Fourmile Canyon Fire Preliminary Findings

U.S. Department of Agriculture Forest Service
Rocky Mountain Research Station
Revised October 12, 2011

Fourmile Canyon Fire Assessment Team

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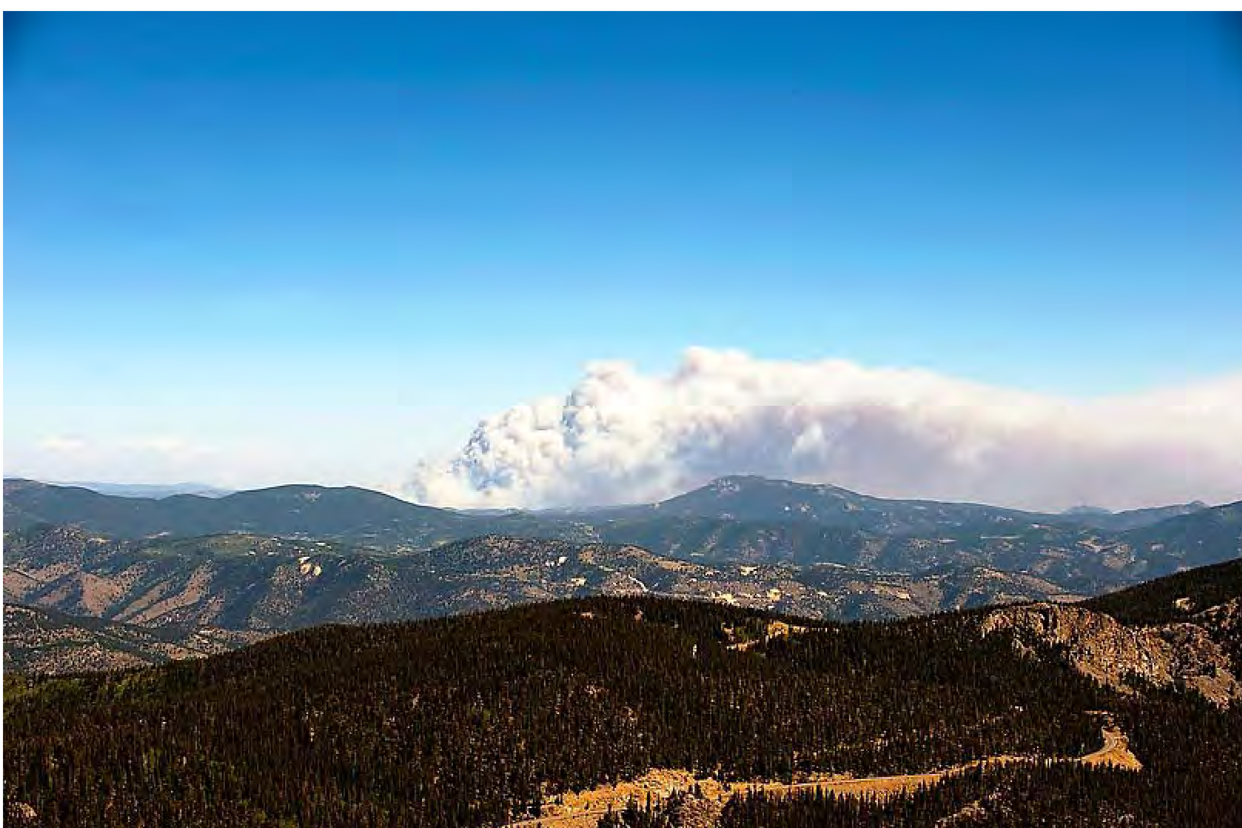

Photo Credit: John Leyba, Denver Post

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This document summarizes the preliminary findings of the Rocky Mountain Research Station Team chartered to assess the Fourmile Canyon Fire. These findings are subject to refinement and change as the Team completes its work.

Introduction

Wildfires are a common occurrence on the Front Range Mountains of Colorado. The fire return intervals in the ponderosa pine forests adjoining the prairie in eastern Colorado historically were in the range of every 5 to 10 years, and currently such fires are aggressively suppressed (Figure 1). Nevertheless, many large fires have burned along the Front Range in the past 30 years as exemplified by the Black Tiger Fire in 1989 and the Hayman Fire in 2002 (Figure 2). Large fires burn under high winds and low relative humidity common to the Front Range of Colorado, when suppression efforts are ineffective. The weather for summer of 2010 along the Front Range was not that abnormal. However, August had above normal temperatures and below normal rain fall and by September the area was in a short-term drought. As such, the fine dead fuels in the ponderosa pine/ juniper and Douglas-fir/ponderosa pine forests west of Boulder, Colorado were dry. Live fuel (trees, grasses, shrubs) moistures were at or just below normal for the time of year. Leaf fall and curing of grasses were following their normal patterns and no vegetative killing frost had occurred by the time of the fire. Down slope winds, a common occurrence in early September along the Front Range, were blowing steadily in the range of 10 to 20 miles per hour with gusts often exceeding 40 miles per hour. On September 6, at 10:02 a 911 call reported a fire burning in the lower portion of Emerson Gulch near where it intersects with Fourmile Canyon Drive. Within six miles of Boulder, the Fourmile Canyon Fire destroyed more homes than any other wildfire in Colorado's history.

Being located near Boulder, the area where the fire burned contained many homes, businesses, and prized recreational lands. Because of these values and the 3,500 residents evacuated from the area, the fire was the nation's top priority at the time. The fire spread conditions of the Fourmile Canyon Fire were very similar to those experienced by the Black Tiger Fire in 1989 and the Hayman Fire in 2002. How it burned, the damage it caused, and how people and agencies respond to such emergencies can reinforce the conclusions of the Black Tiger Fire Case Study (NFPA 1989) and the Hayman Fire Case Study (Graham 2003) that should help prepare for the next wildfire on the Front Range. As such, Senator Mark Udall suggested to Secretary of Agriculture Vilsack and Governor Ritter, that the U.S. Forest Service and the Colorado State Forest Service review the fire to explore these issues as to inform future decisions (Appendix A). The Rocky Mountain Region, in collaboration with the Rocky Mountain Research Station and the Colorado State Forest Service, agreed to assess the Fourmile Canyon Fire. In accordance

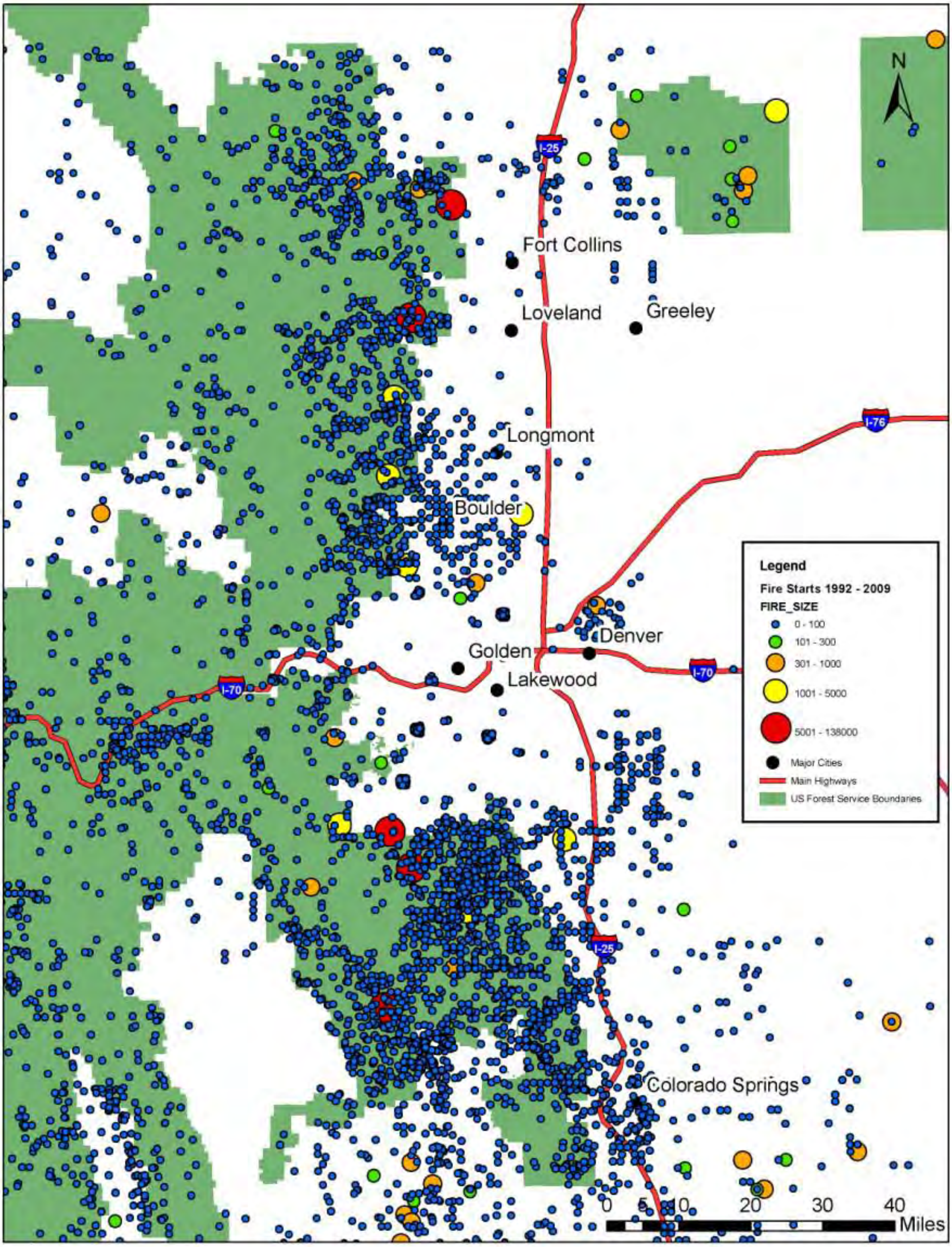


Figure 1. Wildfire history of the Colorado Front Range from 1992 to 2009 expressed as fire start locations by final fire size (see figure 2).

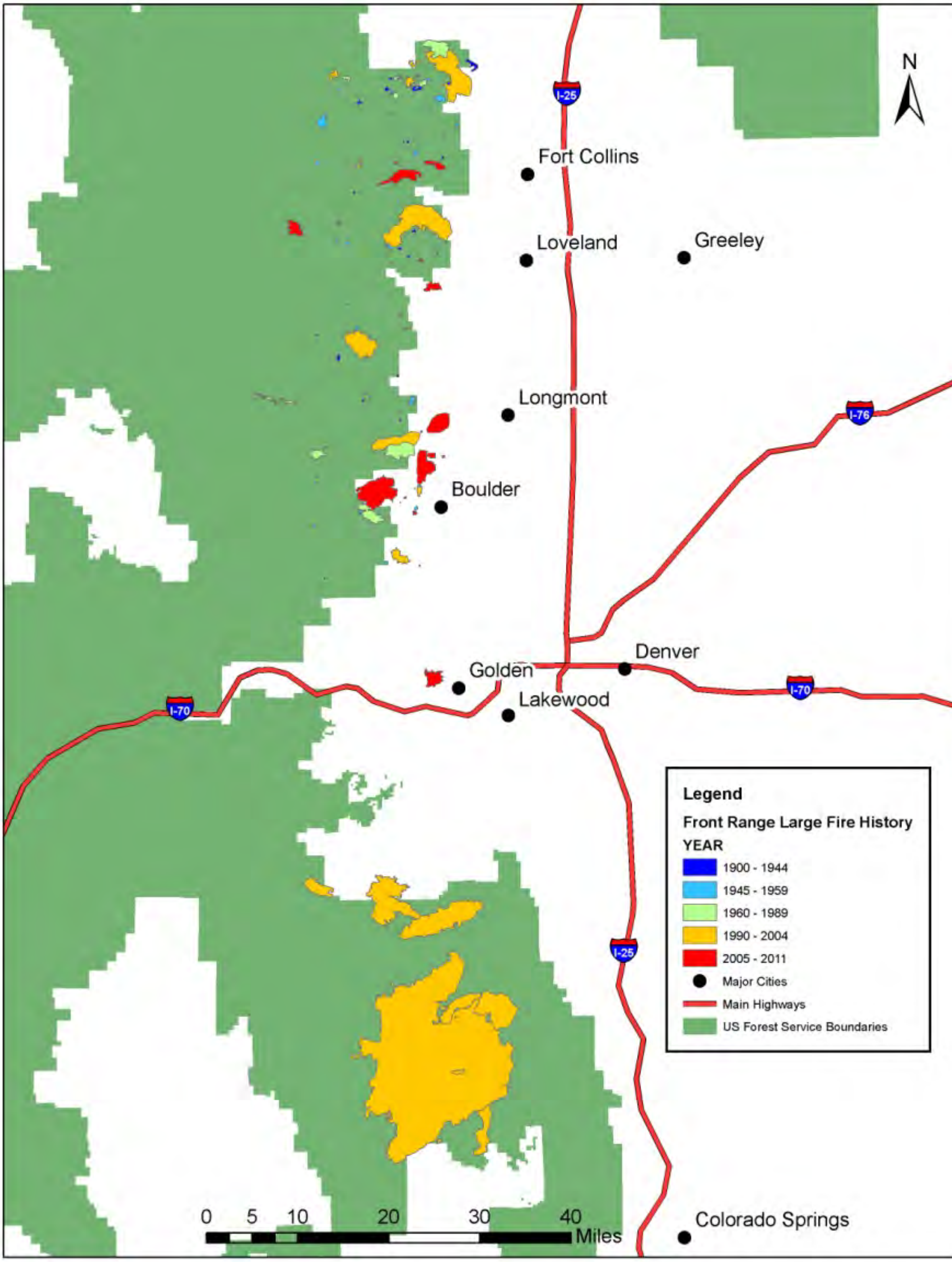


Figure 2. Burned areas of fires by time period. Note that the completeness of spatial fire records is not consistent among agencies responsible for fire suppression and reporting (e.g. Federal, State, County etc.); non-Federal lands tend to show fewer fires because State and County records are not available (see figure 1).

with the Federal Advisory Committee Act (FACA), the Rocky Mountain Research Station assembled a team to assess the fire and this document is a summary of their preliminary findings subject to change and refinement as the assessment process is finalized. At that time the methods, results, and conclusions will be peer reviewed to meet the quality standards of Forest Service Research and Development and will be subsequently published by the Rocky Mountain Research Station.

Methods

Due to limited resources, the Assessment Team made minimal visits to the Fourmile Canyon Fire during and immediately after the fire. However, meteorological, remotely sensed and geospatial data were readily available post-fire and became an important part of the data collected by the Team. A key limitation to these types of reviews is that very little firsthand knowledge of the fire can be gathered so post-fire forensic, interviews, and remotely sensed data dominate. By March, the Team was able to begin in earnest gathering data, which compared to other fires we have assessed, are abundant. We not only gathered data but we filtered it for relevance and validity. Team visits to fire area equaled a total of 60 person days.

Data Collection

Our data collection includes, but was not limited to:

- On site, telephone, letter, and e-mail interviews
    - Colorado State Forest Service
    - U. S. Forest Service
    - Bureau of Land Management
    - Fire Protection Districts
    - Boulder County Parks and Open Space
    - Boulder County Sheriff's Department
    - Boulder County Fourmile Canyon Fire Recovery staff
    - Boulder County Assessor's Office
    - Incident Management Teams
    - Firefighters
    - Rocky Mountain Insurance Information Association

- Remote sensing geospatial information
    - Color infrared satellite imagery
    - Burn severity mapping
    - Photography
    - Home locations

- Media: pictures and videos
    - Denver television
    - Denver news papers

- Law-enforcement and fire department dispatch transcripts

- Boulder County Assessor's Office
  - Valuation
  - Home loss

Physical Setting

The Fourmile Canyon Fire burned along the northern Front Range of the Rocky Mountains approximately six miles west of Boulder, Colorado (Figure 3). The fire burned in an area with rugged and complex topography with elevations ranging from 5,361 to 9,348 feet (Figure 4). Prominent topographic features in the area include: Emancipation Hill, Monument Hill, Bald Mountain, Sugarloaf Mountain, Big Horn Point, and Big Horn Mountain. Fourmile Creek and Gold Run Creek are major drainages within the fire area. Fourmile Creek runs west to east and then turns to the southeast as Gold Run Creek enters from the northwest (Figure 4). Narrow (~< 100 foot) riparian areas are typical along many of the streams. These primary and other drainages in the area contain many steep side slopes with some exceeding 98% or nearly 45 degrees. All (i.e., north, east, west, south) slope aspects are represented in the area where the fire burned. However, long expanses of steep southerly slopes are frequent.

For the most part, the soils in the area are derived from metamorphic and igneous rocks. Along with the steep side slopes many rock outcrops and granitic intrusions occur in the area. These and other parent materials in the area give rise to coarse textured and sandy soils that are poorly developed, shallow, and well drained (USDA-NRCS 2008).

A continental climate typifies the area where the fire burned. An average of 18.7 inches of precipitation falls each year and the mean annual temperature is 51.3^{o} F with a mean annual summer temperature of 70.1^{o} F (Boulder Station 050848, 1893-2010, Western Regional Climate Center). Precipitation occurs primarily during the winter and spring, with the peak precipitation occurring during April and May. Weather patterns during the fire season along the Front Range of Colorado are often punctuated by warm (~ 80^{o} F), dry (~< 20% relative humidity) and strong (20 + mph) winds (Cohen 1976).

Vegetation in the area where the fire burned is typical for the montane zone of the Colorado Front Range, and varies with elevation. The southerly facing slopes, in the lower montane zone (5,900 -7,700 feet), are usually covered by open park-like stands of ponderosa pine, often mixed with Rocky Mountain juniper. Depending on soil conditions, abundant grasses and forbs along with common juniper and mountain mahogany shrubs typify the ground-level vegetation. The northerly facing aspects, which are usually moister than the southerly facing aspects, support mixed stands of ponderosa pine and Douglas-fir. Similar to the southerly facing slopes, a rich understory of common juniper, mountain mahogany and grasses often prevail. Cheat grass, a non-native species and very flammable when dry, is the second most common grass in the area. (Sherriff and Veblen 2007, Krasnow and others 2009, Sherriff and Veblen 2009, Keith and others 2010) (Figures 5, 6, 7).

In the upper montane zone (7,700 – 9,350 feet) relatively dense and mixed stands of Douglas-fir and ponderosa pine usually dominate the north facing slopes with a rich understory of grasses, forbs, and common juniper at ground-level. More open stands of ponderosa pine occupy the

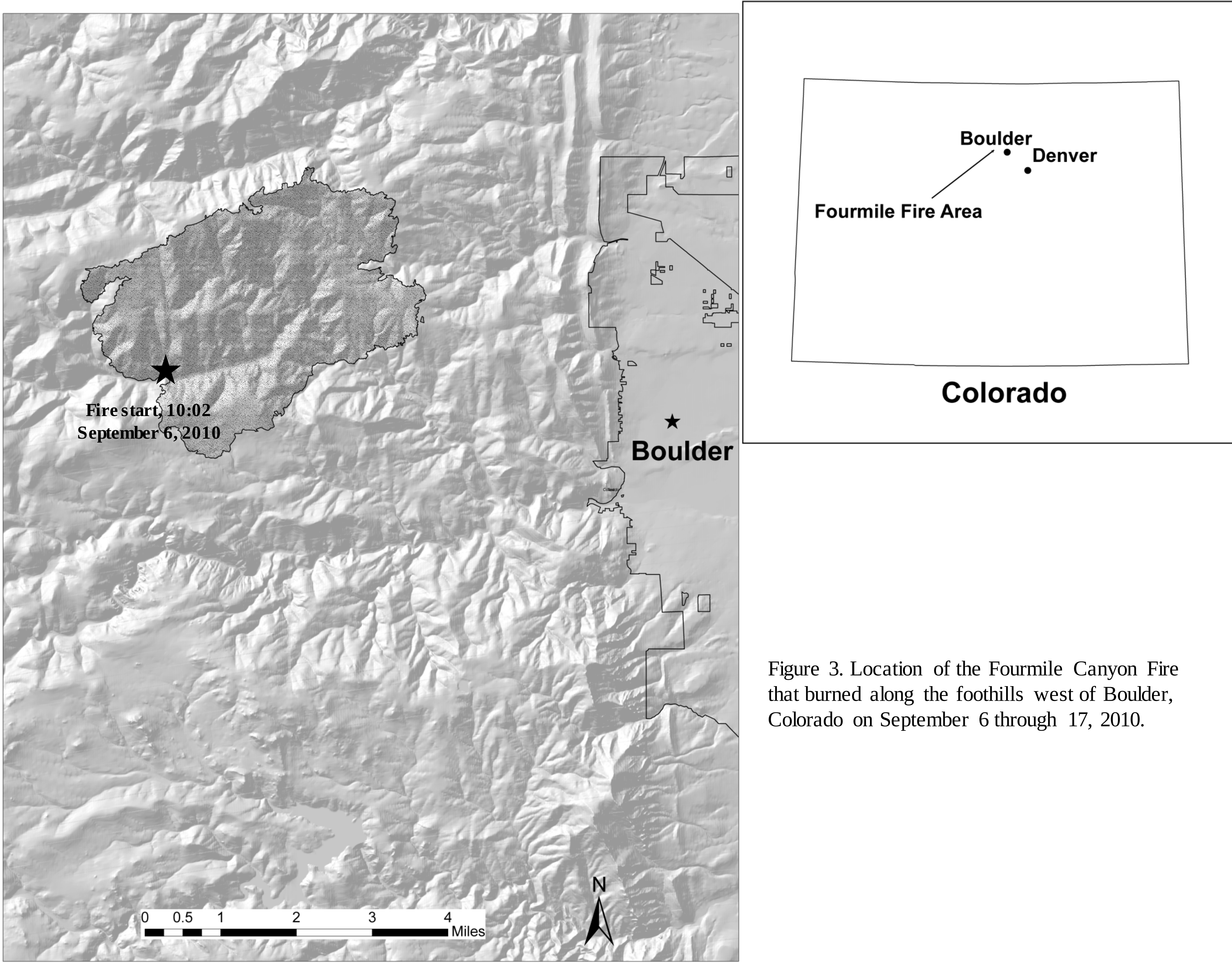


Figure 3. Location of the Fourmile Canyon Fire that burned along the foothills west of Boulder, Colorado on September 6 through 17, 2010.

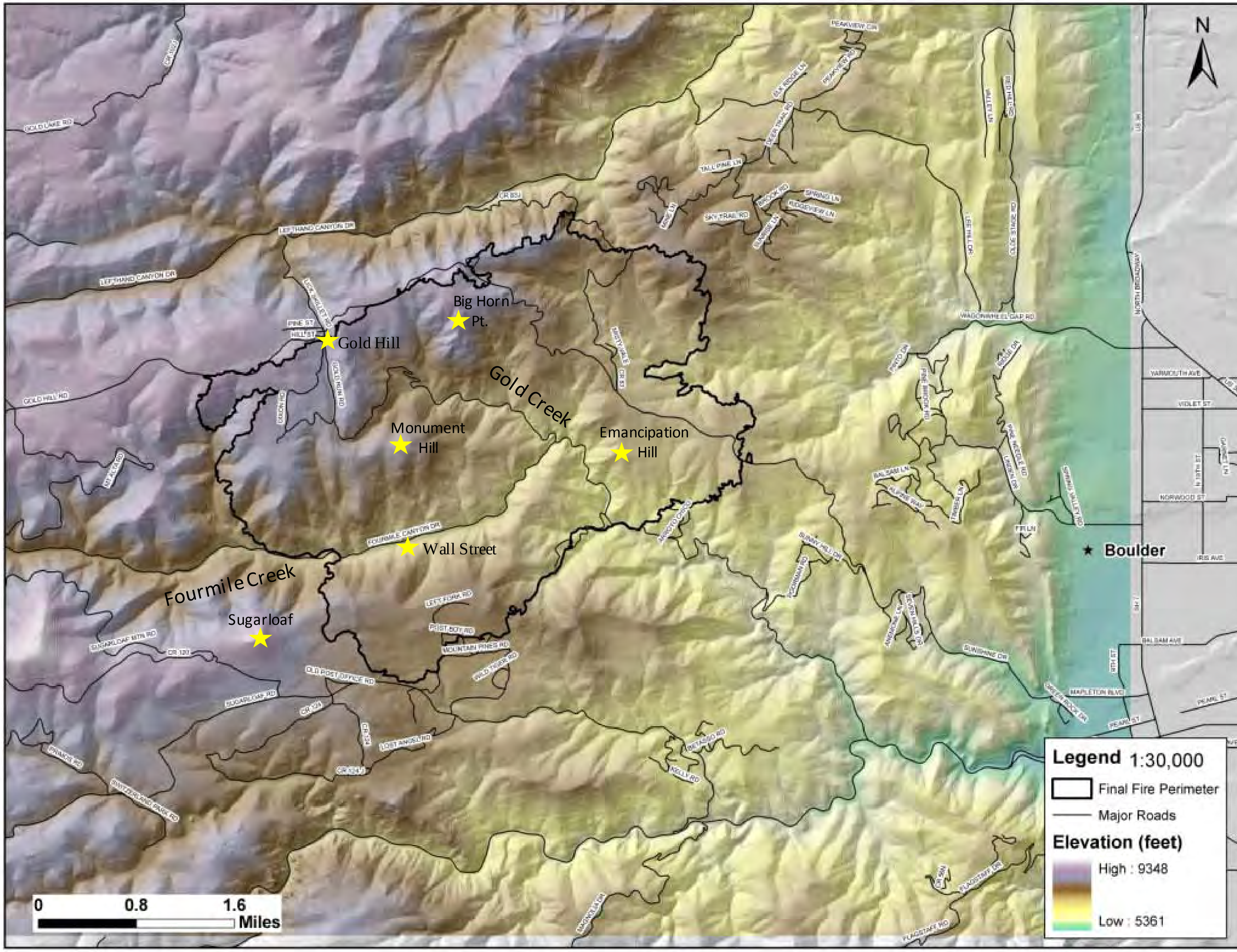


Figure 4. Topography where the Fourmile Canyon Fire burned is very rugged with steep slopes and narrow canyons. Fourmile and Gold Creek are the primary drainages in the area.

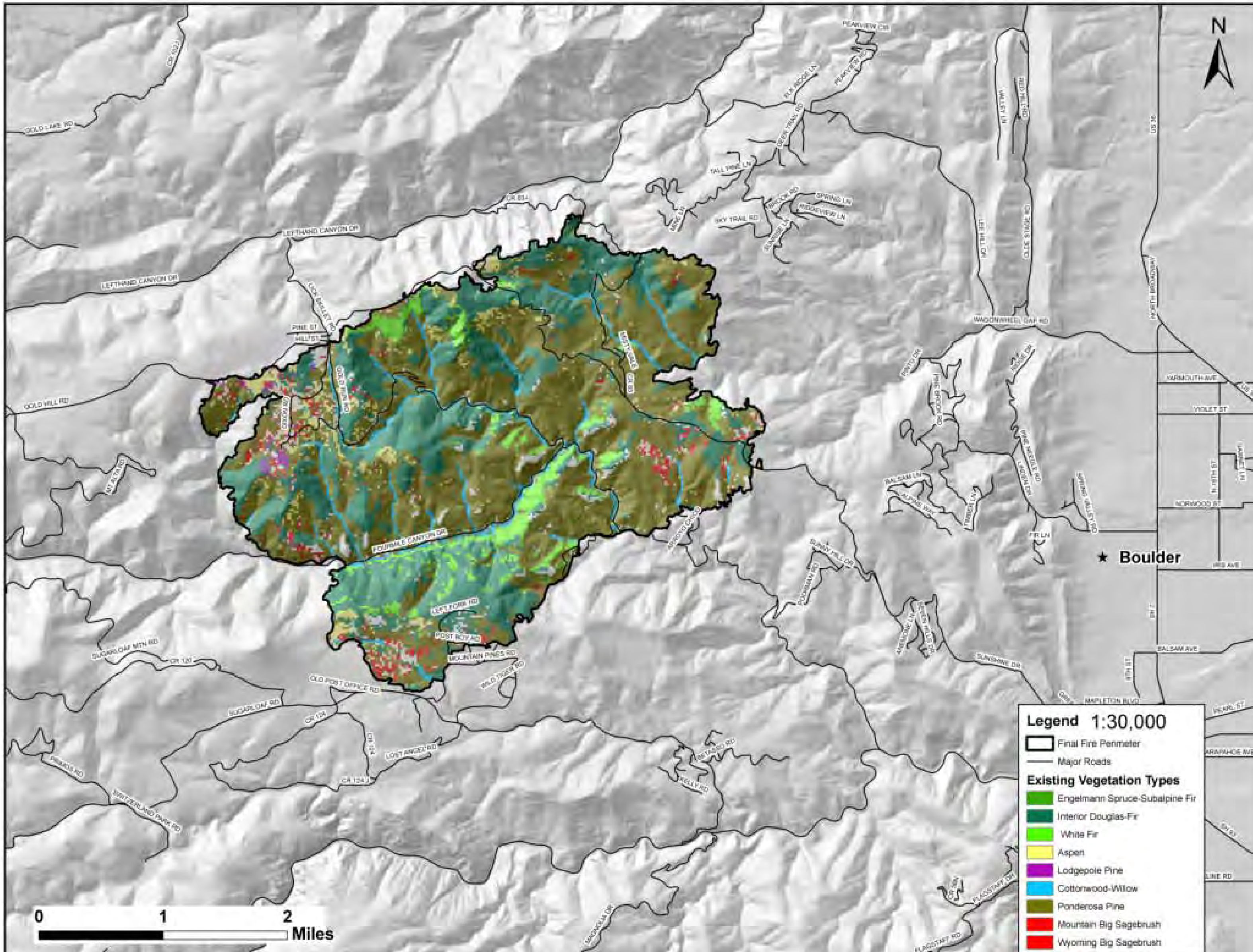


Figure 5. Vegetation where the Fourmile Canyon Fire burned is dominated by ponderosa pine forests on the south facing slopes and Douglas-fir forests on the north facing slopes (LANDFIRE 2010).

