NIST Technical Note 1796

A Case Study of a Community Affected by the Witch and Guejito Fires: Report #2 – Evaluating the Effects of Hazard Mitigation Actions on Structure Ignitions

http://dx.doi.org/10.6028/NIST.TN.1796

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May 2013

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National Institute of Standards and Technology Technical Note 1796
Natl. Inst. Stand. Technol. Technical Note 1796, 107 pages (May 2013)
http://dx.doi.org/10.6028/NIST.TN.1796

This publication was a joint effort between the National Institute of Standards and Technology and the United States Forest Service (USFS).

Cover Page Photo: The Trails Monday 22 October 2007, Photo Courtesy of Michael Bunnell, Used by Permission

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A Case Study of a Community Affected by the Witch and Guejito Fires: Report #2 – Evaluating the Effects of Hazard Mitigation Actions on Structure Ignitions

by

Alexander Maranghides, Derek McNamara, William Mell, Jason Trook and Blaza Toman

Abstract

The National Institute of Standards and Technology (NIST) has a suite of research projects addressing risk reduction in Wildland Urban Interface (WUI) communities. The NIST WUI Team was invited by 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, north of the city of San Diego. There were 270 homes in the Trails community, with 242 within the fire perimeter. Of these, 74 homes were completely destroyed and 16 were partly damaged. 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 images. The data collected and the data analysis are divided into two papers. The first paper, NIST TN 1635 addressed the event timeline reconstruction and general fire behavior observations. This second paper investigates the effect of structure attributes, landscaping characteristics, topographical features and potential wildland fire exposure on structure survivability.

This is the first case study that evaluates hazard mitigation technology effectiveness while accounting for fire and ember exposure and at the same time factoring in defensive actions. The majority of the hazard mitigation treatments evaluated at the Trails Community appeared to be applicable even if they were not all individually effective. The level of fire and ember exposure was identified as having played a significant role in the survivability and destruction of structures with a pattern of increased destruction of residential structures with increased exposure. Additionally, exposure was found to play a significant role in structure survivability with respect to the effectiveness of defensive actions. Defensive actions were over two times more effective in saving structures in low exposure areas compared to high exposure areas. While the Trails community, at the time of the Witch/Guejito fires, did not employ a community wide WUI hazard mitigation plan this case study provides a detailed analysis of the primary hazard mitigation technologies that were present.

KEY WORDS: **Wildland Urban Interface, WUI, fire behavior, community, Witch fire, Guejito fire, Firewise, Firewise effectiveness**

1.0 Background

In this paper, the term Wildland Urban Interface (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.[1] The WUI fire problem is gaining momentum across the southern continental US and is particularly severe across Southern California. Between 2003 and 2010, seven California WUI fires destroyed a total of 9582 structures,[2] on average over 1000 structures per year. These fires resulted in 442 100 hectares (1 092 451 acres) burned. The October 2007 Southern California fires displaced residents in over 300,000 homes. The Witch Creek/Guejito fire (hereafter referred to as the Witch fire), the largest of the fires that occurred during the 2007 California firestorm, burned 80 124 hectares (197 990 acres) and destroyed 1125 residential structures, 509 outbuildings and 239 vehicles; additionally, 77 residential structures and 25 outbuildings were damaged.[3] 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.

It was initially believed that the Trails community was impacted only by the Witch Fire. The After Action Report of the October 2007 Wildfires, City of San Diego Response[5] identified the Guejito Fire as the main fire that hit the Trails. The Witch Fire[6] was ignited in the Witch Creek area east of Ramona, California, about 27 km (17 miles) east of the Trails, at approximately 12:35 pm on October 21, 2007. The cause of ignition was determined as electrical line arcing. The Guejito Fire[7] started twelve and a half hours later at 1:00 am October 22nd, 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 lashing wire. The following excerpt from the After Action Report described the general progression of the Guejito Fire:

> "*The Guejito Fire spread rapidly along the river bottom area of the San Pasqual Valley and southwest toward Highland Valley Road. San Diego Fire Department (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.*"

The combined perimeter of both the Witch and Guejito Fires along with the origins of each fire is shown in Figure 1. Figure 2 portrays the approach of the Witch and Guejito Fires to the Trails community.

The National Institute of Standards and Technology (NIST) WUI Team was invited by the California Department of Forestry and Fire Prevention (CAL FIRE) to collect post incident data from the Witch and Guejito Fires. Early on, the NIST WUI Team initiated a case study within the Witch/Guejito Fire perimeter. The case study is focused on the Trails development at Rancho Bernardo, located 40 km (25 miles) north of San Diego City Center. There were 270 primary residences in the Trails, with 242 located within the fire perimeter (Figure 3). Seventy four homes were completely destroyed and 16 were partly damaged (Figure 3).

The field data collection effort took approximately 1300 person hours over 14 months. Field data were collected by NIST personnel and CAL FIRE Fire Marshals with the support of residents, and the San Diego Fire and Rescue and Police Departments. Field measurements included structure particulars, fire direction and damage to vegetation adjacent to structures. Documentation included over 11 000 digital ground images. The data collected and the data analysis conducted are divided into three papers. The first NIST publication on this study, NIST TN1635[8] addressed the event timeline construction and general fire behavior observations. The current report explores the response of structures within the Trails to the WUI fire. Specifically, this report will attempt to determine the effectiveness of Firewise[9] type actions in reducing structure ignitions at the Trails while considering exposure as well as defensive actions. A third paper will then be developed analyzing the use of fire models in the Trails.

The NIST WUI research effort has three primary components: computer model development, experiments and field data collection. All three components are interlinked and work together towards enabling a reduction of losses at the WUI. This is achieved by the NIST WUI effort in codes and standards as well as work in economics aimed at ensuring the benefit cost effectiveness of hazard mitigation solutions.

Fire behavior models are being developed to help characterize and predict fire behavior in the WUI. At the same time, experimental work is being conducted, with input from post-fire assessments, to characterize and quantify structure ignition vulnerabilities. Modeling and experiments are being used to assess the potential effectiveness of hazard reduction techniques. By implementing this comprehensive methodological approach to studying communities burned by wildfires, the effectiveness and reliability of WUI mitigation techniques might be better assessed.[10]

2.0 Introduction

The extent of the Trails community, at its greatest, is 1.8 km (1.1 miles) from east to west and 1.6 km (1 mile) from north to south. Average elevation of properties within the Trails range from 125 m to 205 m (405 feet to 670 feet) above sea level. The community rests on a knoll and is surrounded by valleys on the north, east and west with higher density residential communities to the south (Figure 3). Highland Valley is to the north at elevations above sea level ranging from 100 m to 110 m (330 feet to 365 feet). Sycamore Creek is to the east at similar elevations and an unnamed ravine is to the west with elevations ranging from 100 m to 135 m (330 feet to 445 feet). Figure 4 portrays topography in and around the Trails along with destroyed and damaged residential structures. There are numerous naturally occurring draws and chimneys present on and close to the western, northern and eastern properties in the Trails. Many of these topographic features extend into the interior of the Trails. Additionally, structures are present in various topographic positions throughout the Trails; some are close to chimneys/draws of various configurations, others are close to ridges and many are at the top of significant slopes.

Figure 5 shows the distribution of property lots in and around the Trails. The Trails consists of 281 lots: 242 residential lots inside the fire perimeter, 28 residential lots outside the fire perimeter, 10 vacant lots and 1 small government owned utility lot. The

Trails directly abuts two large property lots to the north, east and west. The property to the north and east contains wildlands, which are directly adjacent and continue into some Trails residential properties. There are also nurseries on these properties to the east and northwest that do not directly abut residential properties. The property to the east is all wildlands. There is a paved two-lane road to the north and unpaved roads to the east and west. Surrounding the Trails on the south are high density residential property lots.

The housing density within the Trails is approximately 164 homes per km^2 (422 homes per square mile), not considering structures in adjacent communities. Figure 6 portrays primary structure[i] density across the Witch and Guejito Fires. The housing density within the Trails is generally lower than the densities seen to the west and south, but greater than the densities seen to the east. Structure density in the Trails, considering all residential properties surrounding the Trails community, is shown in Figure 7. Lower residential structure densities in eastern, northern and western portions of the Trails are caused by adjacent wildland properties containing no structures as well as the geometry of these residential property lots. As can be seen in Figure 7, these perimeter properties tend to have a different geometry compared to those in the interior portions of the community. The lots on the western, eastern and northern perimeter tend to be longer and thinner with most extending into the wildlands. This varied geometry is further demonstrated by the properties on the "perimeter"[ii] having an average area of 1.7 acres and those on the "interior" of the community having an average area of 1.1 acres.

Wildland vegetation in and directly around the Trails was categorized as the following: Cismontane Alkali Marsh, Coast Live Oak Woodland, Coastal and Valley Freshwater Marsh, Diegan Coastal Sage Scrub, Valley and Foothill Grasslands, Southern Riparian Forest, Southern Cottonwood-willow Riparian Forest, Southern Willow Scrub, Disturbed Wetlands and Non-Native Grasslands. Wildland vegetation community types of Diegan Coastal Sage Scrub, Coast Live Oak Woodland, Valley and Foothill Grasslands and Non-Native Grasslands directly abut or continue onto residential properties in the western, northern and eastern portions of the Trails. Vegetation community types found in Sycamore Creek to the east but not directly abutting residential properties consists of Southern Willow Scrub, Coastal and Valley Freshwater Marsh and Disturbed Wetlands as well as a plant nursery. Highland Valley to the north but not directly abutting residential properties contains Non-Native Grasslands, Southern Willow Scrub, Cismontane Alkali Marsh and different types of Southern Riparian Forest. The ravine to the east is dominated by Diegan Coastal Sage Scrub and Coast Live Oak Woodland[iii] with some Southern Cottonwood-Willow Riparian Forest and a plant nursery further away from residential properties. Other areas within the Trails contain an extremely diverse variety of vegetation with some being very flammable such as Mexican Palms (*Washingtonia robusta*) and Eucalyptus (*Eucalyptus cinerea*) and other residential vegetation also likely being flammable. The vegetation community types mapped are

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[i] Primary structures are considered to be a residential dwelling or a business facility, including Federal, State and local government facilities. The number of residences per dwelling is not considered in Figure 6 or Figure 7.

[ii] In NIST TN 1635, the perimeter of the community is defined by the lots that have a portion of their perimeter adjacent to wildlands.

[iii] The southern areas in the ravine to the east of the Trails contain a more diverse group of vegetation communities compared to what is portrayed in Figure 11.

defined and described in the SanGIS[iv] Vegetation Community Type data set.[11] Vegetation community types within the Trails were not mapped due to this diversity and the fact that there was no mapping of residential vegetation in the SanGIS data set. Ornamental vegetation mapping of interior vegetation was, however, conducted as described in section 5.3.

The report outline is provided here for clarity. Section 3 provides a summary of the objectives and findings from the first Trails Report (NIST TN1635)[8]. Section 4 identifies the objectives of this report while section 5 covers materials and methods used. Section 6 covers data collection, production and analysis limitations. Section 7 lists the results, while section 8 is a discussion of the findings. Section 9 provides a summary, and section 10 offers conclusions and recommendations. Lastly section 11 addresses future work and acknowledgments are provided in section 12. Appendix A provides a complete list of the NIST TN1635 findings, and Appendix B includes the Firewise checklists used. Appendices C and D include the additional field data collection forms used. Appendix E provides information on the derivation of the Normalized Difference Vegetation Index (dNDVI) data set. Lastly Appendix F and G provide additional two and three-way contingency tables.

3.0 Summary of Objectives and Findings in First Trails Report

In order to better understand the fundamentals of fire behavior at the WUI, NIST Technical Note 1635 addressed the following technical questions:

- How far within the Trails 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 and some residential vegetation were identified. Additionally, the fire fighting and structure protection responses taken shortly before and during the fire event were documented. Detailed findings from NIST TN1635 are found in Appendix A.

3.1 Defensive Actions, Fire Timeline and Fire Direction

Information on defensive actions, fire timeline and fire direction were collected as described in NIST TN1635. This fire timeline and human behavior information presented in TN1635 is used here to provide insights to fire behavior and structure vulnerabilities. Additionally, fire direction information provides a potential means to characterize exposure from burning features across the landscape. Finally, locations of fire jumps were used to characterize effective and ineffective property treatments.

Defensive actions are defined here as actions taken by the San Diego Fire and Rescue Department (SDFRD), San Diego Police Department (SDPD), and homeowners to slow down, redirect, control and extinguish any fires during the morning of October 22, 2007.

[iv] SanGIS is the joint City and County of San Diego Geographic Information system. Here San GIS is used to populate the database describing vegetation in and around the Trails community.

The focus is on all actions taken shortly before the approach of the Guejito fire and for approximately 12 hours after its arrival, or until 3:00 pm October 22. No structures were ignited after 1:30 pm and all major fire suppression activity was significantly reduced. A total of 85 defensive actions on 79 properties shown in Figure 8 were identified at the Trails, however, it is possible that a number of defensive actions were not identified. The actions ranged in complexity and scope from SDFRD fire engine crew defending a house with multiple fire hoses to a homeowner putting out a gutter fire with a garden hose. 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 as 15 out of the 16 damaged structures were defended. Table 1 lists the specific defensive actions taken on these damaged structures.

Figure 9 portrays fire direction in the Trails. Fire direction was delineated in the field on hard copy data sheets portraying aerial imagery from Google™ Earth. Several different indicators were used to determine the direction that the fire spread within the Trails. In the wildlands, needle freeze, directional degree of damage to wildland vegetation and the presence of partly damaged golf balls were all used to determine directionality of fire spread. Within the Trails, the extent of burned vegetation around destroyed homes was documented along with the locations that the fire jumped a road. This allowed for the identification of 21 locations representing spotting across the road. Needle freeze, the process of dehydrated foliage aligning or "freezing" parallel to the wind direction, was used to obtain wind direction.[12] Directional scorching was also used to document fire direction within the Trails.

Table 1 Defensive actions taken on 15 out of the 16 damaged residential structures.

Damaged area/ ignition location	**Defensive Action (party responsible)**
decking and railroad ties	Garden hose used to extinguish fires (resident or SDPD)
detached garage and corner of main house/ unknown	Fire contained in garage (SDFD)
detached garage/ unknown	Fire contained in garage (SDFD)
Structure addition under construction	Water from suppression evident (SDFD)
main structure/ outside column (stucco over wood)	Fire contained to outside column (SDFD)
detached garage/ unknown	Fire contained in garage (SDFD)
detached structure/ unknown	Fire contained in detached structure (resident or SDPD)
main structure/ exposed wood beam	Garden hose used to extinguish fires (resident)
decking	Garden hose and bucket (resident)
main structure/ gutter	Garden hose used to extinguish fires (resident)
decking	Garden hoses used (unknown)
detached wood shed, wood fencing	Fire contained (SDFD)
decking	Fire contained to location of origin (SDFD)
roof top solar panels	Spot fires extinguished (SDFD)
deck and main structure	Fire contained to location of origin (unknown)

4.0 Objectives of this Report

There are many different types of guidance available to residential homeowners and builders regarding development and maintenance of properties in a WUI environment. There is, however, a lack of studies assessing the effectiveness of current WUI mitigation guidance for WUI homeowners and builders. Enforceable guidance is found in building codes and standards that are typically determined at the city or county level with some statewide standards existing in states such as California. WUI building codes and standards, however, vary both geographically and over time. Residential WUI mitigation guidance is also provided at the national level from organizations such as Firewise Communities and the National Fire Protection Association (NFPA) [13]. This national level guidance is often adopted or modified by state or local governments when providing recommendations for developing or treating WUI communities. In addition to codes and standards, WUI mitigation guidance for residential properties is typically presented to homeowners and builders in two forms:

1. **Checklists**: these types of guidance provide a set of pre-defined criteria which homeowners or builders can use to ensure the structure has been built or is being maintained to provide protection from wildland fires.
2. **Scored Evaluations**: these types of guidance also provide a set of pre-defined criteria where each WUI treatment has a weighted value resulting in an overall score for the primary structure relating to protection from wildland fires.

The NFPA Firewise Communities program, at the time of the 2007 Witch Fire, had published landscape and construction checklists (Firewise checklists)[13] providing guidance to homeowners and builders on WUI residential property development and maintenance. These checklists are provided in Appendix B. This report evaluates certain aspects of the Firewise Communities checklists in context of the Witch and Guejito Fire affected the Trails Community at Rancho Bernardo. Specifically, this report focuses on:

1. Analyzing if Firewise treatments are applicable within the Trails.
2. Determining if Firewise treatments were present at the Trails prior to the Witch and Guejito Fires.
3. Evaluating the effectiveness of Firewise treatments in reducing structure ignitions at the Trails individually and in context of exposure from flames and embers.
4. Examining the need to know defensive actions in order to determine Firewise treatment effectiveness.

The Firewise checklists reflect Firewise type guidance at the time of the 2007 Witch and Guejito Fires. Additionally, the Firewise checklists are currently provided on websites of many state and local governments responsible for providing WUI mitigation guidance. Given the limited amount of resources available, the Firewise checklists represented a readily available format that could be recorded on paper forms. Finally, the data collection approach might provide an indication of factors to focus future WUI post-fire case studies.

5.0 Materials and Methods

The NIST data collection effort provided 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 of the effort was to collect sufficient information, not only to characterize overall fire behavior in the WUI but also to provide a foundation for future, more in depth, case studies. The following data collection methodology was developed and followed for the NIST data collection effort:

1. Immediately after the fire, the construction characteristics of the destroyed residences as well as damage to some residential vegetation were documented using the field forms shown in Appendix C. This was necessary in order to capture the information before it was lost during community reclamation efforts.
2. Emergency responder data logs were obtained and technical meetings were conducted with first responders to develop an event time line. At the same time, the Trails Homeowners Association (HOA) provided critical input to the timeline.
3. Homeowner technical discussion forms were sent to each homeowner within the Trails community by CAL FIRE and subsequently by the Trails HOA to determine information on structure particulars, vegetation around the structure, defensive actions, fire behavior timeline, weather, and other information.
4. The Trails was revisited by NIST Scientists and California Fire Marshalls to assess properties with non-destroyed structures as per the field form shown in Appendix D. The form was based on the Firewise Checklist in Appendix B.
5. Properties with destroyed structures were assessed as per the Firewise checklist using the data collected in step one above in conjunction with other sources of data as described in the sections below.
6. Responses to the Firewise checklist were normalized in an attempt to provide consistency between observers.
7. Results of the Firewise checklist data collection were used with other data sources to determine the applicability of the WUI treatments, the presence of WUI treatments in the Trails, and the effectiveness of WUI treatments in reducing structure ignition in the Trails.

The data collection effort was conducted with support from CAL FIRE and San Diego Fire and Rescue and Police Department personnel. Additionally, critical support was provided by the Trails HOA.

5.1 Firewise Checklist Data Collection and Processing

In April 2008, following the Witch and Guejito fires, 168 properties without destroyed primary structures but within the fire line were assessed for the presence of the respective Firewise treatments listed in Table 2[v]. Treatments 1a and 19 had clarification added or modifications made to the treatment description before the data collection event as shown in italics in Table 2. The modified Firewise treatments were transferred to a hard copy data sheet and the address, time of data collection, image documentation and team

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[v] Some Firewise treatments present on the Firewise Checklist were not assessed because the determination of these treatments in a post-fire environment was believed to be too difficult to obtain reliable answers.

number for the respective property assessment were recorded. Each property received a rating for the respective treatment as follows:

- **Yes:** indicates the property received the respective treatment (i.e., passed/treated).
- **No:** indicates the property did not receive the respective treatment (i.e., failed/untreated).
- **N/A:** indicates a yes/no value is not applicable for the respective treatment. An example is treatment 22 where a property with no deck would receive a N/A.
- **N/D:** indicates that it could not be determined if the respective property was treated. An example is a completely burned property where the presence of firewood could not be determined.

Table 2 Firewise checklist treatments[vi].

Treatment Number	Treatment Description	Treatment Number	Treatment Description
1a	**Zone 1[vii].** This well-irrigated area encircles the structure for at least 30' on all sides. *(If one section does not meet this it is a "fail")*	12	Set your single-story structure at least 30 feet back from any ridge or cliff; increase distance if your home will be higher than one story.
1b	**Zone 1.** Provide space for fire suppression equipment in the event of an emergency.	13	Use construction materials that are fire-resistant or non-combustible whenever possible. (**The presence of a wood roof, siding, eave, deck, pergola, fence or wood pile receives a "no"***)*
1c	**Zone 1.** Plantings should be limited to carefully spaced low flammability species.	14	Roof construction from materials such as Class-A asphalt shingles, slate or clay tile, metal, cement and concrete products, or terra-cotta tiles.
2	**Zone 2.** Low flammability plant materials should be used. Plants should be low-growing, and irrigation should extend into this zone.	15	On exterior wall facing, fire resistive materials such as stucco or masonry are much better choices than vinyl which can soften and melt.
3	**Zone 3.** Place low-growing plants and well-spaced trees in this area, remembering to keep the volume of vegetation (fuel) low.	16	Driveway 12 feet wide with a vertical clearance of 15 feet and a slope that is less than 5 percent and include ample turnaround space near the house.
4	**Zone 4.** This furthest zone from the structure is a natural area. Selectively prune and thin all plants and remove highly flammable vegetation.	17	Periodically inspect your property, clearing dead wood and dense vegetation at distance of at least 30 feet from your house.
6	Take out the "ladder fuels" — vegetation that serves as a link between grass and tree tops.	18	Move firewood away from the house or attachments like fences or decks. (**30 feet is defined as a minimum distance**)
7	Provide added protection with "fuel breaks" like driveways, gravel walkways, and lawns.	19	*Is the structure free of an attached wood fence?*
8	Keep vegetation pruned. Prune all trees so the lowest limbs are 6' to 10' from the ground.	20	Prevent combustible materials and debris from accumulating beneath patio decks or elevated porches.
9	Remove leaf clutter and dead and overhanging branches.	21	Screen or box-in areas below patios and decks with wire screen no larger than 1/8 inch mesh.
10	Store firewood away from the house. (**30 feet is defined as a minimum distance**)	22	Elevated wooden deck not located at top of hill where in direct line of a fire.
11	Slope of terrain; build on the most level portion of the land.		

After examining the initial data it was discovered that Firewise treatments 10, 13 and 18 also required modification to the treatment description for consistent evaluation. These modifications to the Firewise treatment description are shown in bold in Table 2.

[vi] Treatment descriptions listed in italics were added at the time of data collection. Treatment descriptions listed in bold were added after the data collection. Treatments highlighted in grey were not analyzed.

[vii] The Firewise checklist indicates Zone 1 is closest to the structure; Zones 2-4 move progressively further away.

Properties with destroyed primary structures were evaluated in the office using field and remote sensing data following the complete descriptions shown in Table 2.

Hard copy field forms representing the 168 properties assessed by NIST and CAL FIRE were scanned and entered into a digital format. Certain errors were encountered when reviewing these digital data as follows:

1. Systematic errors identified at a team level. Examples include flipping questions on a sheet, incomplete data sheets, or inconsistencies assigning a N/A value.
2. Ambiguity in the question. An example is question 13 examining combustibles around a structure.
3. Diversity of expert opinion. For example, experts may disagree on what types of vegetation might be low in flammability.

While information was collected regarding the presence of treatments 1b and 16, it was decided not to assess attributes related to first responder access. Treatment 12 was also removed from the analysis due to confusion on what constituted a cliff or ridge. Finally, treatments 2, 3 and 4 were removed from the analysis due to confusion in interpretation of these treatments as described in Section 6 of this paper.

The raw field data were converted into digital format and inspected back in the office in an attempt to provide consistency amongst observers and between evaluations of the destroyed and not destroyed primary structures. This was a difficult process and some treatments might not have been evaluated consistently. Inconsistent use of the value N/A might not have been corrected due to ambiguity in the field and office data. There was also difficulty in transferring the data and data integrity issues arose. An attempt was made to clean up the data but certain errors might remain. The new digital data collection methodology was designed, in part, to address these issues.

Table 3 shows additional remote sensing data sources used for the analysis along with the specific use. All Firewise responses were also inspected using observer comments, homeowner technical discussion forms, first responder technical discussions, assistance from the Trails Home Owners Association (HOA), ground images and other data obtained from the initial Trails assessment. With the exception of treatment 1a and 11, spatial representations of property boundaries were not used in the data normalization process. Also note that there was no normalization process conducted on the destroyed primary structures as the methods used to assess these were the same methods used in the normalization process.[viii]

[viii] Normalization consisted of reviewing the data and checking for consistency across the different data collection teams. As an example, one team misinterpreted one of the questions recoding “yes” when a combustible was present instead or recording “no”.

5.2 Additional Data Processing

In addition to the remote sensing data listed in Table 3, other vector GIS data was acquired and used in this paper as shown in Table 4. The raw LIDAR data listed in Table 3 had points classified to the designations shown in Table 5.[14] These specifications follow the American Society of Photogrammetry and Remote Sensing (ASPRS) LIDAR Point Classes[15] for those features with classification values less than 10. Those features with classification values greater than 10 represent features with no standard LIDAR Point class value and the ASPRS reserved values were assigned. The features extracted for this classification schema were based on potential needs for modeling and ability to delineate vegetation by structural stage.

Polygons representing the horizontal extent of vegetation and building footprints were extracted across the study area from the LIDAR data and fire barrier locations were extracted from color imagery. Additionally, digital elevation models and derivatives were created from the LIDAR ground points. Extracted vegetation polygons were also classified by structural class, vegetation community type and other categorizations using a combination of remote sensing and GIS data sources. Finally, a change in greenness data set was developed from pre- and post-fire imagery (imagery dates listed in Table 3) to help portray, at a coarse level, fire damage to vegetation in and around the Trails community.

Table 3 Remote sensing data used in analysis.

Data Source/Type	Type of Data	Spatial Resolution	Date	Uses
Pictometry™	Oblique Imagery	6 Inch	5/19/06	Verify presence of all Firewise treatments.
Pictometry	Aerial Imagery	6 Inch	5/19/06	Verify presence of all Firewise treatments.
Ortho-rectified Imagery (USGS)	Aerial Imagery	1 Meter	6/2005	Verify presence of treatments 11 and 13. Creation of pre-fire NDVI data set.
Ortho-rectified Imagery (USGS)	Aerial Imagery	3 Inch	3/2005	Verify presence of treatments 11 and 13.
Google™ Imagery	Aerial Imagery	1 Foot	1/2006	Verify presence of all Firewise treatments except treatments 11 and 13.
Ortho-rectified Imagery (San Diego State University)	Aerial Imagery	1 Foot	11/2007	Verify presence of treatments 11 and 13; cleanup LIDAR extracted building footprints; general fire behavior; creation of post-fire NDVI data set.
Light Intensity Detection and Ranging (LIDAR)	Point Measurements of Surface Elevation of All Features	5 Foot Nominal Post-Spacing	3/2005	Verify presence of Firewise treatment 11. Creation of various topographic products and derivates; extraction of building footprints; and creation of vegetation data set.

Table 4 Additional data used in analysis.

Data Source/Type	Type of Data	Uses
Property Boundaries (SanGIS™)[ix]	Vector GIS Data	Firewise Zone Concept Analysis; determining presence of Firewise treatments 1a and 11.
Vegetation Community Types (SanGIS)	Vector GIS Data	Conflated vegetation community types found in this data set to LIDAR derived vegetation polygons.

Table 5 LIDAR point classification values.

Feature	Classification Value
Low Vegetation: ≤2m	3
Medium Vegetation: >2m ≤ 4m	4
High Vegetation: >4m	5
Building	6
Ground	8
Vehicle	15
Pole	16
Bridge	17
Boulder	18
Fire Barrier	19
Deck (material unknown)	20
Solar Panels	21
Tennis Courts	22
Playground Equipment	23

All LIDAR points except ground points were classified using automated and manual techniques found in the ArcGIS™ extension LP360™[x]. Boulder and fire barrier features were extracted as polygons from the 2005 imagery using the ArcGIS extension Feature Analyst™. The techniques used were similar to those described in McNamara et al., 2009 [16] except results were manually adjusted for misclassifications using the 2005 three inch imagery. Additionally, building footprints were derived from the classified LIDAR points, again using LP360 software. These building footprints were manually corrected for misclassifications, occlusions caused by vegetation and other errors as observed in various remote sensing data sources shown in Table 3. The building footprints are estimated to have a horizontal accuracy of about 1.5 m to 3 m (5 ft to 10 ft). LIDAR points representing vegetation were further classified as to the vegetation height categories shown in Table 5. This was again accomplished using LP360 software to subtract the LIDAR recorded height above sea level of the respective vegetation point from the height above sea level of the interpolated ground points on which this LIDAR vegetation point falls. Thereby providing a measure of height above ground for the respective point and allowing for the automatic classification of the remaining unclassified points to the vegetation height categories shown in Table 5. Vegetation polygons representing above ground vegetation by structural stage were then derived from the classified LIDAR point cloud using LP360 software to group and trace LIDAR points in the height categories shown in Table 5. Following this a polygon representing the study area[xi] was delineated. This study area polygon was then erased by polygons in the fire barrier and the building footprint data set

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[ix] Property boundaries used in this analysis had a horizontal accuracy listed as 3 m to 4.5 m (10 ft to 15 ft).

