Fire Technology

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A Case Study of a Community Affected by the Witch and Guejito Wildland Fires

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Abstract. Wildland-urban interface (WUI) fires occur when fire spreads through both wildland and community (structures and vegetation) fuels. These fires are capable of causing significant destruction to both the built and the natural environments. When these fires occur under extreme fire danger conditions (e.g., high winds, low humidity) and in areas of significant population (e.g., San Diego, California) firefighters, and other emergency responders, are significantly challenged by the combination of firefighting and aiding the public. This paper presents the results of an in-depth case study of a community of 274 residences which was subjected to two wildland fires (within 2.5 h of each other) during the October 2007 firestorm in southern California. A significant amount of effort was spent obtaining information from residents and emergency responders to determine the fire spread timeline, structure ignition mechanisms, and defensive actions. Of the 274 residences, 245 were within the fire perimeter, 74 were destroyed, and 16 were damaged. When the first fire front arrived, the rate of structure ignitions peaked at 21 per hour. Direct and indirect ember, or firebrand, attack was responsible for the ignition of 2/3 of the destroyed homes. Defensive actions were taken on one of every three homes. Of the 16 damaged homes, 15 were successfully defended. Further study of this community is ongoing to investigate what currently recommended pre-fire hazard reduction actions could be, and were, implemented and their effectiveness at reducing the likelihood of structure ignition.

Keywords: Wildfire, Wildland urban interface, WUI, Fire, Fire safety, Fire case study

1. Introduction

The National Institute of Standards and Technology (NIST) has a Reduced Risk of Fire Spread in Wildland-Urban Interface (WUI) Communities research program [1]. The program's objective is to develop, by the end of 2013 first generation tools for improved risk assessment and risk mitigation in WUI communities at risk from wildfires. These tools will be developed and tested through a coordinated effort that includes laboratory and field measurements, physics-based fire behavior models, and economic cost analysis models.

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Despite the increasing frequency and losses from WUI fires, there has been relatively little research, compared to fires within structures, on WUI fire spread. This is due, in part, to the fact that the subject of WUI fire research falls between traditional studies of building fires and forest fires, non-overlapping areas that in the past have been the responsibility of different branches of U.S. government (e.g., building fires at NIST in the Department of Commerce and wildland fires at the U.S. Forest Service in the Department of Agriculture). Advances in measurement science are needed to effectively characterize and identify the conditions and mechanisms that result in a high risk of structure ignition across a range of WUI community types and conditions. Also, to date, no study that measures the effectiveness of current risk mitigation practices, whether through wildland fuel treatments or modification of residential fuels, has been conducted.

In this paper, the term WUI refers to locations where topographical features, vegetation types, local weather conditions and prevailing winds result in potential for ignition of structures from flames and embers of a wildland fire [2]. The WUI fire problem is gaining momentum across the Southern continental U.S. and is particularly severe across southern California during the fall occurrence of Santa Ana winds. These seasonal winds can be very dry and warm, creating severe fire danger conditions. Between October 2003 and October 2007, seven California WUI fires destroyed a total of 8877 structures [3], on average over 2200 structures per year. These seven fires resulted in 29 deaths, and over 317000 hectares (783000 acres) burned. The 2003 Cedar fire and the 2007 California Firestorm are among the top four fire incidents for the number of structures destroyed and acres burned. The Witch fire, the largest of the fires that occurred during the 2007 California firestorm, burned 80124 hectares (197,990 acres) and destroyed 1,125 residential structures, 509 outbuildings and 239 vehicles. Additionally, 77 residential structures and 25 outbuildings were damaged. Suppression costs were $18 million. The property damages for the 2007 California Fire Storm, dominated by the Witch fire, are estimated at $1.8 billion [4]. The Witch fire resulted in 45 firefighter injuries and two civilian fatalities.

The Witch fire started on October 21, 2007 at 12:35 pm at the Witch Creek area, east of Ramona in San Diego County. The NIST WUI Team was invited by the California Department of Forestry and Fire Prevention (CAL FIRE) to collect post incident data from the California October 2007 fires. Early on, the NIST WUI Team initiated a case study within the Witch Fire perimeter. The case study is focused on The Trails development at Rancho Bernardo, 40 km (25 miles) north of the City of San Diego. There were 274 homes in The Trails, with 245 within the fire perimeter (Figure 1). Seventy-four homes were completely destroyed and 16 were partly damaged.

The NIST data collection effort was designed to provide the necessary information to characterize the fire approach from the wildlands, the effects of fire within the community and the defensive actions taken. The intent has been to collect sufficient information, not only to characterize overall fire behavior in the WUI, but also to provide a foundation for future case studies. In that light, the following data collection methodology was developed and followed:

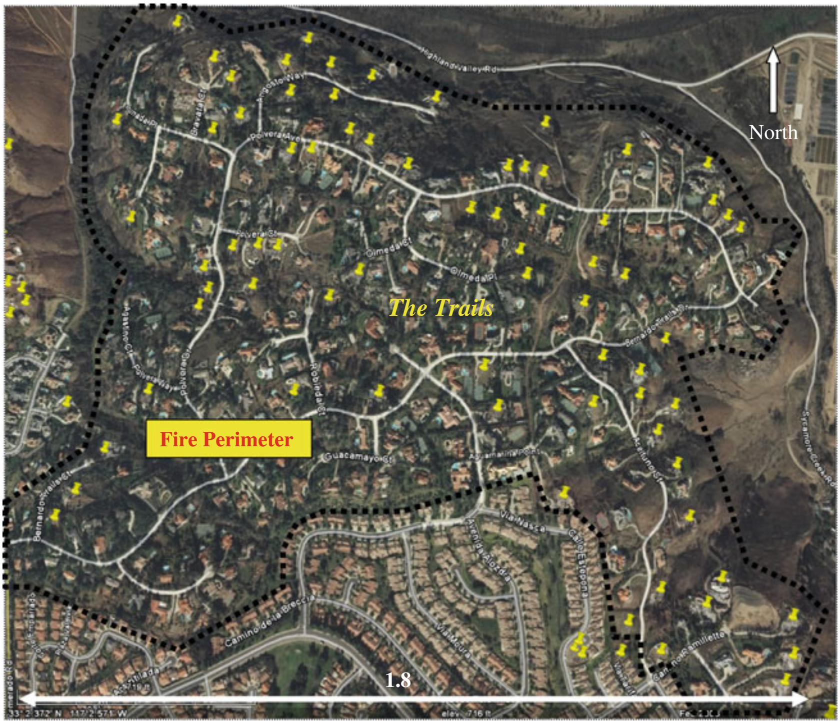

Figure 1. The Trails community, destroyed homes (in *yellow*) and fire perimeter after the Guejito and Witch fires.

1. Immediately after the fire, the construction characteristics of the destroyed residences were documented as well as all the damage to residential vegetation. This was necessary in order to capture the information before it was lost during community reclamation/recovery efforts.
2. Characteristics of the wildlands surrounding the community were then documented and data were collected on the direction and intensity of the wildland fire approach.
3. Technical meetings were conducted with first responders to develop an event time line. At the same time, The Trails homeowners association provided critical input to the event timeline.
4. The community was revisited to collect structure construction and landscaping particulars on all non-destroyed structures.

The field data collection effort took ~1300 person hours over 14 months. Field data were collected by NIST personnel and CALFIRE Fire Marshals with the support of residents, and the San Diego Fire and Police Departments. Field measurements included structure particulars, specifically roof type, proximity of combustibles to the structure, and damage to wildland and residential vegetation. Documentation included over 11,000 digital photo images. The data collected and the data analysis conducted are divided into three initial papers. This paper will address the event timeline construction and general fire behavior observations.

The second paper (work in progress) will explore the response of structures within The Trails to the WUI fire. Specifically, the second paper will use existing WUI hazard reduction guidelines and determine how well these guidelines match the observed structure responses to the fire. The second paper will explicitly look at the structure construction and ornamental vegetation impact of structure survivability. A third paper will then be developed to compare the outputs of different fire models to the observed fire behavior and structural fire responses in the community. It is the intent of the authors to make the post-fire data set self-contained to enable its use by other fire researchers. The data set will be placed on the NIST WUI website at www.fire.nist.gov/wui.

The NIST WUI research effort [5] has three components: computer model development, experiments, and field data collection. All three components are interlinked and work together towards reducing losses in the WUI. Fire behavior models are being developed to help characterize and predict fire behavior in the wildlands and at the interface [6–8]. An illustrative example of a WUI fire model under development is given in Figure 2. At the same time, the experimental work is being conducted, with input from the field data collection, to characterize and quantify structure ignition vulnerabilities [9, 10]. Modeling (including economic models [11]) and experiments will also be used to assess the potential effectiveness of hazard reduction techniques from both a physical process and economic benefit/cost point of view and at scales ranging from a structure to a community. By implementing this comprehensive methodological approach to studying communities burned by wildfires, the effectiveness and reliability of such hazard reduction technologies may be better assessed [12].

1.1. Previous Case Studies

A number of studies have been conducted after WUI fires. Nonflammable roofs were defined in these cases as roofs made of non-combustible materials such as Spanish type, cement, metal or asphalt shingle. In 1973, Howard et al. [13] observed a 95% survival of homes with nonflammable roofs. Foote [14] studied structural survival of the 1990 Paint fire and also observed over 80% survival of homes with nonflammable roofs and a clearance of 9 m (30 feet) or more. The 2007 USDA Angora fire study focused on assessing fuel treatments effects on fire behavior, suppression effectiveness and structure ignition [15]. The report focuses on the wildland fuels treatments; however, it provided little information on structure characteristics. The Home Destruction Examination report of the Grass Valley Fire by Cohen and Stratton [16] has provided a very useful timeline reconstruction; however the report does not directly couple the defensive actions taken to the individual structures. More recently, the Institute for Business and Home Safety (IBHS) had conducted a study of the Witch Fire [17]. The IBHS

Figure 2. This figure is an image from a computer simulation of a fire spreading in the Bernardo Trails area. The computer simulation tool is called WFDS (Wildland-urban interface Fire Dynamics Simulator). The image shows the results from an initial stage of applying the WFDS to study the 2007 fires in the Bernardo Trails area. The horizontal extent of the computational domain is 2000 m by 2000 m. The wind is from the northeast at 20 m/s (which approximates Santa Ana conditions). The WFDS is capable of accounting for the presence of vegetation, structures, terrain, roads, and other fuel breaks using LiDAR and other imagery. In this figure an image from Google Maps is put on the terrain for ease of visual reference.

study's primary objective was to determine the relative merits of property protection measures ranging from individual actions to community-wide actions. Blanchi and Leonard [18] conducted an investigation of structure ignition mechanisms after the 2003 fire in the Duffy community of Canberra, Australia 2003. The report identified that 50% of the ignitions were from embers only, 35% were from embers and radiant heat, while 10% were from radiant heat alone. The report also included the comprehensive survey form that was used in the data collection process. Although the survey has two questions relevant to defensive actions, very limited information on defensive actions taken is presented in the report.

The above listed case studies have in common the lack of linking defensive actions to individual structures. Without factoring in the defensive and suppression actions taken by first responders and homeowners, any conclusions on fire behavior and structure survivability are incomplete and may be erroneous.