Figure 6. Typical open ponderosa pine forest occurring on the Front Range where the prairie transitions to the forest. Photos: Russ Graham.

Figure 7. A mixture of shrubs and grasses dominated the ground-level vegetation where the fire burned. Litter and downed woody material was continuous beneath forested areas. Photos: Mike Tombolato (top), Russ Graham (bottom).

southerly facing slopes, again with a rich understory of shrubs and grasses depending on soil conditions (Figures 5, 8). Endemic levels of mountain pine beetles are active in the area, attacking both lodgepole pine and ponderosa pine. However, unlike other areas of Colorado, the area where the Fourmile Canyon Fire burned, there were no large expanses of beetle killed or attacked trees (Sherriff and Veblen 2007, Krasnow and others 2009, Sherriff and Veblen 2009).

Infrastructure

Settlement began in the area where the Fourmile Canyon Fire burned in 1859 and was in response to gold being discovered. In 1860 a major wildfire burned in the area and the initial gold discoveries dwindled. As a result, the number of residents in the area decreased. In 1872 a rich form of tellurium (combination of gold and telluride minerals) was discovered and once again Gold Hill, Wall Street, and other communities in the area prospered (Figure 4, Figure 9). Mining claims dotted the area and roads connected the mining areas with the processing plants located along Fourmile Creek. As such, a network of steep and narrow roads initially designed for use by wagons and pack trains dissects the area with the Lick Skillet Road giving access to Gold Hill one of, if not the steepest, county road in the United States (Figure 10. This mining legacy has led to a complex and linear land ownership pattern in the area, with private, Bureau of Land Management, Boulder County, Forest Service, and Colorado State Lands intermixed (Jessen 2009) (Figure 11).

We identified 474 homes located within and adjacent (~ < 100 feet) to the final fire perimeter which are protected by the Sunshine, Sugar Loaf, and Gold Hill Fire Districts (Figures 12, 13). Many homes were located on ridge tops, typified by those along Sunshine Canyon Drive, situated in the easterly portion of the area where the fire burned and along Fourmile and Gold Run Creeks. Gold Hill, located on the northern perimeter of the fire, and Wall Street located along Fourmile Creek are two of the historic communities located in the area. A combination of gravel and paved roads such as the Fourmile Canyon and Gold Run Roads, along with Sunshine Canyon Drive provide access to the area.

Pre-fire

Boulder County is prepared for fire emergencies and has been building on the experience gained from past fire events in the county such as the Black Tiger Fire (1989), Olde Stage Fire (1990), Walker Ranch Fire (2001) and the Overland Fire (2003). In late 2009 Boulder County established a Type-3 Incident Management Team which was accepted by the State of Colorado in spring of 2010 as a fully operational team. The county also has an excellent infrastructure (e.g. building, phones, computers etc.) to support major emergency events through the Boulder Emergency Operations Center. Reverse 911 capabilities for evacuation notification has existed since 2000. The local fire districts are prepared for emergencies and have conducted and rehearsed fire scenarios typical of the Fourmile Canyon Fire. The Fourmile Fire District exemplifies this preparedness by having physical maps for distribution to incoming units and to aid in evacuations.

Figure 8. Typical north facing slope occupied by a mixed Douglas-fir and ponderosa pine forest. Note the rather closed canopy conditions of these forests compared to the open conditions of the ponderosa pine forests (see figure 7). Photo: Russ Graham.

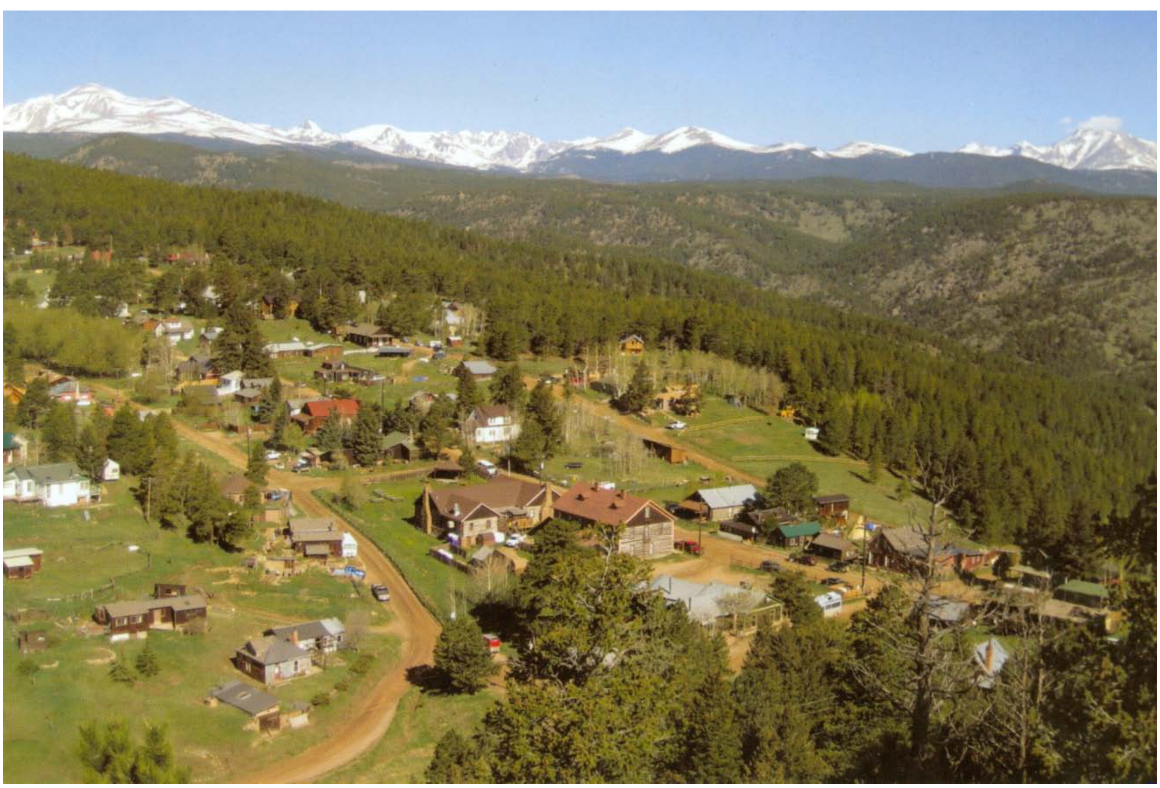


Figure 9. Wall Street and Gold Hill are two of the historic communities located in the area where the fire burned and both were established in 1859. Photos: Russ Graham (top), Dan Steinman (bottom).

Figure 10. Steep and narrow roads initially developed by the mining industry now provide access to the many homes. Photos: Russ Graham.

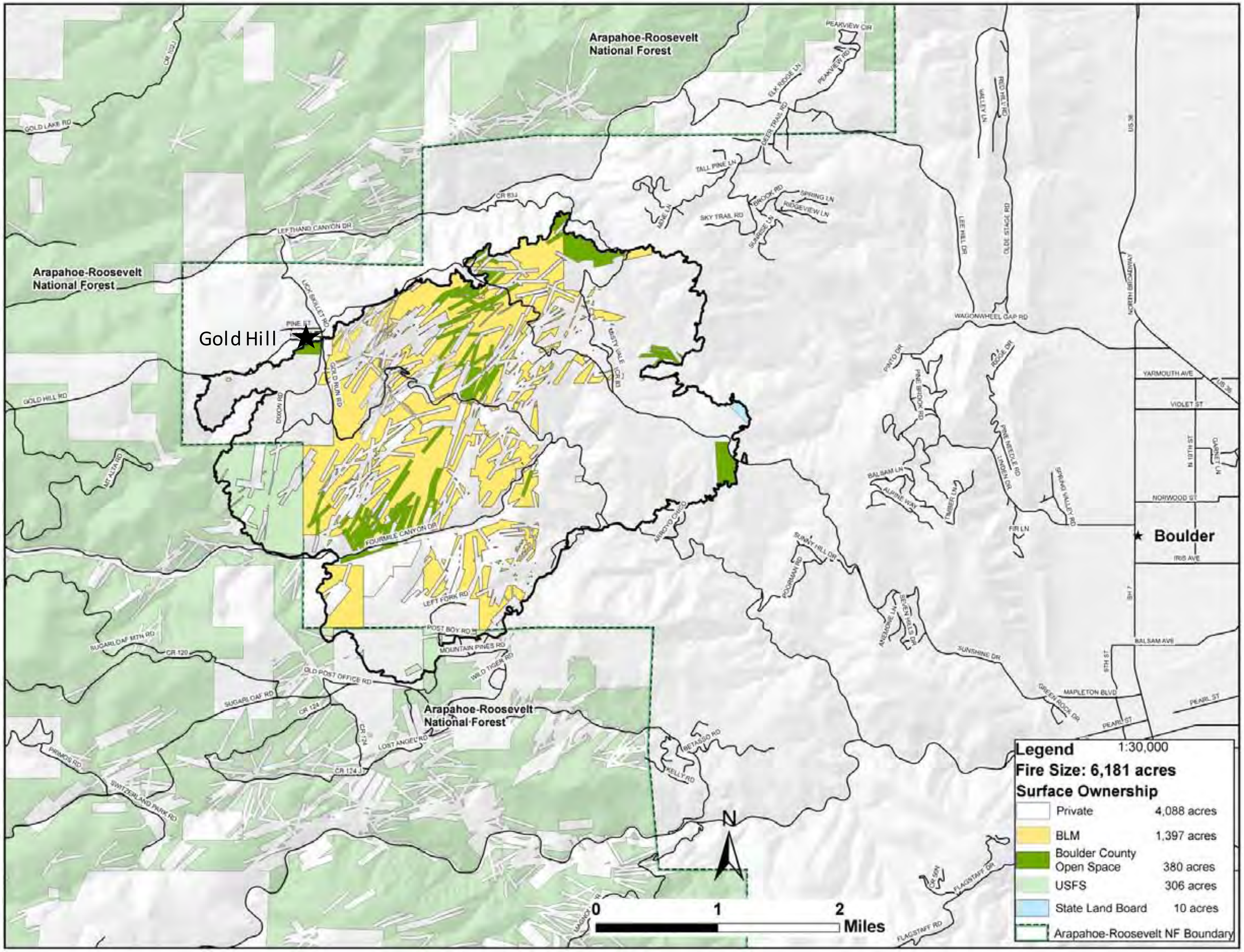


Figure 11. Land ownership within the Fourmile Canyon Fire is very complex as the result of mining. The Lick Skillet Road to Gold Hill from the north is one of the steepest county roads in the United States.

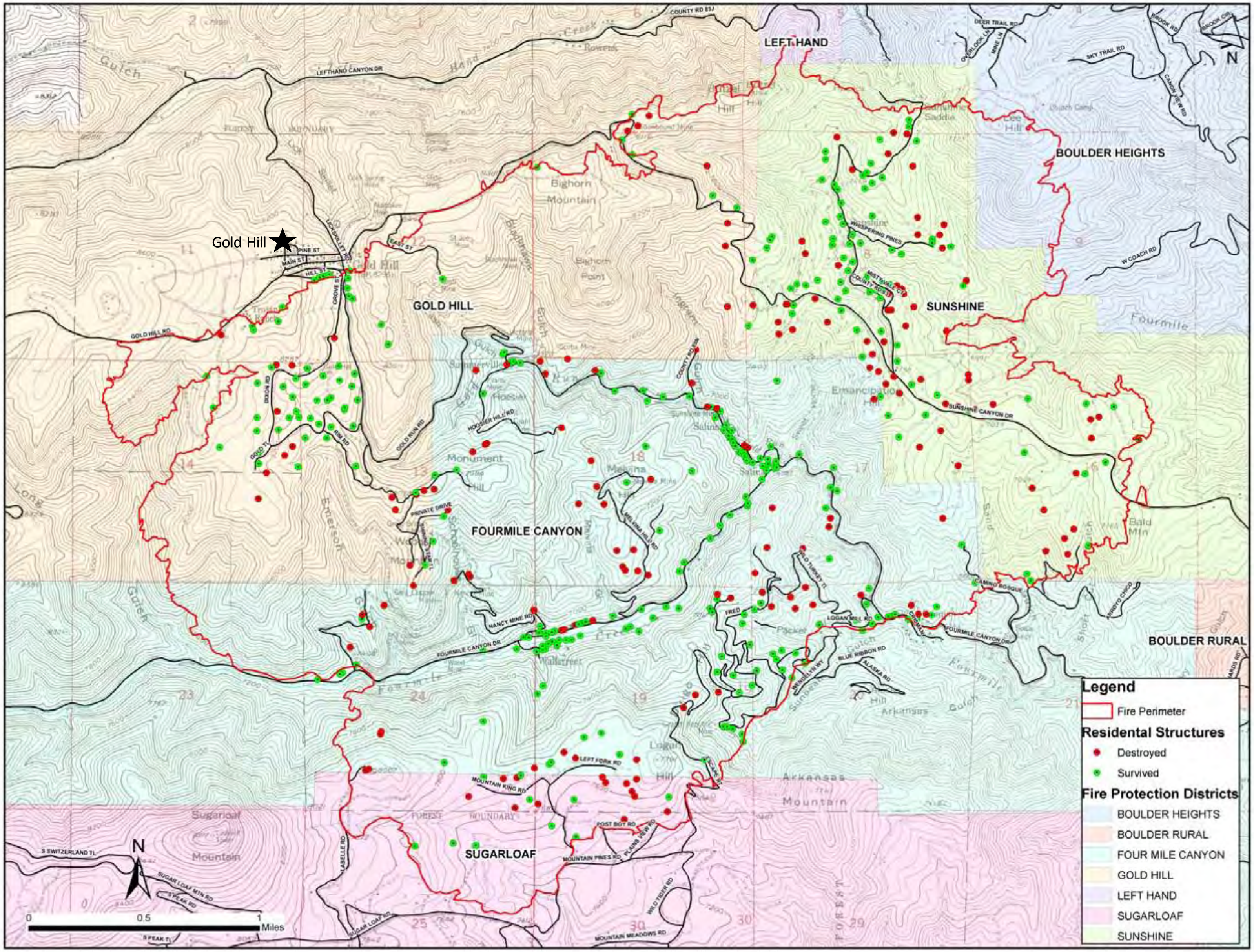


Figure 12. Multiple fire districts provide protection to the over 450 homes and other residential structures located within the area burned by the Fourmile Canyon Fire.

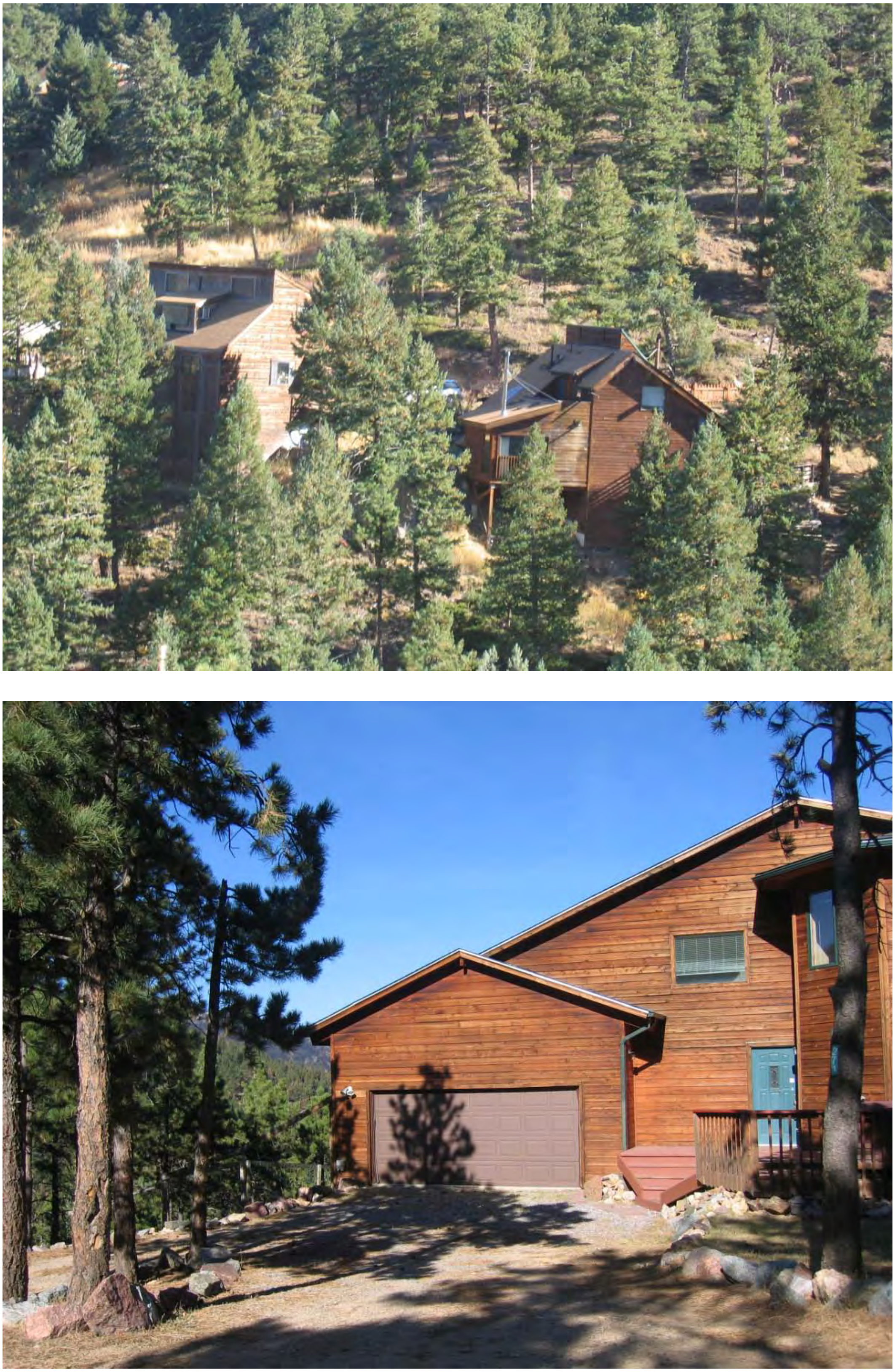


Figure 13. A total of 474 homes were located in the area where the Fourmile Canyon Fire burned. Photos: Russ Graham.

Weather

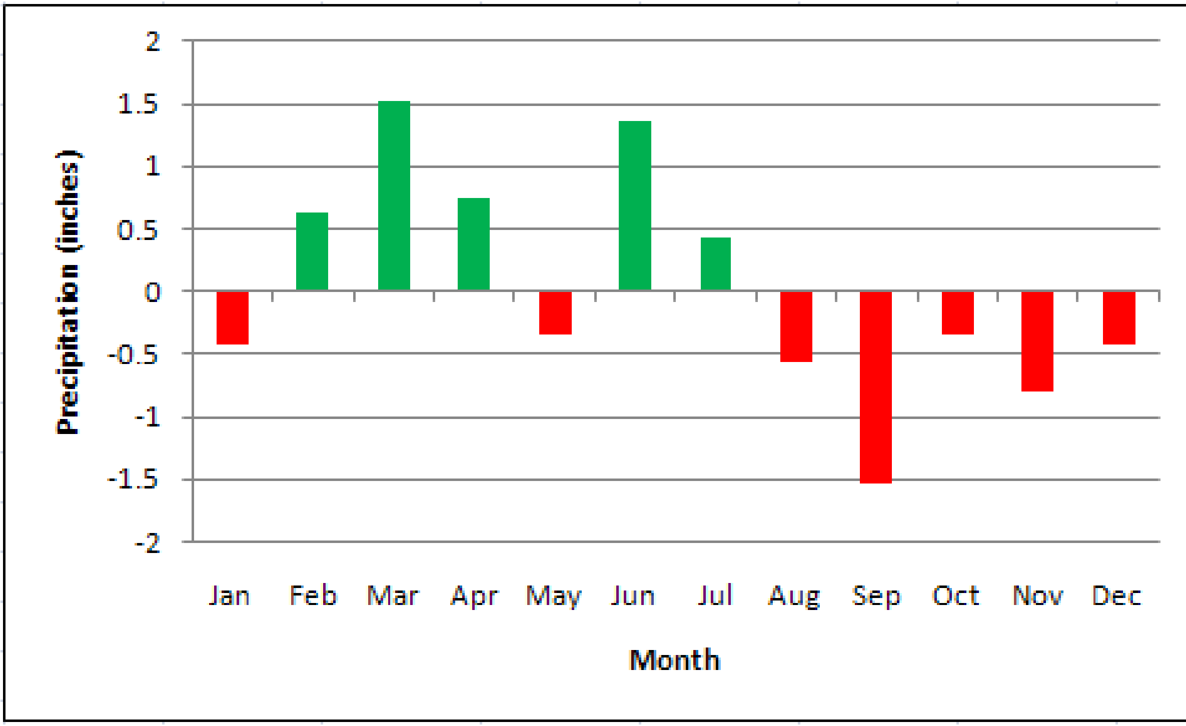
The weather prior to September 6 was normal to wetter-than-normal for most of the spring and summer of 2010 (Figure 14). Beginning in late August, a very dry and warm weather pattern emerged and September ended 4^{o} F above normal in temperature and about 1.5 inches below normal in precipitation. The Palmer Z-Index indicated that short-term moisture conditions in northern Colorado changed from moderately moist in July to severely dry by the end of September, 2010. There are remote automated weather stations (RAWS) and several other weather stations located near the fire area (e.g., city of Boulder, Sugarloaf RAWS, Mesa Lab) that can be used to characterize the local weather during the Fourmile Canyon Fire (Figure 15). The last recorded precipitation prior to the fire at Sugarloaf was August 20, 17 days prior to the fire (Figure 16). This weather pattern facilitated a rise in fire danger as expressed in the Energy Release Component (ERC) of the National Fire Danger Rating System (NFDRS). The fire danger rose from seasonal normal values in mid-August to record levels in early September when the fire started (Figure 17). All of these factors resulted in low moisture contents of the dead fuels in the area where the fire burned to their lowest values of the season.

Winds

Gusts from the west in excess of 20 miles per hour (maximum of 41) were recorded every hour from 07:00 to 16:00 at the Sugarloaf RAWS on September 6. However, winds can be highly altered due to complex topography such as that occurring in the area where the Fourmile Canyon Fire burned. WindWizard (Forthofer 2007), an adaptation of a Computational Fluid Dynamics (CFD) model, can show how topography affects local wind flow. Visualizations from WindWizard are not forecasts but rather high resolution simulations of how wind may flow under different wind speeds and directions in complex terrain. In this case, in the vicinity of Sugarloaf RAWS, even though the predominant winds were blowing from the west over the fire area, within the canyons and draws many wind directions and speeds were possible depending on the location. Also, the higher winds (35 mph+) occurred at the ridge tops especially above Fourmile and Gold Creeks (Figures 4, 18). These multi directional and strong winds were especially evident near the mouth of Emerson Gulch where the fire started (Figure 19).

Fuel Treatments

The intent of fuel treatments is to change fuel structure and composition so when wildfires burn their behavior is such that the fires can be managed (e.g., suppressed, controlled, contained) or the burn severity (what they leave behind) is of a desirable nature (e.g., intact homes, green trees, resilient soils). The efficacy of fuel treatments to produce desired outcomes depends on both how the live and dead vegetation are treated (e.g., vegetation cut, piled, burned, masticated) and how the treated areas are dispersed, shaped, and arranged across the landscape. Much is known about fuel treatment prescriptions from 80-plus years of documentation and research after wildfires (Weaver 1943, Pollet and Omi 2002, Graham and others 2004, Agee and Skinner 2005, Finney and others 2005, Cram and others 2006, Hunter and others 2007, Graham and others 2009, Hudak and others 2011). A large proportion of this evidence applies directly to the ponderosa pine and mixed conifer forests of the Colorado Front Range and the Fourmile Canyon area. This body of knowledge unequivocally demonstrates that changes in fire behavior and subsequent



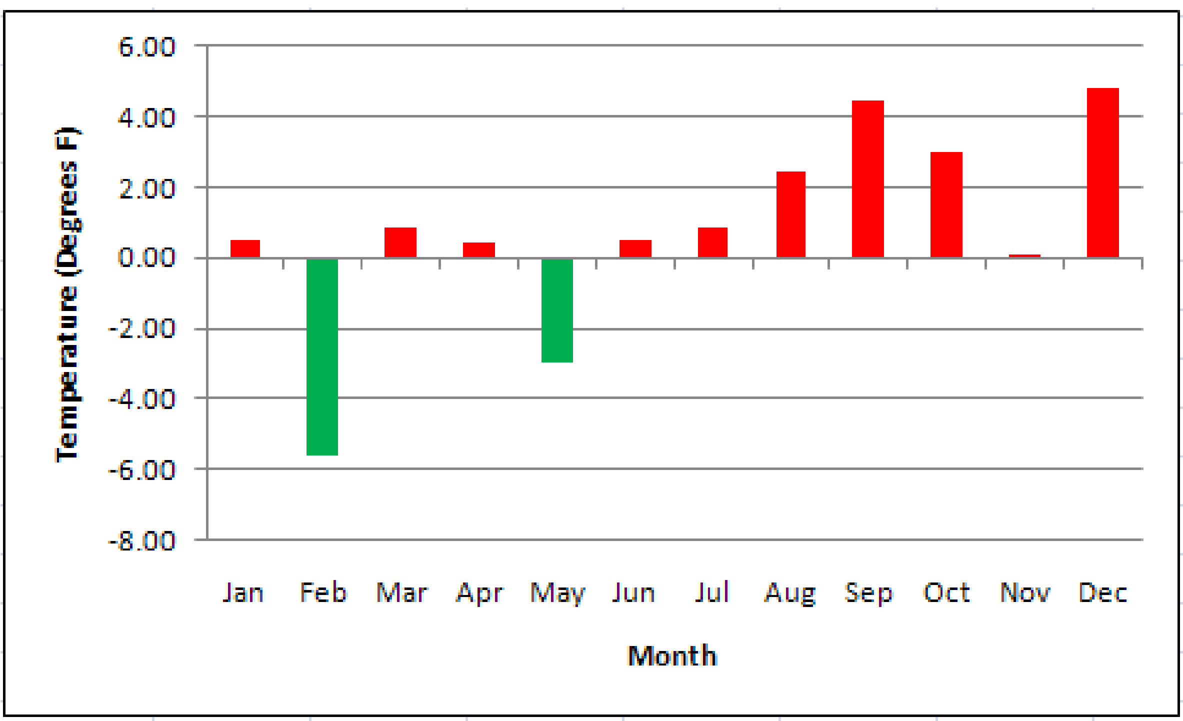


Figure 14. Based on the Boulder Co-op station (#050408) 2010 precipitation (inches) and temperature (Degrees F) were mostly cool and wet February though July and then warm and dry from August through December compared to the 1971 through 2000 climate averages.

