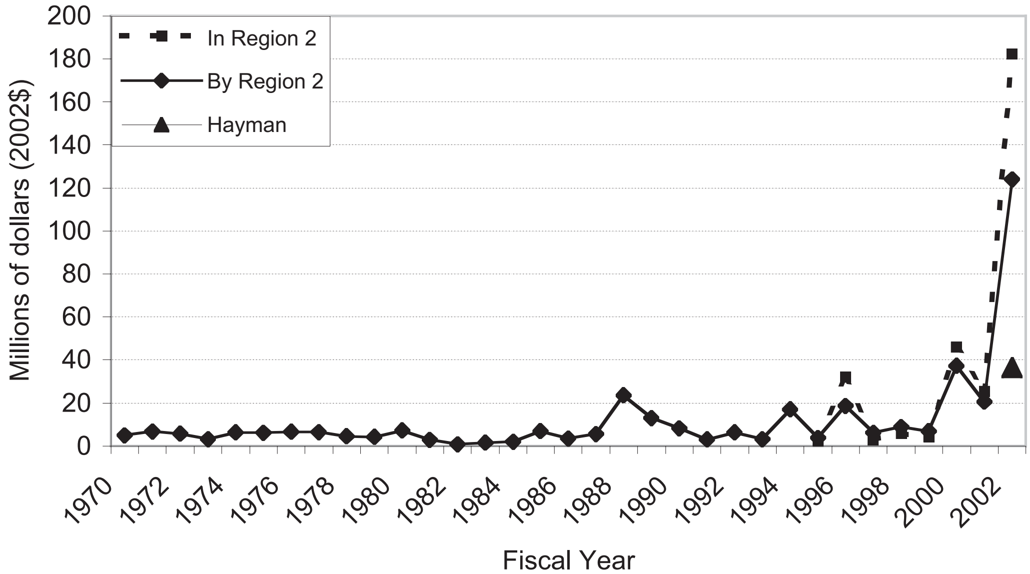

Figure 2—Forest Service fire suppression expenditures (2002$) - Region 2. (Source: USDA Forest Service financial accounting systems)

1996, BAER expenditures began to increase, averaging slightly more than $735,000 from FYs 1996 through 2001. In FY 2002, BAER expenditures by Region 2 reached $22 million, 29 times the 1996 to 2002 average, $14 million of which was attributable to the Hayman Fire.

Looking at the fire from another perspective, we might ask if the Hayman Fire was so expensive because it was so large or if it was so expensive because the cost per acre was much higher than average. If we take the initial $38 million spent by the Forest Service on this fire (before the cost-share agreement was finalized with the State of Colorado) and divide it by 137,760 acres, the cost per acre is around $273. According to NIFMID (National Interagency Fire Management Integrated Database), the fire reporting sys-

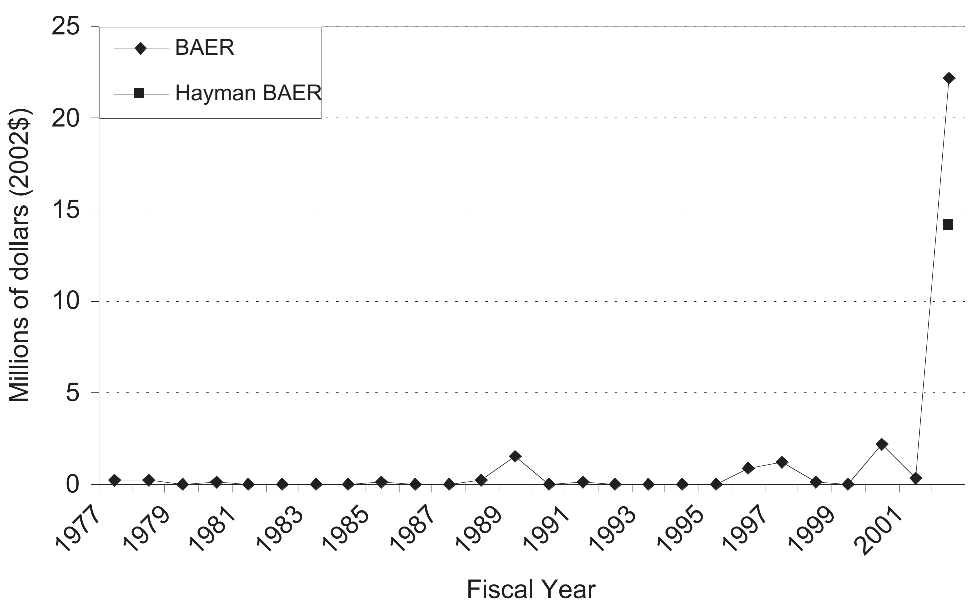

Figure 3—Forest Service, Region 2, Burned Area Emergency Rehabilitation expenditures (2002$). (Source: USDA Forest Service financial accounting systems)

tem used by the Forest Service, since 1970 the Forest Service has been involved in the suppression of 12 fires in Colorado which burned more than 10,000 acres: one in FY 1980, two in FY 1996, two in FY 2000, and seven in FY 2002. The cost per acre on these fires varied widely, from a low of $59 to a high of $522 (both in FY 2002).

Looking at the individual years, no cost information was available for the fire in FY 1980. For the two fires in FY 1996, each of which burned just a little over 10,000 acres, suppression expenditures were about $136 per acre (2002$), substantially less than the $273 per acre for the Hayman Fire. The two fires occurring in FY 2000, each of which also burned a little more than 10,000 acres, cost more than $300 per acre, $349 for one and $509 for the other (2002$), substantially more than for the Hayman Fire. In FY 2002, the cost per acre for the six fires (not counting the Hayman) reported in NIFMID was highly variable: one fire was below $100 per acre, three were between $100 and $200 per acre, and two fires were above $400 per acre. A study conducted by the Rocky Mountain Research Station (RMRS) of Forest Service fires in FY 1996 and 1997 in the western Forest Service regions of the United States (Forest Service Regions 1-6) (unpublished data on file at RMRS, Missoula, MT) showed that G+ fires (fires greater than 5,000 acres) averaged about $568 per acre, with costs ranging from $30 per acre up to $2,900 per acre. This average is significantly higher than the cost per acre for the Hayman Fire. When we restrict the analysis to fires burning 50,000 or more acres, the cost per acre averaged $211, less than the $273 per acre for the Hayman. Suppression expenditures vary widely from fire to fire because many factors have the potential of affecting per acre expenditures, such as topography, access, infrastructure, and the number of acres, though little empirical evidence exists to support these claims.

However, it should be noted that studies have shown that the cost per acre for suppressing fires tends to decline as the number of acres increases (see Schuster and others 1997). The reason for this is not known, but it is widely suspected that larger fires have a greater amount of unburned acres within their perimeter than do smaller fires, thus understating the true cost per acre. According to the Hayman BAER Team, 21,200 acres within the fire perimeter were unburned, or conversely, 116,400 acres were burned. The cost per acre computed using 116,400 acres rather than 137,600 comes to $324, higher than the two fires in FY 1996, but still lower than many of the other Colorado fires. The cost per acre of larger fires may also be lower due to economies of scale: fixed costs are spread out over more acres.

Based on these comparisons, the per acre cost of the Hayman Fire does not seem excessively high. It appears that the large amount of money spent to suppress this fire was largely due to the large land area burned rather than to an extremely high cost per acre. If this fire had occurred in a less populated area, the cost per acre may have been even lower. Much of the suppression effort, both because of the proximity to populated areas and the extreme fire behavior, was focused on protecting structures. Though the State of Colorado provided many of the resources for structure protection, even if we add their estimated expenditures, the cost per acre still is less than $300 per acre. The fact that the cost of structure protection is being spread over such a large acreage tends to make the cost per acre lower than if the same structure protection had been done on a smaller fire (Moore, personal communication).

Fire Suppression Expenditures on the Hayman: We turn now to the specifics of the Hayman Fire itself. From the ICARS data, it was difficult to distinguish initial or extended attack expenditures. The fire grew so rapidly that the line between initial and extended attack and large fire operations is blurred. Charges to the ABC miscellaneous P-code amounted to about $86,000; 65 percent was for hand crews and the remaining 35 percent was classified as support. However, there is also approximately $19,000 worth of estimated expenditures on the first day that were not assigned any sort of P-code in ICARS—74 percent of this was spent on hand crews, 13 percent on camp support, and 6 percent each on aircraft and direct personnel. Because of the difficulty of separating initial/extended attack from the large fire expenditures, the remainder of the report does not make the distinction between the two.

As of May 2003, the bill for suppressing the Hayman Fire came to approximately $42 million (table 2). Initially, expenditures by the Forest Service accounted for 89 percent of suppression expenditures. The Bureau of Land Management spent another $2 million, the State of Colorado spent $1.5 million, and the remaining Federal agencies spent relatively little on the fire.

The final determination of financial responsibility between the Forest Service and the State of Colorado, however, is determined through a cost-share agreement between the two agencies. Initial expenditures by the Forest Service are later allocated between the Forest Service and the State, mainly according to acreage, with a few exceptions. Aviation support costs for the first 72 hours (approximately $495,000) and the expenditures on the East Hayman (approximately $215,000) are to be split 50/50 between the Forest Service and the State. Remaining expenditures are to be allocated according to acreage, with 85 percent of the acres and, therefore, the expenditures

Table 2—Fire suppression and BAER expenditures, as of May 2003 by agency. (Source: USDA Forest Service and USDI financial accounting systems, Colorado State Forest Service)

	FS	BLM	BIA	FWS	NPS	State/local	Total
	Thousands of Dollars						
Before Cost-Share Agreement							
Suppression	37,698	2,265	196	148	397	1,527	42,231
BAER	23,709	—	—	54	48	—	23,811
After Cost-Share Agreement							
Suppression	31,886	2,265	196	148	397	7,339	42,231

Note: This table reflects agency expenditures as shown in the financial systems as of May 2003 and does not reflect the cost share agreement between the Forest Service and the state of Colorado.

being Forest Service responsibility and 15 percent State responsibility. The cost share agreement shows a total of $37,120,356, of which the Forest Service is accountable for $31,307,872 and the State of Colorado for $5,812,785. These numbers differ from the original expenditures shown in the top section of table 2, which are the expenditures showing up in the financial systems as of May 2003 and do not reflect any billing as a result of the cost share agreement. When all adjustments have been made, expenditures among agencies should be as shown in the bottom section of the table: approximately $32 million for the Forest Service and $7.3 million for the State of Colorado (the $5.8 million share of the initial Forest Service expenditures and $1.5 million of additional expenditures by the State). Additional expenditures ($578,000) showing up in the Forest Service's financial system after finalization of the cost share agreement have been added to the Forest Service amount, which is why the Forest Service expenditures shown in the bottom section of table 2 ($31,886,000) do not equal the amount stated in the agreement ($31,308,000). For the remainder of this report, Forest Service expenditures will reflect expenditures before any cost share adjustments since these adjustments are not yet reflected in the financial system.

To begin to answer the question of how money and other resources were utilized in the Hayman Fire for suppression, we broke down the expenditures by each Federal agency into four categories: Personnel Compensation (including benefits), Personnel Travel, Supplies and Services, and Other. A breakdown of expenditures by category was not available for the State expenditures, so the following discussion does not include State expenditures. Overall, about 23 percent of expenditures were for Personnel Compensation, including base pay, overtime, hazard pay, and so on (table 3). Supplies and Services, which include contractual services such as flying contracts, catering services, and so on, as well as cooperative agreements with State agencies, accounted for 74 percent of expenditures. In other investigations of fire suppression expenditures undertaken by the RMRS (unpublished analyses on file at RMRS, Missoula, MT),

Table 3—Fire suppression expenditures for the Hayman Fire, by category and Federal agency, as of May, 2003. (Source: USDA Forest Service and USDI financial accounting systems)

	Agency					
Category	**FS**	**BLM**	**BIA**	**NPS**	**FWS**	**Total**
	Thousands of dollars					
Personnel compensation	6,987	1,537	160	344	127	$9,155
Personnel travel	1,121	130	7	37	20	$1,316
Supplies and services	29,502	423	29	16	1	$29,971
Other	88	175	—	—	—	$263
Total	$37,699	$2,265	$196	$397	$148	$40,705

Note: Breakdown by expenditure category not available for State/local expenditures. Also, Forest Service expenditures do not reflect any adjustments due to the cost share agreement between the Forest Service and the State of Colorado.

expenditures on Personnel Compensation averaged somewhere around one-third of total expenditures, indicating relatively less money was spent on the Hayman Fire for personnel expenses and more for contractual services, such as flying contracts, than is usually the case. The distribution of expenses for the Hayman, however, varies widely by agency. For the Forest Service, personnel expenses made up only 19 percent of the total, with nearly 78 percent of expenditures going to supplies and services. Conversely, the other Federal agencies spent the vast majority of their money on personnel expenses, with Personnel Compensation ranging from 68 percent for the Bureau of Land Management to a high of 87 percent for the National Park Service.

To gain further insights into how money was spent suppressing the Hayman Fire, table 4 shows the breakdown of Forest Service expenditures by major BOC (budget object class) and by P-code (South Hayman, North Hayman, East Hayman). (Budget object classification codes are used by the Federal government to record its financial transactions according to the nature of services provided or received when obligations are first incurred; classes consist of major budget object classes, at the two-digit level, such as 1100, 2500, and so forth, with more specific breakdowns at the three- and four-digit level, such as 1101, 2540, 2541,and so on). For the categories containing the majority of expenses, a more detailed breakdown is provided in table 4. Other agencies are not included

Table 4—Forest Service fire suppression expenditures on Hayman Fire as of May 2003 by budget object category and incident. (Source: USDA Forest Service—Foundation Financial Information System)

Major BOC	Description	Expenditures (thousands of dollars)							
		South Hayman		North Hayman		East Hayman		Total	
		Dollars	Pct of total	Dollars	Pct of total	Dollars	Pct of total	Pct of Dollars	total
0200	**Internal Transactions**	**20**	**<0.1**	**—**		**—**		**20**	**<0.1**
1100	**Personnel Compensation**	**4,905**	**17.8**	**1,369**	**13.9**	**101**	**47.0**	**6,375**	**16.9**
*1101**	*Regular pay - FT-permanent employees*	*960*		*285*		*27*			
1121	*Regular pay – FT-temporary employees*	*262*		*94*					
1165	*Hazard pay*	*282*		*81*					
1170	*Overtime*	*2,466*		*718*		*58*			
1193	*Casual employment*	*802*		159		8			
1200	**Personnel Benefits**	**463**	**1.7**	**139**	**1.4**	**11**	**5.1**	**613**	**1.6**
2100	**Travel/Transportation of Persons**	**788**	**2.9**	**301**	**3.0**	**32**	**14.9**	**1,121**	**3.0**
2200	**Transportation of Things**	**207**	**0.7**	**4**	**<0.1**	**—**		**211**	**0.6**
2300/ 2400	**Rent,Communications, & Utilities/Printing**	**684**	**2.5**	**43**	**0.4**	**11**	**5.1**	**738**	**2.0**
2500	**Other Services**	**19,407**	**70.3**	**7,825**	**79.3**	**51**	**23.7**	**27,283**	**72.4**
2540	*Contractual Services - Other*	*7,850*		*4,567*		*21*			
2541	*Flying Contracts*	*7,250*		*2,723*		*10*			
2550	*Agreements*	*1,475*		*82*					
2551	*Cooperating State Agencies*	*919*		*291*					
2600	**Supplies/Materials**	**1,080**	**3.9**	**180**	**1.8**	**9**	**4.2**	**1,269**	**3.4**
4100	**Grants/Subsidies/ Contributions**	**52**	**0.2**	**11**	**0.1**	**—**		**63**	**0.2**
4200	**Insurance Claims/ Indemnities**	**5**	**<0.1**	**<1**	**<0.1**	**—**		**5**	**<0.1**
4300	**Interest/ Dividends**	**<1**	**<0.1**	**<1**	**<0.1**	**—**		**<1**	**<0.1**
Total		**$27,612**	**100%**	**$9,872**	**100%**	**$215**	**100%**	**$37,698**	**100%**

*Detailed breakdown within major BOC only for categories with substantial expenditures; detailed expenditures will not add up to major categories.
Note: FS expenditures do not reflect any adjustments due to the cost share agreement between the FS and the State of Colorado.

in the BOC breakdown because the Forest Service was responsible for the vast majority of the expenditures. Appendix I provides a detailed description of the BOCs discussed below.

The categories "Other Services" (BOC 2500), which includes contractual services such as flying contracts and catering services, and Personnel Compensation and Benefits (BOCs 1100 and 1200), account for 91 percent of expenditures. Travel (BOC 2100), Rent, Communications and Utilities/Printing (BOCs 2300 and 2400), and Supplies and Materials (BOC 2600) each accounted for another 2 to 3 percent of suppression expenditures and included items such as equipment rental, domestic transportation, car rentals, general supplies and materials, and office supplies.

Nearly three fourths of Forest Service expenditures ($27.2 million) was spent on "Other Services" - 46 percent of these expenditures ($12.4 million) were coded as "Contractual Services – Other" (BOC 2540) and 37 percent ($10 million) as "Flying Contracts" (BOC 2541). "Contractual Services – Other" is a budget object classification code used for contractual services not otherwise classified in the budget object class system, and may include such items as mobile food, mobile commissary, and shower facilities. A large amount of expenditures can get charged to a general category, such as "Contractual Services – Other" for two reasons. First, there may not be a finer breakdown for a particular expense, such as shower facilities. Second, personnel entering expenditures into the financial system may use the more general two- or three-digit class rather than coding the expenditures at a more specific level, the four-digit class, even if a more specific classification exists. This causes problems in interpreting the data from the financial system. For instance, the 37 percent of expenditures coded as "Flying Contracts" may not be the only expenditures for flying contracts. Flying contracts may be entered under the more specific BOC 2541, or under the more general BOC 2540. It may be, therefore, that some flying contract expenditures are included in the $12 million for BOC 2540. However, the expenditures from the financial system roughly compare with the proportion of expenditures spent on aircraft from the ICARS data, indicating that the coding in the financial system was probably done correctly. The BOC data from the financial system shows that 26 percent of total expenditures were coded to BOC 2541, Flying Contracts. The ICARS data show that 25 percent of suppression expenditures were spent on aircraft. The rest of the expenditures in the category "Other Services" were mainly spent on Agreements (BOC 2550) and Agreements with Cooperating State Agencies (BOC 2551).

The majority (51 percent) of the $6.4 million spent on Personnel Compensation was for overtime (BOC 1170). Regular base pay, including salaries for full-time permanent employees (BOC 1101), full-time temporary employees (BOC 1121), and casual employees (BOC 1193) made up another 40 percent of personnel expenditures, with hazard pay (BOC 1165) accounting for 6 percent. Other types of personnel expenditures accounted for less than 2 percent of personnel expenditures.

Looking at the breakdown of expenditures by P-code, more than 73 percent ($27.6 million) of the expenditures on the Hayman Fire were connected with the South Hayman (table 4). The North Hayman accounted for another $9.9 million, while only $215,000 was spent on the East Hayman. As indicated earlier, the East Hayman was set up in case the fire made an eastern run. Charges to the East Hayman occurred only on June 18, 19, and 20. A third Incident Command Team was brought in to meet with community leaders and local fire departments to get agreements in place and to set up a good contingency structure protection plan.

The distribution of expenditures by BOC varies somewhat by P-code. The South Hayman and North Hayman distributions were similar; although somewhat more was spent on Personnel Compensation on the South Hayman and somewhat more was spent on Other Services on the North Hayman. However, the breakdown for the East Hayman varied substantially from the other two. Nearly one-half of all expenses on the East Hayman were for Personnel Compensation, while only 24 percent was for Other Services. Travel/Transportation of Persons accounted for about 15 percent of expenditures on the East Hayman, rather than 2 to 3 percent, as seen on the North and South. The vast difference in the distribution for the East Hayman was because the expenditures were for contingency planning, not fighting fires, meaning no firefighters were assigned, but a lot of overhead and travel expenditures were incurred.

Another way to differentiate among expenditures focuses on who spent the money. This question was answered in an agency context early in this section, where we showed that the Forest Service was responsible for more than 89 percent of suppression expenditures. Now we ask the question: how were the expenditures distributed among Forest Service organizational regions. Though all Forest Service regions may send resources to fight a particular fire, it is expected that the regional organizational unit corresponding to the geographic region in which the fire occurs would incur the majority of the suppression expenses. Region 2, as expected, did incur the majority of the expenses (62 percent) (table 5). Region 15 accounted for another 27 percent of the expenditures. Region 15 is an accounting region designated for tracking national contracts, a new accounting procedure tried out for the first time in

Table 5—Forest Service fire suppression expenditures on Hayman Fire, as of May 2003 by Forest Service Region. (Source: USDA Forest Service – Foundation Financial Information System)

Region	Expenditures (thousands of dollars)	Pct of total expenditures
1 – Northern	82	0.2
2 – Rocky Mountain	23,513	62.4
3 – Southwestern	131	0.4
4 – Intermountain	93	0.2
5 – Pacific Southwest	1,392	3.7
6 – Pacific Northwest	1,479	3.9
8 – Southern	51	0.1
9 – Eastern	64	0.2
10 – Alaska	372	1.0
13 – National Interagency Fire Center	219	0.6
15 – National contracts	10,270	27.2
Other	32	<0.1
Total	$37,698	100%

Note: FS expenditures do not reflect any adjustments due to the cost share agreement between the FS and the State of Coloroado.

FY 2002. Of the $10 million spent on these national contracts, at least $8 million was for flying contracts with another $2 million being coded to "Contractual Services - Other" that consists mainly of expenditures on mobile food, mobile commissary, and shower facilities. The percentage of total expenditures on the Hayman accounted for by the remaining regions ranged from a low of 0.1 percent for the Southern Region to 3.9 percent for the Pacific Northwest Region.

Thus far, we have looked at suppression expenditures on the Hayman Fire in total as described using data from the financial system. From the ICARS data for the South Hayman, we were able to get a picture of how resources and dollars were expended over the course of the fire. Once the fire began, daily expenditures increased rapidly due to the speed with which the fire grew. Suppression expenditures reached a peak of $1.2 million per day on June 18, 2002, a day of extreme fire weather and increased fire activity (fig. 4). After June 18, daily expenditures began to drop due to the arrival of monsoon weather, after which the fire made little progression. Expenditures

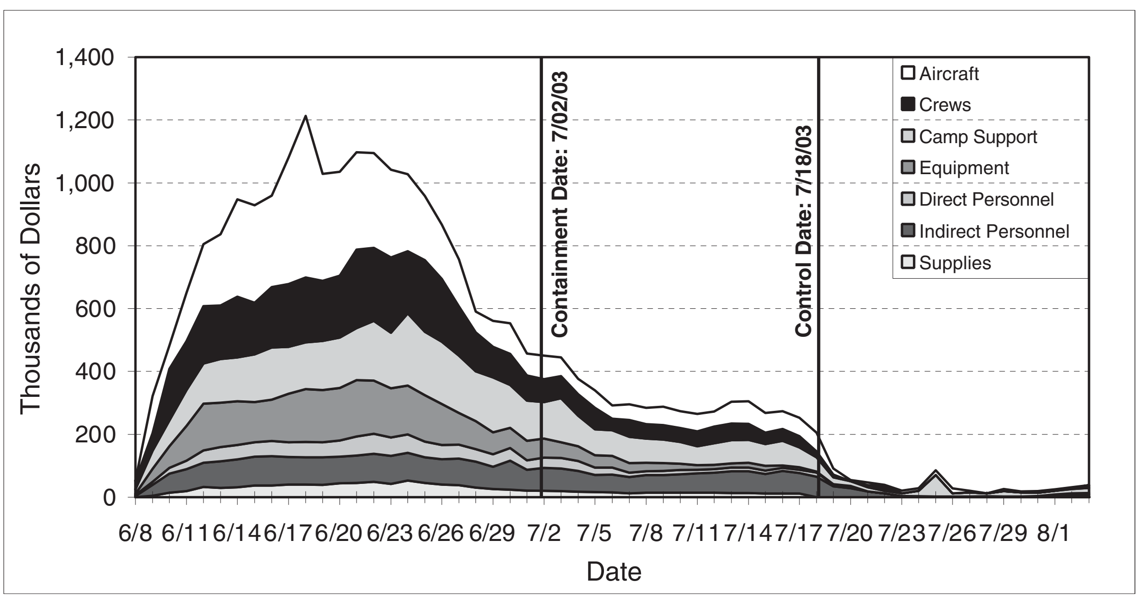

Figure 4—Estimated daily fire suppression expenditures for the Hayman fire by kind, as of August 3, 2002. (Source: USDA Forest Service Incident Cost Accounting and Reporting System)

still were running above a $1 million per day up until June 25, but then began to decrease more rapidly. The Hayman Fire was declared contained on July 2, 2002, which meant a containment line had been established around the entire perimeter and the fire was not expected to increase in size past natural or human made barriers. At this time, estimated expenditures were around $450,000 per day. From the time the fire was declared contained until it was declared controlled on July 18, expenditures averaged $305,000 per day. After the declared control date, expenditures fell substantially, dropping below $100,000 per day with an average of $36,000 per day.

Figure 4 also shows the type of resources used each day. Aircraft expenditures made up the majority of the expenses up until June 24. After that, until about July 22, the majority of expenditures were for camp support or direct and indirect personnel (mainly indirect). Although overall expenditures peaked on June 18, aircraft was the only category to also peak on that day. Indirect personnel peaked earlier, on June 16, although expenses in this category remained fairly consistent until the fire was controlled. The rest of the categories reached their peaks between June 22 and June 24.

Rehabilitation and Restoration: Once the fire was declared contained on July 2, the BAER work began (fig. 5) (although a small amount was spent before this). BAER expenditures increased substantially once the fire was declared controlled on July 18, reaching a high of $208,000 per day on July 29. By August 3 (the last day for which ICARS data were available), daily BAER expenditures had dropped to around $100,000 per day. After August 3, we do not have a daily account of estimated BAER expenditures.

Looking at the daily BAER expenditures in more detail (fig. 6), we can see that until the control date of July 18, the majority of BAER expenditures were for crews. After the fire was declared controlled, most expenditures were for camp support, followed by indirect personnel, and then crews. Expenditures on aircraft were small and only occurred for a few days, July 27 through July 29.

Estimated daily expenditures from ICARS provided a picture of BAER expenditures only up to August 3, 2003. Expenditures obtained from the financial system provide information on overall expenditures (table 6). BAER expenditures as of May 2003 were mainly for "Other Services" (BOC 2500), accounting for 85 percent of the total $24 million of expenditures. The majority (92 percent) of "Other Services" are coded as "Contractual Services – Other" (BOC 2540), with another 5 percent ascribed to Miscellaneous Services and 2 percent to Agreements. Only 8 percent of BAER expenditures were for personnel expenses, with the largest amount of that going to overtime (BOC 1170). This overall expenditure pattern corresponds to the pattern of expenditures in the ICARS data, where the largest expenditure categories were

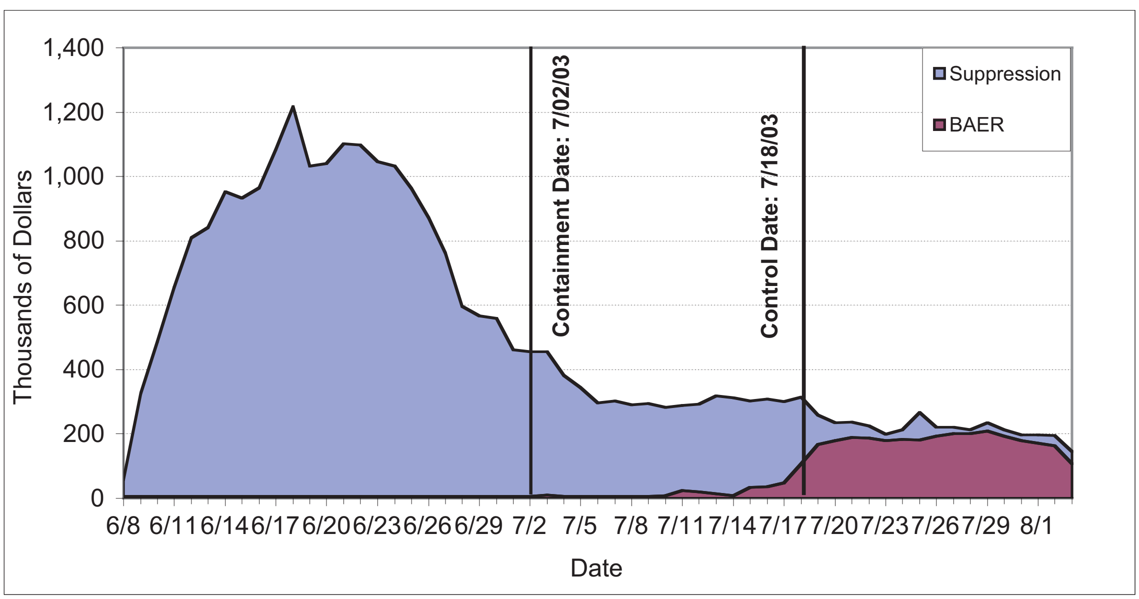

Figure 5—Estimated daily fire suppression and Burned Area Emergency Rehabilitation expenditures for the Hayman fire, as of August 3, 2002. (Source: USDA Forest Service Incident Cost Accounting and Reporting System)

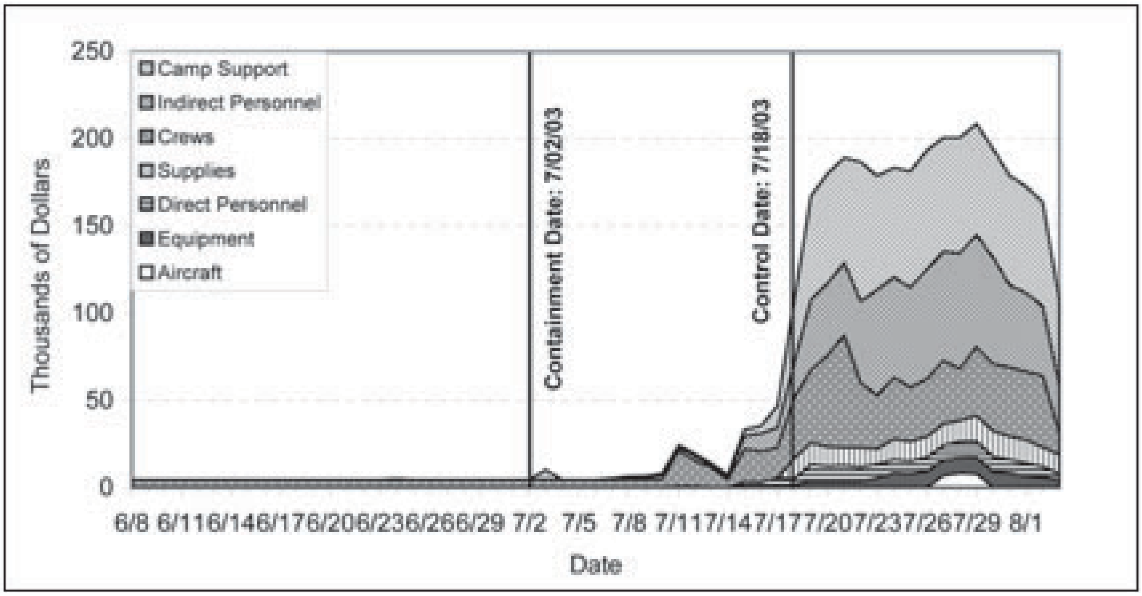

Figure 6—Estimated daily Burned Area Emergency Rehabilitation expenditures for the Hayman fire by kind, as of August 3, 2002. (Source: USDA Forest Service Incident Cost Accounting and Reporting System)

Table 6—Forest Service BAER expenditures on Hayman Fire as of May 2003 by budget object category. (Source: USDA Forest Service – Foundation Financial Information System)

Major BOC		Description	FS expenditures (thousands of dollars)	Pct of total FS expenditures
1100		**Personnel Compensation**	**1,825**	**7.7**
	*1101**	*Regular pay - Full-time permanent employees*	*469*	
	1121	*Regular pay – Full-time temporary employees*	*60*	
	1170	*Overtime*	*665*	
	1193	*Casual employment*	*480*	
1200		**Personnel Benefits**	**177**	**0.7**
2100		**Travel and Transportation of Persons**	**340**	**1.4**
2200		**Transportation of Things**	**45**	**0.2**
2300/2400		**Rent/Communications/ Utilities/Printing**	**688**	**3.0**
2500		**Other Services**	**20,253**	**85.4**
	2540	Contractual Services - Other	*18,688*	
	2550/2559	Agreements	*439*	
	2570	*Miscellaneous Services*	*1,037*	
2600		**Supplies and Materials**	**367**	**1.5**
3100		**Equipment**	**10**	**<0.1**
4200/4300		**Insurance Claims & Indemnities/Interest & Dividends**	**4**	**<0.1**
Total			**$23,709**	**100%**

* Detailed breakdown within major BOC only for categories with substantial expenditures; detailed expenditures will not add up to major category totals

Camp Support and Indirect Personnel, both of which likely fall under BOC 2540—Contractual Services-Other.