2. Objective of this Case Study

To understand the fundamentals of fire behavior at the WUI, the study attempts to address the following technical questions:

- How far within a community did the fire spread?
- To what extent did embers contribute to ignition of structures?
- Why did the fire spread stop when it did?
- Did all the structures ignite from the passage of the wildland fire front, or were some structures ignited later and why?

A timeline was developed for the event, and the damage that occurred to structures, residential vegetation and surrounding wildland vegetation was documented. Additionally, the fire fighting and structure protection responses taken shortly before and during the fire event were also documented. Consideration of the resident evacuation was outside the scope of this study. An analysis of structure construction and landscaping particulars will be documented in the second paper (work in progress).

3. Area of Interest—Rancho Bernardo, The Trails Community

This study is focused on The Trails community at Rancho Bernardo. The community extent is 1.5 km (1 mile) from east to west and 1 km (0.6 mile) from north to south. Community elevations range from 125 m to 200 m (415 feet to 660 feet) above sea level. The community rests on a knoll and is surrounded by valleys on three sides. To the north is Highland Valley, at elevations from 100 m to 110 m (330 feet to 365 feet). To the east is Sycamore Creek at similar elevations while to the west is a ravine at elevations ranging from 100 m to 135 m (330 feet to 445 feet). The community is 23 km (14 miles) east of the Pacific Ocean. The community consists of 283 residential lots (Figures 1, 3). Although some lots on the perimeter of the community are larger, typical lots are $\sim$6,000 m^2 (1.5 acres). At the time of the fires the community consisted of 274 residences; 245 of these were within the fireline; 74 were completely destroyed and an additional 16 sustained various degrees of damage. Housing density is $\sim$116 homes per km^2 (300 homes per square mile). Figure 4 illustrates three different housing densities. The Trails is represented on the left, a community in Rancho Santa Fe, California is shown in the middle and a low density housing area is shown on the right. Note that the houses are not evenly distributed as the "density" becomes lower. The housing density within The Trails is greater than the densities seen outside of Rancho Bernardo but lower than the densities seen to the west of The Trails (Figure 3).

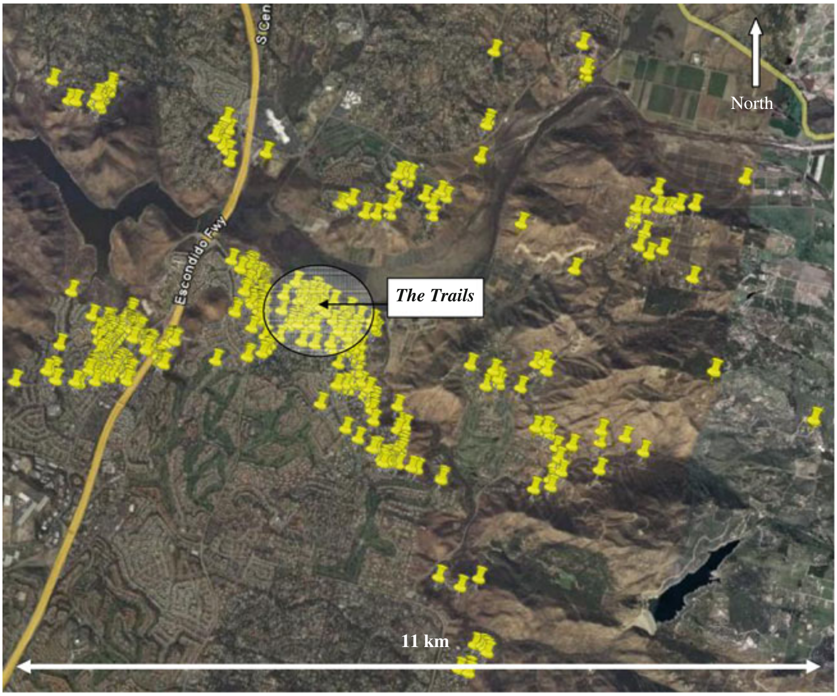

Figure 3. Destroyed structures in the vicinity of Rancho Bernardo, CA.

The Trails
116 homes / km^2
(300 homes / square mile)

Rancho Santa Fe
31 homes / km^2
(80 homes / square mile)

Rural Setting
4 homes / km^2
(10 homes / square mile)

Figure 4. Structure densities in three different WUI settings.

4. Witch Creek and Guejito Fire Ignitions

It was initially believed that The Trails community was impacted only by the Witch Creek Fire. The City of San Diego's After Action Report [19] identified the

Guejito Fire as the main fire that hit The Trails. The Witch Fire [20] was ignited in the Witch Creek area east of Ramona, California, about 27 km (17 miles) east of The Trails, at ~12:35 pm on Sunday, October 21, 2007. The cause of ignition was determined to be electrical line arcing. The Guejito Fire [21] started, twelve and a half hours later, at 1:00 am Monday, October 22, 2007 at Guejito Creek drainage, on the South Side of California State Route 78 and 0.4 km (¼ mile) west of Bandy Canyon Rd., or 10 km (6 miles) northeast of The Trails. The cause of ignition was identified as energized power lines contacting a lashing wire. The following excerpt from the After Action Report [19] described the general progression of the Guejito Fire (note SDFD refers to the San Diego Fire Department):

> The Guejito Fire spread rapidly along the river bottom area of the San Pasqual Valley and southwest toward Highland Valley Road. SDFD strike teams engaged in numerous firefights along the Highland Valley Road and Bandy Canyon Road areas, but in many cases were forced to retreat by the wind-driven flames. It took just over two hours from the start of the Guejito Fire for the first homes in northeastern Rancho Bernardo to be destroyed by fire. The Guejito Fire spread west along Highland Valley Road, eventually spotting across Interstate 15 and ultimately destroying hundreds of structures in West Rancho Bernardo.

Late Sunday night residents of Rancho Bernardo were informed through mass media that the Witch Fire would be arriving at their communities around 11:00 am Monday morning. The ignition of the Guejito Fire well to the west of the Witch Creek Fire caused the anticipated timeline for resident evacuation to be moved into early Monday morning. By ~2:16 am (1 h and 16 min after ignition, the Guejito Fire was identified as posing a significant threat to the Rancho Bernardo Community and the San Diego Fire Chief requested the activation of the City's Emergency Operation Center. Figure 5 contains a map illustrating the origins of the Guejito and Witch Creek Fires, the combined perimeter of both fires and the locations of the weather stations which will be referred to later in this paper. The combined perimeter encompasses the total area burned by both fires.

5. Weather

The following weather synopsis was provided by Tom Rolinksi, USFS Sothern California Predictive Services Program Manager: "Fairly seasonable conditions occurred throughout the region during the week prior to the forecasted Santa Ana wind event. A series of Pacific troughs moved through the region during the period from October 12th through the 20th, some of which brought some light amounts of precipitation to portions of the district.

On the 20th of October, the last of a series of upper level troughs cut across central California and by late in the day had moved into Nevada. Some light precipitation had occurred over the central portions of the state early in the morning with dry conditions elsewhere. Strong and gusty west to northwest winds developed over much of the region as the trough exited the state with the strongest

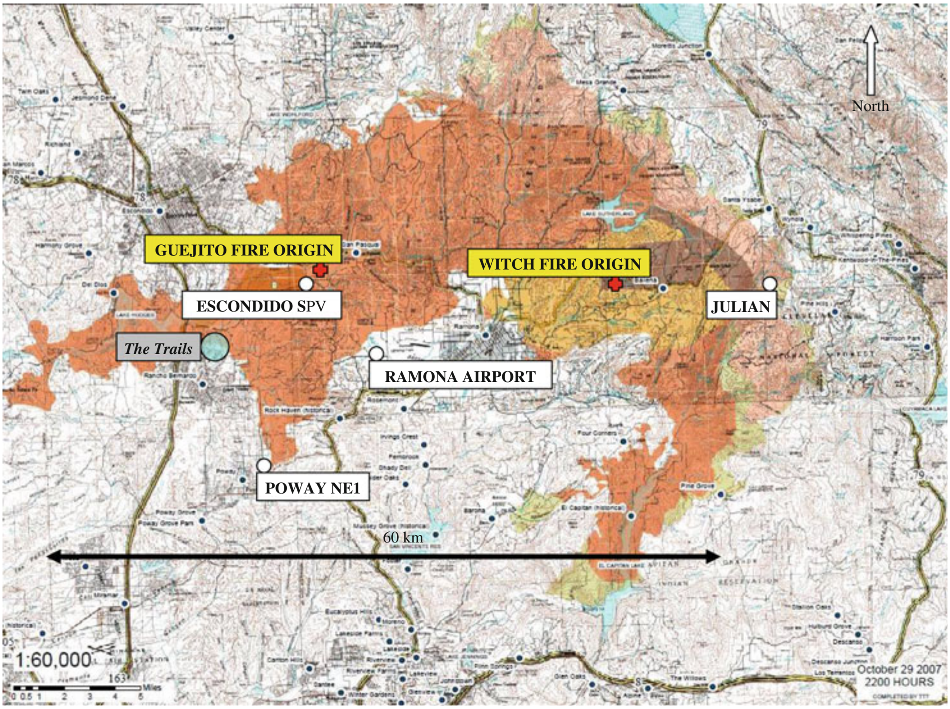

Figure 5. Origins of the Guejito and Witch Creek Fires, the combined perimeter of both fires and the locations of the weather stations used later in the paper (map courtesy of CALFIRE).

winds over the Kern county mountains and deserts. The winds gradually shifted to the north and northeast by very late Saturday night and early Sunday morning, and by daybreak Sunday, the anticipated Santa Ana wind event was underway. Widespread sustained wind speeds of 20 mph to 40 mph were common across much of the area with gusts into the 70 s and low 80 s in the more wind prone areas. These winds persisted throughout the day (although there was some diminishing of the winds by late afternoon) and continued through Monday afternoon at roughly the same strength''.

Weather data for this paper was obtained from MESO West [22] operated by the University of Utah. Four weather stations were used. The stations were selected for their proximity to either the study area or the fire origin. Table 1 lists the particulars of the stations. Figure 5 shows the geographical location of the stations, the fire origin locations for the Witch and Guejito fires, and the location of The Trails community.

The Weather Station at Julian is 10 km due east from the Witch Fire origin. It displayed a wind shift from west to east early on the morning of October 21st 2007. The relative humidity ranged between 30% and 40% prior to the wind shift and was reduced to 16% by noon. By 12:15 pm, the sustained wind at Julian was recorded at 38 km/h and gusting to 69 km/h. The Witch Fire ignited at 12:35 pm.

