

Part 2: Description and Interpretations of Fire Behavior

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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 its 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

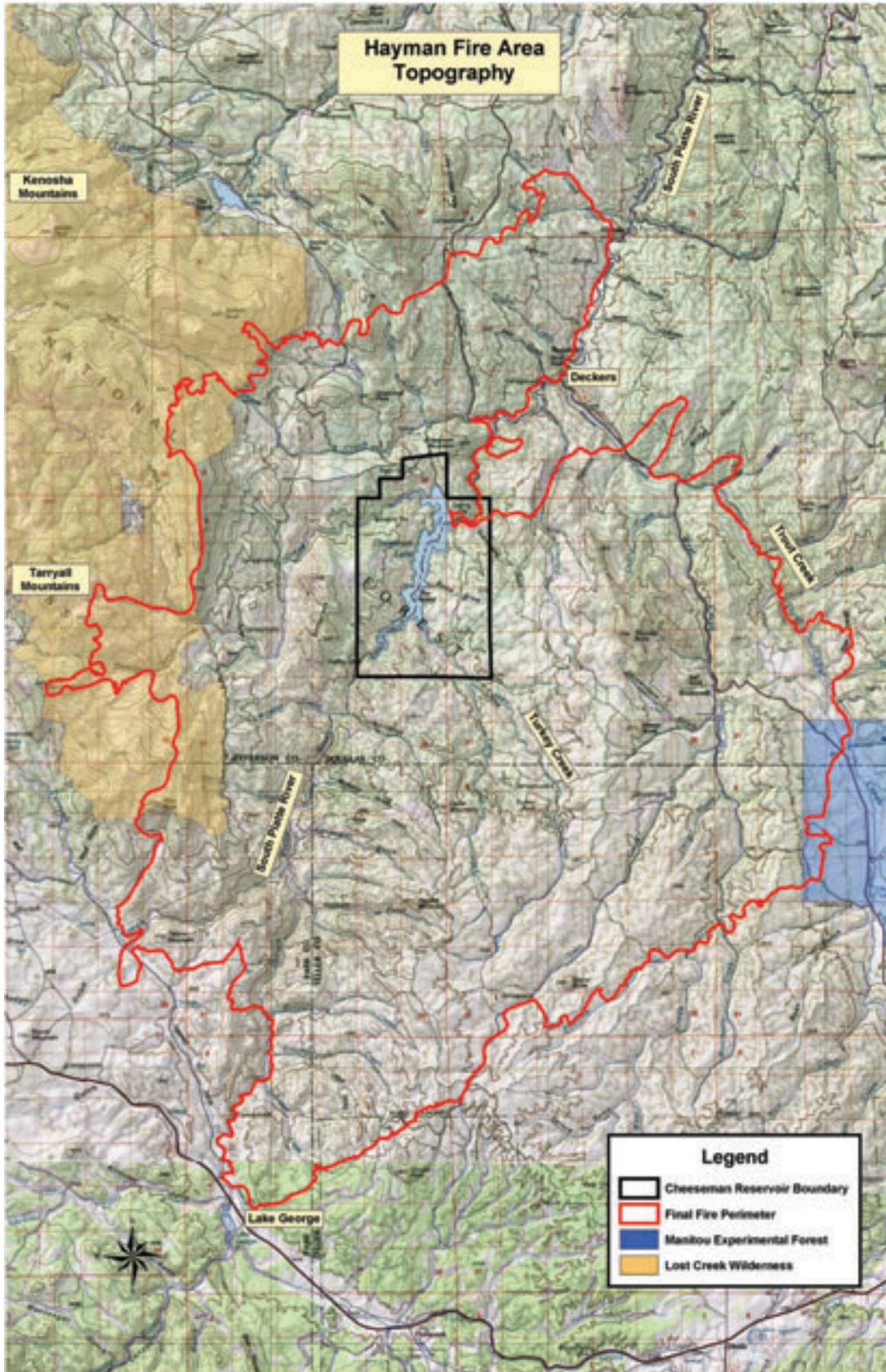


Figure 18—Topography of the Hayman Fire and surrounding landscape.

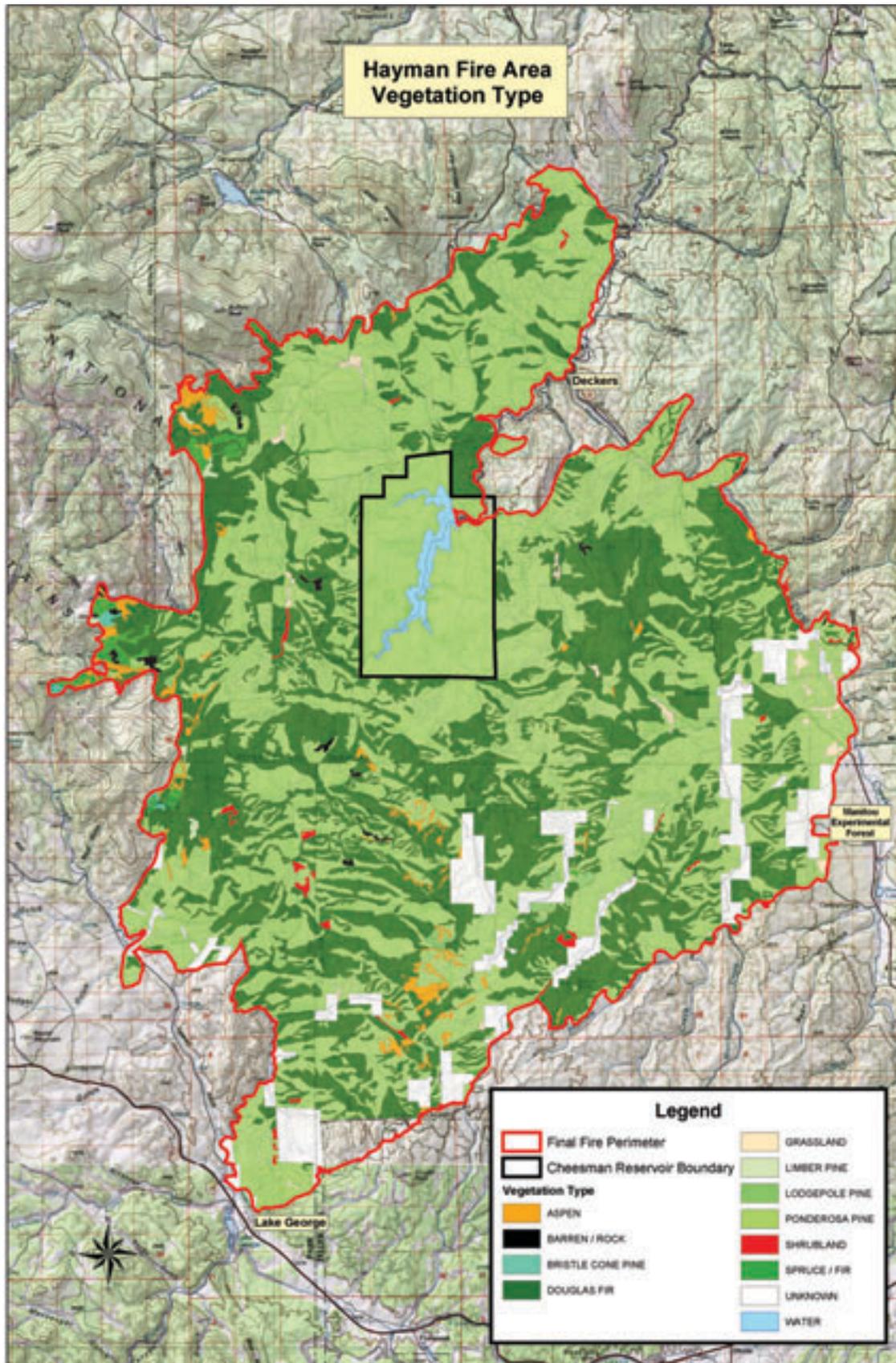


Figure 19—Vegetation classification for the Hayman Fire area.

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).