In addition to BAER projects, other longer term (1 to 5 years) rehabilitation and restoration projects are also planned by the Forest Service in connection with the Hayman Fire. These projects fall under one of seven categories: (1) land and facilities, including trail and road reconstruction, campground and heritage site reconstruction and restoration, (2) habitat restoration, (3) forest health, including noxious weed control, (4) planning and administration, (5) reforestation, (6) watershed restoration, and (7) research projects, such as analyzing soil productivity and the effectiveness of rehabilitation. Nearly $37 million in rehabilitation and restoration projects are planned by the Pike-San Isabel National Forest in connection with the Hayman Fire (table 7), but these projects will only be completed if funding is forthcoming. Approximately a third of this is due to be spent in FY 2003 if funds are available. However, at the time of this report, the Pike had received only $2.95 million in funding from Region 2 for FY 2003 projects. The Pike-San Isabel National Forest is planning on spending the largest amount of money on projects connected with land and facilities ($13.7 million), followed by reforestation at $9.9 million. Research projects make up only $360,000 of the proposed expenditures, with the remaining categories slated for spending of $2 million to $4 million.

Rehabilitation and restoration projects are also occurring on State, County, and private land in connection with the Hayman Fire. Table 8 shows the magnitude of the expenditures connected with these projects.

Table 7—Forest Service rehabilitation and restoration costs associated with the Hayman Fire, by project type. (Source: Pike-San Isabel National Forest)

Project type	FY 2003	Total cost
Land and facilities	5,215,700	13,748,700
Habitat restoration	2,163,900	4,493,800
Forest health	816,500	2,827,500
Planning and administration	1,264,100	3,424,300
Reforestation	243,100	9,896,300
Watershed restoration	509,000	2,026,300
Research projects	255,000	359,500
Total	$10,467,300	$36,776,400

Table 8—Other expenditures associated with suppression and rehabilitation of the Hayman Fire. (Source: NRCS, Colorado; Denver Water; Colorado State Forestry Department)

		Dollars
NRCS Grants [1]	**Rehabilitation of state/county/private lands**	**10,802,800**
Denver Water [2]	Emergency Rehabilitation Immediately following the fire EPA Matching Grant Monitoring and lab work Water treatment	1,300,000 830,000 15,000 85,000
FEMA	Reimbursement to counties for road blocks, traffic control, evacuations, and other non-direct suppression expenses	1,099,679
State of Colorado	Administrative expenses for handling billing of counties and other cooperators	48,906
American Red Cross [3]	Estimated expenditures on Hayman Fire evacuees	765,940

[1] Matching grants: 75% NRCS, 25% land owner for a total of $10,802,800.
[2] Does not include $3.2 million matching NRCS grant ($2.4 million NRCS, $0.8 million Denver Water), which is included in the $10.8 million for NRCS.
[3] Provided by Dennis L. Lynch, Forest Sciences, Colorado State University – prorated from consolidated statewide costs.

NRCS is funding rehabilitation on State, County, and private lands with a matching grant program. NRCS provides 75 percent of the funding and the landowner provides 25 percent. These projects are to protect properties from damage related to increased sediment and/or flooding and to reduce erosion. In order to qualify for funding, the value of the property must be in excess of what it will cost to do the rehabilitation work. Recipients of these matching grants include Denver Water, the State of Colorado, the four involved Counties, numerous camps, such as the YMCA, and private landowners. In some cases, landowners are able to do volunteer work, such as seeding, to pay for their 25 percent of the project.

Estimates of rehabilitation and treatment expenditure by Denver Water in connection with the Hayman total about $5.4 million, $3.2 million of which is to be funded through the matching grant program with NRCS ($2.4 million from NRCS and $0.8 million from Denver Water) (Table 8). Denver Water expects that water treatment expenditures will be less for the Hayman than for the Buffalo Creek fire that occurred in 1996 because a majority of the sediment is being trapped at Cheesman Reservoir. Stroncha Reservoir downstream from the Cheesman Reservoir is the primary treatment intake for Denver Water. However, it is still unknown what the long-term effects on water quality will be.

Other Fire-Related Expenditures: In the course of our investigation, we also came upon several other categories of expenditures connected with the Hayman Fire, but not directly related to suppression or rehabilitation (table 8). The Counties involved expect to receive a reimbursement from FEMA for fire-related activities, such as roadblocks, traffic control, and evacuations, amounting to $1.1 million. The State of Colorado spent $48,906 on administrative expenses connected with the fire, such as handling the billing for the Counties and other cooperators. Also, according to Dennis Lynch of Colorado State University, the American Red Cross spent an estimated $766,000 on disaster relief for Hayman Fire evacuees.

Regional Economic Activity

The Hayman Fire burned during the months of June and July in the summer of CY 2002. When finished, the fire touched on land in Douglas, Jefferson, Park, and Teller Counties, which we refer to as the Primary Impact Area (fig. 7). The 13 Counties adjoining the Primary Impact Area are referred to as the Secondary Impact Area. Our inquiry into regional economic aspects of the Hayman Fire intended to describe historical economic activity in a multi-County impact area, by semidetailed industrial classification, and how that activity level changed during the fire and several

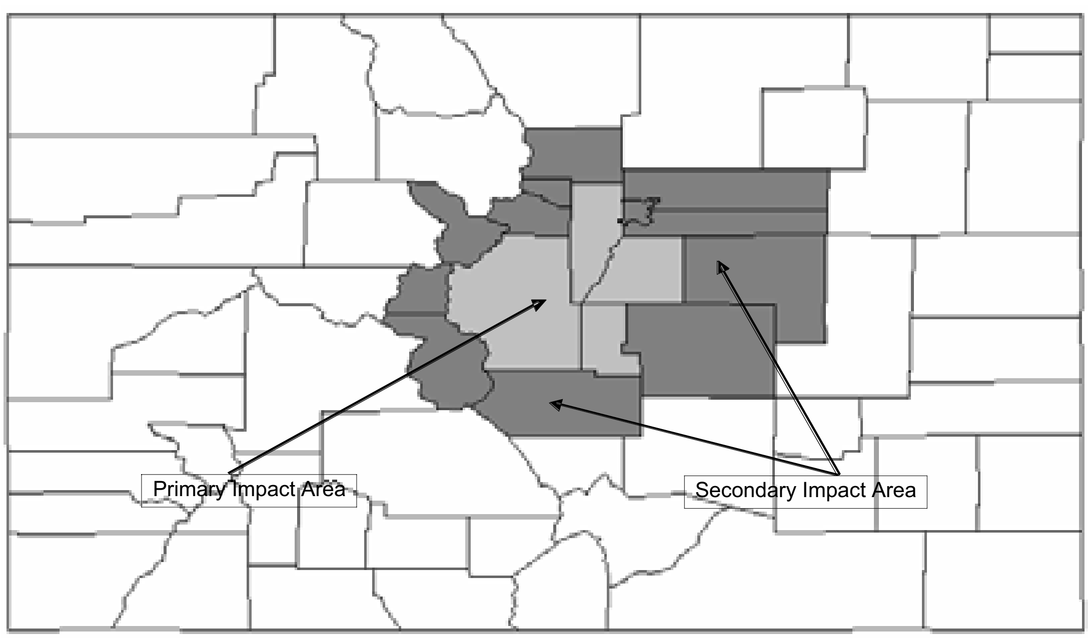

Figure 7—State of Colorado and impact areas.

months thereafter. We focused on the overall economies and tourism-related economic activity in the Primary Impact Area, the Secondary Impact Area, and the State of Colorado. We measured economic activity by wages, employment, and retail sales. Where appropriate, monetary units are expressed in terms of constant, CY 2002 dollars.

In terms of analysis of regional economic activity, we attempted to analyze the direct economic effect of events during the summer of 2002. A typical regional economic analysis would interpret direct economic effects in light of associated indirect and induced effects. Because of ambiguities surrounding the direct economic effects, we chose to not assess secondary effects. Questions may arise as to the relationship between the firefighting expenditures previously discussed and the direct economic effects now being discussed. The relationship is somewhat murky. Firefighting expenditures may or may not affect local economies. That is because some expenditures are associated with national contracts, such as some aviation and food service contracts. Expenditures on these contracts can go to the contractor's corporate office, regardless of where the fire is located. Similarly, firefighter paychecks can be electronically deposited in home bank accounts, unrelated to where the fire is located. This economic activity (employment and wages) will show up in economic accounts at the firefighter's home location. However, some firefighting expenditures make their way into local economies through retail sales. These expenditures have been captured in our analysis.

Prefire Economies: When the Hayman Fire burned into the four-County Primary Impact Area, it affected a geographical area that constitutes a substantial portion of the Colorado economy. According to the Colorado Department of Labor, businesses in the Primary Impact Area employed about 13 percent of the workers and paid about 12 percent of the wages in CY 2001 (CDL 2003). Similarly, according to the Colorado Department of Revenue, the Primary Impact Area accounted for about 15 percent of Colorado's retail sales in CY 2001 (CDR 2003). In consideration of brevity, much of the following discussion will portray economic activity in terms of wages. Discussions of employment and retail sales would be quite equivalent.

The importance of economic activity in the Primary Impact Area is due to Jefferson County. It overwhelms the other Counties, constituting about 75 percent of the wages paid in CY 2001. Douglas County constituted about 22 percent of the wages; Teller County paid about 2 percent; and Park County about 1 percent.

A profile of the Primary Impact Area's economy in CY 2001 is quite reflective of the Colorado economy in general. In fact, the top three sectors of the two economies are the same—Services, Manufacturing, and Retail Trade, in that order. About 34 percent of the wages in the Primary Impact Area were paid by employers in the Services industry (fig. 8), while these sectors accounted for about 37 percent in the Colorado economy. Retail Trade accounted for about 13 percent of the wages paid in the Primary Impact Area and

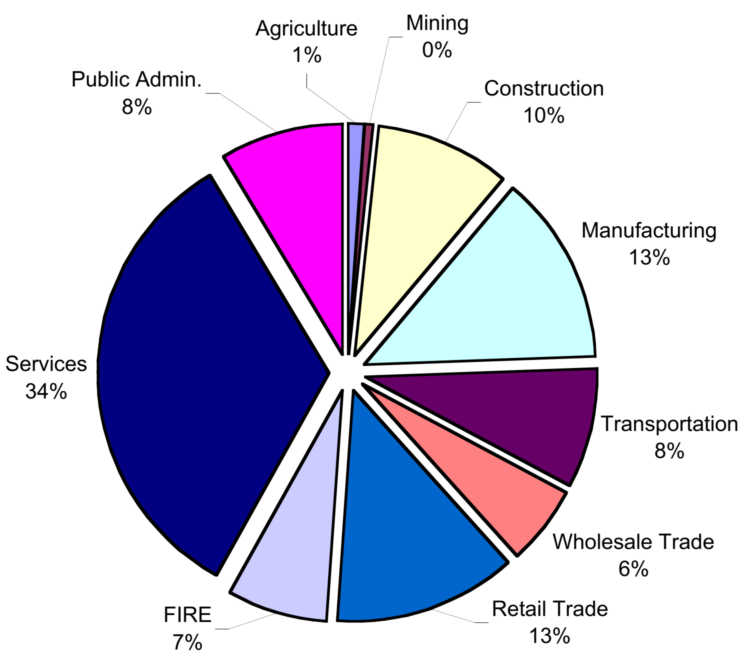

Figure 8—Percent distribution of industry divisions in economy of primary impact area, 2001. (Source: Colorado Department of Labor)

about 10 percent for the State of Colorado. Services and Retail Trade is important to our analysis because the Services industry contains two of our featured economic sectors, Lodging and Recreation, while the Retail Trade industry contains Eating and Drinking establishments.

Because of the dominant role it plays in the Primary Impact Area, the distribution of industrial sectors in Jefferson County closely approximates that of the Primary Impact Area. Moreover, the sizeable role of the Services industry is reflected in all Counties of the Primary Impact Area (fig. 9). But that is where similarities end. The second largest industry, in terms of wages, is Manufacturing for Jefferson County, Construction for Park County, and Retail Trade for Douglas and Teller Counties. These distributions are important to our analyses because the Construction and Manufacturing industries, so important to Park and Jefferson Counties, are not part of our featured, tourism-related industrial sectors.

Our focus on the Eating and Drinking, Lodging, and Recreation sectors is a direct reflection of interest expressed to us about tourism-related activity, so it is important to keep these tourism-related sectors in proper perspective. The Eating and Drinking sector resides within and is a major component of the Retail Trade industry. In fact, wages paid in Eating and Drinking establishments accounted for about one-fourth of all wages paid in Retail Trade in the Primary Impact Area in CY 2001; for Counties, the percentage ranged from 23 percent in Douglas County to 35 percent in Park County. However, because of the large magnitude of the Services industry, the tourism-related sectors play a much more minor role. In total for the Primary Impact Area, the Lodging sector and Recreation sector only accounted for slightly over 4 percent of the wages in the Services industry, with wages in the Recreation sector dominating those in the Lodging sector by 3 to 1. So it is that in CY 2001, tourism-related sectors constituted a scant 5 percent of the wages paid in the Primary Impact Area—3.5 percent from Eating and Drinking, 0.5 percent from Lodging, and 1 percent from Recreation. Considering that wages in the tourism-related sectors include business unrelated to the wildland base, the prospect of discerning a Hayman Fire-induced effect seems remote.

Two situations are noteworthy. First, in Teller County (which accounts for only 2 percent of wages in the Primary Impact Area), the Recreation sector and Lodging sector account for about 54 percent of the Services industry, with Recreation alone accounting for 51 percent; the Recreation sector seems to dominate tourism-related activities in Teller County. Second, in Park County (which accounts for only 1 percent of the wages in the Primary Impact Area), the Recreation sectors and Lodging sectors account for 8 percent of the Services industry, with Lodging alone accounting for 7 percent; the Lodging sector seems to dominate tourism-related activities in Park County.

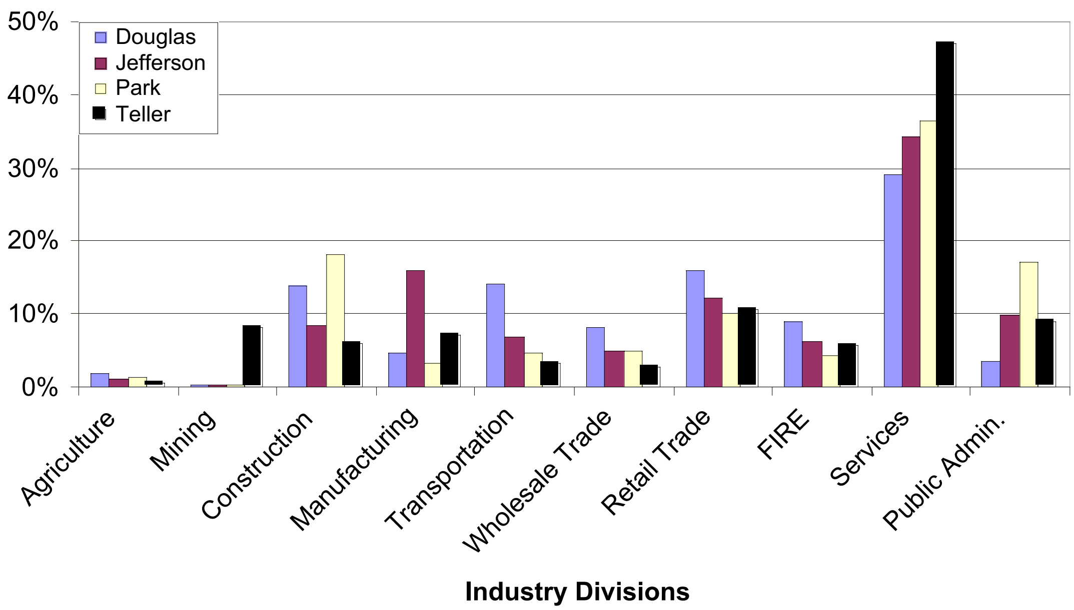

Figure 9—Percent distribution of industry divisions in primary impact area, by county, 2001. (Source: Colorado Department of Labor)

Fire and Postfire Economies: The level of economic activity in an economy, such as the Primary Impact Area, varies by the month and with the measure of economic activity, be it wages, employment, or retail sales (fig. 10). Many factors play a role in determining the monthly level of economic activity, thus complicating our assessment of the role of the Hayman Fire. In the case of the Primary Impact Area, employment averaged about 280,000 per month for the 17 months immediately preceding the Hayman Fire; employment averaged 281,000 for the next 4 months, the fire and postfire months, almost a 0.5 percent increase. Wages averaged $869 million (2002$) per month for the months preceding the Hayman Fire and only $843 million for the next 4 months, a 3 percent decrease. Retail sales averaged $1.281 billion (2002$) per month before the Hayman Fire and $1.329 billion per month during and after the fire, almost a 4 percent increase. At least in terms of the Primary Impact Area, the overall picture of economic activity is mixed but modest.

The analytical question is: What portion of the change in economic activity can be ascribed to events and circumstances taking place during and after the Hayman Fire? To answer this question, we built numerous statistical models to estimate the level of economic activity that would have occurred without the events and circumstances surrounding the Hayman Fire. Those models focused on the Primary Impact Area as well as the associated, individual Counties, the Secondary Impact Areas, and the State of Colorado. They focused on economic activity measured by employment, wages, and retail sales. In addition, they focused on overall economies, as well as the tourism-related sectors of Eating and Drinking, Lodging, and Recreation.

Perhaps it is somewhat difficult to detect changes in economic activity shown in figure 10 because of aggregation. Figure 11 provides a more detailed breakdown of wages in tourism-related sectors of the Primary Impact Area. The relative size of these sectors is easily compared, with wages in Eating and Drinking establishments being roughly two to three times those in the other sectors. In the Primary Impact Area, wages paid in Eating and Drinking establishments averaged about $29.2 million (2002$) per month for the 17 months immediately preceding the Hayman Fire and $30.7 million for the next 4 months, a 0.5 percent increase. A similar situation holds for wages in Lodging and Recreation establishments. Wages in Lodging averaged $3.3 million (2002$) per month for the months preceding the Hayman Fire and $3.7 million for the next 4 months, a 12 percent increase. Wages in Recreation averaged $9.9 million (2002$) per month before the Hayman Fire and $11.6 million per month during and after the fire, a 17 percent increase. The decrease in overall wages shown earlier in figure 10 was not the result of decreases in tourism-related sectors; some other sector(s) caused the decrease.

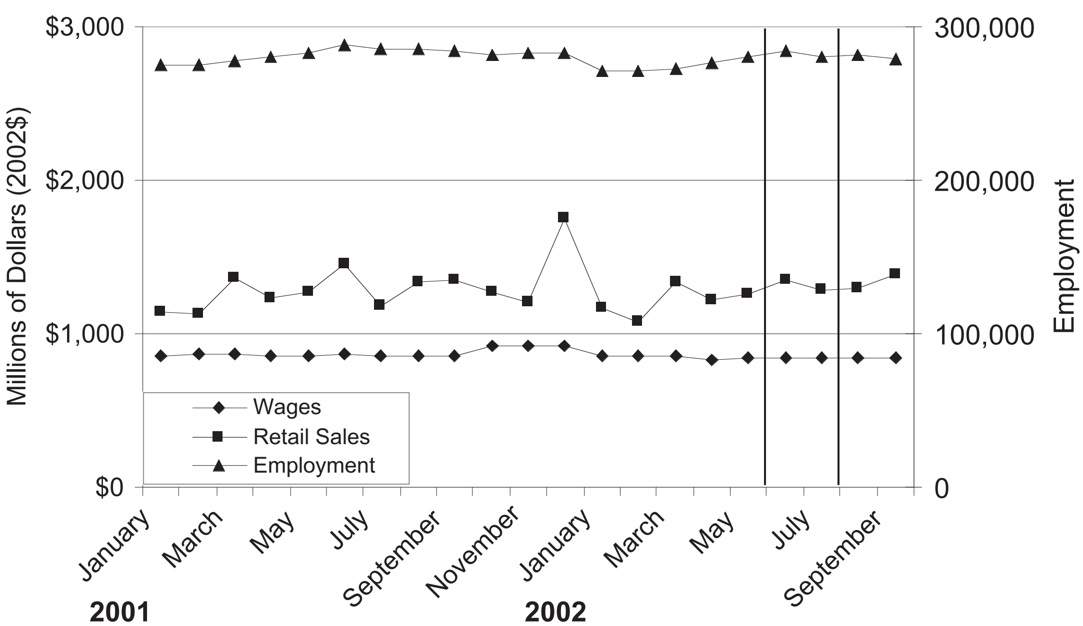

Figure 10—Economic activity in primary impact area, by type of economic activity. (Source: Colorado Departments of Labor and Revenue)

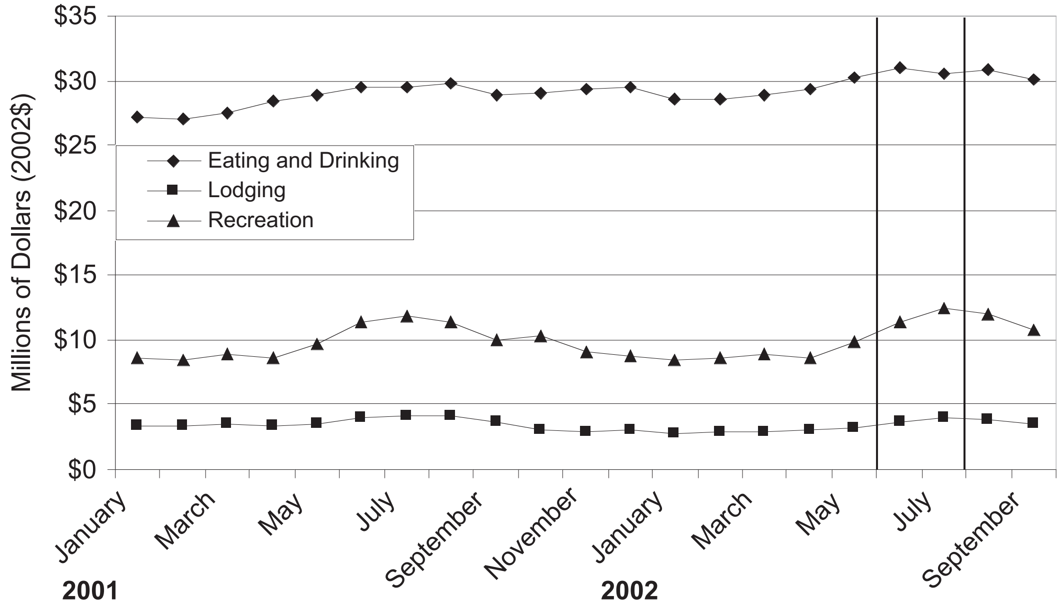

Figure 11—Wages (2002$) in primary impact area, by tourism-related sector. (Source: Colorado Department of Labor)

Figures 12 and 13 also provide information on the tourism-related sectors of the Primary Impact Area. Figure 12 displays employment levels and figure 13 shows retail sales expressed in 2002$. In all cases, the monthly average for the 4 months (June through September) during and after the Hayman Fire exceeds that for the 17 months before the fire. So as in the case of wages, employment and retail sales in tourism-related sectors of the Primary Impact Area showed an increase during and after the fire.

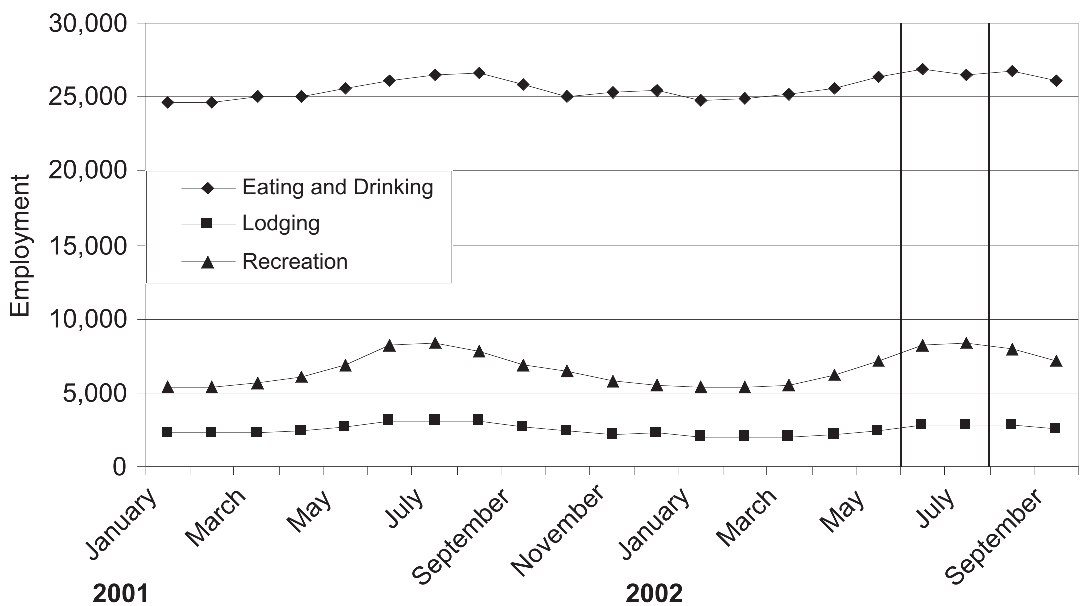

Figure 12—Employment in primary impact area, by tourism-related sector. (Source: Colorado Department of Labor)

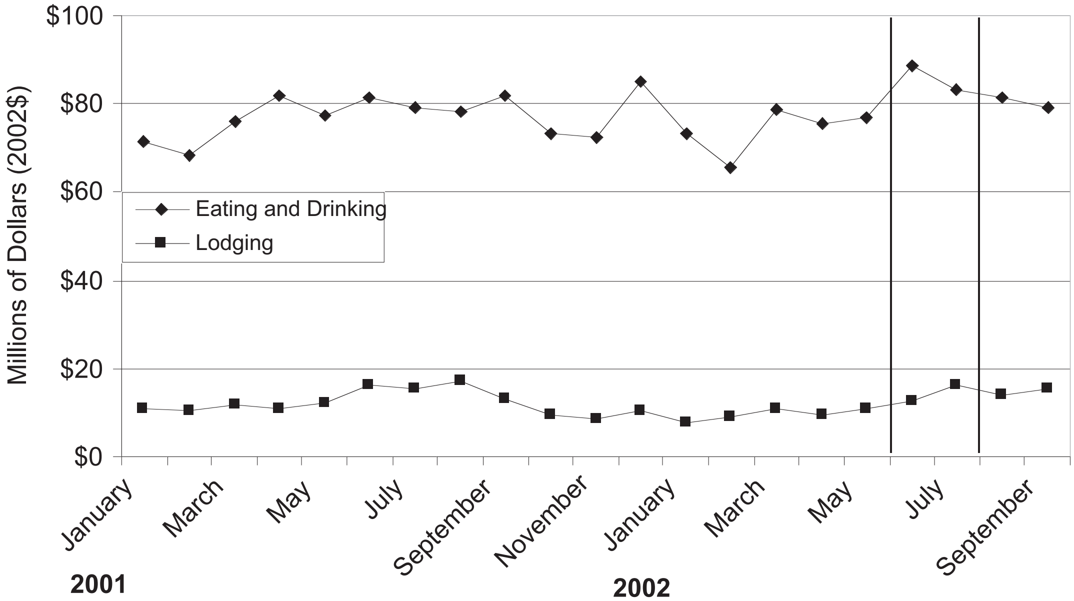

Figure 13—Retail sales (2002$) in primary impact area, by tourism-related sector. (Source: Colorado Department of Revenue)

The impressions of economic activity in the Primary Impact Area portrayed by figures 10 through 13 are both illuminating and deceptive. They are illuminating in that they should dispel the notion that the level of economic activity plummeted during and after the Hayman Fire, especially in the tourism-related sectors. To the contrary, most indicators of economic activity show increases during and after the fire, including tourism-related sectors. The figures are deceptive, however. An increase or decrease in economic activity during and after the Hayman Fire may or may not be related to the fire or other events during the 4 months. For example, the increase in retail sales for Eating and Drinking establishments during the Hayman Fire (fig. 13) could be due to the onset of the summer tourist season; it could be that without the fire, the increase would have been even larger. Similarly, the slight downturn in overall wages for the Primary Impact Area (fig. 10) could have reflected a flattening of the national economy and again have nothing to do with the Hayman Fire.

To further investigate the information displayed in the figures, we constructed statistical models to estimate monthly economic activity that would have happened, absent events and circumstances during and after the Hayman Fire. These models, based on historical monthly data from January 1999 through May 2002, were specific to each measure of economic activity (wages, employment, and retail sales), each economic sector (Eating and Drinking, Recreation, and Lodging), and each geographical area (the Primary Impact Area, the Secondary Impact Area with and without Denver County, and the State of Colorado). The statistical models estimated economic activity in light of national economic trends, economic trends in the Colorado economy, seasonal influences, and the events of September 11, 2001. We built 88 multiple linear regression models. The explanatory capability of these models was generally outstanding, with adjusted R-squares typically above 90 percent. The estimated level of economic activity was compared to the actual level to determine if the actual economic activity during the summer of 2002 was significantly different from that expected, in light of the national and State economies, season of year, and so on.

The effect of events and circumstances surrounding the Hayman Fire on regional economic activity has two time perspectives—during the fire and following the fire. Table 9 shows the results of our analyses to detect changes in economic activity during June and July 2002, the months of the Hayman Fire. First, table rows are organized by type of geographical area and economic activity, while the columns account for economic sectors and the fire months of June and July. If the actual level of economic activity is below that expected (that is, the level estimated via the regression model), that difference is coded with a minus sign (-), meaning the actual level of economic activity (during the Hayman Fire) was less than the level expected based on historical relationships (without events and

Table 9—Results of analyses to identify changes in economic activity in June and July 2002 during the Hayman Fire.

Impact area	County	Economic activity	Eating and Drinking June	Eating and Drinking July	Lodging June	Lodging July	Recreation June	Recreation July	Total June	Total July
Primary Impact Area	Douglas	Wages	-	--	-	--	-	-	-	+
		Employment	-	--	-	--	+	+	+	-
		Retail sales	-	-	-	-	na	na	-	-
	Jefferson	Wages	+	+	-	-	-	-	-	-
		Employment	-	+	0	--	-	-	+	+
		Retail sales	+	-	--	-	na	na	--	+
	Park	Wages	-	+	+	+	--	-	+	+
		Employment	-	+	+	-	--	-	+	+
		Retail sales	-	-	-	-	na	na	-	+
	Teller	Wages	+	-	--	--	-	+	+	+
		Employment	-	+	-	--	-	-	-	-
		Retail sales	-	+	-	-	na	na	+	-
	TOTAL	Wages	+	-	-	--	-	-	-	-
		Employment	-	-	-	--	-	-	-	+
		Retail sales	+	-	--	-	na	na	--	-
Secondary Impact Area	w/ Denver	Wages	-	-	-	++	+	--	-	+
		Employment	-	-	--	-	++	--	--	+
		Retail sales	-	-	-	+	na	na	-	-
	w/o Denver	Wages	+	-	+	+	-	-	+	+
		Employment	-	-	+	+	-	-	-	-
		Retail sales	-	-	-	-	na	na	-	-
State of Colorado		Wages	-	-	+	-	-	-	-	-
		Employment	-	-	+	+	+	-	-	--
		Retail sales	-	-	-	+	na	na	-	-

Key: "+"indicates actual economic activity > expected; "++" indicates statistical significance
"0" indicates actual economic activity = expected
"-" indicates actual economic activity < expected; "--" indicates statistical significance
"na" indicates "not available"

circumstances during the Hayman Fire); if the actual level is above that expected, the difference is coded with a positive sign (+). If the difference is statistically significant (that is, outside the 95 percent confidence interval for each model), it is coded with a double symbol (— or ++).

Table 9 displays few instances of statistically significant differences. There are 21 statistically significant negative differences and only two statistically significant positive differences, out of 176 differences displayed. Consider the case of wages in the Eating and Drinking sector of Douglas County, which is shown as a statistically significant negative difference. The prefire statistical model used to generate this outcome was excellent, with an adjusted R-square of 0.94. That model estimated July wages to be $8.3 million whereas they actually were $7.8 million, about $0.5 million low. Because the $-0.5 million difference exceeded the 95 percent confidence interval of $±0.4 million, the difference was declared statistically significant; that is, there is a 95 percent likelihood that the $-0.5 million difference was not due to chance. Most differences, however, were not statistically significant. This means that although there is some evidence of positive or negative influences on economic activity during the fire months, the evidence is weak. In all sectors, negative differences outnumber positive differences and account for 72 percent of the differences overall.