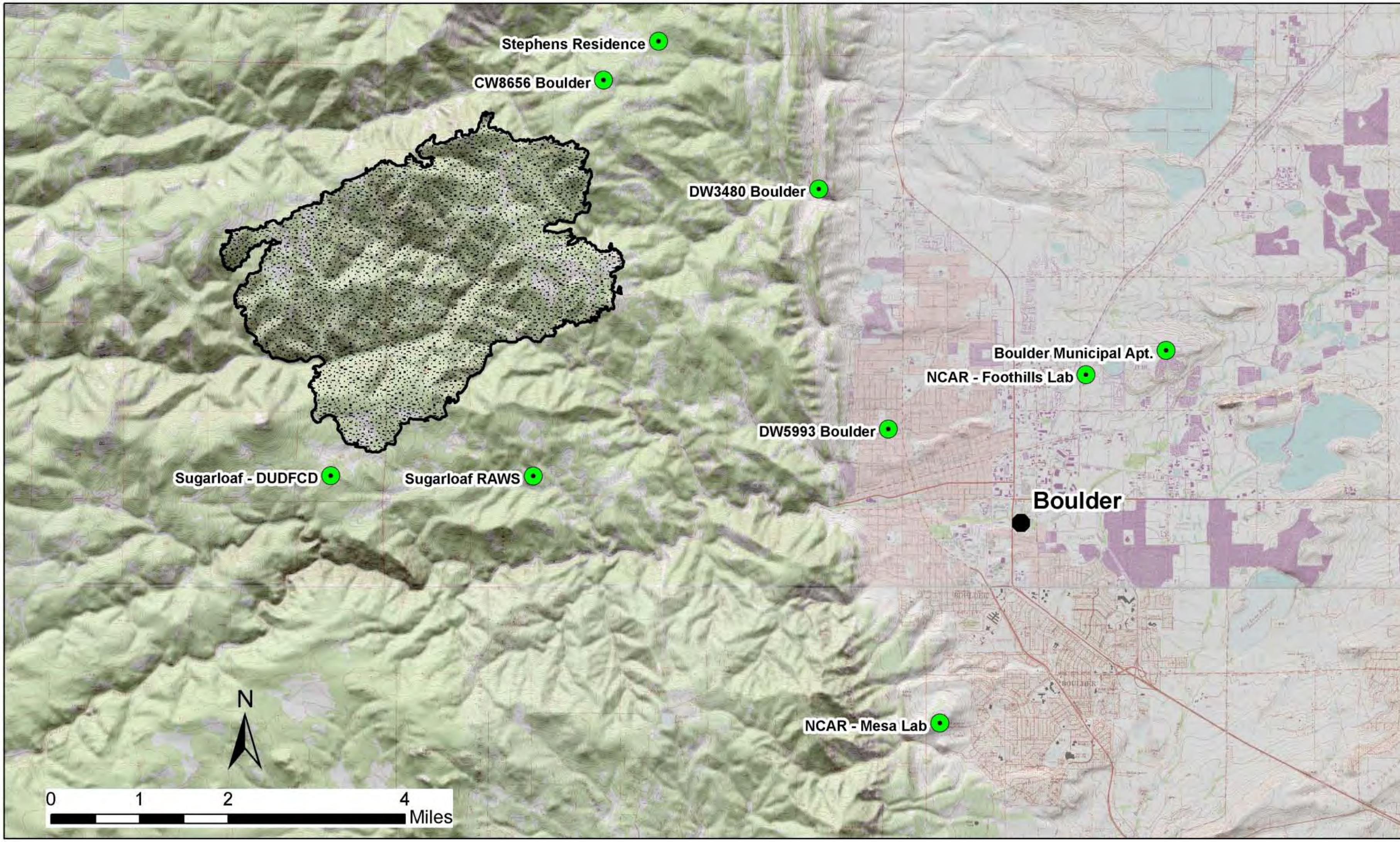


Figure 15. The location of remote automated weather stations (RAWS) and other weather stations located near the area where the Fourmile Canyon Fire burned.

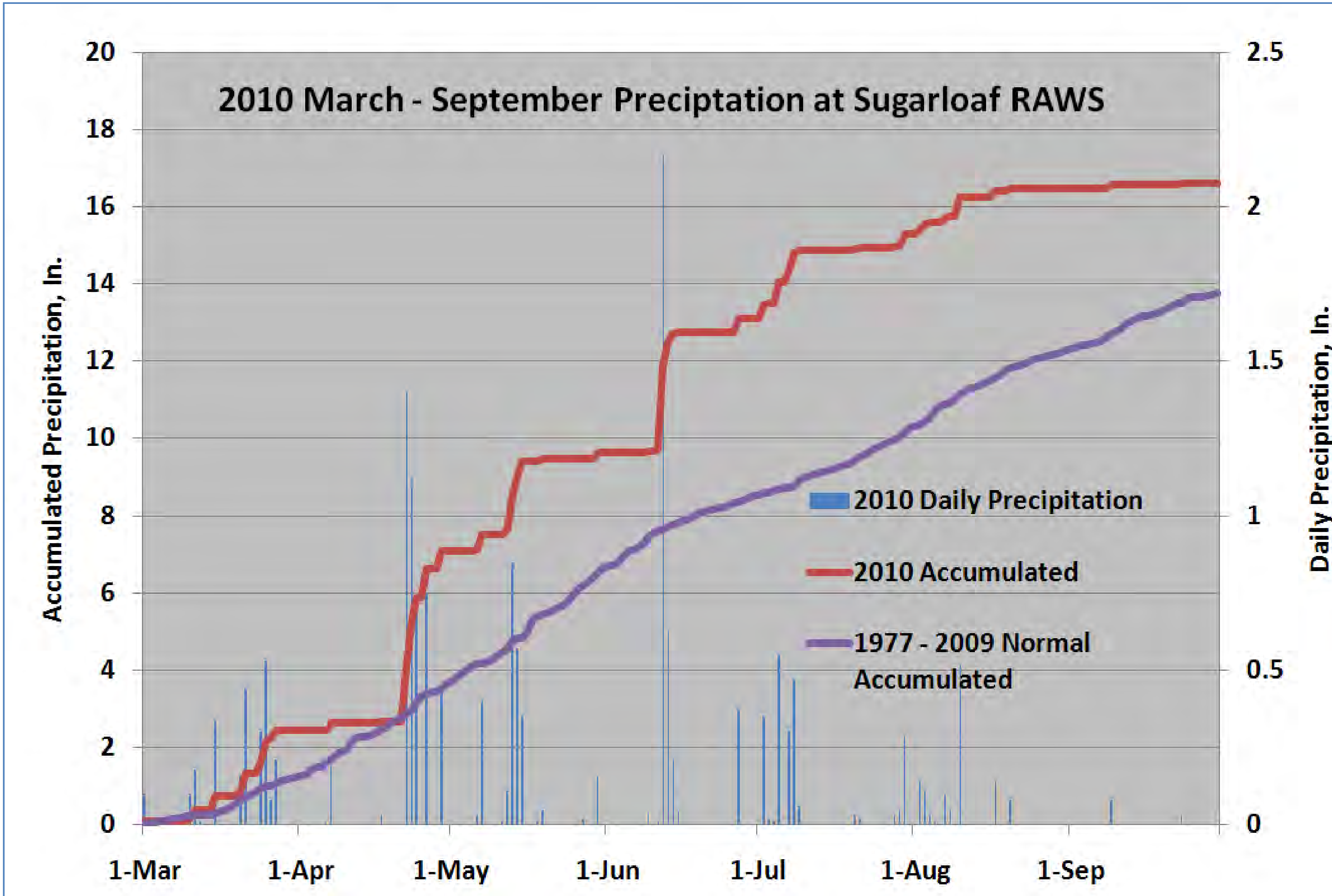


Figure 16. The daily and accumulated precipitation falling at the Sugarloaf remote automated weather Station (RAWS) along with the 1977 through 2009 average precipitation accumulation.

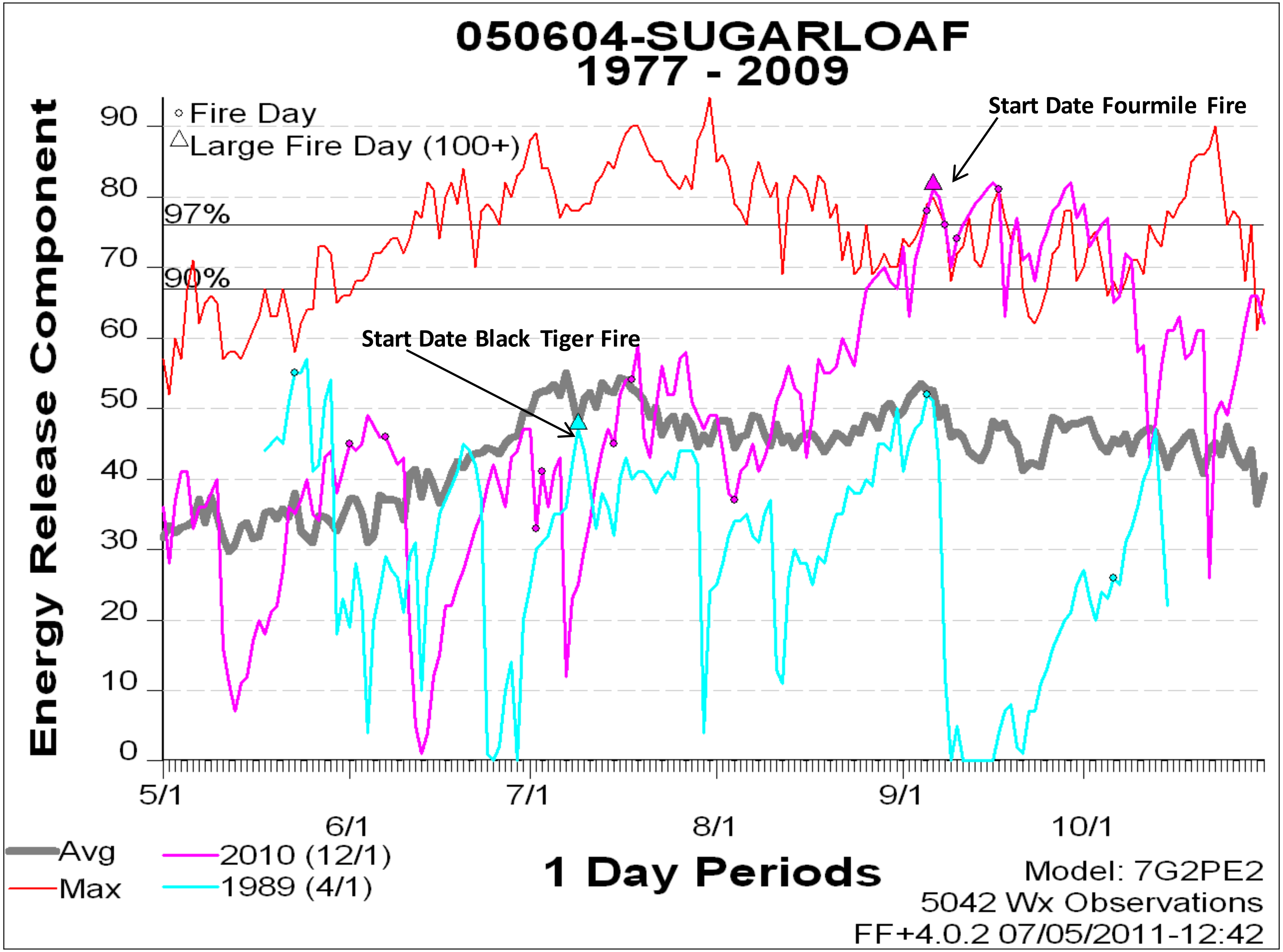


Figure 17. Fire danger as expressed by Energy Release Component (ERC) using on data from the Sugarloaf remote automated weather station (RAWS). The 2010 ERC trace (pink) shows the increasing fire danger in August. When the Fourmile Canyon Fire started the ERC was just above the all-time high for that date. It continued to hover around the all-time maximum through late fall. The start date and seasonal trace for 1989 show the contrast between conditions under which the Black Tiger Fire burned and the conditions for the Fourmile Canyon Fire.

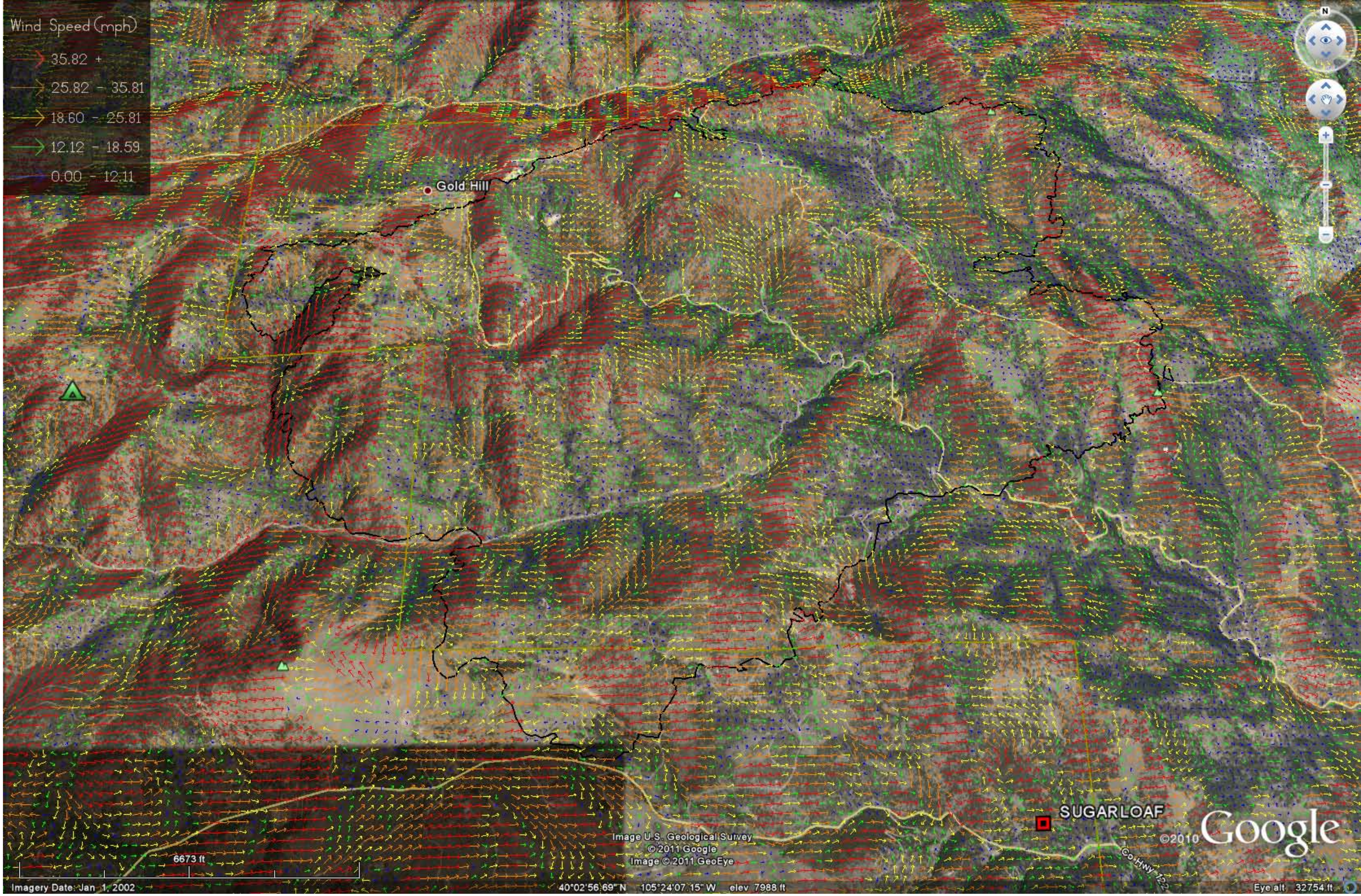


Figure 18. Wind directions displayed (modeled) using the WindWizard software for the Fourmile Canyon Fire area. Note the higher winds (red) blowing along ridges within the area.

Figure 19. Wind directions displayed (modeled) using the WindWizard software for the Fourmile Canyon Fire focusing on where the fire started near the mouth of Emerson Gulch. Note the higher winds (red) blowing along the ridges.

effects are most dependent on changes in surface fuels. In fact, very effective fuel treatment in many studies consists solely of prescribed burning, with no canopy manipulation at all (e.g., Hayman Fire, Finney and others 2003). Canopy treatments start with removing ladder fuels (e.g., shrubs, small trees) and raising the base heights of standing trees by pruning the lowest branches (Figure 20). Thinning overstory trees to increase spacing between tree crowns and decreasing continuity of aerial fuels can be used to decrease the potential for a spreading crown fire. The state of knowledge clearly supports the generalization that canopy treatments alone produce minimal effects on fire behavior or reductions in fire severity to residual trees. It is recognized that thinning followed by removing the surface fuels most often by burning produces the most durable treatment benefits (Graham and others 1999, 2004).

Approximately 600 acres (9.7% of the burned area) of fuel treatment were conducted within the final fire perimeter. These areas included 417 acres of fuel treatments administered by the Colorado State Forest Service (Figure 21). Boulder County Open Spaces has also conducted work in the area northeast of Gold Hill and in the area of Bald Mountain. Additionally, 21 acres of treatment were conducted by the US Forest Service in the Sugar Loaf area. Another 162 acres of treatments were conducted for which no geospatial location data exist. These treatments were also administered by the Colorado State Forest Service and consisted of mainly defensible space projects to individual homes. There are likely additional treatments that have been performed by homeowners throughout the area which we could not account for. Fuel treatment prescriptions obtained from Colorado State Forest Service showed the following treatments:

1. Thinning from below by removing small trees.
2. Chipping the small-diameter limbs on the forest floor.
3. Piling and burning of limbs and the boles of small trees.
4. Piling but not burning the boles of the large trees removed in the thinnings.
5. No broadcast burning of surface fuels (e.g., grasses, twigs, limbs, needles) occurred.

The condition of fuels in treatment units at the time of the Fourmile Canyon fire cannot be known but would depend on the original treatment prescription, fuel accumulation since treatment occurred, and regrowth of vegetation. All of these would vary among treatment units. Pre-treatment photographs were helpful in documenting the nature of some treatments, especially the thinning effects that were readily visible (examples shown in Figure 22). Treatment units that had not burned, but recorded as receiving treatments similar to those nearby areas that had burned, were inspected and suggested an abundance of continuous surface fuels were present in the treated areas. These fuels consisted of grass, litter, dead woody material, brush, small trees, and in some cases piles of large woody material (Figure 23). Canopy and understory thinning did increase the spacing between overstory trees and made the forest more open (Figure 24). However, under the wildfire weather conditions experienced routinely in the Colorado foothills, high fire spread rates (0.5 to 1.0 mph) and high fire intensities (flame lengths of 5 to 10 feet) would be expected. Such intensities would be sufficient to ignite and entirely consume the leaves/needles of the residual overstory trees (Figure 25).

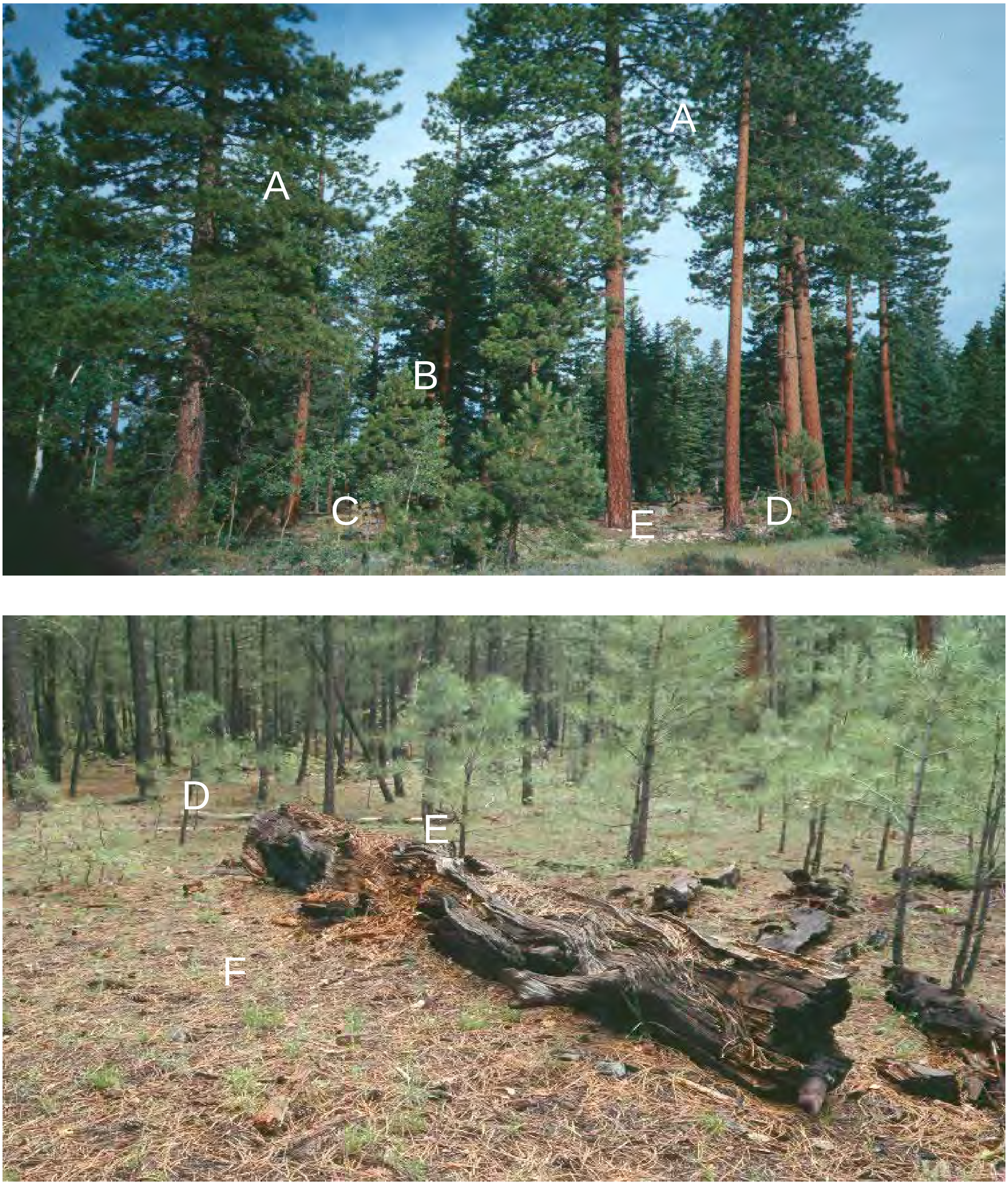


Figure 20. The most effective strategy for reducing crown fire occurrence and burn severity is to 1) reduce surface fuels D, E, F; 2) remove ladder fuels B, C; increase canopy base heights A; and lastly reduce canopy continuity and density A. Photos Russ Graham.

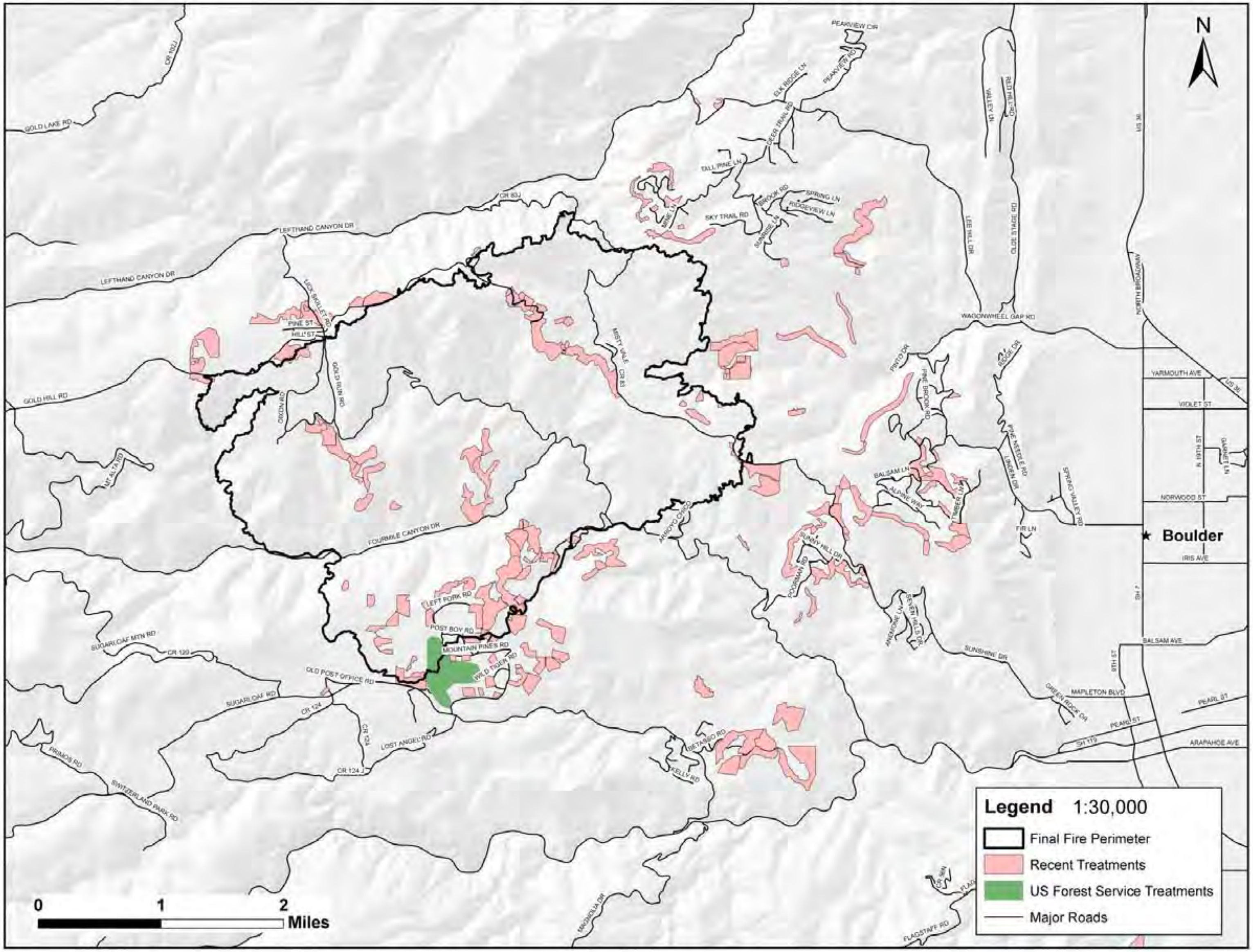


Figure 21. A total of 417 acres of fuel treatment had documented geospatial locations within the area where the Fourmile Canyon Fire burned. The treated areas were located near homes, along ridge-tops, and along roads. An additional 162 acres of treatments did not have geospatial locations and are not shown here. These treatments were mainly defensible space projects surrounding individual homes. Twenty one acres of US Forest Service treatments were also within the fire perimeter.

Figure 22. Examples of fuel treatments within the Fourmile Canyon Fire area. The top pictures show a forest thinned using a masticator (machine that chunks and shreds woody material). Bottom pictures show trees cut by hand and the fuels created by the treatment were chipped. The pre-existing surface fuels were not treated in either unit. Photos: Bob Bundy.

Figure 23. Abundant grasses, shrubs, fine woody, and occasionally small trees and wood piles dominated the surface fuels in areas where fuels had been treated. Photos: Mark Finney.

Figure 24. Thinning used in the fuel treatments appreciably increased the distance between tree crowns. Photos: Chuck McHugh.

Figure 25. Widely spaced trees can readily ignite and burn when crowns extend down to the forest floor near surface fuels. Photos: Mike Tombolato.

Fuels were also treated along several roads in the area. In general these treatments extended to 150 feet on both sides of the road providing a 300 foot wide roadside treatment (Figure 21). Where applicable and feasible, these roadside treatments were connected to treatments located near homes and were designed and implemented to offer the following benefits:

1. Create road corridors that allow safe travel for homeowners leaving and firefighters entering a wildfire area.
2. Create a wildfire defendable zone using a shaded fuel break consisting of moderate to low tree densities with no ladder fuels near homes and communities.
3. Improve forest health by increasing tree vigor through removal of excess and unhealthy trees.
4. Enhance existing quaking aspen clones by greatly reducing the number of conifers in and among the quaking aspen stands.
5. Improve wildlife habitat by creating debris piles and encouraging the development of native grasses.

Hand-falling of trees with chainsaws was the most common method of removing ladder fuels and decreasing tree canopy densities. Within 50 feet of roads the small material (3 inches and less) was often chipped creating a layer of chips six inches and less in depth. Outside of this area and within 75 feet of main roads or homes the fine fuels were piled by hand. In some areas where slope steepness was less than 30%, rather than hand-falling the small trees they were masticated.

This assessment did not find documentation that described the intended treatment performance, either in terms of changes to wildfire behavior under a targeted set of weather conditions, the use of treatments by fire suppression resources, or a possible strategic role of treatments in changing fire progression. Long term maintenance of treatments for re-growth and understory response was not mentioned.