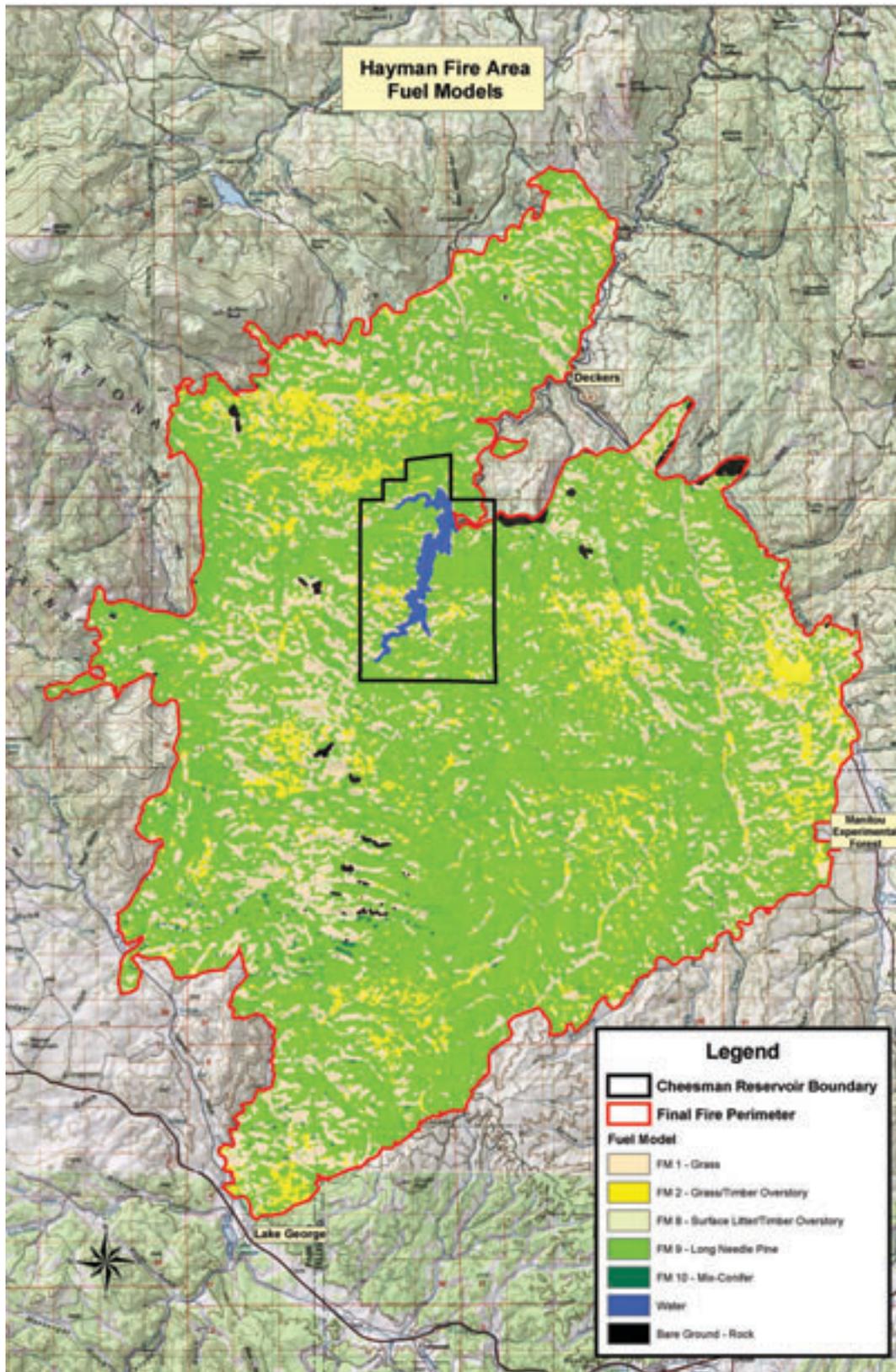


Figure 20—Fuel models assigned to the Hayman Fire area based on forest composition and structure (see appendix C for methodology).

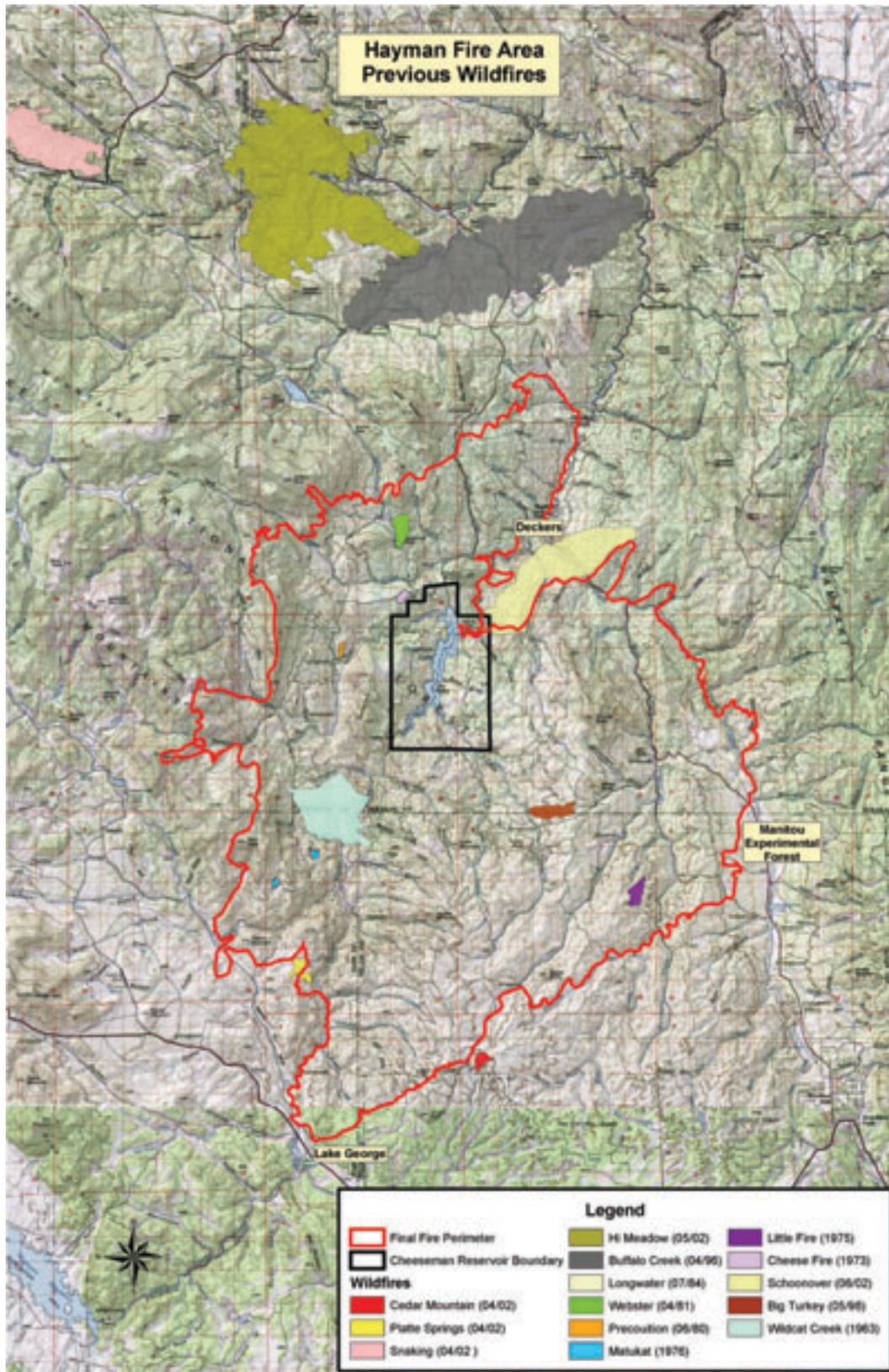


Figure 21—Recent wildland fires occurring in the area burned by the Hayman Fire and surrounding landscape.

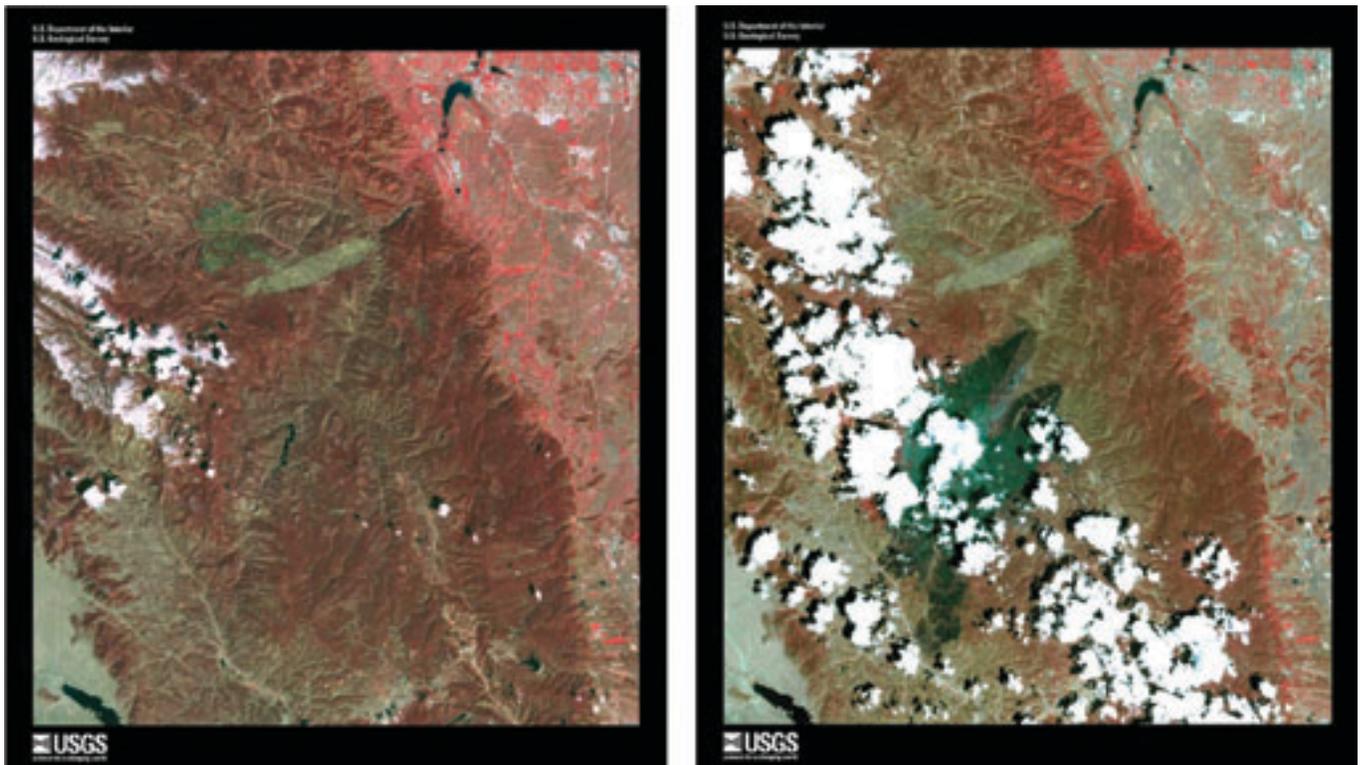


Figure 22—Comparison of false-color thermal infrared satellite imagery before and after Hayman Fire showing the continuous nature of forest cover. Severely burned areas are visible in the 1996 Buffalo Creek Fire (horizontal ellipsoid upper center) and 2000 Hi Meadows Fire (greenish area to the west of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