[x] LP360 for ArcGIS is an extension that provides the ability to create and manipulate LIDAR Layers directly from industry standard LAS files without any time consuming importing or converting processes. http://www.geocue.com/products/qcoherent.html

[xi] The study area consists of the Trails community, the Sycamore Creek water shed to the east, the adjacent western ravine and parts of Highland Valley as seen in Figure 3.

described above. The remainder of the polygons represented vegetated surfaces across the study area, excluding vegetation that covered buildings and fire barriers. Next, the remainders of these polygons were erased by the structural stage vegetation polygons traced from the LIDAR point cloud, leaving polygons with only ground vegetation. These ground vegetation polygons were then combined with the structural stage polygons to produce the final dataset portraying the horizontal extent of the top vegetation layer across the study area, including vegetation covering buildings and fire barriers. Areas representing nurseries or tree farms were classified as "agriculture". The horizontal extent and structural stage of vegetation was not extracted in these areas.

Many of the ground vegetation polygons created above represented large contiguous areas of species such as Manzanita (*Arctostaphylos*) and other shrubs species (broadly grouped here as Diegan Coastal Sage Scrub) with only sparsely scattered LIDAR vegetation returns. The scarcity of LIDAR vegetation returns was due to the high density of the, sometimes low growing but often highly flammable in this case, vegetation and the difficulty in distinguishing between shrub and ground returns in cases such as these. Using manual techniques described below these polygons were edited to reflect changes in vegetation community type and manually identified Diegan Coastal Sage Scrub polygons were re-classified with a height category ≤2m, unless portrayed to be of a greater structural stage class in the LIDAR data. The structural stage vegetation polygons are estimated to have a horizontal accuracy of about 1.5 to 3 meters (5 ft to10 ft).

Other vegetation community types portrayed in the vegetation data set listed in Table 4 were also conflated or transferred to the LIDAR extracted vegetation polygons from the SanGIS vegetation data set. This conflation process was conducted due to the poor spatial representations of the SanGIS vegetation polygons when compared to the LIDAR extracted vegetation polygons. The vegetation community classifications present in the SanGIS data set, however, provide the best estimate of vegetation type available for the study area. Polygons in the wildland areas, generally greater than a quarter acre (less on the wildland edge) were edited to reflect changes in community types based off of aerial photo interpretation from the 2005 three inch spatial resolution imagery and Pictometry™ oblique imagery. Vegetation community type mapping was conducted to help divide lands into wildland versus residential vegetation and as a potential means to prescribe the material properties of vegetation for future fire modeling in the Trails.

Vegetation polygons mapped to a community type were also sub-classified as wildland vegetation with all other vegetation polygons being classified as residential vegetation. This sub-classification followed a conservative approach along the wildland edge only attempting to identify those vegetation community types shown in Figure 11 and there evident continuation into or occluded occurrence in the Trails Community. The exact edge where wildlands ended and residential vegetation began was in some cases quite clear and in other cases more difficult to delineate. Ground photos were coupled with aerial imagery to better discern these edges. Small patches of natural vegetation representing a single or small group of species in the interior of the community might have been missed in this mapping process (< 0.25 acres).

The height class vegetation polygons for non-ground vegetation mapped in the Trails community are displayed in Figure 10. Wildland vegetation community type polygons mapped in and around the Trails are displayed in Figure 11. Vegetation polygons displayed in Figure 10 were not mapped to community types but vegetation polygons displayed in Figure 11 were mapped to structural stage. In fact, though not studied here, this initial mapping of height class greatly facilitated the manual delineation of vegetation community type in the Trails due to differences in structural stage among vegetation community types.

Other derivative products of the LIDAR point cloud included a digital elevation model (DEM) at a 1.5 meter (five foot) horizontal resolution derived from the LIDAR classified ground points using LP360. Ground points were converted to a triangulated irregular network (TIN) and the TIN was converted to a raster DEM using LP360. Again, using ArcGIS, percent slope and aspect grids were derived from the DEM and are shown in Figure 12 and Figure 13, respectively.

In addition to the above derivative products, a change in greenness data set between the 2005 National Agriculture Imagery Program (NAIP) color infrared (CIR) imagery and the post-fire four-band imagery was also created. This change in greenness data set is derived by differencing two Normalized Difference Vegetation Index (NDVI) data sets to produce what is termed a dNDVI data set as described in Appendix E. This data set was not developed for quantitative analysis but as a means to identify where the top vegetation layer burned or was scorched. This data set is used for various map figures and to help portray burned areas in combination with other data for visual data exploration.

In the Trails, the dNDVI data product does not portray vegetation types that were senescent (i.e., no photosynthetically active vegetation) for both pre- and post-fire imagery. Field observations, however, indicated that several grassland areas were consumed by the fire. These areas were typically Diegan Coastal Sage Scrub, Non-Native Grasslands and Valley and Foothill Grasslands. Most of these areas experienced stand replacing fires[xii] and appeared to have helped spread the fires into and through portions of the Trails. These burned areas are also displayed with the dNDVI product shown in Figure 14. All subsequent figures displaying the dNDVI data set have these manually delineated burned areas displayed as white with a transparency of 30%. It should also be noted that Figure 14 does not display areas where the vegetation under-story burned and the vegetation over-story was not burned or scorched.

5.3 Data Analysis Procedures

This section presents the methods used to assess the following items:

1. Applicability of Firewise treatments within the Trails,
2. Presence of Firewise Treatments within the Trails, prior to the Fire,
3. Effectiveness of Firewise treatments in reducing structure ignitions,
4. Effectiveness of Firewise treatments in reducing structure ignitions in context of potential exposure.
5. Effectiveness of Firewise treatments when considering defensive actions as well as locations of defensive actions in context of potential exposure.

[xii] A stand replacing fire kills all or most of the living upper canopy layer (in a forest or woodland, the overstory trees) and initiates succession or regrowth. National Wildfire Coordinating Group, Incident Operations Standards Working Team. 1996. Glossary of wildland fire terminology. PMS 205/NFES 1832. Boise, ID: National Interagency Fire Center, National Fire and Aviation Support Group, Training Standards Team.

Certain methods presented in this section do assess the presence of Firewise treatments collectively but this is not intended to be an analysis of the combined effectiveness of Firewise treatments. The precise integration and accurate analysis of the data collected and produced in this report to determine the factor or, more likely, the set of factors under various scenarios that result in a structure's increased risk of ignition from wildland fire or embers is a complex process. A future report will attempt to address the feasibility of conducting such a task given the available data using various models (e.g. GIS, Logistic Regression, Fire Behavior Models) for demonstration. Nonetheless, an examination of the treatments presented below has been invaluable in the development of the NIST WUI Assessment System deployed at the Tanglewood Complex Fire (Amarillo, Texas 2011) and can be used to provide insight into the data in terms of data collection methodology for future post-fire assessments. More importantly, the NIST data collection methodology utilized in this report does facilitate the analysis of the Firewise treatments evaluated for this study, even if at a specific type of treatment level. The overall analysis framework for the assessment of the effectiveness of Firewise treatments is presented in Figure 15.

5.3.1 Firewise Applicability

Assessing the effectiveness of individual Firewise treatments generally provides an indication of the applicability of the respective treatment. Certain treatments, however, might be exceptions. For example, recommending vegetation irrigation as a treatment might not be applicable in a desert regardless of the effectiveness of the treatment. Beyond this, a qualitative assessment of the applicability of the Firewise Zone Concept at the Trails is also conducted. This assessment involves cartographically displaying two different interpretations of the Firewise Zone Concept at the Trails in conjunction with residential structure damage. One interpretation of the Firewise Zone Concept involves community cooperation in implementing the landscape design principals portrayed in the Firewise Landscaping Checklist and is the approach recommended by the Firewise Program. The second approach involves individual landowners treating only their properties, regardless of their neighbor's property condition and hazards; following the principals portrayed in the Firewise Landscaping Checklist. While this second approach is not recommended by Firewise explicitly a different approach is not presented for situations where community cooperation is not occurring. Consequently, even though data was lacking to completely assess the Firewise Zone Concept this qualitative assessment might provide insight on the appropriateness of the different implementation methods.

5.3.2 Firewise Presence

After evaluation of the applicability of the Firewise treatments, an assessment of several general concepts portrayed in the Firewise Checklists is conducted. The presence of native or wildland vegetation across the Trails was assessed as well as general analyses of slope and aspect on Trails properties. Cartographic display of the various delineations conducted in the vegetation data set also help to portray the presence of various vegetation treatments across the Trails. Finally, the overall presence of assessed Firewise treatments is examined. There are, however, numerous Firewise treatments not assessed in this report such as the type of window present. These treatments were not assessed due to difficulties associated with collecting reliable field data.

5.3.3 Firewise Effectiveness (Individual Treatments)

The effectiveness of assessed Firewise treatments is first analyzed using two-way contingency tables individually for each treatment. This type of analysis was standard when analysis of categorical data with more than one variable is being conducted. Each of the Firewise treatments assessed either had the respective treatment present on the property (i.e. pass) or absent on the property (i.e. fail). Properties where the respective treatment could not be determined or was not applicable were not included as part of the population examined. In this case, two-way contingency tables allow for the display of the frequency of the categorical data classified by the presence/absence of the treatment and the structure response to the Witch and Guejito Fires. Using the Chi-square test of independence the following hypotheses was tested for all assessed Firewise treatments with adequate response frequencies of $n \geq 20$.

> **Ho (null hypothesis)**: *Properties in the Trails at Rancho Bernardo Community* ***have no association*** *between implementation of the respective Firewise Treatment and damage to the property's primary structure from the 2007 Witch and Guejitio Fires.*
>
> **Ha (alternative hypothesis)**: *Properties in the Trails at Rancho Bernardo Community* ***have an association*** *between implementation of the respective Firewise Treatment and damage to the property's primary structure from the 2007 Witch and Guejitio Fires.*

Significant codes for p-values produced by the respective Chi-Square test are: p value < 0.001 (***), p-value < 0.01 (**), and p-value < 0.05 (*). Some Firewise treatments could not be assessed due to their limited presence (low frequencies). It should also be reiterated that this analysis, due to low sample numbers, does not account for the interdependence between treatments that is implied in the Firewise Checklist.

5.3.4 Exposure Determinations

The contingency table analyses and Chi-Square tests described above examine all structures collectively that were determined to be within the combined perimeters of the Witch and Guejito Fires and found within the Trails Community. Traditional methods of quantifying exposure for post-fire assessments typically rely on assessing only the properties containing wildfire destroyed primary structures (USDA 2008 [17]). It is less common for WUI post-fire assessments to examine all structures within the fire perimeter, with some exceptions as evidenced by the Australian bushfires of 2009[18]. Accurate assessment of the effectiveness of WUI treatment guidance might, however, require a more precise quantification of exposure to better understand potential structure vulnerabilities and ignition mechanisms. Exposure in this paper is defined as the fire and ember assault at a particular location in space and time. The concept of exposure discussed in this paper should be independent of the structure construction and ignition vulnerabilities. It is necessary to uncouple the exposure from the ignition vulnerabilities in order to effectively assess vulnerabilities under similar exposure conditions. This applies to both vegetative and structural ignitions. Ideally, the exposure measured for WUI post-fire assessments should be the sum of the fire and ember exposures over time.

Coarse scale assessment of the spatial extent of ember exposures were conducted in this study based on various written and verbal discussions with homeowners and first responders. These assessments aided in characterizing properties as inside or outside the fire perimeter, but the fine scale variation that might have had consequences for structure response to the Fires was not conducted in terms of mapping embers and burned features across the study area. For example, while ember exposure in certain locations in the Trails on the edge of the fire perimeter might have been “significant”, the ember exposure in these areas was likely much less extreme compared to properties directly adjacent to wildlands on aspects facing the oncoming fires containing Manzanita. Consequently, the direct measurement of the sum of the fire exposures over time across the Trails could not be conducted in this study. Instead, two exposure methods were examined that build on the results presented in NIST TN1635 and help to provide insight into quantifying exposure in a post-fire WUI environment when the precise measurement of the sum of the fire and ember exposures over time is not possible. Section 5.3.5 contains a complete description of the exposure methods, while section 6.3 covers exposure determination and section 7.5 the exposure data analysis.

The first exposure method uses the concept of “perimeter” properties as detailed in NIST TN1635. This method defines “perimeter” properties as those that had a portion of their property boundary adjacent to wildlands[xiii], which might continue onto the respective property. The rationale behind this approach is that at the Trails, where the interface with the burning wildlands was often well defined, these structures, which occurred on the eastern, northern and western portions of the community, received a stronger assault from the wildland fire than structures on the southern and interior portions of the community. The approach, while simply implementable at the Trails may be harder to implement in other communities. Nonetheless, the approach is strongly supported by personal observations on fire intensity collected across the Trails.

Due to the possible site specific nature of the first method, a second method is examined that combines high-resolution vegetation and topographic data to delineate the Trails into areas of high and low hazard areas as a potential surrogate for actual exposure. The second method begins by classifying slope and aspect grids into hazardous areas. This type of categorization is also likely site specific (fuels, topography and weather). Appropriate thresholds or categorizations were determined by examining the results of the general assessment of slope and aspect conducted when examining the structural response to the Witch and Guejito fires. Next, areas that meet the threshold for both the slope and aspect grids, as determined as described above, will be extracted. Slope and aspect were derived from 1.5 meter horizontal resolution DEM. These areas of potentially high hazard slope and aspect were used to clip out portions of the vegetation data set produced as described in Section 5.2 to create the high hazard data set.

The theory behind this simple combination of data is displayed in the Fire Triangle where air heat and fuel and necessary for combustion. Areas of high slope (topography) on appropriate aspects facing the local wind (weather) with vegetation (fuels) might have high potential for conditions that could result in high exposure to structures at certain distances (i.e., high hazard areas). Conversely, areas with low slopes on sheltered aspects with no vegetation might result in low exposure to structures at certain distances (i.e., low hazard areas). The high hazard area criteria can be summarized in equation 1 below. High hazard results from the combination of steep slope plus dangerous aspect plus vegetative fuel.

[xiii] Wildlands defined in this study differ from those described in NIST TN1635, which did not include occluded wildlands found in the interior of the Trails.

$$High\ Hazard = (Slopes > Threshold)\ AND\ (Aspect = Thresholds)\ AND\ (Vegetative\ Fuel)$$

Equation 1

The validity of both exposure techniques are examined in terms of structure response to the Witch and Guejito Fires. For method 1, percent damage and destruction can be examined for both the "perimeter" (surrogate for high exposure) and "interior" (surrogate for low exposure) populations. Method 2 can be evaluated in a similar manner but more detailed characterization can be conducted. Examination of method 2 was conducted by determining the percentage of high hazard area present in the down fire direction of each residential structure at distances of 0 m to 9 m (0 ft to 30 ft), 0 m to 30 m (0 ft to 100 ft), 0 m to 61 m (0 ft to 200 ft) and 0 m to 91 m (0 ft to 300 ft) from the structure edge. The down fire direction was manually assigned to each building footprint based on field observations made around destroyed structures. The remainder of the structures used a down fire direction opposite that of the prevailing wind (i.e., northeast). An example of this analysis for a single destroyed structure is shown in Figure 16. The sectors illustrated in Figure 16 point upwind. For each of the directional sector distances employed above, the percentage of high hazard area with respect to the whole area available in the respective sector was tabulated. Thresholds were then employed to each structure categorizing the potential exposure to high and low hazard areas, which were used here as surrogates for high and low exposure.

5.3.5 Firewise Effectiveness (Two Exposure Methods)

Firewise treatments will next be re-evaluated in the context of two different surrogates for exposure delineated at the Trails. This re-evaluation is conducted to determine if there is a difference in the effectiveness of the respective Firewise treatment in high or low exposed areas. For "perimeter" and "interior" classified properties the following hypotheses are tested:

> **Ho (null hypothesis)**: *Properties in the Trails at Rancho Bernardo Community* ***have no association*** *between implementation of the respective Firewise Treatment coupled with perimeter/interior designations and damage to the property's primary structure from the 2007 Witch and Guejitio Fires.*
>
> **Ha (alternative hypothesis)**: *Properties in the Trails at Rancho Bernardo Community* ***have an association*** *between implementation of the respective Firewise Treatment coupled with perimeter/interior designations and damage to the property's primary structure from the 2007 Witch and Guejitio Fires.*

For residential structures classified as high or low exposure using the high hazard method discussed above the following hypotheses are tested.

> **Ho (null hypothesis)**: *Properties in the Trails at Rancho Bernardo Community* ***have no association*** *between implementation of the respective Firewise Treatment coupled with high/low hazard area designations and damage to the property's primary structure from the 2007 Witch and Guejitio Fires.*
>
> **Ha (alternative hypothesis)**: *Properties in the Trails at Rancho Bernardo Community* ***have an association*** *between implementation of the respective Firewise Treatment coupled with high/low hazard area designations and damage to the property's primary structure from the 2007 Witch and Guejitio Fires.*

The hypotheses are tested by fitting a logistic regression with dependent variable structure response (i.e., undamaged and damaged/destroyed) and independent variables of the respective Firewise treatment and the exposure designation (i.e., “perimeter” versus “interior” or high versus low hazard area). The statistical tests are done using the Z-statistic computed on the coefficients of the regression model. To further demonstrate the effect of the respective Firewise treatment and exposure delineations on structure response three-way contingency tables (Section 7.5) showing the frequencies of Firewise treatments by burn status grouped by the respective exposure surrogate category (perimeter/interior; high/low hazard area) will be created. Percent values are also provided in these contingency tables to further illustrate the effect of the treatment. These table are created to help demonstrate the effect of a Firewise treatment and exposure designation on the structure response to the Witch and Guejito Fires.

5.3.6 Defensive Actions

Including defensive actions in the above analysis might be a key to determining WUI mitigation effectiveness. Defensive actions are accounted for in the above analyses by grouping the damaged structures with destroyed. Fifteen of the 16 damaged structures were defended (and it is possible that San Diego Police defended the 16th house). It was, therefore, assumed that these damaged structures would have been destroyed without the defensive actions. There are likely cases where structure ignitions go out on their own but this is believed to be relatively rare. There was also one structure for which the first responders indicated that without their action this structure would have been destroyed. Ideally, this structure should also be included in the damaged/destroyed population; however, the authors could not confirm the effectiveness of the defensive action in this case. Other defensive actions involved some action on the property that could not always be determined and the effectiveness could not be evaluated. Due to this fact it was difficult to analyze defensive actions using the statistical methods described above. Instead, defensive actions will be used to examine ignition mechanisms in damaged structures; thereby providing clues as to the effectiveness of certain WUI treatments. Future studies might allow for the recording of defensive actions with the associated feature on which the action was taken; thereby facilitating the quantification of defensive actions at a higher resolution and, possibly, accounting for these actions in similar methods to those used for exposure. Also, an assessment of the location of potentially effective defensive actions is conducted in context of high/low hazard area. For this assessment structures that were listed as “contained” or “overhauled” were not included as the action was not to protect the structure, but instead to mop-up the already burned structure.

6.0 Data Collection, Production and Analysis Limitations

WUI post-fire assessments present unique challenges in regards to data collection and analysis. Additionally, many of the data production techniques employed in this study on various geospatial data sources have limitations and shortcomings. The techniques used to delineate exposure across the Trails landscape also have limitations. Finally, the analysis procedures employed might suffer from limitations. Consequently, before presenting results of the analysis methods described above it is important to list limitations present in the various data products collected, produced and analyzed in this study in order to have a context for discussing and developing conclusions about the data.

This section discusses these limitations for field data collection, data production, exposure delineation and analysis.

6.1 Field Data Collection

Immediate assessment of the community after the fire is required for post-fire WUI field data collection because site corruption and data loss occurs soon after the fire due to reclamation/recovery efforts. Budget constraints only allowed for properties with destroyed primary structures in the Trails to be assessed immediately following the fire and some of these had properties cleared before they could be assessed. Certain features in a fire damaged environment are also completely consumed leaving little evidence of what might have been there before the fire. Other limitations present in the NIST field data collection are as follows:

- lack of access to certain properties;
- lack of knowledge of property boundaries, for some treatments, to indicate to observers the extent of the property to be assessed;
- inability to identify construction materials both on the ground and from images (e.g. material such as cement fiber board and others sometimes require touching to determine the material type);
- broad analysis of construction materials with more specific assessments lacking;
- incomplete mapping of burned features across the landscape; and
- inconsistencies between data collection and analysis of destroyed and non-destroyed structures.

The direct assessment of the Firewise checklist also presented problems. For instance the Firewise Checklists in their original form might have been interpreted differently compared to the Firewise treatments shown in Table 2. Additionally, even when viewed in its entirety, the Firewise checklist could be interpreted differently by different observers. In short, the Firewise checklists are very difficult to interpret, in terms of effectiveness, in a scientific manner. This, however, might not be any reflection on the actual interpretation of these checklists for performance of WUI mitigation activities by builders and homeowners, which is not assessed in this paper. It is also important to note the potential bias present on properties with significant fire behavior. There is possibly a tendency, although not confirmed in this study, to fail a property for the presence of a particular treatment when there is significant fire damage, even if the treatment was present prior to the fire.

In this study, some observers of undamaged properties did not have access to the entire property due to locked gates or other obstacles. More common was misinterpretation of the actual property boundary. For instance, one observer indicated that the property was "cleared to property line (100 ft)" as a comment for treatment 4 (i.e., Firewise Zone 4) This comment illustrates both the confusion regarding appropriate distances to use for Firewise zones as well as the issue with observers not having property boundaries. In this case the observer interpreted the property boundary to not extend past 100 ft from the structure as this is where the treatment ended. The property boundary, however, extended far past 100 ft and this portion of the property did not seem to be assessed. Due to the lack of property boundaries, care must be taken in interpretation of the presence of Firewise treatments 6, 7, 8 and 9 which correspond to vegetation treatments for the whole property. Ratings for these treatments might not reflect wildlands contained on the respective property in some cases.

Inconsistent interpretation amongst observers regarding the Firewise Zone Concept was also a limitation. The Firewise checklists used in this report do not provide a distance for each zone except zone 1. Other Firewise literature lists zone 1 as 0 m to 9 m (0 ft to 30 ft), zone 2 as 9 m to 30 m (30 ft to 100 ft), and zone 3 as 30 m to 61 m (100 ft to 200 ft)[12]. Firewise literature seems to indicate zone 4 extending from 200 ft to the end of the property when this zone is referenced at all. The exact distances used by observers for zones 2 thru 4 are not known. Additionally, the observer determining the presence of Firewise zone treatments for destroyed homes responded with a N/A when there was not sufficient space around the entire structure to encompass the respective zone. Not all observers for properties with undamaged structures interpreted the zone treatments in this manner but some did. Additionally, some observers of the undamaged structure population appeared to use different distances than those listed above and might have interpreted the zones as a relative measure with respect to their estimation of the particular property boundary. The discrepancy among different observers led to the inability to fully evaluate all Firewise zone treatments.

6.2 Data Production

The digital data also had certain limitations. Light Detection and Ranging (LIDAR) data contains high-resolution elevation data that allows for precise and high spatial resolution delineations of topography, man-made features and vegetation. This LIDAR data was examined for flight overlap issues and the LIDAR data within the extent of the study area was deemed acceptable. LIDAR data cannot, however, see through solid objects such as leaves and accurate assessment of vegetation under-story is lacking in the data products produced for this study, which might have consequences for accurate high/low hazard area delineations. For example, polygons delineated as Coast Live Oak Woodland[xiv] might have extreme differences in under-story vegetation cover where certain vegetation polygons might have had little flame or ember contribution yet were listed as high hazard areas. Additionally, LIDAR data can suffer from occlusions due to flight geometry that cause certain features to be missed. Both the building and vegetation data sets were manually corrected for these errors, when observed. DEM and derivative products produced from this study also suffer from occlusions in densely vegetated areas where the laser pulse could not reach the ground in large quantities. This could have consequences for underestimation or over-estimation of slopes and over generalization of aspects used in this study. Regardless of the above, the LIDAR data represented the best available topographic, building and vegetation structural stage data for the study area.

Multi-spectral imagery utilized in this project suffered from the inability to portray changes in the landscape between the time of pre-fire imagery and the 2007 Witch and Guejito Fires (the most recent pre-fire imagery for the Trails is from the Spring of 2006). The post-fire imagery also did not have the ability to see through solid objects and, consequently, locations with burned under-story vegetation and green over-story vegetation could not be identified. The sensors used to derive the dNDVI data product were not calibrated making quantitative change detection difficult. The dNDVI data product also has issues with shadows where certain areas might be falsely portrayed as

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[xiv] Technical discussions have indicated extensive ember generation from ground litter under the Coast Live Oak Woodland fuel in the northern boundary of the Trails community.

being less green in the post-fire scenario. These areas are particularly prevalent along taller hedge rows. The dNDVI data product was only used for visual data exploration and to give the reader an idea of the extent of burned top of the layer vegetation.

It should also be noted that the wildland vegetation mapped in this paper represents an underestimation, in terms of flammability, of the vegetation species found within the Trails. A better distinction would be flammable versus non-flammable vegetation. IN terms of quantifying the underestimation, the two extremes are on one end that none of the residential vegetation is flammable and at the other end that all residential vegetation is non-flammable. The authors could not make this distinction based on available pre-fire data across the entire study area and the budget did not allow for the delineation of burned vegetation. Instead the categories of wildland and residential vegetation are used as a conservative surrogate for vegetation flammability. When there was difficulty in determining the precise line of demarcation between wildland and residential vegetation, the vegetation was classified as wildland only when there was evidence of fire behavior continuing from the adjacent known wildland polygons into the unknown vegetation polygons. If fire continued from the wildlands into clearly demarcated residential vegetation this line of demarcation would be represented in the final wildland versus residential vegetation categorization.

6.3 Exposure Determinations

The exposure methods used both have the same limitation in that neither directly measures the integral of the fire and ember exposures over time. Additionally, the "perimeter/interior" method does not account for areas on the perimeter where wildland fuel was limited, such as the knoll at the north east corner of the Trails where the rock outcrop significantly reduced the fire intensity due to the reduced wildland fuel loading. Secondly the perimeter/interior approach does not address the intrusion of wildland fuels into the community and the method does not account for the additional exposure threat generated by burning vegetation and structures within the community. The method also does not account for changes in exposure caused by topography. Having listed the limitations, the approach is strongly supported by observations on fire intensity collected across the community.

The second method does quantify certain aspects of fuel quantity in that fire barriers such as rock outcrops are not included, it still does not capture vegetation treatment, and structural stage or material properties of vegetation that might have had consequences for actual exposure. Additionally, this method does account for vegetative fuels (present or absent) in the interior of the community. Finally, the second method does, in a coarse manner, account for changes in exposure caused by topography. Nonetheless, this exposure method still contains additional limitations as follows, all of which are limitations of method 1 as well:

1. The method does not account for changes in fire behavior caused by smaller scale changes in wind (e.g. swirling wind) and topography (e.g. ravines).
2. The method does not account for vegetation quantity and quality (e.g. water content, crown bulk density, ignitability and other vegetation properties).
3. The method does not account for the heat and ember release from different vegetation types.

4. The method does not account for the fact that low hazard areas directly adjacent to high hazard areas will continue to burn if fuel is present (i.e., fuel connectivity is not considered) regardless of slope or aspect.
5. The method does not account for the exposure from burning structures and other man-made features. There is evidence, though not studied in this paper that the burning of structures significantly contributed to the spread of fire within the Trails. This information, primarily in the form of visual observations, was collected both from first responders and residents.

Other limitations are also likely present in each method.[xv]

6.4 Data Analysis Limitations

The post-fire analysis conducted in this paper suffers from a lack of sample populations for some treatments and as a result lacks the statistical analysis of some treatments. This is demonstrated in Table 6 showing the frequency counts of not applicable (N/A) and not determined (N/D) responses for Trails properties by Firewise treatments. Treatments with N/A values are not included as part of the population being analyzed and should not be considered missing. Treatments with N/D values, however, are missing from the population and it is important to determine if these values are missing at random. First, it can be seen from Table 6 that treatments with N/D values tend to be damaged or destroyed, with the exception of Firewise treatments 10, 18, 20, and 21. Firewise treatments 10 and 18 likely have a large number missing that were not damaged or destroyed because a distance was not originally provided in the field data collection sheet for firewood to be stored away from a structure or fence and during the normalization process, the location of firewood could not always be determined. Nonetheless, due to large numbers of missing values for Firewise treatments 10, 18, 20, 21 and 22, the results of the statistical analyses might not be valid and should be viewed with caution. Furthermore, 10 and 18 show discrepancies between the N/D values. The reason(s) for these discrepancies are not known.