Table 1
Geographic Locations of Four Weather Stations

Station name	Station ID	Latitude (°)	Longitude (°)	Elevation (m)
Poway NE1	SDPOY	32.9606	−117.0192	182
Ramona airport	KRNM	33.0375	−116.9158	423
Escondido SPV	CI153	33.0810	−116.9760	119
Julian	JULC1	33.0756	−116.5917	1292

The Ramona airport weather station is 13 km due east from The Trails. The station recorded a dramatic drop in humidity while also recording a rapid increase in wind speed. Similar behaviors were recorded by the Poway NE1station, located 10 km SSE of The Trails, and are summarized in Table 2. Figure 6 displays wind

Table 2
Weather Summary

Station name	Date and time	Wind speed (km/h)	Wind gust (km/h)	Wind direction	Relative humidity (%)
Poway NE1	October 21st 00:45	0	22	North	90
	October 21st 11:45	34	42	North	14
Ramona airport	October 21st 00:45	0	0	East	94
	October 21st 11:53	42	61	East north east	7

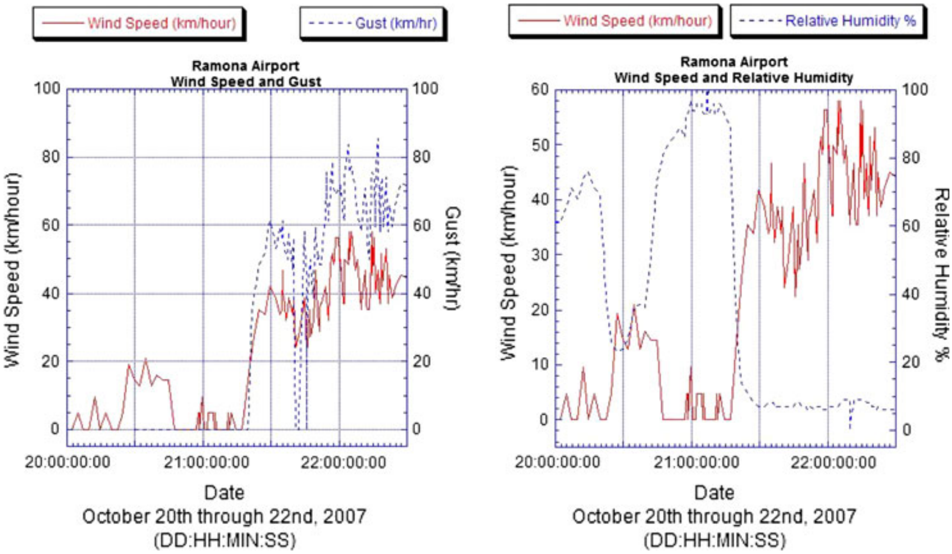

Figure 6. Weather data from Ramona airport.

speed, wind gusts and relative humidity at Ramona airport between October 20th and October 22nd.

Escondido SPV is 2 km southwest of the Guejito fire origin. Although the Escondido SPV data was received by MESO West it did not have the MESO West Quality Check Flag ensuring data reliability. The data displayed similar trends to the Ramona airport data. On October 21st, between 8:00 am and 10:00 am, the relative humidity dropped from 100% to 15% and the wind increased from 11 km/h to 36 km/h. At the time of the Guejito fire ignition, station CI153 reported a relative humidity of 8%.

Limited quantitative information is available for the weather conditions at The Trails during the morning of October 22nd. Residents and firefighters reported "extreme" winds and a residential weather station on Polvera Avenue and facing Highland Valley registered 91 km/h in the early morning hours. Accounting for the possible amplification of the winds due to the Highland Valley NE orientation and northerly wind, it is estimated that wind speeds at The Trails were at least as severe as those at Ramona or Poway.

6. Data Collection

Field data collection was initiated four days after the fire by NIST personnel and CALFIRE Fire Marshals. Field measurements were initially focused on destroyed structures and extent of burn damages through the community. This focus was necessary due to the short life span of that data. Subsequent data collection was focused on the structures that survived the fire. Data included structure particulars, including building construction and roof type, proximity of combustibles to the structure, and damage to wildland and residential vegetation. The impacts of construction type on structure survivability will be addressed in the second paper of this study (work in progress). Documentation included over 11,000 pictures. San Diego Fire and Police departments provided critical information for the development of the event timeline. Similarly, The Trails Homeowners Association provided essential observations from residents. Additional tools used during the study included CALFIRE generated wildland fuel maps, Google Earth™, Microsoft Virtual Earth™ and Pictometry™ information.[1]

7. Wildland Fuel and Fuel Moisture

The CALFIRE Witch Incident Fuel Map [23] contains information on the Witch Fire perimeter and wildland fuel type. Thirteen different fuel types were involved within the perimeter of the Witch Fire. The Highland Valley is covered primarily by Barren/Rock/Other (Fuel Model 99), with Brush (Fuel Model 5) on the western side and Agricultural Lands (Fuel Model 97) on the eastern side. The mount

[1]Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

occupied by The Trails is surrounded by Hardwood/Longpole Pine (Fuel Model 8) to the north and west. A small amount of Brush (Fuel Model 5) can also be found on the western side of the mount and in the main chimney or chute on the northern side off Polvera Drive. The eastern side is primarily Brush, with a couple of patches of Grass (Fuel Model 1). At the base of Sycamore Creek, there is Barren/Rock/Other (Fuel Model 99) surrounding the Creek. Figures 7, 8, 9, 10, 11, and 12 show the inhomogeneities in wildland fuel on the slopes surrounding The Trails before the Witch and Guejito fires. Wildland fuels surrounding The Trails vary in type as well as density. Figures 13 and 14 show Angosto Way, which borders the northern edge of The Trails, before and after the fires. The extent of damage to the canopy on the northern side of Highland Valley road is clearly evident as is the lack of canopy damage up slope, near the structures. Just before the fires reached The Trails, dead fuel moisture for 1 h fuels is estimated at less than 10%.

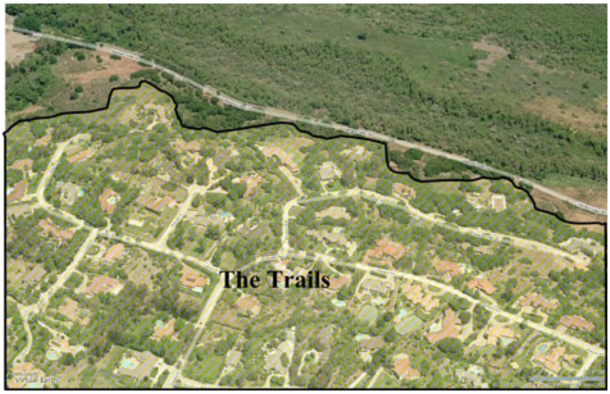

Figure 7. NW corner of The Trails.

Figure 8. North side of The Trails.

Figure 9. East corner of The Trails.

Figure 10. South-east side of The Trails—Sycamore creek.

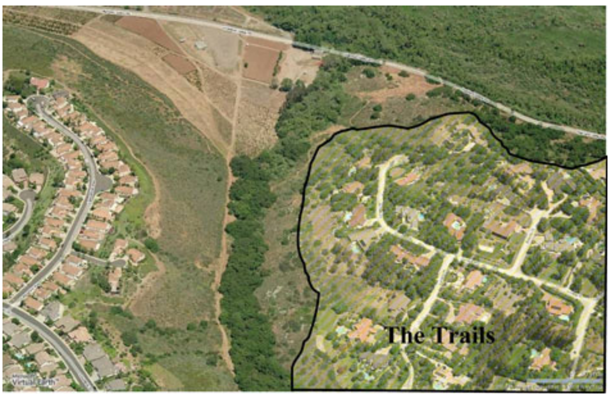

Figure 11. West side of The Trails.

Figure 12. South-west side of The Trails.

Figure 13. Angosto Way before October 22nd, 2007 (Picture taken in 2005).

8. Fire Approach Timeline

The following timeline data for the flame spread of the Guejito and Witch fires on the morning of October 22, 2007 was collected from first responders (technical contact Chief Fennessy, San Diego Fire Department, Director of Operations/ Special Operations, November 2007) and community residents (via Mr. Steve Arnold, President, The Trails Home Owners Association, November 2007). The Guejito Fire started at 1:00 am. By 1:30 am, the head of the Guejito fire met with

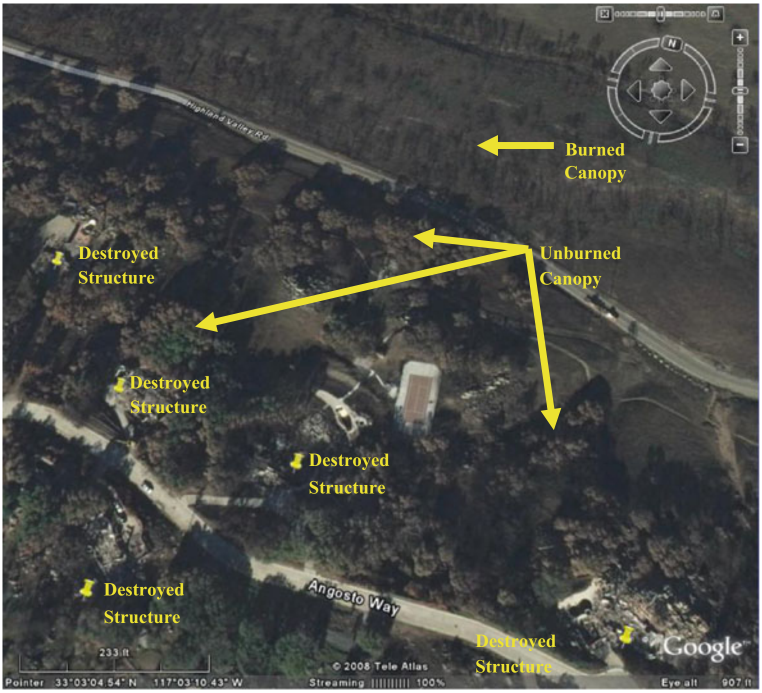

Figure 14. Angosto Way After October 22nd 2007.

Santa Isabel Creek, which bisects Guejito Creek 3.2 km (2 miles) from its point of origin. This suggests an average spread rate of 6 km/h (3.75 mph). Between 3:15 am and 3:20 am, the head of the fire turned southwest and started down Highland Valley. By 3:50 am, the fire front had reached the intersection of Highland Valley Road and Sycamore Creek, covering a distance of 4.5 km (2.8 miles) in a little over 30 min at a rate of 9.0 km/h (5.6 mph). At that time, the fire had reached the perimeter of The Trails. A high intensity fire (based on observations of crown damage) was concentrated around the trees on the river bed to the north of The Trails, with lower intensity burning along the valley floor.

At the time the Guejito fire was moving southwest down Highland Valley, it was also spreading towards the intersection of Bandy Canyon/Highland Valley Road. It reached that intersection by 3:30 am and homes there began to burn.

At the same time, the Guejito fire was moving towards The Trails, the Witch Creek Fire was advancing west. Because of the large magnitude of the Witch Fire perimeter, it has been difficult to identify its exact location over time as it approached The Trails. The following data points provide a general idea of its timeline. By 2:55 am, the Witch Fire reached the San Pasqual Academy one kilometer (0.6 miles) east of the Guejito origin and 23 km from its own point of origin. At 6:00 am, another part of the Witch Fire was making its way down Clevenger canyon 5 km (3.0 miles) east of the Guejito origin, and 23 km from its own point of origin.

