The 2012 Chips Fire, California:
A Case Study of Fire Behavior

Chips fire burning intensely upslope and along Indian Springs ridge in the area previously burned in the 2000 Storrie fire.

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Prepared by:
Jo Ann Fites, Ph.D., AD, Technical Specialist Fire Behavior
Carol Ewell, US Forest Service, Adaptive Management Services Enterprise Team
Ryan Bauer, US Forest Service, District Fuels Officer, Plumas National Forest

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Introduction

The Chips fire started July 29, 2012 in the Feather River Canyon on steep slopes that burned twelve years earlier in the Storrie Fire and again four years later in the Belden Fire. The fire burned 75,431 acres of the Plumas and Lassen National Forests before being contained on August 31, 2012. The fire was very resistant to control, in part because of the steep terrain and lack of accessibility, but also because the fuels which were very dry, consisting of extensive areas of decadent shrubs, snags and logs. The fire burned in elevations ranging between 2200 to 6400 feet. Precipitation patterns during the preceding winter and spring contributed to the very dry fuel conditions as annual precipitation was lower than average and very little of this precipitation occurred as snow, an important mechanism for maintaining higher soil and fuel moistures.

In *higher* elevation areas of the northern Sierra Nevada Mountains, it is unusual for fires to spread readily in areas which have recently burned. Areas that have repeatedly burned in the central (Yosemite National Park) and southern (Kern Plateau, Sequoia National Forest) Sierra Nevada have shown that fire spread tends to be self-limiting when reaching recently burned areas.

At lower elevations in the Sierra Nevada, fires have occurred under similar circumstances to the Chips fire, where dead and down woody material and vegetation regrowth supported fire spread. An example of this influence on fire spread is documented by the National Park Service on the 2009 Big Meadow fire that overlapped the 1990 A-Rock fire in Yosemite National Park near the community of Foresta (http://www.nps.gov/yose/parkmgmt/bigmeadowfirefaq.htm). The A-Rock fire converted the existing mixed conifer forest to an area dominated by a chaparral plant community with scattered patches of trees (van Wagtendonk 2012). Similar fire activity was documented on the 2004 Mineral and Armstrong fires in Calaveras County, CA, where these fires overlapped the 1992 (Old) Gulch fire (S. Beckman pers. comm. 2012).

In Idaho and Montana fire managers found a 10 year period between fires in the same location where fires were self-limiting in middle and higher elevations (Beckman 2007). However, in lower elevations the period was shorter due to grass or shrub fuel type recovery creating horizontal continuity within the fuelbed which contributed to enhanced fire spread.

Fire case studies which examine fuels, weather, fire behavior, and fire ecology can aid in the management of future fires. This case study focuses on the early days of the Chips fire when the fire was burning through the Storrie fire footprint. Scott and Burgan (2005) timber litter 7 (described as “large downed logs” and “heavy load forest litter”) best describes the fuels within the footprint of the Storrie fire. However, no exact fuel models or means to model fire behavior are readily available for fires burning through areas with extensive snags (M.E. Alexander and M.A. Finney, pers. comm. 2012). The information on fire behavior documented here is an important step in the calibration of fire behavior models and supporting fire management decisions for fires burning within recently burned areas where young fuels and a heavy snag and dead-down woody fuel component contribute to fire spread. The objective of this case study is to document and explain some components that influenced fire behavior in the earlier portion of the Chips fire.

Fire Chronology and Development

The Chips fire started near the Pacific Crest Trail, along a lower slope of the Feather River canyon. During initial actions the fire remained small due to slow to moderate rates of spread as the fires burned within the footprints of the recent Storrie and Belden fires. The efforts of the firefighters was another key element of keeping the fire size to a minimum through this period, but due to the steep and difficult terrain efforts to contain the fire were unsuccessful (Figure 1 and 2).

Figure 1. **Top photo -** Initial spread of fire in the steep, difficult to access terrain of the Feather River Canyon, burning through the 2008 Belden and overlapping the 2000 Storrie fire footprints. **Lower photo -** Fire activity during the first days of the fire as it moved along the ridge and began to slop over into the Indian Creek drainage. Initial suppression efforts held the fire on the ridge, before it eventually spotted across firelines. The area was burned in the Storrie fire, and shows the extensive snags and shrubs as dominate fuels. Not visible are extensive downed log component and other surface fuel loading from broken tops of smaller snags.

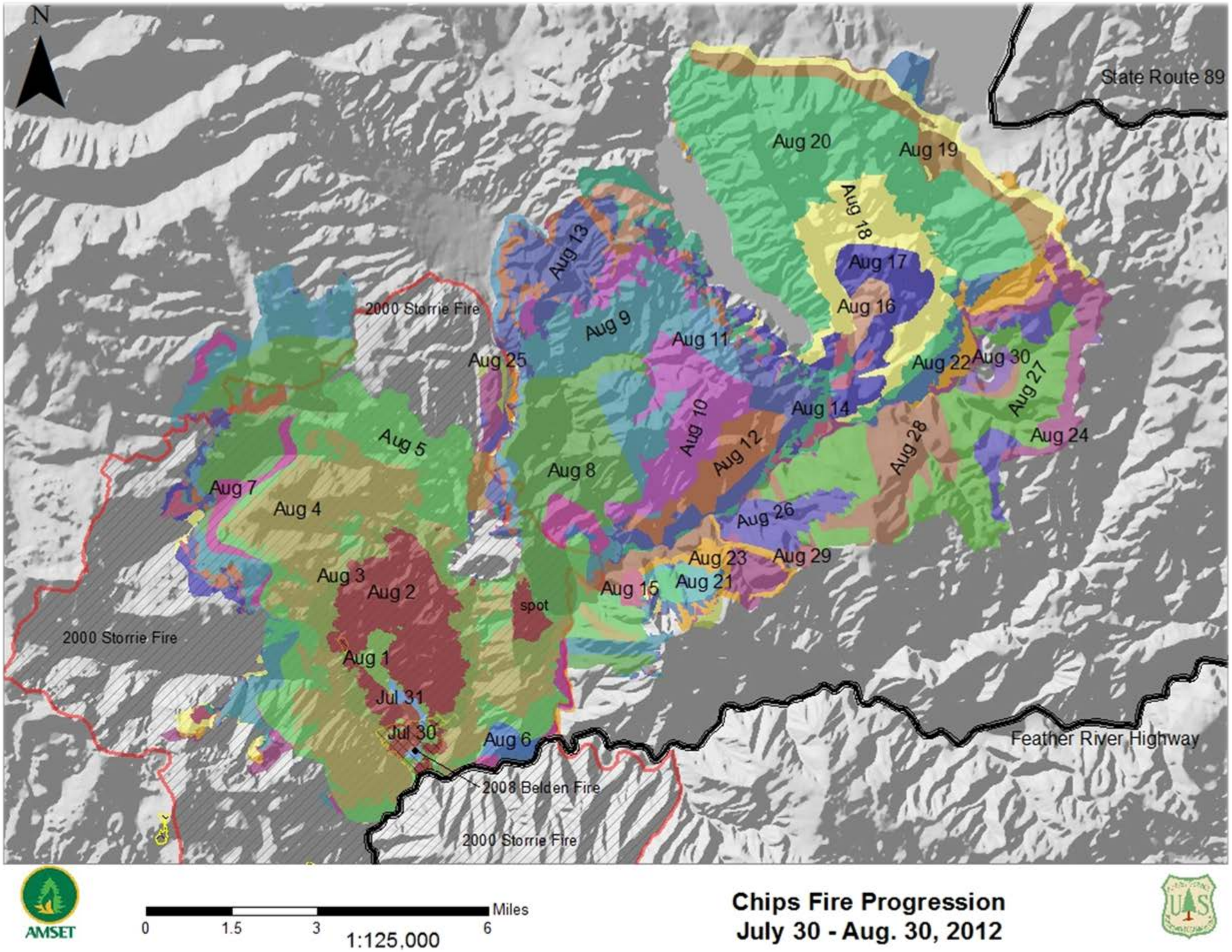

Figure 2. Progression map of the Chips fire from the start on July 30th through to August 30, 2012. This case study focuses on the initial spread in the footprint of the 2000 Storrie fire (diagonal stipe pattern) and 2008 Belden fire (cross hatch pattern). The steep Feather River canyon is visible immediately to the south of the fire origin, where the Feather River highway is shown as a black line.