Fourmile Canyon Fire

Fire weather

On September 6 the weather conditions that directly affected the behavior of the Fourmile Canyon Fire were driven by the changes in the synoptic (large scale) situation. On Sunday, September 5, a low pressure system began moving south and east from western Canada into the Rocky Mountains of the United States (Figure 26 A). This system brought a very dry air mass onto the Colorado Front Range and the fire area (Figure 26 B). The associated cold front passed the fire area early Monday morning, around 01:00, and brought cooler temperatures for September 6 (Figure 26 C, D). However, overnight humidity at the Sugarloaf RAWS only recovered to the mid-thirties from afternoon values below 10 percent occurring on September 5. The tightening pressure gradient along the southern edge of the advancing low-pressure system resulted in much higher wind speeds – changing from about 18 mph at the upper-levels of the atmosphere (500 mb) on Sunday evening in Denver to over 60 mph Monday evening (Figures 26 A, C, E and 27 B). Along with the high winds, the atmosphere became extremely dry. Soundings from Denver show the relative humidity of the air was less than 10% at 12,000 feet above the fire Monday evening, a dramatic change from Monday morning (Figure 27 A). Hourly traces of humidity and wind speed at the Sugarloaf RAWS show extreme fire weather conditions for both

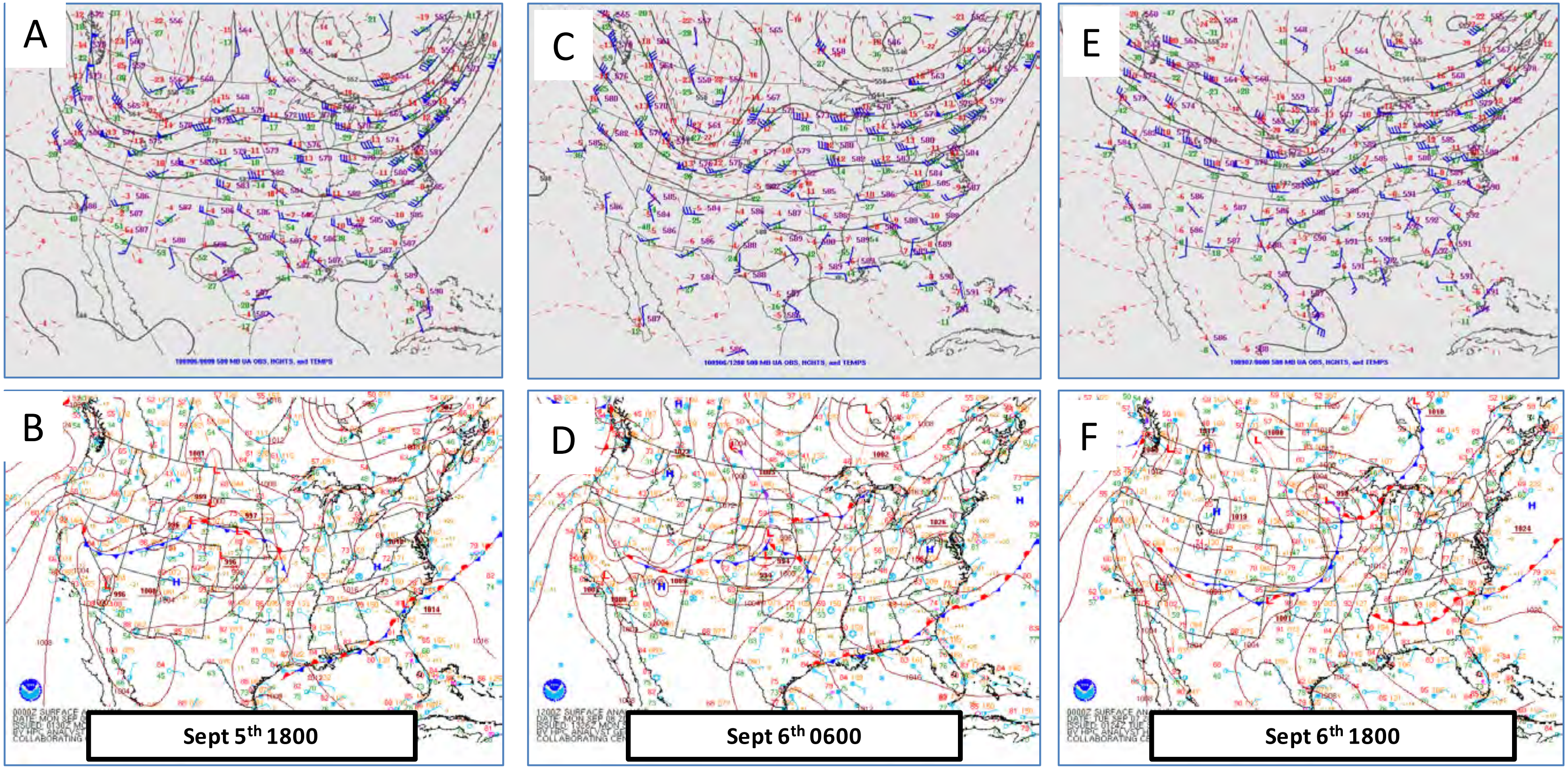
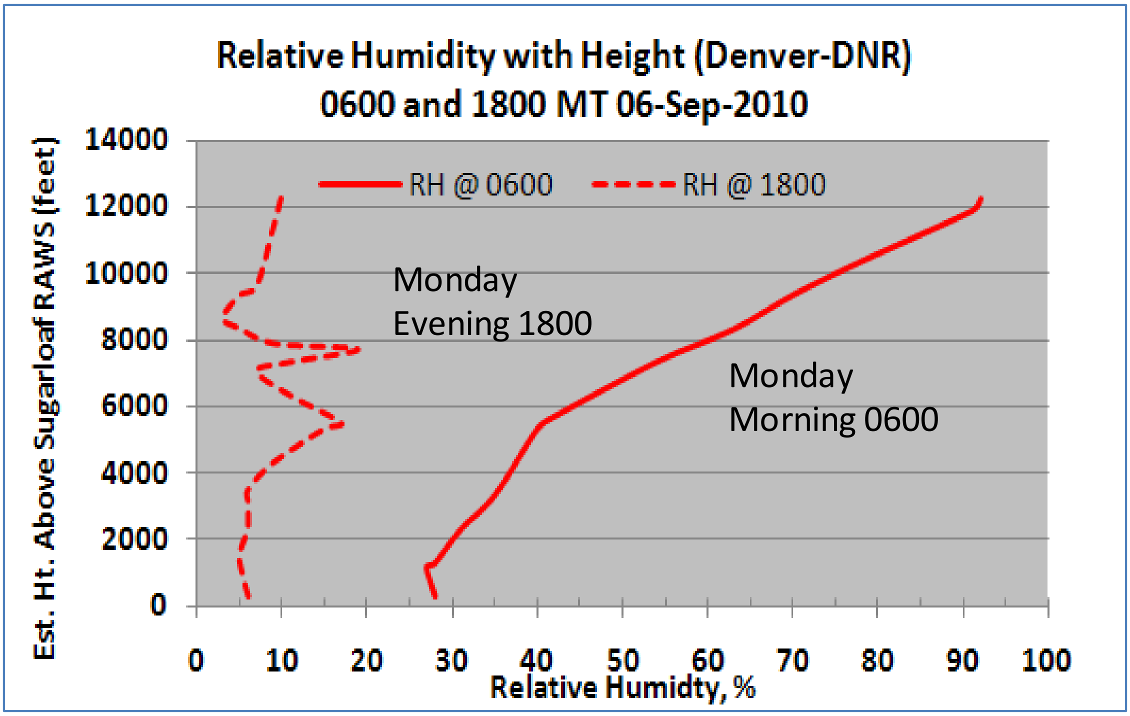


Figure 26. Synoptic (large scale) weather summary for the US showing (A) upper air pressure and wind (500 mb) and (B) surface weather for September 5, 2010 at 18:00 MDT. (C) Upper air pressure and wind (500 mb) and (D) surface weather for September 6, 2010 at 06:00 MDT, and (E) upper air pressure and wind (500 mb) and (F) surface weather for September 6, 2010 at 1:800 MDT.

A



B

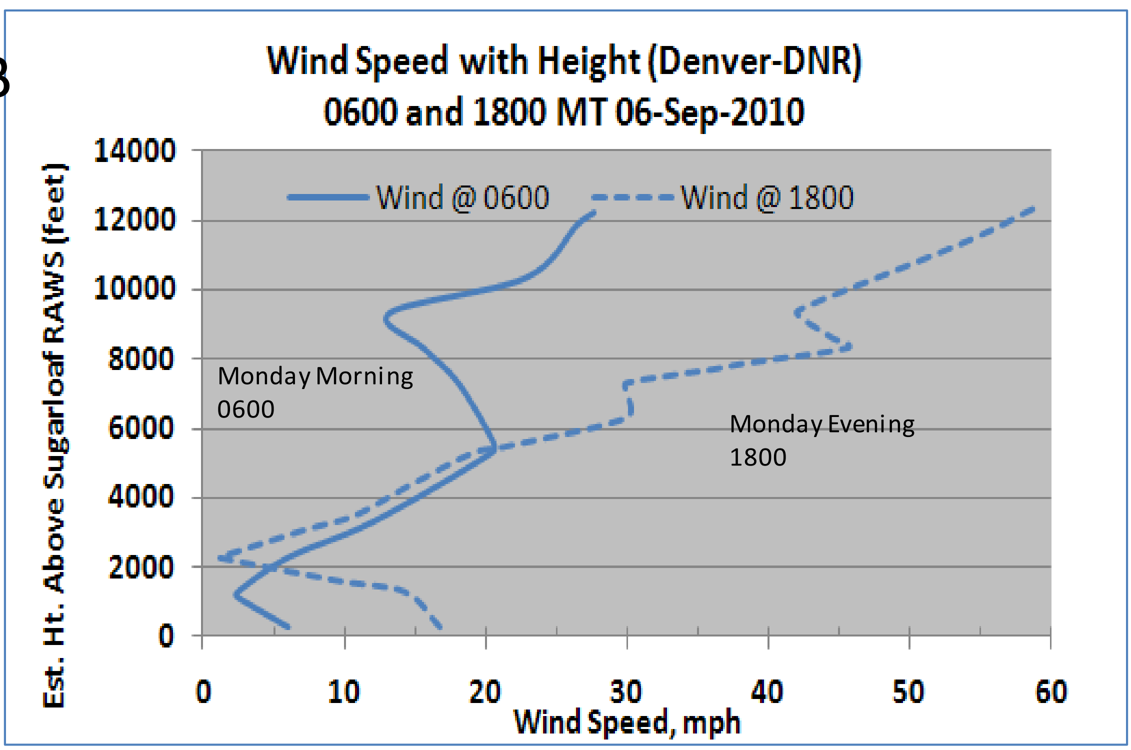


Figure 27. Atmosphere soundings from Denver on Monday, September 6, 2010 show (A) the air relative humidity having a dramatic drying through the entire atmosphere, and (B) speed showing a significant increase for winds at the surface and for winds 5,000 feet above the fire. These conditions do not portray a classic low level jet stream or “Byrams” reverse wind profile.

Sunday September 5 and Monday September 6 (Figure 28). At the time the fire was reported, the air relative humidity was 7 percent and a wind gust of 41 mph was recorded. The relative humidity dropped to 4 percent from about 14:00 to 17:00 and wind gusts from 25 to 30 mph were measured during this time. Between 17:00 and 18:00 winds turned easterly, abated in speed and gustiness, and the air humidity rose from 4 to 14 percent. Figure 28 also shows steadily moderating fire weather conditions for Tuesday through Thursday where air relative humidity did not drop below 15 percent and wind gusts did not exceed 20 mph. Similar conditions were observed at each of the weather stations shown in figure 15, but are not shown here.

Initial response

A 911 call at 10:02 on Monday September 6 reported a fire located near the mouth of Emerson Gulch, where the Gulch intersects with Fourmile Canyon (Figures 3, 29). With the multiple Fire Districts in the area, numerous engines and personnel responded to the fire as well as units from surrounding fire districts, Colorado State Forestry, US Forest Service, and the County and City of Boulder. The control of incoming resources into the fire area, life-safety (firefighter and public), and evacuations were a major concern of the initial attack Incident Commander and the subsequent Type-3 Incident Commander. The Type-3 Incident Management Team (IMT) was dealing with evacuations as late as 21:00 on September 6.

The response of multiple local resources also overwhelmed the local communication systems. Setting up staging areas and establishing command and control of resources coming into and within the area were critical for firefighter and public safety. During the initial attack of the fire, a series of trigger points were established for the initiation of evacuations. However, the fire was moving so fast that these trigger points were often breached before they could be fully initiated. Notifications of evacuations were conducted by Boulder County Sheriff Officer's, on scene fire personnel, and through utilization of reverse 911 calls. Because of this early focus on evacuations and life-safety, fire suppression mainly concentrated on protection of structures where feasible rather than fire containment. While responding units found this frustrating, it likely contributed to the overall safety of firefighters and the general public during the first day of the fire.

The following is a summary for the first three hours of the radio dispatch and 911 call transcripts for the fire.

- The fire was reported at 10:02 on Monday September 6 and there was confusion as to the cause of the fire.
- 10:04 the fire is located just south of a home at 300 Shining Star Trail.
- 10:13 inquiry was made about the availability of air tankers.
- 10:21 Fort Collins dispatch advises that wind conditions will not allow the use of air tankers at this time.
- Fourmile Fire District units arrived on scene, established command and started sizing up the fire at 10:23.
- 10:26 the fire had already spotted to the west across the Emerson Gulch Road from where it started (Figure 29).
- 10:37 a staging area was set-up for incoming resources on Wall Street west of the old mill site (Figure 29).

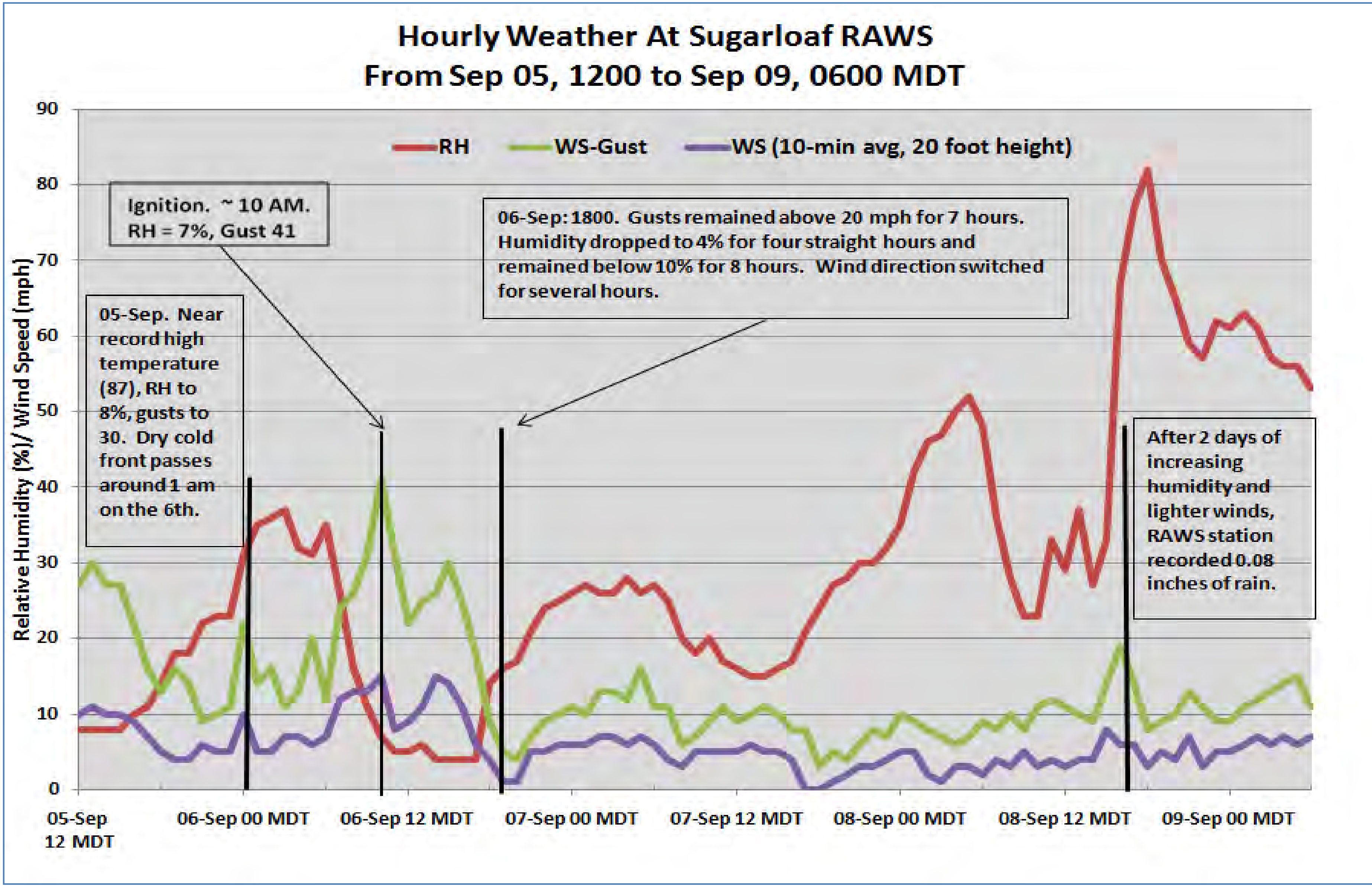


Figure 28. September 5 had air relative humidity (RH) below 10% from 11:00 to 18:00 and wind gusts in the 20s and 30s (mph) all afternoon. A cold front passed around 01:00 on September 6 creating gusty winds but RH only recovered to mid-30's. By 10:00 on the September 6, RH dropped to 7% and a wind gust of 41 mph was recorded the hour the Fourmile fire was reported.

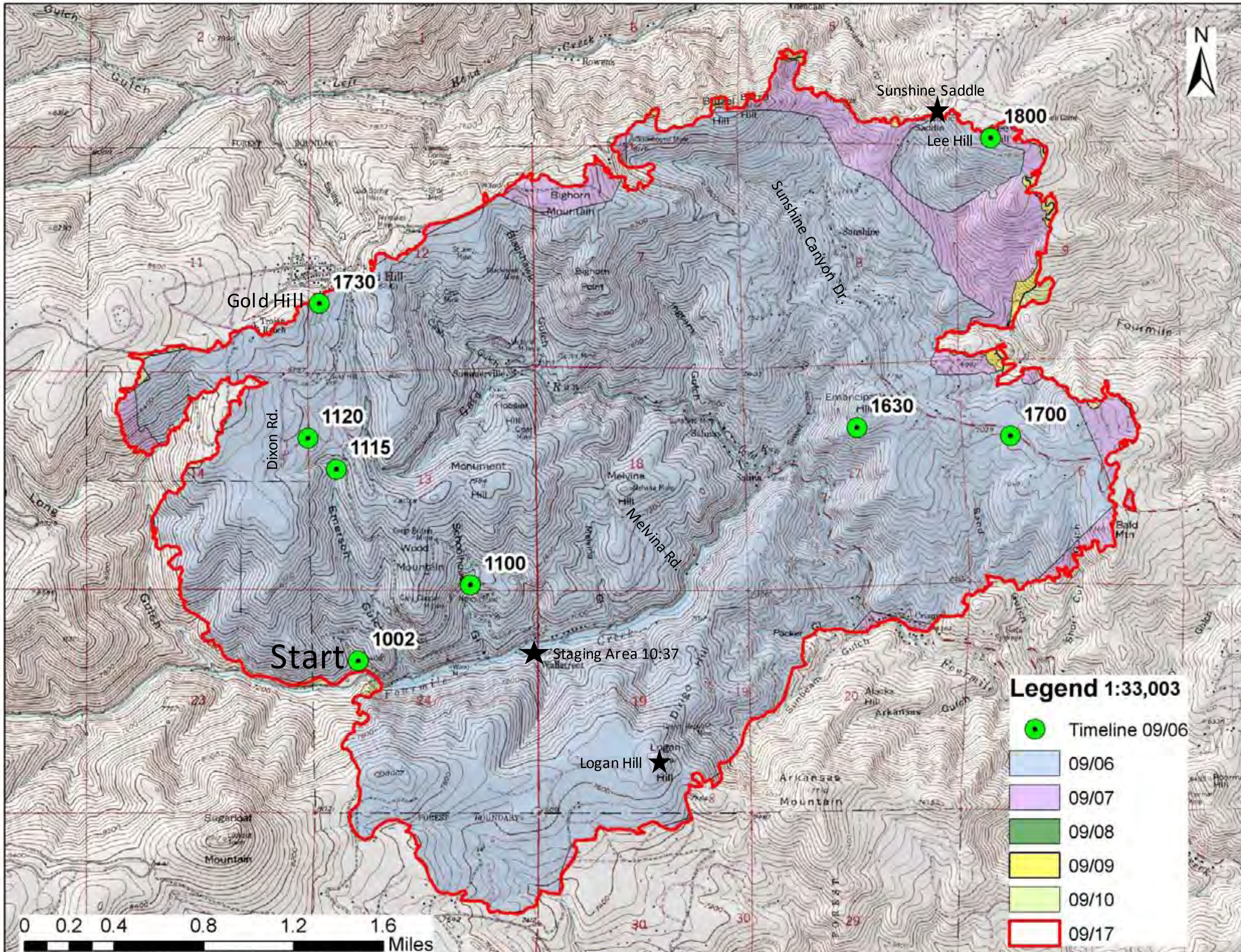


Figure 29. Daily progression of the Fourmile Canyon Fire. The points show the documented fire arrival times on September 6.

- 10:41 flames from below were approaching a home located on a ridge top at 300 Shinning Star Trail.
- 10:55 mandatory evacuation order is issued.
- 11:08 the Boulder County Emergency Operations Center (EOC) is opened.
- 11:14 Boulder County Type-3 Incident Management Team ordered.
- 11:15 fire was burning on the east side of Emerson Gulch and spotting 0.5 mile to the east of the Gulch.
- 11:16 the Incident Management Team (IMT-3) located at 5901 Fourmile Canyon Drive, ordered six structure defense engines and six type-6 engines.
- 11:23 fire crested the ridge near Gold Hill (Figure 29).
- 11:24 flames are located just above Wall Street.
- 11:29 fire is burning along Melvina road.
- 11:32 the fire is reported at 531 Left Fork Road and a home is burning.
- 11:33 Incident Command Post (ICP) and staging area are moved to the Boulder Mountain Lodge.
- 11:33 power is shut-off in Fourmile Canyon.
- 11:42 three houses confirmed destroyed on Melvina Hill road.
- 12:03 incoming units respond to Boulder County Justice Center (BCJC)
- 12:08 reverse 911 calls initiated for the Mountain Meadows area between Arkansas Mountain Road and Sugarloaf and Left Fork roads.
- 12:13 fire was burning near a house at 6556 Fourmile Canyon Road.
- 12:13 Incident Command Post and staging area are moved to the Boulder County Justice Center.
- 12:16 reverse 911 calls issued for a three mile radius around Gold Hill (Figure 29).
- 12:37 lost control of the fire along Mountain King Road.
- 12:41 fire was burning along Logan Mill Road.
- 13:15 fire has crossed Gold Hill Road.
- 13:00 Type-3 Incident Management Team (IMT-3) assumed responsibility for the fire.
- 13:08 Colorado Mountain Ranch was evacuated.

Fire Behavior

The fire was reported at approximately 10:02 on Monday September 6 near the mouth of Emerson Gulch (Figure 29). Fire investigators determined that it began as an escape from a debris-burning pile located on private property east of the Emerson Gulch road and a few hundred yards north of the intersection with Fourmile Canyon Road. Initial responders (including, but not limited to, Boulder County Sherriff's Office, Fourmile Fire District, Sugarloaf Fire District, Gold Hill Fire District, Sunshine Fire District, Colorado State Forest Service) reported flames spreading north and uphill on both sides of Emerson Gulch. Winds were westerly with gusts reported at 41 mph around 10:00 and relative humidity was 7% and descending (Figure 28). West winds and steep south facing slopes surrounding Emerson Gulch forced the fire to spread mostly to the north and east (Figure 29). Hourly moisture content of 1-hour fine fuels were estimated with Nelson's dead fuel moisture meter using weather readings from the Sugarloaf RAWS (Nelson, 2000). The 1-hour fuel moisture at ignition was estimated at 5% and dropped to 2% around 17:00. Observers noted rapid fire spread through the surface fuels in the open ponderosa pine forest with many torching trees and spot fires starting in advance of the fire front (Figure 30). However, tree damage and tree mortality caused by bark beetles had little to no effect on the wildland fuels burned by the Fourmile Canyon Fire, the fire's subsequent behavior, or the final fire size.

September 6, 11:20

Within the first 90 minutes, the fire was observed to have nearly reached Rim Road, about 0.5 miles south of the town of Gold Hill (Figure 29). It was also estimated to have moved east of the Nancy Mine road or perhaps halfway from the Nancy Mine Road to Melvina Road. The south-facing slopes were dominated by open ponderosa pine forests, with some patches or stands having closed canopies. Rocky Mountain juniper trees and common juniper shrubs were also present. Surface fuels in these ponderosa pine forests consisted of perennial grasses, cheat grass, mountain mahogany shrubs, and an abundant amount of pine needles and small branches(Figures 5-7). Fire spread along these south slopes on the surface carried primarily by the grasses with frequent torching of overstory trees (Figures 25, 30). Continuous flame zones developed in the deep needle litter resulting in burning the crowns of the overstory trees (Figure 31). Active crown fire runs also occurred, primarily where the forests were of such density that continuous crown fire could be sustained (Figure 32). Within this same time frame the fire spotted to the south side of Four Mile Creek from where it started and burned uphill torching and crowning the predominantly Douglas-fir tree canopies (Figure 29).

September 6, 12:00

By noon on September 6, the fire had closed to within a few hundred yards of Dixon Road on the north, crossed Melvina Road to the ridge west of Salina on the east, and was probably nearing the ridge west of Logan Hill to the south (Figure 29). It was estimated to be about 3,000 acres by the Incident Management Team. Despite the rapid progress to the east, the fire had not burned into the bottom of Fourmile Canyon, as it was slowly backing downhill into Wall Street on the south facing slope after 13:30 (Figure 33). By ascending the walls of the Fourmile Canyon and reaching the ridges, the fire front was more fully exposed to the strong winds at ridge tops but lacked the alignment of slope and channeling winds through valleys that caused such rapid spread rates seen earlier in the day. Spotting was prevalent from embers generated by the wholesale torching of trees (Figure 25) and spotting distances estimated to be occurring readily at 0.5 miles ahead of the fire front. The spotting allowed the fire to overwhelm and breach the broken topography and fuel changes as the fire spread in an easterly direction (Figure 29). The north-facing slopes of Blackhawk Gulch, Cash Gulch, Gold Run, and smaller unnamed drainages north of Melvina Road exhibited much lower fire intensity because the short-needled Douglas-firs dominated these forests. In addition, these forests tend to be moister than the ponderosa pine forests and the topographic orientation was counter to the direction of the prevailing winds (Figures 18, 29). This vegetation-topographic pattern was evident throughout the Fourmile burn area, and was more distinct than any possible effects of fuel modifications or suppression activities on the fire. In fact, most of the north facing forests occurring along Fourmile Creek remained untouched by fire (Figure 34). Along the ridgeline south of Fourmile Creek, crown fire and torching occurred because of the greater exposure to the wind than along the valley floor and because ponderosa pine forests dominated (Figures 5, 18, 29, 34).

Figure 30. The fire was spreading rapidly and burning with high intensity shortly after it started near the mouth of Emerson Gulch. Photos: Wineteer (top), Rod Moraga (bottom).

Figure 31. Deep flame zones develop beneath ponderosa pine trees and forests because continuous litter and woody surface fuels burn for much longer than grasses. This ultimately results in igniting and torching trees. Photos: Mike Tombolato (top), Unknown (bottom).

Figure 32. Crown fires burned where dense and continuous tree crowns occurred fueled by abundant surface fuels. Photos: Greg Cotopassi (top), Mike Tombolato (bottom).

Figure 33. Fire burning east of Emerson Gulch in the area of Wall Street. Note these surface fires are backing down hill. Photos: Mike Tombolato.

Figure 34. Canyon and valley bottoms, for the most part, did not burn with high intensities. The top scene is an example of high intensity burning on the slopes and ridges above the valley bottom. Homes above the bottoms had a greater chance for high intensity wildfire exposures. (Fourmile Canyon Fire photo). The bottom scene shows north-facing slopes that did not experience high intensity burning. Photo: Chuck McHugh.

September 6, 12:00-20:00

The fire reached Sunshine Canyon Drive by 14:00 as a surface fire and by spotting (Figure 29). At 11:32 the fire had not reached Dixon Road and took it took until 17:30 to reach Gold Hill (Figure 29). The long time required for the fire to move from Dixon Road to Gold Hill was probably because strong west winds kept the north edge burning as a flanking fire (Figures 18, 29). Nevertheless, trees torched because they had low crowns and there was abundant surface fuel (Figure 25). These surface fuel conditions allowed for long-duration intense burning by the fire. At about 16:30, the fire was burning actively on the south side of Sunshine Canyon Drive near Emancipation Hill (Figure 29). Most likely by spotting to the north of Emancipation Hill, the fire crossed Sunshine Canyon Drive prior to 16:30. Spotting advanced the fire to the communication antennas on Lee Hill by 18:37 (at the extreme northeast corner of the fire) (Figure 29) and burned most of the grassy slopes near the antennas **(**Figure 35). This burning exemplifies how far the fire was able to spot as the west slope of Lee Hill was disconnected from the main fire front that was stalled near the bottom of Sunshine Canyon (Figure 29). Here again, the north facing slopes along Sunshine Canyon experienced low fire intensity and low burn severity because of topographic sheltering, presence of Douglas-fir forests, and helped by moderating weather conditions (increasing relative humidity and reduced wind speeds). At the end of September 6 (or one burning period) the fire had burned approximately 5,733 acres or 93% of the total fire area.