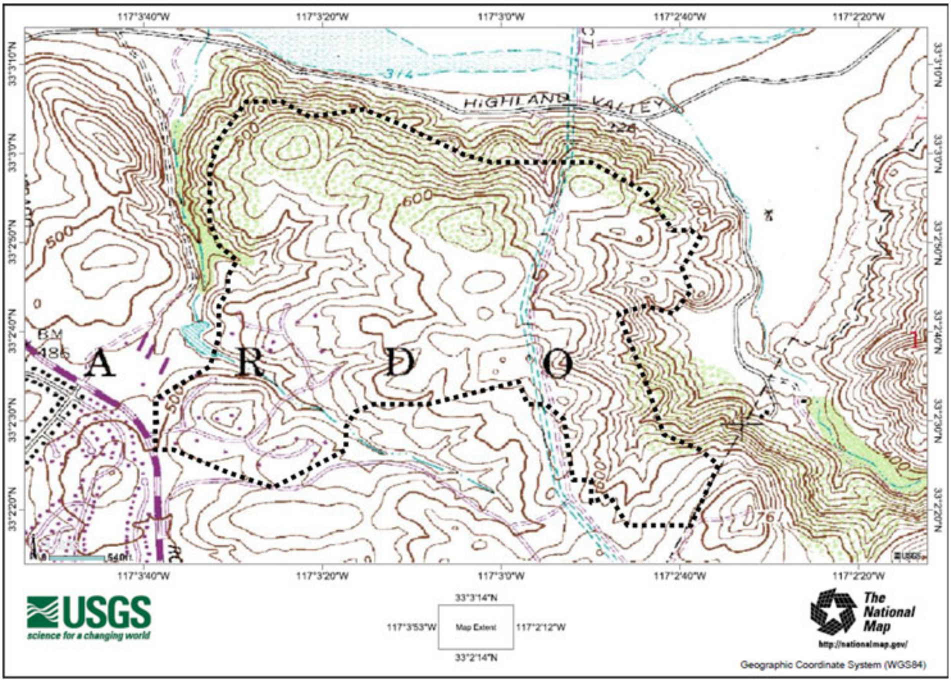

Figure 15. Topographic map and outline of The Trails.

The Trails was assaulted by both the Guejito and the Witch fires. The main front of the Guejito Fire reached The Trails at ~3:45 am Monday morning, October 22, and came from the Highland Valley. It is estimated that the Witch Fire arrived at the southeastern part of The Trails sometime around 6:00 am. Figure 15 shows the topographic characteristics of The Trails and Figure 16 illustrates the approach of the Guejito and Witch fires.

8.1. Timeline Within The Trails Community

The following timeline includes ember exposure, burning vegetation, and burning structure information. The chronological steps vary in duration to better capture the nature of the event. It should be noted that the available data is partial and limited in the sense that the frequency of reported observations is a function of the number of observers present, which was inconsistent and decreased with time. The timeline reconstruction focuses on the destroyed structures, while damaged structures are addressed in Sect. 11, later in the paper. Reported observations of structures that were ultimately destroyed are divided into four categories: (1) ignited—some visible flaming (2) fully involved, (3) almost completely destroyed, and (4) no longer burning. In most cases, only one observation is available for a particular structure. If an observation of a structure no longer burning is the only one available for that structure, and no other information was available for it, the

Figure 16. The Trails—fire approach.

structure is placed in the ''New No Longer Burning'' category in the table and figures.

In the following time reconstruction for destroyed structures, burning structures were reported along with their degree of burning at the time the observation was made (Figure 17). Structures that are fully involved during a time interval could, therefore, possibly have ignited during the previous time interval. This means a potentially significant temporal uncertainty is associated with the actual ignition times of the structures. Even though smoldering could have been present for hours before the flaming occurred, it is estimated that initiation of flaming combustion can be estimated to within 1 h. An attempt is made to estimate structure ignition times and total number of homes burning during each time interval. This is reported later in this section. Structure burning observations are documented in Figure 18. Between 2:30 am and 3:55 am, the Guejito fire ignited structures on the northwestern part of The Trails, and primarily on the perimeter. Over the next 2 h, between 4:00 am and 5:55 am, the structures burning in the interior reached 500 m (1/3 mile) in from the perimeter, the furthest into the community. Between 6:00 am and 9:55 am five new homes are burning on the eastern side of The Trails, with three additional homes burning throughout the community. Between 10:00 am and 1:30 pm, seven more homes burned.

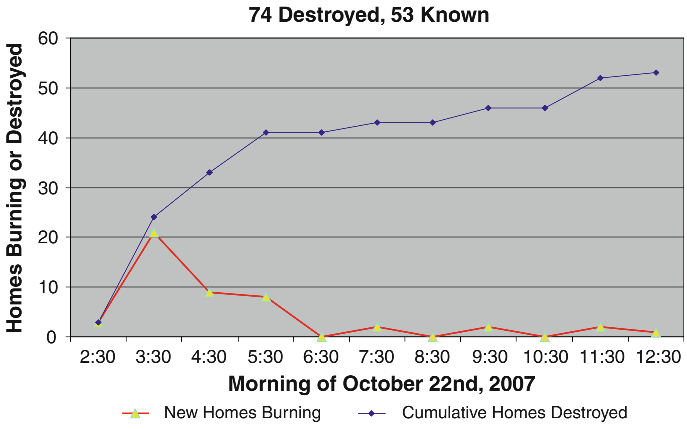

Figure 17. Timeline of structures burning in The Trails.

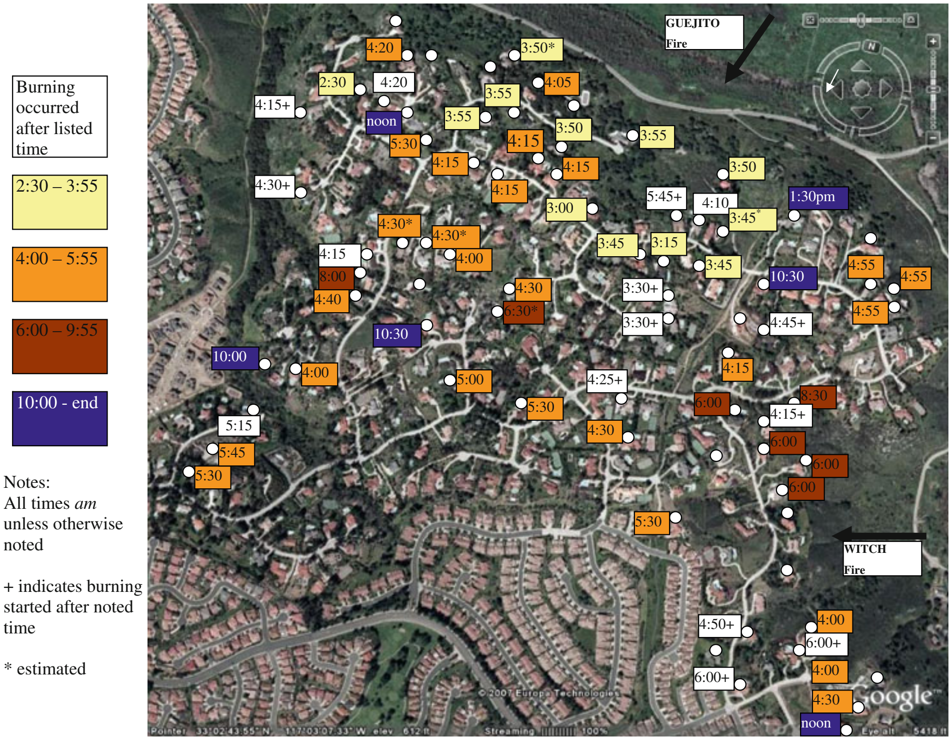

Figure 18. Timeline of structure burning at The Trails.

8.1.1. Monday October 22, 2007: 2:00 AM to 3:30 AM. Embers appear on the perimeter of the community, from the burning wildland fuels as early as 2:30 am. The first vegetation ignitions are reported at 2:30 am and 2:45 am. These ignitions were a result of spotting from the Guejito Fire which, at 2:30 am, was over 4.5 km (2.8 miles) away. Vegetation began to burn in the interior of the community by 3:00 am. Three structures were ignited and six vegetation ignitions were reported throughout the community by 3:30. All three structures were on the northwest side of the community, adjacent to or within 150 m (500 ft) from the wildlands.

8.1.2. 3:30 AM to 4:30 AM. The main fireline of the Guejito Fire reached the community between 3:30 and 4:00. Embers were reported across the entire perimeter of the community as well as in the interior, and there were sixteen different vegetation fires. This was the period of highest reported structure burning activity. Four additional homes were burning between 3:31 am and 3:50 am and sixteen more between 3:55 am and 4:30 am. Out of the 22 new homes that were reported burning in this time period, eleven were showing some flames visible, while the remaining nine were fully involved.

8.1.3. 4:30 AM to 5:30 AM. Active ember attack was still reported across the perimeter and the interior; however the total number of ember observations was reduced to six. Vegetation burning observations were down to two. Nine additional homes were burning in this time window. Seven were showing some flames visible and two were fully involved.

8.1.4. 5:30 AM to 6:30 AM. An additional eight homes were reported burning in this time window, including two that were almost completely consumed. An additional two homes were completely consumed and no longer burning. It was during the end of this time interval that the Witch Fire likely arrived at The Trails from the east. Four out of the ten additional burning homes reported in this time window were on the eastern perimeter of the community.

8.1.5. 6:30 AM to 10:30 AM. In this time window, five additional homes were burning. Additionally, there were three previously unreported homes that were identified as destroyed and no longer burning.

8.1.6. 10:30 AM to 12:30 PM. One new home burned in this window and eight previously unreported homes were identified as completely destroyed and no longer burning.

8.1.7. 12:30 PM to 3:15 PM. The last home was ignited and burned in this time window. In <12 h after the Guejito fire arrived at The Trails no homes were burning.

Table 3 lists the breakdown of destroyed structures as a function of time. The category, “No longer burning,” refers to structures that were already destroyed at the time of the first observation. The category, “Partial data,” refers to structures

Table 3
Timeline of Completely Destroyed Structures

Time window	2:30 am to 3:30 am	3:30 am to 4:30 am	4:30 am to 5:30 am	5:30 am to 6:30 am	6:30 am to 10:30 am	10:30 am to 12:30 pm	12:30 pm to 3:15 pm	Total
Ignited-some flames visible	3	12	7	2	1	1	0	26
Fully involved	0	10	2	4	2	0	1	19
Almost completely destroyed	0	0	0	2	1	0	0	3
New burning	3	22	9	8	4	1	1	48
New no longer burning[a]	0	0	0	0	1	4		5
Total	3	22	9	8	5	5	1	53
Cumulative total	3	25	34	42	47	52	53	53
Partial data[b]	2	7	3	3				15
Unknown								6
Grand total								74
Estimated structure flaming ignitions	13	16	12	4	1	1	1	n/a
Estimated total homes burning	13	29	28	16	5	2	2	n/a

n/a not applicable.
[a] Only data available, [b] Partial data: destroyed structures were not burning at the time of observation.

where observations were made prior to structure ignition, i.e. a subsequently destroyed home was not burning at the time of observation. The data in the table shows that new structure burning observations peak at 22 structures/hour between 3:30 am and 4:30 am. The fire spread very rapidly within the community igniting over 50% (42/74) of the destroyed structures within 3 h after the first reported ignition. After 6:30 am, the number of new structure ignitions dramatically drops off from eight to one or two per hour. An expanded timeline table can be found in Figure 17.