On the third day (August 1, 2012) the fire reached the ridge above Indian Creek (Figure 2). Suppression actions were able to hold the fire on the ridge for a short period of time before the fire burned into an area of high density snags, down logs and shrubs. The fire quickly increased in intensity and developed a large column (Figure 3). Due to unsafe fireline conditions, the fire crews retreated to safer locations, and the fire progressed down the slopes of Indian Creek canyon.

Figure 3. High fire intensity builds a column, as the fire begins to back and roll down the slopes into the Indian Creek drainage. The Haines index was 5 on this day (August 2, 2012). Winds were light, but very dry conditions resulted in heavy fuel consumption and high fire intensity.

On August 2, 2012, the fire spotted 1.5 to 2 miles into the North Fork of the Feather River canyon (Figure 4). Fire intensity increased on multiple segments of the fire because burning material rolled down steep slopes into unburned fuel and then ran rapidly back uphill. This "rolling out" caused about 3,600 acres of fire growth that day. On August 4, 5, 8 and 9th, the fire continued to make substantial runs and increase in size (Figure 1, Table 1). Most fire spread was in a north-east or north direction following prevailing winds and aligned with major drainages. The daily notes and progression map are not always concordant, likely due to time and source of the map.

Figure 4. Spot fire from burning material that traveled 1 ½ to 2 miles ahead of the main fire (August 2, 2012). The Pacific Gas and Electric (PG&E) infrastructure is seen at the bottom of the drainage near the community of Caribou, CA.

Table 1. Observations of fire spread and behavior during the initial stages of the fire. Best available data was used. Acreage growth is based on the fire progression generated from both line scan infrared imagery and low level helicopter-based mapping. Flight data interpretation errors can occur from time of day the imagery is taken, as well as the aspect, elevation, and visibility.

Date	General Observations*	Growth (acres)
29-Jul	Fire started on the lower, mid-slope in the Chips creek drainage.	
30-Jul	Slow progression in 2000 Storrie and 2008 Belden fire footprints. Extremely steep (>55% and >70%) slopes in Feather River canyon	214
31-Jul	Fire started to spread more, moving up the Indian Creek drainage with the wind. Numerous hand crews (including six hotshot crews) built line around the flanks of the fire and worked direct attack to suppress the fire in very steep, difficult to access terrain with high resistance to control (heavy snag and log densities). Firefighters were holding the fire along the ridge and there was some pre-treatment with retardant on ridge.	112
1-Aug	Fire began to spread rapidly up slope in the Indian Creek drainage to the top of Indian Springs ridge and spotted over a mile away on the ridge between Yellow Creek and the Caribou/North Fork Feather River drainage. Fire developed vertically with an impressive column that day. Post-fire observations show very high consumption and forensic evidence of very high intensity.	393
2-Aug	Fire grew significantly (>2000 acres) to the northeast and east, exceeding direct attack suppression capabilities. Fire rolled over Indian Springs ridge, generated rolling material that ignited new spot fires at the bottom of the slope in Squirrel and Cub Creeks and then burned rapidly, with very high intensity up the slope. Similar behavior was experienced on the spot fire in the Caribou drainage.	3,627
3-Aug	Fire grew persistently in all directions, but not dramatically. Heavy smoke (inversion) may have contributed to decreased fire spread.	1,675
4-Aug	Limited fire information was obtained this day due to poor visibility limiting aerial observation and lack of safe ground access.	6,827
5-Aug	Main fire connected with spot fire in Caribou drainage and rolled down toward Belden in the Feather River Canyon. Fire spotted onto Red Hill, across the North Fork of the Feather River. Spotting was in a northeasterly direction, with the prevailing winds. Significant convection columns are now building up each day. Fire remains within the Storrie fire footprint except for the spot on Red Hill.	5,350
6-Aug	Fire grew mostly to the north into the Grizzly Creek drainage.	291
7-Aug	Fire spread was persistent. Heavy smoke and a persistent inversion limited fire activity. High pressure set in, with less vertical development of convective energy.	1,364
8-Aug	Fire moved out of the Storrie fire footprint; spreading into Mosquito Creek, burned slowly for two days with future large fire growth expected.	6,333
9-Aug	Little growth in Mosquito Creek, but great spread to the east, northeast.	5,461
10-Aug	Very active fire behavior. Large fire growth in Mosquito Creek. At 1500 - 1600 the fire spotted 1/2 mile into heavy forest fuels and moved rapidly into heavy mixed conifer forest with significant ladder fuels, down wood and very steep slopes; southeast aspect. Crown fire developed with large column with convective energy.	2,734

** The daily notes and progression map are not always concordant, likely due to time and source of the map.*

Fire Environment

Topography

The North Fork of the Feather River Canyon, with multiple drainages and steep slopes (most >55% and some >70%; Figure 5) comprises the topography of the Chips fire area in the initial part of the fire.

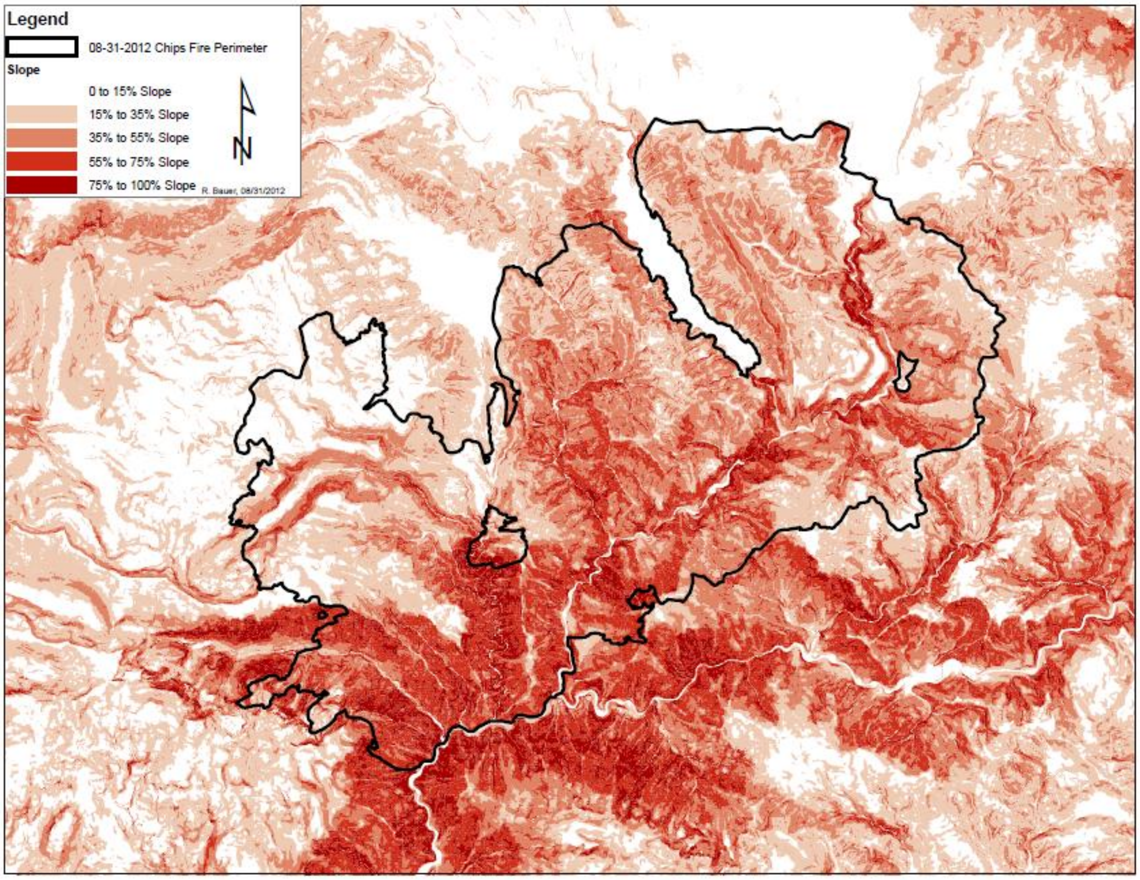

Figure 5. Map of slope classes within the Chips fire area. The majority of the area has slopes that fall between 55 and 70%.