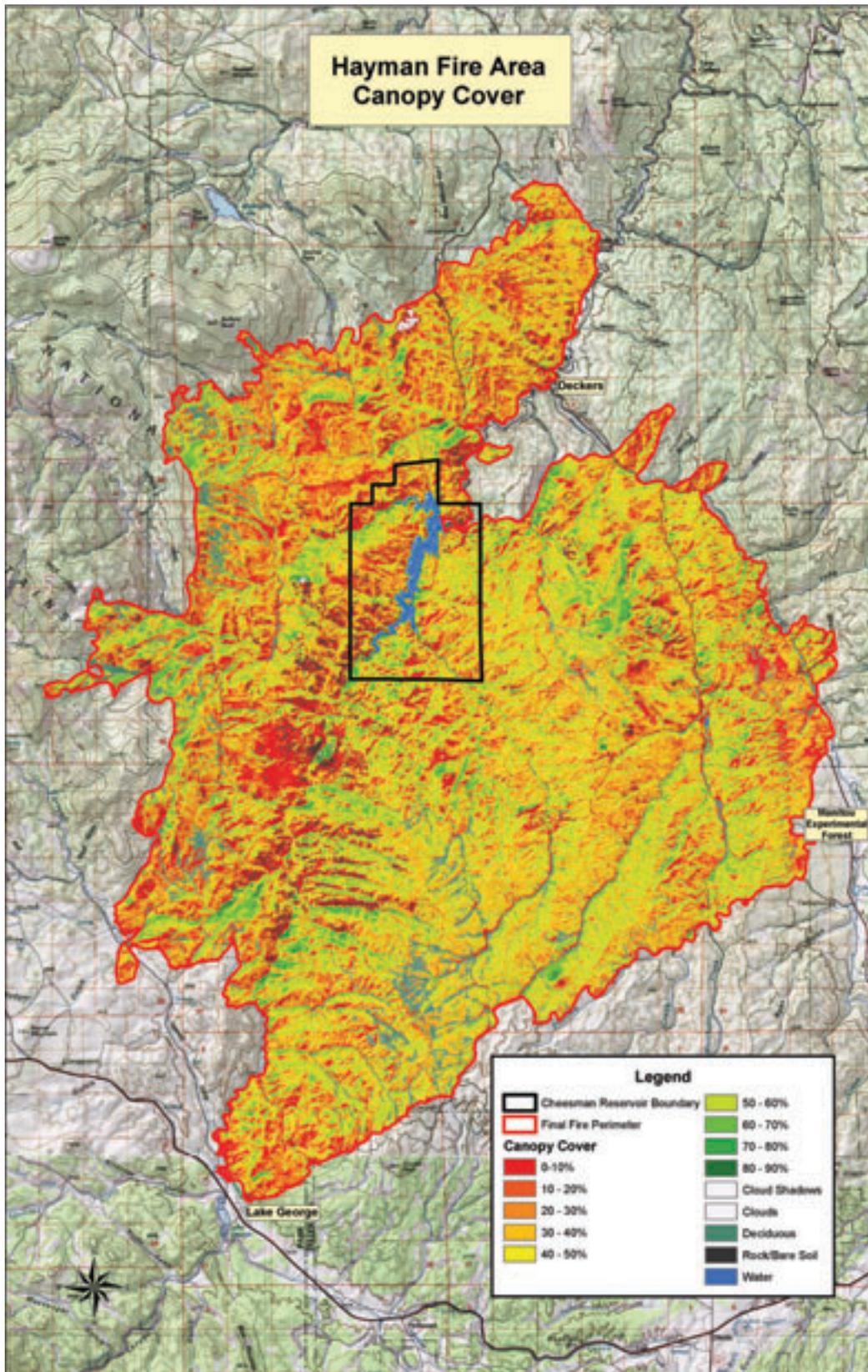


Figure 28—Canopy cover within the Hayman Fire area developed by Merrill Kaufmann from 1997 LANDSAT imagery. The open forests were found southwest of Cheesman Reservoir and burned in the 1963 Wildcat Fire (see fig. 21).



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).

Date	Lake George—8,000 ft elevation					
	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

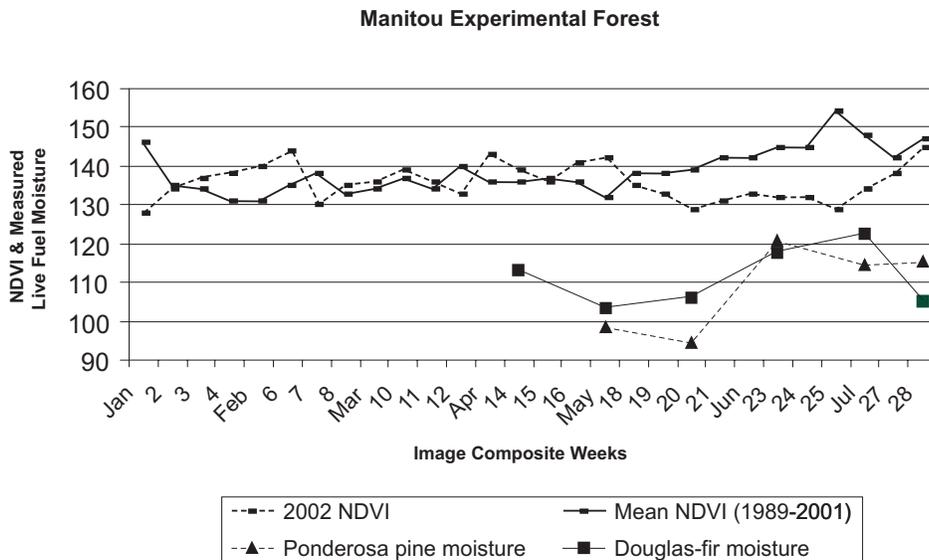


Figure 31—Comparison of 2002 live foliar moisture content sampled at Manitou Experimental Forest with (Normalized Difference Vegetation Index, NDVI) at 1km resolution. Note that samples and remotely sensed moisture content would not be expected to be identical because of different data resolution.

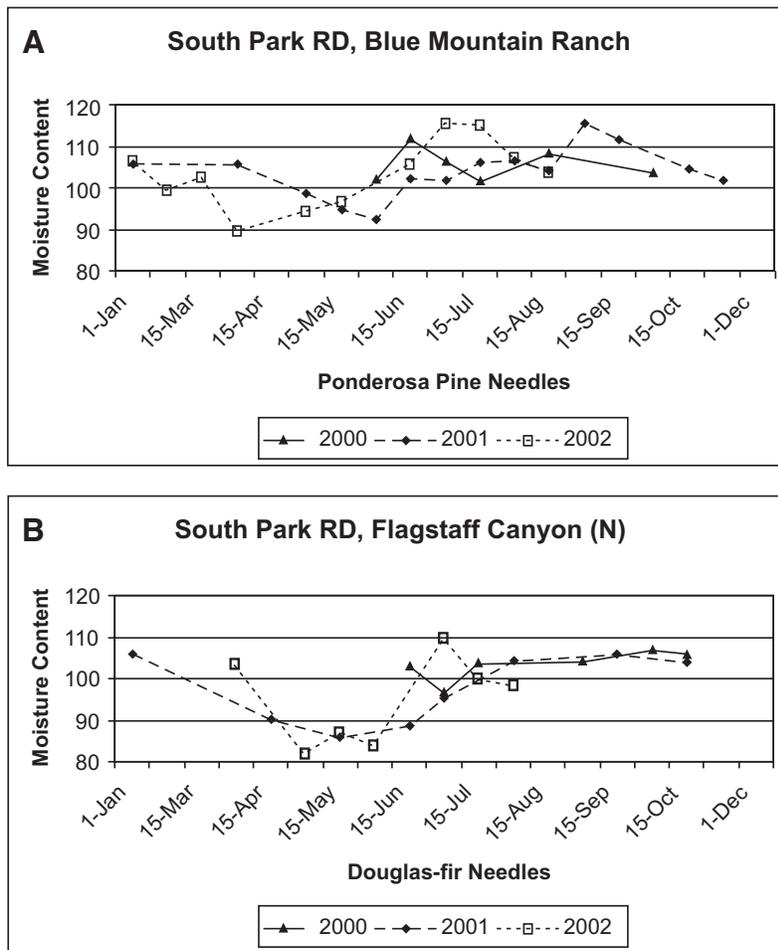


Figure 32—Comparison of moisture content of live foliage fuel samples among the past 3 years from along South Park Road at (A) Blue Mountain Ranch, and (B) FlagStaff Canyon.

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

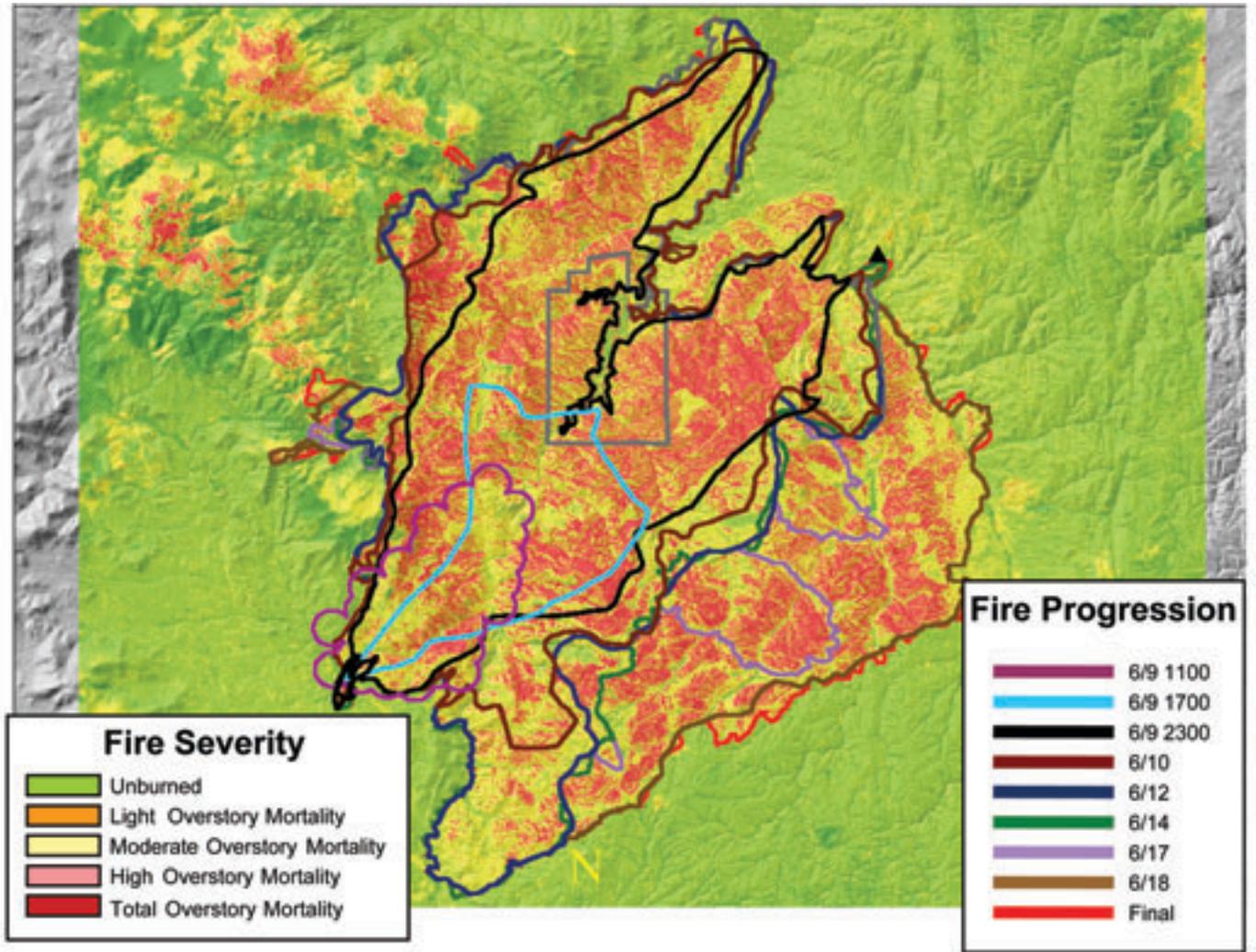


Figure 33—Fire progression map as corrected for perimeter precision and dates and times overlaid with burn severity data (Difference-Normalized Burn Ratio, DNBR) from USGS (http://edc2.usgs.gov/fsp/severity/fire_main.asp). Note that not all days are present because imprecisely mapped perimeters on slow-growth 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