September 7

The fire spread very little on September 7. The burning that did occur was primarily burning islands of vegetation left behind by the spot-driven fire spread on September 6 and burning on the perimeter near Buetzel Hill, the Lee Hill Antenna site, and below Sunshine Saddle. Only 375 acres are known to have burned on September 7, increasing the fire size to 6,108 acres.

September 8

On September 8, the air relative humidity was higher and the air temperature cooler than previous days and 0.08 inches of rain fell at the Sugarloaf RAWS. These conditions allowed additional fire control lines to be constructed and others strengthened. As such, there was minimal fire growth and the fire size remained at 6,108 acres.

September 9

A Red Flag warning was issued for September 9 for high and gusty winds, high air temperatures, and low air relative humidity beginning at 18:00. By 15:00 the speed of westerly winds increased and the relative humidity dropped below 20%. This caused torching of unburned vegetation located in the interior of the fire. South of Lee Hill and in the West Coach Road area, sustained winds of 40 mph and a peak wind gust of 64 mph were reported. These conditions created a spot fire outside of the perimeter control lines of 2-3 acres. This spot was the last perimeter expansion of the fire. Fire size at the end of the day was 6,131 acres based on corrected infrared mapping.

Figure 35. Burned grass surrounding the Lee Hill antennas after 18:37 on September 6. Photo: Mike Tombolato.

September 10

The Red Flag warning that began on September 9 remained in effect for September 10 until 18:00. Observed air relative humidity was in the mid-teens, air temperatures in the mid-sixties to low seventies (degrees F), and peak wind gusts were blowing in the mid to high twenties (mph) during the afternoon. However, no significant fire growth occurred and the final fire size on September 10 was 6,181 acres based on corrected infrared mapping.

September 11 and Later

The fire did not increase in size after September 10 in spite of very unstable and dry air occurring over the fire area on September 12 and 13 as indicated by a forecasted Haines index of 6. In addition, strong west winds blew on September 15 with little impact. The fire was declared 100% contained on September 13.

Fire Suppression

Multiple data sources were employed to describe the suppression activities used on the Fourmile Canyon Fire. For aerial resources, spatial drop locations were obtained from the Operational Loads Management Study (OLMS). All federal contract Large Air Tankers (LATs) collect these data, except for Tanker-48. Single engine aerial tankers (SEATS) are also not included in the OLMS data. Data from the Aviation Business System (ABS), the I-Suite incident data for the Fourmile Canyon Fire, daily use summaries submitted to the Fourmile Canyon Fire Incident Management Teams, and the daily load sheets from the air tanker bases were also incorporated. Additional information on suppression activities were obtained from the daily Incident Action Plans, Unit Logs, interviews with on-scene personnel, and the incident narratives of Richardson's Type-2 IMT Rocky Mountain Team A and Thomas's Type-1 IMT Great Basin Team.

September 6

When the fire was discovered on September 6, aircraft were ordered for initial attack. However, flying was unsafe because of the high wind speeds, and all aircraft were grounded until 17:00. At 11:15 a SEAT (AT-878) was ordered but then cancelled because of the high winds. The fire was rapidly spreading in multiple directions (north towards Gold Hill, to the south towards Sugarloaf and to the east down Fourmile Canyon above Wall Street), and a consolidated suppression effort focusing on perimeter control could not be established (Figures 29-33). At this time suppression efforts concentrated on evacuations, protection of structures when and where feasible, and the control, status, and assignment of incoming resources (Figure 36). By mid-afternoon isolated protection of homes by engines and crews was accomplished along Dixon Road, in the area of the Colorado Mountain Ranch, the town of Gold Hill, Sugarloaf area, and along the north side of Wall Street (Figures 9, 29, 36). It is quite likely that other isolated and undocumented point protection and suppression efforts were taking place.

In the evening (17:00) of September 6, there was a decrease in wind speed and a subsequent shift in wind direction (from west to east) that allowed aircraft to fly for approximately three hours. At

Figure 36. Managing and coordinating resources dispatched to the fire were a major task during the initial attack. Photos: Wineteer.

17:30, tanker 25 and AT-878 dropped retardant to the west of Gold Hill (Figure 37). These drops, in conjunction with a wind shift and ground resources, were attributed to saving Gold Hill from burning. Also, during the evening a total of nine loads were dropped by tankers 25 and 45 near Bald Mountain, located on the eastern perimeter of the fire (Figure 37). The retardant lines created by the air tankers connected to an area where the fuels had been treated in the Boulder County Open Space lands. Drops were also made in the Camino Bosque and Arroyo Chico area (Figure 37). AT-878, a SEAT, also made five drops in the same areas between 18:00 and 20:00 (Figure 37). A total of 25,605 gallons of retardant were dropped during this short period.

September 7

Suppression concentrated on structure protection and occurred where fire behavior allowed for fire fighter safety. In particular, efforts were made to contain the fire south of Lefthand Canyon, east of Mount Alto, north of Boulder Creek, and west of Poorman, Sunshine, Pine Brook Hills, and Lee Hill (Figure 29). Ground crews worked to contain the fire in the area near Lee Hill and south towards Bald Mountain.

Crews working along County Road 83 in the Whispering Pines and Sunshine area had to quit protecting structures between 13:00 and 16:00 because of high intensity and fast spreading fire moving towards Butzel and to southeast of the Lee Hill antenna site. However, crews were able to resume protecting structures in this area when fire behavior moderated. Similarly, because of the fire conditions, a strike team of engines working in the Church Camp area withdrew to the number 2 Boulder Heights Fire District Station. Air tankers were used heavily during this time on the eastern flank (Figure 37).

The flying conditions on September 7 were more favorable with a total of 44 loads (92,446 gallons or 53% of the total) of retardant dropped by one SEAT and seven air tankers. Between the hours of 12:39 and 16:17 numerous drops were made from Lee Hill south towards Bald Mountain. Both of these areas are located on the eastern perimeter of the fire (Figure 38). These drops on the eastern perimeter formed a containment line that was to reinforce hand-lines constructed by crews when they became available (Figures 37, 38). Multiple drops were also made between 17:00 and 18:00 west of Gold Hill near the Colorado Mountain Ranch (Figures 38, 39). One Type-1 and one Type-2 helicopters dropped a total of 61,040 gallons of water throughout the area. Richardson’s Type -2 Incident Management Team assumed command of the fire at 18:00.

September 8

On September 8, weather conditions were favorable for fire suppression as the air relative humidity was in the range of 30%, light winds were blowing, and 0.08 inches of rain fell at the Sugarloaf RAWS between 16:00 and 17:00 (Figures 17, 28). Suppression focused on point and structure protection based on fire behavior and public and firefighter safety. Homes within the fire perimeter and those in or nearby subdivisions (e.g., Pinebrook and Boulder Heights) immediately adjacent to the fire perimeter were prioritized for protection. Hand-line construction continued in the Sunshine Saddle area on the northeastern perimeter of the fire (Figure 29).

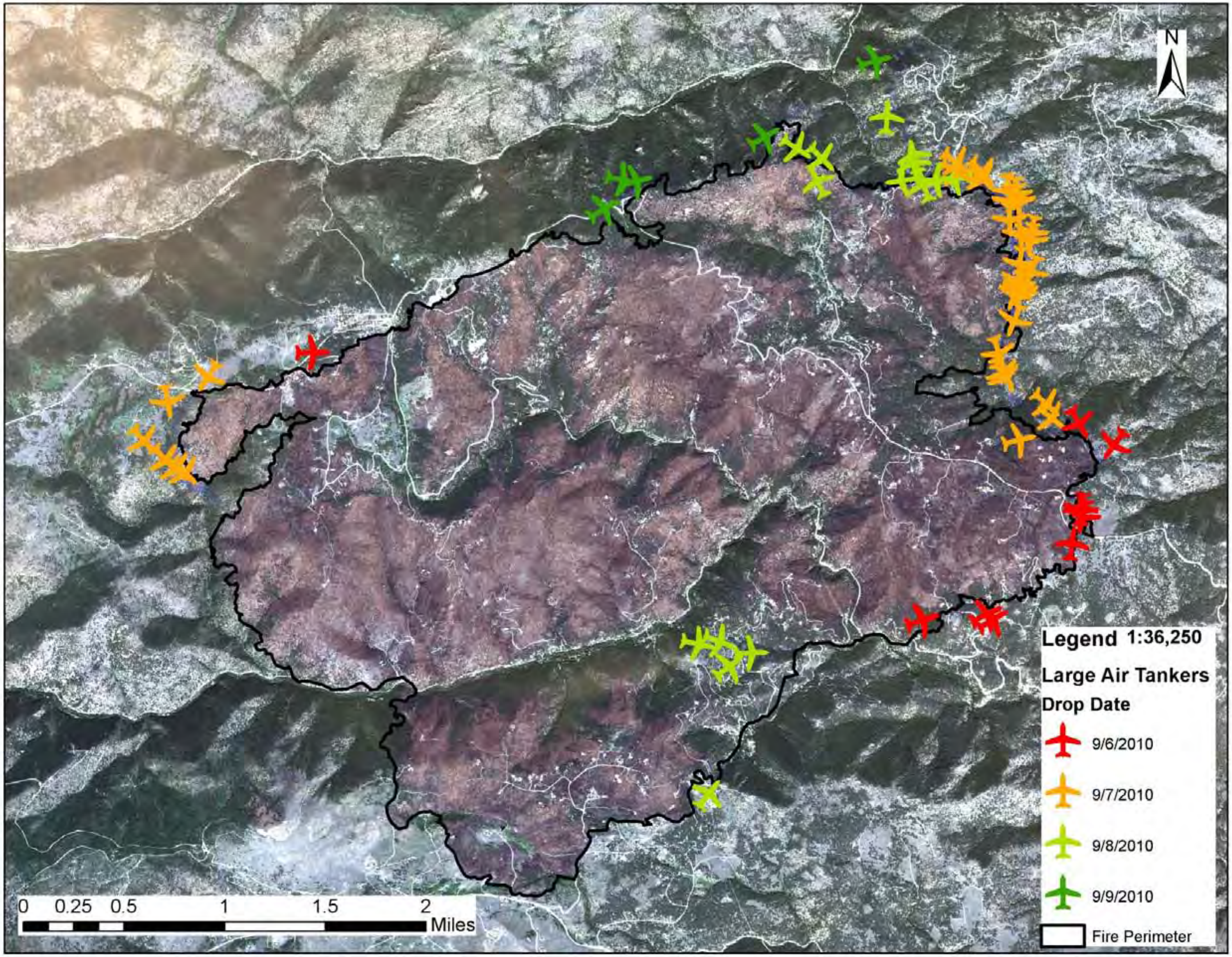


Figure 37. Summary of daily large air tanker activity on the Fourmile Canyon Fire. The figure does not include helicopters or single engine air tankers (SEATS) or Tanker-48. Background is a WorldView satellite image from Digital Globe and is from September 12, 2010 at 11:59.

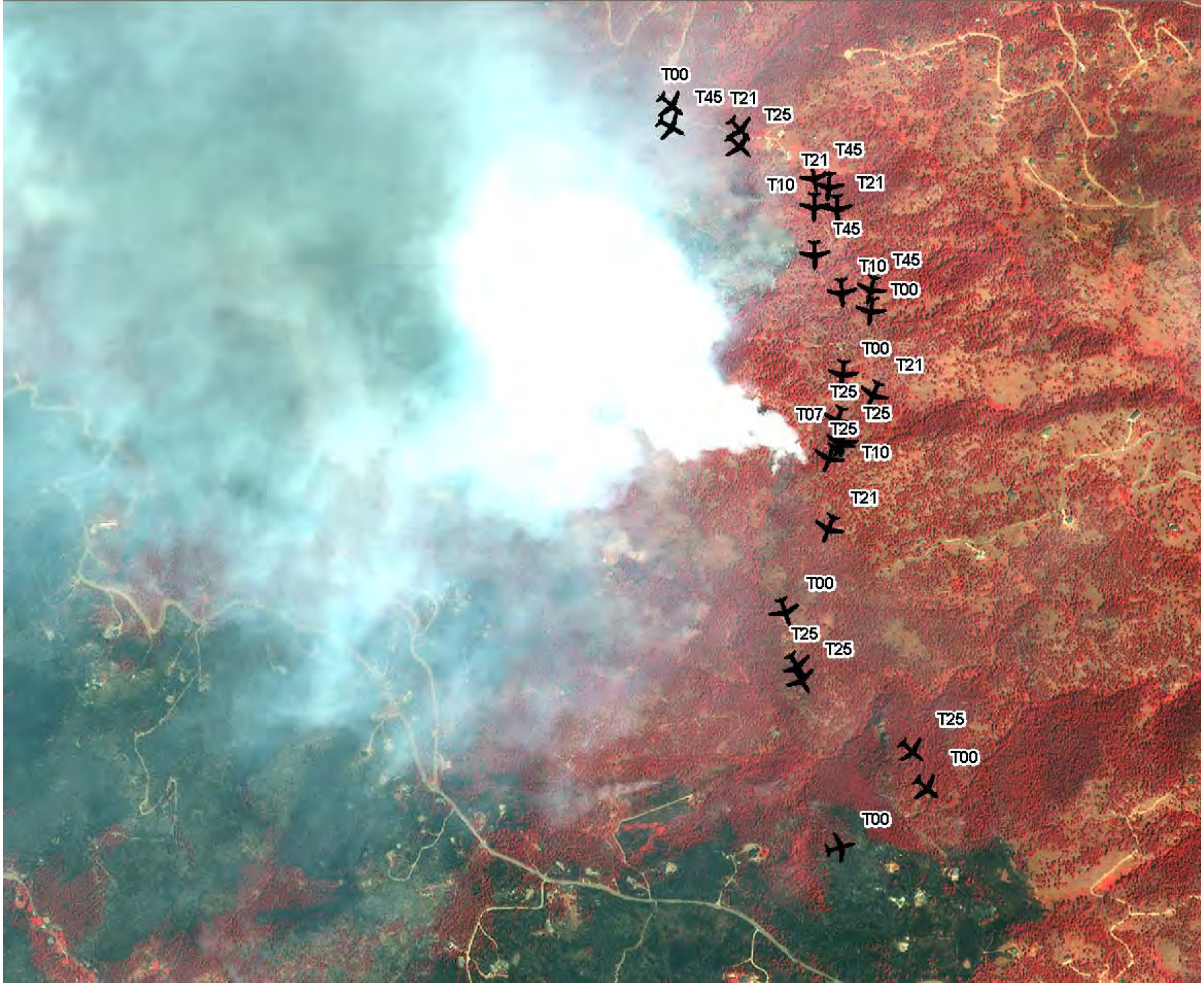


Figure 38. Retardant was dropped in the Sunshine Canyon area on the eastern perimeter of the fire on September 7 between 12:39 and 16:17. The fire made two small runs in the area between 13:00 and 16:00 necessitating the withdrawal of ground forces. Background is a Quick Bird satellite image from Digital Globe taken at 11:42 on September 7, 2010.

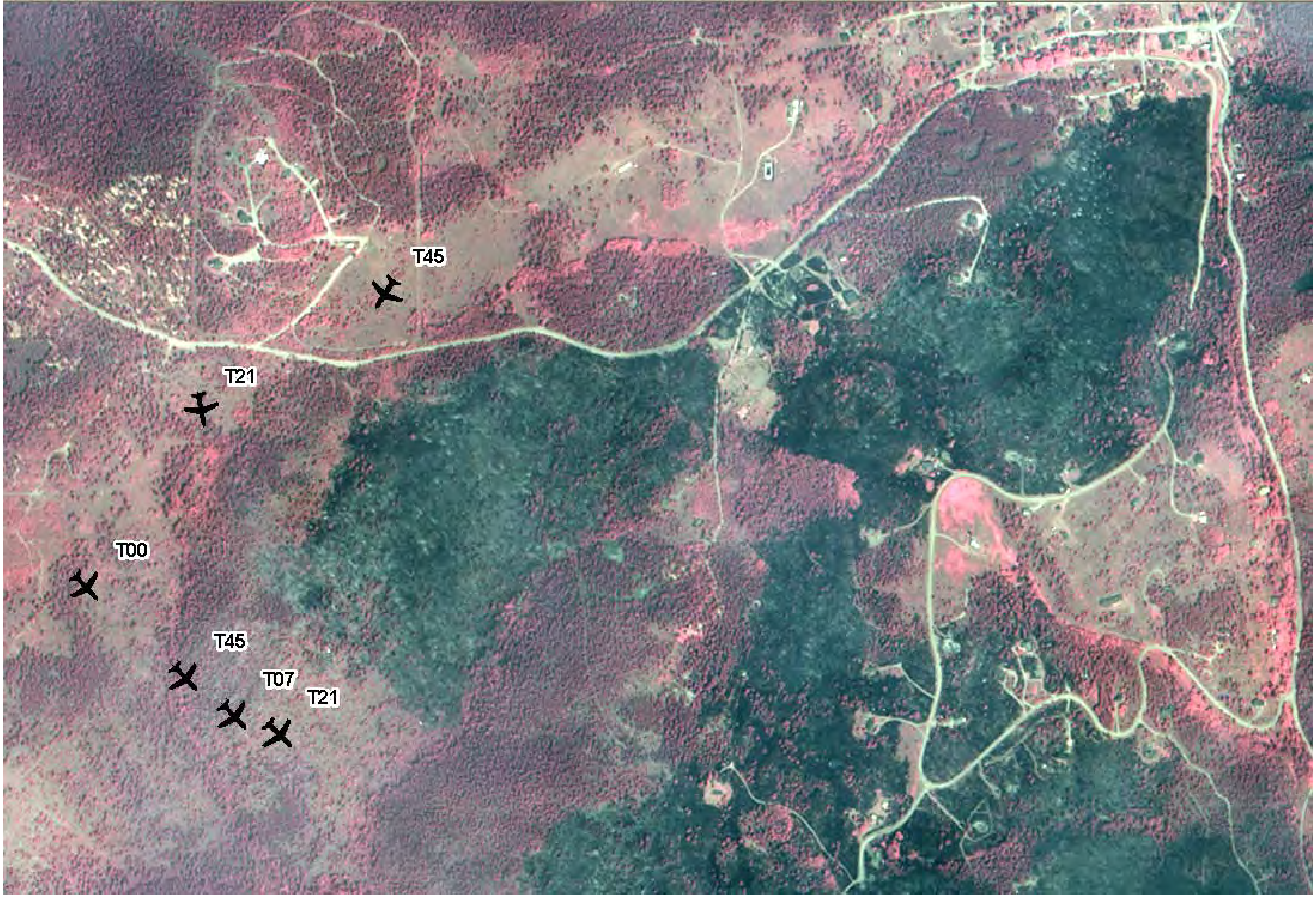


Figure 39. On September 7 retardant was dropped west of Gold Hill and Colorado Mountain Ranch. All drops occurred between 17:00 and 18:00. Background image is a Quick Bird satellite image from Digital Globe taken at 11:42 on September 7.

Ten loads of retardant were dropped between 14:02 and 16:05 in the Boulder Heights area (Figure 40). These drops were connected to an area where the fuels had been treated below the housing subdivision. An additional five drops were made in the Logan Mill area between 10:34 and 11:25 (Figure 41). Twenty two loads of retardant were dropped, totaling 44,741 gallons. The SEAT (AT-878) and Tanker 48 also made one and five drops respectively. However, spatial information on where they dropped this day was not available. Additionally, one Type-1 and one Type-2 helicopters dropped a total of 60,840 gallons of water.

September 9

On September 9, suppression focused on points and homes located within and adjacent to the fire perimeter. Hand-line construction continued near Sunshine Saddle and several retardant drops were made in the area (Figures 29, 37). Five drops (11,357 gallons) were made by five tankers in the vicinity of Snowbound Mine, Butzel Hill, and Boulder Heights between 11:43 and 12:48 (Figure 42). These were the last retardant drops made on the Fourmile Canyon Fire. Crews working in this area used a combination of hand-line, check-line, and cold trailing supported by helicopter water drops and retardant. Three Type-1 and one Type-2 helicopters dropped a total of 79,150 gallons of water.

Thomas’s Type-1 IMT assumed command of the fire at 18:00 on September 9 as crews were changing. At this time, the wind speeds dramatically increased and the air relative humidity dropped below 20%. As such, the intensity of the fire increased in many places requiring the shift-length of the day-crews to be extended. The increased fire intensity initiated coordination with the Boulder City Fire Department in the event that the fire advanced towards Boulder. During the night a spot fire of two to three acres in size was burning across the containment line near the end of West Coach Road. This fire was contained very early in the morning of September 10.

September 10

A Red Flag warning for low air humidity and strong westerly winds until 18:00 was issued on September 10. Strong (10 to 13 mph average with 20 to 29 mph gusts) winds were observed at the Sugarloaf RAWS) from 10:00 to 17:00 and temperatures remained in the 68 to71^{o} F range. However, the air relative humidity never dropped below the mid-teens during the day. Suppression priorities remained for point and home protection throughout the fire area. In particular, efforts were made to contain the fire in the Sunshine Saddle area and keep the fire as near to its existing size as possible (Figure 29). A Type-1 helicopter dropped 10,800 gallons of water and a Type-3 helicopter flew one reconnaissance flight during the day. By mid afternoon all air operations were suspended due to the high winds.

September 11

On September 11 fire suppression focused on protecting the large unburned islands of vegetation, if ignited, would pose a threat to many of the residential areas. Night crews were significantly reduced, consisting mainly of patrols by engines. Three Type-1 and one Type-2 helicopters dropped a total of 51,200 gallons of water.

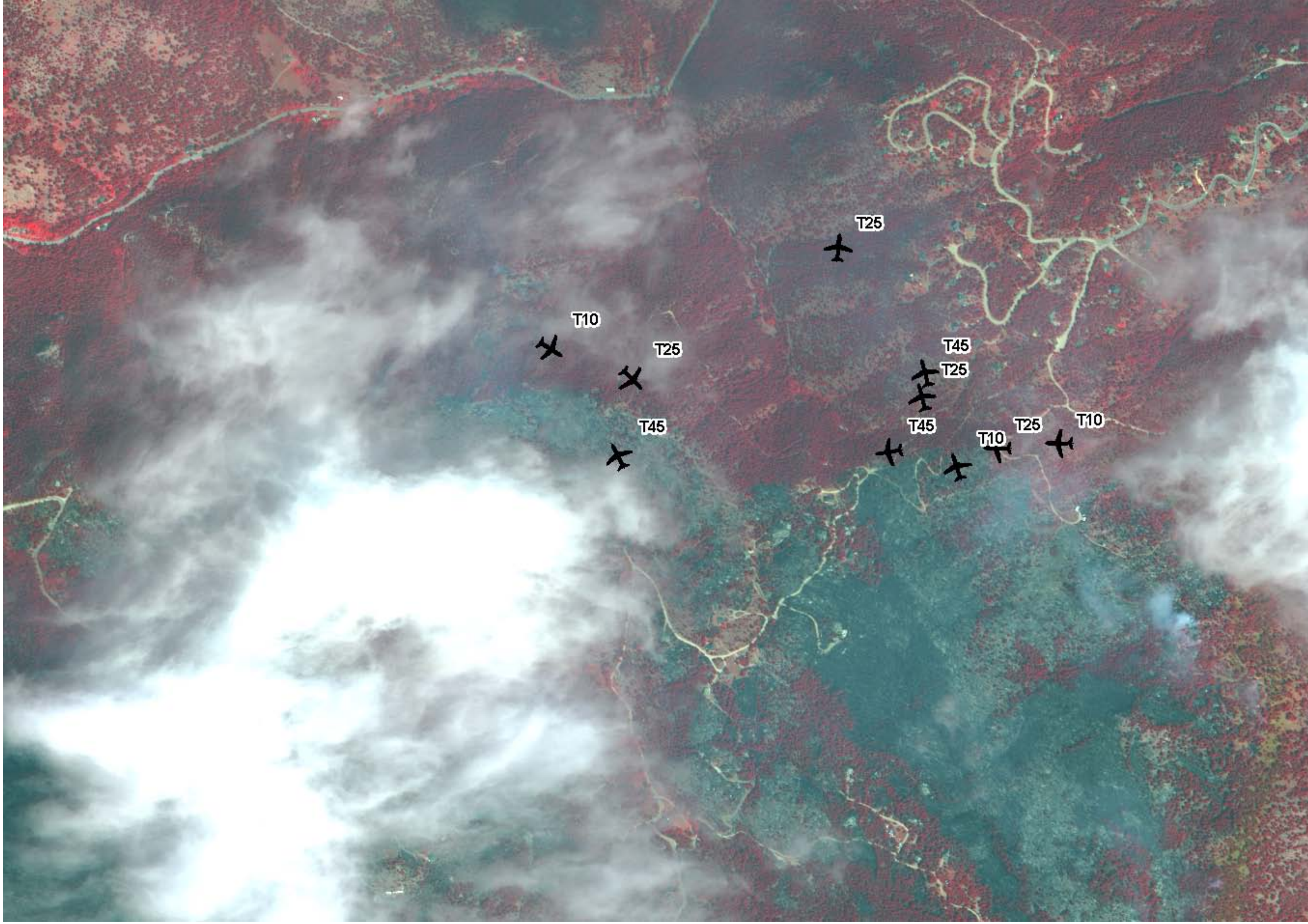


Figure 40. On September 8 ten retardant drops were made adjacent to the Boulder Heights subdivision between 14:02 and 16:05. Backdrop is a GeoEye-1 satellite image taken at 12:08 on September 8, 2010.

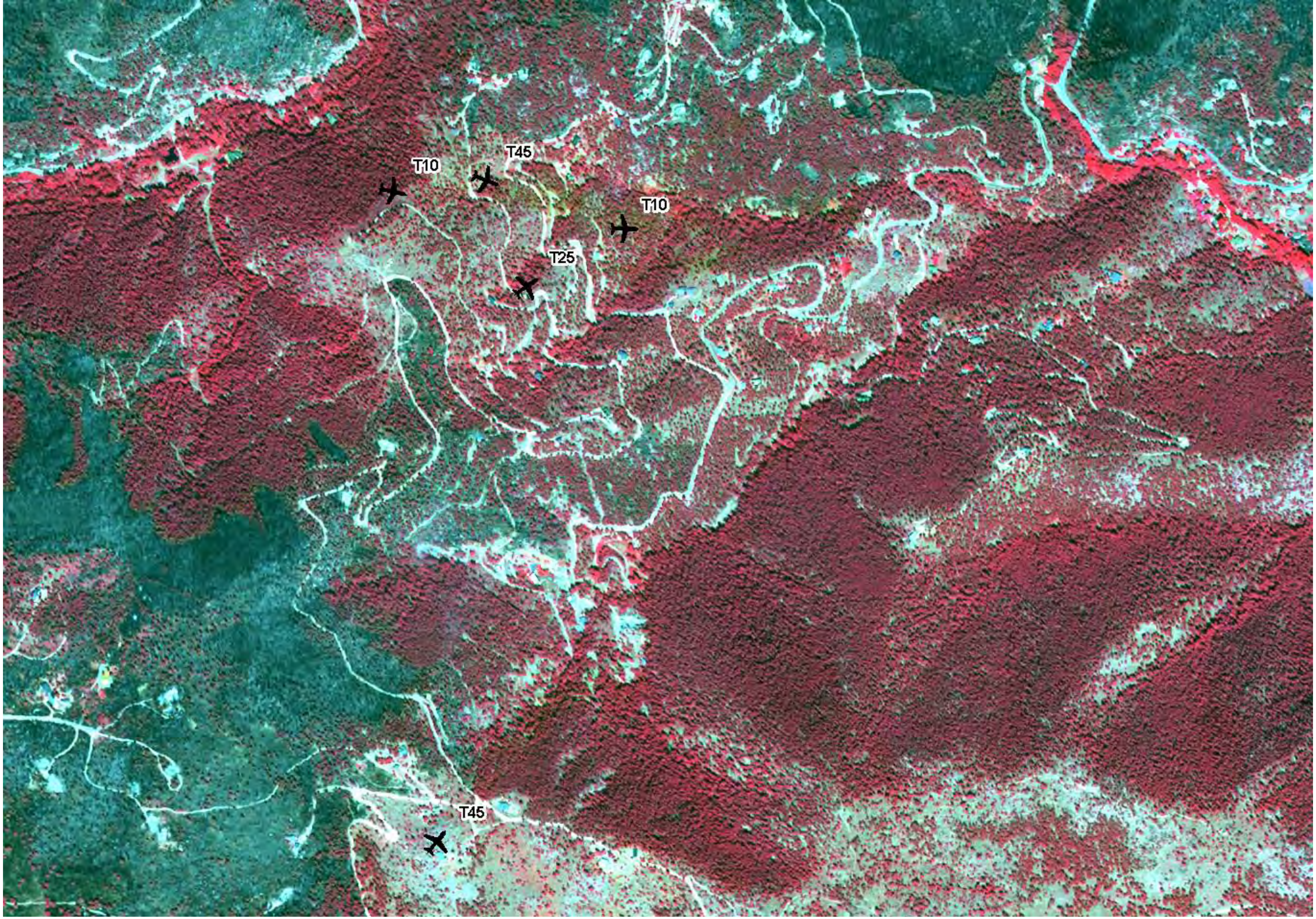


Figure 41. On September 8 several retardant drops were made in the Logan Mill Area . This area was under clouds in available satellite images for September 8, 2010. Background image displayed is a GeoEye-1 satellite image from September 10, 2010 at 11:42. Yellow paths in the image are retardant. A total of 5 drops were made in this area between 10:34 and 11:25.