Table 10 displays information comparable to that found in table 9, except that table 10 focuses on the postfire months of August and September 2002. As with table 9, there are few situations of statistically significant differences between the actual and expected levels of economic activity, even fewer than for the previous 2 months. In fact, there are no statistically significant positive differences and only 12 negative differences. Overall, negative differences account for 67 percent of the differences.

Results displayed in tables 9 and 10 are difficult to interpret. Table 11 has been developed to display

Table 10—Results of analyses to identify changes in economic activity in August and September 2002 after the Hayman Fire.

Impact area	County	Economic activity	Eating and Drinking Aug.	Eating and Drinking Sept.	Lodging Aug.	Lodging Sept.	Recreation Aug.	Recreation Sept.	Total Aug.	Total Sept.
Primary Impact Area	Douglas	Wages	-	-	-	-	-	-	-	-
		Employment	-	-	-	-	+	+	-	-
		Retail sales	-	-	-	-	na	na	-	+
	Jefferson	Wages	+	-	-	-	-	-	-	+
		Employment	+	-	--	-	-	-	+	+
		Retail sales	-	-	-	+	na	na	-	+
	Park	Wages	+	+	-	-	-	-	+	+
		Employment	-	-	-	-	--	-	+	+
		Retail sales	+	+	--	+	na	na	+	+
	Teller	Wages	+	+	-	+	+	+	+	+
		Employment	+	+	-	+	+	-	+	+
		Retail sales	-	+	-	+	na	na	-	+
	TOTAL	Wages	-	-	-	-	-	-	-	-
		Employment	-	-	-	-	-	+	+	+
		Retail sales	-	-	--	+	na	na	-	+
Secondary Impact Area	w/ Denver	Wages	+	+	+	+	-	--	-	-
		Employment	-	--	+	-	-	--	-	--
		Retail sales	+	+	-	-	na	na	-	-
	w/o Denver	Wages	-	-	+	-	-	--	+	-
		Employment	-	-	-	-	-	--	-	--
		Retail sales	-	+	-	-	na	na	--	-
State of Colorado		Wages	-	+	-	-	-	-	-	-
		Employment	-	-	-	+	-	-	-	-
		Retail sales	+	+	-	+	na	na	-	-

Key: "+"indicates actual economic activity > expected; "++" indicates statistical significance
"0" indicates actual economic activity = expected
"-" indicates actual economic activity < expected; "--" indicates statistical significance
"na" indicates "not available"

Table 11—Summary of results to identify changes in economic activity during and after the Hayman Fire.

Impact area	County	Eating and Drinking Fire	Eating and Drinking Post-fire	Lodging Fire	Lodging Post-fire	Recreation Fire	Recreation Post-fire	Total Fire	Total Post-fire
Primary Impact Area	Douglas	M-	W-	M-	W-	W Mixed	W Mixed	W Mixed	W-
	Jefferson	W Mixed	W Mixed	M-	W-	W-	W-	W Mixed	W Mixed
	Park	W Mixed	W Mixed	W Mixed		W-	M-	W-	W+
W+									
	Teller	W Mixed	W+	M-	W Mixed	W-	W+	W Mixed	W+
	TOTAL	W Mixed	W-	M-	W-	W-	W-	W-	W Mixed
Secondary Impact Area	w/ Denver	W-	W Mixed	M Mixed	W Mixed	M Mixed	M-	W Mixed	W-
	w/o Denver	W-	W-	W Mixed	W-	W-	M-	W Mixed	M-
State of Colorado		W-	W Mixed	W Mixed	W Mixed	W-	W-	W-	W-

Key: "W"indicates weak evidence; "M" indicates moderate evidence; "S" indicates
"-" indicates a negative effect; "+" indicates positive effect; "Mixed" indicates negative

summary conclusions relative to changes in economic activity for the fire months (June and July) and the postfire months (August and September). Information in table 11 was developed from information in the boxed, cell clusters of tables 9 and 10 using the following rules: (1) if a cell cluster has five to six positive or negative signs, call it "positive" (+) or "negative" (-), otherwise call it "mixed"; and (2) if a cell cluster has five to six nonsignificant differences, call it "weak" (W); if three to four nonsignificant differences, call it "moderate" (M); otherwise call it "strong" (S). For example, the Douglas County cell for Eating and Drinking displays six negative signs, two of which are statistically significant; according to the rule, this cell would be described as "moderate negative" (M-). This means, according to our research on wages, employment, and retail sales in Eating and Drinking establishments in Douglas County, we believe that events and circumstances during June and July (for example, the Hayman Fire) had a "moderately negative" effect on economic activity.

Information displayed in table 11 can be interpreted in several ways. When viewed horizontally, the focus is on a given geographical area and how it was affected by events and circumstances during and after the Hayman Fire. For example, regarding Park County, events during and after the Hayman Fire seemed generally to have a weak, but negative, effect on economic activity in the tourism-related sectors, but there is some weak evidence of a positive effect on total economic activity in the County. When viewed vertically, the focus is on a particular economic sector for a specific period in time. For example, consider the Lodging sector during the fire months (June and July). Our research indicates there is moderate evidence of a negative effect (M-) on Lodging activity within the total Primary Impact Area, and weak or moderate evidence of a mixed effect on Lodging activity in the Secondary Impact Area and the State of Colorado.

The main message conveyed by table 11 is that we found no strong evidence of any effect, positive or negative, on either the tourism-related sectors or the total economy of the Primary Impact Area or its constituent Counties, the Secondary Impact Area with or without Denver, or the State of Colorado. We found moderate evidence of negative effect, mostly in the Lodging sector for several Counties. But mostly we found weak evidence and much of that was mixed, where one measure of economic activity went up and another went down. Moreover, there seems to be little pattern to these effects—one County going up while another goes down.

Property-Related Losses

According to the County assessors, private real property loss for the four County area directly impacted by the fire was valued at $23,750,000 with an annual assessed value of $3.4 million, resulting in an annual loss of revenue to the Counties of approximately $238,000 per year (table 12). These loss figures include the value of all destroyed structures that had previously been listed on the County assessors' tax roles and decreased land values associated with the Hayman Fire. Property that is tax exempt and structures not listed on County assessors' roles are not included in these loss estimates. For example, exempt property might include lands owned by nonprofit organizations such as Denver Water and the Girl Scouts of America. Property value losses and assessed value estimates are based on the individual assessor's adjustments to property value and property appraisal dates.

Cathy Smith, Operations Manager for Rocky Mountain Insurance Information Association, estimated that insured private property losses totaled $38.7 million. The Association derived this estimate by surveying major insurance companies on their loss experience related to the fire and projecting the final number using a market share calculation. Insured private property losses include loss of or damage to homes, as well as autos, smoke damage, food spoilage, additional living expenses, and loss of insured contents. Some of this $38.7 million is already included in the property loss valuation by the assessors. However, the assessors' figures don't include any personal property losses, or other insured losses other than real property (building and land values).

The Small Business Administration (SBA) makes low-interest, long-term loans to cover uninsured physical losses to homes, personal property, and business property. The SBA also makes loans (Economic Injury

Table 12—Property value lost (dollars). (Source: County Assessors' Office)

	Teller	Douglas	Park	Jefferson	Total
Property value lost	13,737,056	8,132,595	1,771,219	108,969	23,749,839
Assessed value	1,974,831	1,154,189	261,442	9,971	3,400,433
Annual losses in tax revenue	127,351	97,826	11,638	997	237,812

Disaster Loans) to small businesses to help cover financial losses sustained as a result of disasters. Jim Atkins, Congressional Liaison SBA Disaster Assistance - Area 3, provided data regarding total approved loans to the four Counties of Teller, Park, Douglas, and Jefferson (table 13). Total loans in the four Counties associated with the Hayman Fire totaled $4,005,200 with most of the loan approvals, $2,684,700 (67 percent) going to small businesses for financial losses associated with the wildfires. The Federal Emergency Management Agency (FEMA) issued grants to individuals for uninsured expenses totaling $851,600 for such things as lost employment earnings, emergency housing expenses, and personal property losses. Intermountain Rural Electric Association and Excel Energy reported that the Hayman Fire damaged or destroyed power lines valued at $650,000 and $230,000 respectively

Resource Outputs and Values

Much of the data collected on resource outputs and values are simply a compilation of existing data sources and studies. These data provide an overview of some short-term effects of the Hayman Fire. We did not attempt to place a dollar value loss on the effects of the fire on the recreation and tourism industries, but simply identified some of the relevant trend data. The long-term effects of the Hayman Fire are difficult to assess and will require future research after sufficient time has passed.

Tourism and Recreation: It is difficult to isolate the effects of the Hayman Fire on the tourism industry in Colorado from other effects such as the economic recession, declines in air travel relating to fears associated with the September 11 terrorist attack, and the serious drought experienced by Colorado in 2002. Furthermore, reductions in tourism in the summer of 2002 may have been exacerbated by intense media attention of the Hayman Fire and the comments of Colorado Governor Bill Owens describing the scene as a “nuclear winter” and stating “all of Colorado is on fire” (Richardson 2002; McCrimmon 2002). Another difficulty in identifying the economic effects of an event such as the Hayman Fire is that when individuals are unable to participate in planned vacation or recreation activities, many will choose other activities, other locations for the same activity, or both. Isolating the effects of these dislocations on a regional economy is extremely difficult and well beyond the scope of our investigation.

A report generated to assess the effects of the Bitterroot fires of 2000 in Montana (Missoula Area Economic Development Corp. 2002) estimated that tourism-related losses to the area economy totaled $27.3 million, including direct effects of $13.6 million and indirect effects of $13.6 million. These results came from a survey of outfitters and retail businesses involved in tourism-related activities, and confidence in these results was limited by the low response rates (18 percent in one portion of the survey). Due to the limited amount of time available to identify the economic effects of the Hayman Fire, we did not attempt to assess a total value loss to the tourism industry. However, we were able to identify visitation trend information for several different types of recreation facilities and activities that were likely affected by the fire.

The Hayman Fire prompted a general closure order for three Ranger Districts (Pikes Peak, South Platte, and South Park Ranger Districts) of the Pike-San Isabel National Forest. The closure order began June 10, 2002, and continued until July 19, 2002 (small portions of the Pike-San Isabel National Forest including five camping and recreation areas were reopened July 12, 2002). Furthermore, all areas within the Hayman Fire perimeter remained closed to recreation use, at least through March 2003.

Developed recreation sites (campgrounds and day-use fee areas) within the affected districts are operated by two concessionaires, Rocky Mountain Recreation Company (Pikes Peak and South Platte Ranger District) and Canyon Enterprises Inc. (South Park Ranger District). Monthly visitation data for campgrounds are presented in figures 14 to 16 and for day use areas in figures 17 to 19 for January 2000 through

Table 13—Small Business Administration disaster loans for counties included in the Hayman Fire (as of June 25, 2003). (Source: SBA Disaster Assistance Area 3)

	Home		Business		Economic Injury		Total	
County	#	$ Amount	#	$ Amount	#	$ Amount	#	$ Amount
Douglas	5	577,000	1	10,000	7	750,600	13	1,337,600
Jefferson	N/A	N/A	N/A	N/A	4	28,900	4	196,100
Park	1	99,000	N/A	N/A	10	339,600	11	438,600
Teller	6	437,700	1	29,600	40	1,565,600	47	2,032,900
Total	12	1,113,700	2	39,600	61	2,684,700	75	4,005,200

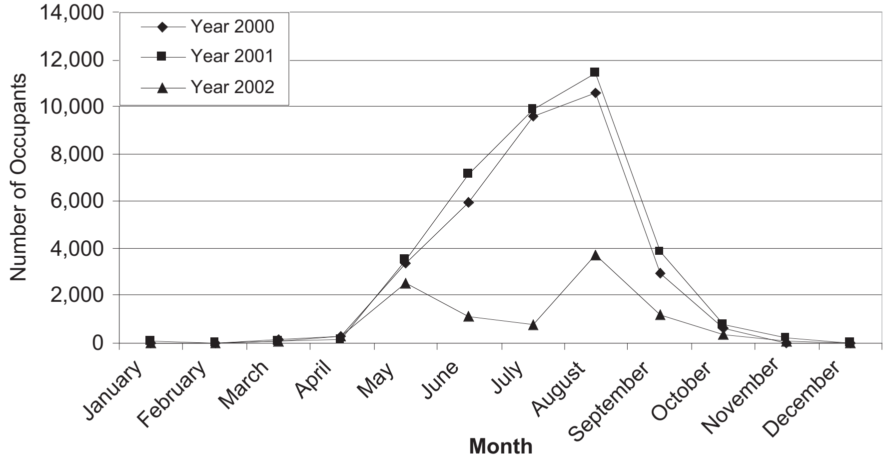

Figure 14—Campground visitation for Pikes Peak Ranger District. (Source: Rocky Mountain Recreation Company)

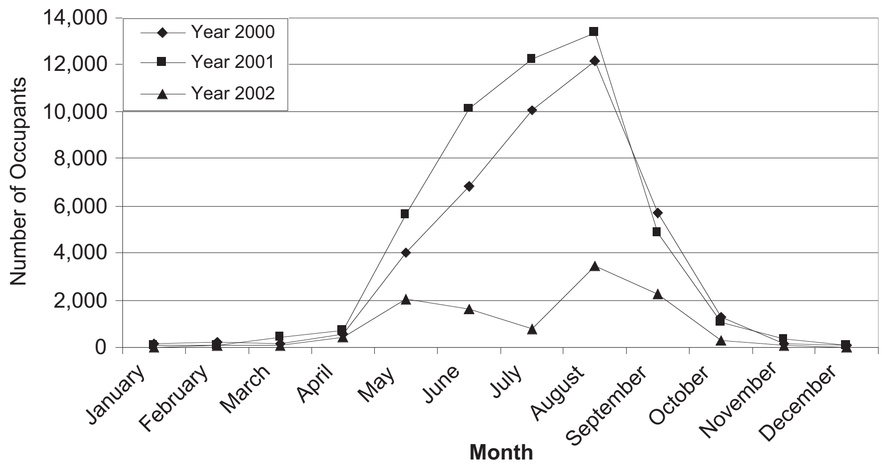

Figure 15—Campground visitation for South Platte Ranger District. (Source: Rocky Mountain Recreation Company)

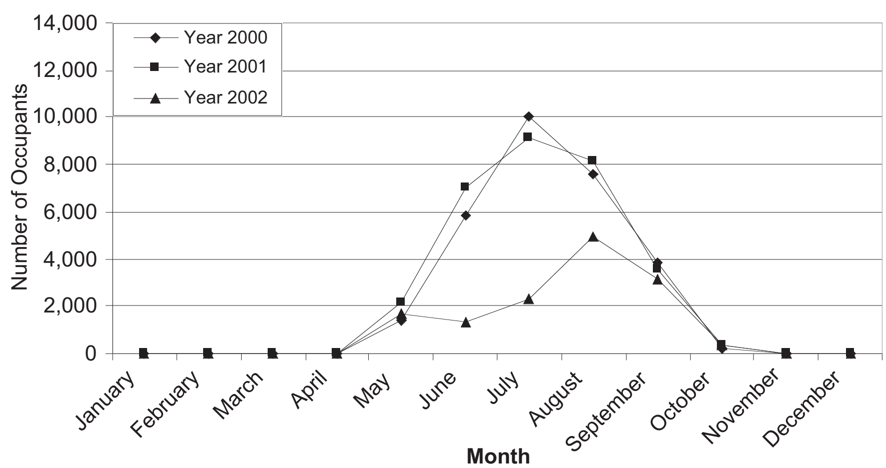

Figure 16—Campground visitation for South Park Ranger District. (Source: Canyon Enterprises Inc)

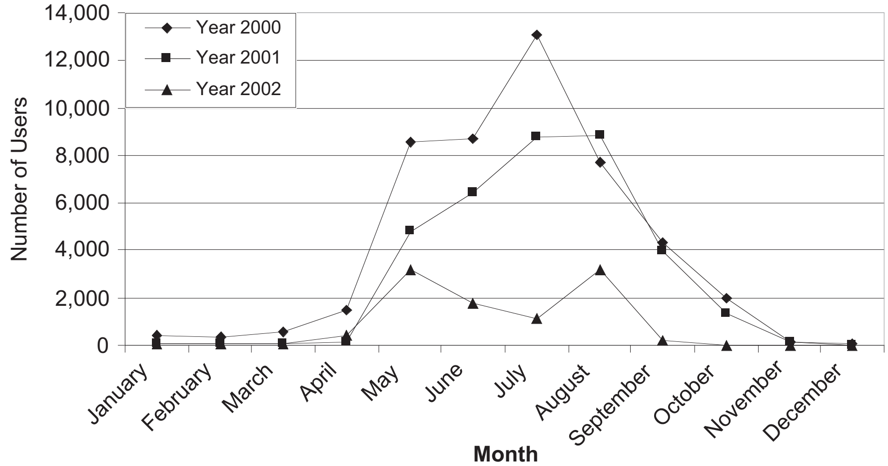

Figure 17—Day use area visitation for Pikes Peak Ranger District. (Source: Rocky Mountain Recreation Company)

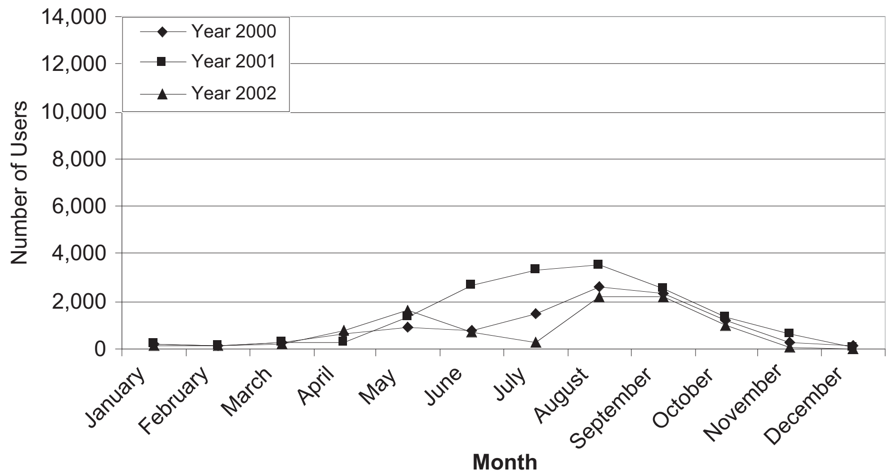

Figure 18—Day use area visitation for South Platte Ranger District. (Source: Rocky Mountain Recreation Company)

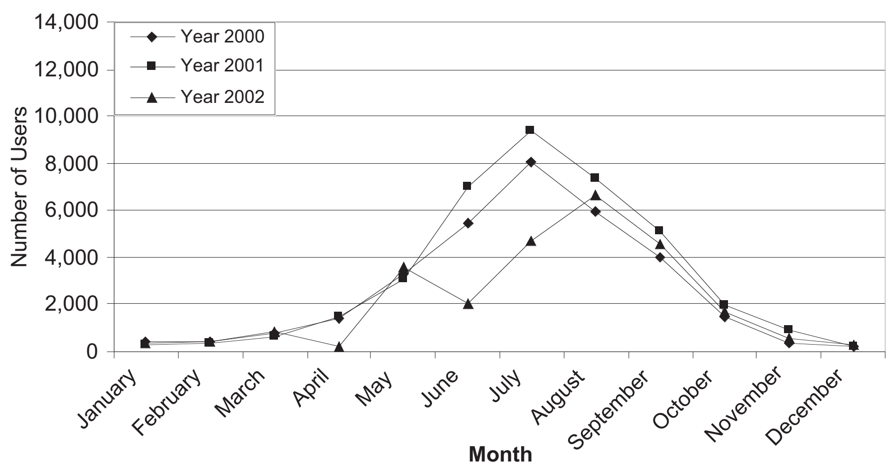

Figure 19—Day use area visitation for South Park Ranger District. (Source: Canyon Enterprises Inc)

December 2002 by Ranger District. Although longer term data would be revealing, accurate visitation data were only available for the 3 years 2000 through 2002. Aggregate data for the three Ranger Districts are presented in figure 20 for campgrounds and figure 21 for day use areas.

The closure occurred during two of the busiest visitation months. On the Pikes Peak Ranger District, the months of June and July accounted for 46 percent of all developed site visitation in CY 2000 and 45 percent in 2001. On the South Platte Ranger District, June and July accounted for 37 percent of all developed site visitation in 2000 and 43 percent in 2001, while on the South Park Ranger District, 48 percent of all developed site visitation occurred in June and July for both 2000 and 2001. Table 14 displays developed recreation visitation by prefire months (January through May), fire months (June and July), and postfire months

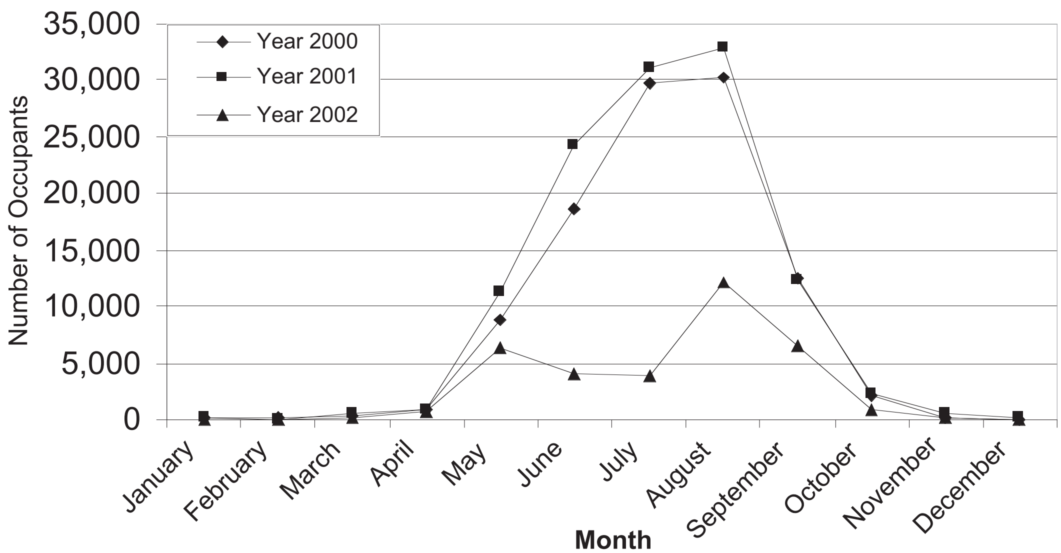

Figure 20—Aggregated campground visitation for the South Park, South Platte, and Pikes Peak Ranger Districts. (Source: Rocky Mountain Recreation Company and Canyon Enterprises Inc.)

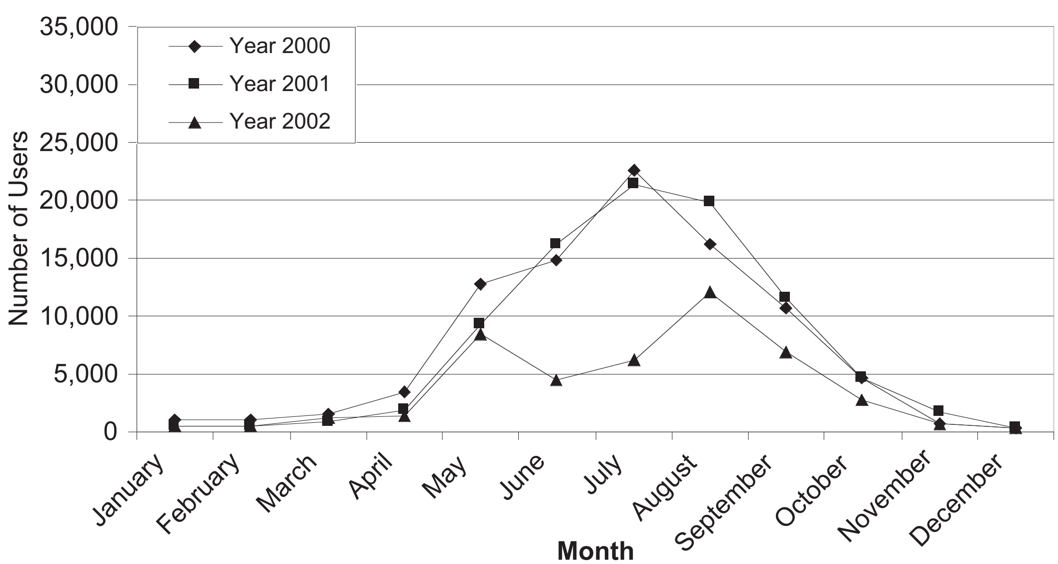

Figure 21—Aggregated day use area visitation for the South Park, South Platte, and Pikes Peak Ranger Districts. (Source: Rocky Mountain Recreation Company and Canyon Enterprises Inc.)

Table 14—Developed recreation visitation by time period by Ranger District (2000 through 2002). (Source: Monthly visitation reports for Rocky Mountain Recreation Company and Canyon Enterprises Inc.)

	Pikes Peak			South Platte			South Park		
	2000	2001	2002	2000	2001	2002	2000	2001	2002
Pre-fire months	15,190	8,840	6,803	7,188	9,189	5,513	7,711	7,965	7,074
Fire months	37,262	32,180	4,834	19,154	28,381	3,420	29,314	32,509	10,372
Post-fire months	28,282	30,573	8,699	25,888	27,958	11,504	23,563	27,680	22,097
Year Total	80,734	71,593	20,336	52,230	65,528	20,437	60,588	68,154	39,543

(August through December) for the three Ranger Districts. Comparing visitation count data for 2002 with prior year levels showed that visitation was slightly down in the prefire months (likely, due in large part to a campfire ban that existed prior to the outbreak of the Hayman Fire), substantially down in the fire months, and remained down in the postfire months in the three affected Ranger Districts. Pikes Peak Ranger District had the most substantial decline from 2001 levels with visitation at 77 percent of the 2001 level during the prefire months, 15 percent of 2001 during the fire months, and 28 percent during the postfire months, with total year visitation at 28 percent of 2001 levels. South Platte District had visitation at 60 percent of 2001 levels during the prefire months, 12 percent of 2001 during the fire months, 41 percent during the postfire months, and total year visitation at 31 percent. South Park District was the least affected with visitation at 89 percent of the 2001 level during the prefire months, 32 percent during the fire months, 80 percent during the postfire months, and total year visitation at 58 percent. It would be revealing to compare visitation trends on the Pike-San Isabel National Forest with visitation data on other National Forests in Colorado for 2002; however, the data are not readily available.

Rocky Mountain Recreation Company estimated that total income in 2002 was $275,000 less than the previous year ($135,000 less on the Pikes Peak Ranger District and $140,000 less on the South Platte Ranger District). Canyon Enterprises Inc. estimated that total income on the South Park Ranger District in 2002 was approximately $107,000 less than the 2001 total.

We also explored the effects of the Hayman Fire on non-Forest Service developed recreation sites near the fire perimeter. Pike-San Isabel National Forest recreation staff members identified four developed recreation sites that were most likely to have been affected by the Hayman Fire. We requested recreation visitation count data from each of the following locations: Florissant Fossil Beds National Monument, Eleven-Mile State Park, Pikes Peak Cog Railway, and Pikes Peak Toll Highway. Monthly visitation data by individual site are presented in figures 22 (Florissant Fossil Beds National Monument), 23 (Eleven-Mile State Park), and 24 (Pikes Peak Cog Railway and Pikes Peak Toll Highway were aggregated for confidentiality). Comparing visitation totals for June and July of 2002 with results from June and July of 2001 showed a decline at all sites, with 2002 visitation at 62 percent of 2001 visitation for Florissant Fossil Beds National Monument, 79 percent for Eleven-Mile State Park, and 85 percent at the Pikes Peak Cog Railway and Toll Highway.

The closure order associated with the Hayman Fire restricted the ability of outfitters and guides with permits to operate on the Pike-San Isabel National Forest to conduct their business and likely caused the following effects: cancellation of existing reservations, the inability of outfitters and guides to offer services to individuals who would have made reservations had the fire not occurred, and the transfer of the guided activities to secondary locations. We were unable to isolate these individual effects; however, we identified the total number of Forest Service client days that permitted outfitters and guides conducted in recent years on the Pike-San Isabel National Forest. Client days are defined as the number of trips times the number of persons taking the trips times the percent of time spent on the National Forest. Total client days for the years 2000, 2001, and 2002 on the Pikes Peak, South Platte, and South Park Ranger Districts are displayed in table 15. On all three districts, total client days were substantially lower in 2002 than 2001, with aggregated outfitter and guide use in 2002 at 75 percent of the 2001 levels. Pikes Peak District was the least affected, with 2002 client days at 86 percent of 2001 levels, while South Platte and South Park Districts were more substantially affected, with 2002 levels at 60 percent and 62 percent of prior year levels, respectively.

Identifying the effects of an event such as the Hayman Fire on dispersed recreation is difficult. In past years Forest Service visitation data have suffered from a lack of accuracy and consistency. The National Visitor Use Monitoring Results (NVUMR) improves the visi-

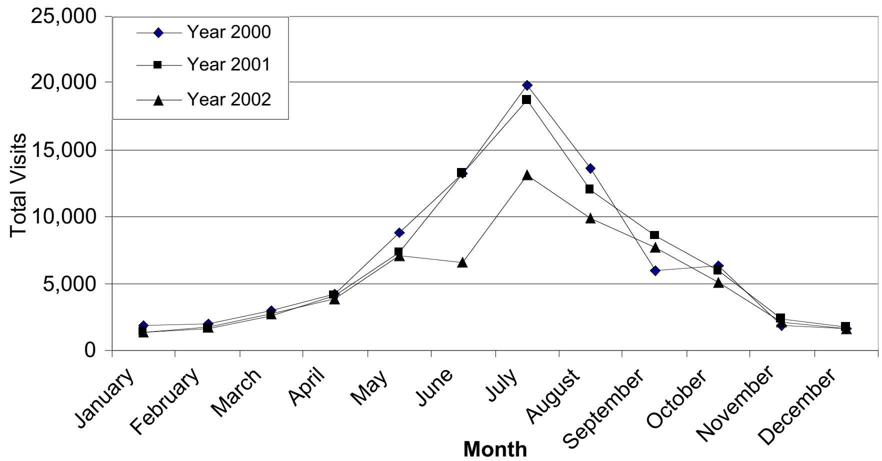

Figure 22—Visitation for Florissant Fossil Beds National Monument. (Source: Florissant Fossil Beds National Monument visitation records)

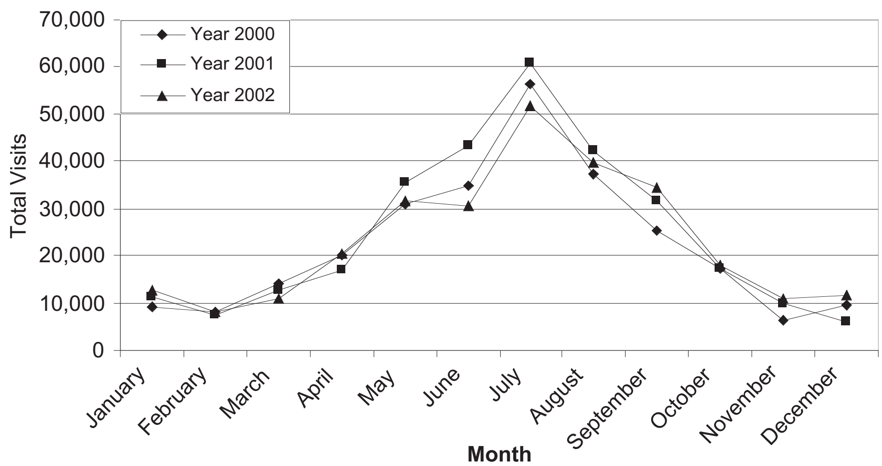

Figure 23—Visitation for Eleven Mile State Park. (Source: Eleven Mile State Park visitation records)

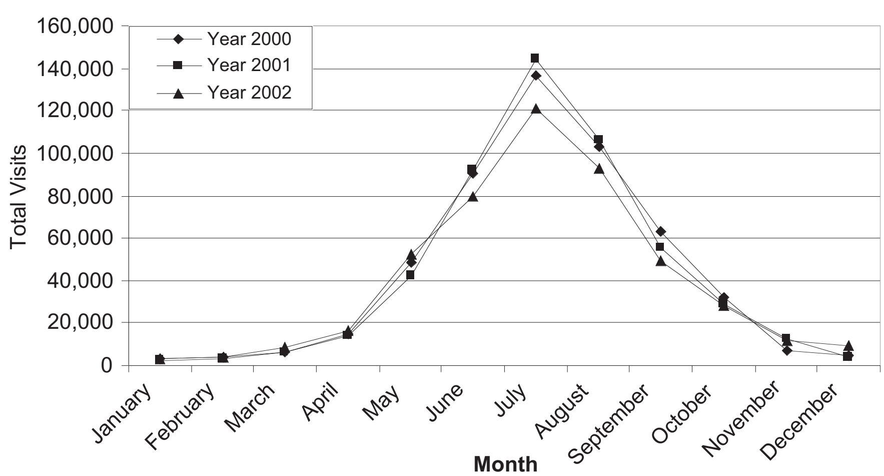

Figure 24—Visitation for Pikes Peak Cog Railway and Toll Highway. (Source: Pikes Peak Cog Railway and Toll Highway visitation records)

Table 15—Outfitter and guide client days by Ranger District. (Source: Actual Use Reports and SUDS records maintained at individual Ranger Districts.)