Fuels – Composition and Loading

During the initial days of the Chips fire the fuels consisted of snags, down logs and shrub regrowth associated with extensive areas that had burned at high to moderate intensity during the 2000 Storrie fire (lower photo of Figure 2 above). Due to various reasons, the drainage of the Storrie Fire and vicinity where the Chips fire occurred were unsalvaged (no trees removed after the fire). Consequently, extensive areas with high snag densities, down logs and fuels, and dense shrub fields dominated the landscape (Figure 6 – left photo). Lower snag densities occurred on less productive serpentine soils (Figure 6 – right photo).

Figure 6. Photo of fuel conditions in the area that had burned in the 2000 Storrie fire. Limited areas were replanted with pine seedlings after the fire (photo on the left). The photo on the right is in a low productivity, serpentine area with lower snag quantities and down woody fuels.

Detailed fuel load estimates were calculated from stand exam data collected in 2010 by the Plumas National Forest (K. Merriam, pers. comm. 2012). The stand exam plots included fuels measurements (Brown et al. [1982] planar intercepts), live tree size and density by species, snag density by species and decay class and size (diameter and height). Two plots were analyzed in detail that represented areas that had burned at high intensity in the Storrie fire footprint. Down fuel and snag fuel loading was calculated using Forest Vegetation Simulator's Fire and Fuels Extension (FVS-FFE, Dixon 2002, Rebain 2010) within the ArcFuels (Vaillant et al. 2012) interface. For snags, the carbon load was doubled to obtain the estimated fuel load (N. Vaillant, pers. comm. 2012). Live fuel understory loading was calculated from canopy cover data using Burgan and Rothermel (1984).

Total fuel loading, including standing snags, was 37 and 247 tons/acre for the two plots (Table 2). Over 200 tons per acre of 1000 hour fuels (down logs) was the primary contributor to the fuel load in plot 79. This loading is consistent with pre-fire observations by Ryan Bauer, District Fuels Officer, Plumas National Forest.

Both natural snag fall rates and wind events over the years contributed to the high downed log densities and heavy fuel loading in the fire area. Multiple high wind events such as in the winter of 2011- 2012 resulted in numerous tops breaking off from snags, which is more common near and on ridge tops. Thousand hour fuel estimates for post-wildfire conditions in the Sierra Nevada were not readily available based on past studies, however, studies from Arizona in ponderosa/mixed conifer and ponderosa stands ranged from 25 to 91 tons/acre (Passovoy and Fule 2006). Snag density and loading (20 to 45 tons/acre) also varied widely due to different pre-Storrie fire tree densities and fire intensity. Shrub fuel loading ranged from 3 to over 9 tons/acre. The most common shrub species was deer brush, which is a deciduous shrub. In 2012 a high dead percentage in the shrub component was observed by local fire managers. This dead loading was likely due to two factors:

- 2012 was a dry year and the leaves were senescing early in the season.
- Precipitation in 2012 was moderately low, but more importantly, what precipitation that did occur came predominantly in the form of rain. A low

snowpack in combination with a late spring cold snap resulted in significant dieback of exposed, young shoots (D. Kinateder, Mt. Hough District Fire Ecologist, pers. comm. 2012). This dieback was readily evident in the condition of shrubs in a nearby unburned area.

Table 2. Post-Storrie fire and Pre-Chips fire fuel loading for two representative plots calculated from stand exam data collected by the Plumas National Forest. The plots were burned in the Chips fire on August 2, 2012.

Fuel loading characteristics		
	Pre-fire fuel load (tons/ac)	
Fuel class	**Plot 79**	**Plot 142**
grass/herb	0	0.1
shrub	9.9	3
litter	0.07	0.41
duff	1.2	1.5
1 to100 hr	3.1	5.8
1000 hr (small)	0.21	4.6
1000 hr (large)	214	1.100
snag	45.2	20.4
TOTAL	**274**	**37**

Fuel Moisture

Low fuel moistures were due to lower than average precipitation (Figure 7) the previous season. More significantly, dead fuel moistures were very low because most of the precipitation came as rain late in the wet season. Generally, in the Sierra Nevada mountain range, snow comprises the bulk of the precipitation. Moisture from the snowpack slowly infiltrates into the soil and fuels on the surface. When the precipitation comes predominantly as rain, infiltration is more rapid and greater run-off occurs, leading to drier soils and surface fuels the following season. The 2011-2012 winter and spring precipitation pattern resulted in very low 1000-hour fuel moisture levels (Figure 8) during the 2012 fire season. The 1000-hour fuel moisture was below 10% at the time of the fire, which is a critically low level.

Foliar moisture levels in the fire area were also low (Figure 9), with live, oven-dried samples of Manzanita leaves at 100% at the time the fire began. Foliar moisture samples of deer brush, a deciduous *Ceanothus* shrub, were not available, but observations were that abnormally high levels of early season senescence was occurring resulting in a significantly lower average foliar moisture level of burnable foliage.

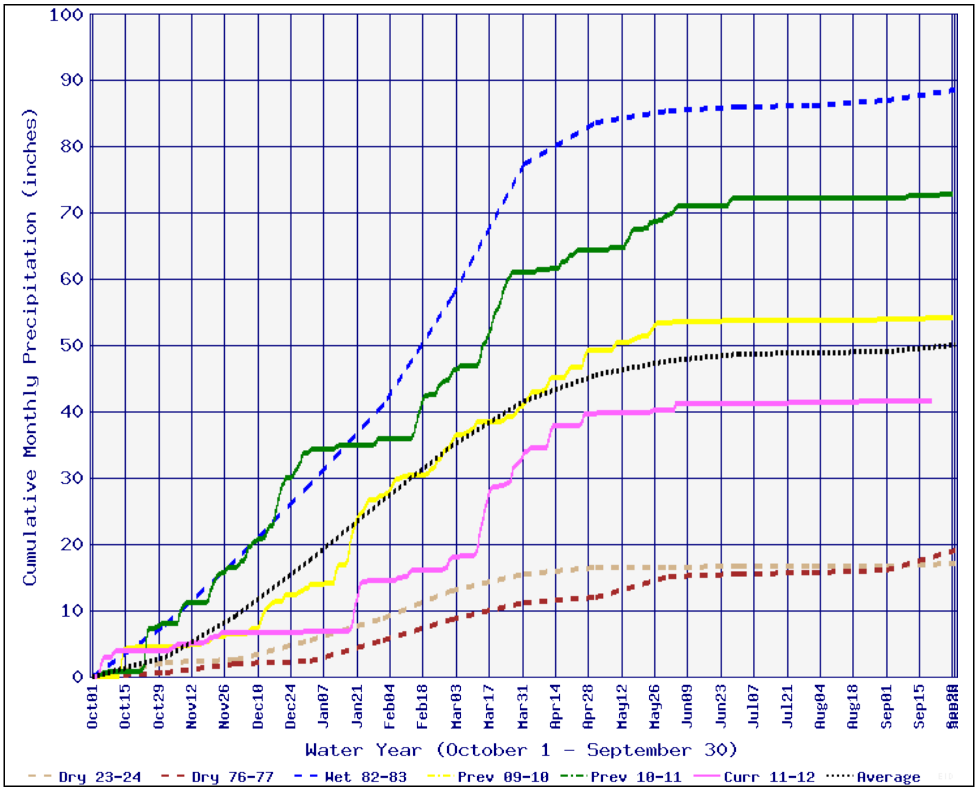

Figure 7. Annual precipitation patterns for the Feather River Basin for 2012, compared to the average, driest and wettest years. 2012 is below average during the summer and was at record low levels for winter 2011-2012. Data and graph from the California Department of Water Resources.