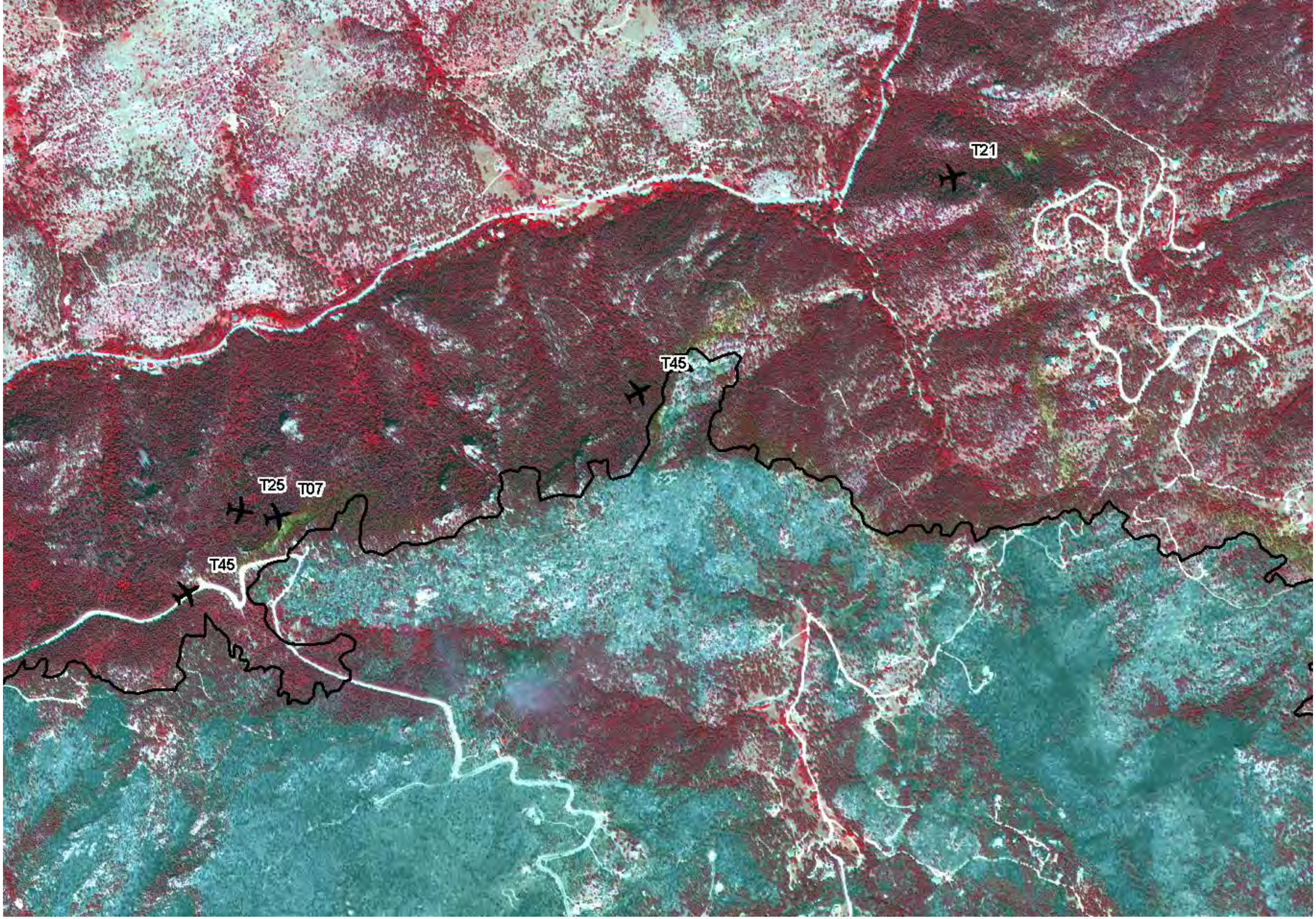


Figure 42. On September 9 a total of five retardant drops were made in the area of Snowbound Mine, Butzel Hill, and the Boulder Heights subdivision between 11:43 and 12:48. Background image is a satellite image by GeoEye-1 taken on September 10, 2010 at 11:42.

September 12

Although dry and unstable air (Haines Index of 6) was present over the fire area, minimal flaming occurred or smoke was generated. As such, no real suppression challenges were presented and no additional perimeter growth occurred. Thomas's IMT was ordered to take on the Reservoir Road Fire, a new start some 12 miles north of the Fourmile Canyon Fire. Numerous ground and air resources were reassigned from the Fourmile Canyon Fire to the Reservoir Road Fire, including the three Type-1 and one Type 2 helicopters. The remaining Type-3 helicopter on the Fourmile Canyon Fire dropped 1,700 gallons of water.

September 13-17

On September 13 suppression focused on locating and extinguishing hot spots and the night shift was reduced to a Division Supervisor and two engines. Suppression focused on completing the mop-up of the fire and the rehabilitation of dozer and hand-lines throughout the fire area. On September 14 the remaining two helicopters dropped the last 8,040 gallons of water throughout the fire area. The fire was declared 100% contained at 18:00 on September 13 with command of the fire transferred back to a local Type-4 IMT at 06:00 on September 17.

Aerial Resources

Because of the high winds, aerial resources (fixed wing and rotor) were used minimally for initial attack on September 6. That evening, when the winds shifted and moderated two large air tankers and one SEAT dropped 25,605 gallons of retardant in the Gold Hill and Bald Mountain areas. Air operations were also suspended on September 10 because of the high wind speeds. A total of 86 loads of retardant totaling 174,149 gallons of were dropped from both large air tankers and one SEAT from September 6 through 9 (Table 1). The majority (78.7%) of the total retardant used on the fire was dropped on September 7 and 8, after most fire spread had occurred.

Type 1, 2, and 3 helicopters were used on the fire beginning on September 7 through September 15. These helicopters dropped 272,770 gallons of water (Table 2). The extensive road network afforded access to the area and only 3,400 pounds of cargo and 93 passengers were flown. The passengers were primarily on reconnaissance flights.

Table 1. The cost of retardant used on the Fourmile Canyon Fire from September 6 through 9, 2011.

Date	Tanker Number	Type	Retardant Cost	Flight Cost	Other Costs	Total Cost	Flight Hours	Gallons Retardant	Number Loads
09/06/10	T-25	P3	25,348.00	15,950.52	387.00	41,685.52	2.43	12,674	5
09/06/10	T-45	P2V	16,562.00	19,410.57	516.00	36,488.57	3.33	8,281	4
09/06/10	AT-878[1]	Seat	9,300.00	6,994.63	132.00	16,426.63	3.05	4,650	6
Daily Total			51,210.00	42,355.72	1,035.00	94,600.72	8.81	25,605	15
09/07/10	T-25	P3	30,600.00	23,896.12	516.00	54,012.12	3.38	15,300	6
09/07/10	T-45	P2V	30,404.00	26,246.22	516.00	57,166.22	4.18	15,202	7
09/07/10[1]	AT-878	Seat	4,732.50	6,857.03	132.00	11,721.53	2.99	4,575	6
09/07/10	T-48	P2V	24,790.00	18,578.25	516.00	43,884.25	3.45	12,395	6
09/07/10	T-10	P2V	16,066.00	18,020.73	516.00	34,602.73	2.87	8,033	4
09/07/10	T-21	P2V	30,418.00	20,999.40	516.00	51,933.40	3.10	15,209	6
09/07/10	T-00	P3	35,192.00	27,299.22	516.00	63,007.22	4.03	17,596	7
09/07/10	T-07	P2V	8,272.00	9,920.82	516.00	18,708.82	1.58	4,136	2
Daily Total			180,474.50	151,817.79	3,744.00	335,036.29	25.58	92,446	44
09/08/10	T-25	P3	25,442.00	12,735.12	172.00	38,349.12	1.88	12,721	5
09/08/10	T-45	P2V	20,838.00	15,571.92	172.00	36,581.92	2.48	10,419	5
09/08/10	AT-878	Seat	602.00	1,444.79	176.00	2,222.79	0.63	700	1
09/08/10	T-48	P2V	20,864.00	14,162.55	172.00	35,198.55	2.63	10,432	5
09/08/10	T-10	P2V	20,802.00	13,311.48	172.00	34,285.48	2.12	10,401	5
09/08/10	T-07	P2V	136.00	1,255.80	172.00	1,563.80	0.20	68	1
Daily Total			88,684.00	58,481.66	1,036.00	148,201.66	9.94	44,741	22
09/09/10	T-25	P3	5,110.00	4,199.88	258.00	9,567.88	0.62	2,555	1
09/09/10	T-45	P2V	8,348.00	5,839.47	258.00	14,445.47	0.93	4,174	2
09/09/10	T-21	P3	5,100.00	3,590.22	258.00	8,948.22	0.53	2,550	1
09/09/10	T-07	P2V	4,156.00	4,269.72	258.00	8,683.72	0.68	2,078	1
Daily Total			22,714	17,899.29	1,032.00	41,645.29	2.76	11,357	5
Total			343,082.5	270,554.46	6,847.00	619,483.96	47.09	174,149	86

Information was developed using Daily Cost Summary data from the fire records box and data in the Fourmile Canyon Fire Incident I-Suite archived database. Table does not reflect the total costs for Large Air Tankers on the Fourmile Canyon Fire. Table only shows costs associated with missions of retardant delivery for those days during the fire.

[1]All daily SEAT data based on invoices obtained from the Colorado State Forest Service. In the incident I-Suite database SEAT entries were combined into a single day entry on 09/09/10 based on the same daily invoices.

Table 2. Costs of helicopters used on the Fourmile Canyon Fire distributed by type from September 7 through 12, 2010.

Date	Number	Type	Flight Costs	Other Costs	Total Costs	Flight Hours	Water (gal.)	Passengers (#)	Cargo (lbs)
09/07/10	N173AC	HEL1	58,348.00	0.00	58,348.00	7.90	50,000		
09/07/10	N28HX	HEL2	12,352.00	0.00	12,352.00	6.60	11,040	6	600
09/07/10	N722LM	HEL3	6,412.00	0.00	6,412.00	3.20		6	300
Daily Total			77,112.00	0.00	77,112.00	17.7	61,040	12	900
09/08/10	N173AC	HEL1	42,983.00	0.00	42,983.00	5.80	51,000		
09/08/10	N28HX	HEL2	9,438.00	0.00	9,438.00	5.30	9,840	4	600
09/08/10	N722LM	HEL3	4,619.00	0.00	4,619.00	1.70		8	
Daily Total			57,040.00	0.00	57,040.00	12.80	60,840	12	600
09/09/10	N173AC	HEL1	40,857.00	0.00	40,857.00	5.50	32,000		
09/09/10	N719HT	HEL1	27,510.00	0.00	27,510.00	3.60	27,600		
09/09/10	N715HT	HEL1	30,917.00	0.00	30,917.00	3.80	12,350		
09/09/10	N28HX	HEL2	7,577.00	0.00	7,577.00	4.20	7,200	2	200
09/09/10	N722LM	HEL3	6,084.00	0.00	6,084.00	3.40		8	
Daily Total			112,945.00	0.00	112,945.00	20.50	79,150	10	200
09/10/10	N173AC	HEL1	0.00	1,884.00	1,884.00				
09/10/10	N719HT	HEL1	14,446.00	0.00	14,446.00	1.70	10,800		
09/10/10	N715HT	HEL1	0.00	2,000.00	2,000.00				
09/10/10	N28HX	HEL2	0.00	942.00	942.00				
09/10/10	N722LM	HEL3	0.00	3,843.00	3,843.00	0.80		3	
Daily Total			18,289.00	4,826.00	23,115.00	2.50	10,800	3	0
09/11/10	N173AC	HEL1	16,056.00	0.00	16,056.00	2.00	12,000		
09/11/10	N719HT	HEL1	14,940.00	0.00	14,940.00	1.80	10,800		
09/11/10	N715HT	HEL1	26,492.00	0.00	26,492.00	3.40	26,000		
09/11/10	N28HX	HEL2	3,186.00	0.00	3,186.00	1.40	2,400	2	200
09/11/10	N722LM	HEL3	4,360.00	0.00	4,360.00	1.40		6	
Daily Total			65,034.00	0.00	65,034.00	10.00	51,200	8	200

Table 2. Costs of helicopters used on the Fourmile Canyon Fire distributed by type from September 7 through 12 (continued).

Date	Number	Type	Flight Costs	Other Costs	Total Costs	Flight Hours	Water (gal.)	Passengers (#)	Cargo (lbs)
09/12/10	N722LM	HEL3	6,062.00	1,175.00	7,237.00	3.20	1,700	8	
Daily Total			6,062.00	1,175.00	7,237.00	3.20	1,700	8	0
09/13/10	N28HX	HEL2	2,224.00	0.00	2,224.00	0.80		4	200
09/13/10	N722LM	HEL3	7,785.00	0.00	7,785.00	5.20		10	
Daily Total			10,009.00	0.00	10,009.00	6.00	0	14	200
09/14/10	N28HX	HEL2	5,751.00	0.00	5,751.00	3.00	5,040	12	1200
09/14/10	N722LM	HEL3	6,252.00	0.00	6,252.00	3.30	3,000	7	
Daily Total			12,003.00	0.00	12,003.00	6.30	8,040	19	1200
09/15/10	N28HX	HEL2	1,357.00	0.00	1,357.00	0.50		5	100
09/15/10	N722LM	HEL3	4,079.00	0.00	4,079.00	0.90		2	
Daily Total			5,436.00	0.00	5,436.00	1.40	0	7	100
Total			363,930.00	6,001.00	363,930.00	79.80	272,770	93	3,400

Information developed using Aviation Business System (ABS) records, Daily Cost Summary data from the fire records box and data in the Fourmile Incident ISuite archived database.
Other Costs: are costs associated with standby
Total Costs does not include the daily availability rate.
Water delivered should be considered an estimate and is likely low as this entry was often incomplete by individual ship.

Fuel Treatment Efficacy

Approximately 600 acres of fuel treatments had been performed within the area ultimately burned by the Fourmile Canyon Fire (Figures 21, 43). After any fire, little evidence remains of when and how treatment units were encountered and burned. This creates considerable uncertainty as to the explanations behind what can be observed post-fire. For example, treatment effects can be very different if the fire was heading (with the wind and or slope), flanking, backing down slope, or if it burned as a result of a mass ignition by spotting (Figures 30, 32, 33). Fuel treatment performance can only be evaluated post-fire based on evidence of changes in fire effects on residual vegetation and sometimes changes in fire progression. It was clear from photographic evidence that pervasive spotting (0.5 mi at 1000 and 1.0 mi by 1400 on September 6) during the Fourmile Canyon Fire allowed the fire to easily breach the narrow fuel treatments located throughout the area where the fire burned (Figure 21, 43).

No evidence that fire progression was altered by treatments was found and the treated areas were probably of limited value to suppression efforts on September 6 because of the intense fire behavior (Figure 32). In some cases the fuel treatments were noted as being ineffective in changing fire behavior because of the large amount of surface fuels present, and because they were not maintained (Boulder Incident Command Team 2010) (Figures 23, 31). Firelines were built in fuel treatment areas on September 8 near Church Camp, but the fire never reached these areas and the final fire perimeter was not coincident with the location of the known treatment units (Figure 43). As such, the changes in fire activity in this area were primarily a result of changing weather (increases in humidity and decreases in wind, see figure 28) and topography (northerly aspect) rather than because of changes in forest structure and composition as a result of a fuel treatment. Several miles of roadside fuel treatments were designed to allow for better driving site distances along the steep and narrow roads but it was not possible to assess the possible role these treatments had in assisting evacuations (Figure 44).

Post-fire satellite imagery clearly showed the absence of changes in stand condition inside treated areas compared to neighboring untreated stands (Figure 43). In some cases, treated stands burned more intensely than adjacent untreated stands, perhaps because of additional surface fuels present as a result of the thinning and higher wind speeds that can occur in open forests compared to those with denser canopies (Figure 44). One clear example of this comes from an area near Gold Hill that burned on September 6. The area was thinned, which allowed the high winds (Figure 28) to facilitate the burning of the slash piles scattered in the understory. These piles were scheduled to be burned but the burning was not complete before the Fourmile Fire occurred (Figure 45).

The description and documentation of fuel treatments performed in the area where the Fourmile Fire burned did not describe under what weather conditions they were to be effective nor were the methods for reducing and maintaining low amounts of surface fuels (litter, grasses and herbaceous fuels) described. The amount and condition of surface fuels present in a forest is the major determinant in fire ignition, spread, and ultimate burn severity (Graham 2003, Graham and others 2004). Although activity fuels (slash or residues from thinning activities) within the Fourmile Fire were often chipped or piled for later burning, no broadcast prescribed fire was conducted. If low intensity prescribed fires would have been applied throughout the 6,000 acres at frequent (e.g., 10 years), they would have consumed litter layers, killed shrubs and small trees (ladder fuels), and pruned the lower branches of overstory trees by scorching (Graham and others 2004, 2007). By increasing the crown base heights of trees and decreasing surface fuels the occurrence of tree torching is reduced (Figure 25).

Based on past studies of treatment performance and under the weather conditions at the time of the fire, the surface fuel conditions in these treatments almost certainly produced high fire intensities and spread rates compared to areas where the fuels were not treated (Figures 43-45). Even where intensities could have been reduced by the treatments, long duration flaming associated with continuous surface fuels ultimately ignited and torched residual trees (Figure 31). Claims of fuel treatment performance around homes by the owners are consistent with the knowledge that the removal of surface fuel plays an important role in changing fire behavior. Evidence of these effects is seen in the live and minimally scorched tree canopies on their property after a low intensity surface fire most likely burned their property (Figure 46).

Treatment units were located adjacent to roads and on ridge-lines which confounds treatment effects with those of topographically related changes in fire behavior (Figures 34, 47). Clear evidence of topographic effects is visible in the post-fire images where north-facing slopes and canyon bottoms suffered minor impacts but had received no treatment (Figures 34, 43). The slim boundary between forest consumed completely by fire and intact north facing forests is coincident with ridgelines and slope changes whether treatments were present or not (Figure 47). Elsewhere, (Gold Hill, Sugarloaf, Bald Mountain, Melvina Road) patterns of burn severity (living, scorched, and consumed conifer foliage) were found to vary independently of fuel treatment locations (Figures 29, 43). It is thus impossible to distinguish the various causes of burn severity, including treatment.

High winds and the low relative humidity of the air during the Fourmile Canyon Fire are common weather conditions associated with all large wildfires along the Front Range foothills (Figure 2, see page 3). Thus, recognizing these conditions is critical when developing fuel treatment prescriptions. By doing so, and appropriately designing (treating surface fuels, ladder fuels, and canopy fuels in this order of importance) fuel treatments in and among landscapes in conjunction with treating fuels in the Home Ignition Zone across the Front Range, the efficacy of fuel treatments can be greatly improved (Figure 20) (Graham and others 1999, Graham 2003, Graham and others 2004, Graham and others 2009, Hudak and others 2011).

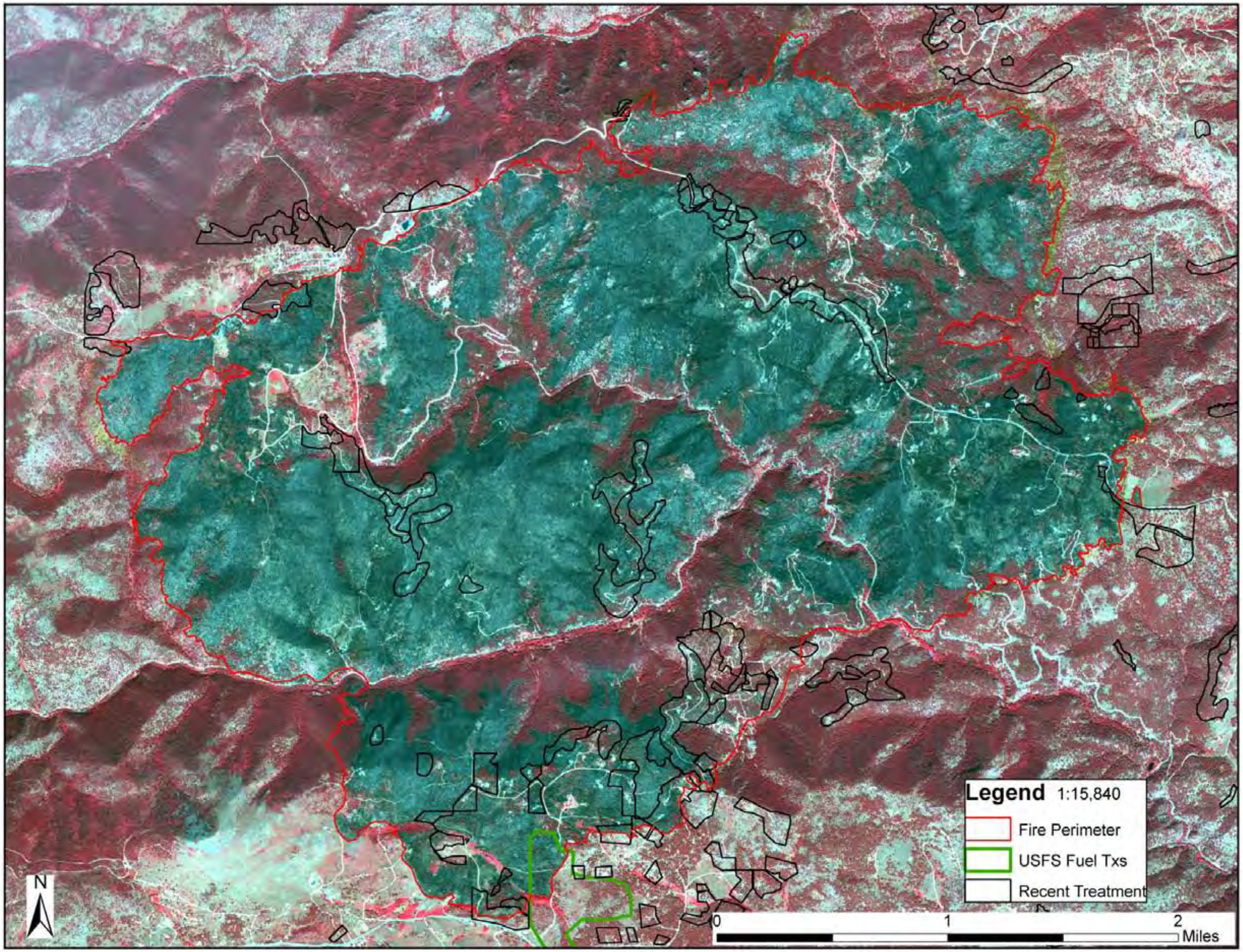


Figure 43. Fuel treatment locations in relation to vegetative burn severity using infrared photography. The areas shaded in blue are burned or black while the red shaded areas are green or alive. Note that many north facing and predominantly Douglas-fir forests did not burn.

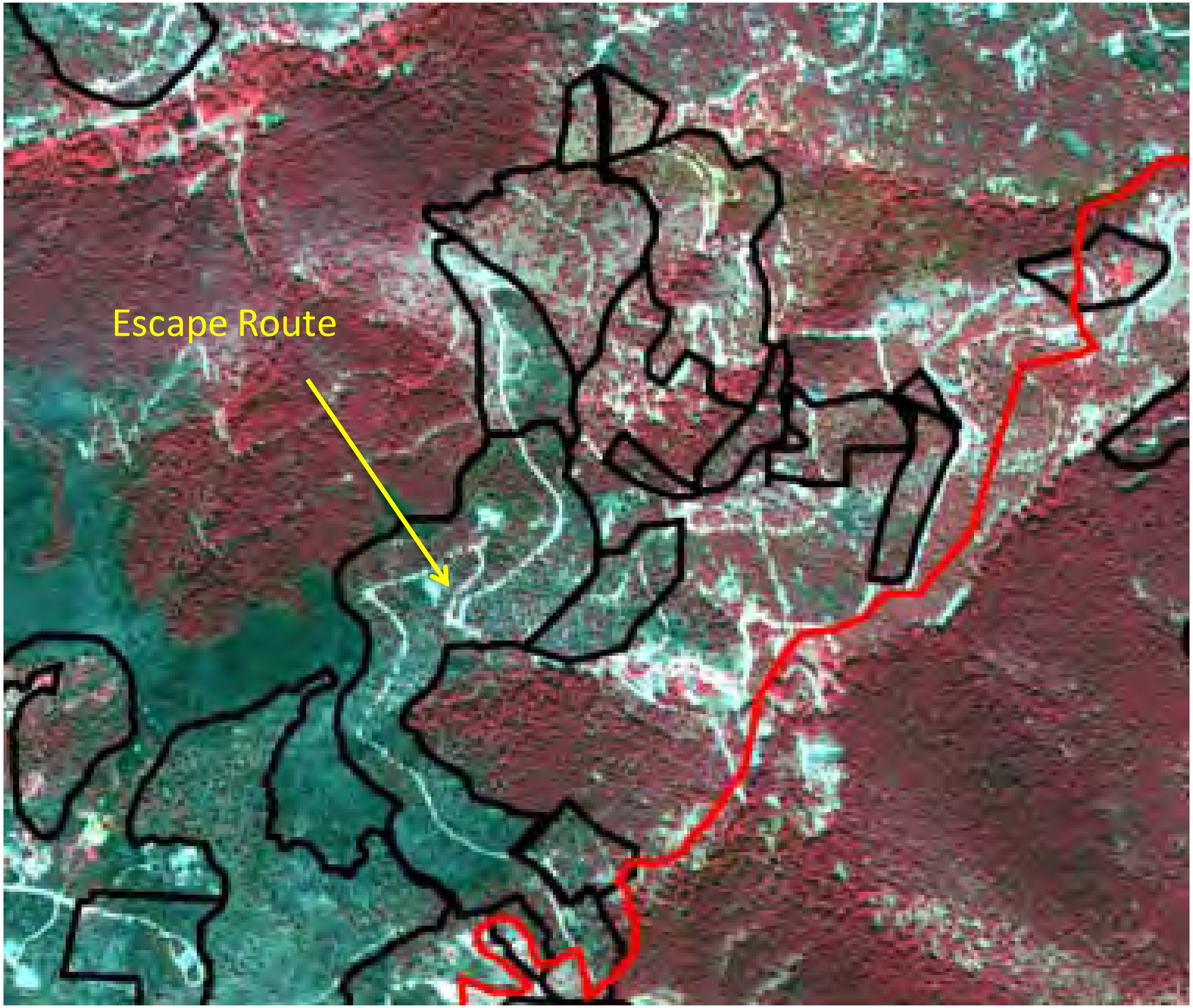


Figure 44. Fuel treatment locations (outlined) in relation to vegetative burn severity using infrared photography. The areas shaded in blue are burned or black while the red shaded areas are green or alive. Note the areas where the fuels were treated along the “Escape Route” were burned more severely than neighboring areas where the fuels were not treated.

Figure 45. The slash piles left after fuel treatments contributed to the fire intensity and the length of time the fire burned. This was exemplified in the area near Gold Hill where the fuels had been treated and the slash piles left. Note the smoke emitting from the individual slash piles.

Figure 46. An example of homeowners treating both canopy and surface fuels around their home that resulted in low burn severity to the vegetation and the home survived a high intensity fire. Note the low burn severity resulting from a surface fire to the left of the home. Photos: Dan Steinman.