Additionally, certain analyses aggregate data at the parcel level. The parcel is a logical unit of analysis in many cases because the WUI problem is a land use problem at some level, and should be studied at the land use level (i.e., individual owner and hence the parcel) but other land units should also be explored such as watershed boundaries. The parcel level of aggregation, however, might not always be appropriate. For example, average values of slope and aspect at the parcel level might not reflect smaller scale changes in topography present on the parcel. Finally, the inability to analyze treatments collectively presents major short comings in regard to analysis of the Firewise treatments because Firewise is meant to be implemented in its entirety, not just selected treatments.[xvi]

[xv] As this is the first study attempting to quantify exposure in a post-fire environment, it was felt that these simplified approaches represented a good starting point. More quantitative assessments might be considered in future research.

[xvi] Collective analysis of hazard mitigation technologies will be explored in future research.

Table 6 Counts of properties with N/A and N/D values by treatment with percentage of residential structures destroyed by N/A and N/D.

Treatment Number	Count Total N/A	Count Total N/D	Total N/A & N/D	Percent Damaged/ Destroyed (N/A)	Percent Damaged/ Destroyed (N/D)	Percent of Total NA & N/D
1A	0	10	10	-	80%	4%
1C	0	9	9	-	100%	4%
6	1	15	16	0%	73%	7%
7	3	11	14	33%	91%	6%
8	2	12	14	0%	83%	6%
9	1	18	19	0%	78%	8%
10	86	56	142	12	27%	59%
11	0	0	0	-	-	0%
12	98	8	106	7%	100%	44%
13	0	7	7	-	100%	3%
14	0	0	0	-	-	0%
15	0	7	7	-	100%	3%
17	2	16	18	0%	94%	7%
18	86	47	133	12%	21%	55%
19	45	14	59	0%	79%	24%
20	116	37	153	49%	49%	63%
21	129	32	161	38%	44%	67%
22	160	25	185	32%	60%	76%

7.0 Results

This section contains results of the analyses conducted in this study. Before examining the effectiveness of Firewise treatments, this section provides an assessment of the applicability of the Firewise Zone Concept as applied to residential properties in the Trails. An assessment of the overall presence of Firewise treatments is also conducted. Next, all 242 residential structures found in the Trails and within the Witch and Guejito Fire perimeters are analyzed for effectiveness of Firewise treatments at an individual level. Then, assessments of the validity of the two exposure methods at the Trails will be presented allowing for analysis of individual Firewise treatments in conjunction with the two exposure methods. The identification of ignition mechanisms is assessed in context of Firewise treatments and defensive actions. Finally, the locations of defensive actions in terms of exposure will also be examined.

7.1 Applicability of Firewise at the Trails (Zone Concept)

Ideal implementation of the Firewise Zone Concept [12] (assuming the distances listed below), particularly in zones two through four (Table 2), would not have been possible throughout the Trails without cooperation among land owners. The size and spatial arrangement of residential properties would result in the inability of property owners to implement each Firewise zone in all directions without overlap from neighbors. The ideal implementation of the Firewise Zone Concept for the Trails is shown in Figure 17. In this implementation the zone of lowest number takes precedence in landscape design considerations. There was no evidence that this type of inter-community cooperation took place within the Trails based on visual examination of pre- and post-fire aerial imagery and discussions with the Trails HOA. The Firewise Communities program recognizes the hazard an untreated property can have on a nearby property and lists a key component of the Firewise Zone Concept as community cooperation.[ix] The Firewise Checklists could, however, be interpreted by a homeowner or builder as not requiring cooperation with neighbors. This property centric approach to landscape design is shown in Figure 18. In this approach, the Firewise Zone Concept is implemented only on the space available on the individual landowner's property. Figure 18 does not include rights of way, which are not delineated in the property boundary data set. The zone distances used in Figure 17 and Figure 18 are as follows: zone 1 as 0 m to 9 m (0 ft to 30 ft), zone 2 as 9 m to 30 m (30 ft to 100 ft), and zone 3 as 30 m to 61 m (100 ft to 200 ft) and zone 4 is 61m to 91m (200 ft to 300 ft)[xvii].

A visual examination of Figure 17 and Figure 18 shows that the ideal implementation has less area in the interior of the Trails in zone 4 compared to the property centric approach. Additionally, the property centric approach of the Firewise Zone Concept sometimes results in zones 1 or 2 abutting a zone 4 or a wildland property but the ideal implementation of the Firewise Zone Concept does not create these potentially hazardous areas in the Trails. Nonetheless, islands of less treated vegetative fuels are created in both implementations of the Firewise Zone Concept. Additionally, implementation in either manner will result in paths of less treated vegetative fuels (i.e., zone 3 and zone 4) in and around the Trails. These islands of less treated vegetative fuels might have aided in spreading the fire within interior portions of the Trails. This is evidenced by the fact that 15 of the 21 fire jumps identified in TN1635 had a zone 3 or 4 involved in the fire jump as shown in Table 7. Twelve of these 15 fire jumps had a destroyed structure in the down fire direction of the jump. When both zones and structures are listed in Table 7 it is not clear exactly which feature contributed fire spread to which other feature, just that there was evidence of burning in both features. The relationship between Firewise Zones 3 and 4 and the dNDVI data set (surrogate for burned vegetation) is shown in Figure 19.

Table 7 Descriptions of 21 fire jump locations identified in the Trails.

Fire Jump From Location	Fire Jump To Location
Zone 3	Destroyed Structure
Zone 1, 2	Zone 3, 4 and Destroyed Structure
Zone 3	Occluded Wildlands (Continuous Path to Destroyed Structure)
Zone 1, 2 and Destroyed Structure	Zone 3, 4 and Destroyed Structure
Zone 3, 4	Zone 3
Zone 3, Destroyed Structure	Zone 1
Zone 4	Zone 4
Zone 3	Zone 3 and Destroyed Structure
Zone 1, Destroyed Structure	Zone 3 and Destroyed Structure
Zone 1, 2	Zone 1, 2 and Destroyed Structure
Zone 1 and Destroyed Structure	Zone 1, 2
Zone 1 and Destroyed Structure	Zone 1, 2
Zone 1 and Destroyed Structure	Zone 1, 2 and Destroyed Structure
Zone 1	Zone 1, 2, 3
Destroyed Building	Zone 3, 4 and Destroyed Structure
Zone 3, 4	Zone 3, 4 and Destroyed Structure
Zone 3	Zone 3 and Destroyed Structure
Zone 3	Zone 3 and Destroyed Structure
Zone 3 and Destroyed Structure	Zone 3
Zone 1, 2 and Destroyed Structure	Zone 1, 2 and Destroyed Structure
Zone 3	Zone 1,2 and Destroyed Structure

[xvii] Even though Firewise literature indicates zone 4 extending to the end of the property, 300 feet is used in this analysis so that the effect of larger parcels is not exaggerated in the analysis.

7.2 Presence of Firewise Treatments at the Trails

In addition to the specific mitigation activities present in the Firewise Checklists, various overall items to consider when designing and installing a Firewise landscape are presented in the checklist to be:

- Local area fire history.
- Site location and overall terrain.
- Prevailing winds and seasonal weather.
- Property contours and boundaries.
- Native vegetation.
- Plant characteristics and placement (duffage, water and salt retention ability, aromatic oils, fuel load per area and size).
- Irrigation requirements.

No assessment was done of specific residential plant characteristics throughout the Trails. However, as detailed below, about 60% of the properties in the Trails were found to be well irrigated for at least 9 m (30 ft) around the entire primary structure.

Native vegetation was also assessed across the Trails, but the distinction in this paper between wildland and residential vegetation is in some cases an arbitrary one in terms of plant flammability and ignitability. That is to say that fire in many cases continued uninterrupted from the wildlands into residential vegetation. The use of the LIDAR derived vegetation data set, however, can help to determine the presence of native vegetation in Firewise zones. Figure 20 shows the frequency counts of properties by bins of percent wildland vegetation grouped by all residential structures, residential structures with no damage, and residential structures that were damaged or destroyed for all four Firewise zones. Figure 20 uses the property centric Firewise Zones.

A visual assessment of overall vegetation placement by structural stage in the interior of the Trails is portrayed in Figure 10, originally presented in section 5.2. The extensive nature of this residential non-ground vegetation shown in Figure 10 displays the culmination of landscape design practices implemented at the Trails prior to the Fires. The result was numerous paths of connected above ground vegetation between the wildlands and residential vegetation, often only broken by roads or driveways. Also shown in Figure 10 are the many vegetation corridors found along property boundaries representing hedge rows or privacy barriers.

A coarse assessment of slope and aspect on Trails properties within the fire perimeter was also conducted to ascertain if topographic considerations were taken into account when designing and installing landscapes and structures in the Trails. Figure 12 and Figure 13 display slope and aspect grids derived from the 1.5 m (5 ft) Digital Elevation Model (DEM) for the Trails community. The slope grid displayed in Figure 12 was used with the ArcGIS Zonal command to derive an average slope value for each property lot. A histogram displaying the distributions of average property slope across the Trails for damaged and destroyed structures, undamaged structures and all structures within the fire perimeter is shown in Figure 21. Taking the average aspect of a parcel, however, is not necessarily logical when grid values are stored as directions (values between 0° and 359° degrees). For example, the average of 359° and 1° is 180°, which would result in an illogical value. In order to account for this in a simplified manner, the aspect grid was reclassified to categorical values displayed in Figure 13, representing the 8 cardinal directions. For each property in the Trails, the majority of pixels in the lot representing one of the 8 cardinal and intercardinal directions were determined using the ArcGIS Zonal command. A histogram displaying the distributions of these data is shown in Figure 22.

An overall assessment of the presence of Firewise treatments analyzed in this report is provided in Figure 23 showing frequency counts of properties by bins of percent of Firewise treatments present on the property. The data for Figure 23 has excluded from the population ten properties that were greater than 50% of the evaluated Firewise treatmentsand could not be assessed. All but one of these ten properties contained a damaged or destroyed primary structure. Finally, it is important to note that not all Firewise treatments were assessed in this analysis.

7.3 Firewise Effectiveness (Individual Treatments)

This section presents the results for the evaluation of the individual Firewise treatments assessed in this study for their effectiveness in reducing damage or destruction to primary structures on residential properties in the Trails. Table 8 through Table 14 show two-way contingency tables and results of the Chi-Square tests for independence between Firewise treatment and structure response for those treatments determined to be statistically significant at a p-value of 0.05 or lower (see section 5.3.3). For each of the treatments, the null hypothesis presented in 5.3.3 is rejected indicating that *Properties in the Trails at Rancho Bernardo Community* ***have an association*** *between implementation of the FIREWISE Treatments listed in* Table 8 through Table 14 *and damage to the property's primary structure from the 2007 Witch and Guejito Fires.* All of the individually tabulated attributes listed in Table 8 through Table 14 are statistically significant at a p-value of 0.001 except Firewise treatment 8, which is statistically significant at a p-value of 0.01 and Firewise treatment 13 which is statistically significant at a p-value of 0.05. [xviii]

Table 8 Treatment 1a contingency table with results of Chi-Square test. Treatment 1a is present (pass) if an irrigated area encircles the structure for 9 m (30 ft) feet on all sides.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	35 (39% ± 10%)[xix]	53 (61% ± 10%)	88
Pass	115 (80% ± 7%)	29 (20% ± 7%)	144
Total	150	82	232
p-value = 0.0000 (***)			

[xviii] The Z-statistic is used to assess the relationship between burn status and various independent variables in a logistic regression. The p-value is the probability of getting a Z-score of this particular magnitude or larger (in absolute value), simply by chance. A p-value of 0.05 or smaller means that the effect being observed is likely real and not chance variation

[xix] See section 5.3.3 for explanation of uncertainty

Table 9 Treatment 7 contingency table with results of Chi-Square test. Treatment 7 is present (pass) if fuel breaks like driveways, gravel walkways and lawns are present.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	59 (49% ± 9%)	61 (51% ± 9%)	120
Pass	90 (83% ± 7%)	18 (17% ± 7%)	108
Total	149	79	228
p-value = 0.0000 (***)			

Table 10 Treatment 8 contingency table with results of Chi-Square test. Treatment 8 is present (pass) if vegetation on the property is pruned to 6 to 10 feet from the ground.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	106 (60% ± 7%)	71 (40% ± 7%)	177
Pass	42 (82% ± 10%)	9 (18% ± 10%)	51
Total	148	80	228
p-value = 0.003 (**)			

Table 11 Treatment 9 contingency table with results of Chi-Square test. Treatment 9 is present (pass) if leaf clutter and dead and overhanging branches are removed from the property.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	61 (51% ± 9%)	58 (49% ± 9%)	119
Pass	86 (83% ± 7%)	18 (17% ± 7%)	104
Total	147	76	223
p-value = 0.0000 (***)			

Table 12 Treatment 13 contingency table with results of Chi-Square test. Treatment 13 is present (pass) if there is no wood roof, wood siding, wood eave, wood deck, wood pergola, wood fence or wood pile on the property.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	133(62% ± 6%)	80 (38% ± 6%)	213
Pass	19(86% ± 14%)	3 (14% ± 14%)	22
Total	152	83	235
p-value = 0.025 (*)			

Table 13 Treatment 17 contingency table with results of Chi-Square test. Treatment 17 is present (pass) if there dead wood and dense vegetation is cleared at least 30 feet from the house.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	76(53% ± 8%)	66 (47% ± 8%)	142
Pass	73 (89% ± 7%)	9 (11% ± 7%)	82
Total	149	75	224
p-value = 0.0000 (***)			

Table 14 Treatment 19 contingency table with results of Chi-Square test. Treatment 19 is present (pass) if there is no wood fence attached to the house.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	51(45% ± 9%)	62 (55% ± 9%)	113
Pass	98 (85% ± 7%)	17 (15% ± 7%)	115
Total	149	79	228
p-value = 0.0000 (***)			

For treatments 1C, 6, 11, 15, 18, 20, 21 and 22 the null hypothesis presented in section 5.3.3 is not rejected indicating that there is **no evidence** that *Properties in the Trails at Rancho Bernardo Community* ***have an association*** *between implementation of the respective FIREWISE Treatment and damage to the property's primary structure from the 2007 Witch and Guejitio Fires for Firewise treatments 1C, 6, 11, 15, 18, 20 and 22.* It should be pointed out; however, that Firewise treatments 18, 20, 21 and 22 had numerous properties where the presence of the treatment could not be determined as described in section 6.4. Proper determination of the presence of the respective treatment might provide the evidence needed to change the results of the hypothesis test for these treatments. Two-way Contingency tables for the treatments 1C, 6, 11, 14, 15, 18, 20, 21 and 22 are shown in Appendix F.

The two-way contingency table for Firewise treatment 10 is shown in Table 15. This treatment was determined to be statistically significant at a p-value of 0.0008. As described in section 6.4 there were a large number of properties where the presence of this treatment could not be determined. It is impossible to tell if these treatments are missing at random or for some underlying reason and the results of this test are therefore questionable. Firewise treatment 14 could not be tested for statistical significance using the Chi-square test due to the fact that all the structures that failed were destroyed, thereby, making the use of the Chi-Square test statistic invalid (Table 16). Nonetheless, the effectiveness of this treatment is demonstrated. Table 17 illustrates further analysis on Firewise treatment 14, roofing construction. The table illustrates the need to collect and analyze data from the entire fire exposed dataset.

Table 15 Treatment 10 contingency table with results of Chi-Square test. Treatment 10 is present (pass) if there is no Firewood within 30 feet of the structure.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	19 (26% ± 10%)	53 (74% ± 10%)	72
Pass	17 (61% ± 18%)	11 (39% ± 18%)	28
Total	36	64	100
p-value = 0.0008 (***)			

Table 16 Treatment 14, roof construction type, classified by damage status.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	0(0%)	13 (100%)	13
Pass	152 (67%)	76 (33%)	228
Total	152	89	241

Table 17 Roofing material example.

	Sample Population	**Destroyed Structures Wood Shake Roofs**	**Destroyed Structures Spanish Tile Roofs**	**Typical Comparisons**	
Typical (only destroyed homes)	74	12	37	**16% of destroyed** homes had wood shake roofs	**50% of destroyed** homes has Spanish tile roofs
Complete (all structures within fire line)	242	12	154		
Technically Valid Comparisons		**100% of exposed** wood shake roofs destroyed	**24% of exposed** Spanish tile roofs destroyed		

7.4 High Hazard Area Determination

The slope threshold was selected at 20%. While steeper slopes are expected to be more hazardous, the 20% was selected as a threshold for capturing the transition from very flat to steep slopes. The prevailing wind during the fires was from the NE, so the NE aspect was elected and was extended from North to East to account for wind fluctuations. Figures 21 and 22 illustrate how the selected slope and aspect thresholds correlate with destroyed, damaged and undamaged structures. Using these thresholds the data set shown in Figure 24 was created and used in the analysis below. Figure 24 is overlaid with the dNDVI data product (showing change in vegetation greenness between before to after the fire), showing the relationship between high hazard areas and burned vegetation. Also shown in Figure 24 is the fact that burned vegetation extends beyond these high hazard areas if fuel is present. Future developments of the exposure method will further exposure the slope and aspect and vegetative fuel domains.

7.5 Exposure Method Evaluations

Evaluation of both exposure methods can be conducted through examination of the structure response differences for each method. For the “perimeter/interior” method, it can be shown that perimeter properties had 54% (43 of 80) of the residential structures damaged or destroyed. Interior properties had 29% (47 of 162) of the residential structures damaged or destroyed. These numbers can be compared to 37% (90 of 242) of the residential structures damaged or destroyed across the entire Trails. Parcels categorized as “perimeter” represented 48% (43 of 90) of the damaged and destroyed residential structures and “interior” parcels represented 52% (47 of 90) of the damaged and destroyed residential structures.

Evaluation for the high/low hazard area method is portrayed in Figure 25 displaying bar graphs showing percent of residential structures damaged or destroyed grouped by bins of percent of high hazard area present between 0 and 200 feet from the structure in the upwind direction.   Figure 25 displays the above described bar graph for the following sector distances: 0 to 30 feet (0 m to 9 m), 0 ft to 100 ft (0 m to 30 m), 0 ft to 200 ft (0 m to 61 m) and 0 ft to 300 ft (0 m to 91 m). Another portrayal of the data shown in Figure 25 is presented in Table 18, displaying frequency counts of structure response with percent destruction by bins of percent high hazard area for four directional sectors from the structure. These losses, as described in Table 18, were for all structures independent of construction or landscaping hazard mitigation solutions. Aggregating the data further it can be seen that at the 30 foot sector and greater than 50% high hazard area in the down fire direction that 69% (20 of 29) of the structures were damaged or destroyed; 66% (25 of 38) at the 30 m (100 ft) sector; 75% (33 of 44) at the 61 m (200 ft) sector; and 76% (34 of 45) at the 91 m (300 ft) sector. As mentioned previously, the high/low method does not account for vegetation treatment and it is possible the lower average percent destruction in the 9 m to 30 m (30 ft and 100 ft) sector is due to this fact.

The “perimeter/interior” method shows different percent destructions for each population with similar numbers of destroyed or damaged structures indicating different exposure might have occurred in these two environments. The high/low exposure method has an even greater percent destruction when looking at greater than 50% high hazard area in the upwind direction of each structure, accompanied by a decrease in sample size, compared to the “perimeter/interior” method. Furthermore, the slope and aspect thresholds employed for this study in the high/low method are verified in Figure 21 and Figure 22. These figures show increased percent damage and destruction to primary structures with slopes greater than 20% and north, northeast and east aspects; the thresholds employed in this analysis. Due to the high/low exposure method first capturing all the structures (242) in the study area at the 200 foot sector distance and the increased percentage of losses for all sector distances at the above 50% high hazard area these thresholds were used to categorize structure exposure into high potential exposure (>50% high hazard area) and low potential exposure (=<50% high hazard area). Additionally, at 61 m (200 ft) any consequence of not accounting for vegetation treatment in the 0 m to 9 m (0 ft to 30 ft) area would be reduced due to the sector increase in size with distance. The purpose of the analysis is to demonstrate how the Firewise attributes affected structure survivability while using a preliminary exposure framework to bin the data into a quantified two tiered exposure system. This exposure framework is being jointly developed by NIST and USFS.

Table 18 Frequency counts and percent destruction of structures by high hazard area for four sector distance (30, 100, 200, 300 feet).

30 Foot Sector Percent High Hazard Area	Damaged or Destroyed	Total (damaged, destroyed and undamaged)	Percent Damaged or Destroyed
Any high exposure area	85	213	40%
0%	5	29	17%
> 0% And =<25%	43	140	31%
> 25% And =<50%	26	49	53%
> 50% And =<75%	12	19	63%
> 75% And =<100%	4	5	80%
100 Foot Sector Percent High Hazard Area	**Damaged or Destroyed**	**Total (damaged destroyed and undamaged)**	**Percent Damaged or Destroyed**
Any high exposure area	87	230	38%
0%	3	12	25%
> 0% And =<25%	34	143	24%
> 25% And =<50%	28	49	57%
> 50% And =<75%	19	32	59%
> 75% And =<100%	6	6	100%
200 Foot Sector Percent High Hazard Area	**Damaged or Destroyed**	**Total (damaged destroyed and undamaged))**	**Percent Damaged or Destroyed**
Any high exposure area	90	242	37%
0%	0	0	0%
> 0% And =<25%	39	153	25%
> 25% And =<50%	18	46	39%
> 50% And =<75%	25	34	74%
> 75% And =<100%	8	9	89%
300 Foot Sector Percent High Hazard Area	**Damaged or Destroyed**	**Total (damaged destroyed and undamaged)**	**Percent Damaged or Destroyed**
Any high exposure area	90	242	37%
0%	0	0	0%
> 0% And =<25%	39	146	27%
> 25% And =<50%	17	51	33%
> 50% And =<75%	28	37	76%
> 75% And =<100%	6	8	75%

7.6 Firewise Effectiveness (Two Exposure Methods)

This section presents the results of the evaluation of individual Firewise treatments assessed in this study for their effectiveness in reducing damage or destruction to primary structures on residential properties in the various exposure categories analyzed in this paper. Table 19 through Table 24 show three-way contingency tables of percent of damaged or destroyed structures by treatment and results of the statistical test employed. The following tables for the statistically significant treatments, show the results of the Ztests on the regression parameters and also the 95% confidence intervals for the percent damaged or destroyed in each category. The first table in each set of two displays the treatment counts and percentages for perimeter and interior structures. The second contingency table displays the treatment values for the high and low exposures as previously defined. For each of the treatments shown in Table 19 through Table 24 the null hypothesis presented in 5.3.5 is rejected indicating that *properties in the Trails at Rancho Bernardo Community* ***have an association*** *between implementation of the respective Firewise Treatment coupled with both exposure designations and damage to the property's primary structure from the 2007 Witch and Guejitio Fires.*

Table 19: Treatment 1a three-way contingency tables. First table shows counts by treatment, burn status and perimeter/interior designation. Second table shows counts by treatment, burn status and high/low hazard area. Treatment 1a is present (pass) if an irrigated area encircles the structure for at least 30 feet on all sides.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	6 (18 ± 12%)	27 (82 ± 12%)	33	**Fail**	29 (53 ± 13%)	26 (47 ± 13%)	55
Pass	31 (72 ± 14%)	12 (28 ± 14%)	43	**Pass**	84 (84 ± 8%)	17 (16 ± 8%)	101
Total	37 (49 ± 12%)	39 (51 ± 12%)	76	**Total**	113 (72%±7%)	43 (28±7%)	156
Firewise Treatment 1a: p-value = 0.0000 (***), perimeter: p-value = 0.001 (**)							
High Hazard Area Exposed Structure				**Low Hazard Area Exposed Structure**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	2 (8 ± 11%)	22 (92 ± 11%)	24	**Fail**	33 (52± 12%)	31 (48 ± 12%)	64
Pass	8 (53 ± 26%)	7 (47 ± 26%)	15	**Pass**	107 (83 ± 8%)	22 (17 ± 8%)	129
Total	10 (26 ± 14%)	29 (74 ± 14%)	39	**Total**	140 (73%±6%)	53 (27± 6%)	193
Firewise Treatment 1a: p-value = 0.0000 (***), exposure: p-value = 0.0000 (***)							

Table 20: Treatment 7 three-way contingency tables. First table shows counts by treatment, burn status and perimeter/interior designation. Second table shows counts by treatment, burn status and high/low hazard area. Treatment 7 is present (pass) if fuel breaks like driveways, gravel walkways and lawns are found on the property.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	10 (27 ± 14%)	27 (73 ± 14%)	37	**Fail**	49 (59 ± 11%)	34 (41 ± 11%)	83
Pass	27(73 ± 14%)	10 (27 ± 14%)	37	**Pass**	63 (89 ± 8%)	8 (11 ± 8%)	71
Total	37 (50 ± 12%)	37 (50 ± 12%)	74	**Total**	112 (72%±7%)	42 (28±7%)	154
Firewise Treatment 7: p-value = 0.0000 (***), perimeter: p-value = 0.0001 (***)							
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	2 (8 ± 11%)	22 (92 ± 11%)	24	**Fail**	57 (59 ± 10%)	39 (41 ± 10%)	96
Pass	8(57 ± 26%)	6 (43 ± 26%)	14	**Pass**	82 (87± 7%)	12 (13 ± 7%)	94
Total	10 (26 ± 14%)	28 (74 ± 14%)	38	**Total**	139 (73%±6%)	51 (27±6%)	190
Firewise Treatment 7: p-value = 0.0000 (***), exposure: p-value = 0.0000 (***)							

Table 21 : Treatment 8 three-way contingency tables. First table shows counts by treatment, burn status and perimeter/interior designation. Second table shows counts by treatment, burn status and high/low hazard area. Treatment 8 is present (pass) if vegetation is pruned on the property.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	26 (44 ± 12%)	33 (56 ± 12%)	59	**Fail**	80 (68 ± 7%)	38 (32 ± 7%)	118
Pass	11 (73 ± 22%)	4 (27 ± 22%)	15	**Pass**	31 (86 ± 11%)	5 (14 ± 11%)	36
Total	37 (50 ± 12%)	37 (50 ± 12%)	74	**Total**	111 (72%±7%)	43 (28±7%)	154
Firewise Treatment 8: p-value = 0.005 (**), perimeter: p-value = 0.001 (**)							
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	6 (18 ± 13%)	26 (82 ± 13%)	34	**Fail**	100 (69 ± 8%)	45 (31 ± 8%)	145
Pass	4 (67 ± 38%)	2 (33 ± 38%)	6	**Pass**	38 (84 ± 11%)	7 (16 ± 11%)	45
Total	10 (25 ± 13%)	28 (75 ± 13%)	40	**Total**	138 (73%±6%)	52 (27±6%)	190
Firewise Treatment 8: p-value = 0.007 (**), exposure: p-value = 0.0000 (***)							

Table 22: Treatment 9 three-way contingency tables. First table shows counts by treatment, burn status and perimeter/interior designation. Second table shows counts by treatment, burn status and high/low hazard area. Treatment 9 is present (pass) if leaf clutter and dead/overhanging branches are removed on the property.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	20 (43 ± 14%)	27 (57 ± 14%)	47	**Fail**	41 (57 ± 14%)	31 (43 ± 14%)	72
Pass	17 (68 ± 18%)	8 (32 ± 18%)	25	**Pass**	69 (87 ± 8%)	10 (13 ± 8%)	79
Total	37 (51 ± 12%)	35 (49 ± 12%)	72	**Total**	110 (73 ± 7%)	41 (27 ± 7%)	151
Firewise Treatment 9: p-value = 0.0000 (***), perimeter: p-value = 0.01 (*)							
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	4 (17 ± 15%)	20 (83 ± 15%)	24	**Fail**	57 (60 ± 10%)	38 (40 ± 10%)	95
Pass	6 (46 ± 28%)	7 (54 ± 28%)	13	**Pass**	80 (88 ± 7%)	11 (12 ± 7%)	91
Total	10 (27 ± 14%)	27 (73 ± 14%)	37	**Total**	137 (74 ± 6%)	49 (26 ± 6%)	186
Firewise Treatment 9: p-value = 0.0000 (***), exposure: p-value = 0.0000 (***)							

Table 23: Treatment 17 three-way contingency tables. First table shows counts by treatment, burn status and perimeter/interior designation. Second table shows counts by treatment, burn status and high/low hazard area. Treatment 17 is present (pass) if dead wood and dense vegetation are cleared at least 30 feet from the house.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	21 (41 ± 12%)	30 (59 ± 12%)	51	**Fail**	55 (60 ± 10%)	36 (40 ± 10%)	91
Pass	16 (76 ± 18%)	5 (24 ± 18%)	21	**Pass**	57 (93 ± 6%)	4 (7 ± 6%)	61
Total	37 (51 ± 12%)	35 (49 ± 12%)	72	**Total**	112 (74 ± 7%)	40 (26 ± 7%)	152
Firewise Treatment 17: p-value = 0.0000 (***), perimeter: p-value = 0.004(**)							
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	7 (23 ± 15%)	23 (77 ± 15%)	30	**Fail**	69 (62 ± 9%)	43 (38 ± 9%)	112
Pass	3 (43 ± 35%)	4 (57 ± 35%)	7	**Pass**	70 (93 ± 6%)	5 (7 ± 6%)	75
Total	10 (27 ± 14%)	27 (73 ± 14%)	37	**Total**	139 (74 ± 6%)	48 (26 ± 6%)	187
Firewise Treatment 17: p-value = 0.0000 (***), exposure: p-value = 0.0000(***)							

Table 24: Treatment 19 three-way contingency tables. First table shows counts by treatment, burn status and perimeter/interior designation. Second table shows counts by treatment, burn status and high/low hazard area. Treatment 19 is present (pass) if a wood fence is not attached to the home.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	10 (26 ± 14%)	29 (74 ± 14%)	39	**Fail**	41 (55 ± 11%)	33 (45 ± 11%)	74
Pass	27 (77 ± 14%)	8 (23 ± 14%)	35	**Pass**	71 (88 ± 7%)	9 (12 ± 7%)	80
Total	37 (50 ± 12%)	37 (50 ± 12%)	74	**Total**	112 (73 ± 7%)	42 (27 ± 7%)	154
Firewise Treatment 19: p-value = 0.0000 (***), perimeter: p-value = 0.0008(***)							
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	3 (11 ± 12%)	24 (89 ± 12%)	27	**Fail**	48 (56 ± 10%)	38 (44 ± 10%)	86
Pass	7 (58 ± 24%)	5 (42 ± 24%)	12	**Pass**	91 (88 ± 6%)	12 (12 ± 6%)	103
Total	10 (26 ± 14%)	29 (74 ± 14%)	39	**Total**	139 (74 ± 6%)	50 (26 ± 6%)	189
Firewise Treatment 19: p-value = 0.0000 (***), exposure: p-value = 0.0000(***)							

For Firewise treatments 1a, 7, 8, 9, 17 and 19 listed in the tables above the improved effectiveness of the treatment in one exposure environment compared to the other is examined. This examination is conducted by computing the difference between the percent damaged/destroyed when the respective Firewise treatment is absent (i.e., fail) and present (i.e., pass) for each exposure category. Additionally, the 95% confidence interval for this difference is derived. These computations are displayed in Table 25 through Table 30. In all cases the interaction is not statistically significant, due to the relatively low sample sizes in some of the groups. Nonetheless, a pattern is shown and further demonstrated in Box Plots displayed in Figure 27.