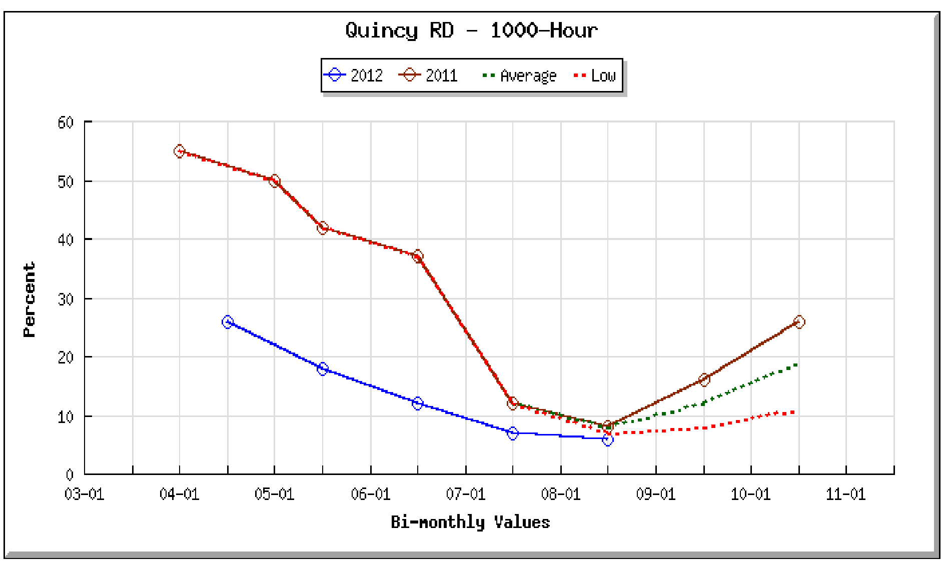

Figure 8. Thousand-hour fuel moisture trends based on measurements from the fuel moisture sampling plot at the Quincy Ranger District weather station in Quincy, CA (approximately 15 miles east of the fire area at a representative elevation).

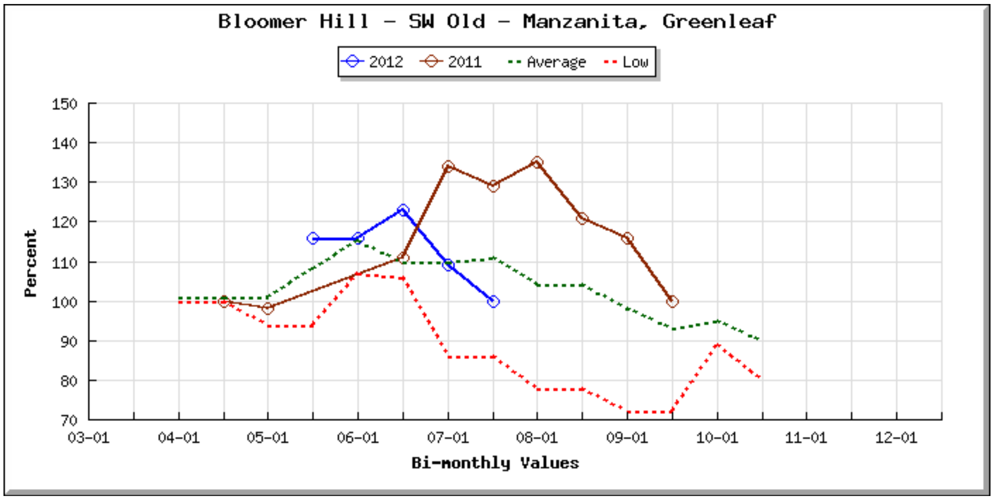

Figure 9. Seasonal trends of foliar moisture from oven-dried samples of Greenleaf Manzanita from Bloomer Hill fuel moisture sampling site, Plumas National Forest.

Fire Weather

Weather during the majority of the fire was not significantly different from historic averages for August. Winds were low, dominated by diurnally driven winds. Data from the Gansner Bar and Red Hill portable remote automated weather stations (RAWS) in the vicinity of the fire was summarized below. Gansner Bar is located at the base of the fire in Feather River Canyon at 2,300 feet; and Red Hill is a hilltop location on the south side of the North Fork of the Feather River at 6,335 feet. Weather data for these stations was summarized using the NFDRS fuel model G which is described as heavy dead, closed, short-needle conifer.

During the initial days of the fire, winds were below 10 miles/hour (Figure 10). Fire crew observations agreed that diurnal and slope wind speeds were low to medium.

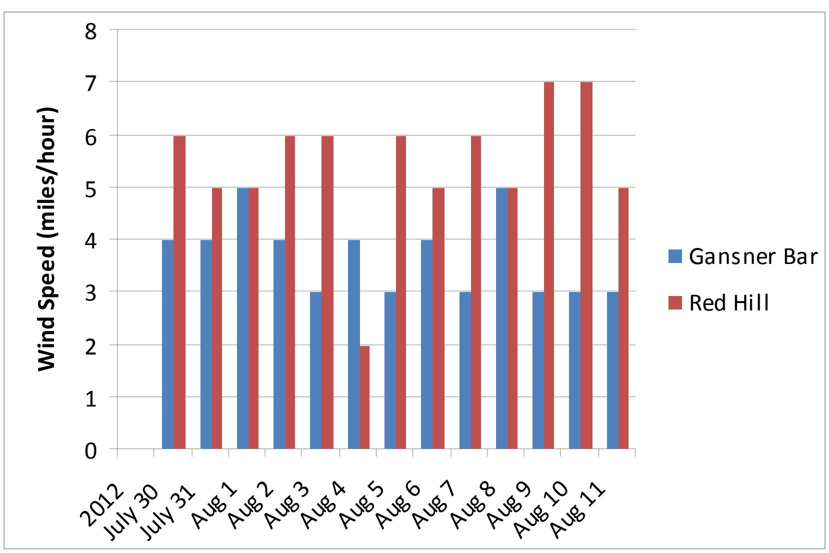

Figure 10. Daily maximum wind speeds from weather stations at Red Hill and Gansner Bar.

Minimum relative humidity across the fire area ranged between 10 and 20 percent most days (Figure 11). Humidity recovery at night was greatest at the Gansner Bar location due to its proximity to the Feather River. July 1 through August 2, 2012 and on August 11th humidity dropped below 10% at Gansner Bar. On Red Hill, humidity was similarly low on August 7, 2012 and extremely low (<5%) on August 10 and 11, 2012.

Maximum temperatures were hot, exceeding 80°F on most days and occasionally exceeded 100°F (Figure 12). Lower temperatures at the Red Hill site reflect the influence of higher elevation and slightly higher wind speeds.