	2000 client days	2001 client days	2002 client days	2002 client days as a pct of 2001
Pikes Peak	37,726	35,763	30,663	86
South Platte	16,028	16,347	10,111	62
South Park	11,893	13,084	7,880	60
Total	64,949	64,604	48,221	75

tation data by using scientific sampling methods and an established study protocol. However, data from the NVUMR are collected at each National Forest on a 4-year cycle, and the information available in the NVUMR is applicable at the Forest level and "it is not designed to be accurate at the district or site level" (Kocis and others 2002). There may be a potential to use the NVUMR data to estimate the effects of an event such as the Hayman Fire in the future (English, personal communication); however, time constraints prohibited exploration for this study. The NVUMR was conducted on the Pike-San Isabel National Forest in FY 2001 (October 2000 through September 2001). Visits totaled 3,868,928 of which wilderness visits totaled 66,681 on the Pike-San Isabel National Forest in FY 2001 (Table 16).

Additionally, we reviewed recent research that attempted to determine recreation valuation and the effects of forest fire on dispersed recreation visitation behavior. Englin and others (2001) and Loomis and others (2001) conducted a recreation visitor survey in 1997 in Idaho, Wyoming, and Colorado including the Pike-San Isabel National Forest. Englin and others (2001) estimated consumer surplus of recreation visitors to Colorado National Forests at $109 per trip using travel cost models. Visitor surveys revealed an initial positive visitation response to a recent fire event with decreasing visitation in subsequent years. Loomis and others (2001) explored the same data and concluded that a recent crown fire had a positive effect on the value and demand for hiking trips and an adverse effect on mountain biking value and demand. It was surmised that curiosity relating to the effects of a fire might influence hikers' value and demand, while mountain bikers were concerned with the difficulty associated with large downed logs and trees in pathways. These results suggest that hiking activity may increase and mountain biking activity may decrease within the Hayman Fire perimeter. Recreation planners may use these results to help adjust management plans for the existing trail system on the Pike-San Isabel National Forest.

It is inappropriate to conclude that all reduction in recreation activity due to the Hayman Fire represents economic loss. When faced with a closed recreation area, many individuals will make alternative recreation plans. However, it is difficult to identify how many individuals made alternative recreation plans due to the Hayman Fire and what those plans entailed. We attempted to explore this question using data from an existing campground reservation system. Reserve America has a contract with the Forest Service to provide reservation services for all Forest Service campgrounds that accept reservations. We requested that Reserve America query its database to identify all reservations that were cancelled during the Hayman Fire closure on the 46 campgrounds within the Pike-San Isabel National Forest that accept reservations. An additional query identified individuals who made subsequent reservations within the Reserve America system during the closure period and the location of their new reservation. A total of 331 campground reservations on the Pike-San Isabel National Forest made within the Reserve America system were cancelled between the dates of June 10, 2002, and July 19, 2002 (the dates of the general forest

Table 16—NVURM visitation use for Pike-San Isabel NF 2001. (Source: NVURM report for Pike-San Isabel NF, Kocis and others 2002.)

National Forest visits		Site visits		Wilderness visits	
Visits	Error rate	Visits	Error rate	Visits	Error Rate
3,868,928	17.9%	4,406,348	16.2%	66,681	32.4%

closure associated with the Hayman Fire). About one in four of the cancelled reservations were subsequently remade within the Reserve America system. Of these new reservations, 58 percent were made to alternative locations within the State of Colorado. Caution should be used when interpreting these data, since it is likely that many who cancelled reservations with Reserve America because of the Hayman Fire made alternative recreation plans that simply did not include reservations through the Reserve America system.

Additional information regarding recreation substitution behavior comes from survey results of the 2001 NVUMR study (Kocis and others 2002). Individuals were asked questions relating to their choice of substitute recreation activities if the area they were interviewed in had been closed. Responses to this question are summarized in table 17. Over 75 percent responded that if the area were closed they would have still participated in some type of recreational activity. Again, these results should be viewed with caution because the question posed to individuals in 2001 did not suggest a closure due to an event of the magnitude of the Hayman Fire and are based on survey questionnaires and not actual visitor behavior.

We were also interested in identifying if large operators that were forced to cancel scheduled camps due to the Hayman Fire were able to make alternative arrangements for their clientele. Recreation managers on the Pike-San Isabel National Forest identified the Girl Scouts of America and the Lost Valley Guest Ranch as two of the organizations that were most severely affected by the fire. We interviewed representatives from two councils of the Girl Scouts, who each operated summer camps closed due to the Hayman Fire in the summer of 2002. Representatives from both councils stated that they were unable to make alternative camp arrangements for the majority of the members who had reservations at one of the closed camps.

The Girl Scouts Wagon Wheel Council (Colorado Springs) camp was within 1 mile of the Hayman Fire. During the summer of 2002, they experienced two evacuation orders and were shut down for 3 weeks. Approximately 400 campers missed camp and had their fees fully refunded. The Wagon Wheel Council estimated their total losses at $110,000.

The Girls Scouts Mile High Council (Denver) camp is contained within the perimeter of the Hayman Fire. The camp was closed down during the initial closure order and had plans to first reopen in May 2003. Fire effects within the camp were relatively minor considering the proximity of the fire, and property losses were estimated at $112,000. Approximately 750 campers were issued complete refunds at $240 to $460 per camper. In the fall season, the camp typically rents its facilities to Girl Scout troops; however, they were unable to provide these services in the fall of 2002 due to access issues relating to the Hayman Fire. Estimates for total value of losses to the Mile-High Council were not currently available.

The Lost Valley Guest Ranch is on the site of an old homestead and was completely within the Hayman Fire perimeter. The guest ranch was shut down from June 9, 2002, through September 1, 2002. The ranch operated a modest fall season at 40 percent occupancy. The owner estimated total losses associated with property damage, lost income, and fire-related expenses at $1.9 to $2.0 million. In January 2003, booking for the 2003 season was 50 percent of normal, and the owner estimates the 2003 season to be down 20 to 25 percent from typical years.

Other Resource Outputs and Values: Once a fire escapes initial and extended attack, a Wildland Fire Situation Analysis (WFSA) report is developed to explore alternative fire suppression strategies and relative resource and suppression costs. Ted Moore, the fire management officer for the Pike-San Isabel National Forest, developed resource loss estimates in the Hayman WFSA under the assumption of a final fire size of 150,000 acres. Estimates of the individual resource dollar losses made within this report, corrected for the actual size of the Hayman Fire, are provided in table 18. Total resource losses were estimated at $50.2 million for a 150,000-acre fire, which

Table 17—Substitute recreation choices for the Pike-San Isabel NF. (Source: NVURM report for Pike-San Isabel NF, Kocis and others 2002.)

Substitute choice	Percent who would have…
Gone somewhere else for the same activity	60.0
Gone somewhere else for a different activity	15.6
Come back another time	11.4
Stayed home	11.0
Gone to work at their regular job	0.6
None of these	1.4

Table 18—Resource loss estimates (dollars) adjusted from WFSA report. (Source: WFSA report dated 6/9/02, Ted Moore, Fire Management Officer Pike-San Isabel NF, author.)

Resource category	Change in resource value
Mature timber	–3,700,000
Forage	–1,430,000
Water storage	–37,000,000
Fisheries	–297,000
Wildlife- other	–2,660,000
Recreation	–992,000
Total	–$47,000,000

adjusted to $47 million based on the actual size of the fire. Water storage was the single most important category, representing 80 percent of total resource value losses. Alternative methods outside the WFSA report for estimating the value of lost water storage capability were not readily available.

Estimated timber losses within the WFSA report, adjusted for actual fire size, were $3.7 million. In discussion with Ted Moore, it was determined that the valuation of timber-related losses within the WFSA report were not adequate. Therefore, timber value losses were estimated by combining reports from the National Fire Management Analysis System (NFMAS) and fire severity maps of the Hayman Fire event. Forest Service acres burned by fire severity and associated timber value losses are presented in table 19. Total timber losses associated with the Hayman Fire were estimated at $34.3 million using this method. This value should be viewed with caution because these values were based on timber sales on the Pike-San Isabel National Forest that were several years old, and a reference year for these values was unavailable. Currently the timber sales program is relatively small on the Pike-San Isabel National Forest. Additionally, timber within the wilderness area burned by the Hayman Fire was valued at $0 using this approach.

Lance Tyler, recreation program manger for the Pike-San Isabel National Forest, provided loss estimates to the Pike-San Isabel National Forest recreation program. Direct recreation infrastructure losses totaled $56,500 on the Pike-San Isabel National Forest. Fee losses from reduced concessionaire revenue in 2002 were estimated at $58,000. Additionally, four recreational residences burned resulting in a loss of annual revenue to the Forest Service of $2,250.

Gary Roper, timber program manager for the Pike-San Isabel National Forest, provided estimates of lost value to planned timber sales and annual programs, such as Christmas tree and firewood cutting, as well as estimates of returns from salvage operations (table 20). One-time losses to proposed timber sales were estimated at $36,750. Annual timber losses were estimated at $62,000 to $ 65,000 with a majority of these losses coming from the personal use Christmas tree program. Total salvage value was estimated at $159,500. These results should be viewed in isolation of the estimated timber losses reported using the NFMAS data. They simply reflect the changes in revenue to the timber program from existing timber sales, Christmas tree sales programs, and expected salvage logging contracts.

Experiencing the Hayman: Human Perceptions, Knowledge, and Behavior Related to the Wildfire

The material in this section largely relates to question areas two and three, but has some overlap with areas one and four as well. Much of the material comes from local residents – the people who lived through and continue to live through the "Hayman experience." Even so, we only address a small portion of a bigger picture that includes all people affected by this fire. We begin this section with a literature review outlining some of what others have learned about how people react to wildfires. We then report on preliminary data collected from Woodland Park Colorado

Table 19—Forest Service acres burned by fire severity class and change in value (dollars) of timber resources due to Hayman Fire. (Source: Hayman burn severity GIS coverage, on file Pike-San Isabel NF.)

Fire severity	FS acres burned	Change in value (dollars)
Low	46,338	–1,440,000
Moderate	21,404	–7,330,000
High	47,697	–25,500,000
Total	115,439	–$34,270,000

Table 20—Effect of the Hayman Fire on the Pike-San Isabel NF timber program. (Source: Gary Roper, Timber Program Manager, Pike San-Isabel NF.)

Sale name	Proposed	Estimated volume	Estimated losses (dollars)
Annual change in value			
Personal use Christmas trees	Proposed annually	5,500 trees/ yr	– 55,000/ yr
Personal use fuelwood	Proposed annually	350-500 cords/ yr	–7,000-10,000/ yr
Total annual losses			–$62,000-65,000/ yr
One-time change in value			
Schoonover	Proposed	3,000 CCF	–33,750
Saloon Gulch Stewardship	Proposed	2 CCF	–2,000
Gunbarrel Stewardship	Proposed	1 CCF	–1,000
Total one-time losses			–$36,750
Salvage			
Road side salvage	Current	3,500 CCF	+24,500
Other salvage	Proposed	20,000 CCF	+135,000
Total Salvage			+$159,500

Residents in August 2002, shortly after the fire. Next we describe the results of two workshops conducted with residents of the Ridgewood subdivision, located within the USDA Forest Service's Manitou Experimental Forest, one a week before the fire broke out, and the other on February 15 and 16, 2003. Finally, we explore the results of followup interviews in Woodland Park, also conducted during February, 2003.

Literature Review

Wildfires are not new events, and it is useful to consider what scientific understandings already exist on social response to wildfires. Knowing the work that has already been done can provide useful insights about what assumptions are and are not correct and help prevent future research from reinventing the wheel. Clearly with fire the number of individuals living in high fire hazard areas who do little to protect their property indicates that people do not necessarily behave in a classically rational manner in the face of a hazard. Indeed, results for research on other natural hazards rarely show the logical progression that might be expected of: awareness of a hazard– increased risk perception – doing something to minimize risk exposure. The fact that individuals do not behave in a classically rational manner makes it even more important to understand what does guide their actions. Some of the variables that many would assume would influence individual responses that have been investigated by natural hazards studies include: awareness, perceived risk, sense of responsibility, and experience. (Perceived risk is based on how serious an individual deems a threat to be coupled with his or her estimation of the probability of experiencing a damaging event. It is important because if an individual deems the risk low he or she is less likely to act to reduce exposure. It is also important because it is extremely subjective, with level of risk and probability calculation influenced by a variety of considerations.)

Until recently only a handful of studies had been done on perception and response to the wildfire hazard, and these focused primarily on understanding individual response (Cortner and others 1990; Gardner and Cortner 1985). Perhaps more than most other natural hazards, effective fire mitigation depends on individual action – it is not just a case of enacting effective building codes (which are integral to hurricane, earthquake, and flood mitigation) but of changing both behavior and opinions on more personal matters of home design, desirable vegetation and aesthetics, and acceptable large-scale fuel management practices. Understanding what shapes an individual's response to wildfire can provide fire managers with useful insights into the most effective ways of working with members of their community. However, individual action alone will not be sufficient.

Awareness and Risk Perception

The study that comes closest to assessing before and after effects of a wildfire is a 1983 survey that compared opinions of homeowners in two wildland urban interface communities in San Bernardino County, California, one which had recently experienced a wildfire and another which had not (Gardner and Cortner 1985). Notably both awareness and risk perception in the affected area were lower than in the unaffected community. Actually experiencing a fire appeared, rather ironically, to dampen awareness and perceived risk as homeowners in the unaffected community also had a higher perception of risk than those in the affected community (Gardner and Cortner 1985). The recent fire apparently created the illusion that a fire was much less likely to occur in the affected community, a reasonable example of gambler's fallacy in action as this was true only for a brief period immediately following the fire. (A good example of the gambler's fallacy occurs when an individual is asked to estimate the probability of heads or tails when flipping a coin. If it comes up heads the first time, most individuals then think the chances of tails coming up next are greater, whereas the probability is still 1/2.) The researchers concluded that this finding demonstrated, along with the ease with which individuals are willing to convince themselves that they won't be affected, the poor understanding respondents had of the fire regime in southern California (Cortner and others 1990).

In examining explanatory variables for current awareness and risk perception, the survey found different variables important in the two communities (Gardner and Cortner 1987). Initial awareness of the hazard was positively correlated with current awareness for both groups. Gender also was correlated with each group, with women having a higher present awareness level, although it was less strong for the unaffected community. However, age was predictive only for the unaffected group (older = more aware) whereas income was only associated (negatively) for the affected area. Newer residents in the unaffected area also were more likely to be aware of the hazard than established residents, perhaps as a result of greater media attention and availability of information on wildfire.

Awareness did show a correlation with perceived risk for both groups. When asked to estimate the likelihood of a wildfire merely occurring in the area, the key variable for both groups was current awareness level. In the unaffected area, other significant variables were education and length of residence—higher education and longer residence each leading to a higher estimated likelihood of a fire occurring. For residents in the affected area, current awareness level was the only significant variable. When asked to estimate the likelihood of a wildfire that caused structural damage, current awareness was significant and positively correlated for the unaffected area but not the affected area, again likely reflecting the illusion of safety created by the recent fire. For the unaffected area, awareness at time of purchase and length of residence were also significant, both positively related. For the affected area, awareness at time of purchase was significant as well as gender and education, with men and those with a higher education less likely to expect a structural fire (Gardner and Cortner 1985).

A survey of residents of the Santa Monica Mountains found that respondents were more aware of the hazard risk than had been expected, although their collective sense of responsibility was lower than anticipated (Loeher 1984). Understanding of causes of the problem was also better than expected, particularly in regard to fuel load concerns and mitigation measures, although much of this information was incomplete. Loeher found that both direct experience and education were predictive for awareness levels and that awareness level in turn was directly related to perceived threat.

In their survey of Florida residents Abt and others (1987) found that although residents generally estimated a high probability and perceived danger from fires, fire was not a high priority in home selection, although newer residents were more likely to include it in their decision. Age and experience were both positively correlated with perceived risk, but education was found to be inversely correlated. Income was correlated, but neither positively nor negatively, with those of middle income showing the lowest perceived risk level. This may be explained by the fact that insurance was also negatively correlated with perceived threat, suggesting that those of middle income have enough resources to buy insurance to cover their losses yet have nothing of overly high value to lose.

A survey of homeowners in Incline Village, NV, found that concern about the wildfire hazard was high: 74 percent of respondents saw the hazard in the Tahoe Basin as moderate to very severe, and 67 percent stated that the hazard was one of their top five concerns about living in Incline Village (McCaffrey 2002). Respondents also had a reasonably accurate knowledge of what causes the current wildfire danger in the area; 63 percent cited local natural processes (such as drought and insect infestation) as contributing a lot to the danger. Fuel load build up also was cited as a major contributor, with 52 percent thinking the fuel build up contributed a lot and 29 percent thinking it contributed some to the hazard.

Notably, individuals who saw the fuel load as contributing a lot were more likely to judge the fire hazard as very severe (83 percent) than those who saw it as contributing some (75 percent) or not much (43 percent). Respondents who thought the fuel load was a major contributor were more likely to live in single-family homes and to be permanent residents than those who thought the fuel load was only a partial or negligible contributor. The study attributed this result to the presence of an active wildfire education program that was primarily targeted at single-family homes and permanent residents.

Similar to the San Bernardino study, the Incline Village study suggests that experience may be most influential when it is second hand. (Although at the time the Tahoe Basin had not experienced a major fire in over 75 years, given the transience of much of Incline's population, many respondents had either directly or indirectly experienced a wildfire elsewhere.) Direct experience had no association with risk perception or putting in defensible space, however. Direct experience had a significant association in only two places. Those with direct experience showed a clear preference for greater State responsibility and less individual responsibility in fire management. Respondents with direct experience were 20 percent more likely to cite cost effectiveness as a very important reason for putting in defensible space. Although one suggested reason individuals may not mitigate is the expectation that they will be "rewarded" with a bigger and better replacement house, this suggests that those who have actually lost or know someone who has lost property realize that any potential gains are not worth it.

Conversely, respondents who indicated that a friend or relative had been threatened by a wildfire were more likely to have a higher risk perception, to have put in defensible space measures, and to have an evacuation plan. Of note was the finding that for respondents with indirect experience, the fact that they knew someone who did not lose a house as a result of defensible space was *more* influential in adoption of defensible space measures than knowing someone who actually lost a house, although both had a positive effect.

Responsibility

The issue of who is responsible for mitigating the hazard is an important one. Loeher (1984) found that residents who took action were also more likely to feel that they were in some way responsible for protecting themselves. While this is heartening, less encouraging is that the general level of responsibility was lower than expected as 37 percent indicated *no* sense of personal responsibility to minimize the risk. However, 19 percent thought mitigation was solely their responsibility and 45 percent felt it was a joint public-private concern (Loeher 1984). Issues of responsibility were frequently found to be intertwined with freedom of choice; accepting some level of personal responsibility for the hazard might implicitly mean tolerating restraints on where one could live, a restraint many were unwilling to accept (Gardner and Cortner 1985; Cortner and others 1990, Abt and others 1990). The San Bernardino study also found that individuals felt that they were not responsible for any defensible space for their home if any of the area fell on government land, and other studies have found that in general individuals prefer to put the burden on the government (Gardner and Cortner 1985; Cortner and others1990). In Incline Village, a greater sense of individual responsibility was associated with higher risk perception but not with increased likelihood of putting in defensible space or having an evacuation plan (McCaffrey 2002).

A recent study in Michigan found that 54 percent of respondents felt homeowners and government shared responsibility, 26 percent felt it was primarily the homeowner's responsibility, while only 6 percent thought it was solely the government's job (Winter and Fried 2000). Focus group interviews of selected study respondents found that most felt homeowners were responsible for fireproofing their property while the government was responsible for education, enforcing burn regulations, and maintaining suppression forces. The fact that fire does not recognize property ownership was cited as a reason why fire protection was every person's responsibility. As one participant stated: "I think a forest fire doesn't care. When a forest fire starts, it's gonna burn anything in the way. It's not gonna say, 'Well, this is government land—I'm going around it'" (Winter and Fried 2000). Although a significant portion of homeowners agreed it was their responsibility to protect their own property, many were unwilling to do anything, preferring the additional risk to the perceived negative aesthetic impact of use of defensible space. "Maybe I should be spraying fire retardant on my cedar chip roof, maybe I should be cutting the branches off, but I'm reluctant to destroy the look of the property by doing all of that cutting and trimming" (Winter and Fried 2000).

Several of the Michigan respondents also felt that carrying insurance fulfilled whatever responsibility they carried. As one resident put it, "If you build there and it burns, you rebuild there. That's between you and your insurance company, or whoever" (Winter and Fried 2000). In this regard, insurance has often been found to be a main disincentive. Combined with disaster insurance it has in fact been found to profit those who do nothing over those who take mitigative action (Gardner and El-Abd 1985).

The Michigan study also provides an interesting example of the ability to externalize responsibility. Respondents attributed much of the fire problem to "ignorant" seasonal residents or tourists. However, the Department of Natural Resources statistics indicate that backyard debris burning is the main ignition source Statewide and that permanent residents are responsible for 80 percent of ignitions (Winter and Fried 2000).

Defensible Space

The tie between awareness, risk perception, and engaging in defensible space or other mitigation is not that clear cut. Although the San Bernardino study found that homeowners were aware of the need to do something and claimed to support vegetation clearance, a large proportion still did nothing: in the effected area 83 percent had done nothing. Reflecting their higher awareness and risk perception levels, homeowners in the unaffected area were more active, with only 43 percent doing nothing (Gardner and Cortner1985).

On a more positive note, Loeher's study (1984) found that only 25 percent of respondents had done nothing. Perceived threat was directly related to taking action; the higher the perceived threat the more likely residents were to obtain information and engage in mitigation. Of those that had done something, 40 percent were choosing "active" measures—intending to stay and protect their property themselves—and 60 percent were engaging in "passive" protection involving brush clearance and use of fire-resistant building materials. The Michigan study found that 75 percent of homeowners claimed to have taken mitigation steps (Winter and Fried 2000).

Abt and others study (1990) of Palm Coast, FL, also found a high rate (67 percent) of residents using some type of defensible space measures, with vegetation clearance the most popular activity (53 percent). Showing a positive effect of experience, 93 percent of the measures put in place were done after a wildfire that occurred in the area in 1985. However, another study after the 1998 Florida fires found a negative association between wildfire experience and intention to take protective action (Jacobson and others 2001).

In Incline Village, 70 percent of respondents reported that they had put in some defensible space measures with 63 percent engaging in vegetation modification (McCaffrey 2002). The most common reason given for why defensible space measures were put in was a sense of responsibility for choosing to live in a high hazard area, with 77 percent of respondents stating it was a very important reason.

The Incline Village study found no associations between accuracy of understanding of the fire problem and either putting in defensible space or having an evacuation plan (McCaffrey 2002). However, higher risk perception did appear to lead to taking some degree of action. There was no association between hazard perception and putting in defensible space measures when the hazard was judged moderately to very severe. However, there was an association when the responses were grouped into very severe and moderately to not very severe. Those who saw the hazard as very severe were 13 percent more likely to have defensible space than respondents who found it less severe. However, having an evacuation plan appears to require a lower level of risk perception as those who saw the hazard as moderately to very severe were 11 percent more likely to have an evacuation plan. In this study, the degree of action taken appears to run parallel with the degree of perceived risk. Moderate risk perception only led to moderate action (having an evacuation plan), while very high risk perception potentially leads to more involved activities such as putting in defensible space measures.

In Incline Village, permanent residents were quite a bit more likely than part-timers to put in defensible space measures (83 percent versus 64 percent) and to have an evacuation plan (44 percent versus 24 percent). They also were more likely to think the fuel load was a major contributor to the hazard (70 versus 48 percent), have a higher risk perception, and a stronger sense of responsibility (McCaffrey 2002). The nature of residency was particularly interesting when significant relationships were looked at for different types of partial use: 4 to 8 months, 1 to 3 months, and weekend and vacations only. Certain variables were found to have a clear relationship with the amount of time spent at the residence. These included putting in defensible space and having an evacuation plan, risk perception, and putting in defensible space because it was the individual's choice to live in a high fire hazard area: all were positively associated with longer periods of residence use. Single-family homes also were found to be 28 percent more likely to have some defensible measures.

Several factors were found to inhibit mitigation. Loeher (1984) found that two hindrances were the issue of how to dispose of cleared vegetation and the need for others to take action for the mitigation to be effective. Uncertainty regarding the effectiveness of various adjustments also frustrated homeowners. This is a common dilemma with mitigation; it is difficult to prove that a house was saved due to mitigation and not just luck. A similar result was found in interviews in three California fire areas by Rice and Davis (1991) who found that the uncertainty around fire, both when it will occur and the effectiveness of mitigation, provided little incentive to do anything especially when other issues were more relevant. They also found the "It won't happen to me" belief prevalent at all levels, whether homeowners or government officials. Nor does experience with fire always lead to improved visions of defensible space. A 1990 wildfire in Michigan left residents with a view of wildfire as uncontrollable and random, leaving them skeptical of both suppression and mitigation activities. The fact that the fire came right up to, but did not burn, a woodshed and skipped over other vulnerable structures, yet destroyed houses with 300 feet of defensible space, left doubt about its usefulness (Winter and Fried 2000).

Prescribed Burning

Prescribed burning is often thought of as one of the more controversial fuel management activities due to issues of air quality and public acceptance. Studies, however, indicate these concerns may not be as problematic as anticipated. While studies from the 1960s and 1970s did indicate public distrust or dislike of prescribed burning, studies from the 1980s show increasing public support (Cortner and others 1990). A 1981 phone survey of Tucson, AZ, residents found that 84 percent knew about prescribed burning and of these, 80 percent strongly approved of its use (Cortner and others 1984). A 1986 survey of western Oregon residents had similar results (Shelby and Speaker 1990). More recently a 1996 survey in the Blue Mountains of Oregon found that 84 percent of residents supported using prescribed burning over not using it (Shindler and others 1996) and a 1998 survey of Incline Village homeowners found 88 percent were aware of prescribed burning and, of these, 94 percent felt it an appropriate management tool (McCaffrey 2002). However, not everyone is supportive. Homeowners in Michigan were quite distrustful of prescribed burning as a fire management tool due to a previous prescribed burn that had escaped, destroying 44 structures and killing one firefighter. "I'm going to get real scared if I see smoke in the air and there's some government person out there saying, 'I'm your friend, I'm watching this over here'" (Winter and Fried 2000).

McCaffrey (2002) found some support for the conventional wisdom that aesthetics, smoke, and loss of control are important concerns; 57 percent of respondents agreed that they did not like the appearance after a burn and that they were worried the burn would get out of control. A lower percentage of respondents (36 percent) agreed that smoke was a health problem for someone in their household. A smaller percentage of Blue Mountain residents (24 percent) agreed that smoke was a health problem for their family while two-thirds agreed that it was acceptable if it helped forest health (Shindler and others 1996). Other potential public concerns expressed by participants in forums on prescribed burning in western Oregon were regarding resource waste and scenic visibility (Shelby and Speaker 1990).

Common factors that influenced approval were concerns about animal mortality (Carpenter and others 1986; Shelby and Speaker 1990), fear of losing control (Shelby and Speaker 1990; Cortner and others 1984); ignition source, size, intensity, and area of fire (Carpenter and others 1986); belief that nature was too complex to be managed and better left alone (Cortner and others 1984; Shelby and Speaker 1990), and whether the fire is perceived to have a positive or negative environmental effect (Carpenter and others 1986; Cortner and others 1984). This last can be quite significant in shaping approval. Carpenter and others (1986) reviewed three previous studies and found that acknowledgement of beneficial effects was the most "pervasive" influence in approving various fire management methods. For example, when combined with age, belief that a fire had a beneficial effect increased likelihood of approval of prescribed fire 33 times (Carpenter and others 1986). McCaffrey (2002) found that more accurate understanding and higher risk perception decreased the strength of concerns about aesthetics, smoke, and fear of a burn getting out of control. In addition, experience with wildfire increased respondent support for the use of prescribed fire as a management tool.

In a recent survey of Florida, California, and Michigan residents, Winter and others (2002) found that support depended on citizen participation, duration of smoke events, effect on aesthetic quality of landscape, and whether the action was cost-effective. One of the most important variables in acceptance was trust, a belief in the credibility and competency of the agency to safely manage the burn.

Whether socio-demographic factors influence approval is not altogether clear. Carpenter and others (1986) found that different factors were relevant for different types of fire: none were correlated to attitudes on let burn policies; education and age were predictive for opinions on fires burning only underbrush; income and age were relevant for management burns; and age and gender predicted approval for prescribed burning, with older males and middle aged females most likely to approve. McCaffrey (2002) found that women were more concerned about smoke and about a burn getting out of control and that part-time residents were more likely to be concerned about postburn aesthetics and loss of control. In Oregon, Shelby and Speaker (1990) found no socio-demographic correlations. This was attributed to the wide level of support for the practice.

Thinning

Fewer studies have been done on the acceptability of thinning. Two studies indicate that thinning is preferred to prescribed burning, with 76 percent in each study preferring selective thinning to prescribed burning for reducing the fuel load (Shindler and others 1996; Shelby and Speaker 1990). Another study showed a fair knowledge of the role thinning can play in enhancing forest health with 90 percent able to identify its benefits for forest growth and fuel load reduction (Cortner and others 1984). In Oregon, those who favored getting an economic return from a forest were more likely to support thinning over prescribed burning (Shelby and Speaker 1990).

In Incline Village, over 75 percent of respondents found all thinning methods (except herbicides) at least somewhat acceptable (McCaffrey 2002). Hand thinning was the least controversial with 80 percent of respondents finding its use fully acceptable. Contrary to some beliefs that timber harvest is a controversial option, salvage logging and selective timber harvest were both fully acceptable to roughly three-fourths of respondents. Thinning with heavy equipment and use of grazing animals had more mixed responses with roughly half finding the methods acceptable, one quarter finding them somewhat acceptable, and the remaining quarter either finding the methods not acceptable or were unsure. The higher percentage of respondents who felt the practices were only somewhat acceptable may reflect their concern over where and how the practice was used. Higher risk perception and experience were associated with greater acceptability of salvage logging and selective timber harvest. Older respondents were more likely to support for the larger scale methods of heavy equipment, salvage logging, and selective timber harvest. The one clearly unacceptable method was use of herbicides, with 50 percent finding them unacceptable and only 13 percent acceptable.

One factor unique to the Tahoe Basin that clearly influenced the degree of acceptability of certain practices was concern about the water quality of Lake Tahoe (McCaffrey 2002). This was cited particularly in regard to herbicides getting into the lake and concern about potential erosion from use of heavy equipment and grazing animals. This fact also may be a reason for the large proportion of residents who found timber harvest and salvage logging acceptable. In the Tahoe Basin any logging that takes place occurs under strict conditions in order to minimize potential erosion problems.

Education and Information

Many studies demonstrate a positive correlation between knowledge of fire issues and support for fire management strategies (Cortner and others 1990). Shelby and Speaker (1990) found that when forest managers gave the public specific information about the reasons, plans, and effects of doing prescribed burns there was a high level of acceptance. The most important information sources (in order) were newspapers and magazines, friends and relatives, and television. Cortner and others phone survey (1984), designed in part to educate, found that only a few minutes of exposure to information on prescribed burning could increase approval. The study also confirmed previous work showing a relationship between education, fire knowledge, and tolerance of various fire management practices. Carpenter and others (1986) found that approval of prescribed burning increased with specific information on fire activity and management and concluded the public could handle "a more sophisticated message than that fire is simply bad." McCaffrey (2002) found that more accurate understanding increased support for most practices, particularly in relation to prescribed burning where accurate understanding of the cause of the hazard was associated with better understanding of the ecological benefits of prescribed burning, support for its use, and less concern about loss of control.