Table 25 Differences between percent damaged/destroyed when the respective Firewise Treatment is absent (i.e., fail) and present (i.e., pass), for Firewise Treatment 1a.

	Difference in % of destroyed between pass and fail
Perimeter	0.54 ±0.18
Interior	0.31± 0.14
High Exposure	0.45 ±0.28
Low Exposure	0.31± 0.14

Table 26 Differences between percent damaged/destroyed when the respective Firewise Treatment is absent, (i.e., fail) and present, (i.e., pass) for Firewise Treatment 7.

	Difference in % of destroyed between pass and fail
Perimeter	0.46 ±0.20
Interior	0.30± 0.12
High Exposure	0.49 ±0.28
Low Exposure	0.28± 0.12

Table 27 Differences between percent damaged/destroyed when the respective Firewise Treatment is absent (i.e., fail) and present (i.e., pass) for Firewise Treatment 8.

	Difference in % of destroyed between pass and fail
Perimeter	0.29 ±0.26
Interior	0.18± 0.14
High Exposure	0.49 ±0.40
Low Exposure	0.15± 0.12

Table 28 Differences between percent damaged/destroyed when the respective Firewise Treatment is absent (i.e., fail) and present (i.e., pass) for Firewise Treatment 9.

	Difference in % of destroyed between pass and fail
Perimeter	0.25 ±0.22
Interior	0.3 ± 0.13
High Exposure	0.29 ±0.30
Low Exposure	0.28± 0.12

Table 29 Differences between percent damaged/destroyed when the respective Firewise Treatment is absent (i.e., fail) and present (i.e., pass) for Firewise Treatment 17.

	Difference in % of destroyed between pass and fail
Perimeter	0.35 ±0.22
Interior	0.33 ± 0.12
High Exposure	0.20 ±0.40
Low Exposure	0.31± 0.10

Table 30 Differences between percent damaged/destroyed when the respective Firewise Treatment is absent (i.e., fail) and present (i.e., pass) for Firewise Treatment 19.

	Difference in % of destroyed between pass and fail
Perimeter	0.51 ±0.20
Interior	0.33 ± 0.12
High Exposure	0.47 ±0.30
Low Exposure	0.32± 0.12

Examination of this data, though not statistically significant, might indicate that for treatments 1a, 7, 8 and 19 the positive effect of having the treatment in the trails for high exposure environments (i.e., "perimeter" or high hazard area exposed structures) is more pronounced compared to low exposure environments (i.e., "interior" or low hazard area exposed structures) in terms of structure response from the Witch and Guejito Fires. For treatments 9 and 17 the effect is similar across all exposure groups examined.

Firewise treatments found to be not statistically significant are shown in Appendix F. In some cases, there is insufficient data to generate reliable statistics. Firewise treatment 10 and 1c are of note in the treatments shown in Appendix F. Firewise treatment 10 was statistically significant in the high/low hazard area exposed population but it was not significant in the "perimeter/interior" method. Again, the large number of properties where this treatment could not be determined made this result questionable. Firewise treatment 1c is not significant individually, coupled with the "perimeter/interior" method, or coupled with the high/low hazard area method. Treatment 1c, however, when evaluated only for high hazard area exposed structures shows that 79% of the structures were destroyed (26 of 33) when this treatment was absent and 6% (2 of 31) were damaged or destroyed when this treatment was present.

7.7 Defensive Actions as a Function of High/Low Hazard Exposure

Before examining locations of defensive action as a function of high/low exposure, it is useful to re-examine Table 1 for various ignition mechanisms on damaged structures in the context of Firewise treatment effectiveness. As can be seen in Table 1, there were 5 damaged structures where the ignition mechanism was, at least in part, the deck. This provides evidence of the effectiveness of Firewise treatment 12 as all five of these structures failed Firewise treatment 12 and the ignition mechanism is known. Table 1 also shows one ignition mechanism of a main structure gutter. This also provides evidence for the effectiveness of the Firewise treatment recommending to "*Keep gutters, eaves, and roofs clear of leaves and other debris*", which was not assessed in this paper due to the impossibility of determining this for a destroyed structure. Additionally, there was one damaged structure where the ignition mechanism was an exposed wood beam, thereby providing more evidence for the importance of the Firewise treatment recommending to "*Use construction materials that are fire-resistant or non-combustible whenever possible*", which was also not assessed in this paper. Finally, one of the damaged structures had wood fencing, combined with a damaged out building, providing further evidence for the importance of the Firewise treatment 19. There are, however, ignition mechanisms shown in Table 1 that are not addressed in the Firewise checklist. These include detached structures and roof top solar panels. Roof top solar panels are less common but detached structures are a common occurrence in the WUI and are not addressed at all in the Firewise Checklists or in this report.

Next, an examination of defensive action locations in context of high/low hazard area using the 50% threshold and 61 m (200 ft) distance as defined in section 7.4. The data was sorted to determine the distribution of defensive actions across high and low exposure properties. The information is summarized in Table 31.

Table 31 Distribution of defensive actions across high and low exposure properties.

High Exposure		Defended	Undefended
Total	43	19 (44%)	24 (56%)
Damaged/Destroyed	33	14 (42%)	19 (58%)
Undamaged	10	5 (50%)	5 (50%)
Low Exposure		Defended	Undefended
Total	199	66 (33%)	137 (67%)
Damaged/Destroyed	57	22 (39%)	35 (61%)
Undamaged	142	40 (28%)	102 (72%)

In high exposure, 14 out of 19 (74%) of defended were damaged or destroyed compared to 22 out of 66 (33%) in low exposure. Additionally, in high exposure, out of the 19 defended 10 were destroyed and 4 damaged, where as in low exposure, out of the 66 defended 10 were destroyed and 12 were damaged. Defensive actions were over twice as effective in low exposure compared to high exposure.

Table 32 Defensive actions types taken on the 19 defended high exposure properties.

Burn Status	Defensive Action Type	Ignition
Destroyed	defensive action taken to save structure	unknown
Destroyed	defensive action taken to save structure	unknown
Destroyed	defensive action taken to save structure	deck ignited three separate times
Destroyed	defensive action taken to save structure	ember in house
Destroyed	defensive action taken to save structure	ember in attic
Destroyed	fire containment - house already destroyed	unknown
Destroyed	fire containment - house already destroyed	unknown
Destroyed	fire containment - house already destroyed	Deck
Destroyed	fire containment - house already destroyed	unknown
Destroyed	fire containment - house already destroyed	unknown
Damaged	defensive action taken to save structure	deck and main structure
Damaged	defensive action taken to save structure	Gutter
Damaged	defensive action taken to save structure	Deck
Damaged	defensive action taken to save structure	Deck
Unburned	defensive action taken to protect structure	vegetation
Unburned	defensive action taken to protect structure	vegetation
Unburned	defensive action taken to protect structure	vegetation
Unburned	defensive action taken to protect structure	vegetation
Unburned	defensive action taken to protect structure	vegetation

The 19 defensive actions in the high exposure areas are further divided into two categories; actions that were taken to protect the primary structure and actions taken to contain the fire and limit spread to surrounding parcels and structures. Table 32 lists these actions. It should be noted that even in the cases where suppression actions were taken on the structure or origin or primary structure, additional actions could have been taken to also prevent fire spread to adjacent properties. Out of the 19 defended structures in high exposure, there were eight deck ignitions (on five structures) and five suppression actions on burning vegetation. It should also be noted that burning vegetation likely was present on other defended structures in high exposure areas. The defensive actions provide significant insight to structure and landscaping vulnerabilities in different exposure conditions and are essential in documenting the successes and failures of hazard reduction solutions.

8.0 Discussion

The sections above present results attempting to analyze the applicability, presence and effectiveness of Firewise treatments. Confounding this task was the need to quantify the extent of radiant heat and embers across the study area coupled with defensive actions performed during the fire in the community. This is believed to be the first post-fire WUI assessment study attempting to account for all these factors and to attempt to fully quantify the exposure. As expected, numerous difficulties and obstacles were present as detailed in section 6.0 above. The following discussion is formatted around the primary objectives of this report:

8.1 Analyzing if Firewise treatments are applicable within the Trails

Beginning with applicability of Firewise Treatments, two factors should be noted. The first is the need for irrigation requirements and the statistical significance of this with regards to structure survivability at the Trails. Given this, the applicability of irrigation treatments must be questioned as a sustainable treatment where water shortage is a problem. The second item considered with regards to applicability is the Firewise Zone Concept. First, visual examination of Figure 18 shows that there are certain properties in the Trails Community where if the Firewise Zone Concept is implemented using the property centric approach, there will be Zone 4 areas in one property directly abutting a Zone 1 or 2 in another property. Consequently, it might be concluded that a different treatment is required where community cooperation is not occurring. The research conducted for this paper could not discover any WUI mitigation advice that presents such a treatment alternative. Again, Firewise does recognize the hazard an untreated property can have on an adjacent property[12] but a different treatment option is not presented, based on the research conducted for this paper. Nonetheless, community cooperation appears to be the ideal treatment based on visual examination of Figure 17 and Figure 18 because it will result in less zone 3 and zone 4 areas in interior portions of the Trails and not create disjointed zones.

While it was not quantitatively shown in this study, visual examination of pre-fire aerial imagery coupled with discussions with the Trails HOA indicate that the property centric approach to treatment was the approach implemented in the Trails. It should also be noted that if the Firewise Zone Concept listed in the Firewise checklist (see Appendix B) was followed strictly, that is, if zones would have been proportioned evenly based on the property size, there would have been even more areas of zones 3 and 4 and more potential paths for the fire to travel from the wildlands into the community. These less treated areas further from the house were typically wildlands, hedgerows or vegetative privacy barriers, and appeared to be main paths of fire through the Trails as shown in Figure 19. Examination of the homeowner technical discussion forms also indicates many areas of fire behavior in these hedge row areas or along property boundaries.

Given the above, there are two concepts regarding the Firewise Zone Concept that might be questioned in an Interface Community such as the Trails. First, the concept of less treatment further from the structure, at least as portrayed in the Firewise Checklist might not be applicable given that no distances are provided. For structures close together this concept might not be appropriate and complete removal of flammable fuels might be required. The second concept that is being questioned in regards to the Firewise Zone Concept relates to the Interface nature of interior at least, portions of the Trails Community. It is possible the Firewise Zone Concept was developed as a result of studying fires that are in Intermix Communities where structure spacing is much greater than the Trails. In these areas a concept of less treatment as you move away from the structure is logical because it is impractical to treat all spaces between structures. In these cases, it is believed by the authors, that the Firewise Zone Concept intends for the fire to burn through the zones 3 and 4, ideally at lower intensities compared to wildlands adjacent to these zones. These low intensity burns combined with treatments that essentially result in nothing burning in Zone 1 and 2 are the essence of the Firewise Zone Concept, in the opinion of the authors who welcome correction from the research community and Firewise in general in this regard. Consequently, the question for an interface type community such as the Trails, again at least in the interior is as follows:

Is it desirable for a wildland fire to burn through sections of the community, even if these sections are greater than 100 feet from a structure?

In fact, this might be the question every WUI Community should ask. When the spacing between structures and/or the property size is of a certain distance or area, not studied in this paper, such that complete treatment (i.e., treatment such that nothing in the zone burns) is not possible, the Firewise Zone Concept is the only logical conclusion. Exact distances, however, for all scenarios are not known by the Fire Science field. This is evident from the wide range of treatment distances recommended at a state level across the United States[xx] and the complete lack of reference to any scientific study (except for 30 Feet International Crown Fire Experiment[19]) to justify these various distances. For interface type communities, however, a concept of less treatment further from the house might not be appropriate, except for properties on the perimeter. For example, properties in the interior portions of the Trails would ideally have no natural areas present. Yet, this is suggested in the Firewise Zone Concept (see Appendix B) as portrayed in the Firewise Checklist. Nonetheless, the effectiveness of actual Firewise treatments in zones 2, 3 and 4 were not assessed in this paper. More importantly, there is no evidence to indicate that

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[xx] In Utah the furthest zone is Zone 3, which starts 100 ft from the structure. Source: Firewise Landscaping for Utah, Utah State University Extention, www.ffsl.utah.gov/firemgt/wui/educationalmaterials/firewiselanscaping..pdf
In Arizona Zones are given different distances from home as a function of uphill and downhill slope and zone 2 can extend beyond 200ft. www.azfireinfo.az.gov/userfiles/file/firewise-8%205x11_4_11_web.pdf

Firewise treatments recommended in zones 2, 3 and 4 were ineffective. Additional research is needed on the effectiveness of treatments as a function of distance away from the structure. Strict implementation of these treatments at the Trails, assuming zones were not proportioned evenly based on property size, might have significantly reduced destruction. Nonetheless, it is believed that the Ideal Firewise Zone implementation (see section 5.3.1) is the only implementation of the Firewise Zone Concept applicable at the Trails, with exact distances not being known. Furthermore, when implementing the Ideal Firewise Zone Concept, it is recommended that homeowners consider relatively small, but potentially significant Zones 3 and 4 that might be in dangerous topographic positions and potentially contribute to fire spread into the community. For these situations, extending zone 1 and 2 type treatments into these areas should be considered.

8. 2 Determining if Firewise treatments were present at the Trails, prior to the Witch and Guejito Fires.

There was no community wide effort to implement the Fire Zone Concept at the Trails. While the Firewise Zone Concept at the Trails could not be quantitatively assessed, the assessment of wildland vegetation across the Trails was undertaken. The data presented in Figure 20 can be aggregated to show that 67% (26 of 39) of the structures with wildland vegetation in zone 1 were damaged or destroyed while 32% (64 of 203) with no wildland vegetation were damaged or destroyed. There were 59% (46 of 78) of the structures with wildland vegetation in zone 2 damaged or destroyed and 27% (44 of 164) with no wildland vegetation damaged or destroyed. There were 54% (42 of 92) of the structures with wildland vegetation in zone 3 damaged or destroyed and 27% (40 of 150) with no wildland vegetation damaged or destroyed. Finally, 69% (64 of 93) of residential structures with wildland vegetation present in zone 4 were destroyed, while 17% (26 of 149) of structures with no wildland vegetation present in zone 4 were destroyed. In every zone, the presence of wildland vegetation, as mapped in this study, on an individual property resulted in an increased percentage of damaged or destroyed structures. The data is summarized in Table 33.

Table 33 Percent Structure Destroyed with and Without Wildland Vegetation in Zones 1 through 4

Zone	With Wildland Vegetation	Without Wildland Vegetation
1	67%	32%
2	59%	27%
3	54%	27%
4	64%	17%

Expanding on the assessment of the presence of certain general recommendations made by Firewise, there is no evidence that local fire history was taken into consideration when designing the Trails Community. Additionally, assuming that the prevailing winds at the time of the Fires was similar to prevailing winds generally found during such wind events at the Trails, it could be said that consideration of prevailing winds and seasonal weather was not conducted. For example, examination of Figure 13, shows how the Trails Community is essentially oriented directly in line of the prevailing winds resulting in a large number of structures being oriented to face these prevailing winds. Forty-three percent (105 of 242) of the structures in the Trails were constructed on lots where the majority of aspects found on the property were facing the prevailing winds at the time of the Fires (i.e., northeast, north, east). Fifty-four percent (57 of 105) of the structures on property lots where the majority aspect was determined to be in the direction of these prevailing winds were destroyed. These destroyed structures represented 63% (57 of 90) of the total structures destroyed in the Trails.

Discussion of the presence of considering site location, overall terrain and property contours can be conducted through examination of the data shown in Figure 21, representing average property slopes. This data shows that 46% (113 of 242) of the structures in the Trails were built on lots where the average of the slopes found on the property was greater than 20%. Fifty-three percent (60 of 113) of the structures on properties with slopes greater than 20% were destroyed or damaged representing 66% (60 of 90) of the total structures destroyed or damaged in the Trails. Finally, examination of the overall presence of Firewise treatments can be discussed in context of Figure 23 where it can be seen that 58% (141 of 242) of residential properties in the Trails had less than 50% of the evaluated Firewise treatment present.

8.3 Evaluating the effectiveness of Firewise treatments in reducing structure ignitions at the Trails.

Evaluation of the effectiveness of individual Firewise treatments found that treatments 1a, 7, 8, 9, 13 , 17 and 19 (section 7.6) all showed an association between implementation of the respective Firewise treatment on the property and damage or destruction to the property's primary structure. While Treatment 14 could not be tested statistically, all structures(16/16) with wood shake roofs in the Trails were destroyed. This provides some evidence of the effectiveness of this Firewise treatment. Firewise treatment 10 was also found to show an association between implementation of the respective Firewise treatment on the property and damage or destruction to the property's primary structure. The large number of properties where the presence of firewood could not be determined, however, makes this conclusion questionable. The lack of statistical significance for other treatments does not indicate that the treatments are ineffective or would not be effective in different environments.

8.4 Mapping fire exposure profiles within the Trails.

An attempt was made to evaluate two distinct exposure determination methods. The first, perimeter interior method was introduced in the NIST TN 1635. The second, based on slope, aspect and vegetative fuels was defined in this paper. The mapping of exposure conducted in this paper emphasizes the importance of topography, fuels and weather but is limited in that fuel type and quantity is not considered. Additionally the exposure associated with burning structures, a significant source of flames and embers, was not factored into the exposure calculation. Also, assessment of topography, though conducted from high resolution elevation data, is likely too coarse and does not encompass microscale effects caused by topographical features such as chimneys, canyons, ridges and other features. Vegetation treatment is also not considered in this exposure mapping and the mapping does not account for the fact that fuels adjacent to these high hazard areas will and did burn. Finally, distance is not directly considered and utilization of methods similar to those discussed in the Australian Bushfire Study[20] coupled with enhancement of the remote sensing derived vegetation data based on field data might be beneficial in quantifying the distance required for treatments to be effective.

Nonetheless, a visual examination of Figure 24 indicates potential association between burned vegetation areas and the mapped high potential exposure areas. Also seen in Figure 24 is the extension of burned vegetated areas, often from and between highly exposed areas. Areas of potential high exposure with changes in greenness highlighted in white outside the fire perimeter shown in Figure 24 are in most cases shadow areas or areas with man-induced vegetation changes between pre and post-fire imagery.

Also, clearly portrayed in Figure 25 is the concept of increased destruction with increased exposure. This is further specified in Figure 20 showing the increase in destruction with increased wildland vegetation present on the property. Other relationships not explored include calculation of the distance to steep slopes, percentage area of fire breaks, vegetation structural stage and numerous others. Future research will examine some of these factors in greater detail using fire behavior models, more complex GIS models, logistic regression and/or other modeling techniques as appropriate.

8.5 Evaluating the effectiveness of Firewise treatments in reducing structure ignitions in context of potential exposure.

Evaluation of the effectiveness of individual Firewise treatments combined with the various exposure designations indicates that treatments 1a, 7, 8, 9, 17 and 19 all showed an association between implementation of the respective Firewise treatment on the property and damage or destruction to the respective Firewise treatment in all exposure environments. It is possible that for Firewise treatments 1a, 7, 8 and 19, the effect of having the treatment in a high exposure environment is more pronounced compared to the effect of having the treatment in a low exposure environment.

8.6 Evaluating of defensive action in terms of Firewise treatments and as a function of exposure.

Analysis of the effectiveness of the defensive actions provide significant insight to structure and landscaping vulnerabilities in different exposure conditions and are essential in documenting the successes and failures of hazard reduction solutions.

8.7 Future WUI post-fire case studies.

While not all obstacles could be overcome in this first analysis they did provide enormous assistance in the design of a new data collection system as employed in the Amarillo Texas Fires of 2011[21], the development of an exposure scale and the ongoing enhancement of NIST's data collection system and associated training. Despite the high spatial, spectral and temporal resolution of the remote sensing data available and the extensive field surveys, more timely and extensive data collection is required for complete accounting of all the potential factors. Nonetheless, the results presented above provide valuable insight into the WUI problem.

9.0 Summary

First, the applicability and presence of Firewise attributes within the Trails was assessed. Next, treatments were evaluated across the parts of the community that were within the fire line. The exposure concept was introduced and two different approaches were evaluated. The perimeter, interior exposure model was first introduced in NIST TN1635, the first Witch/Guejito report. The second approach computed high and low exposures as a function of slope, aspect and vegetative fuel. Firewise effectiveness was further evaluated using both exposure approaches. Lastly, defensive actions were evaluated in the context of ignition mechanism and Firewise treatment, and the locations of these defensive actions with respect to high/low hazard areas were assessed. The following statements summarize the findings from this study of the Witch and Guejito Fires:

- The majority of the Firewise treatments evaluated at the Trails Community appeared to be applicable even if each of them were not fully effective.
- Firewise irrigation treatments might not be applicable in a desert environment such as the Trails for long-term effective mitigation if water shortages occur.
- The Firewise Zone Concept, as described in the Firewise Landscaping Checklist (see Table 2), if not implemented with community cooperation when there are overlapping zones from different owners might result in the creation of hazardous areas.
- Vegetative fuel removal and not fuel displacement is necessary for housing densities such as at the Trails. This is necessary as fuels distant from the primary structure can be very close to a neighboring structure.
- WUI mitigation advice, such as provided by Firewise, that is designed to allow a wildland fire to burn through a community might not be appropriate for interface type WUI communities or where structures are closely spaced and lot sizes are relatively small.
- Fifty eight percent (141 of 242) of the structures in the Trails had less than 50% of the evaluated Firewise treatments present.
- Fire vulnerabilities such as local area fire history, site location, overall terrain, prevailing winds, seasonal weather, property contours and native vegetation did not appear to be considered in design of the Trails community.
- There is a pattern of increased destruction to residential structures with increased exposure to slopes greater than 20%, for northeast, north and east aspects, and for vegetated surfaces at the Trails. Vegetation treatment was not considered in this analysis.
- Individually, implementation of Firewise treatment numbers 1, 7, 8, 9, 13, 17 and 19 were associated with a reduction in damage and destruction to residential structures at the Trails.
- Individually, implementation of Firewise treatment numbers 1, 7, 8, 9, 17 and 19 were associated with a reduction in damage and destruction to residential structures in both low and high exposure environments as evaluated at the Trails.
- Individually, implementation of Firewise treatment numbers 1, 7, 8, and 19 in a high exposure environment might show a more pronounced effect in terms of

structure response compared to implementation in low exposure environments at the Trails.

- Defensive actions showed treatment 22 to be effective as well as Firewise treatments to "*Keep gutters, eaves, and roofs clear of leaves and other debris*" and to "*Use construction materials that are fire-resistant or non-combustible whenever possible*"; both of which were not assessed in this paper due to the impossibility of determining treatment presence for a destroyed structure.
- For structures in high exposure areas, 74% of the defended structures were damaged or destroyed compared to 33% in low exposure.
- For the 19 defended properties, 10 contained destroyed structures and 4 damaged, whereas in low exposure, of the 66 defended properties, 10 were destroyed and 12 were damaged.
- Defensive actions were over two times more effective in saving structures in low exposure areas compared to high exposure areas.

Again, it must be remembered that any correlation among the various treatments was not assessed in the above analyses. Additionally, more precise methods of quantifying exposure might be required such as delineation of burned features across the area and mapping of ember assault. Finally, it is important to note that this study was based on an uncoupled analysis of exposure and structure ignition. The more these mechanisms can be uncoupled, the more fully quantifiable structure response to WUI fires might become.

10.0 Conclusions/Recommendations

This study emphasizes the importance of conducting specific actions when performing WUI post-fire assessments. WUI post-fire assessments aimed at determining the effectiveness of hazard mitigation technologies should involve:

1. Evaluating all structures exposed and their characteristics, not just what was destroyed.
2. Quantifying the fire and ember assault on a structure at a particular location in space and time as practical or researching exposure surrogates for simpler quantification.
3. Measuring and recording the type, location and effectiveness of defensive actions.

The above activities, particularly when combined, can provide critical insight into structural response. For example, the statistical analyses performed above all require data related to the entire population of data, both destroyed and undamaged. Additionally, combining defensive actions with the identification of damaged structures leads to a clear evaluation of ignition mechanisms and consequences in regard to treatment effectiveness. This is apparent in the case of elevated wood decks on top of a hill, which were not statistically significant due to the lack of data, but assessment of the damage coupled with defensive action associations allowed for the identification of these features as ignition mechanisms. This also demonstrates the effectiveness of this treatment, at least in some instances at the Trails. Nonetheless, performing the above activities to precisely measure and record the complex set of variables involved in full quantification of a post-fire environment is a challenging endeavor. As this study represented the first attempt at such a task, certain activities were conducted at coarser scales than what might ultimately be necessary to fully evaluate the effectiveness of Firewise treatments. This approach also allowed for a framework to build and enhance the data collection methodology for more refined and/or variable data collection activities. Most importantly, this approach allowed for an assessment of certain aspects of current WUI mitigation advice.

No Firewise treatments were found to be ineffective in this study, although not all treatments were evaluated, while many had different levels of effectiveness. Additionally, many of the treatments analyzed at an individual basis were found to be effective in all exposure environments assessed for this paper. There was, however, some evidence that structure response to treatment might be different in different environments. This might suggest the need for different treatment options depending on the scenario. Given the findings of this study, it is recommended that:

1. Additional field data collection studies are conducted to provide insight into structural response in both high and low exposure environments.
2. The exposure concept is further developed to enable valid comparisons of structural response within and across incidents.
3. Research is conduced to provide the technical foundation for improving the current Firewise Checklist (see Table2). Specifically, the detailed relationship of exposure and structure vulnerability needs to be developed. This will lead to improved testing standards for new construction and improved guidance for retrofit.
4. An unambiguous checklist should be developed to facilitate the implementation of hazard reduction techniques by homeowners. The authors have concluded that new checklists are required for different scenarios (e.g. intermix versus interface communities; existing construction versus new construction).
5. The concept of structure vulnerability should be further developed. When coupled with exposure, this approach should yield improved tools for predicting structure destruction.

11.0 Future Work

Future work using post fire data will explore the capabilities and limitations of using different fire behavior models to simulate and predict fire behavior at the Trails Community.

The data collection methodology developed from the work at the Trails has already been implemented in other field post-fire studies[21]. Future work will involve analyzing the Amarillo data[22] using the lessons learned from this report as well as improving the methodology for future deployments.

This first case study has identified a need for additional high and low exposure data. While the benefits of Firewise type attributes are significant in low exposure environments, additional post-fire field data collections in high exposure areas will provide insight into the effectiveness of these treatments under more severe exposure conditions.

The development of exposure characterization will continue and the introduction of burning structures into the exposure determination will be explored using GIS and WFDS. Additionally, vegetation characterization will be explored as well as the potential for introducing the effects of dangerous topographical features such as chimneys or ravines.

A structure destruction potential method may be fruitfull and future work will consider its development. A simple framework will be initially developed as outlined below for coupling exposure and vulnerabilities. Initial focus will be on determining the potential reliability of such a framework. The proposed destruction potential concept is outlined in equations 3 and 4, where *a, b, c* and *d* are constants for the four classes of attributes that represent the structure and landscaping vulnerabilities and access for defensive actions on and around the structure. The exposure characterization used will initially be the high/low concept presented here. Additional refinements in the exposure characterization will be introduced as they become available.