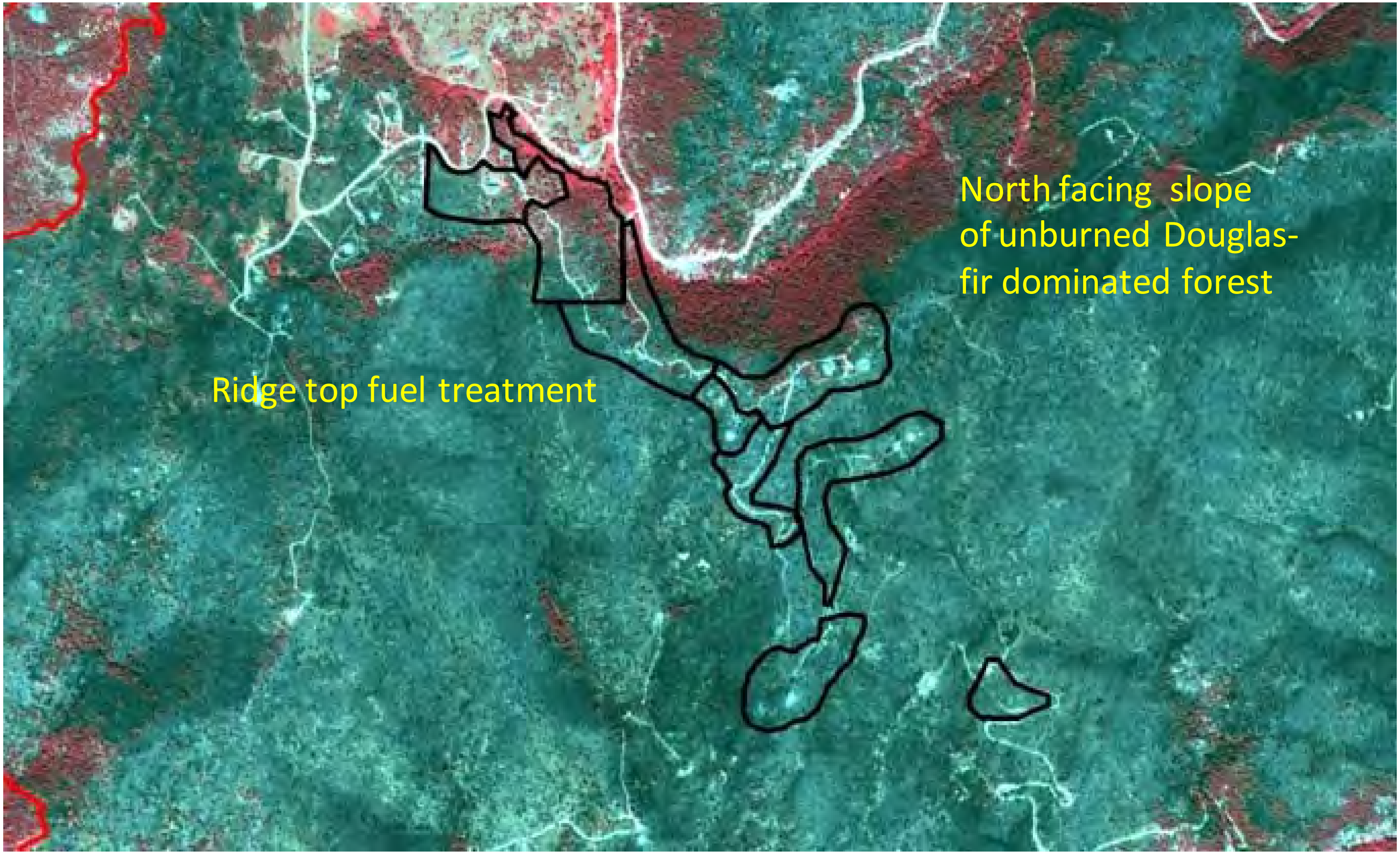


Figure 47. When fuel treatments were located along the ridge tops the efficacy of the fuel treatment in modifying fire behavior and/or burn severity is confounded by the change in topography and in this case vegetation. The areas shaded in blue are burned or black while the red shaded areas are green or alive. Note that north facing and predominantly Douglas-fir forest did not burn next to where the fuels were treated.

Home Destruction

Residential Wildfire Results

These findings address the residential (e.g., home) fire destruction during the Fourmile Canyon Fire. The threat to and destruction of residential development by fire in wildland vegetation has become known as the wildland-urban interface (WUI) fire problem. The following preliminary findings are from our examination of the WUI fire.

A total of 474 homes lie within the final wildfire perimeter or within ~ < 100 feet of it (Figure 48).

Total of 168 or 35.4% of the homes were destroyed.
29 homes (17.3 %) were ignited by crown fire.
139 homes (82.7 %) were ignited by surface fire.
157 homes were destroyed within the first 12 hours.

The wildfire perimeter and an adjacent ~ < 100 feet included all 474 homes on the first day roughly starting at 10:00 and ending at 18:00. High fire spread rates and firebrand spot ignitions combined to produce rapid fire growth rates accompanied by high intensity burning. These extreme burning conditions overwhelmed wildfire suppression efforts. Because of the rapid growth rate, wildfire quickly spread to and beyond the widely dispersed residential areas resulting in hundreds of homes being exposed to potential ignition in a brief period of time. Simultaneous flame and firebrand exposures resulted in simultaneous home ignitions that overwhelmed structure fire protection capabilities. House-to-house fire spread largely did not occur due to relatively low home density. In addition, fire spread to fully involve a home is slow compared to wildfire spread. This and low residential density means burning homes did not significantly enhance wildfire behavior. The Fourmile Canyon Fire home destruction scenario followed the same pattern as other WUI fire disasters that have occurred in the U.S. This pattern is described by the sequence shown in (Figure 49).

The overwhelmed structure fire protection capability can be seen by comparing the available firefighting resources at the end of the first burning period on September 6 (25 engines/water tenders and 200 personnel, Figure 50) with the estimated total number of exposed homes (474) and destroyed homes (157) during that period. If there had been no life safety limitations (not realistic) and we assume two firefighters per house, the available resources could not protect more than three-quarters of the exposed homes at the end of September 6. There were nearly 20 homes for each engine and water tender during the principal period of house exposure. This scenario of overwhelmed wildfire suppression and structure protection capabilities is comparable to the findings of previously examined home destruction associated with extreme burning conditions (rapid fire spread rates and high fire intensities).

With most residents evacuated and firefighters unable to protect most homes, any home with a sustained ignition resulted in total destruction. However, the total destruction of homes is not indicative of high intensity, massive flame fronts engulfing a destroyed home. Rather, all homes with any sustained ignition freely burned to total destruction due to a lack of available people to

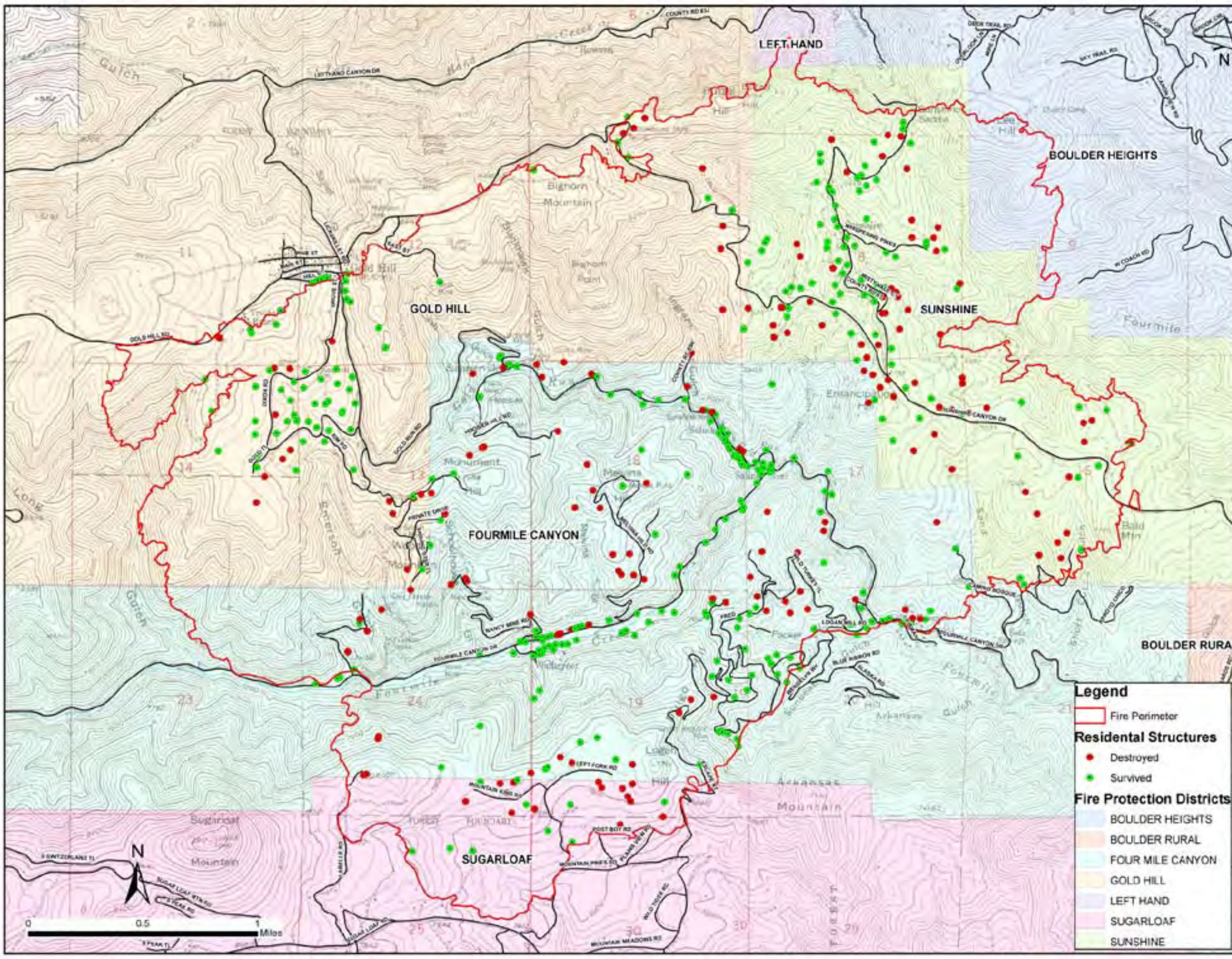


Figure 48. Destroyed homes were distributed throughout the area burned by the Fourmile Fire.

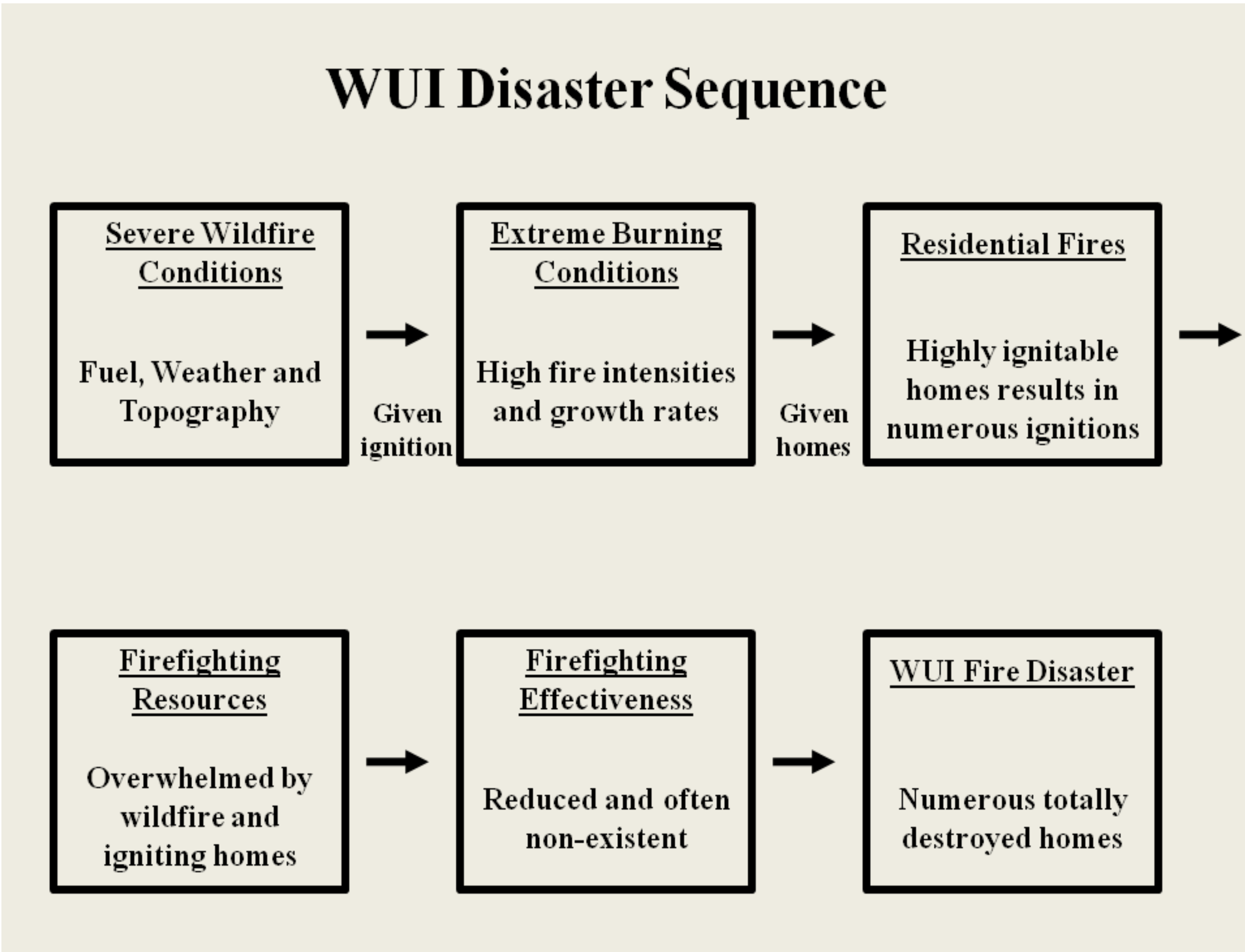


Figure 49. The (WUI) disaster sequence begins with overwhelming wildfire conditions simultaneously igniting numerous homes. Hundreds to thousands of homes exposed to flames and firebrands overwhelm structure protection. Note, however that WUI fire disasters depend on highly ignitable homes (upper right box). If ignition resistant homes do not ignite, then firefighters can effectively protect homes. The inevitable wildfire occurs without disastrous residential destruction.

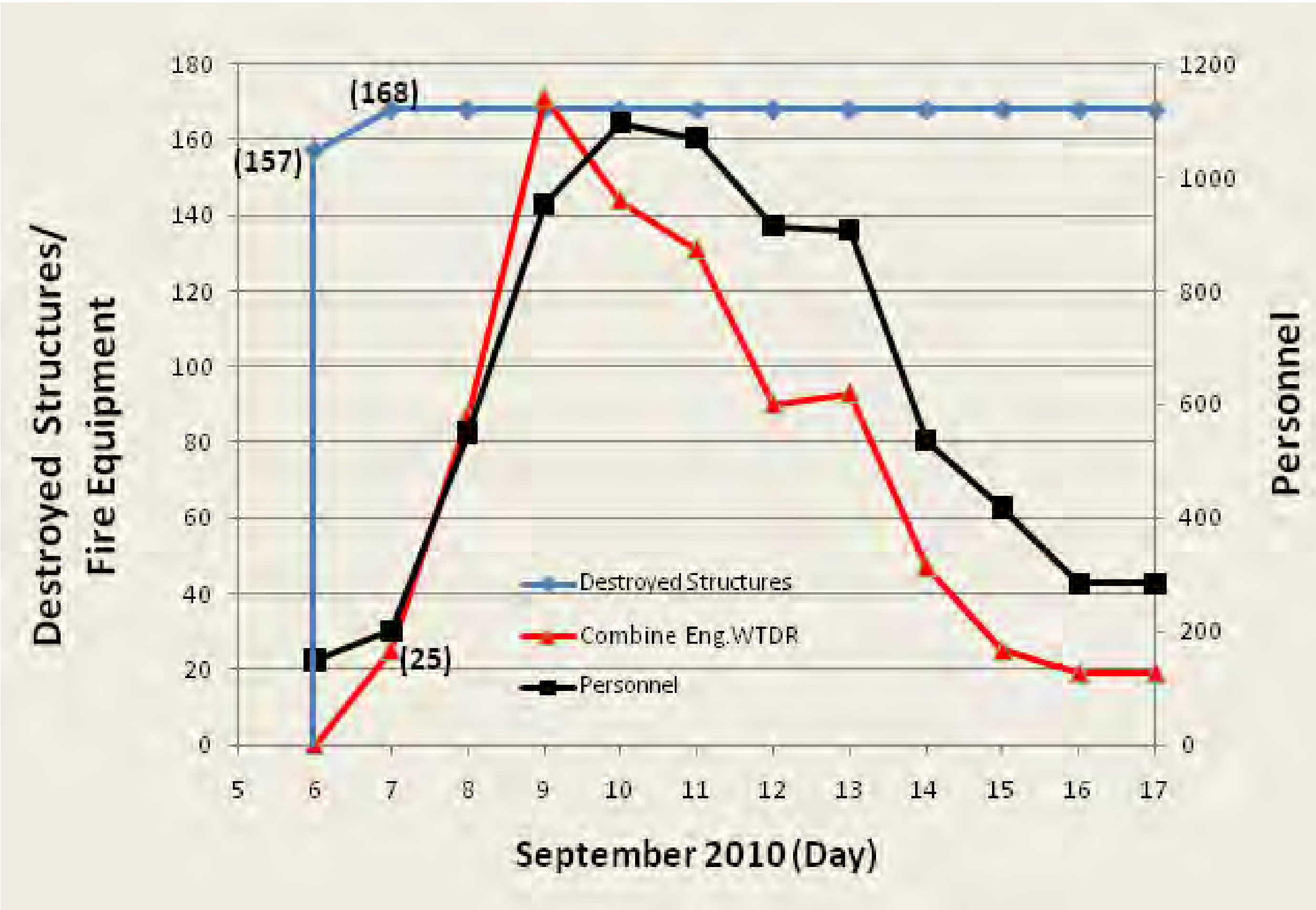


Figure 50. The estimated available firefighting resources at the end of September 6 was 25 engines and water tenders and 200 personnel. This is compared to an estimated 157 destroyed homes at the end of that period. Given highly ignitable homes, available firefighting resources were minimally capable of protecting all the affected residential areas by the end of September 9.

extinguish initial ignitions (Figure 50). Although most of the 168 destroyed homes burned within the first 12 hours (est. 157 homes), continued burning within or near the wildfire perimeter resulted in some homes destroyed the following day or two (est. 11 homes).

Analysis of Home Destruction

Homes ignite and burn during wildfires when the requirements for combustion, a sufficiency of fuel, heat, and oxygen are sustained at one or more places on a home. If homes do not ignite, homes do not burn and if homes do not burn during a wildfire then the WUI fire disaster does not occur. This is evident from the disaster sequence shown in Figure 49. Given the inevitability of future wildfires and thus wildfires with extreme burning conditions that overwhelm fire protection, focusing on reducing home ignition potential is the key to preventing WUI fire disasters. In the context of WUI fire disasters, a house is the fuel and all things burning around a house (including other structures) are the heat. Oxygen is always sufficient in this context (Figure 51).

We can define the residential fire destruction during the Fourmile Canyon Fire in terms of the requirements for combustion.

WUI fire destruction occurs when the wildfire spreads from wildland fuels to residential fuels. For this to occur the wildfire must be close enough for its lofted firebrands and/or flames (sufficient heat) to ignite the flammable parts (sufficient fuel) of a home.

Reducing the house fuel availability in relation to reducing the surrounding heat sources can significantly reduce home ignition potential. An understanding of how the requirements for combustion are met during a wildfire provides the means for examining home destruction during wildfires and ultimately how to reduce home ignition potential-effective WUI fuel treatment.

Existing research on how residential fire disasters occur and how homes ignite during wildfires indicates that given extreme burning conditions, home characteristics in relation to a home’s immediate surroundings (100 feet) principally determine home ignition potential. Thus home ignition commonly occurs over small distances- a few tens of feet or less. This area is called the *home ignition zone* (HIZ). During extreme burning conditions, the flames of burning objects beyond 100 ft (outside the HIZ) do not directly ignite a home’s combustible materials. Fire spreading into the HIZ or fuel ignited by firebrands must be closer than 100 ft and/or contact flammable parts of a home before direct flame ignition occurs. Also, home ignitions from firebrands require burning embers from a wildfire and/or burning residential fuels to accumulate on flammable surfaces before ignition can occur. The surviving house in Figure 52 is an example of a low ignition potential HIZ. These low intensity ignition causes are revealed as varying degrees of unconsumed vegetation and other flammable materials adjacent to total home destruction (Figure 53).

Homes can survive or burn within areas of high and low intensity fire (Figure 54). We expect home destruction due to high intensity exposures (close proximity crown fire) and survival with low intensity (or no) fire spreading to a home. But past examinations indicate WUI fire destruction commonly occurs with low and moderate intensity exposures. Frequently within

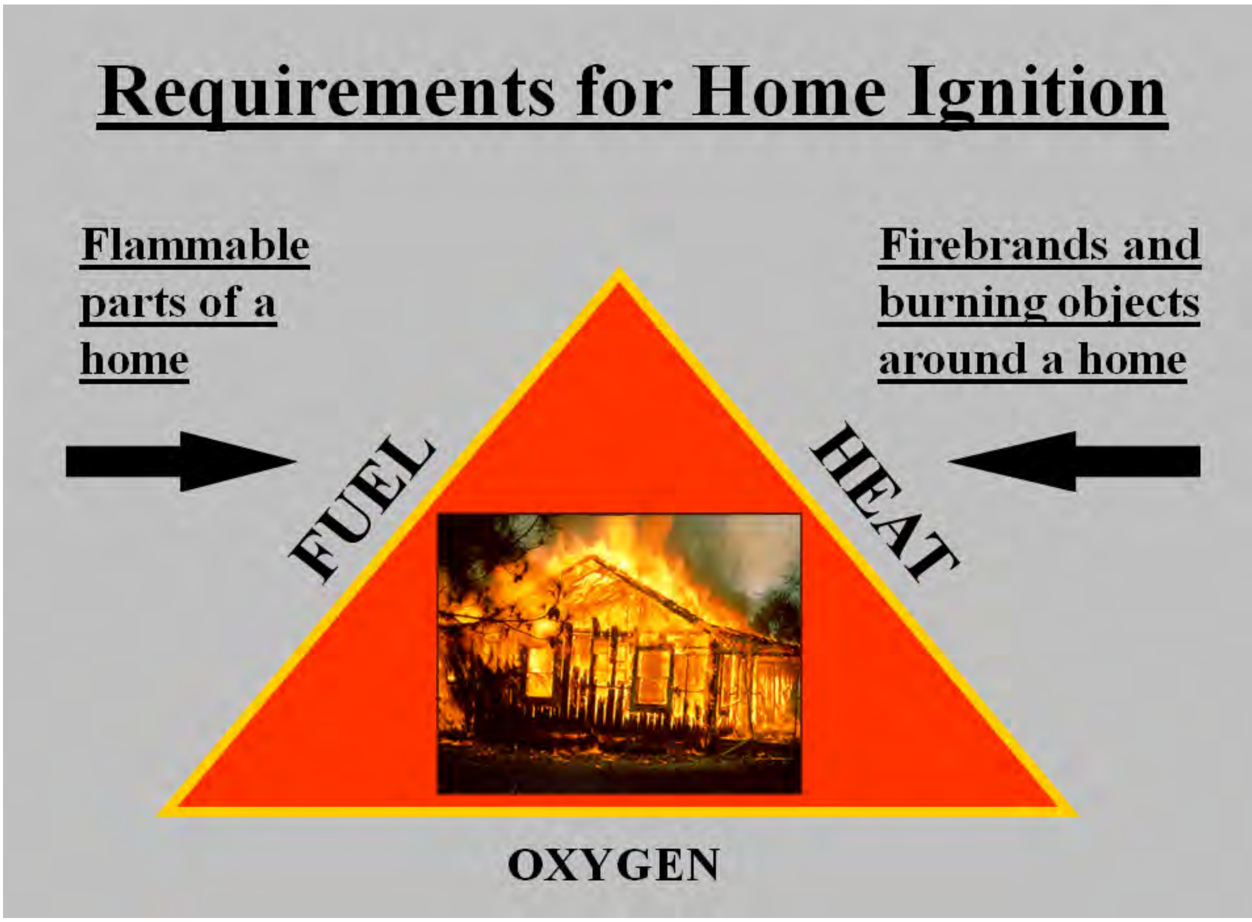


Figure 51. Homes sustain ignition by meeting the requirements for combustion—a sufficiency of fuel (home), heat (burning objects around a home), and oxygen is always sufficient. Home ignitions do not require massive flame fronts to burn through residential areas; firebrands accumulating on flammable surfaces and low intensity surface fire contacting a wood wall can be sufficient.

Figure 52. This is an example of a home ignition zone (HIZ) and how it reduces ignition potential within 100 feet of a home. Home construction was nonflammable or ignition resistant. Areas adjacent to the home were irrigated plantings or nonflammable materials. Firebrands landing on and around the home had few flammables to ignite. Surface fires were not eliminated within the HIZ but importantly, were restricted by the landscaping design from burning to contact the home. Trees that would produce high intensities were separated thereby reducing the chances of canopy burning and when not prevented, the burning canopies produced significantly less radiant heating to the home. Photo: Joe Amon, Denver Post.

Figure 53. An example of total home destruction surrounded by unconsumed vegetation indicates ignitions associated with a low intensity exposure. The lack of available fire protection resulted in small ignitions sustaining and free burning to total destruction. Photo: Boulder County Sherriff.

Figure 54. Home destruction and survival are associated with both high and low intensity fire exposures. Most destroyed homes occur with low intensities in the home ignition zone (HIZ).

areas of residential development, roads, driveways, utility corridors and the house sites themselves break the vegetation continuity thereby disrupting high intensity tree canopy fire spread. However, surface fires continue spreading and firebrands from burning tree canopies are lofted downwind to ignite vegetation, structures and homes. This was evidenced in the Fourmile Canyon Fire and helps explain how we found 83 percent (139/168) of the Fourmile Canyon Fire home destruction not directly caused by the intense wildfire. Notably, low intensity burning tended to occur in canyon and creek bottoms with higher intensities above on slopes and ridges (Figure 34).

The Fourmile Canyon Fire produced a pattern of destruction and survival consistent with previously examined WUI fire disasters, i.e. the 65 percent Fourmile Canyon Fire home survival or greater is common. Using the HIZ and requirements for combustion as analysis guides, we generally examined home destruction and survival related to wildfire flame exposure. We estimated wildfire flame exposure (high intensity, low intensity) based on the degree of consumed vegetation and other flammables surrounding a home. Consistent with home ignition potential as determined by the limited area of the HIZ, we found home survival within areas of destruction, destruction within areas of survival and homes destroyed surrounded by unconsumed, green vegetation (Figure 55).

Our examination only related home destruction to a categorical estimation of flame intensity (Figure 55). Because of home site disturbances during the time from home destruction to our examination (September to March) we could not determine more specific categorical causes for ignition and survival. We were able to categorically describe home destruction with greater reliability than home survival. Fire protection was clearly not effective and could be eliminated as a factor when total home destruction was the outcome; however, the varying degree and effectiveness of fire protection could not be reliably described in most cases of home survival. Additionally, we could not attribute even categorical causes for home survival without knowing home exposures to flames and firebrands and how those exposures interacted with home ignition vulnerabilities.

Home ignition potential principally determined by the HIZ has profound implications for preventing future WUI fire disasters and thereby enhancing life safety and firefighter effectiveness during extreme burning conditions.

- Residential fire protection effectiveness and enhanced life safety during wildfires with extreme burning conditions depends on HIZ conditions resulting in low home ignition potential.
- The HIZ is largely owned by the homeowner or homeowners in higher density residential development. That means the authority for reducing vulnerability to wildfire rests with the homeowner(s). Thus, WUI fire disasters cannot be prevented without homeowners actively engaged in producing and maintaining low home ignition potential. During extreme conditions fire protection effectiveness depends on homeowners creating and maintaining low home ignition potential.
- Given the inevitability of wildfires on the Colorado Front Range, we have the opportunity to significantly reduce the potential for WUI fire disasters during extreme burning conditions. However, this opportunity requires a change of approach—an approach focused on reducing home ignition potential within the HIZ rather than increasing expensive fire protection capabilities that have proven to be strategically ineffective.

Figure 55. Top photo shows a surviving (O) home with destroyed neighbors (X). The middle photo shows destroyed homes (O) with surviving neighbors. The bottom photo shows destroyed home with adjacent green vegetation.

Social – Economic

Fire Management Costs

Total fire management (suppression, emergency management, and post fire rehabilitation) is estimated at $14.1 million; however, final fire costs have not been finalized. The State of Colorado estimates total suppression cost for the Fourmile Canyon Fire of $10.1 million. Cost breakdowns by day and resource type are available from the I-Suite database maintained by the incident command teams during the fire event. The I-Suite database accounts for $9,959,068 in suppression expenditures between September 6 and September 16, 2010. It is not unexpected that reported final fire cost may differ from those listed in I-Suite for several reasons including charges billed after September 16, 2010.