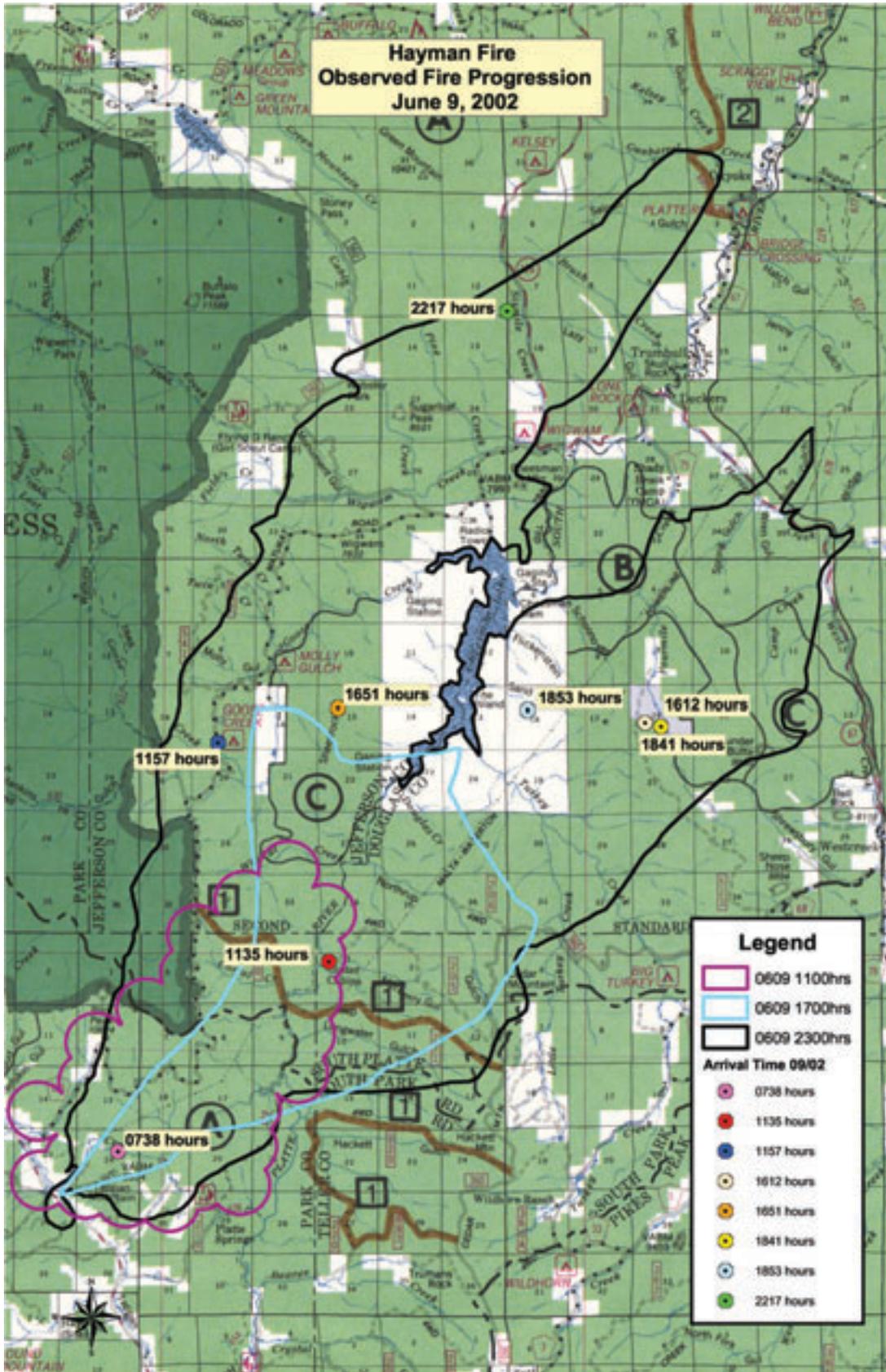


Figure 34—Fire progression map for June 9 showing observed fire locations for comparison.



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



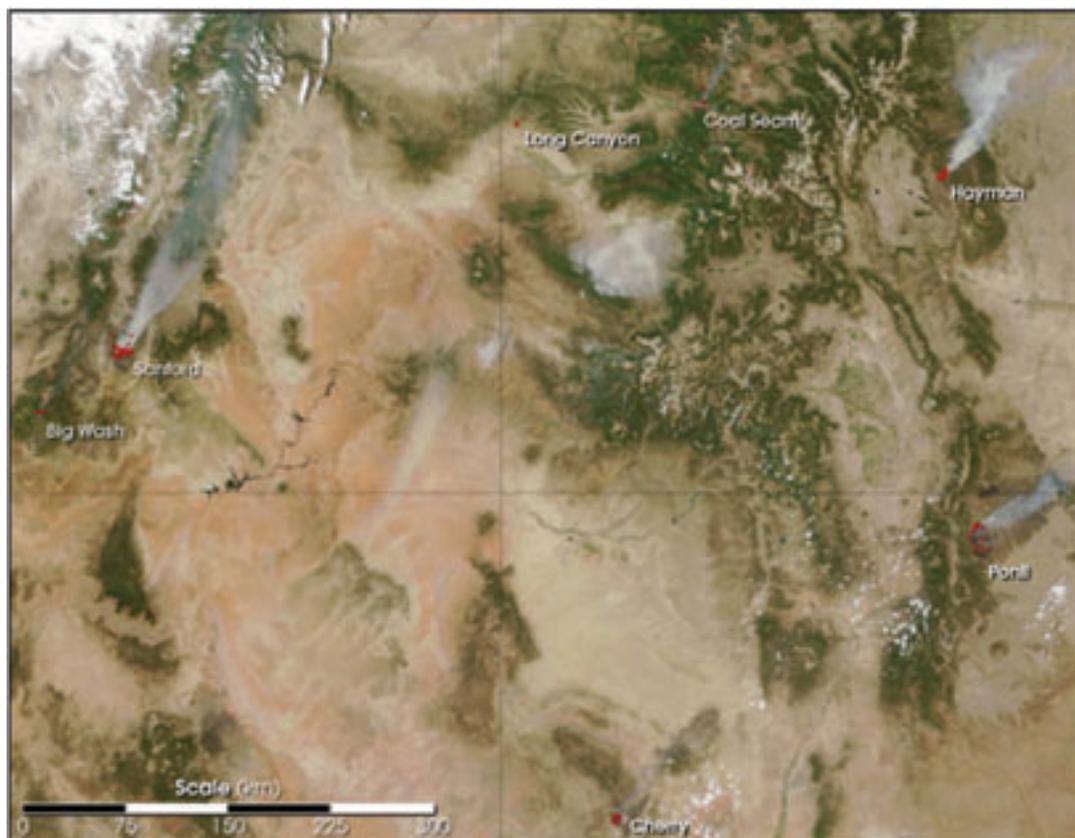
Figure 39—A convection column developed early on June 9 because of the extreme weather conditions (winds sustained at 20+ mph with humidity about 8 percent).

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.

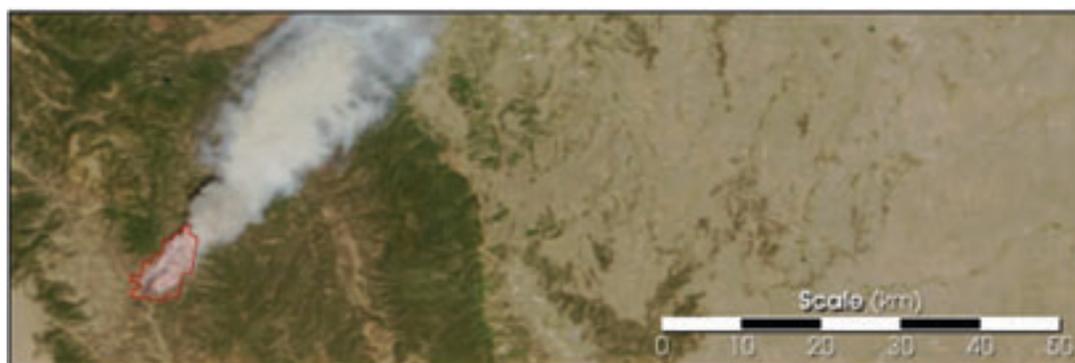
June 9: The upper level low pressure system that established in the northwest moved southeast over Idaho (fig. 12). This strengthened the upper-level flow over the Rocky Mountain front, producing a subsiding airmass and forcing dry and warm upper air toward the ground surface. Humidity remained between 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



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Hayman Fire Detail

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 wildfire (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)