Vulnerability = ***a****(Combustibles near home)* **–** ***b****(Fuel break/irrigation) +* ***c****(Combustible construction)***-*** ***d****(Access for defensive actions)* **equation 3**

Structure Destruction Potential = Vulnerability x Exposure **equation 4**

12.0 Acknowledgements

This work would not have been possible without the contributions of, CAL FIRE, San Diego Fire and Rescue and Police Departments and the residents of the Trails, including Mr. Steve Arnold. Additionally, this work would not have been possible without Carol Ostergren of the United States Geological Survey (USGS) and the USGS geospatial data services, who provided most of the remote sensing data used in this analysis. This work is in part funded by the Joint Fire Science Program Project 11-1-3-29, “Evaluating the Effectiveness of Mitigations Activities in the Wildland Urban Interface”.

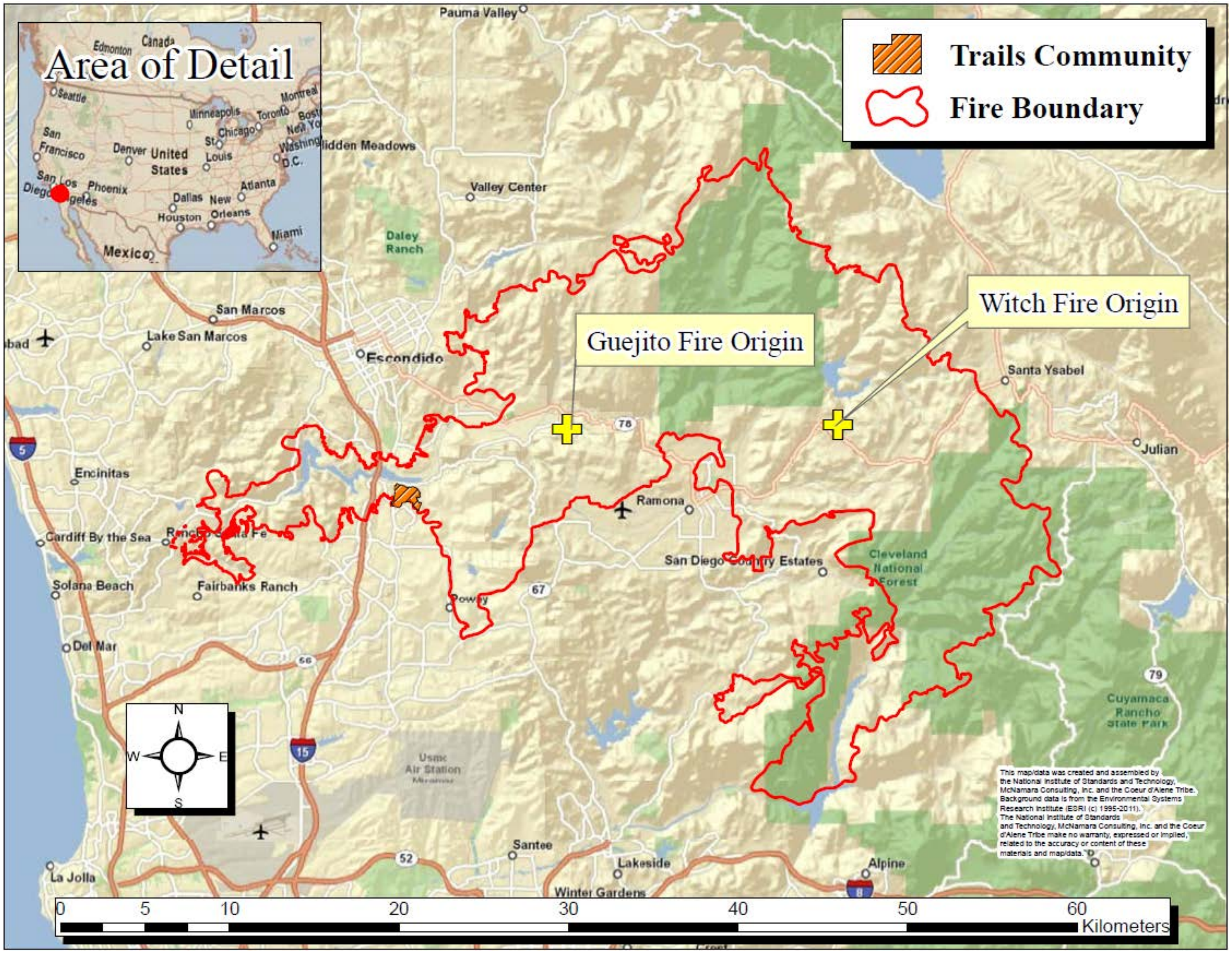

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Figure 1 Overview of the entire extent of the Witch and Guejito Fires in context with the United States. Also portrayed is the study area within the fire perimeter and the origins of the fires.

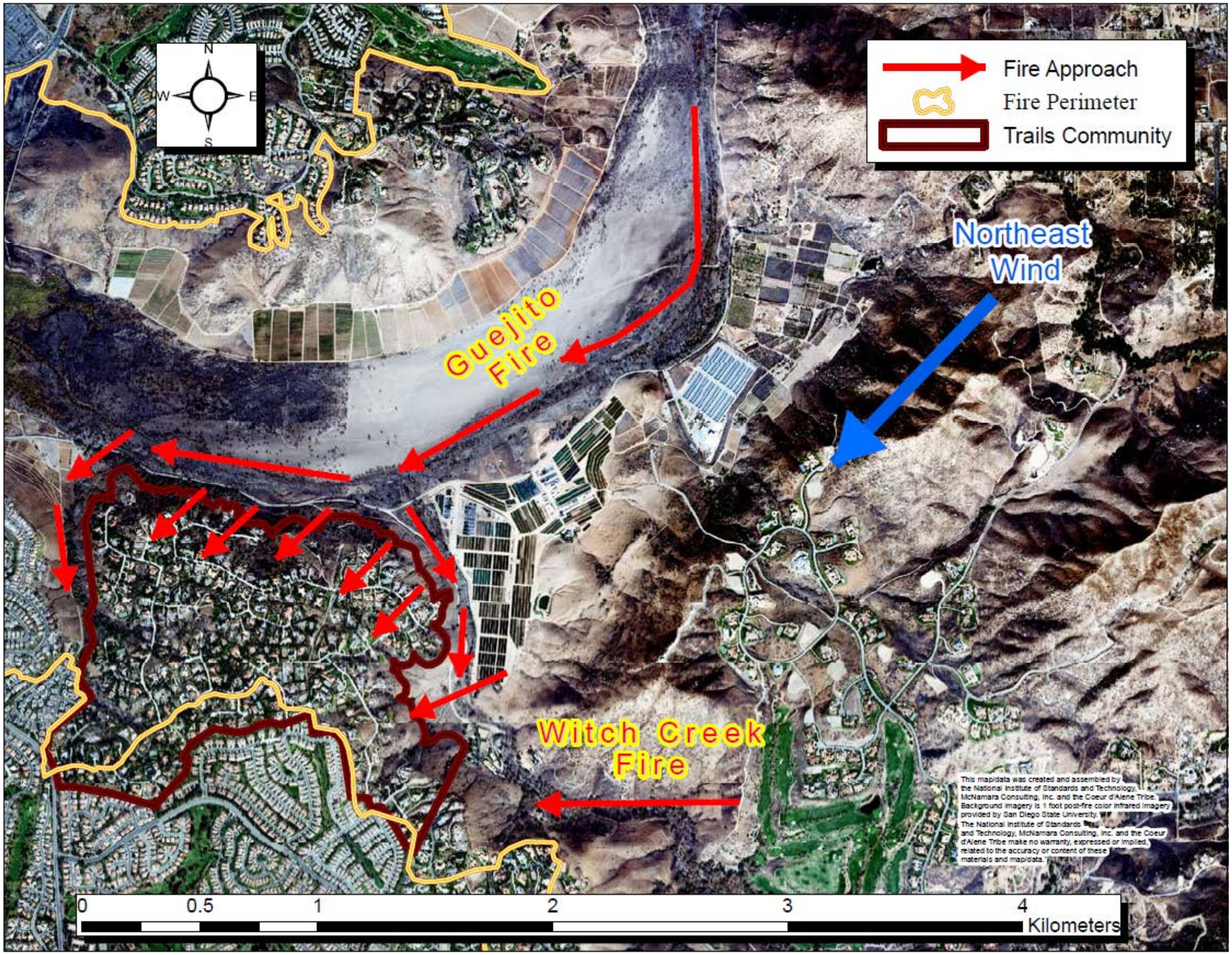

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Figure 2 Fire approach to the Trails Community from the Witch and Guejito Fires. Back ground imagery is 1 ft (0.3 m) horizontal resolution color imagery flown shortly after the fires.

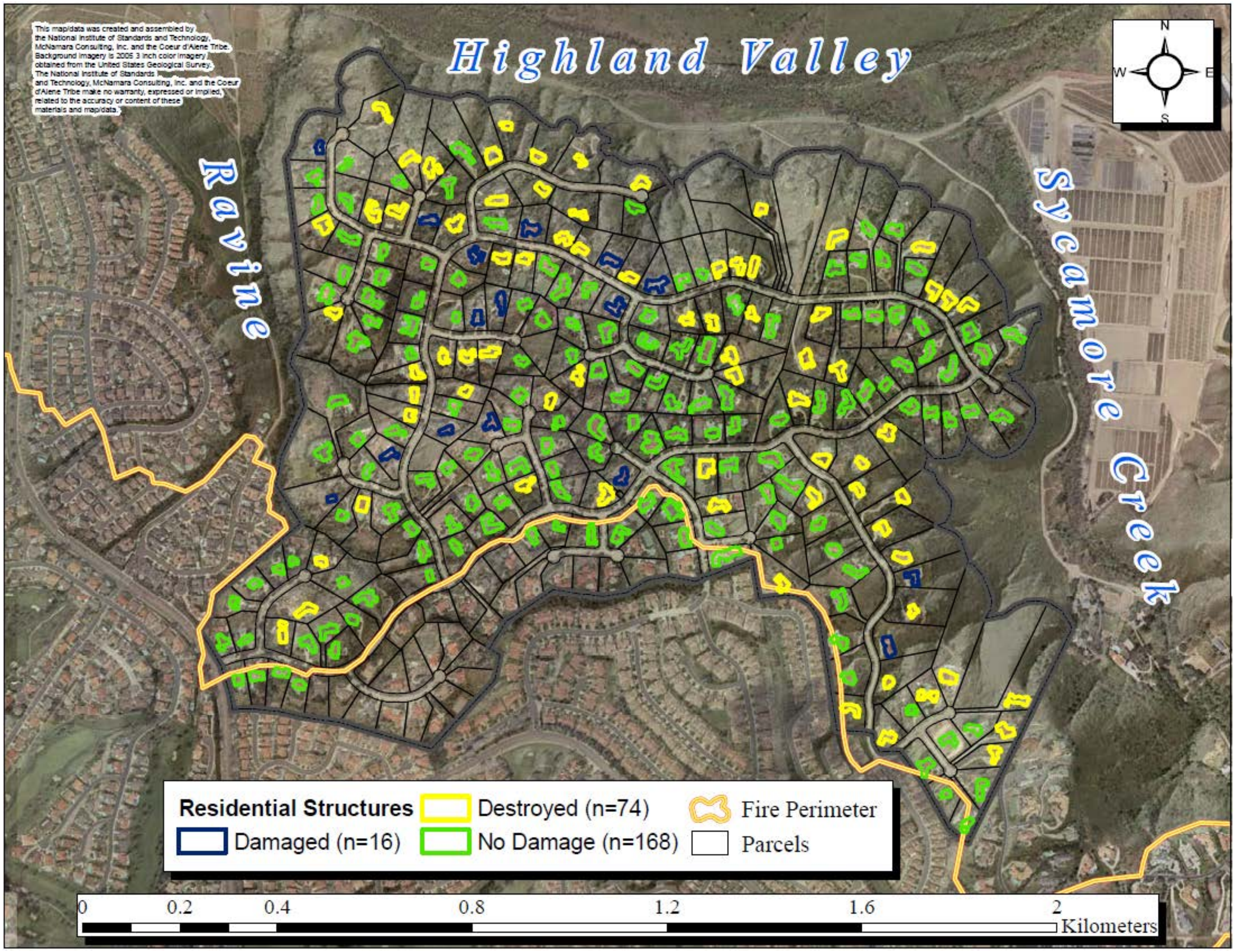
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Figure 3 Trails community in relation to Witch fire perimeter with primary structures displayed by damaged status. Back ground imagery is 3 inch (8 cm) horizontal resolution color imagery from 2005.

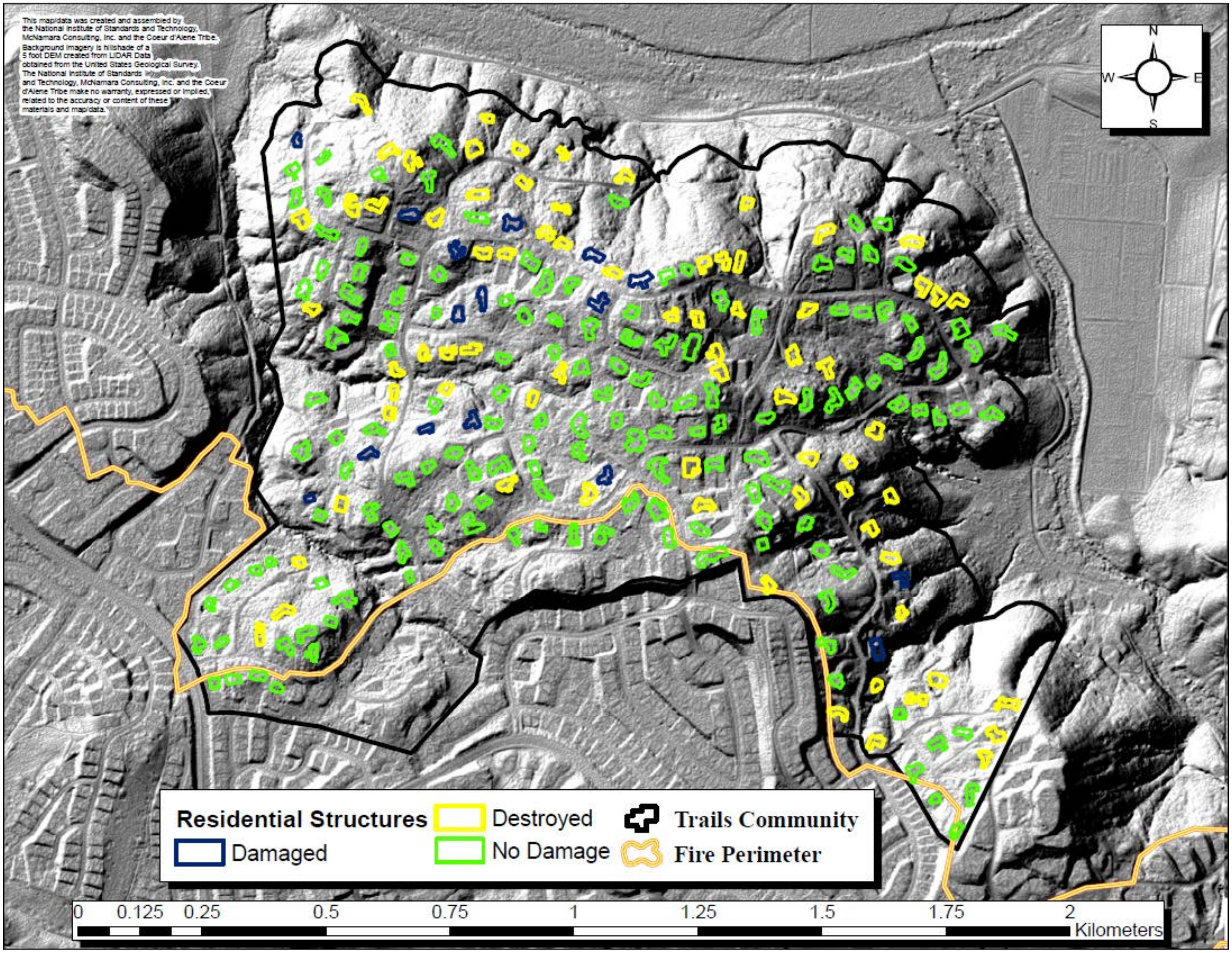

Figure 4 Hillshade portraying topography in and around the Trails. Hillshade created from Light Intensity Detection and Ranging (LIDAR) derived 1.5 m (4.9 ft) digital elevation model obtained from the United States Geologic Survey (USGS).

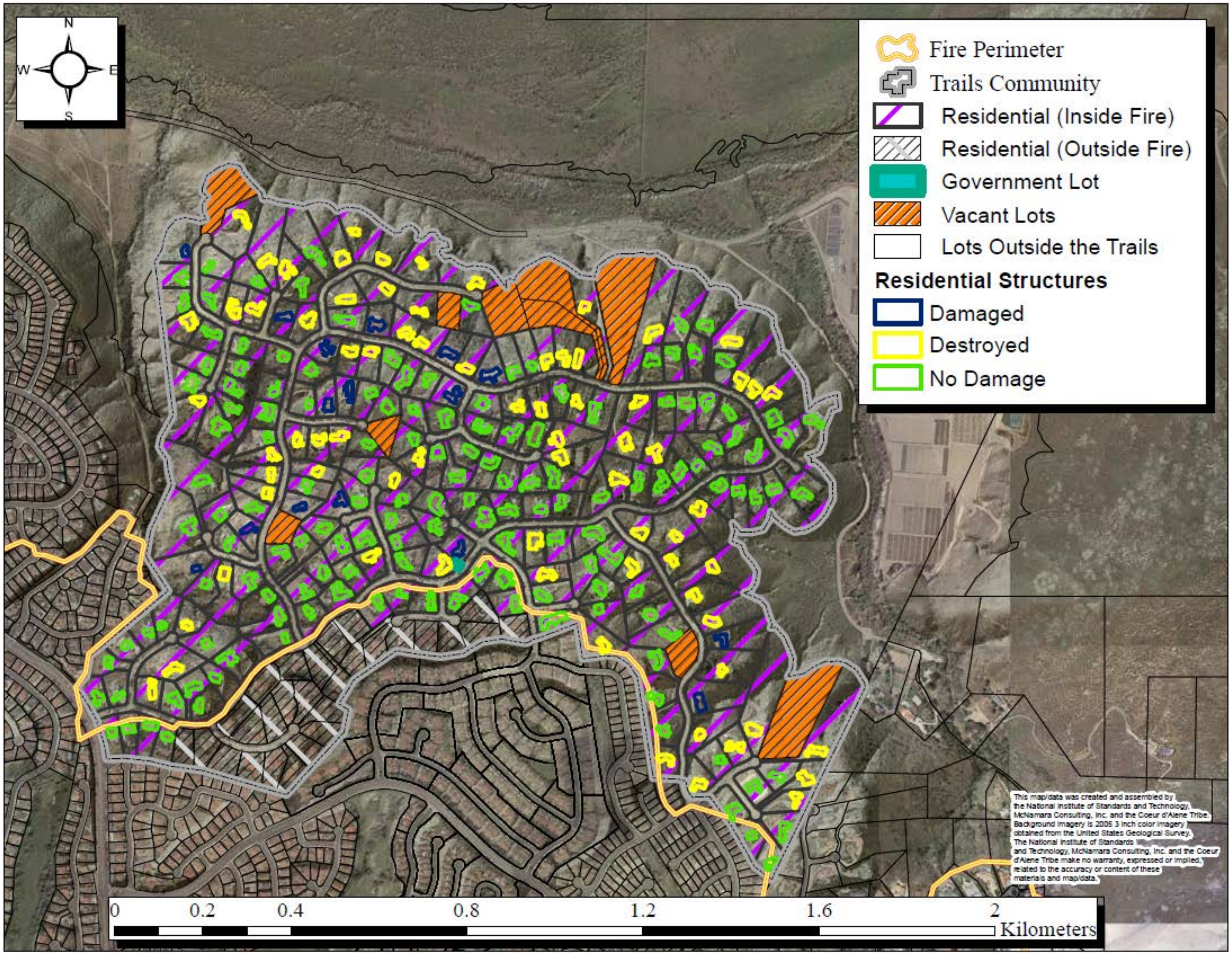

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Figure 5 Property lot types in the Trails Community. Back ground imagery is 3 inch (8 cm) horizontal resolution color imagery from 2005.

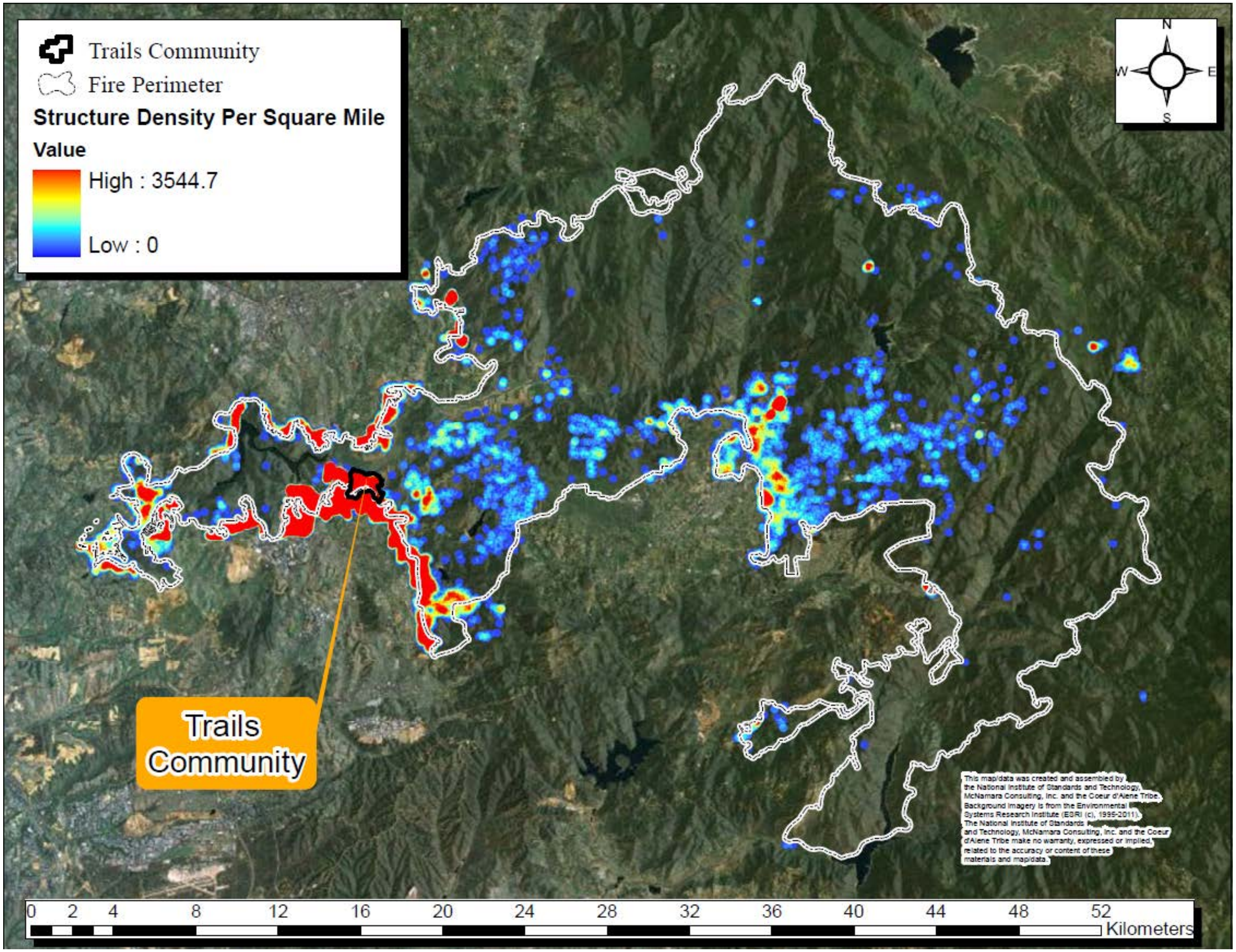

Figure 6 Primary structure densities per square mile for the Witch and Guejito Fires. Derived using the ArcGIS™ Point Density Tool with a circle window having a radius of approximately 200 meters (660 feet) and an output cell size of 3 m (10 ft).

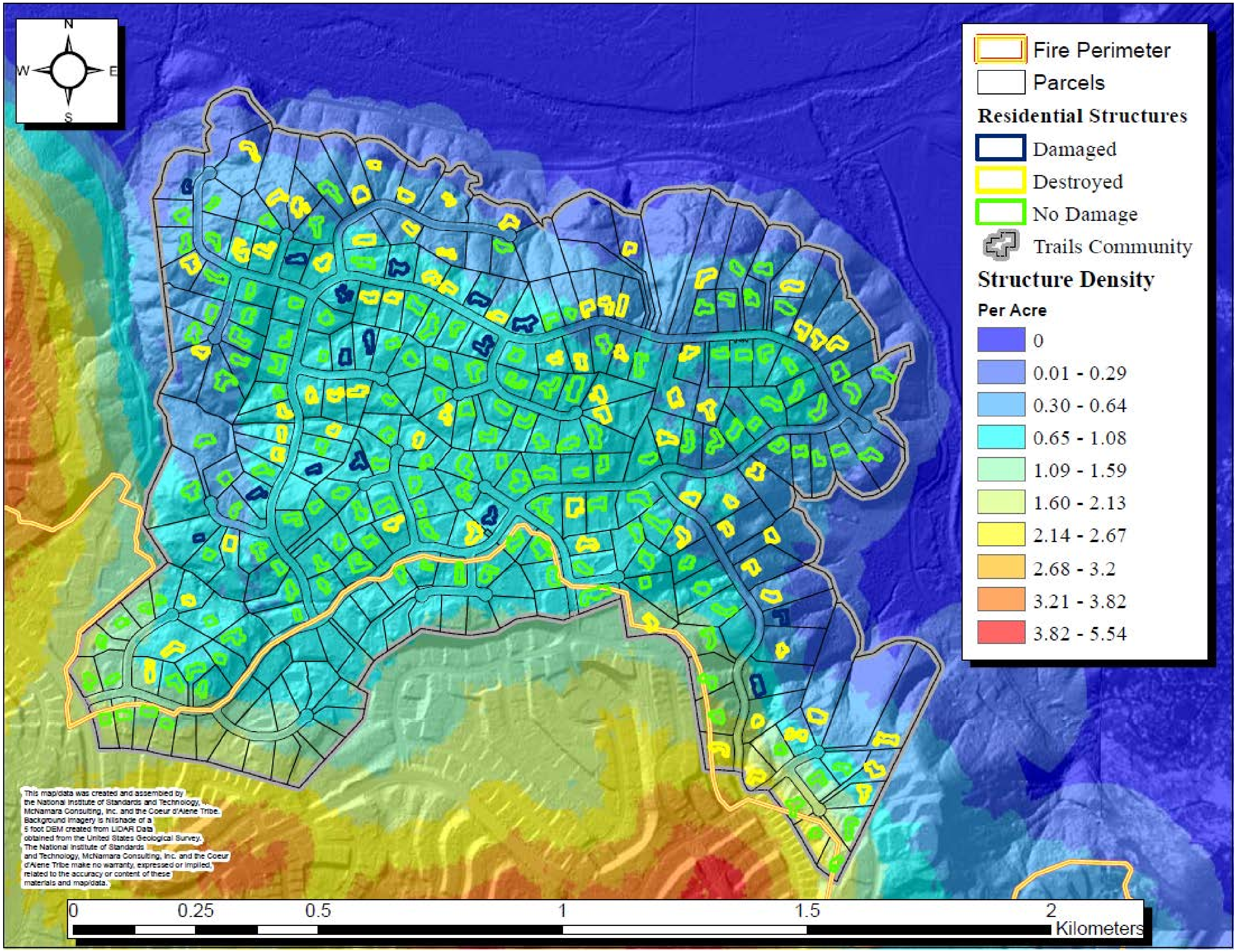

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Figure 7 Residential structure density in and around the Trails. Derived using the ArcGIS™ Point Density Tool with a circle window having a radius of approximately 200 m (660 ft) and an output cell size of 3 m (10 ft).