To obtain an estimate for the number of homes burning in the community at any one time, the following assumptions are considered:

- It takes 2 h from flaming ignition of a house to no longer burning.
- Reports of homes ignited with some flames visible can be used to identify structure ignition times.
- Reports of homes fully involved can be moved back 1 h and used to approximate ignition in the previous time interval.
- Reports of homes almost completely destroyed can be moved back 2 h and used to approximate ignition in the new time interval.

In Table 3, the rows labeled Estimated Structure Ignitions and Estimated Total Homes Burning are created using the above assumptions.

8.2. Fire Spread Within The Trails Community

Different tools were used to document fire spread within The Trails. The extent of burned vegetation was documented along with the locations where the fire jumped a road. Several different indicators were used to determine the direction of fire spread. In the wildlands, needle freeze as defined below, directional degree of damage to wildland vegetation, and the presence of partly damaged golf balls were all used to determine the direction of fire spread. In this document, the perimeter of The Trails is defined by all lots that have direct contact with the wildlands.

Within The Trails, vegetation burned on both sides of a road implied spotting across the road, 21 times. Road width in The Trails was ~30 ft. Out of those, 18 were on the perimeter of the community and the remaining three were on interior roads. Out of the 18 road jumps along the perimeter region, 15 were located on lots with destroyed structures on the perimeter side of the road; two out of the remaining three were located on lots adjacent to destroyed structures. Additionally, 10 out the 18 jumps had destroyed homes on both sides. It is not known if the fire jumps occurred before or after the structures on the perimeter were burning. That is, it is not clear whether burning vegetation (through embers or direct flame contact) or embers generated by structures caused the fire spread.

The limited data available do show that in two cases structures in the interior ignited before structures on the perimeter. It is therefore possible that the wildland front ignited interior structures 0.2 km (1/8 mile) from the perimeter by spotting or continuous flame spread through vegetative fuel. This hypothesis, however, cannot be confirmed because of the limited spatial/temporal resolution of the currently available data.

Needle freeze information, the process of dehydrated foliage aligning or "freezing" parallel to the wind direction, was also used to obtain wind direction [24]. Flame spread direction indicators such a V patterns of burned vegetation and burn damage around the leeward side of trees were collected in and around The Trails. Figure 19 illustrates flame spread and needle freeze around and within The Trails.

A survey of the perimeter of The Trails and valley floor identified a number of golf balls that were partially embedded in the ground. These were used to obtain general quantitative information of the direction of the oncoming fire front, or highest heat flux, since the surface of the golf ball facing the direction of the oncoming fire front melted (Figure 20). GPS coordinates and a compass heading were used to document this information. The yellow arrows in Figure 18 depict the information collected from the geo-located golf balls. The general flame spread direction information obtained from the golf balls is consistent with the other flame spread information collected from first responders.

Figures 18, 19 and 21 illustrate the fire line progression within The Trails. The fire lines, represented by solid lines in Figure 21, are assembled by joining together the observations at different times throughout the community. A fire line data point is associated with either vegetation or a structure burning. The two earliest reports of fire in the community occur at 2:30 in the morning, over an hour

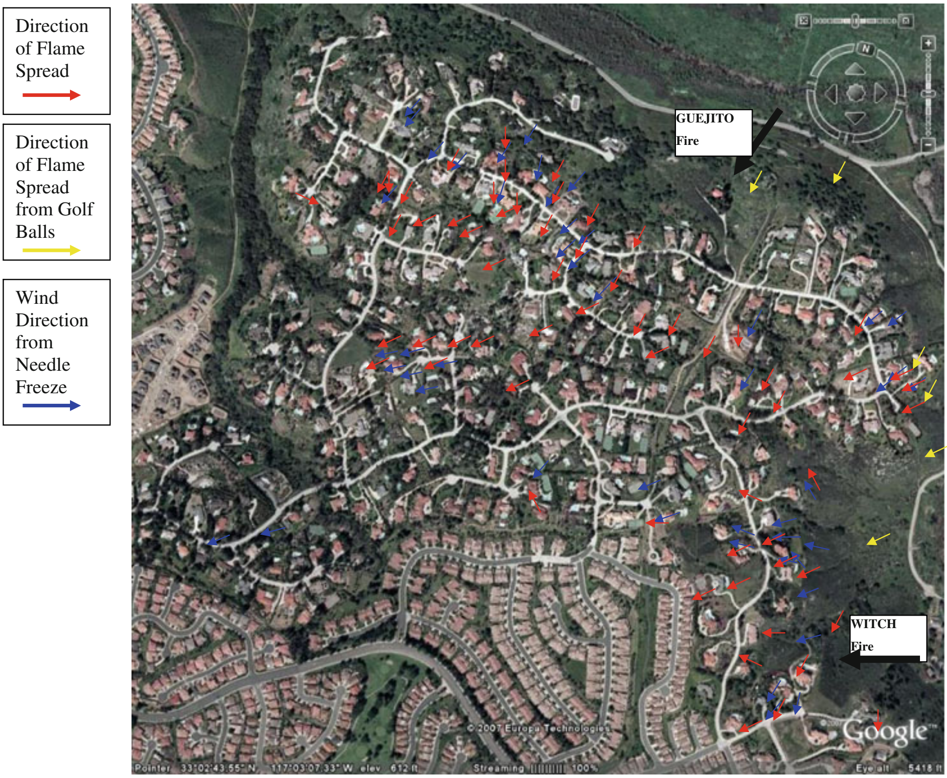

Figure 19. The Trails—flame spread and needle freeze.

before the main fire front of the Guejito fire arrived from the wildlands at 3:50 am. Between 2:45 am and 3:10 am, there were three reports of embers on the northern part of the community. The prevailing wind direction was from the north east so it is most likely that these embers were coming from the Guejito fire front. Reports of embers on the Sycamore Creek side (eastern side) were provided at 3:50 am, the same time the main fire front reached The Trails. The fire line then progressed in the community by moving further on the eastern and western sides where wildland fuel is present and almost reached its final configuration by 5:30 am. Based on first responder accounts, the wind veered from the northeast to the east shortly before 6:00 am. This wind shift arrived at The Trails shortly before the Witch fire. It is likely that the shift in wind direction slowed and eventually resulted in a cessation of the fire spread within The Trails; however, given the data available, this cannot be confirmed.

9. Structure Exposure to Fire and Embers

Embers from the wildlands were observed in the community as early as 2:30 am, well before the main fire front which arrived at 3:50 am. The embers that arrived

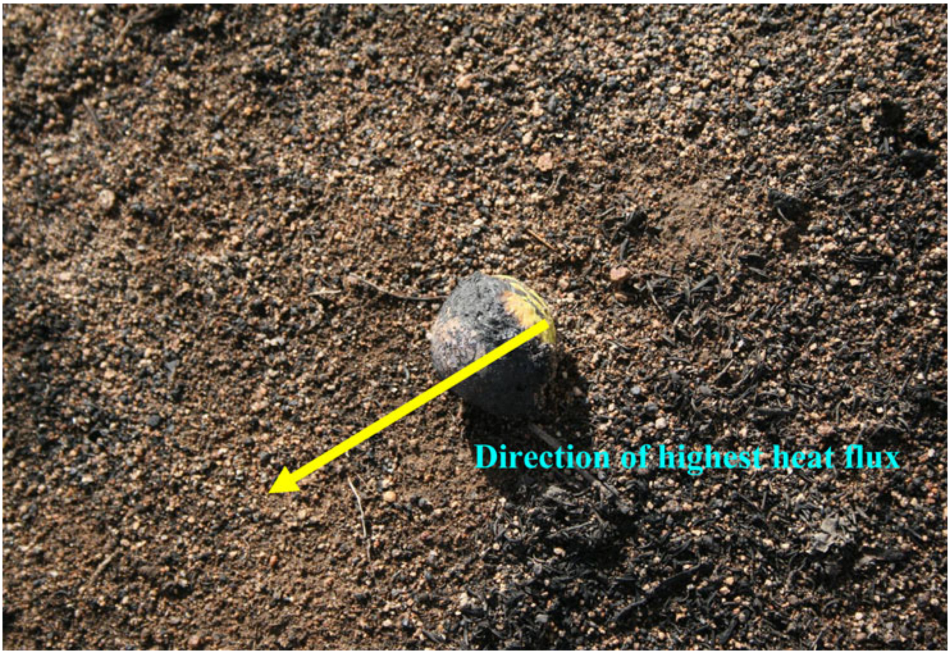

Figure 20. Golf ball providing direction of highest heat flux.

before the main front contributed to three structure ignitions or less than 5% of the total destroyed structures. This is based on multiple first hand observations from first responders (police and fire) and homeowners. Additionally, there were six documented separate vegetation ignitions from embers. Most of the damage to structures and vegetation was done by the main fire front which arrived ~1 h later.

The relationship between wildland fuel and the number of destroyed structures in two areas of The Trails requires consideration. From [15], the CALFIRE Witch Incident Fuel Map, the wildland fuel down slope of Angosto Way (western end of the northern perimeter) consisted of hardwood/long pole pine trees. Direct observations and discussions with SDFD and homeowners confirmed the presence of significant surface litter that generated large quantities of wind-blown burning embers. It is likely that the locally large embers flux contributed to the local destruction of structures, however little information is available at this point to substantiate this hypothesis. Despite the fact that the wildland fire did not make the transition to crowning in that location, seven out of nine homes on that road were destroyed. Additionally, of the two remaining structures, one was actively defended.

The wildland fuel adjacent to Polvera Avenue (north perimeter) varied as a function of location. On the western side, Angosto Way was at a lower elevation than Polvera Avenue, and had significant coverage of hardwood with surface litter. From Olmeda Place (center of northern perimeter) to the eastern end of the

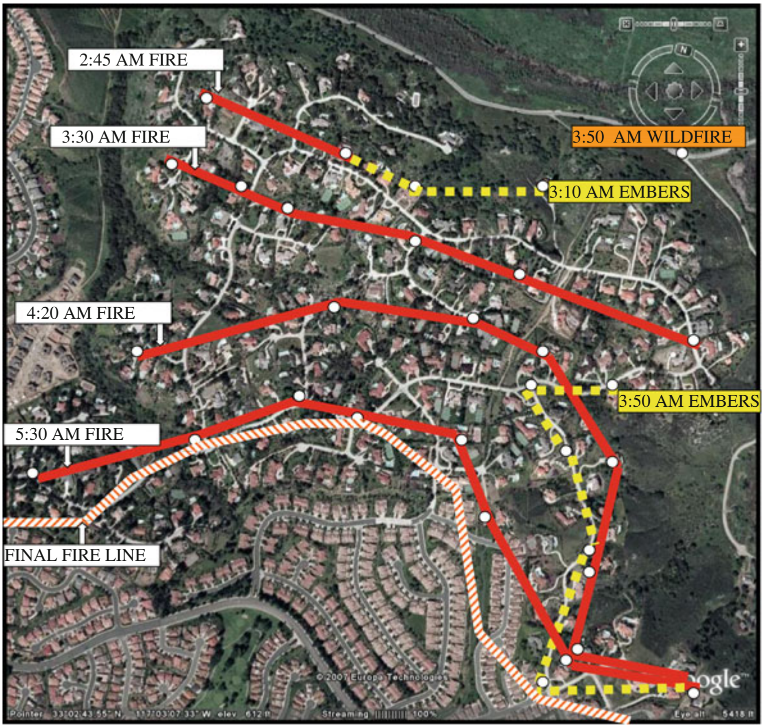

Figure 21. Fire line progression within The Trails.

northern perimeter, the fuels consisted of intermixed hardwoods and brush. At the eastern end of Polvera Avenue there is a rock outcrop (see Figure 22). This outcrop reduced the local wildland fuel loading and provided a fire break for the structures to the north (up slope) of it.