However, while Michigan residents may have received fire hazard information, experience (actual or virtual via the news media) was found to be the main influence on perception. The study also found that while homeowners strongly supported education programs to reduce fire ignitions and generally recognized homeowner responsibility for defensible space, they placed little emphasis on educating homeowners on the topic (Winter and Fried 2000).

Despite the prevalent availability of information on wildfire hazard and defensible space, there is poor public use of it. Gardner and Cortner (1985) found that while individuals wanted information they were unaware of the available brochures. Loeher (1984) found that respondents tended to disregard information from fire departments and insurance companies because they had a low level of trust in them and the information they furnished.

The Incline study suggests one reason why there has been poor public use of available information as it found that effectiveness of educational efforts depended on the information source (McCaffrey 2002). General media sources were of questionable value—having either a limited affect, in the case of magazines and newspapers, or a negative influence, in the case of television. Educational materials on the other hand had a positive affect on risk perception and acceptance of more controversial aspects of prescribed burning. In addition, personal contacts increased support for more controversial aspects of various mitigation practices. The study also found that whether a human information source (such as a fireman) was perceived as a government contact or a personal contact was related to the type of practice involved. If respondent concerns were centered at a governmental (for example, salvage logging) or a more personal level (such as smoke), the parallel type of contact was most influential.

Social Impacts of Wildfire—Hayman Fire, Woodland Park, CO, Case Study: Preliminary Results

Woodland Park Colorado is a small town west of Colorado Springs on U.S. Route 24 and within a few miles of the Pike National Forest. The Hayman Fire burned to the southwest, west, northwest, and north of the town and approached within a few miles of it. While Woodland Park was never evacuated, it was on standby for evacuation frequently throughout the period of greatest fire activity. The information was collected to support a larger study ongoing in Forest Service Region's 1 and 4, funded by the National Fire Plan, and whose purpose is to develop an improved understanding of social monitoring protocols for communities impacted by wildfire. The study comprised a brief, preliminary summary of the results of interviews conducted with 55 residents and knowledgeable "key informants" in and around the community of Woodland Park, CO, in the wake of the Hayman Fire. It was prepared on the basis of field notes and recollections of field researchers.

Summary of Emergent Themes from Respondent Interviews

Impacts: We began by asking respondents to talk about the local impacts of the fire *as they saw them*. For present purposes, we categorize them as generally positive or generally negative.

Positive: Respondents in this case study stated that the most positive impact resulting from the fire was the way the community (Woodland Park and the surrounding areas) "pulled together" and helped each other out. They often cited the example of donations of food and supplies for the firefighters as well as money for the volunteer fire departments. The shared experiences of preparing homes and subdivisions for the fire and the evacuation process created opportunities for people to get to know each other and work together. Respondents also cited other positive impacts such as an increased sense of community, the strength, consideration, and kindness of people; an awareness of the wildfire hazard and what needs to be done to improve the situation (thinning, road access) and an awareness of the volunteer fire departments and their needs. Some members of homeowners associations indicated that conflicts (regarding usage of common resources, membership fee for these resources, and so forth) among residents prior to the fire disappeared after the fire. They mentioned that now they had to tackle a common hardship together.

Some also cited positive or little impacts on certain sectors of the economy including lodging, service stations and convenience stores, restaurants, and grocery stores. These businesses supplied services not only to firefighting agencies, but also to evacuees. Some evacuees had to leave with little notice and did not have time or forgot to grab essentials such as toiletries or sufficient clothing. These supplies were purchased at local businesses and/or received through social service agencies.

Negative: The negative impact on the economy of the area and on individuals as well as the loss of natural resources was often mentioned. The tourist sector was hit especially hard. The area has many campgrounds, trails, and ORV areas. The forest was closed during and after the fire, drastically reducing the number of visitors. Parts of the forest have reopened, but negative publicity and perceptions about the area have kept people away. The concessionaire for the developed campgrounds on PSINF estimated that revenues were significantly lower this year. Flooding danger and resource damage will prevent some campgrounds from opening next year. In the long term, the concessionaire thought that return visits would be low due to the loss of natural beauty. A business owner who sells ORV and snowmobile equipment estimated that he lost 80 percent of his business. He is not sure if his business will survive the winter. "Making it through the winter" was a common theme. Respondents expressed concern that tourist/summer oriented businesses would not "make it through the winter" due to a loss in revenue.

The impact on the building and construction industry was apparently mixed. Some respondents said that this sector was hit hard, while someone in the contracting business said that he had more than he could handle.

Another financial impact was on the local volunteer fire departments. The loss of property tax revenue will severely impact the Mountain Communities Fire Department because most of the destroyed homes were in their district. The departments will also need to repair and replace equipment. Funds for this are available through several sources, including El Pomar (Statewide fund), local donations, and the Colorado State Forest Service.

Individuals, including volunteer firefighters, also suffered income losses because they were not able to work. There were a couple of anecdotes that some volunteer firefighters lost their "regular" jobs, although the employers claimed that it was not due to time lost to firefighting duties. Others were not able to work because they had been evacuated or had stayed to protect their homes. A few businesses, such as the Lutheran Valley Retreat and the concession campgrounds, placed out-of-work employees in jobs in other areas.

Impacts on physical health seemed generally to be minimal. A couple of respondents mentioned that they or relatives with asthma and other breathing problems had to leave the area. One elderly woman died from an asthma attack brought on by the smoke. The smoke was not persistent in the Woodland Park area and many said that there were only a few intensely smoky days.

The impact on mental/emotional health (at least in the short-term) appeared to be more pronounced. Many reported high levels of stress and anxiety due to the fire and evacuation. The concern over the loss of home and property, not being able to return after being evacuated, the perception of misleading or inaccurate information, and the perceived insensitivity (at times) of law enforcement officers were often mentioned as stress inducers. Interviewees stated that they dealt with the stress by staying busy (for example, going to work, volunteering) and by staying informed. One evacuee stated that he and others in his subdivision "felt like criminals" because they had to sneak into their homes after being evacuated to get things and work on the property. In this area and others people were evacuated days or weeks before the fire actually reached their homes. People wanted the opportunity to go back for things they had forgotten and to "fireproof" their homes. Some of those who were escorted in after the area had burned claimed that they were locked in vans and not allowed to get out and look at their homes and/or retrieve belongings for more than a few minutes.

Residents who lost their primary home due to the fire are living through an on-going traumatic experience. Elderly people who planned to use their (now) burned vacation home as a primary residence after their retirement are also experiencing substantial grief. People who did not have fire insurance and "lost everything" expressed helpless and desperate feelings about their future. Younger people who lost their homes tended to express a greater resiliency, while retired people who "lost everything" said they felt desperate. As would be predicted from previous research and experience, people who lost their homes often expressed anger toward the USDA Forest Service and firefighters. Residents who lost their homes reported asking themselves "…why my house, but not others…why did they let my house burn?" One respondent stated that he is still having trouble with comprehending exactly what happened to him. A retired couple told the interviewer that the most difficult thing to deal with was to remember that their house used to exist. They expressed grief at having lost everything that they had accumulated. They stated that money simply could not buy back these memories.

For those who were evacuated for long periods, "not knowing what was going on" with their homes from day to day was "nerve-wracking and frustrating". Such people often expressed the complaint that they could not get updated, concrete, and reliable information during the fire.

Almost all people who incurred property damage expressed significant frustration about the reimbursement process they had to go through with their individual insurance companies. Overwhelming amounts of paperwork, along with remembering and listing lost belongings, were common complaints. Many such respondents also complained that their insurance companies were neither cooperative nor sympathetic concerning their losses.

Most Oft-Mentioned Impact: The loss of the forest resources and physical beauty of the area were most often mentioned. Also mentioned was the impact (positive and negative) on the economy. Flooding and erosion and a decline in real estate values were also frequently mentioned by those who did not incur any damage, while not surprisingly, the loss of houses and possessions was more frequently mentioned by those who incurred damages.

Attribution: We also asked respondents what they believed were the "fundamental causes" of the fire and its damage. Respondents generally attributed the fundamental causes to the drought and poor forest health or "lack of management." Contributing factors were high winds, lack of thinning, lack of prescribed burning, and failure to fully utilize all firefighting resources when the fire started. Most thought that the fire was inevitable and the ignition source itself was not important, saying that if the fire hadn't been started by an individual, something else such as lightning, a tossed cigarette, or a hot catalytic converter would have started it.

Most respondent who *did not personally incur any damage* thought that the fire had been fought effectively and that it was not controllable. Some were critical of the Forest Service and claimed that if the agency had been more aggressive at the beginning, the fire could have been controlled and kept small. Specific examples included the alleged failure of the Forest Service to call on and/or utilize local volunteer fire departments and the failure to use large bulldozers from Cripple Creek mining operations as well as the alleged failure to use National Guard slurry bombers stationed in Colorado Springs.

It is worth emphasizing again that critical comments concerning the USDA Forest Service were especially common among people who personally incurred property damage or lost a home. For these individuals, personal losses overwhelmed concerns about such things as firefighter safety. On the other hand, those who did not incur property damage tended to believe that firefighter safety should be a higher priority than protecting property. Again, this result is consistent with previous research on attribution and wildfire (Carroll and others 2000).

Restoration: We also asked respondents about ongoing resource restoration efforts in the wake of the fire. Respondents mentioned cutting of hazard trees, seeding, mulching, and erosion control as the things they noticed going on in the burned area. Most noted that the Forest Service couldn't do such work on private land. A few knew that money for restoration/rehab on private land was being transferred through HayRAC. Efforts on private land were thought to be less extensive due to the time, labor, and expense involved. (The Natural Resource Conservation Service is heading up efforts on private land, but money is limited and resources are scarce, in part due to many fires this year and a resulting high demand for money and supplies). Some private landowners wanted to begin restoration and rehab efforts on their property but felt they could not do so productively until the Forest Service finished work on National Forest land, which was often sited above the private property in question.

Many noted that aspen, grasses and other plants have sprouted since the fire. It was noted that brush and small trees would make the area relatively green within 5 to 10 years, but many lamented that "not in my lifetime" would the large trees return.

Information: We also asked respondents about the adequacy, timeliness, and appropriateness of fire related information available from various government sources to them (1) before, (2) during, and (3) after the fire.

Prefire: (It should be noted that primary responsibility for "fire wise" programs in the study area rests with the Colorado State Forest Service, which did have active programs ongoing prior to the fire.) From the perspective of postfire respondents, prefire education and prevention information seemed, in retrospect, to be somewhat limited both in its scope and in the response by residents. Respondents mentioned receiving brochures or flyers in the mail. They also mentioned that the volunteer fire departments offered information at pancake breakfasts and at the fire stations. While most thought that the information was good and easy to understand, most admitted that they had not undertaken such measures prior to the fire event.

During: This topic requires some context. Previous research and past fire experience indicates that communication between agencies responsible for firefighting and residents of fire-effected communities is often problematic (Carroll and others 2000). This generally appears to be the case for a number of reasons. One reason is that the responsible agency is often in the position of being the bearer of bad tidings to residents. Another is that natural resource managers are trained to look at fire analytically, whereas, for residents, a threat to their house or beloved special places is a highly emotional and personal experience. Thus, what fire managers are trained to think and talk about in a fire situation is often quite different from what is on the minds of residents. Third, there is some research evidence to suggest that there is a "natural" psychological tendency for people who suffer tangible losses from disaster situations to look for a human agent to "blame". In wildfire situations, that agent is usually the entity charged with fighting the fire.

In this particular case, interviews with line Forest Service officers indicated that the forest supervisor, being aware of the inherent difficulties in communications involving a fire of the magnitude of the Hayman Fire, appointed a team of off-forest District Rangers to lead the Forest Service communication process for the fire. In addition the local County sheriff took it upon himself to personally notify residents who lost their homes. Nonetheless, as we will briefly describe below, the communication process was not without its difficulties from the perspective of at least some fire-affected residents.

Information sources used by residents during the fire included Web sites, neighbors, firefighters, public meetings, local television stations (Denver, Colorado Springs), the Red Cross, hearsay, radio scanners, and the Java Junction Coffee Shop.

Overall, respondents thought the quality of information from the above-mentioned sources during the fire was good. The Teller County Web site was highly praised, as was the information from Java Junction. This establishment turned into a gathering place for off-duty firefighters, and they passed on current information on fire suppression activities. A Web site that had satellite photos of the Hayman and other fires was also praised. Some opined that TV stations in Denver disseminated more reliable information than that those in Colorado Springs. Some also indicated that TV news often seemed to be overly dramatized.

Respondents tended to be somewhat critical of the nightly meetings sponsored by the Forest Service, saying that the information at these meetings was, at times, "inadequate" and "outdated." Some complained that the information was delivered in an impersonal manner. Some thought that the information was "controlled" and that there was little input from local sources such as Red Cross, the city of Woodland Park, and Teller County. Some pointed out that the nightly meetings were originally held for evacuees, but it turned out that many nonevacuees also attended.

A number of complaints regarding the quality of information were expressed by evacuees in particular. Typically, they wanted to know at a given point in time whether their houses still stood or when they could return to their homes. This type of information was not always available when it was desired, creating frustration on the part of evacuees. Final confirmation about whether one's house was burned often took more than a week, according to some people who lost their homes.

Post: At the time of the interviews, many respondents were often not aware of much of the information that had been disseminated after the fire regarding resource, economic, and health impacts. Sources included reports on TV and in newspapers; meetings on restoration work and flooding; a Forest Service publication called "Out of the Ashes," and newspaper/TV reports on volunteer rehab and restoration work days. The quality of this information was generally labeled as "good" by those who did see it.

Relationship with the Forest Service: Locals appear to have generally good relationships with the Forest Service. Some mentioned that there had been some anger over the cause of the fire (its alleged ignition by a Forest Service employee) but nothing that appears to be long-lasting. The inability of the Forest Service (the National Forest Systems branch) to work with private landowners on fire prevention and restoration was mentioned as a problem. One fairly persistent theme was the perceived need for the Forest Service to improve its existing working relationships with volunteer firefighters and other groups/agencies involved in fire prevention and control.

Community Capacity: For present purposes, community capacity can be described as the extent to which a community possesses the resources (broadly defined) and ability to allow it to cope with a disturbance event such as a fire. In the case of Woodland Park, community capacity can generally be described as high. Respondents pointed to the outpouring of donations and help for evacuees during the fire as one example of this. The effort to evacuate pets and livestock, the work of the Forest Fire Victims Task Force (which organized virtually over night and serves as a safety net for those without other resources to fall back on) and the leadership of Tracie Bennitt of Java Junction were also mentioned as an example of community capacity. The community was described as good, supportive, and compassionate. As one respondent stated: "Everybody pitched in and there was good energy."

Other Issues and Concerns: One expressed concern had to do with the potential evacuation of Woodland Park (something that nearly happened, but in the end was not needed) and whether that could have been done effectively and safely. For example, respondents reported rumors about the highway out of town being partially closed. The impact on the tourism sector was also mentioned.

Some mentioned that there were not enough places for pets and livestock that were evacuated. The animal shelter exceeded its capacity (15 dogs) and housed 54 dogs during the fire. Woodland Park Saddle Club was also full of horses and livestock. Some residents were forced to take their pets to their friends' houses in Colorado Springs or Denver.

Needs: There were no strongly expressed needs for goods and services related to local fire suppression capacity (although as we note above many felt the Forest Service could have used existing local capacity more effectively). Again, many mentioned the outpouring of donations that helped firefighters and evacuees. The Red Cross was oft cited as being "great" and meeting the immediate needs of many evacuees. There were concerns about where Woodland Park residents would go if the entire community had been evacuated.

There were suggestions that community meetings in the specific subdivisions that were on stand-by or near the fire would have been helpful rather than sole reliance on centralized meetings and "telephone trees." It was also suggested that off-duty law enforcement officers could have escorted evacuated homeowners back to their homes to retrieve more belongings during times that such homes were not under immediate threat.

One impact issue worth noting is the difference in circumstances faced between renters and homeowners in the wake of a fire. Renters appear to have been affected disproportionately harder than homeowners when their residences burned. Renters' insurance is not required as homeowners insurance generally is and thus is not common. Also, renters may be limited in the kinds of things they can or are willing do for fire hazard reduction around the house and property: landlords may not do anything or may restrict tenants from doing so.

One source of help for homeowners who face losses from disasters such as large wildfires is the Federal Emergency Management Agency (FEMA). FEMA has provided assistance for fire victims of the Hayman Fire. However, those who live in nontraditional residences such as recreational trailers or RVs (of which there were a number in the community) were not eligible to receive compensation from FEMA for the loss of their residence. Such people had to turn to the Forest Fire Victims Task Force or the Red Cross for assistance. One respondent who incurred damage to cattle, fencing, and grassland for her ranching business did not receive compensation from FEMA. The person could not operate her business this year because the permitted area was burned and there was no other place to graze the cattle. She complained that despite these damages she could not get any compensation.

On the subject of FEMA, there was considerable frustration expressed by County officials concerning notification of the accounting rules for compensating the County for fire-related expenses. The main complaint was that the County was not notified by FEMA until after the fact concerning the detailed information FEMA requires in order for the County to be eligible for compensation for various functions and expenses.

The Future: The final topic covered in respondents' interviews concerned their vision of the future for the forest, their family, and their community A future fire in the unburned areas is a real possibility in the minds of many respondents. However, most feel the possibility of a fire within the perimeter of the burned area is low, as there "is nothing left to burn."

The fire experience has clearly increased awareness of wildfires and made a potential future fire more of a reality in peoples' minds. However, most respondents at the time of the interviews were not planning to take any particular actions to "firesafe" their homes and properties against future events. Explanations for a lack of such activities range from "the damage has already been done" to the aesthetic preference for trees near their homes. This is a subject clearly worthy of attention in a followup survey.

Many respondents who lost their homes stated that they planned to rebuild their homes again in the same spot. When they were asked whether they would put extra effort into fire prevention measures for their new house, many answered in the negative. The reason was that they loved to be surrounded by trees; therefore, thinning conflicted with their original purpose to build their house in such a setting.

Stakeholder Perceptions of Wildfire Risk Reduction Strategies, Fire Management Treatments, and Forest Conditions

The catastrophic fire season during the summer of 2000 spurred many groups and individuals to consider how best to reduce the risks associated with such events. One significant reaction to the fires of 2000 originated in Congress, which provided support for the USDA Forest Service within the context of a National Fire Plan to dedicate the resources necessary to develop and design approaches that can help prevent these problems in the future. A key element of the National Fire Plan goals was to involve local communities in the design and implementation of fire management plans. Traditionally, the Forest Service and other land management agencies have used technical expertise to determine the optimal fire management plan, informed the public that a certain treatment was going to be implemented and then accept comments on the proposed action. The objective of the study whose results are described in this section is to more proactively involve the public in determining the desired future condition of the forest landscape and how best to achieve that condition. The preliminary nature of this section provides a starting point for analyzing individuals' perceptions and actions regarding fire and fuels management issues.

Including the public in such decisions is a relatively new concept for public land management agencies. Many have argued that decisions regarding the management of forested landscapes should be left to forest professionals because such decisions require a detailed knowledge of technical material. Others believe that technical knowledge is only required to implement the decisions that are made and not to determine the desired condition of the forest. It is important to understand the role that the public can play in making decisions regarding the desired future condition of the forest landscape and how to achieve that condition. This project focuses on the question of how to include the public and the amount and type of information that is useful for meaningful public input into the decisionmaking process related to fire management issues.

To effectively implement a fire and fuels management strategy requires an understanding of how the public will react to the various strategy options. It is critical to design treatment options that are scientifically sound; however, it is also important to make sure that the public will support such actions. This section describes the results of two workshops on different approaches to forest and fuels management conducted with the residents of the Ridgewood Homeowners Association (RHOA). These sessions focused on the following topics:

- Baseline knowledge and experience with fire events
- Preferences toward various fuel treatment options
- Helpfulness and credibility of various information sources
- Risk perceptions regarding fire issues
- Risk reduction behaviors and strategies
- Fire and fuels management responsibility
- Characteristics of the RHOA participants

The RHOA is uniquely positioned to provide important insight into the affected public and its preferences on fire and fuels management issues. The RHOA is surrounded by the Manitou Experimental Forest, which is in the Pike-San Isabel National Forest. The residents of RHOA were evacuated for 8 days during the Hayman Fire and they have experienced several fires in the area prior to the Hayman. Based upon the RHOA's location and previous experience with fire events, we approached the community to participate in a long-term study designed to better understand the effect of information on fire and fuels management options as well as to better understand both the voluntary and involuntary risks that people face living in wildland urban interface.

In early June of 2002 (about 10 days before the Hayman Fire) 63 residents of the Ridgewood HOA (42 percent of the total residents of the RHOA) participated in the first workshop. The primary focus during this phase of the study was on the impact of different amounts and types of information on residents' preferences for fire management of a specific forested area. To expand on the information collected during the workshop in June, we conducted the followup session with the RHOA in February 2003 (about 6 months after the Hayman Fire was contained). Thirty-two residents participated in this session (24 also participated in the June workshop). The February session was designed to collect preliminary information on the wildfire risk perceptions of wildland urban interface residents as well as some followup information from the June workshop.

The results of these workshops on homeowner risk information are presented in the following order. First, we present the results of the wildfire knowledge and expertise measures for these residents. Second, we discuss the helpfulness and credibility of various types of wildfire information sources for these residents. Third, the findings for a number of wildfire risk measures, including risk perception, risk vulnerability and risk severity are presented. Fourth, we take a comprehensive look at specific homeowner risk reduction behaviors and the possible motivating factors that influence homeowner decisionmaking, including their evaluation of the effectiveness of these behaviors and confidence in their ability to conduct these behaviors on their property. Fifth, we discuss the homeowner perceptions of the level of responsibility that they place on various entities for wildfire management and prevention. Sixth, we report a description of the homeowners' preferences for various forest treatment options both prior and since the Hayman Fire. Finally, a description of their demographics is presented to provide a more comprehensive picture of these wildland urban interface residents.

Knowledge and Experience

Ridgewood residents were asked to assess how well informed they were about wildfire risks to what extent they find wildfire information relevant, how motivated they are to learn more about the wildfire risks, and the type of information that they have used in the last year along with its respective degree of helpfulness. All measures were rated using a 7-point Likert scale with 1=not at all informed, relevant, motivated, helpful to 7=very informed, relevant, motivated, helpful. Residents assessed themselves as well informed (M=6.4 out of 7), information that they used as very relevant (M=6.8), and they are very motivated (M=6.5) to learn more about the connection between wildfire risks and undertaking defensive actions, even though they considered themselves to be "well informed." These three measures were highly correlated and were therefore combined into a composite measure, **perceived knowledge**. This measure of perceived knowledge will be used in subsequent analysis and discussion.

In addition to asking residents about their level of knowledge, relevance of the knowledge and willingness to learn more, we were also interested in their direct experience with wildfire. None of the residents had any structures on their property destroyed by the Hayman Fire although they were all evacuated for 8 days in late June 2002. In addition, 25 residents stated that they knew of people in other communities or areas that were impacted by wildfire. As expected, each participant indicated a strong awareness of wildfires and the risks that they face living in a location surrounded by a forest landscape.

Information and Credibility

The members of the RHOA that participated in February 2003 were asked their opinion regarding wildfire information sources and the credibility of these sources. Residents were asked to identify the sources of information regarding wildfire risks and rate the degree of helpfulness (1=not at all helpful to 7=very helpful). The most highly rated sources of information were the County and city fire departments and the Colorado State Forest Service (M=6.5 and 6.4, respectively). The USDA Forest Service, media reports, and Firewise community information were also rated as relatively helpful sources of information (M=5.4, 5.6, and 5.8, respectively). Finally, friends and neighbors were rated somewhat helpful as a source of information on wildfire risks (M=4.1). Other sources of information were identified but not by a significant number of homeowners.

Understanding the level of credibility that people attach to various individuals, organizations, as well as local, State, and Federal agencies can be helpful in identifying potential future strategies to communicate with the public. Residents were asked, based on their prior experiences with these entities, to rate the degree of credibility associated with the organization as an information source for issues surrounding wildfire (1=not at all credible to 7=highly credible). Table 21 presents the means for each set of social entities that residents felt were credible (or noncredible) sources of information regarding wildfire risks. Two additional sources of information were included by two residents: the Sheriff's department and Ridgewood HOA. Both were rated as extremely credible by the two individuals. Research reports and environmental organizations were rated somewhat less credible than all the other entities. Although bordered by Forest Service lands, the Ridgewood

Table 21—Creditable sources of information on wildfire risks as perceived by Ridgewood residents.

Social entities used as information sources	Mean credibility rating[1] (std. dev, n)
US Forest Service	5.0 (1.48, 20)
US Park Service	6.5 (.69, 28)
County/City Fire department officials	6.1 (1.4, 23)
Colorado State Forest Service	5.3 (1.2, 30)
Neighbors and Friends	5.4 (1.5, 20)
Research Reports	3.4 (2.1, 19)
Environmental Organizations	3.1 (1.5, 27)
Media Reports	6.3 (.58, 3)

[1]1 = not at all credible to 7 = highly credible.

residents rated the Forest Service as less credible than the Park Service, County and city fire officials, and media reports.

Risk and Vulnerability Perceptions

The third set of measures investigated residents' feelings of risk vulnerability, the perceived level of risk likelihood, and the perceived risk severity of wildfire. There were four measures of risk vulnerability, including the level of concern about the effects of wildfire, the seriousness of the consequences of wildfire, the degree of physical vulnerability to homeowners and their families, and the degree of vulnerability to their property and possessions. These variables were all rated using 7-point Likert scales anchored by 1=not at all concerned, serious and vulnerable to 7=very concerned, extremely serious, and very vulnerable. These four measures were highly correlated resulting in the creation of a composite measure of **perceived vulnerability**. The average evaluation of wildfire vulnerability was M=6.79, sd=.45. This demonstrates that even 6 months after the devastation of the Hayman Fire, residents still feel vulnerable to the potential impact of wildfire, both personally and with regard to their possessions and property.

Furthermore, a correlation analysis shows that perceived vulnerability and perceived knowledge are positively correlated (r=.399), demonstrating that those residents who feel highly vulnerable to the effects of wildfire are also those that consider themselves highly informed about wildfire issues. This might suggest that, despite having expertise in wildfire issues, homeowners believe that there are significant involuntary wildfire risks that influence their perceptions of vulnerability. Evidence of this concern was found during the session when residents indicated they felt very vulnerable (M=6.4, sd=.89) when they completed considerable defensible work and their neighbors did not do this work. This indicates that wildfire education is needed to address these sources of vulnerability.

Residents' perceptions of the likelihood of wildfire occurring near their home were measured using two scales. First, they were asked the likelihood of a fire happening near their home within the next couple of years (1=no chance to 10=certain to happen). Second, they were asked what the chance was of being impacted by a wildfire on a scale of 0 to 100 (where 0=no chance to 100=certain to happen). The scales were strongly correlated (r=.722), therefore, a composite measure of **risk perception** was created. This composite measure revealed that residents rated the likelihood of a wildfire occurring near their home at 77.9 percent. Both perceived vulnerability and risk perceptions were significantly correlated (r=.37), demonstrating the strong link between residents' beliefs about vulnerability and the high probability of a wildfire event occurring.

Additionally, homeowners were asked to rate the severity of the impact of a wildfire on their lives and property (1=no harm at all, 10=extremely devastating). Residents felt strongly that the consequences of a wildfire would be severe and very devastating (m=8.8, sd=1.1). A correlation analysis reveals that perceived vulnerability and perceived severity are correlated (r=.398), indicating that perhaps homeowners' perceptions of vulnerability stem from the strong beliefs that wildfires will have devastating consequences.

Homeowner Risk Reduction Behaviors and Strategies

To better understand the link between perceived risk, intended behaviors, and actual behaviors, the residents were asked what they have done or intended to do for a set of actions identified by the Firesafe council (see table 22 for the list of specific actions). The residents were asked to indicate their likelihood of performing certain defensible actions on their property (1=probably will not do to 5=already done). Additionally, the motivation for risk reduction behavior decisions was examined. Homeowners were asked to rate both the perceived effectiveness of doing a particular defensible action and their confidence in their ability to conduct the defensible action (1=not at all effective/confident to 7=very effective/confident, respectively). These measures, perceived effectiveness of the Firesafe actions and residents' confidence in their ability to conduct these Firesafe actions, focus on specific actions that residents can implement on their property. The confidence measures reflect the homeowner's ability to do the work themselves or to have the resources necessary to hire someone to undertake the task.

Table 22—Resident's beliefs about wildfire risk reduction activities.

Action	Behavioral Intention 1=prob. will not do 5=already done	Effectiveness of action 1=not at all eff. 7=very eff.	Confidence in action 1=not at all 7=very conf.
SPECIFIC ACTIONS [mean (sd)]			
Defensible space	3.7 (0.8)	6.3 (0.9)	6.7 (0.5)
Fire resistive plants	2.4 (1.6)	5.6 (1.1)	6.2 (1.3)
Fire resistant roof	3.2 (1.6)	6.3 (0.9)	6.0 (1.8)
Fire resistant decks	1.6 (1.8)	5.8 (1.3)	5.8 (1.8)
Clear dead branches	3.8 (0.8)	6.4 (0.7)	6.8 (0.5)
Home easily identified	3.7 (0.9)	6.5 (0.8)	6.6 (1.1)
Plant away from house	3.1 (1.5)	6.5 (0.7)	6.5 (0.9)
Plant away from power lines	3.3 (1.3)	6.2 (0.8)	6.5 (1.0)
Work with neighbors	1.6 (1.5)	5.8 (1.3)	5.8 (1.5)
Stack firewood away from house	3.8 (0.8)	6.4 (0.9)	6.9 (0.2)
Contact local FD	2.9 (1.6)	5.9 (1.0)	6.5 (0.9)
Average Rating		6.17	6.42
GENERAL ACTIONS			
Actions prevent fires		5.2 (1.6)	
Ability to avoid wildfires		3.0 (1.9)	
Average Rating		4.09	
Confident in your ability to protect self			4.6 (1.4)

In addition, residents were asked to rate the possibility of preventing wildfires from impacting them and if the risk of wildfire was easy for them to avoid (1=not at all possible/very difficult to 7=very possible/very easy). Residents were also asked more generally about the confidence in their ability to protect themselves and their property from the risk of wildfire (1=not at all confident to 7=very confident). This second set of effectiveness and confidence measures focused on more general actions related to wildfire. This is in contrast to the more specific Firesafe actions discussed previously. Both the specific and general measures of effectiveness and confidence provide a more detailed picture of what people elect to do and why they select some actions and not other actions. Also, information regarding which defensible actions homeowners undertook before and after the Hayman Fire was collected. Additionally, homeowners rated which defensible actions they planned on doing over the long run (1=not at all likely to 7=very likely). These questions were intended to determine if residents understood the importance of incorporating these defensible actions into their lifestyle while living in the wildland urban interface.

The specific measures of effectiveness described above were rated at M=6.17, SD=.68, while the second, more general set of effectiveness measures were rated M=4.09, SD=1.36 (see table 22). There is a significant difference between these two sets of response efficacy measures ($t=7.0$, $p<.01$), which can be attributed to the difference in the level of abstractness of the two sets. The first set focuses on the effectiveness of specific actions such as removing dead branches from your roof, putting in a fire resistant roof, whereas the second set focuses on more generalized actions such as the possibility of "preventing wildfire danger." Residents believed more strongly that specific behaviors can be effective to mitigate wildfire risks, but overall, the involuntary risks of wildfire are not as likely to be preventable.

The same process was conducted for the confidence measures as was described above for the effectiveness measures. Measures were taken of the confidence that residents held in their ability to conduct the specific Fire Safe actions. This set of measures had a mean rating of 6.42 (see table 22). The second set of confidence measures is a more general measure of residents' confidence in their ability to protect themselves and their property from wildfire risks. This measure was rated by residents as 4.6 on a scale of 1 to 7 with 1=not at all confident in protecting myself and my property and 7=very confident in my ability to protect myself and my property. This can also be explained by the varying degrees of abstractness in the measures. Overall, residents believed that the various defensible actions were effective, and they were confident in their ability to implement these actions, although they were less certain about their overall confidence in their ability to protect themselves from the effects of wildfire.

The second step of the process investigated the connection between residents' likelihood to undertake a specific action with their belief in the effectiveness of this action and their confidence in their ability to conduct the action. Table 22 presents the mean ratings (and standard deviations) for all three sets of individual measures.