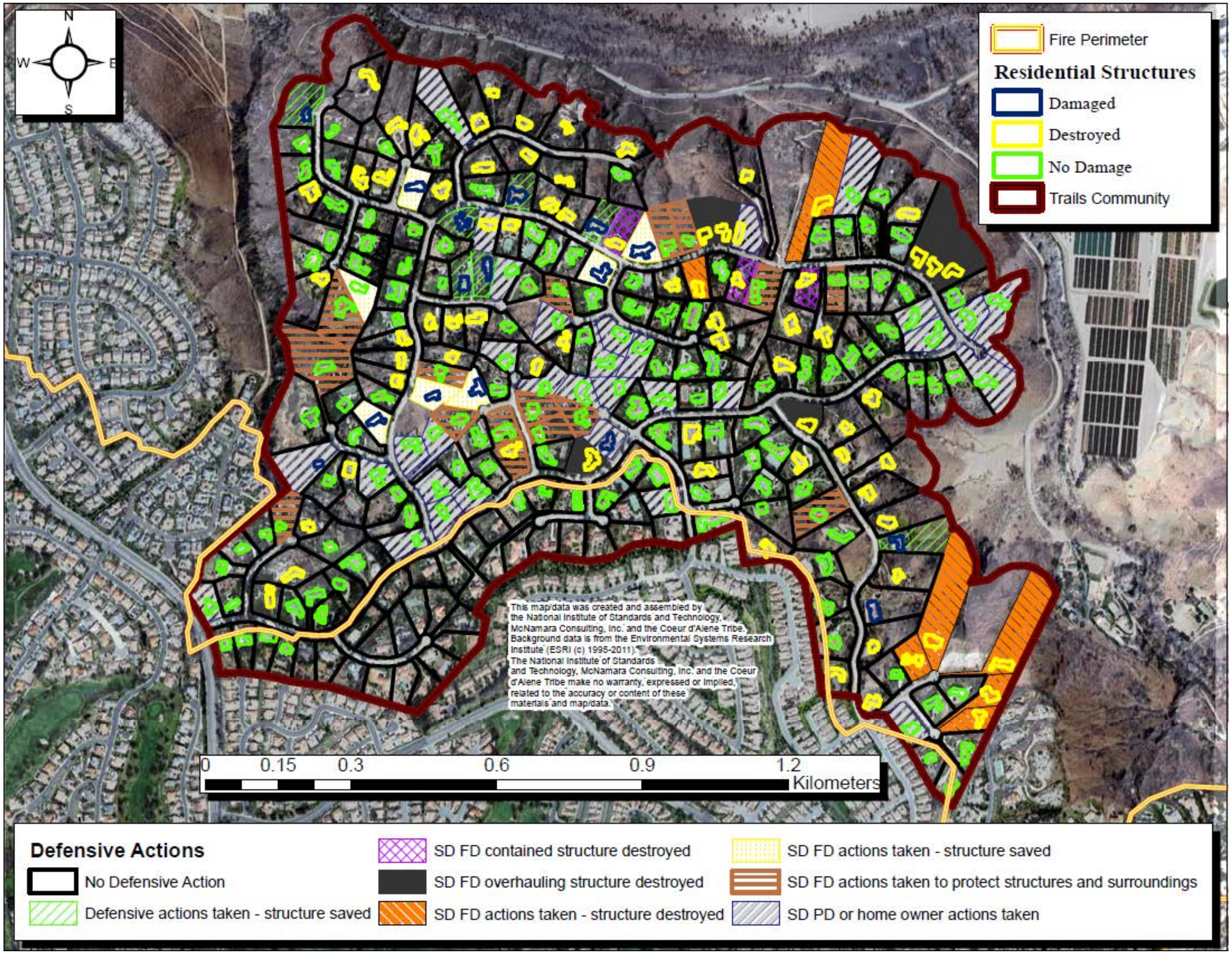

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Figure 8 Defensive actions on residential properties overlaid with primary structures displayed by damaged status. Back ground imagery is 1 ft (0.3 m) horizontal resolution color imagery flown shortly after the fires.

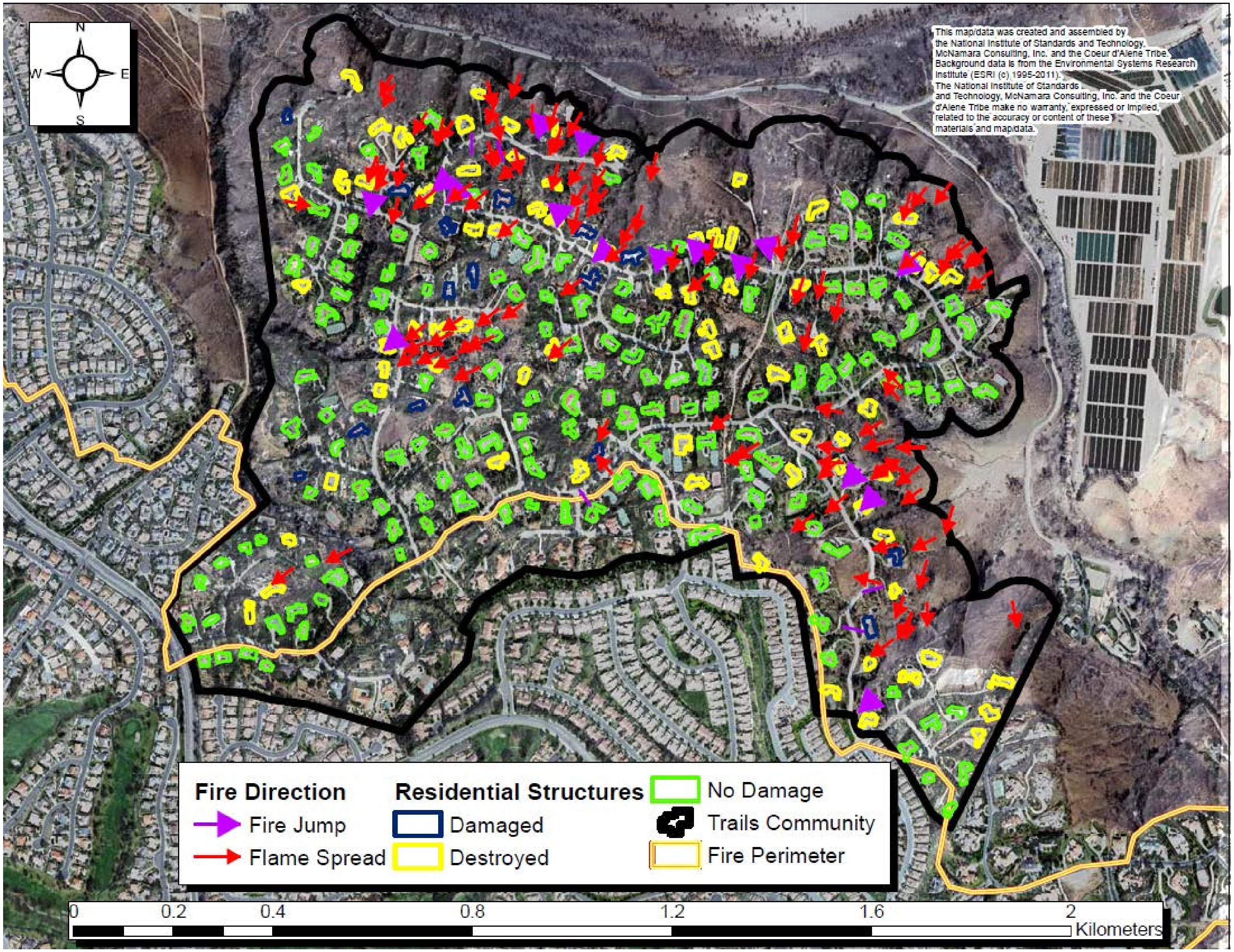

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Figure 9 Fire direction in the Trails overlaid with primary structures displayed by damaged status. Back ground imagery is 1 ft (0.3 m) horizontal resolution color imagery flown shortly after the fires.

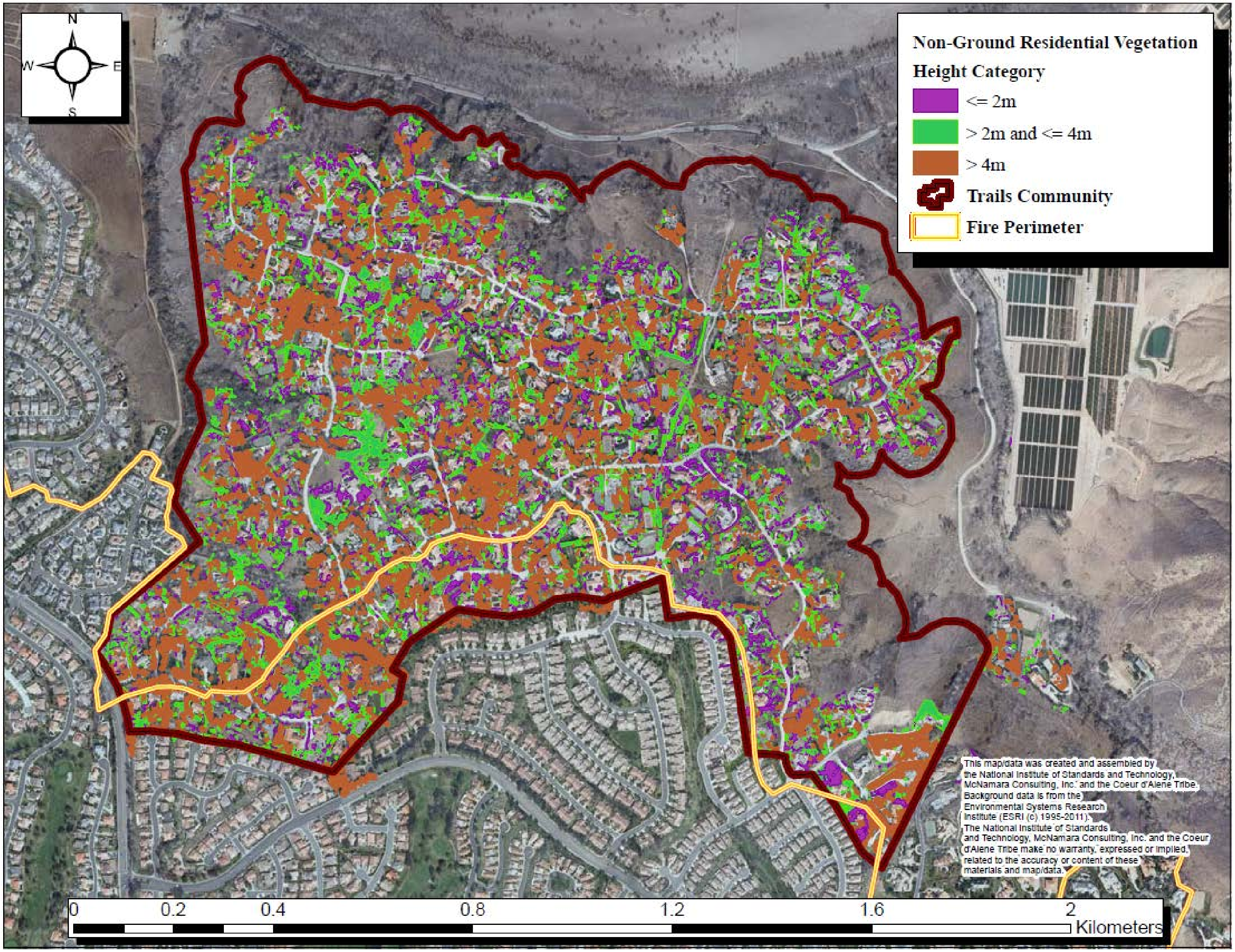

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Figure 10 Above ground residential vegetation in the Trails overlaid with the Fire perimeter. Back ground imagery is 1 ft (0.3 m) horizontal resolution color imagery flown shortly after the fires.

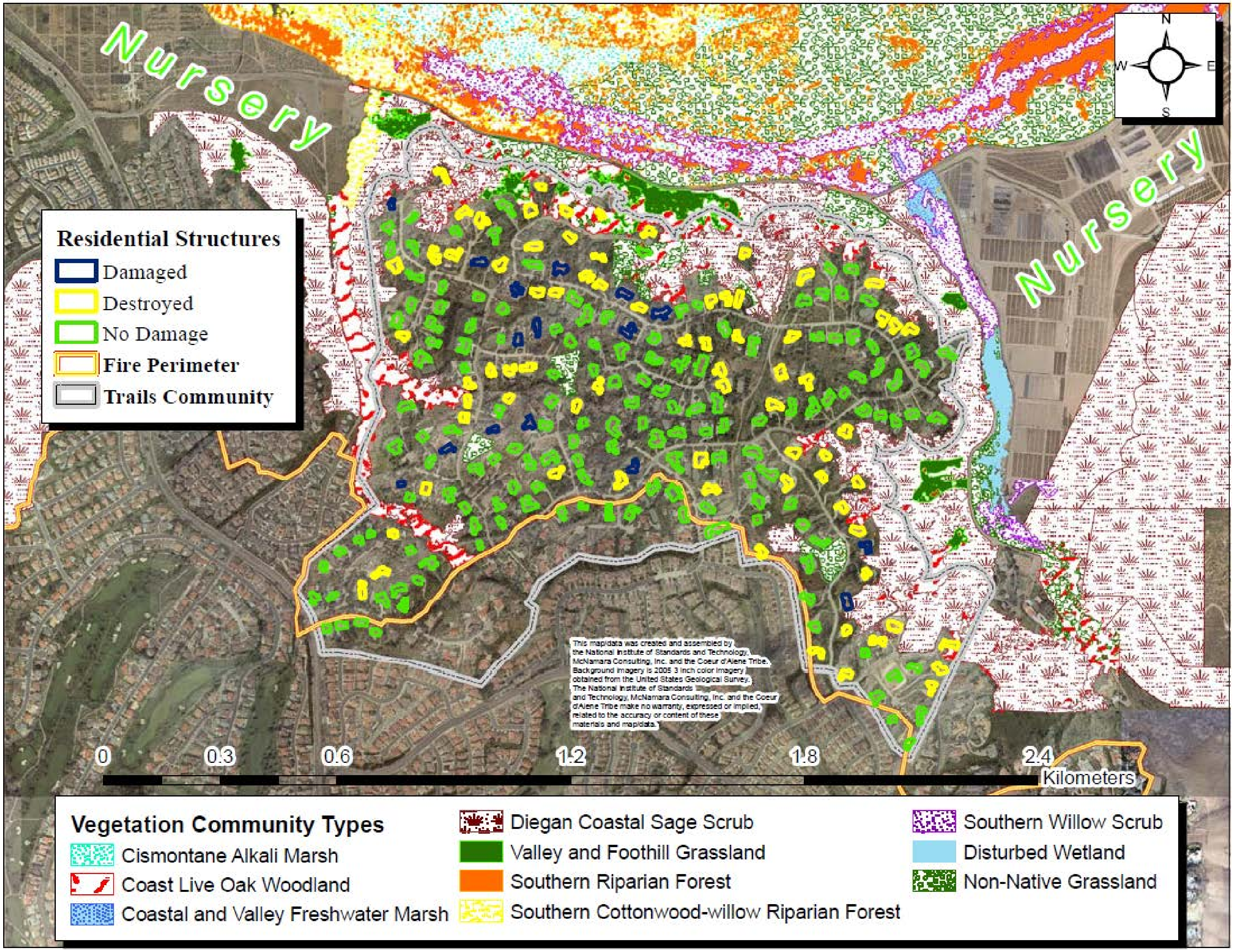

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Figure 11 Wildland vegetation community types in and around the Trails overlaid with primary structures displayed by damaged status. Back ground imagery is 3 inch (8 cm) horizontal resolution color imagery from 2005.

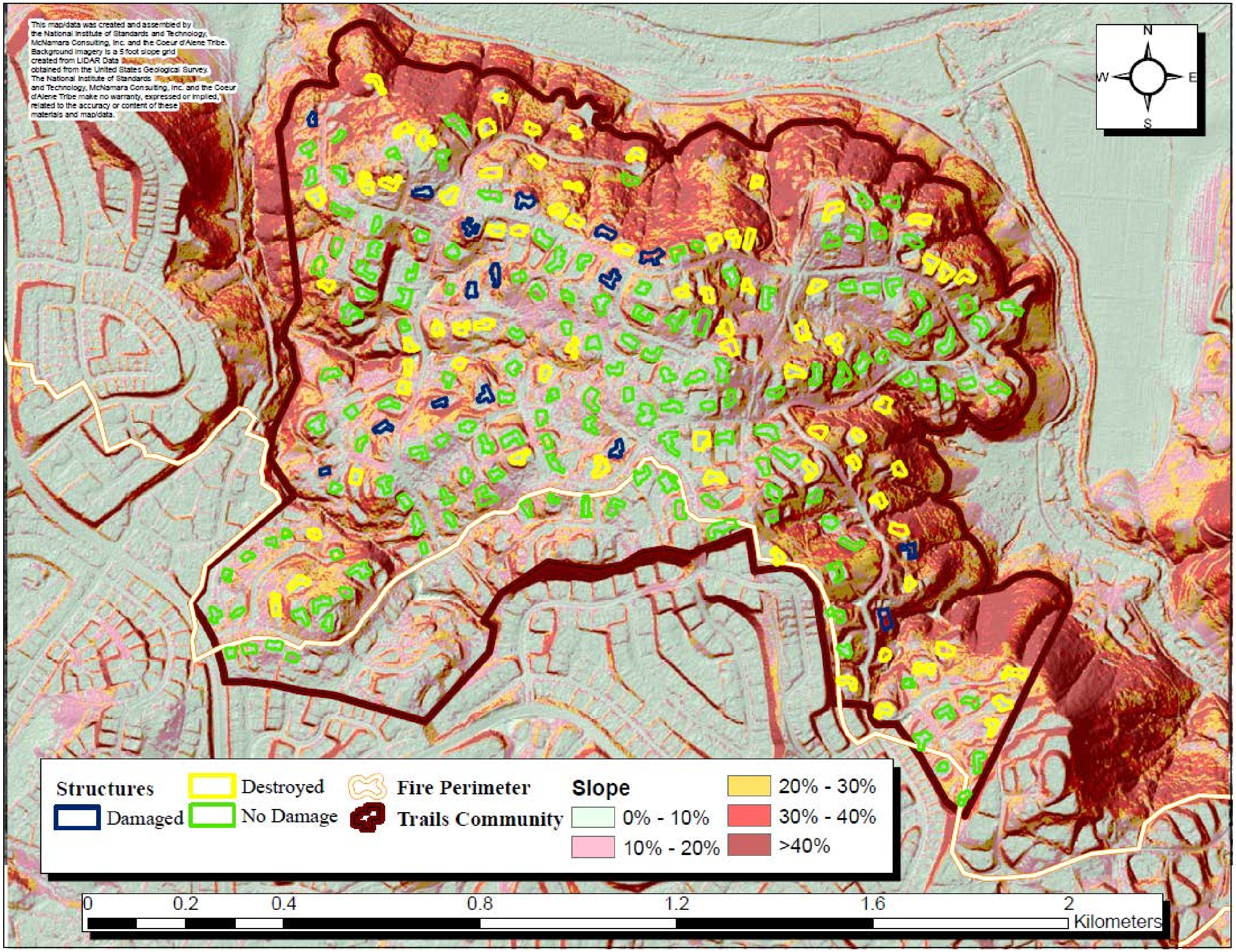

Figure 12 Trails percent slope raster data set derived from LIDAR 5 foot DEM overlaid with residential structure damage and destruction.

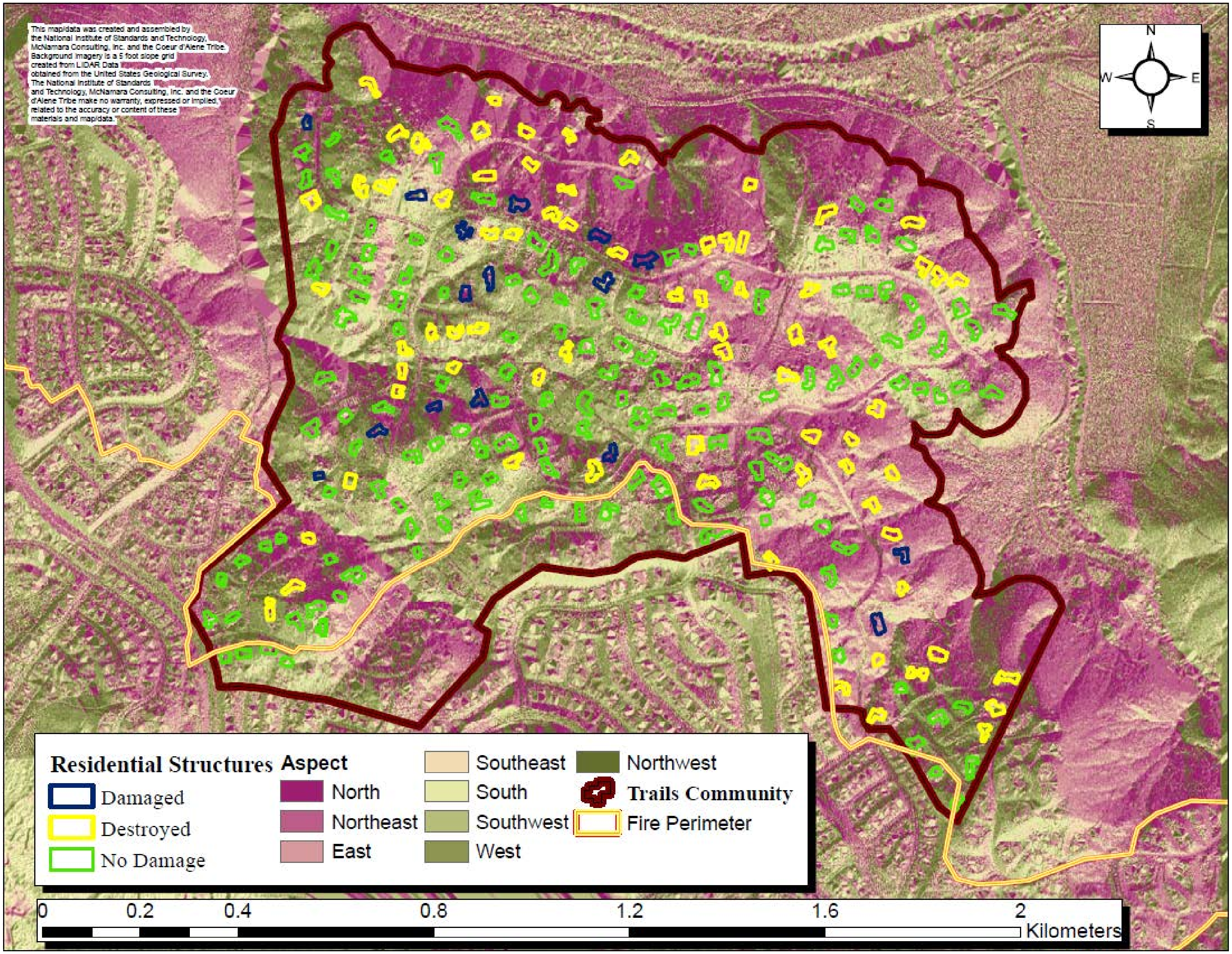

Figure 13 Trails aspect raster data set derived from LIDAR 5 ft (1.5 m) DEM and reclassified to eight directions and overlaid with primary structures displayed by damaged status.

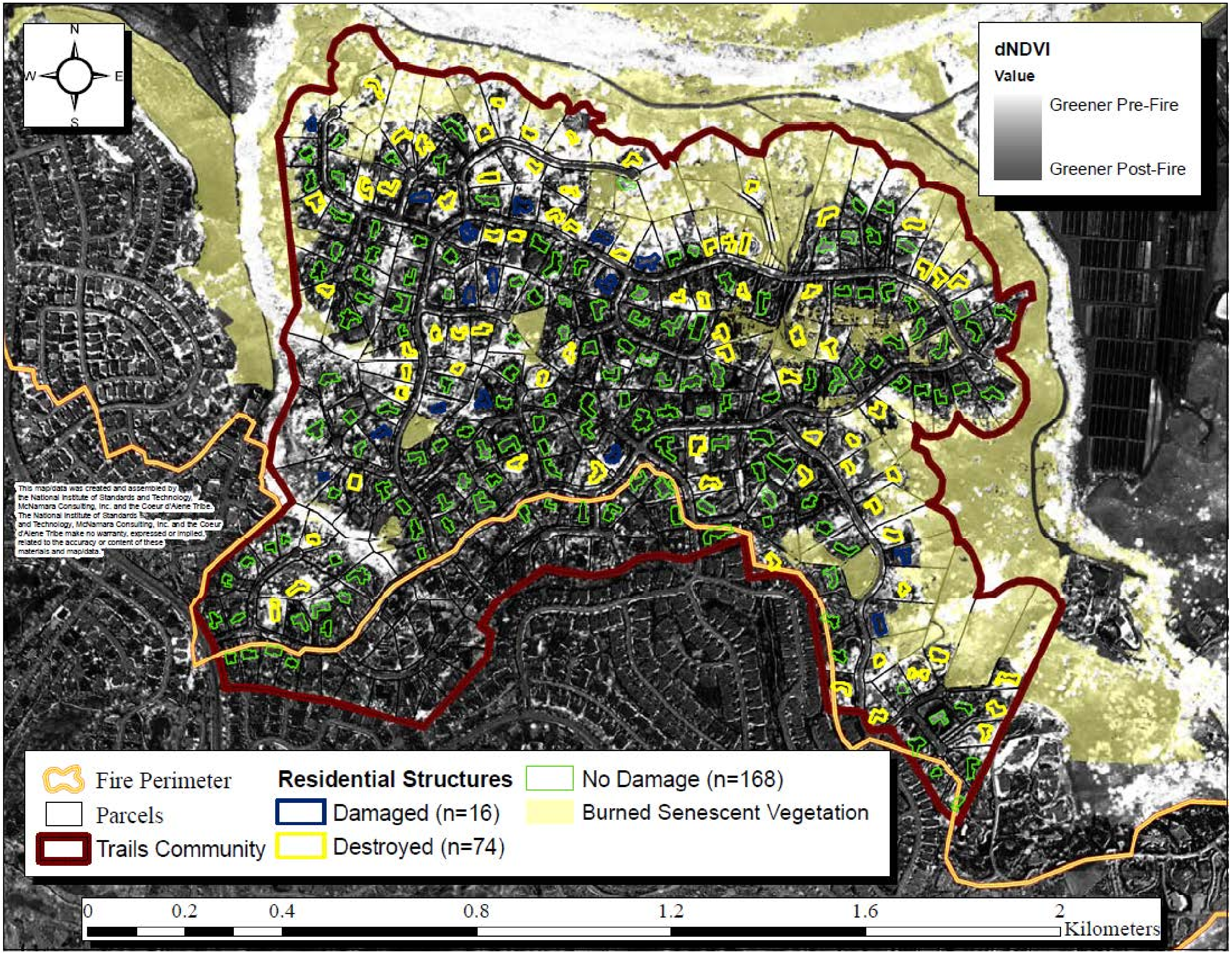

Figure 14 Potential change in vegetation greenness (dNDVI) between 2005 and 10 days after the Witch and Guejito Fires.