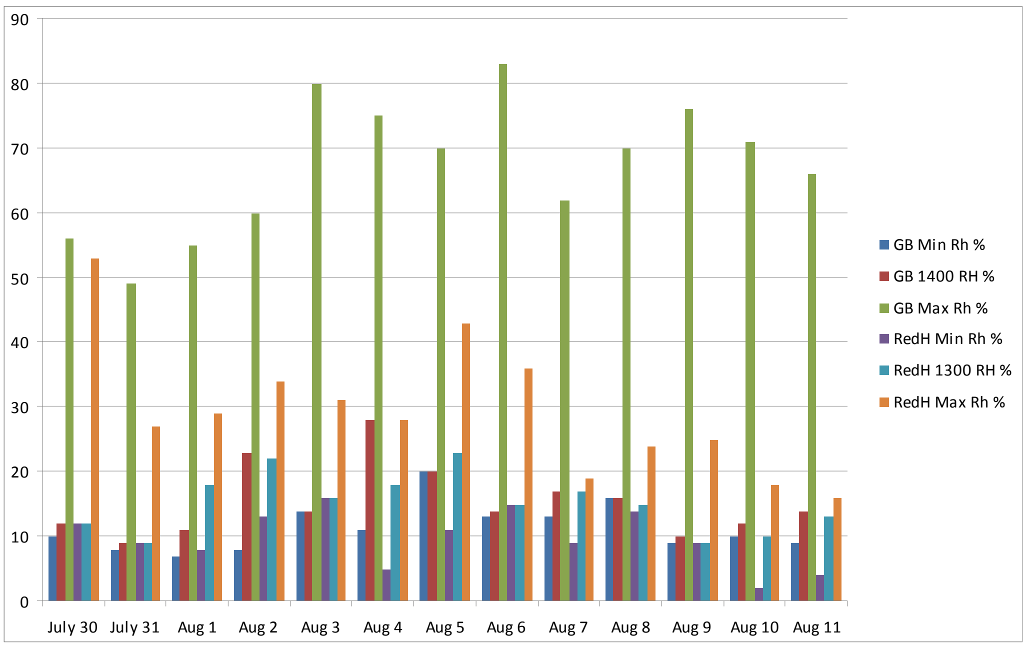

Figure 11. Humidity data from the Gansner Bar (GB) and Red Hill (RedH) RAWS. Minimum (Min Rh), maximum (Max Rh), and 1300-1400 hour humidity are displayed.

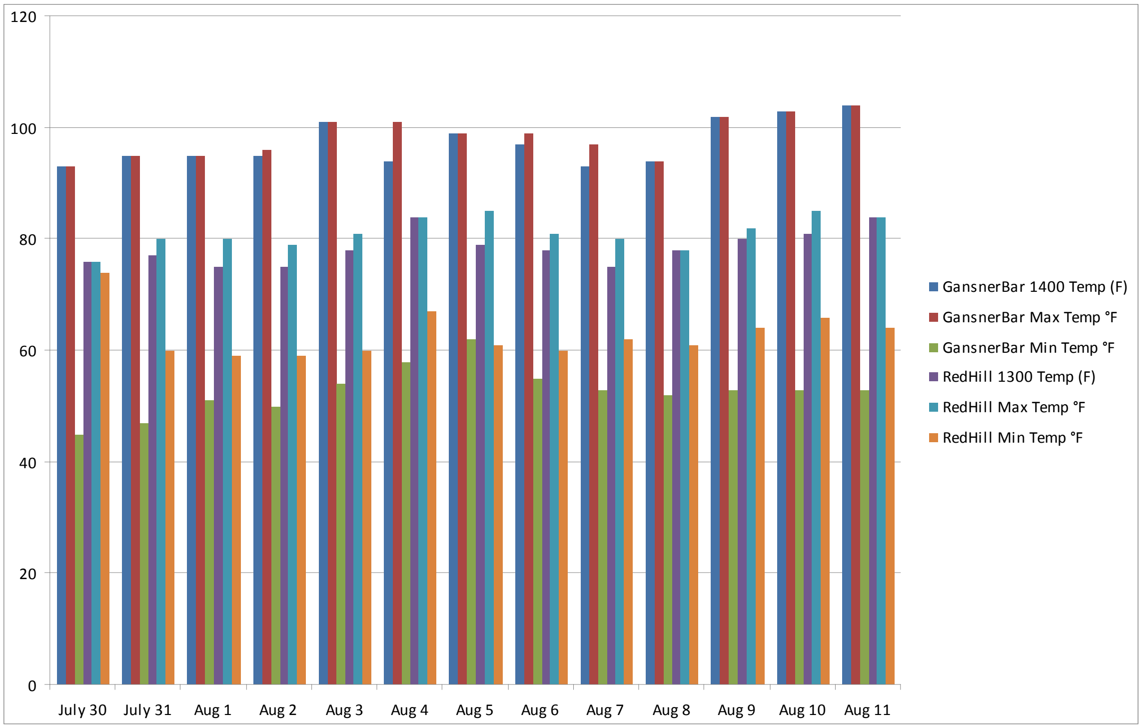

Figure 12. Temperature data from the Gansner Bar and Red Hill RAWS.

Fire Danger

Trends in the energy release component (ERC) for the Chips fire area exceed the 97th or extreme levels during the 2012 fire season (Figure 13). The ERC is a dimensionless number related to the 24-hour potential, worst case total energy released per unit area within the flaming zone of the fire. ERC relates to the amount of fuel available to burn and gives the larger fuels more influence. ERC is sensitive to fuel model and has good predictability of day to day variation in fire intensity (wind is not used, NWCG 2012, S-491 Workbook). ERCs presented in this report were generated from weather data recorded by the Quincy RAWS and Colby Mountain RAWS. The Quincy RAWS is located southeast of the Chips fire and is representative of the lower elevation fire areas. The Colby Mountain RAWS is located northwest of the Chips fire and is representative of the upper elevation fire area.