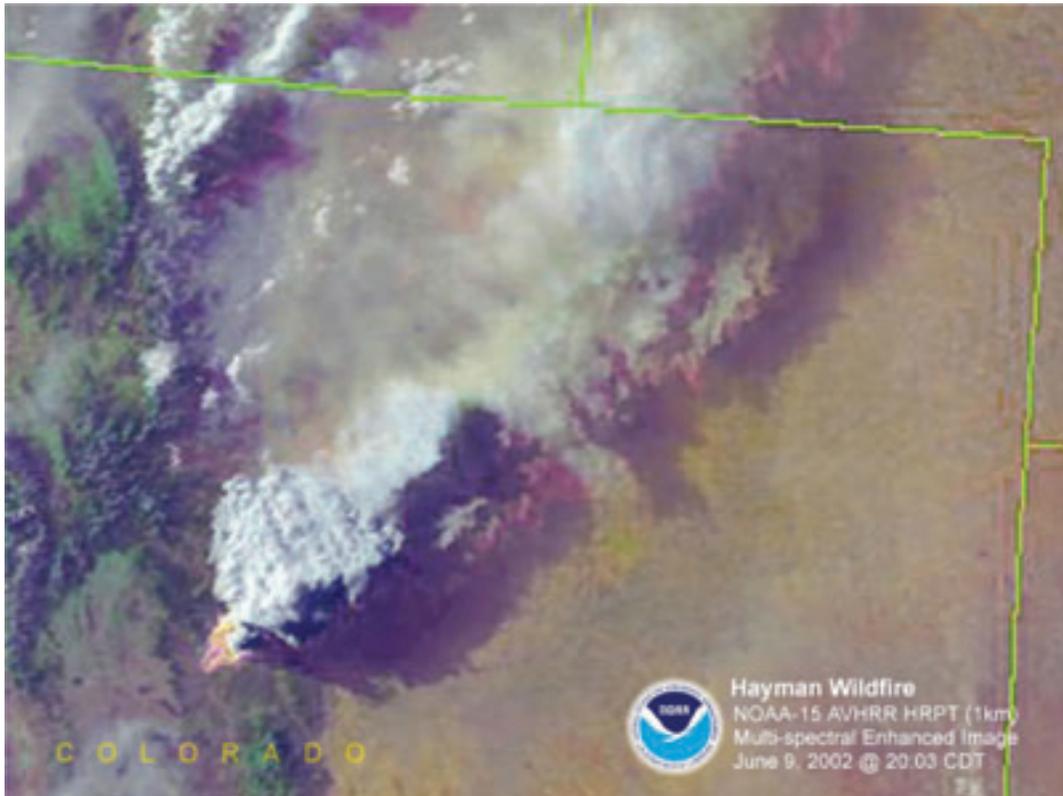


Figure 42—Satellite image of Hayman Fire at 1903 hrs on June 9 shows convection column and smoke plume extending across Denver into Wyoming.

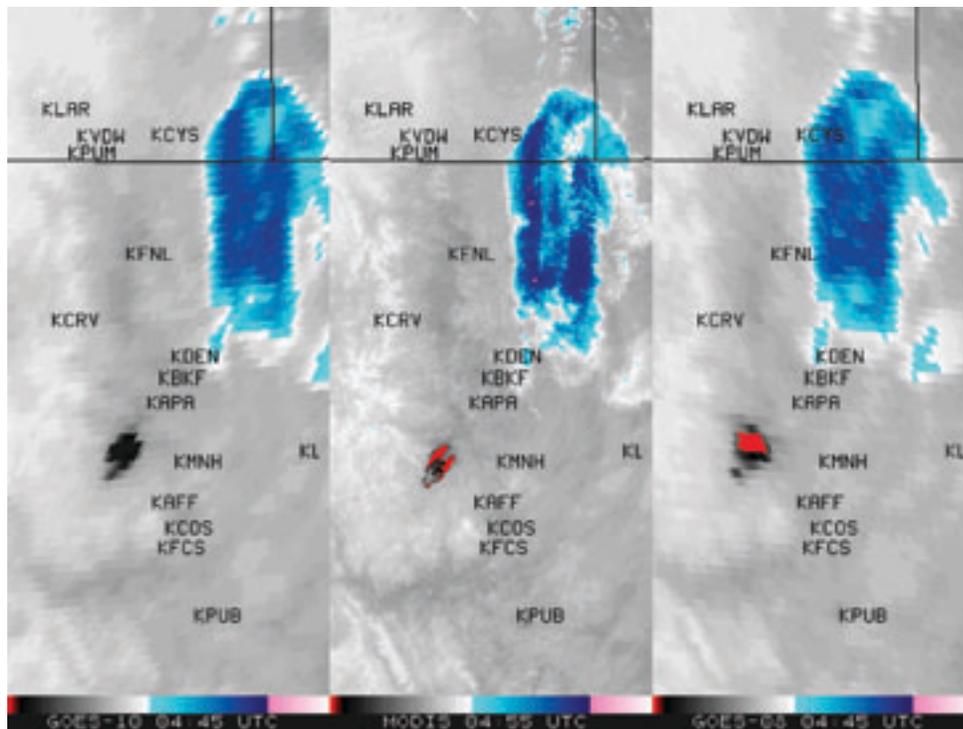


Figure 43—Thermal signature from MODIS satellite imagery (center) clearly shows forked shape of Hayman Fire at approximately 2300 hrs on June 9 that resulted from the presence of Cheesman Reservoir and the Schoonover fire (see fig. 34).

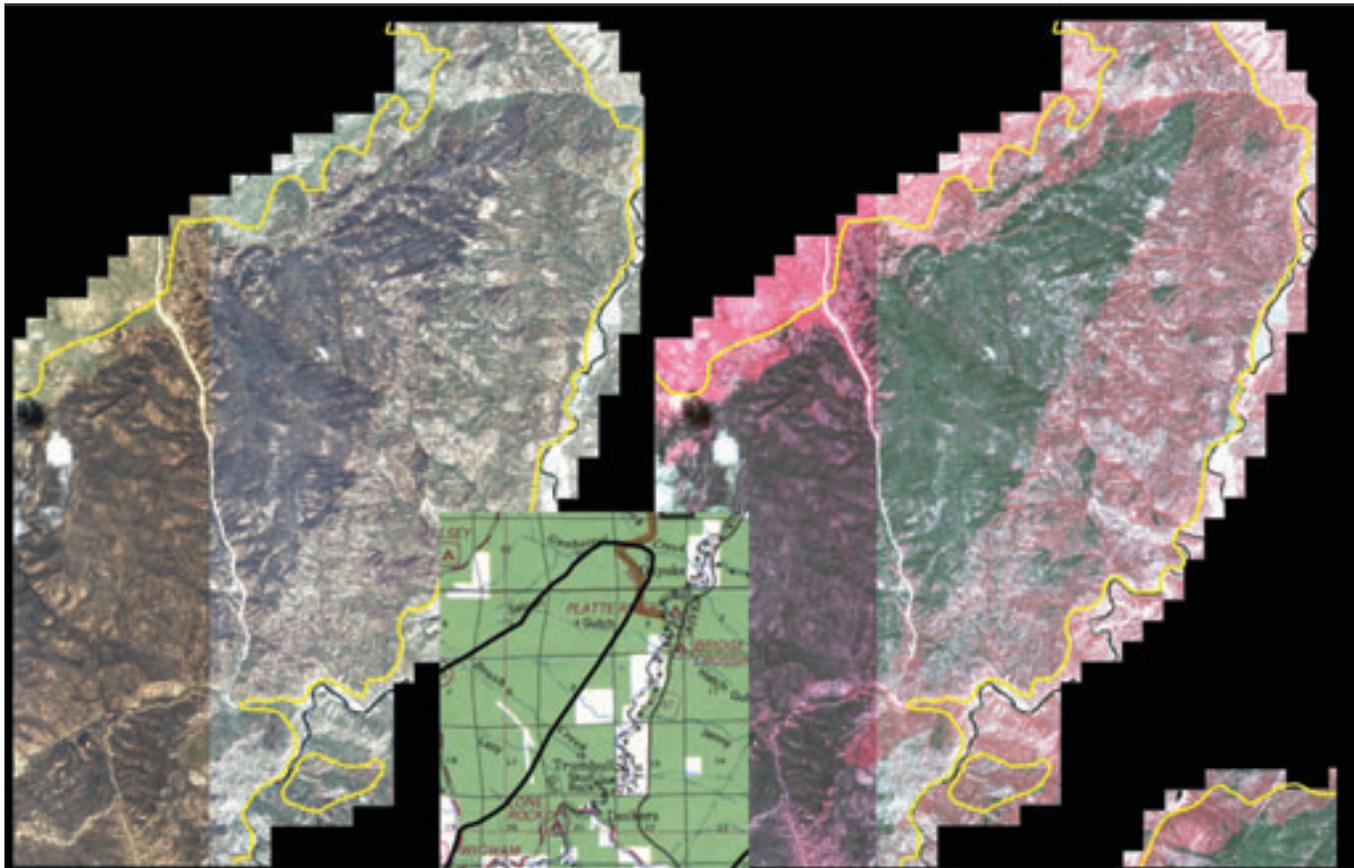


Figure 44—Satellite images of the “arrowhead” severity pattern at the north end of the western head of the fire. Fire severity is more difficult to differentiate in the visible image (left) than the false color infrared image that depicts live plant tissues as pink. This burned toward the end of the 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 threshold 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