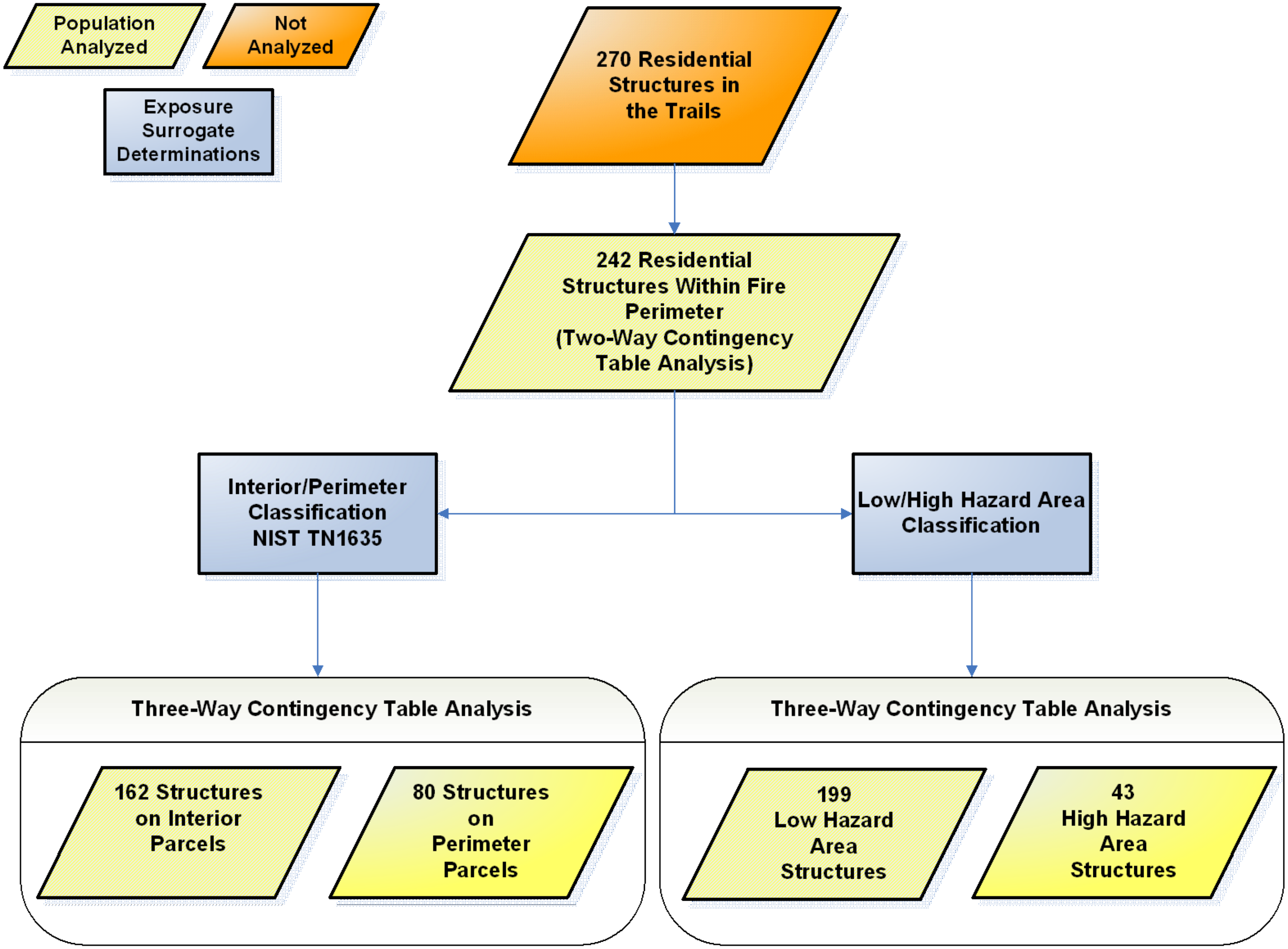

Figure 15 Overview of data analysis steps

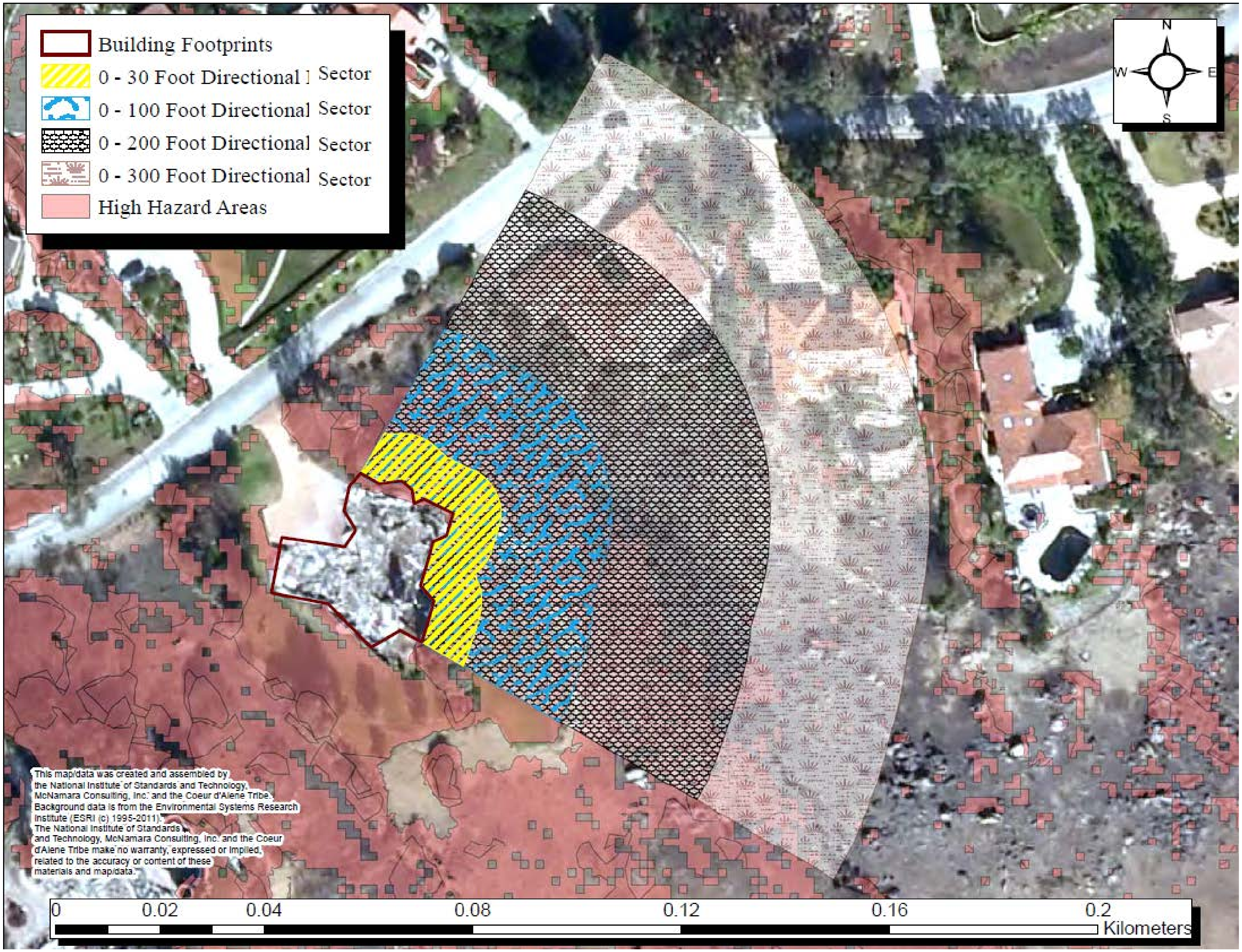

Figure 16 Example of directional sector employed on destroyed structure at the Trails. All sectors begin at zero and continue the specified distance. Sectors for 30 ft, 100 ft, 200 ft and 300 ft (9 m, 30 m, 60 m and 90 m) distances have portions excluded by the other sectors.

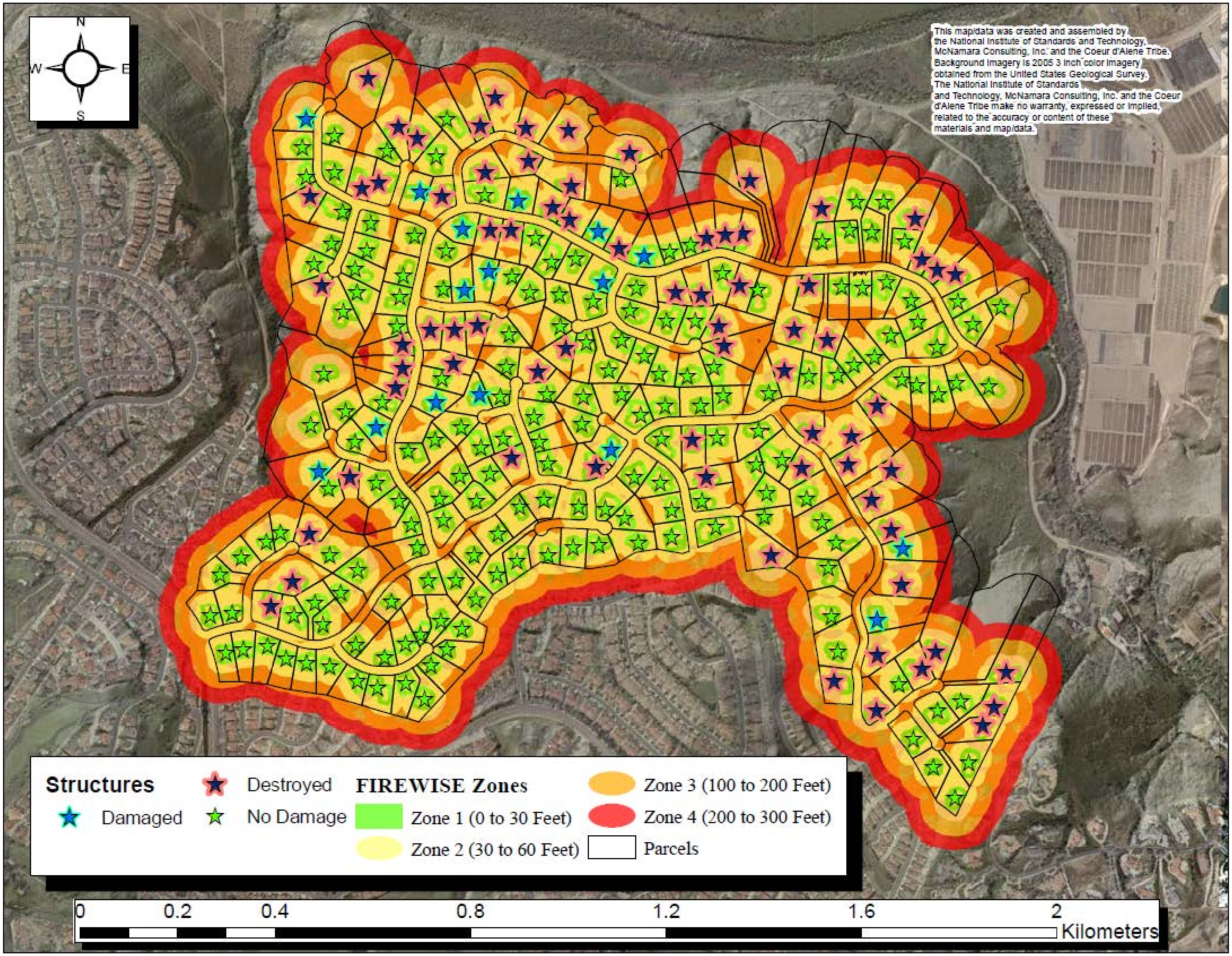

Figure 17 Geographic distribution of Firewise Zones assuming homeowner cooperation.

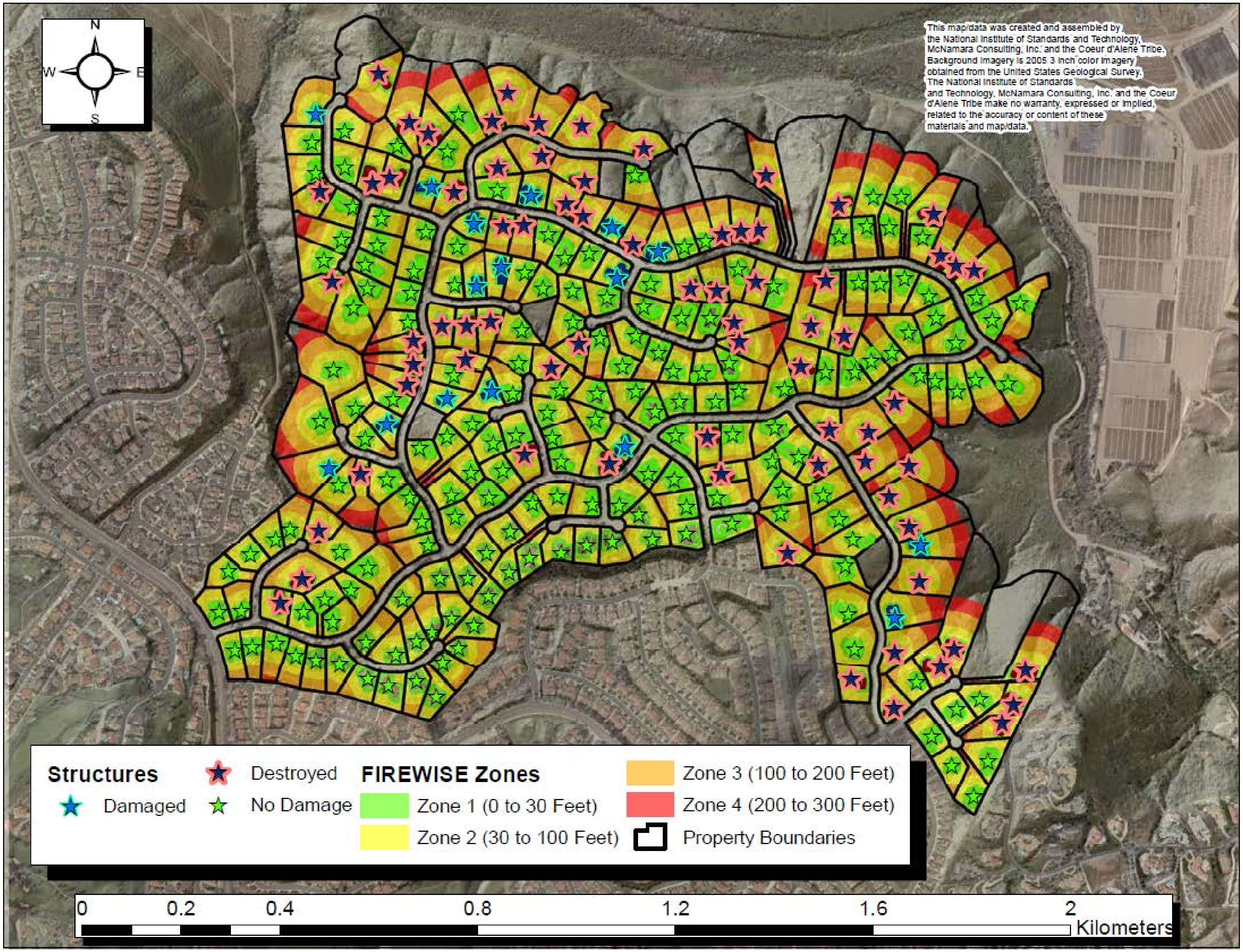

Figure 18 Firewise Zones viewed at an individual property level. Back ground imagery is 3 inch (8 cm) horizontal resolution color imagery from 2005.

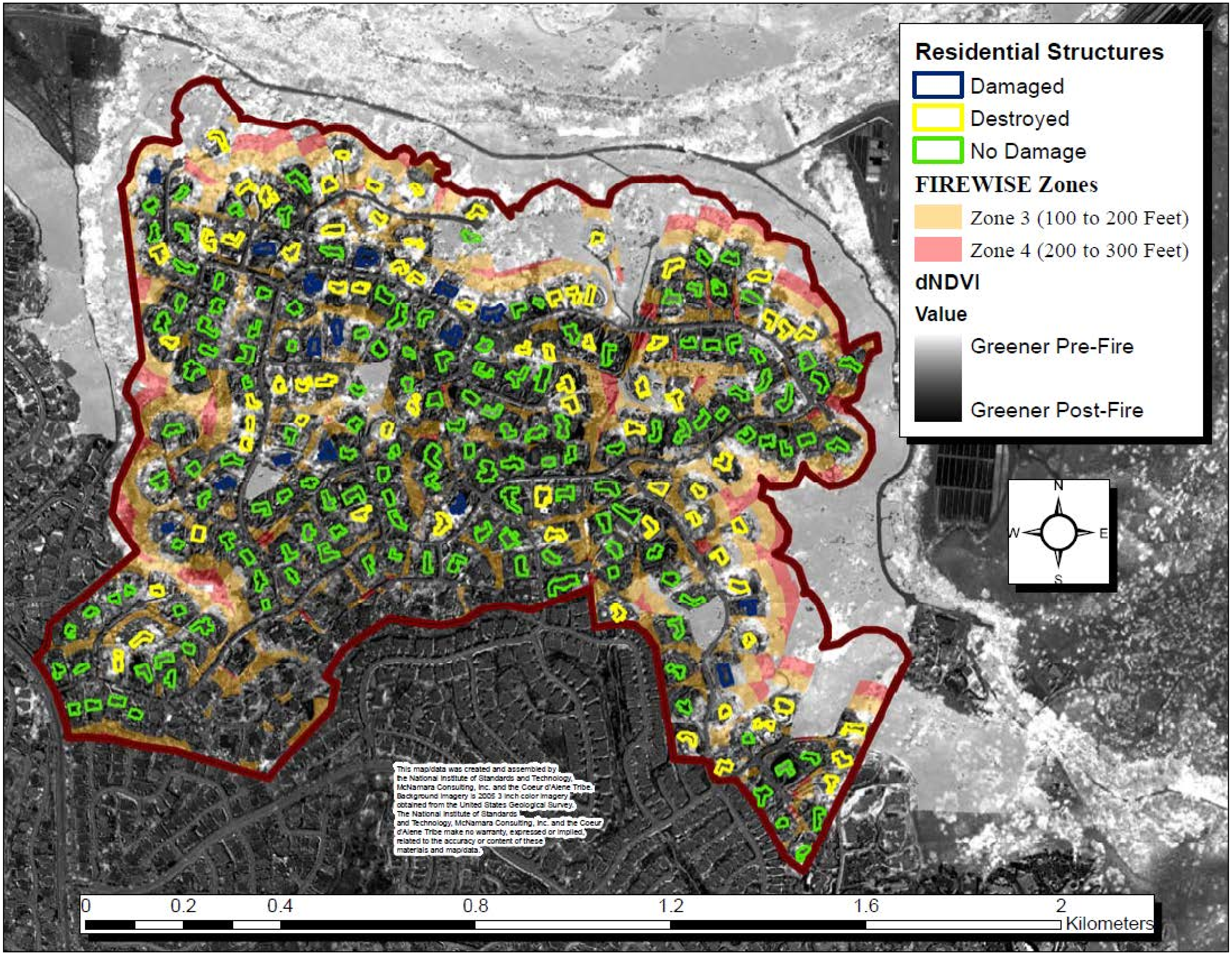

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Figure 19 Relationship between Firewise Zones 3 100 ft to 200 ft (30 m to 61 m) and Zones 4 200 ft to 300 feet (61 m to 91 m), and dNDVI (surrogate for burned vegetation) overlaid with primary structures displayed by damaged status.

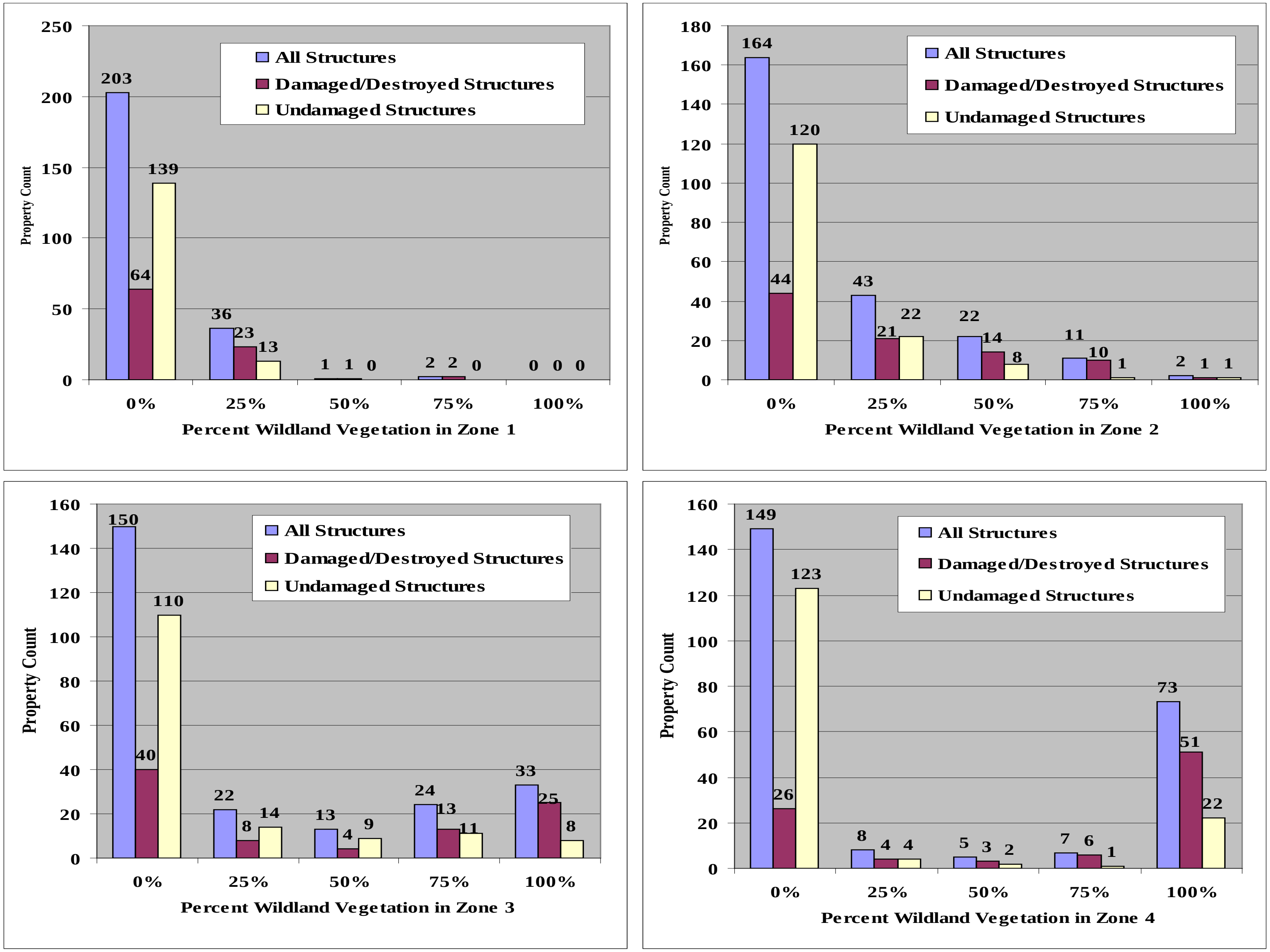


Figure 20 Frequency counts of structures by bins of percent of wildland vegetation found on the property for four zones.

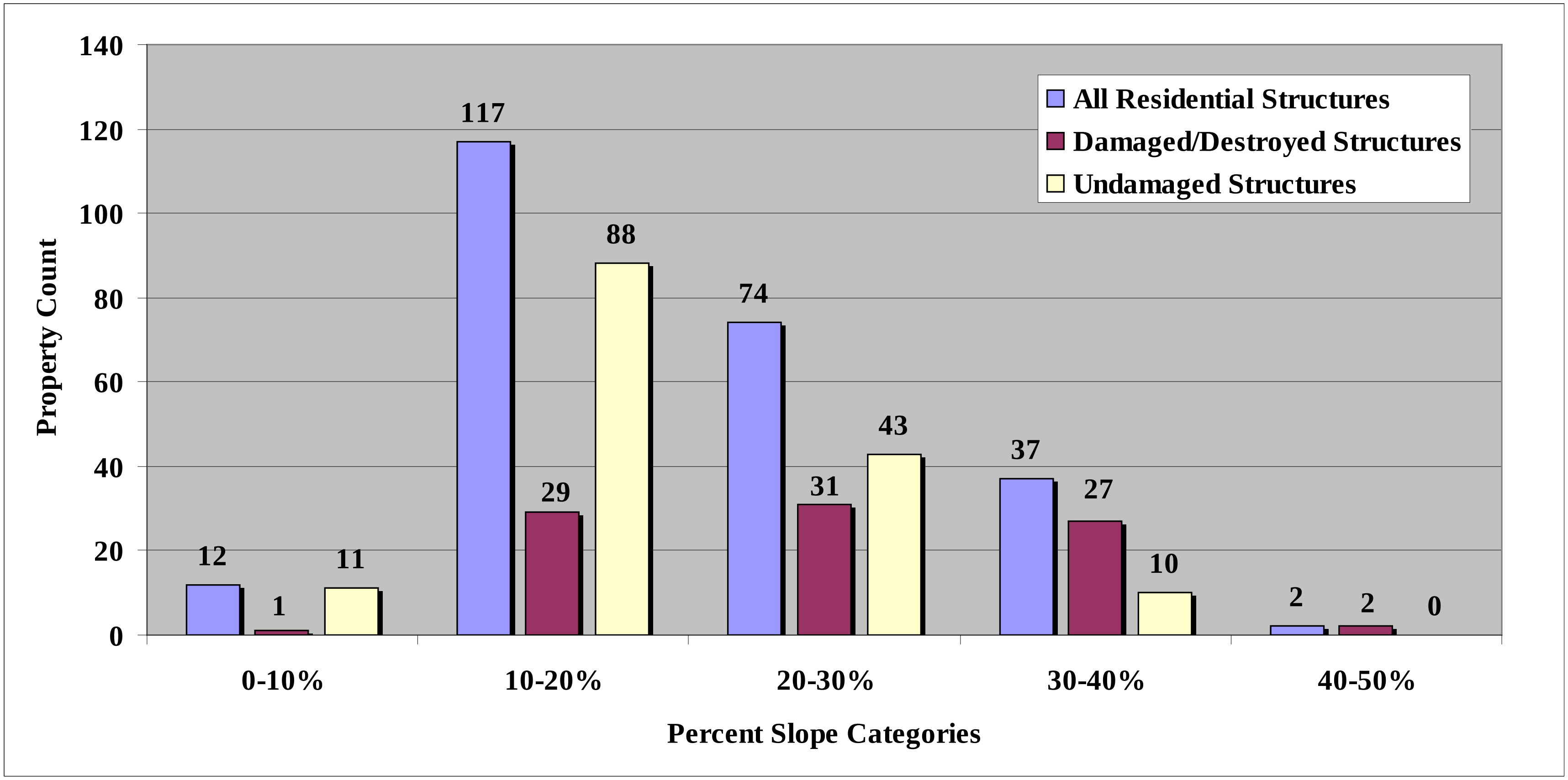


Figure 21 Frequency counts of properties by bins of average percent slopes found on properties for all structures, undamaged structures and damaged/destroyed structures.

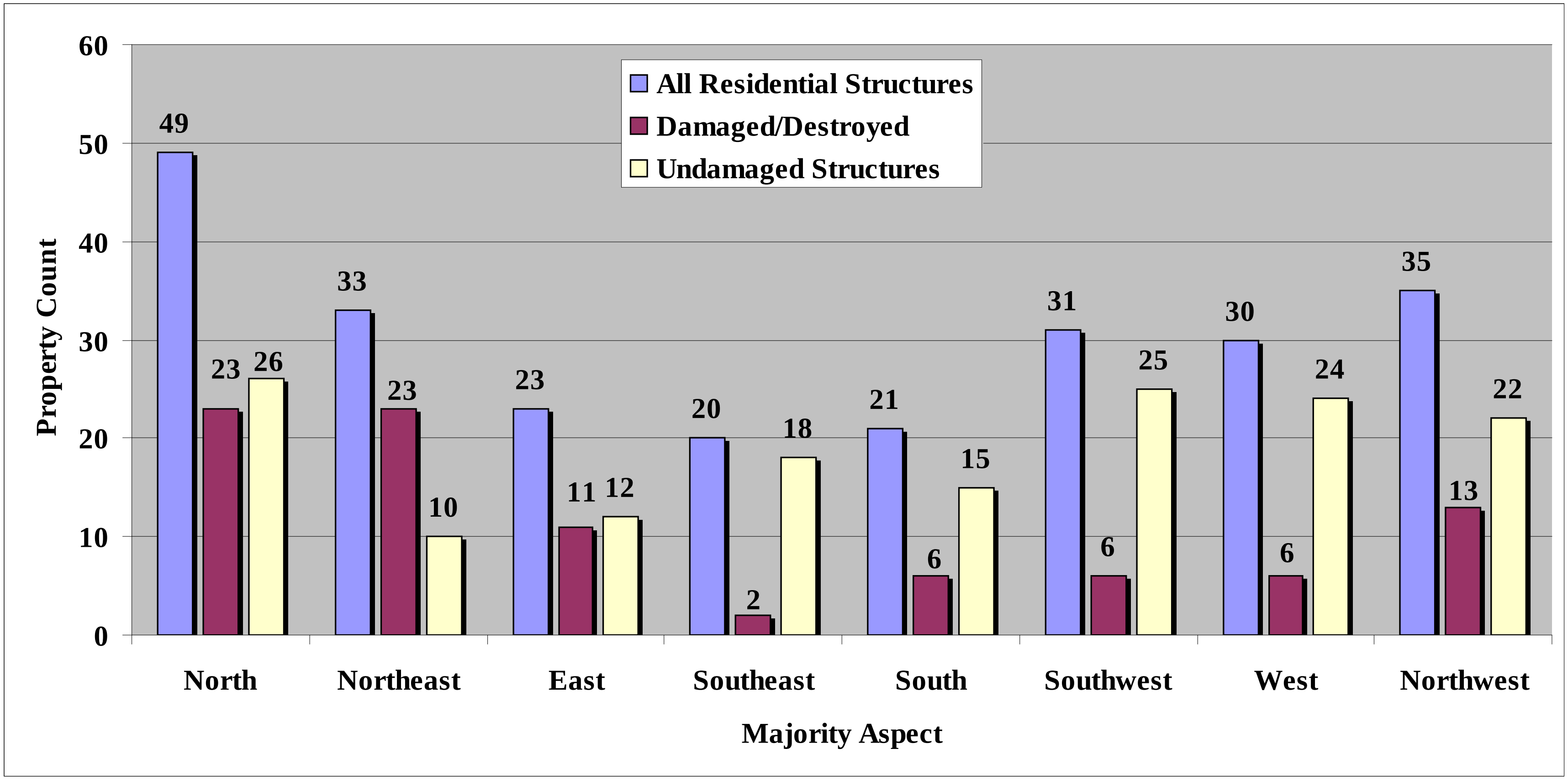


Figure 22 Frequency counts of properties by bins of the majority of aspects found on properties for all structures, undamaged structures and damaged/destroyed structures.