On the eastern perimeter of the community, the fuel down slope of Aceituno Street was primarily brush, with one patch of hardwood trees covering approximately one hectare (2.47 acres), and one patch of grass approximately the same size. The damage to the wildland fuels was extensive in this area. The structural damage along Aceituno Street was focused on the wildland side of the street, with seven out of nine homes destroyed, compared to two out of nine on the western (i.e., interior) part (see Figure 1). Out of the two surviving structures on the perimeter, both were damaged and one had been defended.

The exposure to embers within the community varied with location and time. As the main fire front arrived, ember exposure reached further into the community. The presence of embers continued to increase as more structures were ignited on the perimeter and within the community. At the perimeter of the community embers preceded the main fire front by ~1 h. In the interior, the data available does not allow us to differentiate spatially between ignitions by embers or by the fire front.

Figure 22. Rock outcrop acting as a fire break.

10. Defensive Actions

A number of defensive and fire suppression actions were taken in The Trails before, during, and after the arrival of the Guejito and Witch fires. Documenting defensive actions is essential to correctly interpreting fire behavior and structure survivability data. Defensive actions are defined here as actions taken by SDFD (San Diego Fire Department), SDPD (San Diego Police Department) and homeowners, to slow down, redirect, control and extinguish any fires during the morning of October 22, 2007. No attempt will be made to examine SDFD and SDPD doctrines, policies or decision making. The purpose of this section is to examine the actions taken in the context of structure survivability. This is necessary to develop a more complete understanding of the mechanisms and conditions leading to structure ignition.

A case is presented here to illustrate this. One homeowner was convinced that his house survived because, prior to evacuating, he turned on the lawn sprinkler system. He was unaware that a fire engine had spent 2 h defending his house. It is not possible to accurately estimate the total impact of all defensive actions; however, the effects of defensive actions on damaged structures are clearly seen since 15 out of the 16 damaged structures were defended (see Sect. 11).

The focus of the analysis is on all actions taken shortly before the approach of the Guejito fire and for ~12 h after its arrival, or until 3:00 pm Monday afternoon. Figure 23 illustrates the impacts of the identified defensive actions taken at

Figure 23. The Trails defensive actions.

The Trails during that period. Although fires reignited and new spot fires were started after that period, no homes were ignited after 1:30 pm and all major fire suppression activity was significantly reduced.

Data collection and technical discussions were conducted with the SDFD, SDPD and The Trails Home Owners Association. A total of 85 actions were identified at The Trails, between 2:00 am and 3:00 pm Monday, October 22. However, there is no way of knowing how many actions were not identified. The actions ranged in complexity and scope, from a SDFD fire engine crew defending a house with multiple fire hoses, to a homeowner putting out a gutter fire with a garden hose. Out of the 85 identified actions, 48 were carried out the by SDFD, and 37 by the SDPD or residents of The Trails.

10.1. Perimeter Versus Interior Defensive Actions

Of the 85 identified actions, 32 were on the perimeter and the remaining 53 in the interior of The Trails. In relative terms, defensive actions were identified on 39% of perimeter structures and 32% of interior structures. Half of the actions taken by the SDFD were on the perimeter and the remaining half were in the interior of The Trails.

10.2. Defensive Actions on Burning Structures

There were 11 fire containment actions and 25 defensive actions aimed at saving structures on fire. The SDFD, SDPD, and homeowners all contributed to suppressing homes on fire. Of the 25 defensive actions taken on burning structures, 15 were successful yielding a success rate of 60%. Ten of the defended homes on fire were lost. Additionally, due to the extreme rate of structure ignitions and the limited number of resources available, 54/74 or 70% of the destroyed homes were not defended. Lastly, 49 actions were taken on undamaged structures with unknown influence on structure survivability. Figure 24 illustrates the relationships between the defensive actions taken and the numbers of structures damaged or destroyed.

10.3. Timeline of Defensive Actions

Technical discussions with the SDFD identified that a strike team of six engines was at The Trails at ~2:45 am. At 3:00 am, after a short safety brief, the engines took their positions around The Trails. Many residents were still in The Trails. Of the six engines, three were involved in resident evacuations. The remaining three engines worked on protecting residences for the next 3 h. At ~6:00 am, the SDFD engines left The Trails to pursue the Guejito fire. SDFD returned at The Trails at

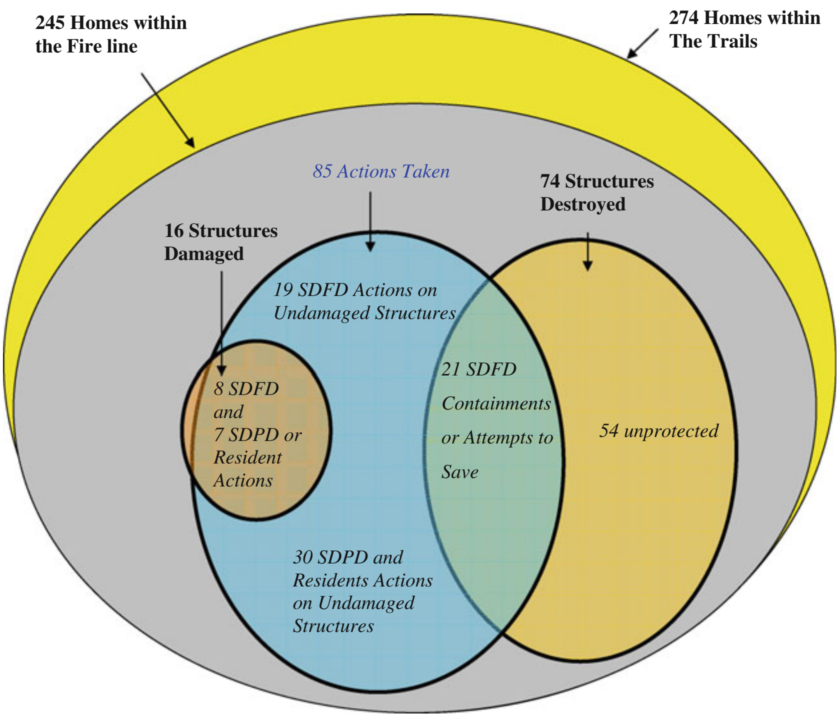

Figure 24. Impacts of the defensive actions taken at The Trails.

~10:00 am with different crews and at least seven engines and remained there until the event was over, well into Tuesday.

SDPD started arriving at the scene at ~3:30 am. Over 80 police officers were involved in the evacuation of residents from The Trails community. The majority of the evacuation occurred between 4:00 am and 6:00 am. At 4:30 am, a small fraction of the police personnel left The Trails. The remaining police personnel patrolled the neighborhood and contributed to fire suppression and control. However the defensive actions taken by SDPD after 4:30 am were not documented due to NIST resource limitations, and could not be differentiated from resident defensive actions.

Table 4 contains information on the timeline of defensive actions. There were 48 separate San Diego Fire Department actions identified, including 30 that were taken before 3:15 pm. Additionally, there were 37 separate actions taken by The Trails residents and SDPD, 14 of which were identified as taken before 3:15 pm. Table 5 contains timeline information on the destroyed homes that were defended. Information on the damaged homes can be found in Sect. 11 of this paper.

Of the 12 homes that were defended while burning, attempts were made to save eight. Of these eight, four were defended when the Guejito fire hit the community, one shortly after 10:00 am, and the remaining three between noon and 1:30 pm.

Between 3:00 am and 3:00 pm, the San Diego Fire Department saved eight structures where ignitions had taken place (see next section), and attempted to save an additional 10 that were lost. In addition, actions were taken on 11 struc-

Table 4
Timeline of Defensive Actions

Time window	2:30 am to 6:30 am	6:30 am to 10:30 am	10:30 am to 3:15 pm	Total known
SDFD	12	No fire suppression/control actions	18	30
SDPD	No fire suppression/ control actions	All SDPD fire suppression/ control actions started after ~6:30 am		–
Resident	7	5	2	14

Table 5
Homes that were Defended While Burning

Time window	2:30 am to 3:30 am	3:30 am to 4:30 am	4:30 am to 5:30 am	5:30 am to 6:30 am	6:30 am to 10:30 am	10:30 am to 12:30 pm	12:30 pm to 3:15 pm	Total
Ignited-some flames visible	2/3	2/11	1/5	0/2	1/1	2/2	0	8/24
Fully involved	0	1/9	0/2	0/4	0/2	0	1/1	2/18
Almost completely destroyed	0	0	0	0/2	2/2	0	0	2/4
Defended while burning	2/3	3/20	1/7	0/8	3/5	2/2	1/1	12/46

tures to contain or overhaul the fire (reducing the potential for secondary fires). Additional actions were also taken that affected fire behavior and reduced fire severity. However, these actions were not directly linked to the survival of particular structures. Such actions included the displacement of flammable materials from the vicinity of structures and the suppression of spot fires.

11. Partially Damaged Structures

Out of the 245 homes within the fire line, 16 homes (7%) were damaged and 74 homes (30%) were destroyed. Numerous additional properties suffered smoke damage (sometimes extensive). This is not addressed here. Burned ornamental vegetation, sometimes extensive, is also not covered here. The 16 damaged structures had varying degrees of damage ranging from burned detached garages to small amounts of burn damage on the main house. Defensive actions were identified 15 out of the 16 damaged homes. Table 6 lists the type of damages and the time, if known, and type of defensive action taken on the 16 homes. Of the 15 defended structures, eight were defended by the SDFD, and five by residents or the SDPD. Unless specified the ignition location is unknown. For one of the damaged structures no defensive actions have been reported to date. Five out of the 15 defensive actions occurred before 6:00 am, seven occurred after 8 am, and the times for two defensive actions have not been identified. Figure 25 contains the locations of the damaged homes; numbers on Figure 25 correspond to House Number in Table 6.

It is not possible to know how the fire would have progressed if no defensive actions had taken place. There was only one damaged and unprotected structure within The Trails. The other 15 damaged structures were defended. Since 15 of the 16 damaged structures were defended, it is very likely that most if not all ignited structures would have been destroyed had there been no defensive actions. In that case, the destroyed to total ratio would have increased from 30% to a minimum of 37% for The Trails.

11.1. Interior Versus Perimeter Structural Losses

In this study, the perimeter of the community is defined by the lots that have a portion of their perimeter adjacent to wildlands. Figure 26 shows the interior and perimeter boundary for The Trails. Out of the 74 destroyed structures, 38 were on the perimeter and the remaining 36 were in the interior of the community. Forty percent of homes on the perimeter were destroyed (36/82), compared 20% in the interior (36/163). As described in Sect. 9, there was significant wildland fuel variability along the perimeter of The Trails. This fuel type and loading variability resulted in locally different fire and ember exposures. In the interior of the community, structure losses were a result of exposure to embers generated from burning wildland and residential vegetation and structural fuels.