There was a significant, positive correlation between behavioral intentions and response efficacy for removing dead branches and brush from roof and chimney (r= .54) and stacking firewood away from any structure (r= .56). Therefore, the beliefs about the effectiveness of these mitigating actions likely influenced the decision to implement these behaviors. There was a significant, positive correlation between behavioral intentions and confidence in getting a fire safety check on your property (r= .56), planting trees away from any structures (r= .43), putting a fire resistant roof on structures (r= .675), and putting fire resistant undersides to decks and balconies (r= .50). As would be expected, residents who felt confident in their ability to carry out these actions were much more willing to actually implement them. This has important educational implications for fire prevention education.

There was a significant, positive correlation between the effectiveness of some fire reduction behaviors and the confidence that residents reported in engaging in these behaviors. The actions include developing a 30-foot minimum defensible space around one's structures (r= .46), planting low-growing, fire-resistive plants on one's property (r= .51), making sure that one's home is easily identifiable and accessible from main roads (r= .39), and clearing common areas with neighbors in the HOA (r=.75). Thus, residents believe that there is a strong link between the effectiveness of these actions in reducing the impact of fire and their confidence in being able to actually accomplish these actions.

Another piece of information critical to better understanding peoples' response to wildfire impacts came from determining what, if any, defensible actions were undertaken after the Hayman Fire. Residents were asked to write down any actions that they started after the fire and evacuation took place. These actions are listed in table 23.

Table 23 demonstrates that residents were motivated to take actions following the Hayman Fire, with 18 of 32 (57 percent) reporting having started at least one of the above defensible strategies since the Hayman Fire. Less than half of the residents, 14 of 32, (43 percent), report having completed all the respective actions prior to the Hayman Fire.

Another important inquiry is to understand the reasons why homeowners living in the wildland urban interface do **not** engage in various risk reduction behaviors. Residents were asked to explain why they would select "not to do this action" on their property. The results included eight actions that residents would not consider undertaking in the future. The results are summarized in table 24.

The behaviors the residents would continue (or intend to continue) to undertake on a regular basis as long as they continue to live in the wildland urban interface were also considered. The objective of this question was to determine if residents realized the importance of making these wildfire risk reduction

Table 23—Wildfire risk reduction activities undertaken by residents after the Hayman Fire.

Actions taken after the Hayman Fire	Number of Residents (n=32)
Removing trees from near structures	8
Clearing common areas	4
Putting in fire resistant undersides	2
Creating defensible space	11
Remove dead branches/brush from roofs	6
Stack firewood away from structures	5
Fire safety inspections	4
Making home easily visible & accessible from road	2
Nothing – already started everything before fire	14

Table 24—Resident's reasons for not engaging in wildfire risk reduction activities.

Actions not undertaken	Reason not undertaken	Number of undertaken residents (n=32)
Fire resistant plants	Did not need this type of protection	5
	Due to drought, do not need to plan anything	8
Fire resistant roof	Too costly	5
Fire resistant decks	Don't have this structure	3
	Too costly	10
Trees planted away from house	Trees hold too much value	5
Plants/trees away from Power lines	Trees are Aspens—fire resistant	2
Work with neighbors/HOA	Not necessary	7
	Don't see anything happening in the short run	2
Stack firewood away From house	House made of wood—makes no difference	1
Fire safety inspection/	Not needed	3

behaviors a part of their way of life while living in the wildland urban interface. They were asked to list each of the actions and the respective likelihood of doing it in the long run. Only two of the 33 (6 percent) residents did not list any actions that they would undertake over the long run. The other 31 residents listed at least three actions that they realized were critical for undertaking over the long run (see table 25). All actions were selected by at least two residents and all were rated 5 or above on a scale of 1=not at all likely to 7=very likely by the residents. This is a clear demonstration that residents understand, at least in principle, the importance of incorporating these wildfire risk reduction strategies into their lives.

To increase the understanding of residents' motivation for undertaking or not undertaking certain wildfire mitigation actions, they were asked to explain the biggest impediment to implementing risk reduction behaviors. Table 26 presents the varied responses from the RHOA.

Three responses in table 26 are of particular interest. These three measures are related to the "involuntary risk" dimension of mitigating wildfire risks: "can't fight nature," neighbors have done nothing, and USDA

Table 25—Residents' perceptions on critical long run wildfire risk reduction actions.

Risk reduction actions in long run	Number of residents selecting to undertake action
Create minimum 30 ft. defensible space	29
Plant low-growing, fire resistive plants	2
Put a fire resistant roof on your home	5
Put fire resistant undersides on decks/balconies	5
Remove dead branches from roof & chimney	19
Home is easily identifiable	7
Trees planted away from structures	19
Trees planted away from utility lines	7
Clear common areas	10
Stack firewood away from structures	16
Fire safety inspection of your home	2

Table 26—Impediments to implementing risk reduction activities.

Biggest impediment	Number of residents
Age of resident	2
Nature – "can't fight nature"	6
It takes too much time	4
Drought conditions	2
Neighbors have done nothing	4
US Forest Service has done too little	10
Lack of funds by state & federal agencies	2
Need place to haul slash	11
Cost of undertaking these actions	6
Lack of help to do these actions	7
"I" don't want to do it!!	2
Don't know what to do!!	1

Forest Service has done too little. In other words, these homeowners believe that their own actions will not make a significant difference in saving their lives, resources, and property from wildfire. Almost two-thirds of the participants (63 percent) have indicated that these involuntary aspects of wildfire risk influence their decision as to whether or not to undertake mitigating behaviors on their properties. This has important implications for the types of educational materials and messages that should be conveyed to homeowners in the wildland urban interface.

Responsibility

An increased understanding of homeowners' perspectives on who is responsible for reducing risks of wildfire is also of interest. This can provide insights regarding various aspects of risk, including voluntary and involuntary dimensions. Homeowners were asked how **responsible** (1=not at all responsible to 7=very responsible) should they, their homeowners' association, and the USDA Forest Service be for protecting their property (the resulting means were M=6.8, 5.3, and 6.2, respectively). Additionally, residents were asked to rate how vulnerable they would feel if they had finished considerable defensible space work but their neighbors had done nothing (in other words, involuntary risk). They rated this question on a scale of 1=not at all vulnerable to 7=very vulnerable (M=5.8). These measures represent: **voluntary risk** (that is, homeowners' responsibility), **involuntary risk – agencies** (Forest Service and HOA responsibility), and **involuntary risk – neighbors,** with associated means of 6.8, 5.8 (average of 5.3 and 6.1), and 5.8, respectively. Clearly, these residents feel very responsible for defending their own properties, yet there is considerable sentiment for *all* the neighbors (neighbors and agencies) to do their part as well.

A correlation analysis demonstrates that voluntary risks as well as involuntary risk associated with agencies are both significantly positively correlated with perceived effectiveness (r=.29 and .37, respectively). Thus, residents find a direct link between both their own sense of responsibility as well as the Forest Service and the HOA's responsibility for reducing risks and the degree of effectiveness of their own mitigating actions. The correlation between involuntary risk associated with neighbors' lack of actions is significant and positively correlated with perceived vulnerability(r=.43). Therefore, the idea of homeowners' involuntary risk may be one of the significant explanations for their feelings of vulnerability to the impacts and effects of wildfire. Finally, perceived knowledge and involuntary risk associated with neighbors is significantly correlated (r=.52). Thus, a higher level of knowledge about wildfire issues is once again linked with a higher level of vulnerability, perhaps stemming from involuntary risks of living in a neighborhood in the wildland urban interface with little being done by neighbors (including the Forest Service) to protect residents' lands.

Forest Treatment Tools

The last set of questions that residents answered was related to their preferences for various types and combinations of active fire and fuels management tools. These types of tools included prescribed fires, mechanical removal, and chemical treatment for insect infestations as well as the possibility of doing nothing at all. The residents of the RHOA were asked to rate their preferences in June 2002 prior to the Hayman Fire, and then a subset of the residents rated their preferences for the same tools in February 2003, 6 months after the Hayman Fire (1=least preferable to 7=most preferable). Table 27 presents the results for both sets of preference ratings.

The preferences for prescribed fire and prescribed fire in combination with mechanical removal have remained constant since the Hayman Fire. This group is somewhat supportive of using prescribed fire, though most prefer that the land managing agencies utilize mechanical removal alone. There are stronger preferences for mechanical removal since the Hayman Fire; preferences increased from 5.7 in June 2002 to 6.3 in February 2003. Since the fire, this subset of residents feels less favorable toward chemical treatments and any combination including chemical treatments. This group also has strong beliefs that "no active fire management" is not a preferred alternative, and this belief has remained stable throughout their devastating fire season

Table 27—Residents' preferences for fire and fuels management tools.

Management tool	Preferences (mean & std. dev.)	
	May 2002	Feb. 2003
	n=63	*n=24*
Prescribed fires	4.0 (2.0)	4.0 (1.8)
Mechanical removal	5.7 (1.4)	6.3 (.82)
Chemical treatment	4.9 (1.8)	3.6 (1.7)
Prescribed fires & mechanical removal	5.0 (1.9)	4.9 (1.8)
Prescribed fires & chemical treatment	4.2 (1.7)	3.2 (1.6)
Mechanical removal & chemical treatment	5.0 (1.7)	3.9 (1.8)
No active fire management	1.6 (1.2)	1.7 (1.8)

Characteristics of Ridgewood HOA Residents

Finally, Ridgewood residents were asked to provide the following demographic information: age, gender, education, location of primary residence, years lived in the area, part-time or full-time resident of the area, household income level, and their proximity to a National Forest. The average resident for the February 2003 sample is between the age of 55 and 64, has a college degree, has lived in the area for 10 years as a full-time resident, has a household income level of $75,000 or more, and lives within 1 mile of the closest National Forest or National Grasslands. The June 2002 sample is similar to the February group, although their age was somewhat younger, 45 to 54 years, and their average household income somewhat less, $50,000 to $75,000. Table 28 provides an overview of the demographic information.

Hayman Fire – 9 Months After: What Has Happened and What do People Think?

While much attention is paid to what happens during a wildfire, understanding what happens in a community after a fire is also important. Once the main firefighting resources leave, what happens? Immediately after a fire many express the resolution to take action. But how does this play out once the fire is no longer an immediate memory? How has the fire affected the community 9 months down the road? To gain an understanding of these issues, key informant interviews were conducted in February 2003 to assess what has happened around the area of Woodland Park in relation to community impacts, increased mitigation work, and rehabilitation efforts. Most specifically the interviews were interested in lessons that could be learned from the fire that might be applied to future fires. Due to the limited timeframe available for the study, interviews were limited to representatives of relevant government and nonprofit organizations. Hence, the ability to draw conclusions about specific changes in individual behavior was limited. However, all but one interviewee were local residents, and many had lived in areas directly affected by the fire and had been evacuated. The interviews indicate that while much has gone right postfire, there remains considerable frustration with what many see as the failure of Federal agencies to take advantage of local resources.

Although the fire left people on edge into November and there is some anticipation that this edginess will come back once fire season starts, for most people worries about the economy, war, and drought play a more prominent role. In general, the more serious physical and mental effects related to the fire were considered to mostly have played out, although there still remains a great deal of sensitivity about certain issues. Assessments of the degree of economic impact were varied. At a County level the financial effect was considered to be minor. Instead, small businesses and individuals appear to have borne the brunt of negative impacts. Certain businesses, particularly those that provided food during the fire or provide local services, were seen to have emerged reasonably well while many businesses that were tourist reliant have been hard hit. Local volunteer fire departments in general were not hurt as much as had been expected due to donations of money and equipment. However, one fire department, Mountain Communities, did suffer significantly. The majority of houses that were lost were in its district, and its future revenue base is likely to be reduced by almost half as a result of decreased property values. Even if all the houses are rebuilt and property values increase, the fire department is expected to suffer long-term financial constraints due to Colorado's Tabor Amendment which limits government revenue growth to that of the prior year multiplied by a factor based on state population growth and inflation.

Table 28—Demographics information for Ridgewood residents.

Demographic category, total number in sample	Number (February 2003) 32	Number (May 2002) 63
Age Groups:		
18-25	0	1
26-34	0	1
35-44	4	9
45-54	7	23
55-64	15	21
65 or older	6	8
Gender:		
Male:	16	33
Female:	16	29
Education Level:		
Some high school	0	1
High school	5	10
Some college	6	12
College degree	10	16
Postgraduate work	1	9
Graduate degree	8	14
Other (technical degree)	2	1
Primary Residence – Ridgewood HOA	32	61
Average Years lived in area:	9.7	9.8
Full-time residents:	32	61
Income level:		
Less than $15,000	0	1
$15,000 – 24,999	0	2
$25,000 – 34,999	1	2
$35,000 – 49,999	3	5
$50,000 – 74,999	10	17
$75,000 – over	14	30

At the County and community level, several activities are being undertaken to be better prepared. At this level, the long-term level of exposure to wildfire and associated damages combined with availability of resources provide a good impetus for action. Most efforts are based on weaknesses identified during the Hayman Fire. For instance, problems with communication have led to efforts to resolve compatibility issues that arose and to improve dependability of the communication system with establishment of more communication towers. During the fire the assessor provided GIS information and aerial photos of property in the fire area to both the Incident Command and local fire departments that had proven useful and plans were under way to provide these to each fire department at the beginning of the coming fire season. It was also suggested that the availability of GIS information, aerial photos, and detailed knowledge of individual property at the assessors office puts them in the best position to accurately identify as quickly as possible what property is lost to a fire. In future fires, this could hopefully minimize frustrations felt by some homeowners after the Hayman Fire who were given a seesaw of changing information as to whether their house had survived.

It was harder to tell the amount of activity being undertaken by individuals to be better prepared. Some interviewees felt little was being done while others thought there was increased interest. Some had expected more requests for technical assistance; others suggested that people were just doing it on their own without the need for assistance. Increased use of the mulching program, where homeowners could bring cut vegetation to a central drop off point, was cited by several interviewees as evidence that much work was being done. In addition, a number of local high school students are expecting to spend the upcoming summer working for local homeowners to put in defensible space measures. Conversely, several people had heard of homeowners who saw no incentive for putting in defensible space as they didn't care if their house burned if the land around it burned. One reason suggested for less activity than expected was that those not burned out stopped going to public meetings before their focus turned to rehab and defensible space issues.

Most postfire activity involves rehabilitation of burned land. Given the area that was severely burned and the local soil type, erosion has been of particular concern in the Hayman area. Although a great deal has been done to rehabilitate burned areas on both public and private property, there was much dissatisfaction with its implementation. There were concerns by private landowners about investing a significant amount of money to prevent erosion on their land when nothing was being done on the public land above theirs. This concern parallels defensible space issues where landowners often argue that it is pointless to do any fuels management on their land if neighboring property owners do nothing. And as with trying to respond to such defensible space concerns, the extent of the lands the Forest Service manages constrains its ability to rapidly respond to each individual landowner who wants the Forest Service land adjacent to their property treated immediately. Despite these concerns, to date the bulk of private land rehabilitation projects have been assisted with Natural Resources Conservation Service (NRCS) contracts.

Another frustration with the rehab process is related to the matching funds NRCS provides private property owners for rehab work. Private property owners were told after the fire to go ahead with needed work, to keep the receipts and they would be reimbursed for 75 percent of the total. However, legislation providing the funding was not passed until the end of September and did not include authority for retroactive payment. Given that some homeowners were spending from $60,000 to $100,000 on rehabilitation, having to shoulder the full burden of the cost has forced some homeowners to finance the work via second mortgages or credit cards. Further, the May 8 cut-off of rehab funds—based on a 220 day clock from the day the agreement was signed—was seen as inappropriate given that little work can be done in the winter. Frustration was also expressed about conflicting information coming from the Forest Service and the NRCS about appropriate rehab methods and the degree of damage that required rehab work. Such contradicting messages from different Federal agencies did little to inspire trust among landowners.

General views on the role of the Forest Service varied – many felt that they had fought the fire well and done a good job with rehab while others were mistrustful of their actions: feeling that they did not do enough early on to fight the fire, not trusting that rehab was taking place, and suspicious of the continued closure of the forest. Notably, there was clear respect for individual Forest Service employees yet often a critical view of the Forest Service as an agency. Individuals were cited for their professionalism, knowledge, dedication, communication skills, and willingness to stay after meetings to answer questions. However, as an agency the Forest Service was often criticized for being arrogant, disdainful of local knowledge, obfuscating, and mired in red tape. The ability to differentiate individual Forest Service employees from the organization was shown in a reverse but similar manner in relation to Teri Barton, the Forest Service employee criminally charged with having set the Hayman Fire. Although there remains considerable animus toward Barton, it was generally felt that people recognized that her actions were done as an individual and not as an agency representative.

Much of this criticism revolved around treatment of volunteer fire departments during the fire. There was continued bitterness about the limited role that the Incident Command allowed local fire departments to have during the fire. The sense that they were being forced to stand on the sidelines while outsiders with no local knowledge took over did not go over well. It was felt that the Forest Service did not recognize or respect the professionalism of the volunteer fire departments, which in fact had the appropriate equipment and training for fighting a wildfire. They also had plenty of experience with the Incident Command System and with fighting wildfires, being involved in initial attack on numerous small fires during the course of each year. (One interesting question that was raised in this regard was the percent of initial attacks that are carried out by local fire departments versus the Forest Service.)

There was a strong sense that locals had a vested interest in stopping the fire and in protecting houses that the Forest Service did not have. Several interviewees pointed to the fact that many of the destroyed houses were lost to ground fires and could have been saved had the local fire departments been allowed to remain in threatened subdivisions. In addition, it was felt that local knowledge, such as location of in holdings and terrain intelligence, could have been valuable in firefighting efforts.

There was recognition that it was not a simple situation, that many people didn't necessarily understand the complexity and danger of what they were volunteering for, and that incident commanders had justifiable concerns about the training and knowledge of volunteer firefighters. In addition, the red card (required physical fitness testing for Federal employees before they can go on fires) issue was recognized and no easy solution was seen. Given that most volunteer firefighters tend to be "gray haired," it was argued that requiring a red card was seen as a reason to completely exclude the volunteer firefighters from helping, and this was viewed as arrogant and foolish.

The need to take advantage of what locals already know and are doing was seen as particularly important given the strong dislike for outsiders telling people what to do.

Hayman Recovery Assistance Center (HayRAC) and its Evolution into a Community Based Collaboration Network

The material in this section is adopted from the report, "Hayman Recovery Assistance Center: Interim Report of Incident Structure Model," by the Hayman Recovery Assistance Center Team, July 7, 2002.

Initial Formation of HayRAC: While failure to take advantage of local resources caused significant resentment, successful use of local resources also occurred and points to the benefits of taking advantage of local knowledge and experience. The most notable example of such a partnership was the creation and perpetuation of the Hayman Recovery Assistance Center (HayRAC). Started by the Pike San Isabel National Forests, Cimmaron and Commanche National Grasslands (PSICC) Acting Forest Supervisor as a multiagency one-stop assistance center, attention quickly turned to identifying ways to keep the organization active after suppression to coordinate postfire efforts.

The center was developed to help continue all the strong relationships that were developed previous to and during the intense time of the Hayman Fire. As one would expect with any incident of the Hayman Fire's complexity, the PSICC has been immersed in the aftereffects of the fire on the Forest, the communities, and the land. The Assistance Center allows the Colorado State Forest Service and the PSICC to develop their strategy to deal with the changed conditions they'll need to address in their program or work.

It was deemed important for the Center to immediately assist in community and public healing, natural resource recovery, and any related incidents such as flooding. The Center was to develop strategies for public participation and information sharing on the rehabilitation and restoration efforts in the short and long term. Facilitation of direct restoration efforts on private lands has been a priority for the Center.

Other specific immediate actions included:

- Facilitate recovery assistance and provide one-stop shopping for affected communities and individuals.
- Coordinate volunteer opportunities, recommend strategies for implementation, set up strategy for donations, and serve as a liaison with organizations to help identify donation opportunities. Identify potential partners and partnership opportunities. Pursue these aggressively.
- Provide information distribution and coordination for short-term restoration activities (Burned Area Emergency Rehabilitation (BAER) and Emergency Watershed Program (EWP) activities).
- Public and community awareness: Deliver key messages identified in the communication plan while there is a high interest; focus on defensible space and ecosystem restoration in dry forest types near communities.

In addition, key long-term objectives for the Center included:

- **Be a central source of information**.

The HayRAC will collect and distribute consistent information to assist individuals, communities, and businesses affected by the Hayman Fire. The information collected and distributed will include fire information, Burned Area Emergency Rehabilitation information, disaster recovery assistance information, defensible space information, volunteer coordination, and long-term restoration information. The Center's staff also will serve as a coordination point and information source to assist citizens needing support from other agencies not physically present at the Center.

Information about the Center's services will be distributed to the media as well as at community meetings and posted on the Center website at:

http://wildfires.nwcg.gov/colorado/hayman/index.shtml

- **Facilitate interagency recovery assistance to communities and individuals**.

HayRAC will coordinate information from local, State, and Federal agencies involved in developing strategies to provide the most effective public service to individuals, communities, and businesses affected by the Hayman Fire.

- **Provide a mechanism to coordinate interagency restoration and recovery efforts within the community**.

The HayRAC, in Castle Rock, will be designed to provide "one-stop shopping" for recovery and restoration information. The HayRAC will be staffed 7 days a week with representatives from public and nongovernmental service organizations to provide assistance to fire victims. In addition, a temporary/part-time Satellite Recovery Center will be established about an hour away in Woodland Park to provide similar services to those available through the Castle Rock office.

In addition, the HayRAC will facilitate coordination between restoration agencies to ensure timely, effective response to rehabilitation needs.

- **Collaborate with the public on the Forest's short- and long-term restoration needs, both within the burned area and outside the impacted area**.

HayRAC will provide critical information to the public and agencies regarding the Burned Area Emergency Rehabilitation Program. Providing this information will help ensure that rehabilitation efforts will promote and focus on achieving short- and long-term restoration needs.

HayRAC will use opportunities during community meetings and contacts at the assistance center, satellite center, and field contacts, and contacts with various agencies and nongovernmental organizations to understand how to collaboratively address restoration needs. From these sensing efforts, HayRAC will develop strategies to address needs that arise.

- **Coordinate and facilitate volunteer programs to support community and forest restoration efforts**.

HayRAC will facilitate a volunteer program that assists the local, State and Federal agencies in the coordination of donations, partnerships, and volunteerism.

- **Create an understanding in the community on how to prepare for and cope with wildland fire and possible flooding as a result of the fire.**

HayRAC will work cooperatively with private landowners, communities, local, State, and Federal agencies to ensure that the need for defensible space and general fuels reduction is well understood so that preparation for the next wildfire can begin immediately. HayRAC will also present an educational program in fire ecology and fire history so that participants understand the following:

- o What are natural and unnatural processes?
- o How aggressive fire suppression has contributed to the "problem."
- o Why fires are burning so hot, cost so much, and are destroying so many structures.
- o What needs to be done to reduce the impact of wildfires?
- o Who are the key players in finding national and local solutions?
- o What actions can people take to help develop those solutions?

In addition, HayRAC will develop a program to help landowners and communities prepare for rehabilitation and long-term restoration and raise awareness of flood potential and how to proactively prepare to deal with it.

The Coalition for the Upper South Platte Takes Over: HayRAC was established to communicate with agencies, communities and other entities associated with the fire recovery effort. Originally the Center worked under the direction of Pueblo Area Command. When Area Command was no longer needed, supervision was transferred to the Pike-San Isabel National Forest. The original organizational staffing was focused on individuals with communication, leadership, and organizational skills. As the organization evolved to meet the objectives, it became clear that there was a need to pass on responsibility for running the center. Using work done after the Bitterroot fires as a model, PSICC folks sought a local organization that could take over long-term administration. The Coalition for the Upper South Platte (CUSP) was identified as a group both willing to take on the task and with a mission that meshed well with HayRAC's rehabilitation and education goals.

CUSP was created in 1998 in part as a result of the 1996 Buffalo Creek fire which at the time was the largest in Colorado history (11,800 acres), and a subsequent large rain event that caused significant damage from flooding, erosion, and siltation. Forming in part due to a wildfire, forest health and fire management issues were a key part of the group's mission to improve the water quality and ecological health of the South Platte watershed from the beginning. In July, with the Hayman Fire not yet controlled, watershed stakeholders met to determine a path that would help heal the community and the land. To that end, they formed a Community Collaboration Network with overall goals of (1) expedite and enhance implementation of rehabilitation and recovery efforts from the Hayman Fire with emphasis on impacted communities; (2) expedite and enhance implementation of efforts to restore forest health to reduce the intensity and impacts of future fires; and (3) build an effective network that can more efficiently address community needs in future emergencies, including post-Hayman flooding and future fires. This effort merged with HayRAC, and CUSP, which was formally known as the Upper South Platte Watershed Protection Association, was asked to take on a leadership role in coordinating these efforts. CUSP agreed to provide:

a. Administrative support and assistance.

b. Point of contact and coordination of requests for assistance.

c. Project coordination for special projects identified by community stakeholders, such as coordinating volunteer work days on public and/or private lands

d. Database management for information including lists of clients (those impacted by the fires), volunteers, and so forth.

e. Fiscal host for grants, donations, or other funds.

f. Assistance to the community stakeholders to develop a memorandum of understanding that umbrellas all interested parties.

g. Technical expertise, information, services, and/or other resources as necessary to fulfill the purpose of this center.

In the beginning of August, CUSP began operating a HayRAC office, with 800-phone service for impacted individuals, agency personnel, the media, and volunteers calling for help, or to help. CUSP coordinated more than 40 volunteer events (6,000+ worker hours of volunteer time) in a 6-week period, and will continue to coordinate these types of events for the next several years. CUSP has sought and received funding to assist livestock owners with meeting hay needs. CUSP staff members have attended dozens of meetings with members of the public and public officials and have responded to dozens of media requests for information, as part of the public outreach needs. CUSP has facilitated the efforts of working committees that will address the long-term, collaborative efforts of the network.

Additionally, CUSP coordinates a fire recovery steering committee consisting of six subcommittees: Funding; Education; Volunteers; Emergency Preparation and Response-flooding; Water Quality/Erosion Control/Land Restoration/Natural Resource Protection; and Social Services and Outreach. Each of these subcommittees comprises local agency representatives, local congressional aides, private citizens, and County government representatives. These committees are meeting regularly to formulate strategies that address their particular theme.

Accomplishments as of February 2003: There has been impressive public interest in helping with postfire work, and HayRAC has played a vital role as a clearinghouse for volunteer efforts. They have organized 48 rehabilitation days using more than 3,100 volunteers putting in over 22,000 hours of work. Volunteers have been affiliated with a variety of organizations including school and church groups, Federal employees (as part of the Combined Federal Campaign), and corporations such as Coors, Toyota, AT&T Broadband, and REI. Notably, volunteers have not just been from the surrounding area but have been from out of Colorado and even from Brazil and Japan. Most of HayRAC work has been done on private land in tandem with the NRCS. but in spring 2003 the volunteers will start working on National Forest land.

HayRAC/CUSP's educational efforts are also important. Members work to promote knowledge of forest health and fire management issues with everyone they have contact with—from landowners to volunteers. In addition, the organization often helps mediate relations between individuals and Federal agencies by helping individuals better understand the functions and limitations of different government agencies, such as the fact that the Forest Service is not allowed to work on private land. Finally, the organization has performed a less formal but important function of listening. By providing a local nongovernmental forum for individuals who needed to talk about their frustrations, broken dreams, health issues, and so forth, CUSP has provided a vital outlet for the strong emotions created by such a catastrophic event.

Although the organization has had no problem finding adequate labor, adequate funding has been a different issue. Last summer's difficulties with fire funding meant that the Forest Service could only provide $20,000 of a promised $100,000. During the fall the organization survived in large part on personal resources. However, when it was finally announced in December that it would soon have to close its door due to funding issues, money began to come in from sources as diverse as the City of Aurora (which receives 90 percent of its water from the South Platte watershed), Phillip Morris, the National Forest Foundation, and singer/entertainer Jimmy Buffet. In addition a memorandum of understanding has been established with the Forest Service where HayRAC will be first in line for relevant excess property.

Other Interview Findings

Another local organization that has played a significant role in facilitating local adjustment to the fire is the Forest Fire Victims Task Force. Affiliated with a preexisting social service nonprofit, the organization had the knowledge and contacts to rapidly obtain funding and community trust. Its purpose was to provide assistance to individuals who needed help but did not fit within Federal guidelines. To date the organization has spent $135,000 helping 121 families by providing money to cover items such as lost wages, lodging, and food and clothing. Operating with an all volunteer staff of up to 70 people, the group has an impressive administrative cost rate of 0.09 percent. Not directly involved with Forest Service concerns, the groups only suggestion was that rather than waiting until the end of the fire to initiate a dialogue with local groups, such efforts should begin within the first 3 days of any major fire to allow the time necessary to organize and establish relationships needed to ensure a smooth transition when Federal resources pull out.

Several more general themes emerged from the interviews. The importance of the visual in understanding what was being done was continually noted. One of the more appreciated aspects of the public meetings during the fire was use of PowerPoint to show why it was so difficult to fight the fire. The influence of visual understanding was particularly evident in relation to beliefs about how much rehabilitation work was actually being done on Federal lands. Because, as of July 2003, the forest continued to be closed (for reasons of safety and protection of rehab work) the only evidence the public can see of rehabilitation work is from the road. This was interpreted by some as a case of cosmetic whitewashing (rehab has only been done along roads) and by others as problematic only because it does not allow people to truly understand the level of effort agencies have actually engaged in.

Another repeated theme was concern with reinventing the wheel. Several interviewees commented that it sometimes felt like Federal agencies had never previously dealt with a wildfire or disaster. While locals wanted involvement and consultation both during and after the fire they wanted to do it by building on agency experience and not starting from scratch. One example involved the public consultation to prioritize rehabilitation efforts. It was felt that the meeting was too open-ended with no suggestions about best practices to start the discussion. Rather than arriving with a blank paper people wanted a list of potential issues to take into consideration. Another interviewee commented that was hard to believe that there was no already developed, generic computer program to track victims. It was suggested that it would make sense to have a standardized package developed that could be provided with every major incident

The effect of the large scale of the fire was also noted. The extended suppression time meant that incident commanders and staff were rotated out every 2 weeks. This left the community with no sense of continuity of contact, hindering communications and trust. It was suggested that at a minimum a community liaison remain in place for the duration of the fire. Comments also were made about the size and severity of the fire inducing a sense of fatalism in several homeowners. There also was criticism of coordination and resource issues that arose as a result of the split incident command between the northern and southern sections of the fire.

Toward the Development of Postwildfire Social/Economic Monitoring Protocols

Our team was unable to make much progress on developing the set of protocols suggested in our fourth analysis question area. We did develop independent first cuts at separate social and economic protocols. Both of these need considerable refinement and, ideally, they should be integrated to the degree possible in developing a final protocol. However, additional work is beyond the scope of this report. In what follows, we provide: (1) a summary of ongoing work taking place in Forest Service Regions 1 and 4 spinning off of the 2000 fires that will take us at least part way down the road on the development of a social monitoring protocol, and (2) a brief description of a possible framework for an approach for designing an economic monitoring protocol.

Design and Implementation of a Long-Term Social Monitoring Protocol for Community Impacts and Recovery/Rehabilitation Needs Following a Catastrophic Wildfire Such as the Hayman

In response to the 2000 fires in the northern Rockies, Region 1 and Region 4 embarked on an effort to develop and evaluate a protocol for more monitoring the effects of wildfire on communities and the effectiveness of postfire recovery efforts. This project is still in the early phases of development and evaluation. Thus far, the R1/R4 research team has developed a draft, “Event-driven model of social impacts of wildland fire,” and is currently conducting fieldwork and analyzing data collected during the summer of 2002 to evaluate this model as a framework monitoring for community/social dimensions of fire recovery efforts.

The draft model is described as “event-driven” to give consideration to all the different activities that occur prior to, during, and following a fire event. This event-driven model was selected as the heuristic device in order to (1) develop guidelines on what to monitor, (2) determine steps needed to gather needed information, and (3) expand our understanding of how agency actions before, during, and after a fire event affect communities. However, it is recognized that this model, like all models, is a simplified representation of reality, and that caution is warranted in applying it to model complex social impacts

An “event-driven” model was selected because it provides a structural view of the decisions that are made during a wildland fire emergency. By focusing on decisions and their consequences, an event-driven model indicates where changes in decisions and the decisionmaking process can reduce potential negative consequences on the community; likewise, it may show what decisions may be made that might lead to positive consequences for communities. For example, communities face a preparedness decision. While many communities may not have prepared themselves for a large-scale fire event, this lack of a decision is a decision itself. By working with these communities, agencies can have a positive impact.