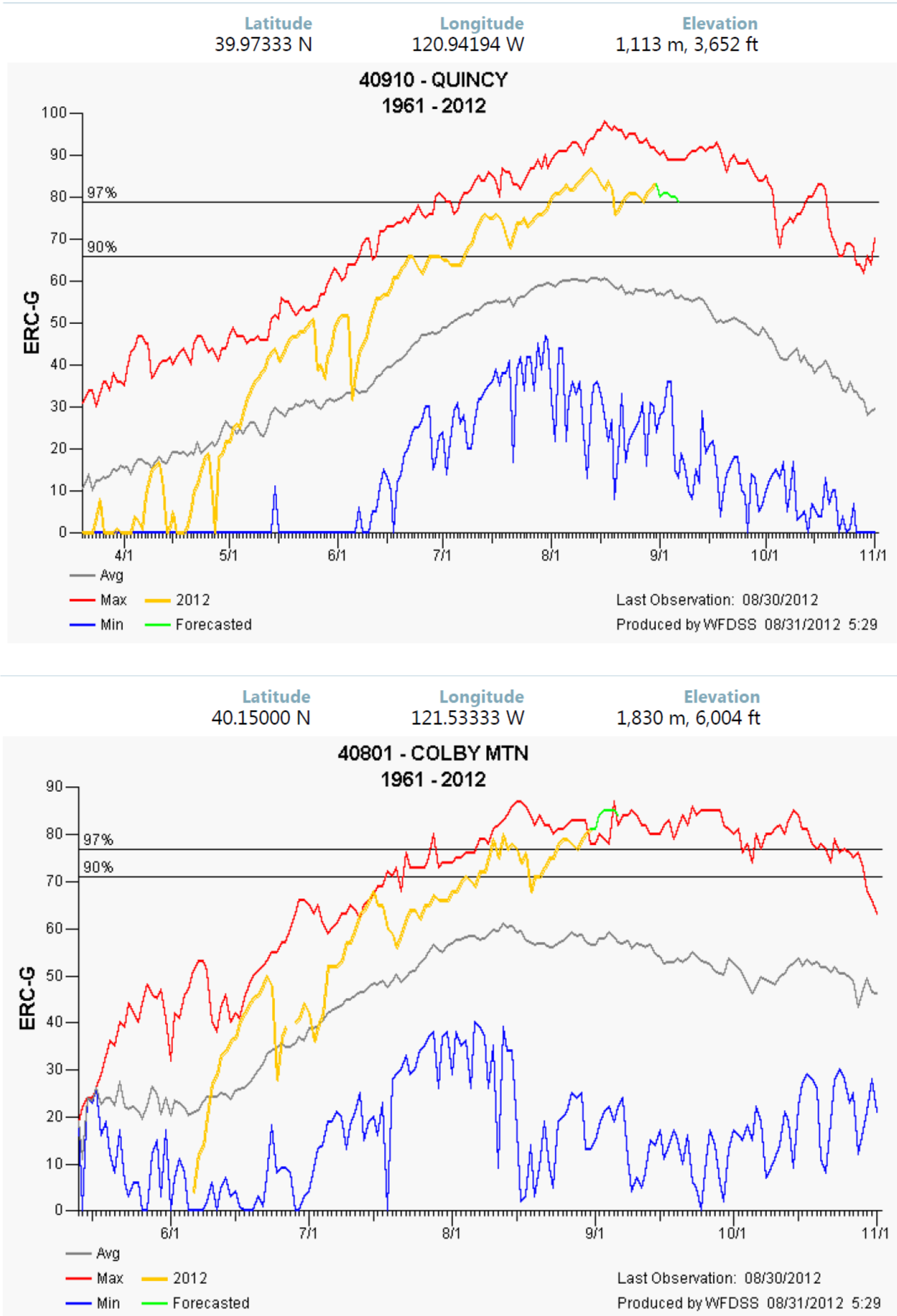

Figure 13. Seasonal trend in Energy Release Component for the area based on the Quincy (top graph) and Colby Mountain (bottom graph) RAWS.

Fire Behavior

The ERC was a good predictor of fire behavior during the Chips fire, particularly during the initial days of the fire. During the duration of the fire the Haines Index was between 5 and 6 (index from 1 to 6, with 6 as the strongest correlation of atmospheric instability and large wildfire growth). The Chips fire occurred in the transition from the west to east side of the Sierra Nevada, where the crest is bisected by the Feather River. Pete Duncan, Plumas Deputy Fire Management Officer, confirmed that the Haines Index is a good predictor of intense fire behavior on the Chips fire area and more easterly portions of the Forest (Figures 14 and 15).

Figure 14. Fire burning intensely up a slope and along Indian Springs ridge in the area previously burned in the Storrie fire.

Figure 15. A column developed from the Chips fire in early August.

Rates of spread on the Chips fire were not always high due to inversions dampening fire behavior. The spread pattern of the Chips fire was slower burning under the smoke inversion layer, and then long distance spotting and consumption of greater acreages when the atmosphere was unstable (inversion layer cleared). The column sometimes bent over, but generally developed vertically, but column collapse or air draw into the center of the column did not occur (P. Duncan, pers. obs. 2012). Whether or not the Chips fire demonstrated plume dominated fire behavior continues to be a point of contention among individuals assigned to the incident. Synoptic fire weather or a specific weather pattern/ type was not a clear driver of fire behavior, but appeared to be within the range of normal summer weather conditions for this area. Some days had higher winds than others (about once a week; R. Laeng pers. comm. 2013), but in general the fire was not wind driven, so alignment with steep slopes, major drainages, and receptive fuels were the main drivers of fire behavior (see previous weather section for more).

Fire Spread

The spread on the Chips fire was highly variable. The fire would either move steadily aligned with steep slopes or main drainages as well as receptive fuels influenced by light wind; or it would accelerate rapidly after building up heat from combustion in accumulations of dead fuels and dry live understory vegetation, and spot forward in snags and logs. Rates of spread through the Storrie fire footprint were estimated by: fireline personnel on the ground, aerial observations during major runs, and mapped progression of the fire along with burning period observations (R. Bauer, pers. obs. 2012).

From July 30 through August 1, 2012 rates of spread were estimated by fire crews to vary between 10 and 30 chains/hour (Table 3). These rates of spread match estimates from progression maps and calculation of duration during the primary burning period (R. Bauer, pers. obs. 2012). Crews observed rapid spread in the shrub layer, with spotting into and between down logs and especially snags. Spotting distances varied from short-range (tens to hundreds of feet) to miles (1/2 to 2 miles).

Table 3. Estimated rates of spread from progression maps and observed burning period.

date	Rate of spread (chains/hr)	Spotting distance (miles)
29-Jul		
30-Jul	27	
31-Jul		
1-Aug	11 - 24	1 ½ - 2
2-Aug		
3-Aug	4 - 7	
4-Aug		
5-Aug	7 - 17	
6-Aug	7 - 21	
7-Aug		
8-Aug		
9-Aug		
10-Aug	72	

Fireline Intensities

Fireline intensity was high to extreme during the initial days of the fire. Total energy release and fireline intensity were estimated based on measured fuel loads, estimated consumption and observed rates of spread. Firefighting resources made onsite, direct observations of the fire's rate of spread and consumption. The second method was a quantitative estimation of intensity.

Initially, while the Chips fire was burning through an area that had burned twice in the previous 12 years (2000 Storrie and 2008 Belden fires), crews used a direct attack strategy because fire behavior and rates of spread were low enough. This strategy became ineffective and Chips fire was not contained during this period due to spotting, fire creeping under logs after aerial retardant application, and alignment with steep slopes. Additionally, an initial attack engine reported that the fire burned actively at night.

Just two days after the fire started, as the fire burned through extensive areas of snags, shrublands and heavy downed, dead fuel loads, direct attack was not possible. Low live foliar moistures (100%) and a high proportion (estimated to be >30%) of dead 1- and 10-hour fuels contributed to high intensity fire behavior and rates of spread exceeded 20 to 30 chains per hour.

Quantitative estimates of fireline intensities (Table 4) and total heat energy release (Table 5) were made using two recently measured stand exam plots (obtained from K. Merriam and J. Sherlock, pers. comm. 2012) representative of the higher end of fuel loads. Plots used to quantify heat release burned during the initial days of the fire when rates of spread were the greatest, and fire activity exceeded the capability of assigned suppression resources. Estimates of fuel consumption are based on post-fire observations where high intensity fire burned through the Storrie fire footprint (Figure 16) and paired photos (Figures 17-19).

Figure 16. Post-fire conditions along the Indian Creek trail, where extreme fire intensity occurred during a large run on August 1, 2012. The white and red imprints of logs that were completely consumed are evident as well as shrub bases showing >90% consumption. There are also charred remnants of snags, with 70 to 90% consumption evident.

Steep slopes, combined with the heavy fuels and regrowth since the Storrie fire, and a range of observed spread rates resulted in a wide range of calculated fireline intensities. Fireline intensity ranged from 419 to 16,638 Btu/ft/s. The fire's total heat energy release ranged from 776 to 80,980 Btu/ft/s (calculated from all energy produced including post-frontal flaming and smoldering combustion). Heat per unit area ranged from 5,706 to 61,305 Btu/ft^2 (Tables 4-5, Appendix II). In comparison to Andrews and Rothermel (1982), fire intensities calculated for the two study plots are at and above the maximum charted (1,000 Btu/ft/s) in their tables, but still fall within the crown fire portion of their graphic. Andrews and Rothermel (1982) interpret fireline intensities greater than 1,000 Btu/ft/s as *"crowning, spotting, and major fire runs are probable, control efforts at the head of the fire are ineffective."* Nomogram prediction tools in Rothermel (1983) make a useful comparison to the Chips fireline intensity and energy release calculations. Using Rothermel's nomogram for fuel model 13, heavy logging slash and high wind speeds, the highest fireline intensity charted is about 9,200 Btu/ft/s (at a rate of spread of 125 ch/hr) and a maximum heat per unit area of 5,000 Btu/ft^2.

Anderson's (1968) case study report on the 1967 Sundance Fire had estimated fireline intensity over a 12 hour period using Byram's (1959) method at 22,500 Btu/ft/sec during the Sundance fire's major crown fire run.