Table 6
Damaged Structures and Defensive Actions

House number	Damaged area/ ignition location	Defensive action (party responsible)	Time action was taken
1	Decking and railroad ties	Garden hose used to extinguish fires (resident or SDPD)	Before 6:00 am
2	Detached garage and corner of main house/unknown	Fire contained in garage (SDFD)	10:00 am to noon
3	Detached garage/unknown	Fire contained in garage (SDFD)	10:00 am to noon
4	Structure addition under construction	Water from suppression evident (SDFD)	Unknown
5	Main structure/outside column (stucco over wood)	Fire contained to outside column (SDFD)	After 3:00 pm
6	Detached garage/unknown	Fire contained in garage (SDFD)	10:00 am to noon
7	Detached structure/unknown	Fire contained in detached structure (resident or SDPD)	7:00 am
8	Main structure/exposed wood beam	Garden hose used to extinguish fires (resident)	8:00 am
9	Decking	Garden hose and bucket (resident)	9:00 am
10	Main structure/gutter	Garden hose used to extinguish fires (resident)	3:00 am to 5:00 am
11	Decking	Garden hoses used (unknown)	3:00 am to 6:00 am
12	Detached wood shed, wood fencing	Fire contained (SDFD)	3:00 am to 6:00 am
13	Decking	Fire contained to location of origin (SDFD)	3:00 am to 6:00 am
14	Roof top solar panels	Spot fires extinguished (SDFD)	After 10:00 am
15	Deck and main structure	Fire contained to location of origin (unknown)	Unknown
16	Main structure/wood crate	None known	–

12. Structure Ignition Data

In the 2 weeks following the Guejito and Witch fires, the damage to vegetation and data on the destroyed homes were documented. The initial focus on the destroyed structures was aimed at collecting the necessary information prior to the initiation of cleanup and reconstruction. Structures were assigned to three categories of potential ignition mechanisms:

Figure 25. Damaged structures. See Table 6 for further information on each house according to number on figure.

12.1. Category A—Uninterrupted Vegetative Fire or Ember Ignition

Category A was defined as potential structure ignition due to continuous fire spread through vegetation to the structure. This category is, by definition, limited to the perimeter of the community as roads provide a vegetative fuel break. Figure 27 shows an example of a category A structure. The 19 structures in this category had burned vegetation right up to the structure. In all 19 cases, residential vegetation carried the fire to the structure. Note, that there is no way to determine, short of an eyewitness account, if radiative and convective heat flux from the burning vegetation were responsible for igniting the structure, or if embers resulted in structure ignition independently, or a combination of both.

12.2. Category B—Vegetative Fire or Ember Ignition

Category B was defined as structures where there was burned vegetation sufficiently close to the structure to be a potential source of structure ignition. However, the burned vegetation near the structure was not ignited due to continuous fire spread through vegetative fuels (i.e., further from the structure there was surrounding unburned vegetation). In this case, it was assumed that the vegetation

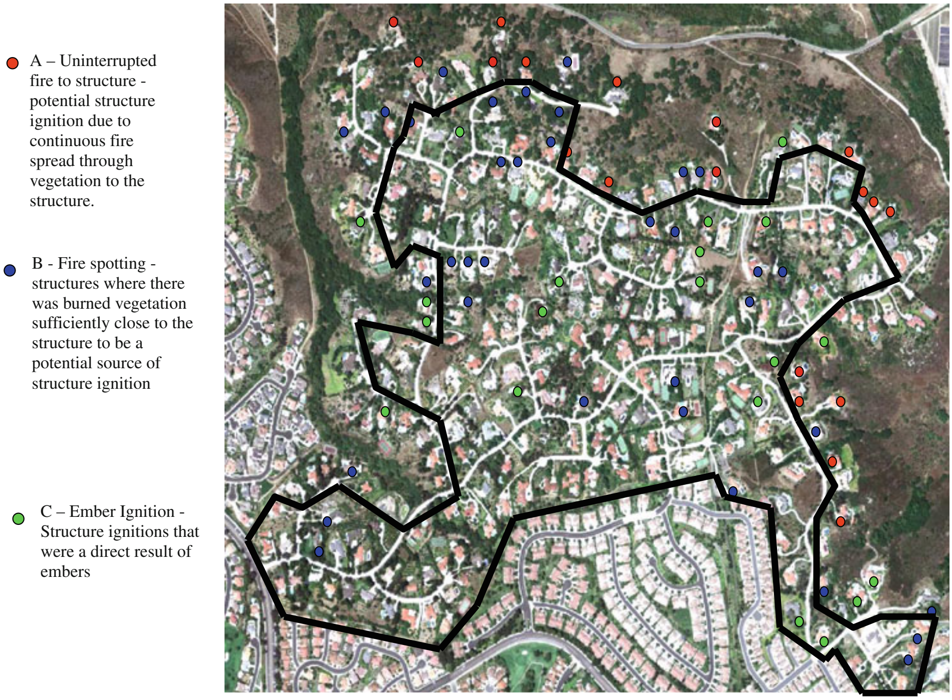

Figure 26. The Trails—ignition categories of destroyed structures and perimeter/interior outline.

near the structure was ignited via embers. Figure 28 shows an example of a category B structure. Embers were involved in either igniting residential vegetation or directly igniting the structure (which then ignited the vegetation near the structure). Table 7 shows that the 35 structures in category B were not limited to the interior of the community, with almost one out of every three being on the perimeter of The Trails.

12.3. Category C—Ember Ignition

Category C was defined as structure ignitions that were a direct result of embers. This category had 20 out of the 74 destroyed structures. Figure 29 shows an example of a category C structure. This was determined from the very limited damage to vegetation surrounding the structure. There were structures in both the interior and the perimeter of the community that fell in this category.

Direct flame impingement from structure to structure ignitions was not identified as a significant contributor to fire spread within The Trails. Out of the 74 homes that were destroyed only two sets were closer than 13.5 m (45 ft). This observation does not apply to embers generated from burning structures, as there are several reports of structures coming apart in the high Santa Ana winds and

Figure 27. Structure ignition category A.

Figure 28. Structure ignition category B.

generating large quantities of embers ranging in size up to golf ball size and larger [18].

Embers could have potentially ignited all structures. However, a conservative estimate of ember ignitions is the sum of structures in categories B and C. This is 55 out of the 74 destroyed structures. Thus, in this particular scenario, over two out of every three structure ignitions involved embers. Embers were involved either by igniting vegetation that could have ignited the structure (category B), or by direct ignition of the structure (category C).

Table 7
Ignition Categories A, B, and C

Ignition category A—uninterrupted fire spread through vegetation (19/74)	Ignition category B—fire spotting over residential vegetation (35/74)	Ignition category C—embers[a] (20/74)	Total
Perimeter: 19/19 Interior: –	Perimeter: 11/35 Interior: 24/35	Perimeter: 8/20 Interior: 12/20	Perimeter: 38 Interior: 36

IA Interior A, *IB* Interior B, *IC* Interior C, *IT* Total Interior Structures, *PA* Perimeter A, *PB* Perimeter B, *PC* Perimeter C, *PT* Total Perimeter Structures.

[a] Embers could have potentially ignited all structures.

Image 1

Fire spotted to vegetation next to structure and possibly onto structure

Image 2

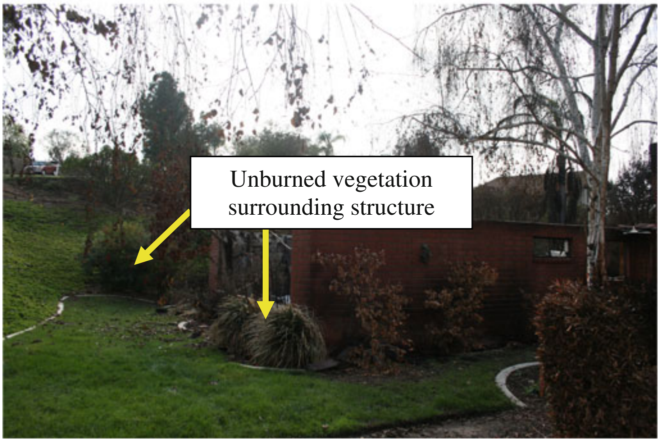

Figure 29. Structure ignition category C (Images 1, 2).

Table 8
Homes Destroyed—Interior

Ignition category A—uninterrupted fire spread through vegetation (A = 19)	Ignition category B—fire spotting over residential vegetation (B = 35)	Ignition category C—embers[a] (C = 20)
IA = 0 IA/A: N/A IA/IT: N/A	IB = 24 IB/B: 24/35 (0.70) IB/IT: 24/163 (0.15)	IC = 12 IC/C: 12/20 (0.60) IC/IT: 12/163 (0.075)

IA Interior A, *IB* Interior B, *IC* Interior C, *IT* Total Interior Structures, *PA* Perimeter A, *PB* Perimeter B, *PC* Perimeter C, *PT* Total Perimeter Structures.
[a] Embers could have potentially ignited all structures.

Table 9
Homes Destroyed—Perimeter

Ignition category A—uninterrupted fire spread through vegetation (A = 19)	Ignition category B—fire spotting over residential vegetation (B = 35)	Ignition category C(IC)—embers[a] (C = 20)
PA = 19 PT/A: 19/19 (1.0) PA/PT: 19/82 (0.25)	PB = 11 PB/B: 11/35 (0.30) PB/PT: 11/82 (0.15)	PC = 8 PC/C: 8/20 (0.40) PC/PT: 8/82 (0.10)

IA Interior A, *IB* Interior B, *IC* Interior C, *IT* Total Interior Structures, *PA* Perimeter A, *PB* Perimeter B, *PC* Perimeter C, *PT* Total Perimeter Structures.
[a] Embers could have potentially ignited all structures.

The distribution of categories A, B, and C in the perimeter and interior of The Trails are listed in Tables 7, 8, and 9. Of the 245 structures that were within the fire line 163 were in the interior of the community and 82 were on the perimeter.

While category A is found only on the perimeter of the community by definition, categories B and C are found both on the perimeter and in the interior of The Trails. Category B, with 35 out of the 74 destroyed structures, has the largest percentage (47%) of structures of all three categories.

The ratio of interior structures in ignition category B (IB) to the total number of interior structures (IT) is 0.15. This is identical to the ratio of perimeter structures in ignition category B (PB) over the total number of perimeter structures (PT) indicating that spotting was involved equally in the ignition of perimeter and interior structures.

The equivalent ratios for ignition category C have respective values of 0.075 and 0.10. While not identical, the numbers are very similar indicating that embers were a direct source of structure ignitions on the perimeter as well as in the interior of this community.

Table 10
Time Distribution of Potential Structure Ignition Categories A, B, and C

Time window	2:30–3:30	3:30–4:30	4:30–5:30	5:30–6:30	6:30–10:30	10:30–12:30	12:30–3:15	Partial or unknown time data	Total
A	1	7	1	2	1	0	0	7	19
B	2	12	3	2	2	1	0	13	35
C	0	4	3	2	2	0	1	8	20
Total	3	23	7	6	5	1	1	38	
Cumulative total	3	26	33	39	44	45	46	74	74

The time distribution of potential structure ignition categories A, B, and C are described in Table 10. Seven out of the 12 category A ignitions (60%) were first observed burning between 3:31 am and 4:30 am. Similarly 12 out of 22 category B ignitions (55%) and 4 out of 12 category C ignitions (30%) were burning during that same time window. From 4:30 am to 3:15 pm, the limited data in the table show that the Bs and Cs have almost the same time history. Figure 30 shows how the As, Bs and Cs are spatially and temporally distributed.