Daily cost, and cost by resource category are available in Table 3 and Figure 56. Over the duration of the fire the largest cost component was for engines representing 30 percent of total cost ($2,975,766). This was not surprising given the number of homes within the fire perimeter and the extent of the point protection mission. Aviation costs represented 15 percent of total fire cost ($1,508,529) of which approximately 9 percent of total cost ($892,272) were spent on retardant drops from large air tankers. We estimated that 93 percent of the area burned in the first day of the fire while only 6 percent of the suppression costs were incurred. A total of 20 percent of all suppression expenditures were made in the first two days of the fire (September 6 and 7). The value of the suppression investment after the initial fire run was in reducing loss from future fire spread and home protection that may have prevented additional home loss. However, the potential for the fire to expand beyond the established perimeter in absence of suppression was not assessed.

An established Cost Share Agreement identifies final cost responsibility by partner. Costs were distributed based on early estimates of proportion of jurisdiction within the final fire perimeter. The agreement has Boulder County, through the State of Colorado Emergency Fire Fund, responsible for 67 percent (FEMA Category H Federal Wildfire Assistance Grants will cover 75 percent of approved costs), BLM 28 percent, and Forest Service 5 percent – although BLM and FS typically do not reconcile costs as per established interagency agreements. Table 4 presents suppression costs breakdown by partner prior to redistribution of funds based on the Cost Share Agreement and updated assessment of area burned by partner showing that Federal Lands constitute 28 percent not the 33 percent as estimated with the cost share agreement.

Final suppression cost was $1,634 per acre. The Forest Service and Department of Interior utilize a regression based cost model for performance reporting to Congress known as the Stratified Cost Index (SCI) (Gebert and others 2007). The SCI is based on ignition characteristics, and coarse proxies of values at risk. Per unit fire cost of $1,634 is more than 1 standard deviation greater than the SCI estimate of $437 per acre. It is important to note that the high level of private values and associated losses within the fire perimeter makes this fire unique and this was primarily a State fire so the SCI may not be representative.

Boulder County spent $492,104 on non-suppression related emergency management such as road blocks, evacuations, sheltering animals, etc. partially covered under FEMA Fire Management

Table 3. Costs of suppressing the Fourmile Canyon Fire distributed by suppression activity from September 6 through 16, 2010.

	9/6/2010	9/7/2010	9/8/2010	9/9/2010	9/10/2010	9/11/2010	9/12/2010	9/13/2010	9/14/2010	9/15/2010	9/16/2010
Air Tanker	$211,474	$328,601	$151,134	$182,124	$17,133	$1,806	$0		$0	$0	$0
Aviation(tot)	$221,018	$453,732	$266,371	$317,908	$58,647	$86,898	$27,550	$30,007	$20,090	$15,779	$10,529
Engines	$223,511	$446,172	$423,607	$385,376	$358,075	$368,680	$276,070	$206,371	$121,279	$86,706	$79,919
Direct	$519,822	$1,145,048	$1,052,208	$1,126,669	$846,181	$845,246	$656,585	$513,352	$264,002	$176,073	$154,245
Support	$57,402	$230,414	$291,497	$428,022	$368,087	$312,397	$276,753	$261,308	$229,866	$139,903	$63,988
Total	$577,224	$1,375,462	$1,343,705	$1,554,691	$1,214,268	$1,157,643	$933,338	$774,660	$493,868	$315,976	$218,233

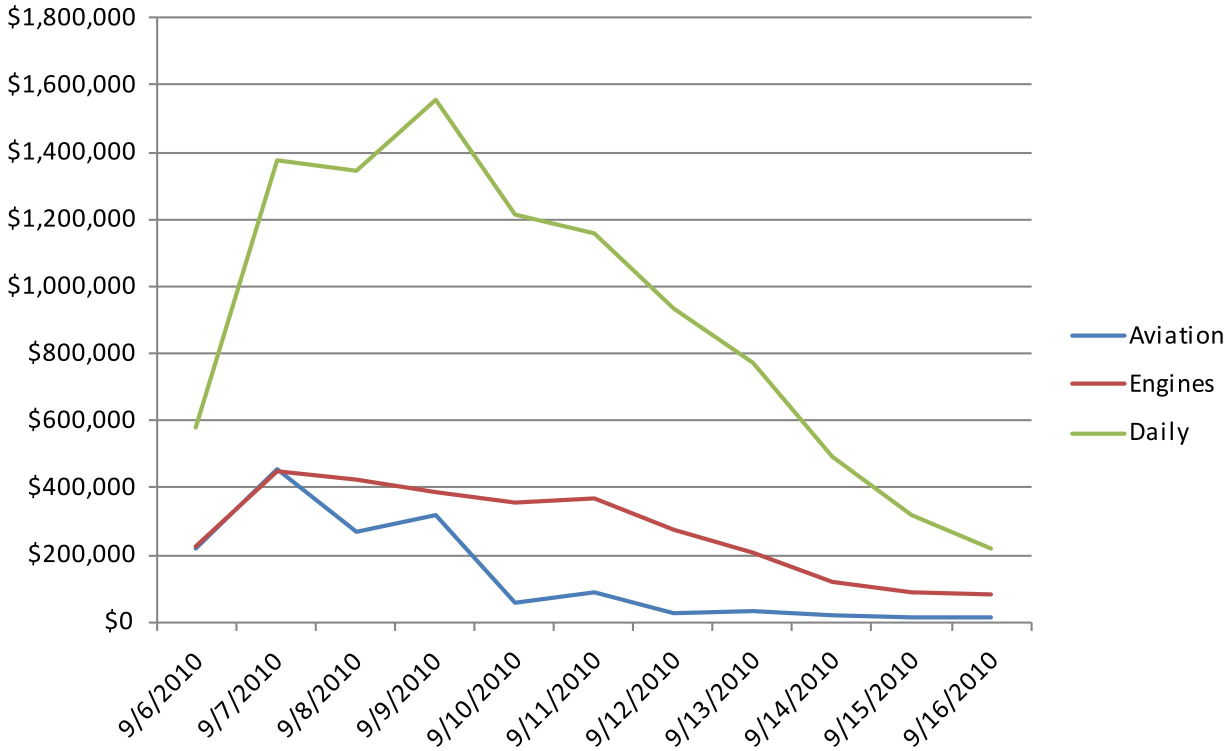


Figure 56. Daily suppression costs for the Fourmile Canyon Fire peaked on September 9.

Table 4. Expenditures incurred by the different by agencies responsible for the Fourmile Canyon Fire.

Agency	2010 expenditures	Acres	Percentage acres	Percentage cost
	Federal expenditures			
BIA	$14,758	0	0	0.1
FWS	$24,453	0	0	0.2
NPA	$79,620	0	0	0.8
BLM	$494,836	1397	22.6	5.0
USFS	$3,316,837	306	5.0	33.3
Total Federal	$3,930,503	1703	27.6	39.5
State and County	$6,028,565	4478	72.4	60.5
Fire total	$9,959,068	6181	100.0	100.0

For all suppression costs, including aircraft, outside of mutual aid:
Boulder County - 67 %
Bureau of Land Management - 28 %
USFS - Arapaho Roosevelt NF - 5 %

Assistance Grant Category B. FEMA has reimbursed the County for 75 percent ($369,078) of these costs with an additional reimbursement of donated services of $79,592 (this reimbursement cannot exceed 25 percent of Category B expenditures). Total cost under these categories, including donated services, is $571,696.

Boulder County reports a total of $3.4 million in external grants received for rehabilitation and recovery of the burned lands. Of this $2.2 million was from federal sources with the state of Colorado contributing the remaining $1.2 million. The recovery grant for Fourmile Emergency Stabilization was funded at $2.7 million (Federal: $2.2 million, State: $500,000). In the initial emergency stabilization report mulching treatments were estimated to represent a majority of total costs. Asbestos debris removal was funded at $500,000.

Economic Losses

Economic losses were primarily associated with the loss of private property. The Rocky Mountain Insurance Information Association estimated $217 million in insured losses shortly after the fire. The Association is scheduled to provide updated insured loss values approximately one year following the event. Indirect economic costs such as homeowner displacement, disruption of economic activity, and recreation value loss were not estimated due to the complexity of estimating these costs. Additionally, we do not have any information on potential smoke related health issues stemming from the fire.

The Boulder County Assessor's Office reported that total taxable property loss exceeded $125 million (personal communications Rex Westin, Senior Residential Appraiser). Tax loss to Boulder County in 2011 equaled $822,852, with 2010 tax loss equal to $51,045 (partial year adjustment for lost structures, land value could not be adjusted). Lost tax revenue in 2012 and beyond is dependent on the number of homes rebuilt and the recovery of the characteristics of the properties. The Boulder County Assessor's office has an established property appraisal process for subsequent years. The value of building contents lost (both insured and uninsured) and the cost associated with displacement and relocation were not estimated. However, many homeowners appear to be underinsured (see insurance discussion below). A follow up survey of homeowners who either had their homes damaged or destroyed suggested that over half were underinsured and the average estimated cost to replace and or repair minus insurance was $195,000.

Research suggests that significant reduction in home sale price, adjacent, but not within the perimeter of large wildfires can occur. For example, five years after the Buffalo Creek fire near Pine, Colorado in May of 1996, there was a $17,100 to $18,500 (15% to 16%) loss in median home value relative to expected sale prices if there had been no fire (Loomis 2004). Similarly, wildfires in northwest Montana have had a dramatic effect on home sale prices suggesting sale prices of homes within three miles of a wildfire burned area were 12.7% ($33,053) lower than equivalent homes at least 12 miles from a fire. Sale prices of homes between three and six miles from a wildfire burned area were 7.3% ($18,884) lower than equivalent homes at least 12 miles from a fire (Stettler and others 2010). However, there is anecdotal evidence that residential sales in areas proximate to Fourmile Canyon Fire were active following the fire with a number of residents who lost their homes in the fire choosing to purchase homes in the vicinity of the fire instead of rebuilding (personal communication, Rex Westen- Senior Residential Appraiser, Boulder County Assessor's Office 6/28/2011).

Social Attitudes

Numerous damaging wildfires have occurred in Colorado since 1976, several of which occurred along the Front Range. People have been killed and 100s of homes destroyed within the hundreds of thousands of acres burned (Table 5). These fires provide the context for the attitudes of the people living in and near where the Fourmile Canyon Fire burned. Post- fire surveys of residents were not administered due to time constraints associated with Federal survey approval requirements through the Office of Management and Budget. However, surveys had been conducted of WUI residents within Larimer and Boulder Counties in 2007 regarding wildfire risk perceptions and mitigations efforts. Of the respondents within the original survey 127 were within areas evacuated during the Fourmile Canyon Fire. The evacuees' perceptions of wildfire risk and what specific actions residents had taken to mitigate the risk within the evacuated area were ascertained for this subsample of the original survey by Brenkert-Smith and Champ (2011).

Overall survey respondents were fairly familiar with wildfire, with 83% reporting being somewhat or very aware of wildfire risk when they bought their current residence and 61% had experienced a wildfire within 10 miles of their property. A high proportion (83%) of respondents knew someone who was evacuated due to wildfire and 38% knew someone whose residence was lost or damaged due to a wildfire. Within the survey area it appears that many residents had conducted some level of mitigation work on their property. Only 4% of the survey respondents reported not taking any of the actions. Within the survey residents were queried on 12 different types of mitigation efforts. On average, Fourmile respondents implemented 6.52 measures. The mitigation effort with the highest level of participation (72%) was removing dead or overhanging branches within 30 foot perimeter of the home. Installing fire resistant siding and installing screening over roof vents were the two activities with the lowest reported frequencies.

A critical finding was that despite their relatively high familiarity with wildfire, most respondents did not believe that characteristics of their structure and the immediate surroundings of the structure were significant factors influencing the likelihood of a wildfire damaging their property within the next five years. Specifically, only 20% of respondents believed that vegetation on their own property and only 9% believed that the physical characteristics of the house were major contributors to the chances of wildfire damaging their property. These perceptions are refuted in the scientific literature and the structure ignition assessment within this report.

Fuel Treatment Costs

A substantial amount of fuel treatments had occurred within and adjacent to the final fire perimeter since 2002. We estimated that a total of 600 acres of fuel treatments were within the fire perimeter. Most of these treatments were coordinated through the Colorado State Forest Service (CSFS) fuel treatment grant program. Associating total cost of treatments that were engaged by the fire is difficult due to the fact that many projects were split between areas within and approximate to the fire perimeter and areas beyond the perimeter. Additionally, there were three significant treatments; one Forest Service treatment and two treatments completed by

Table 5. Significant wildfires have occurred on federal, state, and private lands throughout Colorado. Source: http://csfs.colostate.edu/pages/wf-historical-facts.html

Year	Fire Name	Size/No. Homes Destroyed	Fatalities
1976	Battlement Mesa	880 ac	3
1978	Murphy Gulch	3,300 ac/1 unoccupied home	0
1989	Black Tiger	1,778 ac/44 homes	0
1990	Olde Stage	3,000 ac/10 homes	0
1994	South Canyon	2115 ac	14
1994	Hourglass Fire	1,275 ac/13 bldgs.	0
1996	Buffalo Creek	12,000 ac/10 homes	0
1999	Battlement Mesa	9 homes	0
2000	Hi Meadow	10,800 ac/51 homes	0
2000	Bobcat	10,599 ac/18 homes	0
2000	Bircher (Mesa Verde)	19,709 ac	0
2001	Carter Lake/Armageddon	1,216 ac	0
2002	Snaking	2,590 ac	0
2002	Cuerno Verde	388 ac/2 homes	2
2002	Schoonover	3,860 ac/13 structures	0
2002	Trinidad Complex	32,896 ac	0
2002	Iron Mountain	4,400 ac/100+ cabins, etc.	0
2002	Coal Seam	12,209 ac/29 homes	0
2002	Hayman	137,760 ac/133 homes	5 (accident enroute)
2002	Missionary Ridge	70,485 ac/56 homes	1
2002	Miracle Complex	3,951 ac	0
2002	Million	9,346 ac/11 homes	0
2002	Mt. Zirkel Complex	31,016 ac	0
2002	Big Elk	4,413 ac	3
2002	Big Fish	17,056/lodge & 7 cabins	0
2002	Long Mesa	2,601 ac/3 homes	0
2002	Panorama	1,700 ac/4 homes	0
2003	Brush Mountain	5,292 ac	0
2003	Overland	3,439 ac/12 homes	0
2003	Cherokee Ranch	1,200 ac/2 homes	0
2004	Picnic Rock	8,908 ac/1 home	0
2005	Mason	11,357 ac	0
2006	Mauricio Canyon	3,825 ac	0
2006	Yuma County	23,000 ac	0
2006	Thomas	3,347 ac	0
2006	Mato Vega	13820 ac	0
2010	Four Mile Canyon	6181 ac/ 168 homes	0

Boulder County Open Space. A total of 74 projects totaling 823 acres coordinated by CSFS were within one-half mile of or contained within the final fire perimeter. Within the final fire perimeter 417 spatially located acres were treated and an additional 162 non-located acres were treated under this program. The non identified acres tended to be defensible space projects surrounding individual homes. Within the fire perimeter, 21 acres were treated by the US Forest Service and 3.5 acres were treated by Boulder County Parks and Open Space.

Estimated total fuel treatment costs for activities covered under the CSFS grant process within and adjacent to the fire perimeter total $1.175 million with grant funding of $506,000 BLM funding $94,000 and awardee matching of $576,000. This results in a cost per acre of $1,430 ($1,577 adjusted to 2010 dollars). Past research on fuel treatments in Colorado showed treatment costs ranging between $840 and $1330 per acre adjusted to 2010 dollars (Lynch and Mackes 2003). Thus treatment costs appear to be on the higher end than past averages although the small size of treatment units may explain the difference. Two treatments adjacent to the fire perimeter were conducted by Boulder County Parks and Open Space in 2007 and 2008. The Bald Mountain project treated a total of 50 acres at a cost of $118,000 or $2,350 per acre (2.5 acres of the treatment were spatially identified within the fire perimeter). The Gold Hill project treated 12.5 acres at a cost of $59,800 or $4,784 per acre. The Forest Service conducted a 100 acre fuel treatment in 2005 with 21 acres contained within the final fire perimeter. Forest Service costs were estimated at $480 per acre.

Summary

Weather

- The spring and summer of 2010 along the Front Range were cooler and wetter than normal.
- By late August a very dry weather pattern emerged.
- No vegetative killing frost had occurred by September 6.
- On September 5, the day before the fire, near record high temperatures were recorded.
- A dry cold front passing on the night of September 5 resulted in minimal increases in the air relative humidity during the night.
- At 10:00 on September 6 the air relative humidity was 7%, dropped as low as 4% and remained below 10% until 17:00.
    - Gusty winds, not unusual along the Front Range, were consistently blowing at 35 mph with gusts greater than 40 mph.
    - Highly impacted by the steep and complex topography, strong surface winds were blowing in many directions.
- On September 6, the fire danger expressed as Energy Release Component (ERC) of the National Fire Danger Rating System was at a record level for early September.
- The prolonged period of exceptionally low air relative humidity coupled with windy conditions during the first day of the fire were major contributors to the fire's rapid spread rate (0.5 to 1.0 mph) and high intensity burning.

Fire behavior

- Only fires that burn under extreme weather, e.g., high winds, low air relative humidity, and burn dry fuels escape initial attack. As such, this understanding is important for explaing the fire behavior and management opportunities in these forests under the modern fire regime.
- Surface fire dominated how the fire behaved, but tree torching and crown fires frequently occurred in dense stands.
- At ignition the fine dead fuels (grasses, needles etc.) had a moisture content of 5%.
- At ignition the probability of these fuels igniting was 55% and by 17:00 the probability of ignition was 90%.
- When reported at 10:02 the fire was spotting over 0.5 mile and experienced surface fire spread rates of over 0.5 mph.
- Most fire growth was over by 20:00 with the last burning occurring near the Lee Hill antenna site. By this time on September 6, 93% of the total area burned.

Fuel Treatments

- The treated areas were small and narrow. They ranged from 1 to 50 acres in size with only 4 units greater than 20 acres in size.
- No performance metrics were defined for the fuel treatments-that is, the environmental conditions in which the treatments were to be effective in modifying fire behavior were not defined.

- Thinning trees to a specified density (residual basal area) or spacing was the prescription often negotiated with land owners. In addition, the treatments were often focused on improving the health of the forest (removing diseased and malformed trees, i.e., dwarf mistletoe) rather than modifying fire behavior.
- High winds and low air humidity during the Fourmile Canyon Fire are common weather conditions associated with all large wildfires along the Front Range and, thus, should be accounted for in any fuel treatment prescription.
- Pervasive spotting observed during the Fourmile Canyon Fire easily breached the narrow fuel treatment units and rendered them of limited value to containment efforts.
- The abundance of grasses, forbs, shrubs, and often branches and twigs that could have been removed through judicious surface treatments (e.g., prescribed fire) occurring within the areas where the fuels had been treated contributed to the high fire intensities and fire spread rate observed.
- Post-fire satellite imagery clearly shows the absence of changes in stand condition inside treated areas compared to neighboring untreated stands. In some cases, treated stands appeared to burn more intensely than adjacent untreated stands, perhaps because of additional surface fuels present as a result of the thinning. One clear example of this comes from near Gold Hill where the piles of slash were scattered in the understory of a thinned stand but had not been burned.
- Claims of fuel treatment performance around homes by the owners are consistent with the knowledge that additional attention to surface fuel removal plays an important role in changing fire behavior. Evidence of these effects is seen in the generally green tree canopies occurring on their property.
- Treatment units were located adjacent to roads and ridges which confounds treatment effects with those related to topographic and/or vegetative changes.

Suppression

- At time of ignition and throughout the first day a consolidated suppression effort focusing on perimeter control of the fire was not established. This was because the fire was rapidly spreading in multiple directions (north towards Gold Hill, to the south towards Sugarloaf and to the east down Fourmile canyon above Wall Street) and later towards Sunshine Canyon Road. The overall emphasis was placed on life safety, evacuations, point protection when and where safely feasible and the control, status and assignment of incoming resources.
- At ignition the high winds prohibited the use of any aircraft including air tankers and helicopters until 17:00 on September 6. No helicopters were used on the first day.
- In the evening of September 6 when the winds shifted and moderated two large air tankers and one SEAT dropped 25,605 gallons of retardant in the Gold Hill and Bald Mountain areas. A total of 86 loads of retardant totaling 174,149 gallons of were dropped from both large air tankers and one SEAT from September 6 through 9. On September 7 and 8, 78.4% of the total retardant used on the fire was dropped.
- Type 1, 2, and 3 helicopters were used on the fire beginning on September 7 through September 15. These helicopters dropped 272,770 gallons of water. Because of the extensive road network in the area only 3,400 pounds of cargo and 93 passengers were flown. The passengers were primarily on reconnaissance flights.

Home destruction

- A total of 474 homes were located within and adjacent (~ < 100 feet) to the final wildfire perimeter.
- 168 or 35.4% of the homes within the burned area were destroyed by the Fourmile Canyon Fire. This is consistent with the percentage of homes destroyed in other wildland-urban interface (WUI) fire disasters.
- Within the Fourmile Canyon Fire
  - 29 homes were ignited by crown fire
  - 139 were ignited by surface fire
  - 157 homes were destroyed within the first 12 hours
- The initial rapid fire growth and intense burning overwhelmed fire suppression and structure fire protection capabilities.
- The low housing density did not result in house-to-house fire spread; the slow rate of home fire involvement and burning compared to wildfire spread did not enhance overall wildfire behavior/intensities.
- 83% of home destruction was associated with surface fire and consistent with other WUI fire disasters. This indicates survival or loss of homes exposed to wildfire flames and firebrands (lofted burning embers) is not determined by the overall fire behavior or distance of firebrand lofting but rather, the condition of the Home Ignition Zone (HIZ) – the design, materials and maintenance of the home in relation to its immediate surroundings within 100 feet.
- We have the opportunity to significantly reduce the potential for WUI fire disasters during extreme burning conditions such as the Fourmile Canyon Fire, but this opportunity depends on homeowners creating and maintaining low home ignition potential within the HIZ.
- For a HIZ to be successful in preventing a home from burning is predicated on the home having ignition resistant materials and with the homeowner removing flammable debris from on and around the house and maintaining this condition. If flammable vegetation is not continuous (landscaping, driveway, etc.) to the home it is difficult for firebrand ignited spot fires to contact the home. Also if trees within about 100 ft are not continuous the potential for active crown fire is minimal and even if individual trees do torch, they present minimal radiant heating to the house.

Social/economics

- The Fourmile Canyon Fire destroyed the highest (168) number of homes with the greatest loss in value ($217 million insured loss) in Colorado since 1976 when wildfire records started.
- Total fire management (suppression, emergency management, and post fire rehabilitation) is estimated at $14.1 million.
- County, state and federal agencies partnered with landowners to treat approximately 600 acres within the area where Fourmile Canyon Fire burned.
  - Projects administered by Colorado Forest Service within and proximate to the fire perimeter totaled 823 acres at a total cost of $1,175,000 or $1430 per acre.
- Boulder County Assessor’s Office reports taxable property loss of $125 million resulting in a tax revenue loss in 2011 of $822,852 and a 2010 tax loss of $51,045.

- Interestingly, 127 of the landowners evacuated during the Fourmile Canyon Fire were surveyed in 2007regarding their perceptions of their wildfire risk and mitigations efforts.
    - Overall survey respondents were fairly familiar with wildfire, with 83% reporting being somewhat or very aware of wildfire risk.
    - Only 4% of the survey respondents reported not taking any actions to reduce their risks
    - A critical finding was that most landowners surveyed prior to the fire did not believe that characteristics of their home and immediate surroundings were significant factors influencing the likelihood of a wildfire damaging their property within the next five years. These perceptions are refuted in the scientific literature and the home ignition assessment within this report.

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Appendix A:

Senator Udall’s letter requesting a review of the Fourmile Canyon Fire.

MARK UDALL
COLORADO

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WASHINGTON, DC 20510
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United States Senate

WASHINGTON, DC 20510

September 15, 2010

The Honorable Bill Ritter, Jr.
Governor
State of Colorado
136 State Capitol
Denver, CO 80203

The Honorable Tom Vilsack
Secretary
U.S. Department of Agriculture
1400 Independence Ave., S.W.
Washington, DC 20250

Dear Governor Ritter and Secretary Vilsack:

I had the opportunity to tour the Fourmile Canyon Fire area after it was effectively contained on Monday, September 13. I was struck by the severity of this fire and the substantial loss of property. This tour was a humbling reminder of the heroic efforts conducted by first responders in attacking the fire and making sure that people were evacuated to safety, resulting, thankfully, with no lives being lost.

I was also struck by the seemingly indiscriminate nature of the burn areas and how some houses and structures were spared while others—in some cases right next door—were totally destroyed. Like the destructive Hayman Fire in 2002, I think the experience of this fire may provide some lessons on the nature of wildfires along the Front Range and can help provide some useful information on how we might better respond to and mitigate such damage when future fires occur.

Shortly after the Hayman Fire, I asked the U.S. Forest Service to conduct a study to review the fire and its behavior so that we could learn from that experience. The result was a useful report that examined this fire from many angles. I am writing today to seek a similar study of the Fourmile Canyon Fire. Since this fire included many non-federal as well as some federal lands, I am suggesting that this review be jointly convened by the state and the U.S. Forest Service.

As you know, the Fourmile Canyon Fire in Colorado occurred in an area where previous wildfires had occurred and where some small, fuels-reduction projects were conducted. This area includes both wildland-urban interface zones and areas of high natural resource values, including wildlife habitats and important watersheds. I believe it would be instructive to take a close look at the behavior of this fire, examine the factors that led to its intensity, and see if the way it behaved when it encountered these previously affected or treated areas can be instructive in designing future risk-reduction projects.

I also believe we should examine the use of the aerial firefighting resources (tankers and helicopters), because questions have been raised about the availability, quality and costs of these resources in attacking this fire.

In addition, once the immediate crisis is over, it will be necessary to start making decisions about ways to begin restoration of this and other burned areas. In this instance, too, the Fourmile Canyon Fire area could be a very useful case study to determine what can and should be done after such a large fire to prevent or minimize erosion and other damage. Sound, cost-effective restoration methods will be especially important in light of the severe drain on the Forest Service's funds caused by the need to fight so many large fires, which will make it that much harder to finance critical restoration work.

Accordingly, I suggest that the U.S. Forest Service and the Colorado State Forest Service establish a "Fourmile Canyon Fire Review Panel" composed of local, state and federal experts to explore these issues and help guide future decisions. Its purpose would be to focus on the future, rather than attempt to assign blame for past events, and as a balanced panel including experts with varied backgrounds, it might well have wider credibility with various groups than would a panel of less broad membership.

As soon as practicable—and after all the needs related to managing the Fourmile Canyon Fire and the Reservoir Road Fire have been completed—I suggest that this review get started on looking at the following issues (this is not meant to be an exhaustive or exclusive list of topics):

1. What conditions – including fuel, forest structure, prior fuel treatment, topography, weather, wind and land ownership – affected the behavior and intensity of the fire? To what degree did these factors influence where the fire was stopped, how hot the fire burned, whether soil was damaged, etc.?

2. What was the effectiveness of thinning treatments on lands in the area in stopping or slowing the fire, reducing fire intensity, and reducing soil damage?

3. What was the effectiveness of prescribed burns in influencing the fire?

4. To what extent did the fire behave differently (all other factors being equal) in roaded and unroaded areas?

5. To what degree and under what circumstances were firefighting activities successful/not successful in limiting the spread of the fire (e.g. bulldozing firelines)? Were the aerial suppression resources timely, readily available and effective in attacking the fire (when those resources could be applied safely)? To what extent was controlling the fire dependent on the weather? How effectively was money/resources spent in fighting the fire?

6. What factors influenced which structures burned?

7. To what extent were local or county regulations followed with respect to defensible space or other fire-related policies? To what extent does variation in these policies account for structures saved or lost?

8. What science exists to determine the effectiveness of varying post-fire restoration treatments?

9. What types of transparent monitoring protocol and reports (for forest regrowth, water monitoring, sedimentation, endangered species recovery, etc.) should the various jurisdictions put in place to continue to learn from the fire?

10. Under what circumstances and across what areas can/should control areas be established to observe natural recovery?

As you know, it is imperative to put a high priority on reducing the risk of catastrophic fires to communities in the wildland-urban interface as we work to restore the natural, beneficial role of fire in forest ecosystems. I think a review panel along the lines suggested above will help to build greater consensus about how to move toward those goals.

And, even though the bark beetle epidemic and other insect infestations may not have had an effect on this fire, this review and the lessons learned from this fire also may have value and application in areas heavily impacted by insects and disease.

I look forward to working with both of you on this important review.

Sincerely,

Mark E. Udall
U.S. Senator