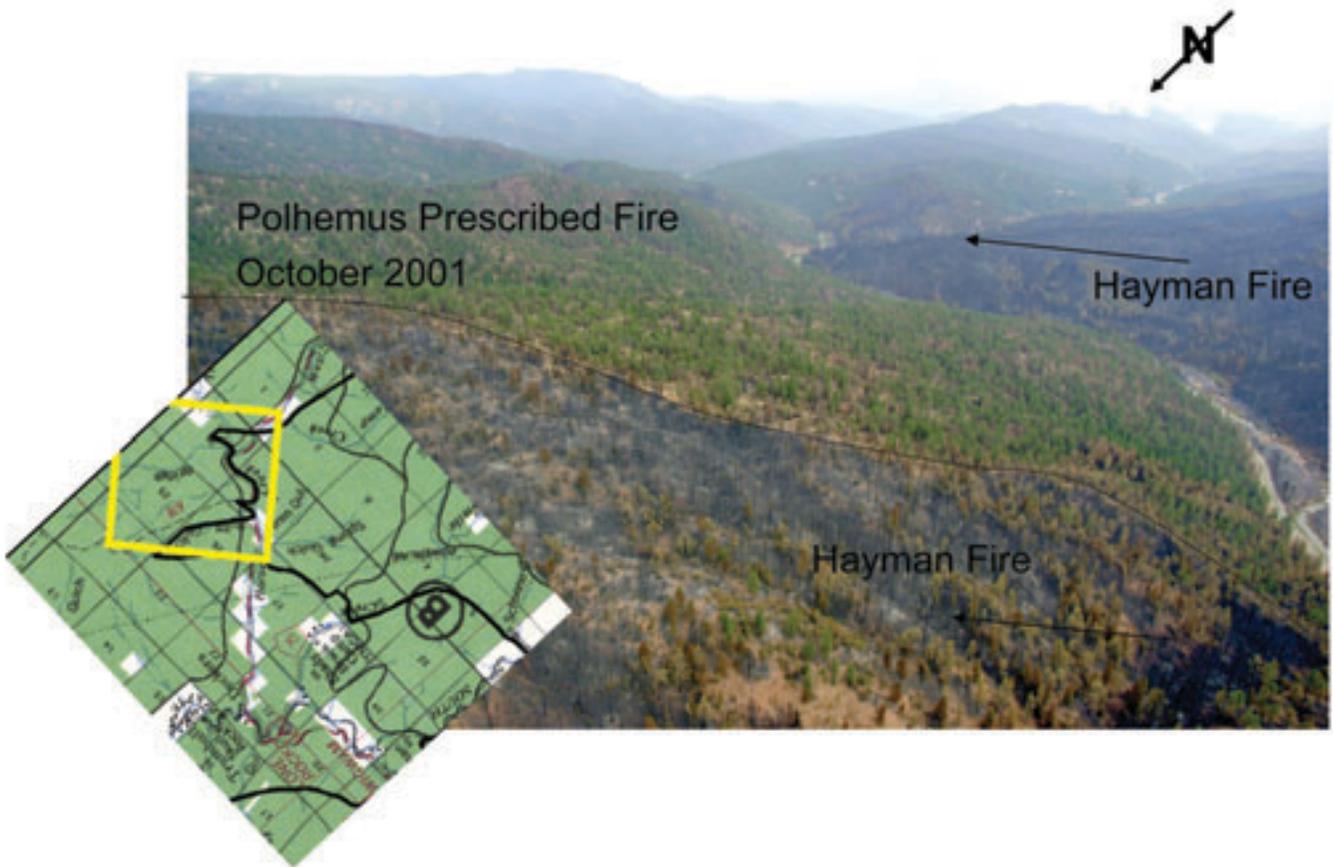


Figure 47—Photograph of border of the Polhemus (fall 2001) prescribed burn and the Hayman Fire. The Hayman Fire moved from the southwest (right side) and did not burn into the Polhemus prescribed fire unit (green) but burned as an intense surface fire and crown fire in the adjacent area on the same slope.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

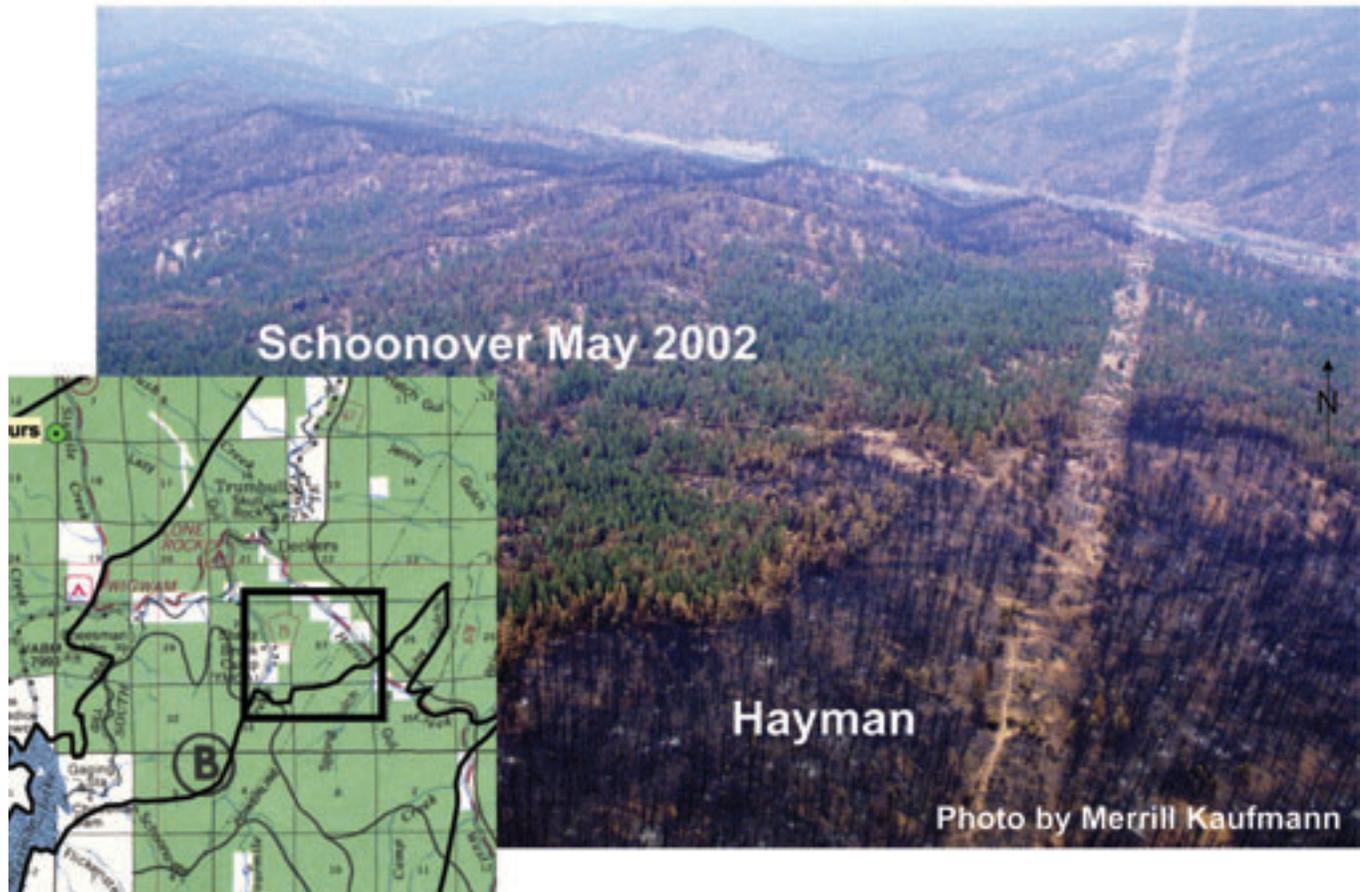


Figure 49—Green strip of underburned forest divides the Hayman Fire (left) and Schoonover wildfire (May 2002, right). The green strip was underburned by the Schoonover fire 3 weeks before the Hayman Fire occurred and was not reburned by the Hayman Fire. Note the power line corridor in the picture and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

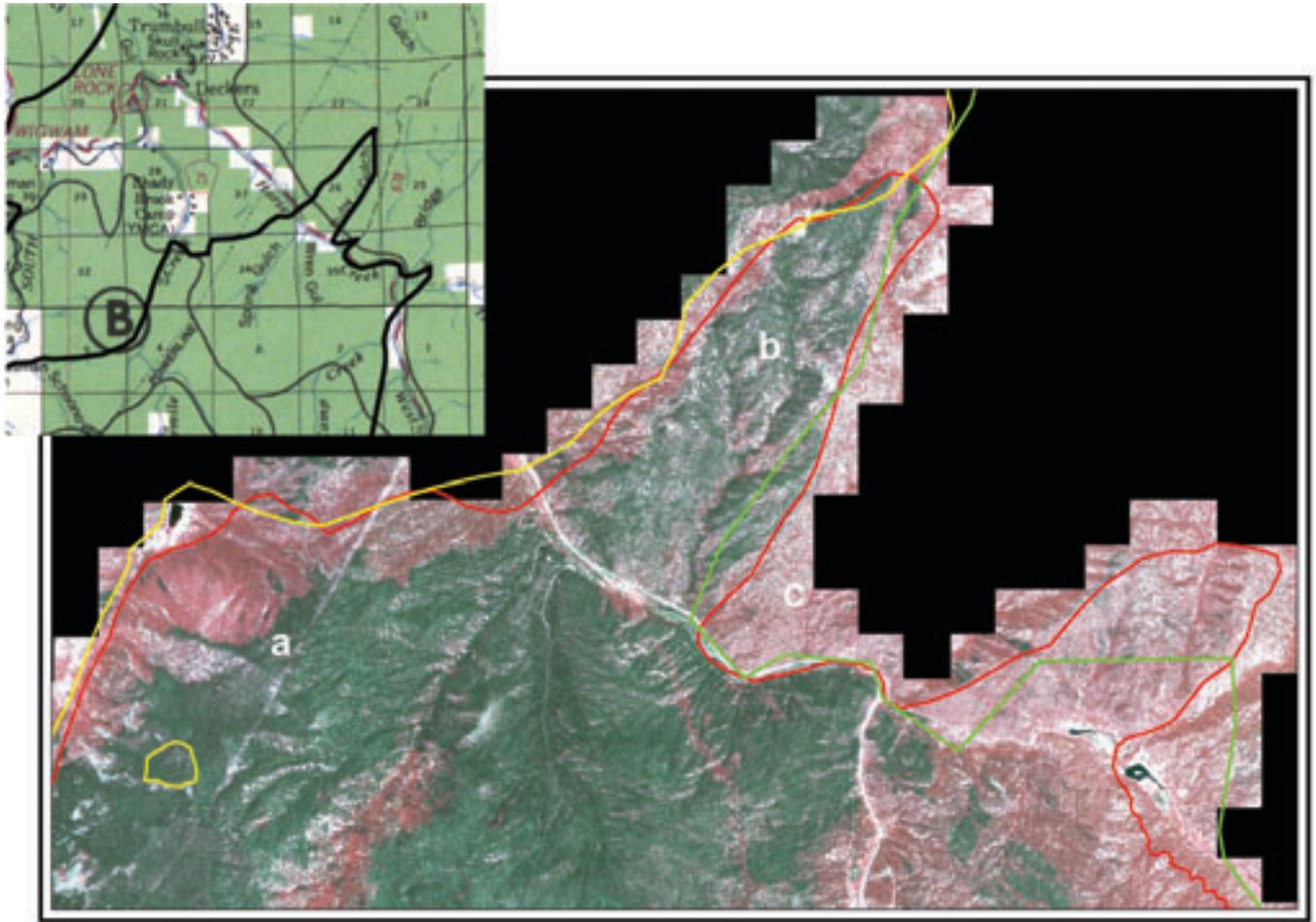


Figure 50—False-color infrared satellite image (IONOS, Space Imaging Inc.) shows consumed forest canopy (black) inside Hayman Fire (a) and (b) compared to live forest canopy (pink) in adjacent Schoonover wildfire, left of (a) and (b), and the Polhemus prescribed burn (c). Fire perimeters mapped for the 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.