Such an event-driven model must itself meet a number of criteria. First, it must consider the effects of the social and political context within which decisions are made. This context considers attitudes toward wildland fire, general social feelings, and perceptions about fire suppression and management, and allocations of time and money to policies dealing with preparedness, suppression, and recovery actions. Second, the model must consider that actions occur at multiple scales and must be able to deal with those differing scales. To address multiple scales, the event-driven model focuses on the types of decisions that are made. Third, the model must consider the various disciplines involved in fire management and community decisions. There are multiple disciplines, including sociology, political science, management science, ecology, psychology, and so on. Again, the event-driven model proposed here deals with decisions and actions. The knowledge contained in different disciplines is viewed as contributing to the decision. Fourth, the model should consider the causes and contexts for decisions. In this case, the model attempts to show how decisions are linked in a fire event—thus addressing causes—and acknowledges the significance of context in influencing not only what decisions are made, but also in affecting the types of impacts that occur. Fifth, the model should acknowledge that a variety of responses and impacts occur. The model is focused on agency decisions that affect the community and thus is somewhat narrow in this sense. However, within the context of this goal, the model attempts to be inclusive.

The model contains four major components: (1) the context for fire management decisions; (2) decisions that occur prior to a fire event; (3) decisions that occur during a fire event; and (4) decisions that occur following the event. The decisions that occur within each of these four major components are influenced by other decisions; the experience with these decisions itself influences decisions made in events in the future. Specific decisions that contain implications for variables that might be monitored are shown in table 29. The following sections include discussion about each of the three major actions/decisions in the event driven model.

The next step in the development of the model is to identify indicators of effects and effectiveness for the different items listed in table 29. This will be done in

Table 29—Summary of agency actions that affect communities as suggested by an event-driven model of fire effects. The table lists types of items that might be monitored by agencies.

Before-Event Actions That Affect a Community

1. Community Preparedness (e.g., % firewise, fire suppression plans, development/zoning plans)
2. Federal Preparedness
3. Agency-Community Interactions (e.g., communication protocols, specificity, frequency, trained firefighters, certification of local equip operators, etc.)
4. Awareness (forest ecology, disturbance, fire & suppression strategies awareness, media training).
5. Neighborhood social capital (covenants, prep. events, fire suppression capital).

During-Event Actions That Affect a Community

1. Suppression Strategy and Tactics (direct attack versus property protection strategies)
2. Evacuation Alerts and Orders (who, where, when).
3. Entry restrictions (who, where, when)
4. The Use of Local Facilities, Resources and Supplies.
6. The Presence of Fire Crews and Emergency Personnel in the Community
7. Inter-organizational Relations and Information Management

Post-Event Actions That Affect A Community

1. Assessment
2. Reconstruction (Things – Infrastructure, homes businesses)
3. Restoration (Process – Rehab, stabilization, salvage)
4. Audit (Policy Change) – Monitoring, Prevention/Mitigation/ Preparedness (fuels, houses, subdivisions), Suppression (Strategies, priorities), Restoration

consultation with fire managers. The team will use this preliminary list of indicators to guide additional fieldwork and data collection. The data will be used to evaluate the completeness and usefulness of the indicators as tools that communities and agencies can use to evaluate and monitor community fire preparedness, effects of fire suppression efforts, and priorities and success of postfire recovery efforts.

A Framework for Anticipating and Understanding Economic Concerns Associated with Catastrophic Events Such as the Hayman Fire

Large-scale catastrophic events such as the Hayman Fire have many economic ramifications. These are as varied as the people and organizations and the economic relationships among them that make up what we call "the local economy." To a novice, a stream of concerns and opinions expressed about a myriad of economic topics by various persons and groups may seem spontaneous, random, and entirely unanticipated. But there are clear patterns in this seeming complexity. And persons charged with preparing for, managing, and coping with the reality of such events can exploit these patterns to anticipate what these concerns might be and who may raise them, and by doing so be prepared to act in a confident and informed manner. We present here a simple framework built from these patterns and relationships that can be used to anticipate the broad scope of economic concerns.

We seek a framework so that when we hear an expression of concern, for example, we can quickly appreciate the economic meaning of it. We can do this by noting who is expressing the concern, the role they are playing, and the temporal context in which they are saying it, and then matching the verbatim expression with a typology of economic meanings. The framework offered here is in the form of a series of matrices that highlight the relationships between typologies of economic topics and the principal actors or participants in a local economy. The universe of what we call "economics" is characterized by three broad topics: Economic Allocation, Economic Equity, and Economic Stability. Essentially all economic concerns are ultimately motivated by one of these general dimensions. Similarly, an economy is viewed as consisting of various types of actors: Businesses, State and Local Governments, Federal Government, and Individuals. The roles each of these plays include: Producers/Service Providers, Owners, and Consumers. Three phases of an event provide a crude temporal context: Preparedness, Management, and Coping. Table 30 provides detailed descriptions of these parts of the framework.

Table 31 is an example of the framework matrix for the Preparedness Phase and is organized as follows. Economic actors and the roles they play are arranged along the left side of the matrix as row headings. The three broad topics of the economic typology are the column headings. The row/column intersections illustrate specific instances in which a particular actor playing a particular role might express a concern relating to one of the economic topics. Knowing who is saying what and in what role points to the deeper economic meaning. Three important attributes of these row/column intersections should be noted. First, not every intersection necessarily makes sense in terms of indicating a meaningful relationship between actor and economic topic. The matrix is used to focus attention on the possible meanings. Examples are given where the relationship is relevant to large-scale events. Second, there are many literal variations in how concerns might be expressed relating to any specific row/column intersection in the matrix. For example, terms or phrases like "losses," "costs," or "hardship" may all be used to describe the same concern. Finally, the row/column intersections capture only the concerns of an actor's own self-interest. That is, transitive concerns of one actor about the economic behavior of another are not captured. The possibility that some communities actually gain from a catastrophic event is also not captured here. Tables 32 and 33 apply the same framework to the Management and Coping Phases, respectively.

Once more fully refined, the framework could be used in several ways although the foremost purpose would be to help mangers anticipate concerns that may be raised about an event and to illustrate how to find the deeper economic meaning of these concerns. In appreciating these deeper meanings, managers may more readily empathize with those who raise concerns and with the economists they might turn to for analysis and evaluation. Further, by anticipating these concerns, a path for addressing them may become clearer. For example, some economic concerns sure to be raised can be answered quickly by obtaining readily available current information. Others, once their deeper economic meaning is appreciated, may require more lengthy investigation, perhaps even long-term research. In these cases, it might prove prudent to establish in-place monitoring or assessment programs to acquire economic information prior to the time at which the concern is actually raised. As noted above, the refined framework may most importantly provide a simple tool both for being prepared for the economic concerns that will be expressed about large-scale events and being able to act on them in a confident and informed manner.

Table 30—Explanation of framework components

Framework components	Explanation
Actors	
Businesses	Private sector commercial and non-commercial firms that produce goods and services, including non-governmental organizations (NGOs), trade associations, and public enterprises
State and Local Governments	Various forms of sub-national governance such as State, municipal, county, township, and special districts
Federal Government	Federal governance, including land managing agencies
Individuals	Individual persons and groups of persons (e.g., families, communities, networks, associations)
Actor Roles	
Producers/Service Providers	Using land, labor and capital to create goods and services.
Consumers	Using goods and services.
Owners	Controlling real property and financial assets.
Economic Typology	
Economic Allocation	The efficiency with which resources are allocated among competing uses to greatest economic advantage.
Economic Equity	The fairness with which economic benefits and costs are distributed.
Economic Stability	The trends and rates of change in economic parameters like the prices of goods and services, the costs of financial services, employment, and economic growth or decline.
Temporal Phases	
Preparedness	A time period in which preparedness, planning, and prevention activities predominate.
Management	A time period during which the immediate needs of managing and addressing an event are paramount.
Coping	A time period in which the principal activities address the aftermath of an event.

Table 31—Framework for understanding economic concerns in the event preparedness phase.

		Economic topics of concern		
		Economic allocation	**Economic equity**	**Economic stability**
Economic Actors and Roles	**Businesses**			
	As Producers/Service Providers	**Market Perceptions** – Concerns about customer's perceptions of risk and danger resulting, e.g., in reduced visits.	**Tax Incidence** – Concerns about the fairness of tax and fee burdens.	**Financial Risk** – Concerns that risk premiums may affect access to capital.
	As Owners	**Risk** – Concerns about the costs of risk as in higher insurance costs.	**Tax Incidence** – Concerns about the fairness of tax and fee burdens.	**Financial Risk** – Concerns that risk premiums may affect access to capital.
	State & Local Governments			
	As Service Providers	**Protection & Safety Infrastructure** – Concerns about the cost of providing protection and safety services.	**Preparedness** – Concerns about the responsibility and accountability for preparedness planning.	**Financial Risk** – Concerns about pooling financial risk and providing sustainable funding.
	As Owners	**Protection Infrastructure** – Concerns about the cost of protecting assets.		**Reliable Supply** — Concerns about maintaining reliable supplies of goods and services, e.g., water, timber, clean air.
	Federal Government			
	As Service Provider	**Protection & Safety Infrastructure** – Concerns about the cost of providing protection and safety services.	**Preparedness** – Concerns about the responsibility and accountability for preparedness planning.	**Financial Risk** – Concerns about pooling financial risk and providing sustainable funding.
	As Owner	**Protection Infrastructure** – Concerns about the cost of protecting assets.		**Reliable Supply** — Concerns about maintainingreliable supplies of goods and services, e.g., water, timber, clean air.
	Individuals			
	As Producers/ Service Providers			
	As Consumers		**Tax Incidence** – Concerns about the fairness of tax and fee burdens.	**Financial Risk** – Concerns that risk premiumsmay affect access to capital.
	As Owners	**Risk** – Concerns about the costs of risk, e.g., higher insurance costs, defensible spaces.	**Tax Incidence** – Concerns about the fairness of tax and fee burdens.	**Financial Risk** – Concerns that risk premiums may affect access to capital.

Table 32—Framework for understanding economic concerns in the event management phase.

		Economic topics of concern		
		Economic allocation	**Economic equity**	**Economic stability**
Economic Actors and Roles	**Businesses**			
	As Producers/Service Providers	**Business Consequences** – Concerns about loss of business revenues.		
	As Owners	**Business Consequences**– Concerns about loss of business revenues and/or business assets, e.g., loss of structures.		
	State & Local Governments			
	As Service Providers	**Emergency Management Services** – Concerns about the costs of event management activities, e.g., suppression, damage control.		**Fiscal Accommodation** – Concerns about immediate access to financial resources.
	As Owners	**Asset and Infrastructure Consequences** – Concerns about losses to infrastructure and/or natural assets.		
	Federal Government			
	As Service Provider	**Emergency Safety Infrastructure** – Concerns about the costs of event management activities, e.g., suppression, damage control.		**Fiscal Accommodations** – Concerns about immediate access to financial resources.
	As Owner	**Asset and Infrastructure Consequences** – Concerns about losses to infrastructure and/or natural assets.		

Table 32—(Con.)

		Economic topics of concern		
		Economic allocation	**Economic equity**	**Economic stability**
Economic Actors and Roles	**Individuals**			
	As Producers/Service Providers	**Livelihood Consequences** – Concerns about job loss and/or income losses		
	As Consumers *As Owners*	**Asset and Infrastructure Consequences** – Concerns about infrastructure losses, e.g., homes.		**Fiscal Accommodation** – Concerns about immediate access to financial resources.

Table 33—Framework for understanding economic concerns in the event coping phase.

		Economic topics of concern		
		Economic allocation	**Economic equity**	**Economic stability**
Economic Actors and Roles	**Businesses**			
	As Producers/Service Providers	**Business Consequences** – Concerns about chronic loss of business revenues	**Indirect Business Consequences** – Concerns about chronic business losses via supply and/or demand links	**Market Image** – Concerns about customer's perceptions of damage resulting, e.g., in reduced visits.
	As Owners	**Business Consequences** – Concerns about rebuilding and/or reconstructing business volumes and/or business assets.	**Livelihood Consequences** – Concerns about job and/or income losses.	**Debt Burden** – Concerns about debt burden and effects on access to capital.
	State & Local Governments			
	As Service Providers	**Government Finance Consequences** – Concerns about tax revenue reductions, e.g., sales tax and user fee revenues.	**Coping and Recovery** – Concerns about the responsibility and accountability for economic planning, development, restructuring, and recovery.	**Sustainable Financing** – Concerns about funding sustainable methods of financing coping activities.

(con.)

Table 33—(Con.)

		Economic topics of concern		
		Economic allocation	Economic equity	Economic stability
Economic Actors and Roles	**State & Local Governments**			
	As Owners	**Restoration/ Rehabilitation/ Reconstruction** – Concerns about reduced productive capacity of natural assets, reconstruction and rehabilitation costs.		**Liabilities**— Financial liabilities for negligence or fault.
	Federal Government			
	As Service Provider	**Government Finance Consequences** – Concerns about tax revenue reductions, e.g., user fee revenues.	**Coping and Recovery** – Concerns about the responsibility and accountability for economic planning, development, restructuring, and recovery.	**Sustainable Financing** – Concerns about finding sustainable methods of financing coping activities.
	As Owner	**Restoration/ Rehabilitation/ Reconstruction** – Concerns about reduced productive capacity of natural assets, reconstruction and rehabilitation costs.		**Liabilities**— Financial liabilities for negligence or fault.
	Individuals			
Economic Actors and Roles	*As Producers/Service Providers*	**Livelihood Consequences** – Concerns about job and/or income losses	**Indirect Livelihood Consequences** – Concerns about job and/or income losses, environmental justice.	
	As Consumers		**Consumption Consequences** – Concerns about reduced opportunities, e.g., access to businesses, recreation opportunities.	
	As Owners	**Recovery Consequences** – Concerns about rebuilding and/or reconstructing costs.	**Indirect Wealth Consequences** – Concerns about loss of value, e.g., scenic quality imputed into value of home.	**Debt Burden** – Concerns about debt burden and effects on access to captial.

Summary and Conclusions

In the introduction to this report we discussed the complexity of the effects a catastrophic wildfire such as the Hayman has on human social and economic systems. We also pointed out that unlike many ecological effects of a wildfire, the geographic scale of influence for social/economic effects extends considerably beyond the area actually burned. Finally, we indicated that a complete catalog of all effects would be difficult to compile, partly because it will be many years before they all play out. As noted in the Hayman Analysis Interim Report on Ecological Effects, *"an 1851 fire"* near Cheesman Reservoir *"created treeless openings that were still present in 2002."* (Romme and others 2002). If this is any indication, no human alive during the Hayman Fire will live long enough to see the burned area recover to anything like it was prefire. Those who used this area have lost something and they will need to look elsewhere to replace it, and the local economies likely have lost the economic contributions those users made.

Our review only focuses on social and economic effects that manifested themselves during the fire or in the 6 months immediately following the fire. We addressed selected questions from four question areas:

1. How do we begin to get a handle on the various economic effects (both during and after the fire) associated with the Hayman Fire?
2. How have stakeholder positions toward fuel treatments been influenced by the fire; that is, what were they prefire and during the fire, and what are they now? How do stakeholders partition blame for the fire among various possible organizations, climatic conditions, and so forth? How do we work to build broad-based consensus on implementing fuels management treatments to reduce the risk of another Hayman Fire along the Colorado Front range in the future?
3. What have individuals, organizations, and communities learned from the Hayman Fire experience? How has the collaborative HayRAC project worked to facilitate the beginning of recovery for affected communities? What needs for additional education remain; for example, what does the general public need to know about forest management? How do we capitalize on the "teachable moment" that will exist only for a short while to get important lessons across? It appears there is a need to educate many on a wide variety of issues relating to natural resource management/wildfires. How do we institutionalize memories of lessons learned from the Hayman incident, especially in the face of a rapidly changing/growing population? In other words, how do we enhance community preparedness for future wildland fires?
4. How would we design and implement a long-term social and economic monitoring protocol for community impacts, recovery/rehabilitation needs, and risk preparedness following the Hayman Fire? What pieces of such a plan could be put into place in the near future?

We accomplished this by conducting four studies, one on economic and social effects of the fire, one involving prefire and postfire workshops with the Ridgewood Homeowners Association, one involving interviews with key informants in the Woodland Park area in August 2002, soon after the fire was suppressed, and one involving another set of interviews with Woodland Park area representatives of governmental and nonprofit organization members in February 2003, about 6 months after the fire was suppressed. Many findings are scattered throughout the report, and appendix II has a list of the more important ones. Next we present some of the more important conclusions.

Economic Effects

The economic aspects of a large-scale fire occurring in proximity to human populations, such as the Hayman Fire, are difficult to measure and highly variable. Some aspects are straight forward and relatively easier to measure, such as the actual suppression expenditures or property losses. Assessing other aspects, such as the effect on a regional economy, or changes in recreation and tourism, are easily confounded by other factors, such as general economic downturns or a shift of economic activity from one location to another.

While the Hayman Fire was not extraordinarily expensive when looked at on a cost per acre basis, the size of the fire made it one of the most expensive fires in the last several years. No fire in Colorado's history has cost as much to suppress. The $38 million spent by the Forest Service on the Hayman Fire was more than three times the average annual suppression expenditures (1992 through 2001) for all of Region 2. Adding expenditures by the State and the other Federal agencies, suppression expenditures totaled more than $42 million. In addition to the money spent fighting the fire, rehabilitation and restoration expenditures (already expended and planned) connected with the fire are expected to cost at least another $74 million. Looking at the distribution of suppression expenditures for the Federal agencies, a larger percentage of money was spent on the Hayman Fire for supplies and services, and a smaller percentage on personnel expenses, than is usually case, most likely due to the severity of the fire which hampered direct suppression efforts by firefighting crews.

Additional expenditures related to the fire totaled almost $2 million. These expenditures included FEMA reimbursements to Counties for roadblocks, traffic control, and evacuations, as well as administrative expenses for the State of Colorado connected with handling the billing for the Counties and other cooperators, and disaster relief by the American Red Cross.

The proximity of the fire to human populations led to a loss of 600 structures, including 132 residences. Real property losses were substantial, totaling $24 million, with a majority of the losses occurring in Teller County ($14 million) and Douglas County ($8 million). Total insured private property losses (which include the real property losses stated above) were considerably larger, estimated at $38.7 million. Loans and grants from SBA and FEMA for uninsured losses totaled almost $4.9 million. Additionally, damage to transmission lines was estimated at $880,000.

More difficult to measure are the effects on resource values (including tourism and recreation) and the regional economy. The fire closure order occurred during the busiest time of the tourist season. Concessionaires who manage the developed recreation sites within the affected Ranger Districts of the Pike-San Isabel National Forest reported a total decline in revenue in 2002 of $382,000 from 2001 levels. Representatives from all four non-Forest Service developed recreation sites outside the fire perimeter that we interviewed reported decreased visitation levels for the fire months of June and July 2002 relative to levels in June and July of 2000 and 2001. Outfitter and guide use on the affected districts in 2002 was at 75 percent of the 2001 level. However, it is possible that recreation losses occurring within the vicinity of the Hayman Fire were offset by gains to other areas of Colorado. Other resource loss estimates on the Pike-San Isabel were substantial, dominated by lost value from water storage capacity ($37 million) and timber ($34 million).

We found little evidence of a substantial economic decline in the Primary Impact Area—the four affected Counties during the months of the Hayman Fire. We developed a number of time series models to estimate regional economic activity in the absence of the Hayman Fire and compared those estimates with the observed levels of economic activity during the summer of 2002. Statistically significant differences between the observed economic activity and estimated values were relatively rare. However, there were substantially more significant negative differences than significant positive differences. This may indicate that, at least in some areas and sectors modeled, the Hayman Fire did decrease economic activity. That more substantial effects were not detected is probably due to (1) tourism-related sectors constitute a relatively small part of the economies in the Primary Impact Area and (2) the economies of the Primary Impact Area are large, complex, and able to withstand economic shocks.

Conclusions from the Wildfire Mitigation Adoption Literature

Findings from the fire studies mirror much of the general hazard thinking on mitigation and highlight certain variables to examine in understanding individual response specifically to the wildfire hazard. These studies confirm that increased awareness leads to higher risk perception but show a less clear link between high risk perception and engaging in mitigation. While most studies found over two-thirds of the population had done some type of mitigation, only the Santa Monica and the Incline Village studies found a significant positive association between risk perception and likelihood of putting in defensible space.

The studies also highlight the uncertain role of experience in shaping both risk perception and mitigation efforts. In Florida, intentions to take protective actions were negatively correlated with experience (Jacobson 2001). In both San Bernardino and Incline Village *actual* experience appeared to dampen awareness and risk perception but *secondary* experience increased awareness and risk perceptions levels and encouraged implementation of defensible space. Similarly, in Michigan direct (and negative) experience merely created skepticism for defensible space measures. However, in Santa Monica experience was positively related to awareness levels, and in Florida it was positively related to perceived risk and appeared to have led to increased implementation of defensible space.

These studies thus give some, albeit limited and dated, insights into public response to the wildfire hazard and mitigation measures. They also suggest the need for more research, including a better understanding of the roles of community action and of broader social factors and contexts on response to wildfire. Several studies are currently under way with National Fire Plan and Joint Fires Sciences Program funding that will provide a more indepth understanding of public response to the fuel hazard from both the individual and the community level. Some of the preliminary results include:

- Support for previous findings that greater understanding leads to more support for fire mitigation efforts (Shindler, Ryan, Vogt).
- The importance of trust in the implementing agency in garnering acceptance for fuel management practices (Shindler).
- Active fire mitigation partnerships can help build trust (Monroe and Nelson).

- Five landscape values are key in influencing acceptability of any vegetation modification: privacy, wildlife viewing, recreation, aesthetics, and the ideas of naturalness (Monroe and Nelson).
- The importance of use of existing networks and partnerships in facilitating active management (Jakes and others 2003).
- Educational materials need to be site specific (Monroe and Nelson).
- The importance of taking local ecology, history, and values into consideration in working with the public on fuels management issues.
- While practices such as thinning and defensible space may be familiar concepts to many, there is limited or inaccurate understanding of what the practices actually entail—often what individuals *think* a practice involves conflicts with their landscape values.
- The importance of use of existing networks and partnerships in facilitating active management.

Conclusions from Ridgewood Homeowner's Association Workshops

RHOA residents participated in two workshops, one held in June 2002 and the second held in February 2003 to gain insights into wildland urban interface resident's decisions, perceptions, and preferences regarding wildfire risk issues. Homeowner knowledge and experience, risk perceptions, preferences for forest treatment options, and homeowner risk reduction behaviors were investigated. Additionally, the underlying factors that potentially motivate homeowners' mitigating actions were also pursued.

The RHOA, located adjacent to the Manitou Experimental Forest on the Pike National Forest, comprises residents who have had notable experience with wildfire, are quite knowledgeable on these issues, and yet are still motivated to learn more. This group of homeowners recognizes the need for active management on the forest and realize the potential dangers that wildfire poses. The homeowners most preferred treatment option is mechanical removal (even more since the Hayman Fire). Second, they prefer prescribed fire in combination with mechanical removal, and finally they are somewhat neutral on prescribed fire. Interestingly, this preference has remained constant from before to 6 months after the Hayman Fire.

The degree of information "helpfulness and credibility" of various organizations and individuals provides additional insights into some of the reasoning behind these preferences for active treatments. According to these residents, the city and County fire departments are helpful and perceived as highly credible entities, while research reports and environmental organizations were not viewed as helpful or credible sources. The Colorado State Forest Service also gives out useful information, though it is only perceived as somewhat credible as an institution. The USDA Forest Service, bordering many of these residents' land, is viewed as providing somewhat helpful information and as less credible than the Park Service, County, and city fire departments, State Forest Service, and neighbors and friends. This could explain some of the trepidation associated with prescribed fire; the residents may view prescribed fire as something needed but not preferable because they know the Forest Service is the entity implementing the treatments. These sentiments for prescribed fire may also reflect the knowledge about the Forest Service employee who has pled guilty to starting the Hayman Fire. An avenue for future research would be to expand the treatment questions to include different agencies/entities carrying out the various treatment options and investigate the link between the entities' credibility and the homeowners' preferences for active treatment options.

The residents of the RHOA feel highly vulnerable to the effects of fire, highly susceptible to the consequences of fire, and residents also feel that there is a high probability (78 percent) that a wildfire will occur near their home in the near future. Yet, the measures of perceived efficiency for both specific and general risk reduction actions only explain a few of the homeowners' mitigating actions. Perceived effectiveness of Firesafe council actions and residents' confidence in their ability to carry out these Firesafe actions are highly correlated; therefore these residents feel that the mitigating actions are, for the most part, very effective and they also believe strongly in their ability to carry them out. The question then remains as to why there aren't more mitigating actions being implemented on homeowners' lands.

Almost two thirds of the homeowners state that involuntary impediments are deterrents to putting in place various risk reduction strategies. The residents' strong feelings of vulnerability from wildfire risks are enhanced by inaction of their neighbors, thereby negating the effect of homeowner risk reduction actions. The residents not only believe that they are responsible for defending their property, but also that all neighbors, including homeowners, the Forest Service, and the HOA, should be involved in mitigating these risks. If one player opts out, these homeowners feel that their vulnerability remains significant. It appears that a community response to wildfire mitigation, where all landowners "buy in" would be an effective avenue to reduce the risks of wildfire.

Based upon the information from the RHOA, there are numerous implications for mitigating the risks to wildfire. Information on wildfire issues should be disseminated through city and County fire departments, which hold more credibility with homeowners. To effectively communicate risk reduction strategies with the RHOA the messages need to address the entire picture of reducing risks, including strategies that not only consider lands in the immediate vicinity of the homes, but also farther-removed lands that can perhaps impact the state of the wildfire (perhaps, crown fire to a ground fire). The land managing agencies, neighbors, and homeowners' association must all acknowledge their own part in reducing these risks. Education should focus on including the actions of the land managing agencies and other community projects so that homeowners feel it is truly community effort and that it is not something they are doing on their own. Additionally, to gain support for prescribed fire as a treatment option, the Federal, State, and local governments need to educate residents about the benefits of prescribed fire, and perhaps even the benefits of prescribed fire over mechanical removal.

The preliminary nature of the work to date must be considered in evaluating the generalizability of these findings. Although the RHOA's experience provides an excellent foundation to begin understanding the public's positions on fire and fuel's management they are by no means a representative sample from which to draw general conclusions. Continued work in this area which is being funded under the National Fire Plan, will focus on collecting similar data from groups and individuals that are more representative of the general public.

Conclusions From Postfire Interviews/ HayRAC

Postfire experience points to the importance of identifying and establishing relationships with preexisting community assets and organizations early on in a wildfire incident. This can help incorporate local knowledge into firefighting and rehabilitation efforts and establish a recovery base that will continue once emergency Federal agency personnel and resources have left the community. The success of HayRAC/CUSP and the Forest Fire Victims Task Force occurred because they already had a local context and relationships that could be rapidly built on. Such partnerships should be developed as early as possible during the fire by the incident command, and several interviewees thought that they should be developed by local Federal officials well before any fire. Such up front collaboration was seen as a good way to systematize actions, increase efficiency, and decrease potential contention between locals and Federal agencies by building trust. While trust has been shown to be important in all natural resource management matters, it is particularly important with wildfires where a crisis brings in powerful outsiders to work in a community for a limited but highly emotional period of time.

There are clearly several areas where lack of public understanding of the complexities of wildfire management and rehabilitation contributed to a sense of discontent. For instance, while many evacuees expressed frustration with being forbidden to go back to their homes, there was little understanding of how thin law enforcement was stretched and that people were restricted from going back to houses not only just for safety reasons but also as the only manageable means of preventing burglaries in evacuated areas on a fire that size. Along with continuing to work to educate the public about forest health and fire management issues, it also appears worthwhile to include information about what is involved in firefighting and rehab efforts, including limitations. In this way when a major fire does occur, public expectations hopefully will be more realistic. The importance of the visual is worth noting in educational efforts. Because "appearance counts for a lot," efforts to explain what is being done should take this into account, suggesting that guided trips onto the closed forest to show rehab projects would be a worthwhile activity.

Nor should the educational process be one way. Federal fire managers need to work to better understand the actual capabilities and limitations of volunteer fire departments. There also appears to be room for increased interagency learning. While agencies have over time developed effective means of coordinating policy and actions during a fire, similar efforts need to be made with rehabilitation work, particularly between the Forest Service and NRCS. It was suggested that perhaps what is needed is a national, interagency, rehabilitation coordinator.

Finally, perhaps the best recommendation was provided by individuals working at HayRAC/CUSP who continually stated that, given the complexity and importance of rapidly developing effective solutions to minimize current and future wildfire damage, it is important to think out of the box as much as possible. Instead of relying on traditional and often engrained methods and approaches, the ability to be open to new and adaptive techniques and to meet locally identified needs will be critical.

We pointed out at the beginning of this report that the mix of social and economic effects of a large fire such as the Hayman, especially when it occurs within the wildland urban interface, is both a complex and far ranging story. Although this report is rather lengthy, it still only begins to tell this story in part because of the social and economic consequences of the Hayman Fire that will play out over time. Consequently, there will be ample opportunity for additional social and economic Hayman Fire analyses. We recommend that these analyses be conducted because a more complete rendition of this story is needed for at least two reasons. First, there is much to be learned from the as yet untold portions of the story that will be applicable to future wildfire events. Second, the Hayman Fire has taken on national significance by becoming an example of a consequence of what is wrong with current forest management policy in this country. Consequently, the more we can learn from it, the more we can use the Hayman experience to inform future debates over both forest and wildfire management strategies.

Acknowledgments

We express our deep appreciation to the other members of our team who made many valuable contributions to this effort including Jason Stoker, now with the Eros Data Center, Sioux Falls, SD. Mike Retzlaff in the Forest Service Denver Regional Office, Jim Raymond with Douglas County, John Hill of the Pike and San Isabel National Forest, and Rocky Wiley of Denver Water.

We also express our deep appreciation to the many USDA Forest Service, Department of the Interior, State and County employees, and others who provided timely information and data for this study. Instrumental to this study were the staff at the Pike-San Isabel National Forest supervisor's office and the recreation staff at Pikes Peak, South Platte, and South Park Ranger Districts who provided us with much of the needed data. We also thank employees with the USDA Forest Service Inventory and Monitoring Institute for their assistance in collecting data and providing technical assistance, employees at the other Federal lands agencies (USDI Bureau of Land Management, National Park Service, Fish and Wildlife Service, and Bureau of Indian Affairs) for providing data on suppression and BAER expenditures, representatives from Reserve America and associated Forest Service contracting officers and staff for their help with recreation use data, as well as representatives from the Pikes Peak Toll Highway, Pikes Peak Cog Railway, Eleven-Mile State Park, and Florissant Fossil Beds National Monument. Many State of Colorado employees also provided us with data and assistance, including employees at the Colorado State Forest Service, the Colorado Department of Revenue, the Colorado Department of Lands, and the Colorado Demographers Office. We also received valuable assistance from the Assessor's Offices of Douglas, Jefferson, Park, and Teller Counties, Denver Water, and Rocky Mountain Recreation Corporation and Canyon Resources, Inc. Dennis Lynch, Forest Sciences, Colorado State University, also provided us with some valuable information and contacts regarding NRCS grants, insured and uninsured property losses, and power facilities. Other agencies that helped provide us with the data included in this report include the NRCS, FEMA, SBA, and the Rocky Mountain Insurance Information Association. Finally, this study would not have been accomplished in the time allotted without the invaluable assistance of Dan Loeffler and Michael Krebs, our two research assistants, and as always, the excellent statistical support and expertise of Rudy King, statistician at the Rocky Mountain Research Station in Fort Collins, CO.

Finally, we acknowledge the valuable contributions to this report made by four reviewers, Tony Cheng and Dennis Lynch of Colorado State University and Linda Langner and Anne Hoover of the Forest Service Research Washington Office.

References

Abt, Robert, David Kelly, and Mike Kuypers. 1987. The Florida Palm Coast Fire: An Analysis of Fire Incidence and Residence Characteristics. *Fire Technology* 23(3):186-97.

Abt, R.C., Mike Kuypers and J.B. Whitson. 1990. Perception of Fire Danger and Wildland/Urban Policies after Wildfire. *Fire and the Environment: Ecological and Cultural Perspectives,* March 20-24, 1990, pp. 257-59.

Carpenter, Edwin H., Jonathan G. Taylor, and others. 1986. Targeting Audience and Content for Forest Fire Information Programs. *The Journal of Environmental Education*, 17(3):33-41.

Carroll, Mathew S.; Findley, Angela J.; Blatner, Keith A.; Mendez; Sandra Rodrigues; Daniels, Stephen E.; Walker, Gregg B. 2000. Social assessment for the Wenatchee National Forest wildfires of 1994: targeted analysis for the Leavenworth, Entiat, and Chelan Ranger Districts. Gen. Tech. Rep. PNW-GTR-479. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 114p.