13. Summary and Discussion

The Witch Fire was spreading towards the Rancho Bernardo area of San Diego, CA when the Guejito fire ignited. The proximity of the Guejito fire origin to the Rancho Bernardo area dramatically reduced the available time for resident evacuation and resource deployment. The net result was that in The Trails community, resident evacuation was conducted as the fire reached the community. Additionally, half of the firefighting resources available were involved in resident evacuation. The impact of the Guejito fire from embers (spotting ignitions) before the main fire front reached the community was very limited, with only three home ignitions and six reported vegetative fires. The arrival of the front at ~3:45 am resulted in a very rapid increase in structure ignitions, exceeding 20 per hour at its peak. As the structure ignitions continued, however the rate decreased to nine per hour by 5:30 am, then to eight per hour by 6:30 am. After the Witch Fire reached the community, shortly after 6:00 am, the ignitions of structures dropped to one or two per hour.

The rapid ignition of structures after the main fire attack demonstrates that, with the limited available resources, effective fire prevention is essential to reducing losses. Tested and implementable guidance for homeowners, communities and land use officials are essential to reducing losses in the future.

The contributions of the SDFD, SDPD, and homeowners significantly reduced the losses from these fires. Thirty percent of structures within the fireline were defended. Actions by the SDFD saved a number of homes, as did actions from homeowners. Even though structures were saved by residents, in the case of The Trails, smoke inhalation, egress considerations, and limited visibility all contrib-

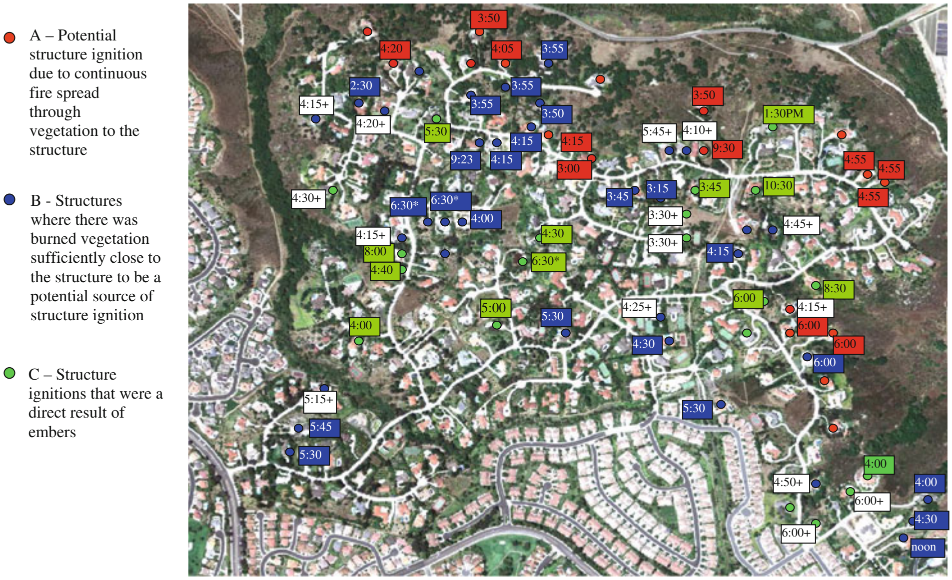

Figure 30. Potential structure ignition categories A, B and C.

uted to generating a very high risk environment. Many additional actions were taken that limited fire spread; however, their effects are not traceable.

The development of a timeline for fire spread through the wildland fuels and then through The Trails has been able to provide insights on fire behavior at the WUI. Figure 31 summarizes much of the spatial and temporal information. The findings to date are divided into two categories: (1) general fire behavior, and (2) defensive actions and structural losses.

13.1. Commonly Held Beliefs in Light of These Findings

This study focused on only 5% of the structure losses from the Guejito and Witch fires. The area of the study is not one where individual homes were spaced on 16 hectare lots (40 acre), which would result in tens of meters of defensible space surrounding homes. Rather, The Trails is a suburban development on the edge of Rancho Bernardo, with lots ranging from 0.5 hectare to 2 hectares (1.25 acres to 5 acres). Several observations were made during this study that contradict some commonly held beliefs. For example, a commonly held belief is that only homes on the perimeter ignite from the wildland assault. This was not the case in The Trails. Homes on the perimeter and in the interior of the community started burning before the wildland front arrived at the community.

Another common belief is that homes take only 40 min to burn. In reality, burn time is a function of construction material, home size, home configuration, and weather (wind). Observations from first responders and homeowners confirm that several homes burned for over 2 h. Lastly, it is frequently believed that in extreme events like the Witch fire, no defensive actions are taken to protect structures. In

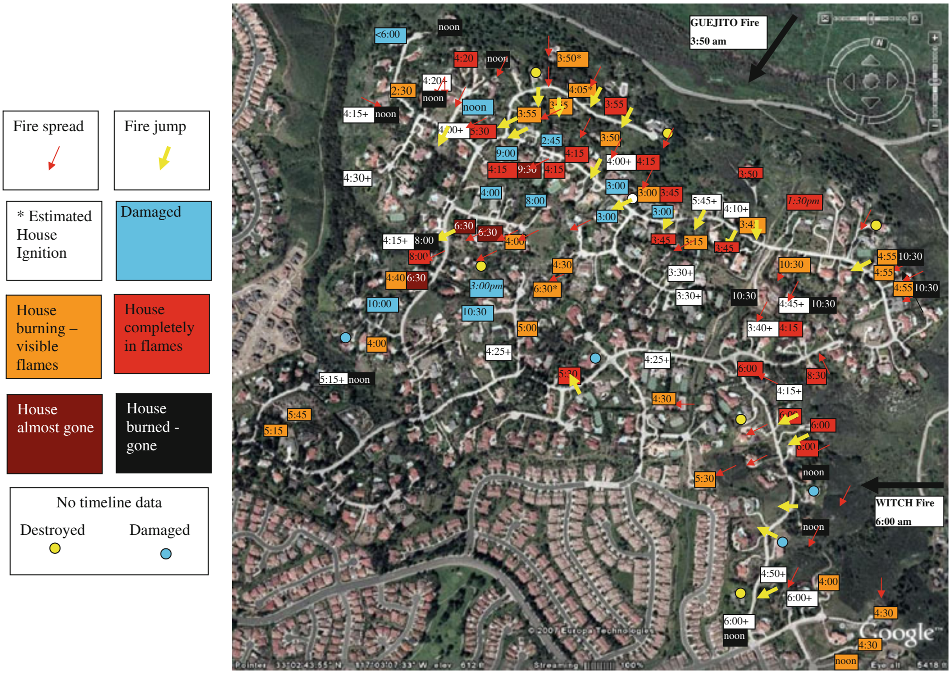

Figure 31. House burning times, fire spread and fire jumps.

the case of The Trails, research this study found that one out of every three homes were defended by the home owners, fire or police department personnel. These defensive actions significantly affected fire behavior and structure survivability and should be an essential component of WUI post fire case studies.

13.2. Summary of General Fire Behavior

- The Guejito fire approached The Trails at a fire spread rate of 9 km/h.
- Fire spread rate within the community dropped to 0.35 km/h.
- Embers from the approaching wildland fire front started arriving at the community an hour before the main fire front, traveling a distance of 9.0 km.
- The ignitions generated by embers prior to the arrival of the main fire front were limited to three homes and several patches of ornamental vegetation. These ignitions occurred 9.0 km ahead of the main front.
- The fire spread up to 500 m into the interior of the community

13.3. Summary of Structural Losses and Defensive Actions

- The arrival of the wildland fire front, not the preceding embers, caused the majority of the damage and overwhelmed the first responder resources.
- 70% of the destroyed homes were not defended.

- 60% of defended structures which were burning were saved.
- Over 50% of the structures were ignited within 3 h after the main front of the Guejito fire hit the community.
- At its peak, right when the wildland fire front reached the community, structure ignitions reached 21 per hour.
- It is estimated that 29 of the destroyed structures (40%) were burning at the same time.
- Two out of every three destroyed homes were ignited directly or indirectly by embers.
- Direct ember ignitions occurred from the arrival of the wildland fire front and for the next 9 h.
- Direct ember ignitions accounted for one out of every three destroyed homes.
- Embers were responsible for the ignitions of structures on the perimeter and in the interior of the community.
- 40% of structures on the perimeter were destroyed compared to 20% in the interior of the community.
- Defensive actions were taken on one out of every three homes in The Trails.
- Fifteen out of the sixteen damaged homes were successfully defended. No defensive actions have been identified on the sixteenth damage home.
- Impact of defensive actions was significant, and probably reduced losses from over 37% down to 30%.

14. Unanswered Questions

Despite the extensive data collection and analysis, there are several questions that remain unanswered. The information available has not been sufficient to determine how many home ignitions were a direct result of the wildland fire and how many resulted from structure to structure fire spread via structure generated embers. Additionally, the full impact of all the defensive actions was not quantified. Although it is likely that most of the 15 damaged structures would have burned without intervention, over 60 documented actions were taken with potentially significant yet unquantifiable ramifications to fire spread and structure ignitions. To provide implementable risk reduction technologies, the fire and ember exposure needs to be characterized. Post fire studies, laboratory and field experiments, and fire modeling are all needed to capture the true flame and embers exposures and structure vulnerabilities.

The reach of the wildland fire into the community was not determined. The limited data available shows that, in the vicinity of fire jumps from the perimeter to the interior of the community, there are two cases were structures in the interior ignited before structures on the perimeter. It is, therefore, possible that the wildland fire front ignited structures 0.2 km in from the perimeter. This hypothesis, however, cannot be confirmed because of the limited spatial/temporal resolution of the currently available data. Additional information to answer this question should be collected in the future in the form of better resolved timelines of structure ignitions. This may be accomplished by ground observations or remote sensing platforms such as unmanned aerial systems.

15. Future Work

There is a need for more case studies of entire fires. This study only focused on 5% of the losses from the Guejito and Witch fires. Future studies should explore how different types of neighborhoods behave under different WUI fire conditions. The influence of type of construction, age of homes (affected by different building codes), and housing density should all be explored. Structure ignition from the wildland fire versus burning structures should also be characterized for different housing densities and constructions.

A second paper is being developed on the structural response of homes in The Trails. The primary objective of the second paper is to examine how structure construction and landscaping attributes affected structure survivability. Exposure to embers and radiation as well as the defensive actions will again be factored in. Specifically, as mentioned in the introduction, the second paper will apply different WUI hazard reduction guidelines to the community and determine how well the guidelines match the observed structure responses to the fire. The third paper will compare the outputs of different fire models to the observed fire behavior and structural fire responses in the community.

Only by conducting methodical studies (field data collection, experiments, and modeling) of destroyed communities that have partly or fully implemented hazard reduction principles, like Firewise [25], will we be able to assess the reliability and effectiveness of such treatments. It is critical that the guidance generated for the public should be tested and implementable in order to reduce future WUI losses.

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