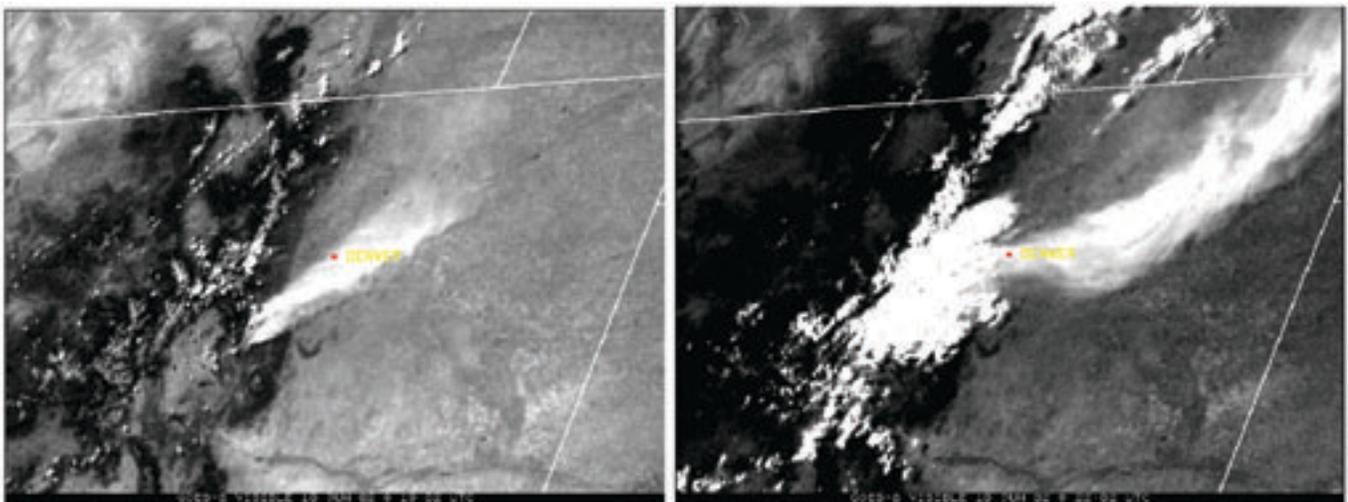


Figure 52—Two satellite images show effects of the arrival of the cold front at about 1400 hrs on June 10. (A) before cold front fire was building two convection columns (1300 hrs). (B) after cold front passage cumulus clouds formed over Front Range and wind shift distorted smoke plume trajectory.

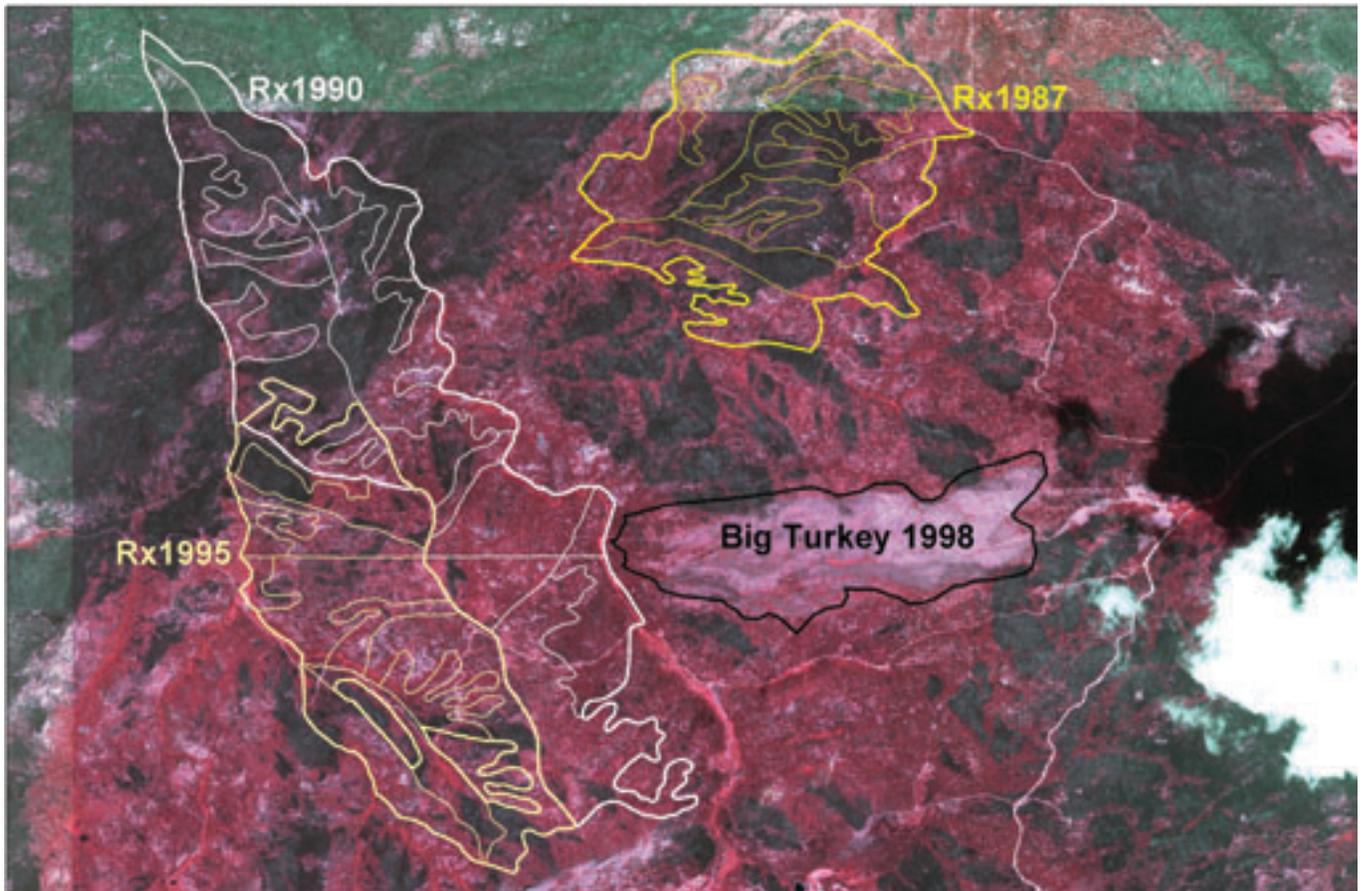


Figure 53—False-color infrared satellite imagery (IKONOS, Space Imaging Inc.) shows fire severity patterns within the Turkey prescribed burns (1987, 1990, and 1995). Pink areas are live vegetation compared to dark burned areas. Stand boundaries are delineated within treatment units and suggested that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

cally 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).

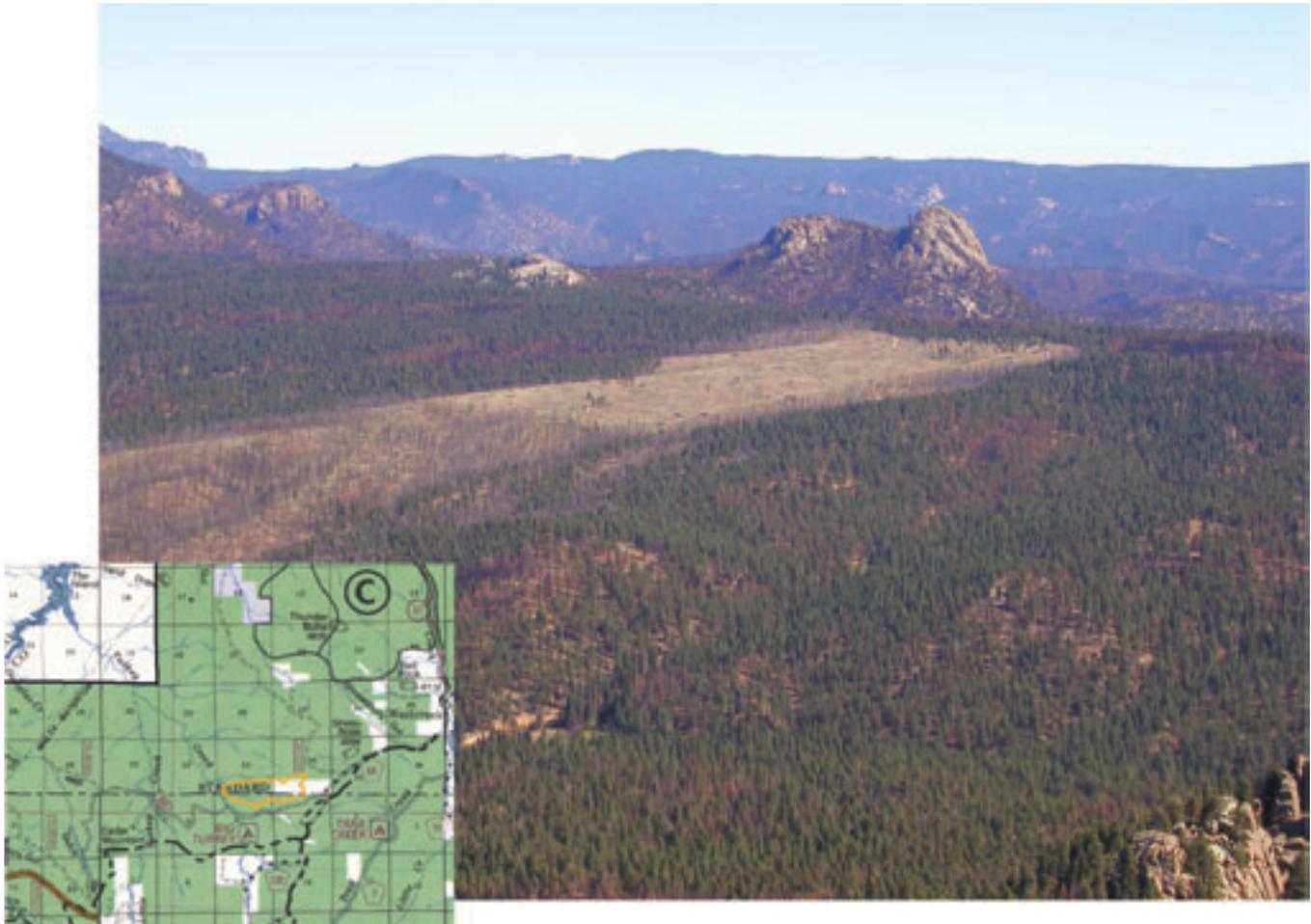


Figure 54—Oblique view of area burned by the Big Turkey wildfire (1998) looking northeast. Area in the foreground was inside the prescribed fire unit Turkey 1990. This area was burned between June 10 and June 13. (Photo by Rick Stratton)