Colorado Department of Labor (CDL). 2003. Unpublished Colorado employment and wage information. On file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula, MT.

Colorado Department of Revenue (CDR). 2003. Unpublished Colorado retail sales information. On file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula, MT.

Cortner, Hanna J., Philip D. Garner, and Jonathan G. Taylor. 1990. Fire Hazards at the Urban-Wildland Interface: What the Public Expects. *Environmental Management*, 14(1):57-62.

Cortner, Hanna J., Malcom J. Zwolinski, and others. 1984. Public Support for Fire-Management Policies. *Journal of Forestry*, 82(6):359-60.

Englin, J.; Loomis, J.; Gonzalez-Caban, A. 2001. The dynamic path of recreational values following a forest fire: a comparative analysis of states in the Intermountain West. Canadian Journal of Forest Research. 31:1837-1844.

English, Donald. 2003. [Personal communications]. January 29. Athens, GA: U.S. Department of Agriculture, Forest Service, Southern Research Station, Forestry Sciences Laboratory

Gardner, Philip D., and Hanna J. Cortner. 1985. Public Risk Perceptions and Policy Response toward Wildland Fire Hazards in the Urban/Rural Interface. *Fire Management: The Challenge of Protection and Use*, April 17-19, 1985, pp.153-72.

Gardner, Philip D., and Hanna J. Cortner. 1988. An Assessment of Homeowner's Perceptions of Wildland Fire Hazards: A Case Study from Southern California. In *Arid Lands—Today and Tomorrow,* Emily Whitehead, ed., Westview Press, Boulder, Colorado, pp.643-57.

Gardner, Philip D., Hanna J. Cortner, and Keith Widaman. 1987. The Risk Perceptions and Policy Response Toward Wildland Fire Hazards by Urban Homeowners. *Landscape and Urban Planning,* 14:163-72.

Gardner, Philip D. and L.P. El-Abd. 1985. *The Study of the Impacts of Severe Wildland Fires and Disaster Relief Program on Homeowners*, United States Forest Service, Riverside.

Incident Cost Accounting and Reporting System (ICARS). [Software]. 2002a. U.S. Department of Agriculture, Forest Service. Available: http://www.fs.fed.us/r6/fire/incident/ (February 2003)

Incident Cost Accounting and Reporting System (ICARS). 2002b. Unpublished ICARS database for the South Hayman. On file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula, MT.

Jacobsen, Susan K., Martha C. Monroe, and Susan Marynowski. 2001. Fire at the Wildland Interface: The Influence of Experience and Mass Media on Public Knowledge, Attitudes, and Behavioral Intentions. *Wildlife Society Bulletin*, 29(3):929-937.

Jakes, Pam J. , K Nelson, R Land, M Monroe, S Agrawal, L Kruger , and V Sturtevant. 2003. "Homeowners, Communities, and Wildfire: Science Findings from the National Fire Plan ." *Proceedings of the Ninth International Symposium on Social and Resource Management*, Pam Jakes. GTR NC-231. USDA Forest Service, North Central Research Station.

Kocis, S.M.; English, D.B.K.; Zarnoch, S.J.; Arnold, R.; Warren, L. 2002. National Visitor Use Monitoring Results: Pike-San Isabel National Forest and Comanche and Cimaron National Grasslands. U.S. Department of Agriculture, Forest Service, Region 2.

Loeher, Larry L. 1984. Fire Hazard: The Dimension of Resident's Attitudes. *Living in the Chaparral of Southern California,* held in Los Angeles, California, October 20, 1984, pp 51-62.

Loomis J.; Gonzalez-Caban, A.; Englin, J. 2001. Testing for differential effects of forest fires on hiking and mountain biking demand and benefits. Journal of Agricultural and Resource Economics 26(2):508-522

Machlis, Gary E.; Kaplan, Amanda B.; Tuler, Seth P.; Bagby, Kathleen A.; McKendry, Jean E. 2002. Burning questions: A social science research plan for Federal wildland fire management. Contribution Number 943. Idaho Forest, Wildlife and Range Experiment Station. Moscow ID 253p.

McCaffrey, Sarah. 2002. For Want of Defensible Space a Forest is Lost: Homeowners and the Wildfire Hazard and Mitigation in the Residential Wildland Intermix at Incline Village, Nevada. Dissertation, University of California at Berkeley, 300 pages.

McCrimmon, Katie Kerwin. 2002. Politics on front line at fires. Rocky Mountain News. [Denver, CO], June 15.

Missoula Area Economic Development Corp (MAEDC). 2002. Assessment of the economic impact of the wildfire disaster of 2000 on Montana's tourism and forest products industry. On file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula, MT.

Monroe, Martha (University of Florida) and Kristen Nelson (University of Minnesota) *Public perceptions of defensible space and the use of prescribed fire in the wildland-urban interface"* Research for North Central Research Station supported by the National Fire Plan

Moore, Ted. 2003. [Personal communication]. March 6, 2003. Pueblo, CO: U.S. Department of Agriculture, Forest Service, Pike-San Isabel National Forest.

National Wildfire Coordinating Group (NWCG). 1998. Fireline Handbook. NWCG Handbook 3. PMS 410-1. NFES 0065. On file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula, MT.

Office of Management and Budget (OMB). 1987. Standard Industrial Classification Manual, 1987. Springfield, VA: National Technical Information Service. 705 p.

Rice, Carol L. and James B. Davis. 1991. *Land-use Planning May Reduce Fire Damage in the Urban-Wildland Intermix*, General Technical Report PSW-127, Pacific Southwest Research Station, Berkeley, California.

Richardson, Valerie. 2002. Hot rhetoric shills tourism. Washington Times. [Washington D.C.] , June 24.

Ryan, Robert and Blanchard, Brian P. (University of Massachusetts)."Community perceptions of wildland fire risk and fire hazard reduction strategies at the wildland-urban interface in the Northeastern United States." Research for North Central Research Station supported by the National Fire Plan

Schuster, Ervin G.; Cleaves, David A.; Bell, Enoch, F. 1997. Analysis of USDA Forest Service fire-related expenditures 1970-1995. Res. Paper PSW-RP-230. Albany, CA; Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, 29 p.

Shelby, Bo, and Robert W. Speaker. 1990. Public Attitudes and Perceptions about Prescribed Burning. In *Natural and Prescribed Fire in Pacific Northwest Forests,* John D. Walstad, Steven R. Radosevich, and David V. Sandberg, eds., Oregon State University Press, Corvallis, pp 253-59.

Shindler, Bruce (Oregon State University). *Public acceptance of fuels reduction and forest restoration practices: survey of citizens in communities adjacent to National Forests in Minnesota, Wisconsin, and Michigan."* Research for North Central Research Station supported by the National Fire Plan and for Joint Fire Science Program

Shindler, Bruce, Michelle Reed, Beth Kemp, and James McIver. 1996. *Forest Management in the Blue Mountains: Public Perspectives on Prescribed Fire and Mechanical Thinning,* Dept of Forest Resources, Oregon State University, Corvallis, Oregon.

U.S. Department of Commerce, Bureau of Census (USDC-BOC). 2003. Unpublished North American Industrial Classification System codes and titles. On file at: www.census.gov/epcd/www/naics.html

U.S. Department of Commerce, Bureau of Economic Analysis (USDC-BEA). 2003. Unpublished United States personal income and price deflator information. On file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula, MT.

Vogt, Chirstine (Michigan State University) Predicitng public acceptance of fuel management at the Lake State forest interface. Research for North Central Research Station supported by the National Fire Plan and for Joint Fire Science Program

Winter, Greg, and Jeremy S. Fried. 2000. Homeowner Perspectives on Fire Hazard, Responsibility, and Management Strategies at the Wildland-Urban Interface. *Society and Natural Resources,* 13:33-49.

Winter, Greg, Christine Vogt, and Jeremy S. Fried. 2002. Fuel Treatments at the Wildland-Urban Interface: Common Concerns in Diverse Regions. *Journal of Forestry*, 100(1):15-21.

Appendix I: Selected Budget Object Classification Codes

BOC	Description
1100	Personnel compensation
1101	Regular salaries and wages paid directly to civilian full-time, permanent employees located in the U.S. and its possessions
1121	Regular salaries and wages paid directly to civilian full-time employees in appointments established for a limited period of time, generally less than a year
1165	Hazard pay differential – payment above the basic rate because of assignments involving irregular or intermittent performance of duties that subject the employee to unusual hazards or physical hardships
1170	Overtime
1193	Casual Employee Time Reports employment. – Contract payments amounts paid to individuals on a contract or purchase order basis when only their personal services are supplied
1200	Personnel benefits
2100	Travel and transportation of persons
2200	Transportation of things – contractual charges incurred for the transportation of things and for the care of such things while in process of being transported. Includes postage used in parcel post and rental of trucks.
2300	Rent, Communication, and Utilities – User charges assessed for buildings and other rental space and charges for communications and utility services (Does not include rental of transportation equipment, which falls under with 2100 or 2200.
2400	Printing and Reproduction
2500	Other services – Charges for contractual services that are not otherwise classified. Also included are agreements with other cooperating agencies.
2540	Contractual services - Other
2541	Flying contracts
2550	Agreements – cooperative agreements between Forest Service and state agencies, or between permitters and private parties.
2551	Cooperating state agencies
2559	Other agreements
2570	Miscellaneous services – includes ADP data acquisition and motor pool services
2600	Supplies and materials – charges for commodities that are ordinarily consumed within 1 year, that are converted in the process of construction or manufacturing, or that are used to form a minor part of equipment or fixed property
3100	Equipment
4100	Grants, subsidies, and contributions
4200	Insurance claims and indemnities
4300	Interest and dividends

Appendix II: Selected Findings

Many of the findings contained in the body of this report are listed here by report topic area for easier reference.

Selected Economic Aspects of the Hayman Fire

Four general economic aspects of the Hayman Fire were investigated: suppression and rehabilitation expenditures, regional economic activity, property-related losses, and resource outputs and values.

1. Suppression and Rehabilitation Expenditures

1) FY 2002 was an extremely expensive fire season for Region 2. Over the last three decades, Region 2's annual fire suppression expenditures averaged $8 million (not counting FY 2002). Before FY 2000, only two years—FY 1988 and FY 1996—saw expenditures as high as $20 million.

2) FY 2002 was a record-breaking year. Expenditures spent fighting fires in Region 2 totaled $182 million, more than four times the amount spent in FY 2000, the next most expensive year.

3) Although the $38 million in Forest Service expenditures for the Hayman Fire accounted for only about 20 percent of this total, Region 2 spent more money on suppressing the Hayman Fire than the total yearly suppression expenditures in any year except FY 2000 or FY 2002.

4) In FY 2002, BAER expenditures in Region 2 reached $22 million, 29 times the 1996 to 2002 average, $14 million of which was attributable to the Hayman Fire.

5) The $38 million spent by the Forest Service on this fire for suppression amounts to about $273 per acre.

6) The Hayman Fire bill for suppression and Federal BAER expenses as of May 2003 comes to more than $66 million, with 64 percent associated with suppressing the fire and the other 36 percent for BAER

7) Expenditures by the Forest Service account for 89 percent of suppression expenditures and more than 99 percent of BAER expenses.

8) The final determination of financial responsibility between the Forest Service and the State of Colorado is determined through a cost-share agreement between the two agencies. Initial expenditures by the Forest Service are later allocated between the Forest Service and the state, mainly according to acreage, with a few exceptions, with 85 percent of the acres and, therefore, the expenditures being Forest Service responsibility and 15 percent state responsibility. When all adjustments have been made, expenditures should total approximately $32 million for the Forest Service and $7.3 million for the State of Colorado (the $5.8 million share of the initial Forest Service expenditures and $$1.5 million of additional expenditures by the state).

9) Region 2 accounted for 62 percent of Forest Service Hayman suppression costs and national contracts such as aviation and food service contracts accounted for 27 percent.

10) In addition to BAER projects, nearly $37 million in expenditures for other longer-term (1 to 5 year) rehabilitation and restoration projects are also planned by the Pike-San Isabel National Forest, including $13.7 million on projects connected with land and facilities and $9.9 million on reforestation

11) Other rehabilitation expenditures include $10.8 million in NRCS grants to state, County, and private landowners (including $3.2 million to Denver Water). In addition to the NRCS grant, Denver Water expects to spend another $2.1 million on rehabilitation, monitoring and lab work, and water treatment.

12) Other fire-related expenditures include $1.1 million in FEMA reimbursements to the affected Counties for roadblocks, traffic control and evacuations; $49,000 in administrative costs for the State of Colorado for administering the billing for the Counties and other cooperators, and an estimated $766 thousand in disaster relief by the American Red Cross for the Hayman Fire evacuees.

2. Regional Economic Activity

1) For the four Counties containing the Hayman Fire, Jefferson, Teller, Park and Douglas, (the Primary Impact Area), employment averaged about 280 thousand per month for the 17 months immediately preceding the fire; employment averaged 281 thousand for the next four months, the fire and postfire months. Wages averaged $869 million (2002$) per month for the months preceding the fire and only $843 million for the next four months. Retail sales averaged $1.281 billion (2002$) per month before the fire and $1.329 billion per month during and after the fire.

2) In the Primary Impact Area, wages paid in Eating and Drinking establishments averaged about $29.2 million (2002$) per month for the 17 months immediately preceding the Hayman Fire and $30.7 million for the next four months. A similar situation holds for wages in Lodging and Recreation establishments. Wages in Lodging averaged $3.3 million (2002$) per month for the months preceding the Hayman Fire and $3.7 million for the next four months. Wages in Recreation averaged $9.9 million (2002$) per month before the Hayman Fire and $11.6 million per month during and after the fire.

3) The monthly average employment levels in tourism-related sectors (Eating and Drinking, Lodging, and Recreation) in the Primary Impact Area, for the four-month period (June-September) during and after the Hayman Fire exceeds that for the 17 months before the fire.

4) Attempting to isolate the events and circumstances surrounding the Hayman Fire, we constructed numerous statistical models to control for national economic conditions, seasonal variation, and so on. Although we found some evidence of positive or negative influences on economic activity during the fire months (June and July) and during the postfire months (August and September), the evidence is weak and unconvincing.

3. Property-Related Losses

1) According to the assessors in the Primary Impact Area, real private property loss for the four County area was valued at $23,750,000 with an annual assessed value of $3,400,000, resulting in an annual loss of revenue to the Counties of approximately $238,000 per year.

2) Total insured private property losses were estimated at $38,700,000 (including the real property valued by the assessors at $23.7 million).

3) SBA and FEMA issued loans and grants for uninsured losses totaling $4,005,200 and $851,600 respectively.

4) Damage to power lines was estimated at $880,000.

4. Resource Outputs and Values

1) The Hayman Fire prompted a general closure order for three Ranger Districts (Pikes Peak, South Platte, and South Park Ranger Districts) of the Pike-San Isabel National Forest. The closure order began June 10, 2002 and continued until July 19, 2002 (a small portion of the Pike-San Isabel National Forest including five camping and recreation areas were reopened July 12, 2002). Furthermore, all areas within the Hayman Fire perimeter remained closed to recreation use, at least through March 2003.

2) The closure occurred during two of the busiest visitation months. On the Pikes Peak Ranger District, the months of June and July accounted for 46 percent of all developed site visitation in CY 2000 and 45 percent in 2001. On the South Platte Ranger District, June and July accounted for 37 percent of all developed site visitation in 2000 and 43 percent in 2001, while on the South Park Ranger District, 48 percent of all developed site visitation occurred in June and July for both 2000 and 2001.

3) Pikes Peak Ranger District had the most substantial decline from 2001 levels with visitation at 77 percent of the 2001 level during the prefire months, 15 percent of 2001 during the fire months, and 28 percent during the postfire months, with total year visitation at 28 percent of 2001 levels. South Platte district had visitation at 60 percent of 2001 levels during the prefire months, 12 percent of 2001 during the fire months, 41 percent during the postfire months, and total year visitation at 31 percent. South Park district was the least affected with visitation at 89 percent of the 2001 level during the pre- fire months, 32 percent during the fire months, and 80 percent during the postfire months.

3) A comparison of visitation totals for June and July of 2002 with results from June and July of 2001 showed a decline at all sites, with 2002 visitation at 62 percent of 2001 visitation for Florissant Fossil Beds National Monument, 79 percent for Eleven-Mile State Park, and 85 percent at the Pikes Peak Cog Railway and Toll Highway

4) On all three districts, total client days were substantially lower in 2002 than 2001, with aggregated outfitter and guide use in 2002 at 75 percent of the 2001 levels. Pikes Peak district was the least affected, with 2002 client days at 86 percent of 2001 levels, while South Platte and South Park districts were more substantially affected, with 2002 levels at 60 percent and 62 percent of prior year levels, respectively.

5) A total of 331 campground reservations on the Pike-San Isabel National Forest made within the Reserve America system were cancelled between the dates of June 10, 2002 and July 19, 2002 (the dates of the general forest closure associated with the fire). About one in four of the cancelled reservations were subsequently remade within the Reserve America system. Of these new reservations, 58 percent were made to alternative locations within the State of Colorado.

6) The Girl Scouts Wagon Wheel Council (Colorado Springs) camp was within one mile of the Hayman Fire. During the summer of 2002, they experienced two evacuation orders and were shut down for three weeks. Approximately 400 campers missed camp and had their fees fully refunded. The Wagon Wheel Council estimated their total losses at $110,000.

7) The Girls Scouts Mile High Council (Denver) camp is contained within the perimeter of the Hayman Fire. The camp was closed down during the initial closure order and has plans to first reopen in May of 2003. Fire effects within the camp were relatively minor considering the proximity of the fire, and property losses were estimated at $112,000.

8) The Lost Valley Guest ranch was shut down from June 9, 2002 through September 1, 2002. The ranch operated a modest fall season at 40 percent occupancy. The owner estimated total losses associated with property damage, lost income, and fire-related expenses at $1.9 to $2.0 million. In January 2003, booking for the 2003 season was 50 percent of normal, and the owner estimates the 2003 season to be down 20 to 25 percent from typical years.

9) Total resource losses were estimated at $50.2 million for a 150,000-acre fire, which adjusted to $47 million based on the actual size of the fire. Water storage was the single most important category representing 80 percent of total resource value losses.

10) Direct recreation infrastructure losses totaled $56,500 on the Pike-San Isabel National Forest. Fee losses from reduced concessionaire revenue in 2002 were estimated at $58,000. Additionally, four recreational residences burned resulting in a loss of annual revenue to the Forest Service of $2,250.

11) One-time losses to proposed timber sales were estimated at $36,750. Annual timber losses were estimated at $62,000 to $ 65,000 with a majority of these losses coming from the personal use Christmas tree program. Total salvage value was estimated at $159,500.

Individual Experiences

Next, we turn our attention to key findings from the studies that looked at individuals and their experiences.

Woodland Park, Colorado, Case Study: Preliminary Results

1) In terms of the social impacts of the Hayman Fire as perceived by Woodland Park case study, participants stated that the most positive impact resulting from the fire was the way the community (Woodland Park and the surrounding areas) "pulled together" and helped each other out.

2) In terms of negative impacts, the negative impact on the economy of the area and on individuals as well as the loss of natural resources, were mentioned often.

3) Finally, the loss of the forest resources and physical beauty of the area was most often mentioned impact, positive or negative.

4) In terms of beliefs about the fundamental causes of the fire held by Woodland Park case study, participants generally attributed the fundamental causes to the drought and poor forest health or "lack of management". Contributing factors were high winds, lack of thinning, lack of prescribed

burning, and failure to fully utilize all firefighting resources when the fire started. Most thought that the fire was inevitable and the ignition source itself was not important, saying that if the fire hadn't been started by an individual, something else such as lightning, a tossed cigarette, or a hot catalytic converter would have started it.

5) Most participants who *did not personally incur any damage* thought that the fire had been fought effectively and that it was not controllable. On the other hand, critical comments concerning the USFS were especially common among people who personally incurred property damage or lost a home

6) Information sources used by residents during the fire included Web sites, neighbors, firefighters, public meetings, local television stations (Denver, Colorado Springs), the Red Cross, hearsay, radio scanners, and the Java Junction Coffee Shop.

7) Overall, participants thought the quality of information from the above-mentioned sources during the fire was good. The Teller County Web site was highly praised, as was the information from Java Junction.

8) Participants tended to be somewhat critical of the nightly meetings sponsored by the Forest Service, saying that the information at these meetings was, at times, "inadequate" and "outdated". Some complained that the information was delivered in an impersonal manner.

9) For opinions about relationships with the Forest Service by Woodland Park case study participants, locals appear to have generally good relationships with the Forest Service. Some mentioned that there had been some anger over the cause of the fire (i.e. its alleged ignition by a Forest Service employee), but nothing that appears to be long-lasting.

10) The inability of the Forest Service to work with private landowners on fire prevention and restoration was mentioned as a problem. One fairly persistent theme was the perceived need for the Forest Service to improve its existing working relationships with volunteer firefighters and other groups/agencies involved in fire prevention and control.

11) The Federal Emergency Management Agency (FEMA) has provided assistance for fire victims of the Hayman Fire. However, those who live in non-traditional residences such as recreational trailers or RVs (of which there were a number in the community) were not eligible to receive compensation from FEMA for the loss of their residence.

12) There was considerable frustration expressed by County officials concerning notification of the accounting rules for compensating the County for fire-related expenses, primarily because the County was not notified by FEMA until after the fact concerning the detailed information FEMA requires in order for the County to be eligible for compensation for various functions and expenses.

13) For issues pertaining to the future as perceived by Woodland Park case participants, the fire experience has clearly increased awareness of wildfires and made a potential future fire more of a reality in peoples' minds. However, most participants at the time of the interviews were not planning to take any particular actions to 'fire safe' their homes and properties against future events. Explanations for a lack of such activities range from "the damage has already been done" to the aesthetic preference for trees near their homes.

Ridgewood Homeowner's Association Study

In considering the following findings, it is important to keep in mind that the sample size used in this preliminary study is both small and nonrepresentative of the larger population of fuels reduction stakeholders who were impacted by the Hayman Fire. Future efforts funded by the National Fire Plan will extend this analysis to the broader Hayman population, as well as to the rest of the Colorado Front Range and the Forest Service's Southwestern Region (Region 3) of Arizona and New Mexico.

1) Residents perceive themselves as well informed, information that they used as very relevant, and they are very motivated to learn more about the connection between wildfire risks and undertaking defensive actions, even though they considered themselves to be 'well informed'

2) The most highly rated sources of wildfire risk information in terms of helpfulness, were the County and city fire departments and the Colorado State Forest Service. The US Forest Service, media reports, and Firewise community information were also rated as relatively helpful sources of information. Finally, friends and neighbors were rated somewhat helpful as a source of information on wildfire risks.

3) Even six months after the devastation of the Hayman Fire, residents still feel very vulnerable to the potential impact of wildfire, both personally and with regard to their possessions and property.

4) Those residents who feel highly vulnerable to the effects of wildfire are also those that consider themselves highly informed about wildfire issues. This might suggest that, despite having expertise in wildfire issues, homeowners believe that there are significant involuntary wildfire risks that influence their perceptions of vulnerability.

5) For example, when residents indicated they felt very vulnerable when they completed considerable defensible work and their neighbors did not do this work. This indicates that wildfire education is needed to address these sources of vulnerability.

6) Residents rated the likelihood of a wildfire occurring near their home at 77.9 percent. Both perceived vulnerability and risk perceptions were significantly correlated, demonstrating the strong link between residents' beliefs about vulnerability and the high probability of a wildfire event occurring.

7) Residents felt strongly that the consequences of a wildfire would be severe and very devastating. A correlation analysis reveals that perceived vulnerability and perceived severity are correlated, indicating that perhaps homeowners' perceptions of vulnerability stem from the strong beliefs that wildfires will have devastating consequences.

8) Overall, residents believed that the various Fire Safe defensible actions were effective, and they were confident in their ability to implement them, although they were less certain about their overall confidence in their ability to protect themselves from the effects of wildfire.

9) Resident's beliefs about the effectiveness of Fire Safe mitigating actions likely influenced the decision to implement these behaviors. Also, as would be expected, residents that felt confident in their ability to carry out these actions were much more willing to actually implement them.

10) There was a significant, positive correlation between the effectiveness of some fire reduction behaviors and the confidence that residents reported in engaging in these behaviors, including developing a 30-foot minimum defensible space around one's structures, planting low-growing, fire-resistive plants on one's property, making sure that one's home is easily identifiable and accessible from main roads, and clearing common areas with neighbors in the homeowner's association. Thus, residents believe that there is a strong link between the effectiveness of these actions in reducing the impact of fire and their confidence in being able to actually accomplish these actions.

11) Residents were motivated to take actions following the Hayman Fire, with 18 of 32 (57 percent) reporting having started at least one of the Fire Safe defensible strategies since the fire. Less than half of the residents, 14 of 32 (43 percent) report having completed all the respective actions prior to the fire.

12) Almost two thirds of the participants (63 percent) indicated that involuntary aspects of wildfire risk ("can't fight nature", neighbors have done nothing, and US Forest Service has done too little) influence their decision as to whether or not to undertake mitigating behaviors on their properties. This has important implications for the types of educational materials and messages that should be conveyed to homeowners in the wildland urban interface.

13) Residents feel very responsible for defending their own properties, yet there is considerable sentiment for *all* the neighbors (i.e., neighbors and agencies) to do their part as well.

14) Residents find a direct link between both their own sense of responsibility as well as the Forest Service and the HOA's responsibility for reducing risks and the degree of effectiveness of their own mitigating actions.

15) Homeowners' involuntary risk (arising from the failure of neighbors and agencies to undertake fuels reduction measures) may be one of the significant explanations for their feelings of vulnerability to the impacts and effects of wildfire.

16) A higher level of knowledge about wildfire issues is linked with a higher level of vulnerability, perhaps stemming from involuntary risks of living in a neighborhood in the wildland urban interface with very little being done by neighbors to protect residents' lands.

February 2003 Interviews with Key Informants

1) The interviews indicate that while much has gone right post fire, there remains considerable frustration with what many see as the failure of Federal agencies to take advantage of local resources.

2) Although the fire left people on edge into November and there is some anticipation that this edginess will come back once fire season starts, for most people worries about the economy, war, and drought play a more prominent role.

3) In general, the more serious physical and mental effects related to the fire were considered to mostly have played out, although there still remains a great deal of sensitivity about certain issues.

4) Assessments of the degree of economic impact were varied. At a County level the financial effect was considered to be minor. Instead, small businesses and individuals appear to have borne the brunt of negative impacts. Certain businesses, particularly those that provided food during the fire or provide local services, were seen to have emerged reasonably well while many businesses that were tourist reliant have been hard hit.

5) At the County and community level, several activities are being undertaken to be better prepared. At this level, the long-term level of exposure to wildfire and associated damages combined with availability of resources provide a good impetus for action. Most efforts are based on weaknesses identified during the Hayman Fire.

6) For instance, problems with communication have led to efforts to resolve compatibility issues that arose and to improve dependability of the communication system with establishment of more communication towers.

7) During the fire the assessor provided GIS information and aerial photos of property in the fire area to both the Incident Command and local fire departments that had proven useful and plans were underway to provide these to each fire department at the beginning of the coming fire season.

8) It was also suggested that the availability of GIS information, aerial photos, and detailed knowledge of individual property at the assessors office puts them in the best position to accurately identify as quickly as possible what property is lost to a fire. In future fires, this could hopefully minimize frustrations felt by some homeowners after the Hayman Fire who were given a seesaw of changing information as to whether their house had survived.

9) Increased use of the mulching program, where homeowners could bring cut vegetation to a central drop off point, was cited by several interviewees as evidence that much work was being done.

10) Conversely, several people had heard of homeowners who saw no incentive for putting in defensible space as they didn't care if their house burned if the land around it burned.

11) Although a great deal has been done to rehabilitate burned areas on both public and private property, there was much dissatisfaction with its implementation.

12) There were concerns by private landowners about investing a significant amount of money to prevent erosion on their land when nothing was being done on the public land above theirs. This concern parallels defensible space issues where landowners often argue that it is pointless to do any fuels management on their land if neighboring property owners do nothing.

13) Another frustration with the rehab process is related to the matching funds NRCS provides private property owners for rehab work. Private property owners were told after the fire to go ahead with needed work, to keep the receipts and they would be reimbursed for 75 percent of the total. However, legislation providing the funding was not passed until the end of September and did not include authority for retroactive payment, leaving some homeowners who from $60,000 to $100,000 to shoulder the full burden of the cost via second mortgages or credit cards.

14) Further, the May 8th cut-off of rehab funds—based on a 220 day clock from the day the agreement was signed—was seen as inappropriate given that little work can be done in the winter.

15) Frustration was also expressed about conflicting information coming from the Forest Service and the NRCS about appropriate rehab methods and the degree of damage that required rehab work. Such contradicting messages from different Federal agencies did little to inspire trust among landowners.

16) General views on the role of the Forest Service (Forest Service) varied – many felt that they had fought the fire well and done a good job with rehab while others were mistrustful of their actions: feeling that they did not do enough early on to fight the fire, not trusting that rehab was taking place, and suspicious of the continued closure of the forest.

17) Notably, there was clear respect for individual Forest Service employees yet often a critical view of the Forest Service as an agency. Individuals were cited for their professionalism, knowledge, dedication, communication skills, and willingness to stay after meetings to answer questions. However, as an agency the Forest Service was often criticized for being arrogant, disdainful of local knowledge, obfuscating, and mired in red tape. The ability

18) Much of this criticism revolved around treatment of volunteer fire departments during the fire. There was continued bitterness about the limited role that the Incident Command allowed local fire departments to have during the fire. The sense that they were being forced to stand on the sidelines while outsiders with no local knowledge took over did not go over well.

19) There was a strong sense that locals had a vested interest in stopping the fire and in protecting houses that the Forest Service did not have. Many of the destroyed houses were lost to ground fires and could have been saved had the local fire departments been allowed to remain in threatened subdivisions. In addition, it was felt that local knowledge, such as location of in holdings and terrain intelligence, could have been valuable in firefighting efforts.

20) However, there was recognition that it was not a simple situation, that many people didn't necessarily understand the complexity and danger of what they were volunteering for and that incident commanders had justifiable concerns about the training and knowledge of volunteer firefighters.

21) In addition, the red card issue was recognized and no easy solution was seen –given that most volunteer firefighters tend to be "gray haired"—it also was argued that using this as a reason to completely exclude them from helping was arrogant and foolish. The need to take advantage of what locals already know and are doing was seen as particularly important given the strong dislike for outsiders telling people what to do often found in areas prone to wildfire and efforts are being made to rebuild these relationships.

22) There has been impressive public interest in helping with postfire work and HayRAC has played a vital role as a clearinghouse for volunteer efforts. To date they have organized 48 rehabilitation days using over 3100 volunteers putting in over 22,000 hours of work. To date most of HayRAC work has been done on private land in tandem with the NRCS but this coming spring the volunteers will start working on USFS land.

23) HayRAC/CUSP's educational efforts are also important. Member's work to promote knowledge of forest health and fire management issues with everyone they have contact with—from landowners to volunteers.

24) In addition, the organization often helps mediate relations between individuals and Federal agencies by helping individuals better understand the functions and limitations of different government agencies, such as the fact that the Forest Service is not allowed to work on private land.

25) Although the organization has had no problem finding adequate labor, adequate funding has been a different issue. Last summer's difficulties with fire funding meant that the Forest Service could only provide $20,000 of a promised $100,000. During the fall the organization survived in large part on personal resources. However, when it was finally announced in December that it would soon have to close its door due to funding issues money began to come in from sources as diverse as the City of Aurora (which receives 90 percent of its water from the South Platte watershed), Phillip Morris, the National Forest Foundation, and Jimmy Buffet. In addition an MOU has been established with the Forest Service where HayRAC will be first in line for relevant excess property.

26) Another local organization that has played a significant role in facilitating local adjustment to the fire is the Forest Fire Victims Task Force. Affiliated with a pre-existing social service non-profit, the organization had the knowledge and contacts to rapidly obtain funding and community trust. Its purpose was to provide assistance to individuals who needed help but did not fit within Federal guidelines.

RMRS
ROCKY MOUNTAIN RESEARCH STATION

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals.

Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

Research Locations

Flagstaff, Arizona
Fort Collins, Colorado*
Boise, Idaho
Moscow, Idaho
Bozeman, Montana
Missoula, Montana
Lincoln, Nebraska
Reno, Nevada
Albuquerque, New Mexico
Rapid City, South Dakota
Logan, Utah
Ogden, Utah
Provo, Utah
Laramie, Wyoming

*Station Headquarters, Natural Resources Research Center, 2150 Centre Avenue, Building A, Fort Collins, CO 80526

Federal Recycling Program Printed on Recycled Paper