Some of the higher fireline intensities calculated in this report exceed commonly reported and published fireline intensity levels expected for non-crown fire (Andrews and Rothermel 1982, Alexander 1982). This was due to several factors:

- First, the sample plots were chosen to represent a worst-case scenario. These plots had very high fuel loadings, and plot 79 could even be considered an outlier (fuel loading is so high that it is not representative of the majority of the area).
- Secondly, the amount of fuel consumed in the flaming fire front required estimation of consumption rates due to the difficulty of obtaining these field measurements. Some of these estimates could have led to inflated fireline intensity values.
- Third, the highest rate of spread in Tables 4 and 5 could be due to fire spread through spotting, which increased the calculated fireline intensity values.

However, despite the sources of error in estimating fireline intensities, the results presented in this report suggest that fireline intensities in recently burned areas with high shrub, coarse woody, and snag fuel loadings can be higher than expected given our current knowledge and experience base.

Table 4. Fuel loading calculated from stand exam plots, estimated consumption, and fireline intensity in areas that burned previously in the Storrie fire. Fireline intensities were calculated using a high proportion of fine fuels burned and these estimates may be representative of **what burned during the fireline combustion**. Calculations were completed with three different rates of spread based on observations (progression map, R. Bauer, S. Murphy, and Fulton Hotshot pers. comm. 2012).

Fuel characteristics		**Fuel consumption assumptions during fireline combustion**		**Fireline Intensity (Btu/ft/s)**		
fuel class	**pre-fire fuel load (tons/ac)**	**fraction burned (scale of 0 to 1)**	**fuels consumed (tons/ac)**	**ROS low (4 ch/hr)**	**ROS high (27 ch/hr)**	**ROS very high (72 ch/hr)**
Plot 79						
grass/herb	0	1	0	0	0	0
shrub	9.9	0.5	4.95	129	871	2,323
litter	0.07	1	0.07	2	12	33
duff	1.2	1	1.2	31	211	563
1- to 100-hr	3.1	1	3.1	81	546	1,455
1000-hr (small)	0.21	1	0.21	6	37	99
1000-hr (large)	214	0.1	21.4	558	3,766	10,044
snag	45.2	0.1	4.52	118	796	2,121
TOTAL	**274**		**36**	**925**	**6,239**	**16,638**
Plot 142a						
grass/herb	0.1	1	0.1	3	18	47
shrub	3	0.5	1.5	39	264	704
litter	0.41	1	0.41	11	72	192
duff	1.5	1	1.5	39	264	704
1- to 100-hr	5.8	1	5.8	151	1,021	2,722
1000-hr (small)	4.6	1	4.6	120	810	2,159
1000-hr (large)	1.10	0.1	0.11	3	19	52
snag	20.4	0.1	2.04	53	359	957
TOTAL	**37**		**16**	**419**	**2,827**	**7,537**

Table 5. Fuel loading calculated from stand exam plots, estimated consumption, and total heat energy released by the Chips fire in area that had burned previously in the Storrie fire. The total heat energy release was calculated with the fireline intensity formula, but includes **all energy produced including post-frontal flaming and smoldering combustion**. Calculations were completed with three different rates of spread based on observations (progression map, R. Bauer, S. Murphy, and Fulton Hotshot pers. comm. 2012).

Fuel characteristics		**Fuel consumption assumptions**		**Total Heat Energy Release (Btu/ft/s)**		
fuel class	**pre-fire fuel load (tons/ac)**	**Total fraction burned (scale of 0 to 1)**	**Total fuels consumed in fire (tons/ac)**	**ROS low (4 ch/hr)**	**ROS high (27 ch/hr)**	**ROS very high (72 ch/hr)**
			Plot 79			
grass/herb	0	1	0	0	0	0
shrub	9.9	0.8	7.92	207	1,394	3,717
litter	0.07	1	0.07	2	12	33
duff	1.2	1	1.2	31	211	563
1- to 100-hr	3.1	1	3.1	81	546	1,455
1000-hr (small)	0.21	1	0.21	5	37	99
1000-hr (large)	214	0.6	128.4	3,348	22,599	60,263
snag	45.2	0.7	31.64	825	5,569	14,850
TOTAL	**274**		**173**	**4,499**	**30,368**	**80,980**
			Plot 142a			
grass/herb	0.1	1	0.1	3	18	47
shrub	3	0.8	2.4	63	422	1,126
litter	0.41	1	0.41	11	72	192
duff	1.5	1	1.5	39	264	704
1- to 100-hr	5.8	1	5.8	151	1,021	2,722
1000-hr (small)	4.6	1	4.6	120	810	2,159
1000-hr (large)	1.10	0.6	0.66	17	116	310
snag	20.4	0.7	14.28	372	2,513	6,702
TOTAL	**37**		**30**	**776**	**5,236**	**13,962**

Fire Effects and Consumption

Paired photos (Figures 17 to 19) were taken by the Mt. Hough District Fire Ecologist, Dave Kinateder. These photos were taken from a fixed point and individual snags can be referenced pre- and post-Chips fire. Heavy consumption of shrub, herb, grass, snag, and downed fuels is evident. Note these paired photos are not representative of the steeper slopes that made up a large portion of the fire footprint. See the slope map, Figure 5 above.

Figure 17. Paired photos from a fixed point in overlapping area of the Chips and Storrie fires.

Figure 18. Paired photos from a fixed point in overlapping area of the Chips and Storrie fires.

Figure 19. Paired photos from a fixed point in overlapping area of the Chips and Storrie fires.

Resistance to Control

The National Wildfire Coordinating Group (2012) defines *resistance to control* as the relative difficulty of constructing and holding a control line as affected by resistance to line construction and by fire behavior. Resistance to control was great on the Chips fire due to both the difficulty of constructing and holding control line as well as fire behavior. During the first day of the fire, when it was burning in lighter fuels inside the 2008 Belden and 2000 Storrie fire footprints, resistance to control was high based on a number of factors including, ineffectiveness of aerial applied retardant, short range spotting, and alignment with steep slopes. The fire burned on very steep terrain and in very dry and heavy fuels. The fireline intensities, heat per unit area, and rates of spread exceeded levels where direct attack is a safe or feasible strategy (Andrews and Rothermel 1982). Fireline construction on the Chips fire required great effort due to the steep terrain and heavy fuels such as logs and snags which hindered line construction.

Concluding Remarks

The Chips fire burned with high intensity because of high fuel loads, very dry fuels, and steep topography. Winds were mostly calm, but relative humidity was low and temperatures high. This is similar to what has been observed on other regional fires burning under similar conditions. What was different about this fire, compared to many others in the Sierra Nevada mountain range, is that it burned intensely in an area that had been burned only twelve years ago. Other areas of the Sierra Nevada at higher elevations in Yosemite National Park (Collins et al. 2009) and wilderness areas of the Sequoia National Forest have shown opposite patterns (Vaillant 2009, Ewell et al. 2012). These well studied areas have shown that fairly recent fires tend to cause reduced fire behavior and even stop fires that burn subsequently into them. Fires which have burned in previously burned areas in patterns similar to the Chips (mentioned in the introduction) in and near Yosemite National Park and Stanislaus National Forest illuminate the need to address this growing trend. As more fires burn in recent fire perimeters in low elevations in the Sierra Nevada, fire and land managers will have to adapt their management strategies to these potential high fireline intensity events.

The contribution post-fire vegetation conditions have on resistance to control highlights the need to manage forested landscapes proactively. The snags, coarse woody debris and shrubs/young tree fuels in the area of the old Storrie fire created fuel conditions which supported high fire growth and intensity. Within the Chips fire perimeter, snag densities were high in most areas and were observed to contribute substantially to fire behavior in terms of combustion, ember production, and spotting receptors. The intervening, dense shrub layer was dominated by species that readily resprout or germinate after fire. These shrub species will likely return at high densities again.