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

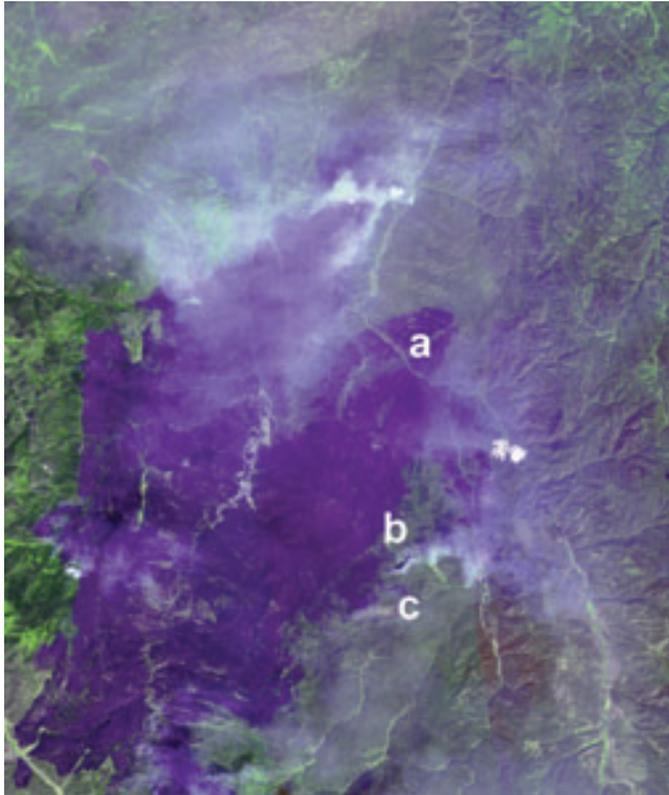


Figure 55—Satellite imagery showing burned area within the Hayman Fire on June 13. Several points are visible, (a) green strip separating the Schoonover wildfire on the north (May 2002) from the Hayman Fire on the south, (b) the green diagonal strip indicating the edge of the fire at the end of the June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

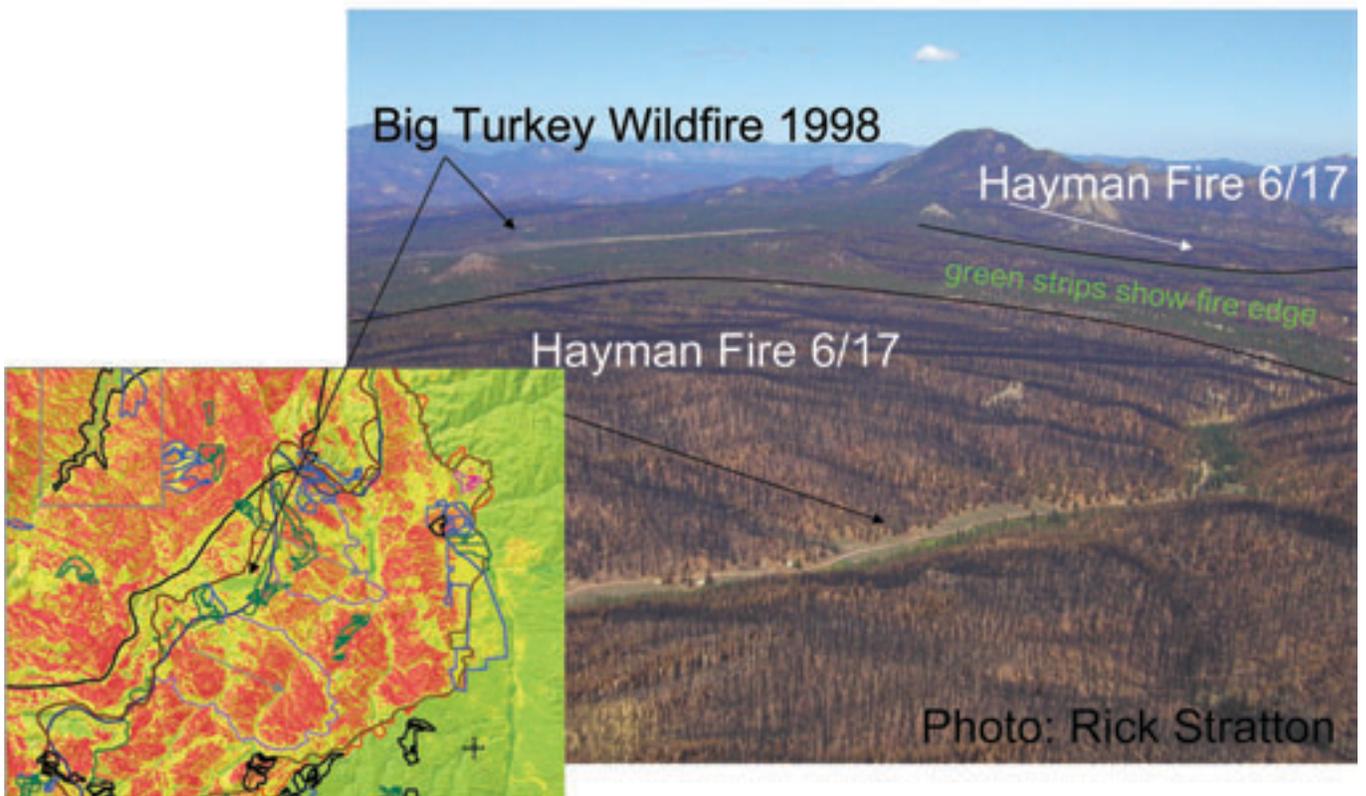


Figure 56—Oblique photograph showing the green bands of conifer forest at the locations where the two heads of the fire stopped after the burning period on June 17. Note that these heads originated from the north and south of the Big Turkey wildfire and adjacent prescribed burns (Rx1990, Rx1995). (Photo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

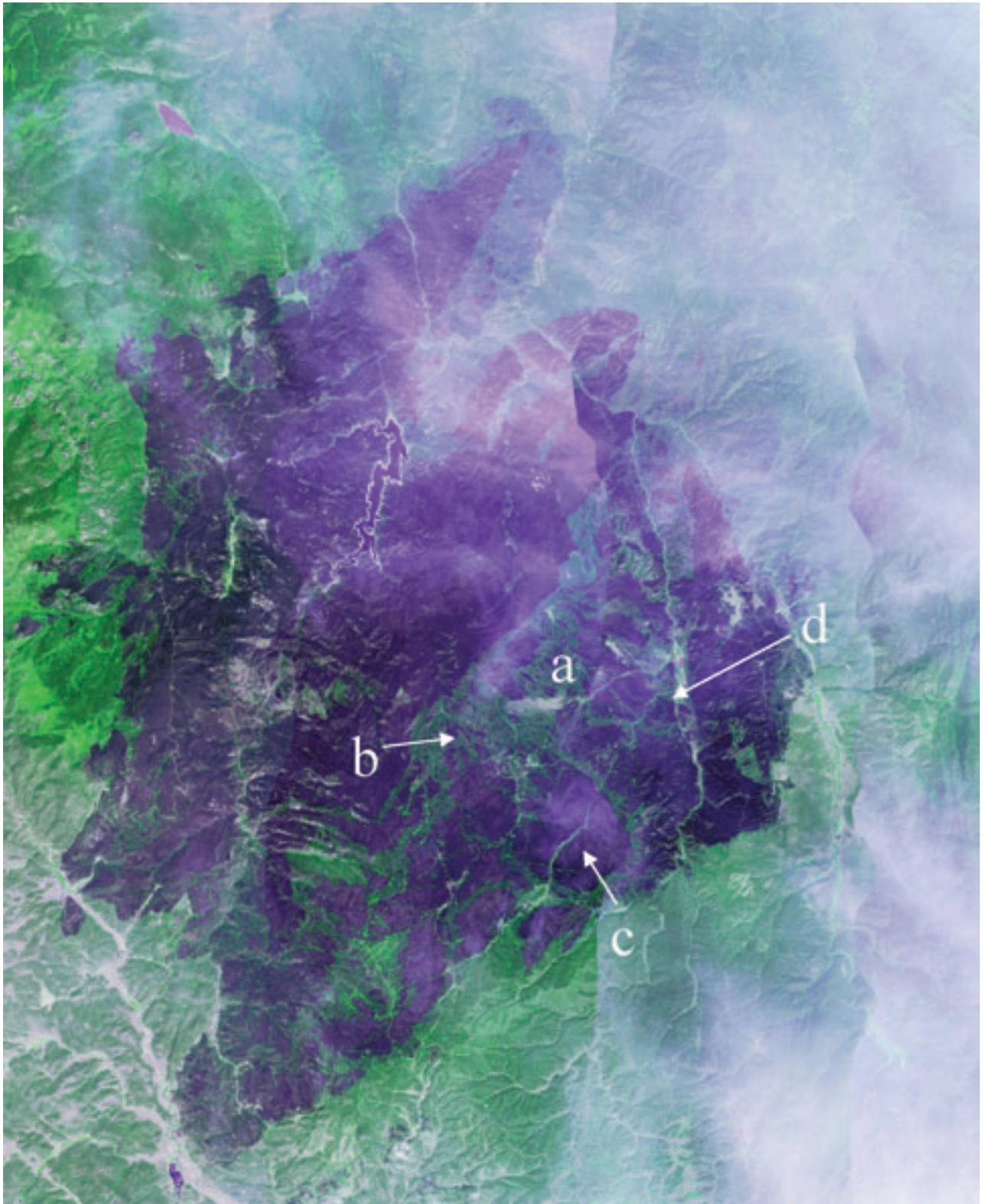


Figure 58—Satellite imagery showing burn pattern of the Hayman Fire on June 20. Several features are well illustrated: (a) the Big Turkey wildfire (1998), (b) the origin of the southern major crown fire run on June 17 in untreated fuels south of the Turkey 1995 prescribed burn, (c) the area burned by 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.