There have been few if any studies conducted in fuels dominated by large logs and snags. Consequently, no fuel models have been developed for these conditions (M.A. Finney, pers. comm. 2012). Two earlier publications provided relative indices of fire spread based upon the relative density (Barrows 1951) and spacing (Fahnestock 1970) of snags. In these publications, snag densities of greater than 4 snags per acre and spacing less than 33 feet were considered thresholds for greatly increased fire behavior potential, particularly if the snags were “shaggy” (had loose bark, fine branches and lichen). Note that fuel loading and fireline intensity were calculated from only two plots which were hand-picked to represent worst case scenarios within the Storrie and Chips fire area. More plot data is available to represent the full range of fuel loading variability across the landscape.

In the future, risk assessments of not treating fire areas in the lower elevations of the Sierra Nevada should include consideration of the resistance to control inherent to post-fire fuel conditions in these areas and the proximity of other values-at-risk including infrastructure, private land, and natural resources. A consequence of not actively managing fuels within the Storrie and Belden fires was that fuel conditions evolved to support fire behavior which displayed a high resistance to control. The elevated resistance to control resulted in extensive areas of high severity effects and high suppression costs associated with a long duration fire. Ager et al. (2011) suggest that numerous fire behavior metrics (fire spread rates, intensity, and burn probability/fire size) and ecological risks must be analyzed at multiple spatial scales to conduct improved wildland fire risk assessments. Damage to highly valued assets and resources must also be incorporated into these risk assessments. The Plumas and Lassen National Forests' Fire Management Plans explain the location and reasoning for wildfire suppression and management actions that include human protection, natural resources, and other objectives and goals.

These fuel conditions and associated fire behavior create significant restoration questions about fire hazard and risk in low elevation mixed conifer forests. Restoration strategies need to be developed and implemented on a broader scale and at a faster pace in order to mitigate the fire hazard and large fire potential. Secondly, restoration strategies for post-fire conditions in low elevation high severity burn areas are needed to address this evolving understanding of potential fire behavior within burn areas. It is also clear that new fuel models need to be developed to facilitate improved fire behavior predictions so that restoration strategies can be weighed utilizing post-restoration fire behavior expectations.

This case study only represents a few aspects of the Chips fire. The fire effects and impacts on soils, watersheds and wildlife are also important and play an important, if not primary, role in restoration decisions.

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Appendix I. Calculation of Combustion and Fireline Intensity

Fireline intensity **–** Fireline intensity was calculated from estimates of flame front spread rate and fuel consumption in the flaming front (Alexander 1982, Byram 1959). Byram (1959) defined fireline intensity, "I" (Btu/ft/sec), as the rate of heat release (in the flaming front) per unit length of fire front. He computed fireline intensity as:

I = H W R

where
H = average heat content of fuel consumed (kJ/kg or Btu/lb)
W = Weight [load] of fuel consumed in the flaming front (kg/m^2 or lb/ft^2)
R = forward rate of spread (m/sec or ft/sec)

Although Byram referred to "W" as available fuel, which often means **all** fuel consumed, not just that consumed in the flaming front, it is evident from his discussion that in the calculation, W is meant to be the amount of fuel consumed in the flaming front.

No simple method exists for estimating the amount of fuel consumed during the flaming stage. In forested fuel complexes, especially those with heavy loads of duff and coarse woody debris, flaming fuel consumption is a very small fraction of total fuel consumption. Dr. Fites shows her estimates of the percent of fuel consumed in the flaming front based on field observations during the Chips fire in the 'fraction burned' columns in Appendix II. Dr. Fites used the same equation for fireline intensity for total heat energy release but defined W as the total estimated fuel consumption rather than just flaming fuel consumption. The inclusion of post-flaming fuel consumption makes total heat energy release a larger quantity than fireline intensity (see difference in Appendix II tables). Heat per unit area was calculated with the same intensity formula above, except with no R value (HPA = HW).

Heat content (H) was assigned a reasonable value of 18,000 kJ/kg (Finney 1998) for the calculations listed in this report. Dr. Alexander (pers. comm. 2013) recommended using an equivalent amount, 7,744 Btu/lb, as found in the Forestry Canada Fire Danger Group (1992).

Appendix II. Fuel Loading and Fireline Intensity Calculations

Table 1. Fuel loading calculated from representative stand exam plots, estimated consumption, fireline intensity, and heat per unit area assuming three different rates of spread (ROS) during the Chips fire in area that had burned previously in the Storrie Fire.
Assumed low fuel consumption (50% of shrub, 10% of large 1000-hr fuels and snags) during fireline combustion.

Fuel Characteristics		Fuel consumption during fireline combustion		Fireline Intensity (Btu/ft/s)			Heat Per Unit Area (Btu/ft^2)
fuel class	pre-fire fuel load (tons/ac)	fraction burned (scale 0-1)	fuels consumed (tons/ac)	ROS low (4 ch/hr)	ROS high (27 ch/hr)	ROS very high (72 ch/hr)	
plot 79							
grass/herb	0	1	0	0	0	0	0
shrub	9.9	0.5	4.95	129	871	2,323	1,759
litter	0.07	1	0.07	2	12	33	25
duff	1.2	1	1.2	31	211	563	426
1- to 100-hr	3.1	1	3.1	81	546	1,455	1,101
1000-hr (small)	0.21	1	0.21	6	37	99	75
1000-hr (large)	214	0.1	21.4	558	3,766	10,044	7,604
snag	45.2	0.1	4.52	118	796	2,121	1,606
TOTAL	**274**		**36**	**924**	**6,239**	**16,638**	**12,596**
Plot 142a							
grass/herb	0.1	1	0.1	3	18	47	36
shrub	3	0.5	1.5	39	264	704	534
litter	0.41	1	0.41	11	72	192	146
duff	1.5	1	1.5	39	264	704	533
1- to 100-hr	5.8	1	5.8	151	1,021	2,722	2,061
1000-hr (small)	4.6	1	4.6	120	810	2,159	1,634
1000-hr (large)	1.1	0.1	0.11	3	19	52	39
snag	20.4	0.1	2.04	53	359	957	725
TOTAL	**37**		**16**	**419**	**2,827**	**7,538**	**5,706**

Table 2. Fuel loading calculated from representative stand exam plots, estimated consumption, total heat energy released, and heat per unit area assuming three different rates of spread (ROS) during the Chips fire in area that had burned previously in the Storrie Fire. **Assumed high fuel consumption (80% of shrub, 60% of large 1000-hour fuels, and 70% of snags) for total heat energy release.**

Fuel Characteristics		**Total Consumption**		**Total Heat Energy Release (Btu/ft/s)**			
fuel class	**pre-fire fuel load (tons/ac)**	**Total fraction burned (scale 0-1)**	**Total fuel load consumed (tons/ac)**	**ROS low (4 ch/hr)**	**ROS high (27 ch/hr)**	**ROS very high (72 ch/hr)**	**Heat Per Unit Area (Btu/ft^2)**
Plot 79							
grass/herb	0	1	0	0	0	0	0
shrub	9.9	0.8	7.92	207	1,394	3,717	2,814
litter	0.07	1	0.07	2	12	33	25
duff	1.2	1	1.2	31	211	563	426
1- to 100-hr	3.1	1	3.1	81	546	1,455	1,101
1000-hr (small)	0.21	1	0.21	5	37	99	75
1000-hr (large)	214	0.6	128.4	3,348	22,599	60,263	45,621
snag	45.2	0.7	31.64	825	5,569	14,850	11,242
TOTAL	**274**		**173**	**4,499**	**30,368**	**80,980**	**61,305**
Plot 142a							
grass/herb	0.1	1	0.1	3	18	47	36
shrub	3	0.8	2.4	63	422	1,126	853
litter	0.41	1	0.41	11	72	192	146
duff	1.5	1	1.5	39	264	704	533
1- to100-hr	5.8	1	5.8	151	1,021	2,722	2,061
1000-hr (small)	4.6	1	4.6	120	810	2,159	1,634
1000-hr (large)	1.1	0.6	0.66	17	116	310	235
snag	20.4	0.7	14.28	372	2,513	6,702	5,074
TOTAL	**37**		**30**	**776**	**5,236**	**13,962**	**10,570**