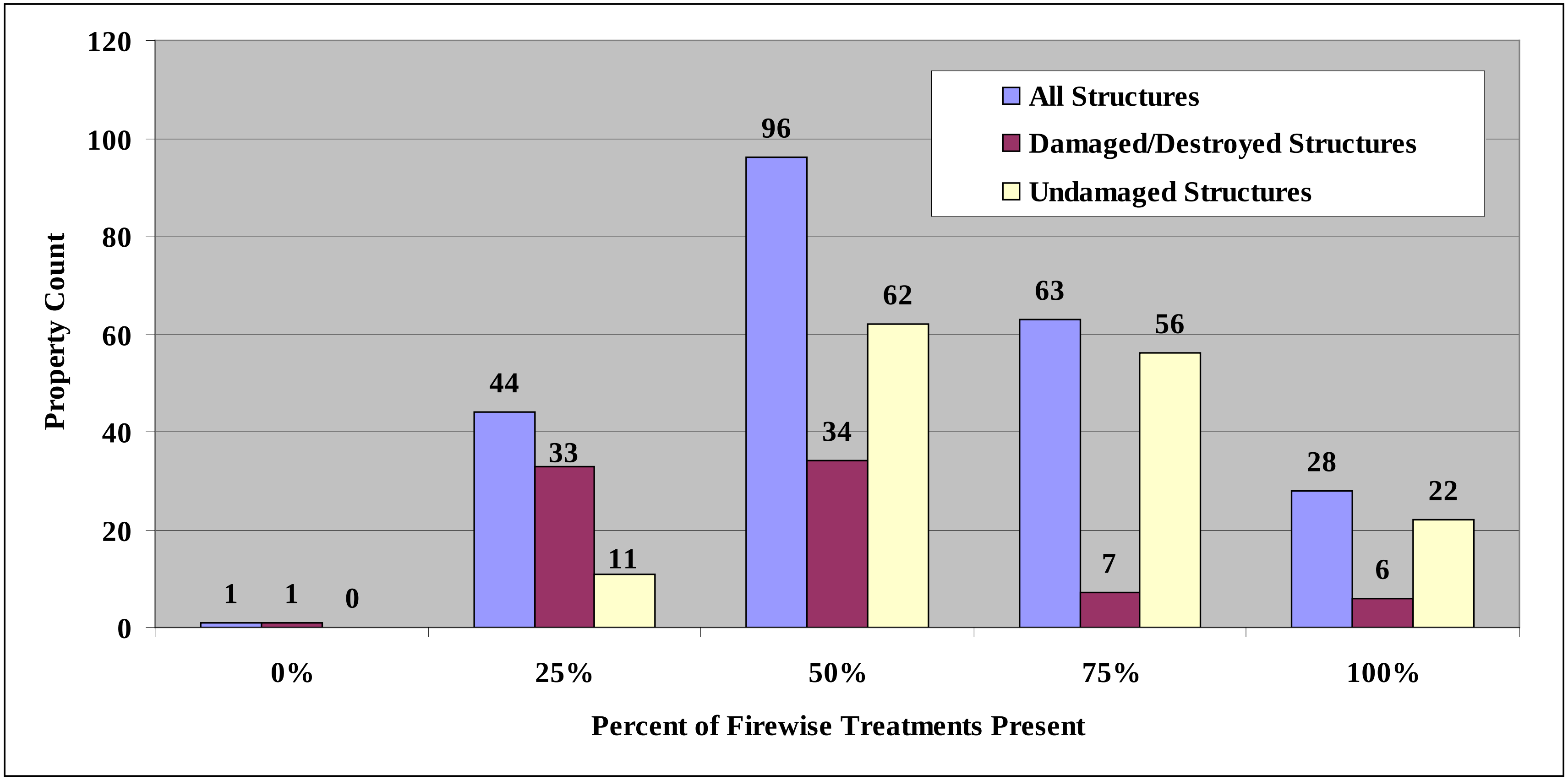


Figure 23 Frequency counts of properties by bins of percent of Firewise Treatments present on property for all structures, undamaged structures and damaged/destroyed structures where the presence of treatments on the property could be determined for greater than 50% of the Firewise Treatments assessed.

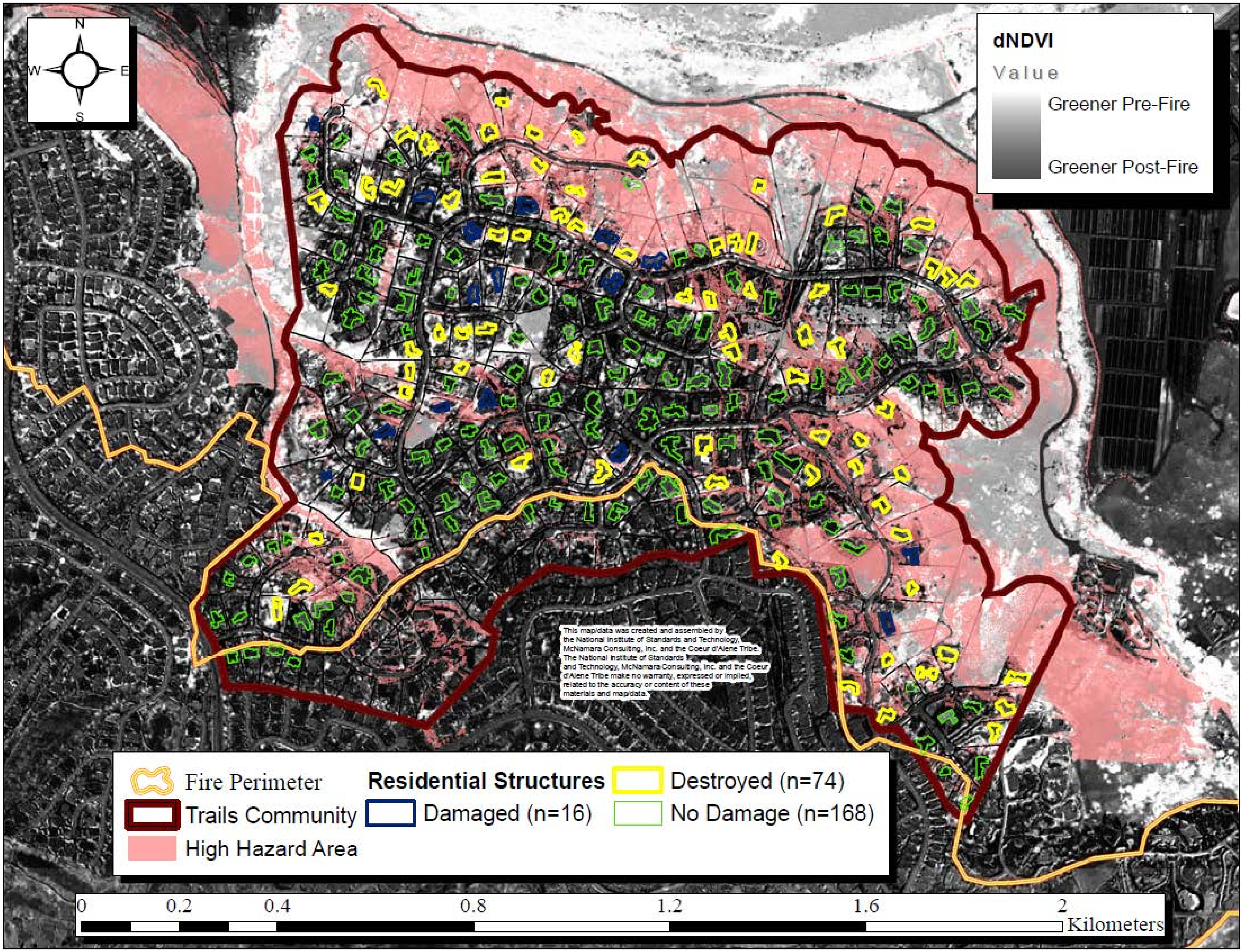


Figure 24 Areas with high slopes (>20%); northeast, north and east aspects; and vegetation (shown in yellow) overlaid on the modified dNDVI data set

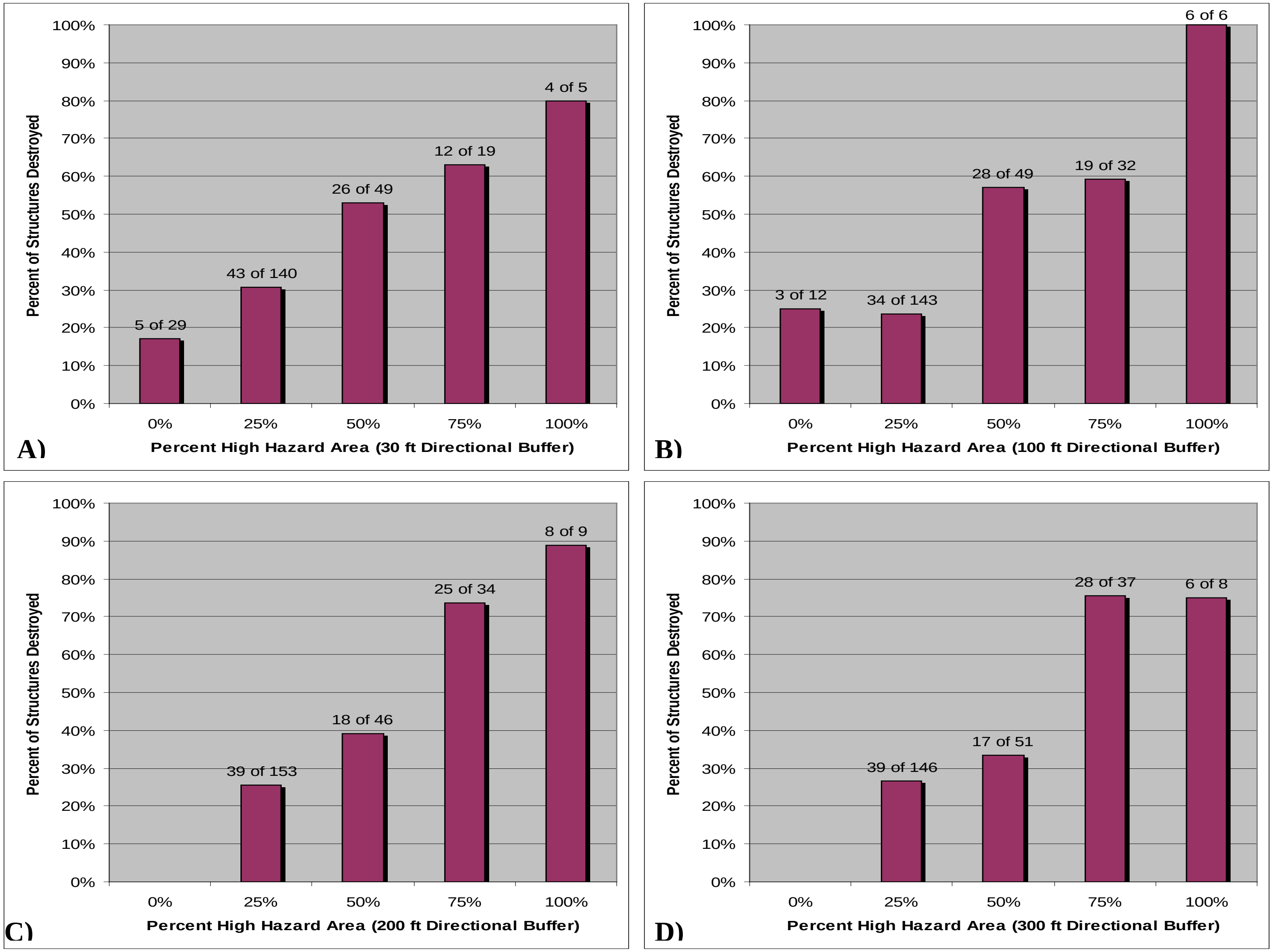


Figure 25 Bar graphs portraying percent primary structures destroyed by bins of percent of wildland vegetation present in the respective sector distance. A) Shows results for 0 ft to 30 ft (0 m to 9 m) sector. B) Shows results for 0 ft to 100 ft (0 m to 30 m) sector. C) Shows results for 0 ft to 200 ft (0 m to 61 m) sector. D) Shows results for 0 ft to 300 ft (0 m to 91 m) sector.

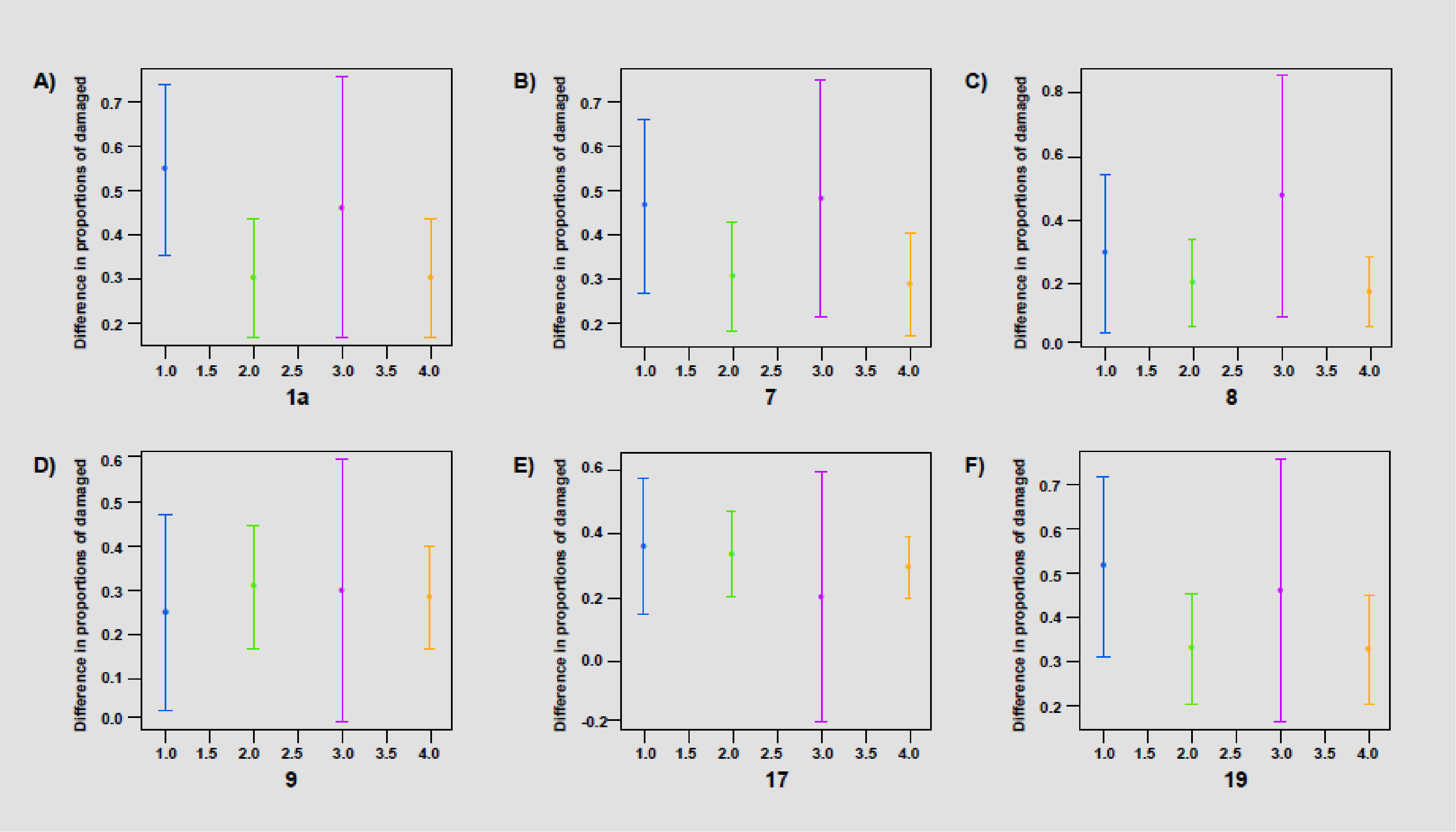


Figure 26 Boxplot showing 95% confidence interval for the interactions between individual treatments and perimeter/interior parcels and high/low exposure parcels. The 1st line (blue) represents perimeter; 2nd line (green) is interior; 3rd line (purple) is high exposure; 4th line (orange) is low exposure.

Appendix A
NIST TN1635 Findings

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, resident evacuation was conducted as the fire reached the community. Additionally, half of the fire fighting 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 approximately 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 contributed 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 30 summarizes much of the spatial and temporal information. The findings to date are divided into two categories; general fire behavior, and defensive actions and structural losses.

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.
- Fire spread up to 500 m into the interior of the community.

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 on fire were saved.
- Over 50 % of the structures were ignited within 3 hours 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 embers ignitions occurred from the arrival of the wildland fire front and for the next nine hours.
- 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 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 %.

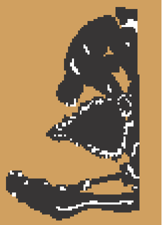
Unanswered Questions

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. Even though 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 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 highly temporally resolved structure burning. This may be accomplished by ground observations or remote sensing platforms such as unmanned aerial systems.

Appendix B
Firewise Checklists

FIREWISE Landscaping



Firewise Landscaping Checklist

When designing and installing a firewise landscape, consider the following:

☐ Local area fire history.
☐ Site location and overall terrain.
☐ Prevailing winds and seasonal weather.
☐ Property contours and boundaries.
☐ Native vegetation.
☐ Plant characteristics and placement (duffage, water and salt retention ability, aromatic oils, fuel load per area, and size).
☐ Irrigation requirements.

To create a firewise landscape, remember that the primary goal is fuel reduction. To this end, initiate the zone concept. Zone 1 is closest to the structure; Zones 2-4 move progressively further away.

☐ **Zone 1.** This well-irrigated area encircles the structure for at least 30' on all sides, providing space for fire suppression equipment in the event of an emergency. Plantings should be limited to carefully spaced low flammability species.

☐ **Zone 2.** Low flammability plant materials should be used here. Plants should be low-growing, and the irrigation system should extend into this section.

☐ **Zone 3.** Place low-growing plants and well-spaced trees in this area, remembering to keep the volume of vegetation (fuel) low.

☐ **Zone 4.** This furthest zone from the structure is a natural area. Selectively prune and thin all plants and remove highly flammable vegetation.

Also remember to:

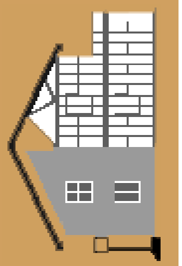
☐ Be sure to leave a minimum of 30' around the house to accommodate fire equipment, if necessary.
☐ Widely space and carefully situate the trees you plant.
☐ Take out the "ladder fuels" — vegetation that serves as a link between grass and tree tops. This arrangement can carry fire to a structure or from a structure to vegetation.
☐ Give yourself added protection with "fuel breaks" like driveways, gravel walkways, and lawns.

When maintaining a landscape:

☐ Keep trees and shrubs properly pruned. Prune all trees so the lowest limbs are 6' to 10' from the ground.
☐ Remove leaf clutter and dead and overhanging branches.
☐ Mow the lawn regularly.
☐ Dispose of cuttings and debris promptly, according to local regulations.
☐ Store firewood away from the house.
☐ Be sure the irrigation system is well maintained.
☐ Use care when refueling garden equipment and maintain it regularly.
☐ Store and use flammable liquids properly.
☐ Dispose of smoking materials carefully.
☐ Become familiar with local regulations regarding vegetation clearances, disposal of debris, and fire safety requirements for equipment.
☐ Follow manufacturers' instructions when using fertilizers and pesticides.

Access additional information on the Firewise home page: ***www.firewise.org***

Please see the other side of this sheet for the ***Firewise Construction Checklist.***



FIREWISE Construction

Firewise Construction Checklist

When constructing, renovating, or adding to a firewise home, consider the following:

- ☐ Choose a firewise location.
- ☐ Design and build a firewise structure.
- ☐ Employ firewise landscaping and maintenance.

To select a firewise location, observe the following:

- ☐ Slope of terrain; be sure to build on the most level portion of the land, since fire spreads more rapidly on even minor slopes.
- ☐ Set your single-story structure at least 30 feet back from any ridge or cliff; increase distance if your home will be higher than one story.

In designing and building your firewise structure, remember that the primary goals are fuel and exposure reduction. To this end:

- ☐ Use construction materials that are fire-resistant or non-combustible whenever possible.
- ☐ For roof construction, consider using materials such as Class-A asphalt shingles, slate or clay tile, metal, cement and concrete products, or terra-cotta tiles.
- ☐ Constructing a fire-resistant sub-roof can add protection as well.
- ☐ On exterior wall facing, fire resistive materials such as stucco or masonry are much better choices than vinyl which can soften and melt.
- ☐ Window materials and size are iimportant. Smaller panes hold up better in their frames than larger ones. Double pane glass and tempered glass are more relaible and effective heat barriers than single pane glass. Plastic skylights can melt.
- ☐ Install non-flammable shutters on windows and skylights.
- ☐ To prevent sparks from entering your home through vents, cover exterior attic and underfloor vents with wire screening no larger than 1/8 of an inch mesh. Make sure undereave and soffit vents are as close as possible to the roof line. Box in eaves, but be sure to provide adequate ventilation to prevent condensation.
- ☐ Include a driveway that is wide enough to provide easy access for fire engines (12 feet wide with a vertical clearance of 15 feet and a slope that is less than 5 percent) . The driveway and access roads should be well-maintained, clearly marked, and include ample turnaround space near the house. Also provide easy access to fire service water supplies, whenever possible.
- ☐ Provide at least two ground level doors for easy and safet exit and at least two means of escape (i.e., doors or windows) in each room so that everyone has a way out.
- ☐ Keep gutters, eaves, and roofs clear of leaves and other debris.
- ☐ Make periodic inspections of your home, looking for deterioration such as breaks and spaces between roof tiles, warping wood, or cracks and crevices in the structure.
- ☐ Periodically inspect your property, clearing dead wood and dense vegetation at distance of at least 30 feet from your house. Move firewood away from the house or attachments like fences or decks.

Any structures attached to the house, such as decks, porches, fences, and outbuildings should be considered part of the house. These structures can act as fuel bridges, particularly if constructed from flammable materials. Therefore, consider the following:

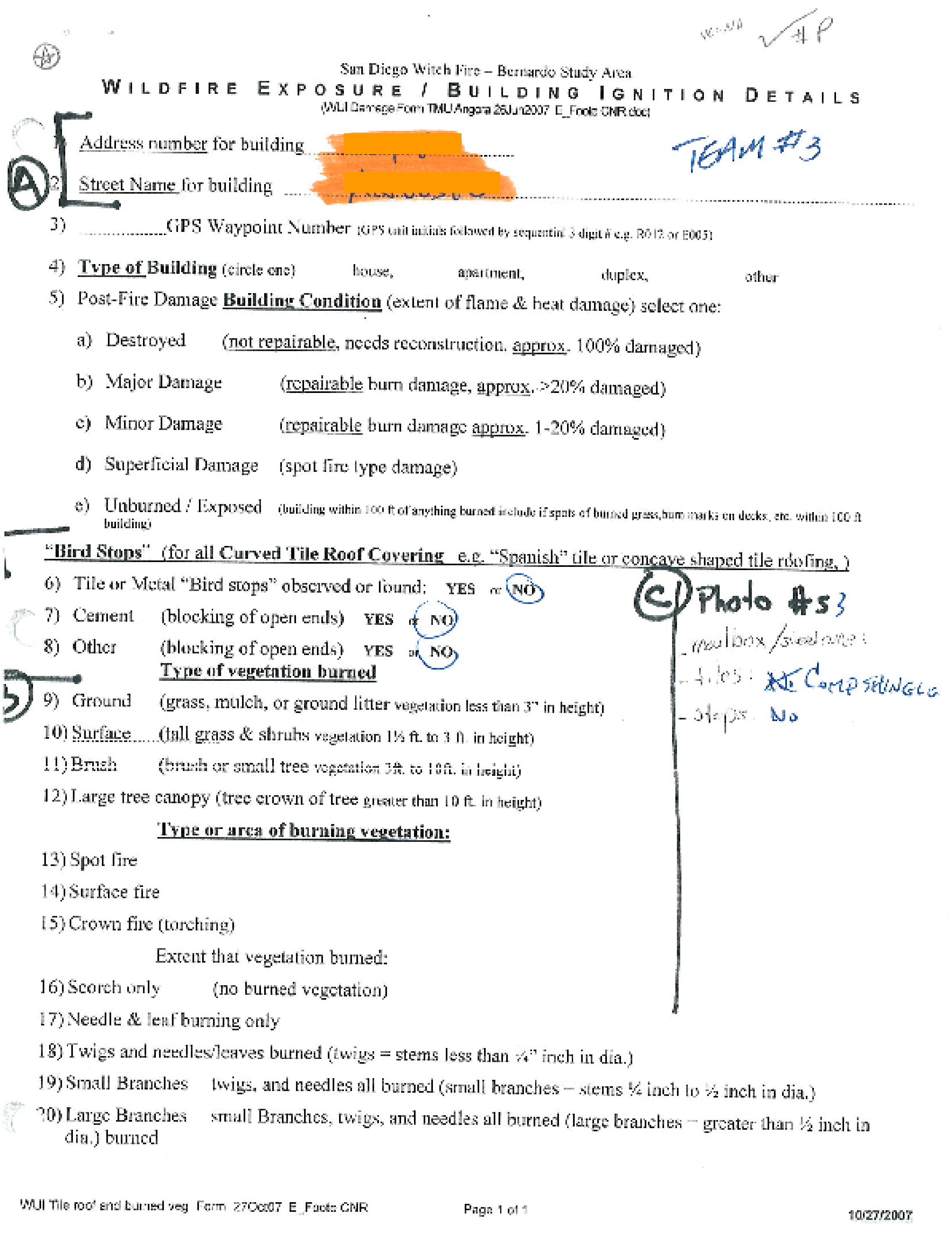
- ☐ If you wish to attach an all-wood fence to your house, use masonry or metal as a protective barriers between the fence and house.
- ☐ Use metal when constructing a trellis and cover it with high-moisture, low flammability vegetation.
- ☐ Prevent combustible materials and debris from accumulating beneath patio decks or elevated porches. Screen or box-in areas below patios and decks with wire screen no larger than 1/8 inch mesh.
- ☐ Make sure an elevated wooden deck is not located at the top of a hill where it will be in direct line of a fire moving up slope. Consider a terrace instead.

Access additional information on the Firewise home page: ***www.firewise.org***

Please see the other side of this sheet for the ***Firewise Landscaping Checklist.***

Appendix C

NIST Field Data Collection Used for Assessing 74 Destroyed Structures



✓ #P

San Diego Witch Fire – Bernardo Study Area

WILDFIRE EXPOSURE / BUILDING IGNITION DETAILS

(WUI Damage Form TMU Angora 26Jun2007 E_Foote CNR.doc)

TEAM #3

Ⓐ

1) Address number for building [redacted]

2) Street Name for building [redacted]

3) ....GPS Waypoint Number (GPS unit initials followed by sequential 3 digit # e.g. R012 or E005)

4) **Type of Building** (circle one) house, apartment, duplex, other

5) Post-Fire Damage **Building Condition** (extent of flame & heat damage) select one:

a) Destroyed (not repairable, needs reconstruction, approx. 100% damaged)

b) Major Damage (repairable burn damage, approx. >20% damaged)

c) Minor Damage (repairable burn damage approx. 1-20% damaged)

d) Superficial Damage (spot fire type damage)

e) Unburned / Exposed (building within 100 ft of anything burned include if spots of burned grass, burn marks on decks, etc. within 100 ft building)

"Bird Stops" (**for all Curved Tile Roof Covering** e.g. "Spanish" tile or concave shaped tile roofing.)

6) Tile or Metal "Bird stops" observed or found; **YES** or [✓ **NO**]

7) Cement (blocking of open ends) **YES** or [✓ **NO**]

8) Other (blocking of open ends) **YES** or [✓ **NO**]

Type of vegetation burned

9) Ground (grass, mulch, or ground litter vegetation less than 3" in height)

10) Surface (tall grass & shrubs vegetation 1½ ft. to 3 ft. in height)

11) Brush (brush or small tree vegetation 3ft. to 10ft. in height)

12) Large tree canopy (tree crown of tree greater than 10 ft. in height)

Type or area of burning vegetation:

13) Spot fire

14) Surface fire

15) Crown fire (torching)

Extent that vegetation burned:

16) Scorch only (no burned vegetation)

17) Needle & leaf burning only

18) Twigs and needles/leaves burned (twigs = stems less than ¼" inch in dia.)

19) Small Branches twigs, and needles all burned (small branches – stems ¼ inch to ½ inch in dia.)

20) Large Branches small Branches, twigs, and needles all burned (large branches – greater than ½ inch in dia.) burned

Ⓒ Photo #s 3

- mailbox / sidewalk :
- tiles : ~~NO~~ Comp SHINGLE
- steps : No

WUI Tile roof and burned veg Form 27Oct07 E_Foote CNR Page 1 of 1 10/27/2007

M4-7

●

FIRE SPREAD N/E

APPEARS PATIO ON EAST END
WAS CONTRIBUTING FACTOR

● 12968 - FIRE SPREAD N/E & N/W
𝍸 𝍸 TREES X𝍸 |

𝍸 | TREES

Appendix D

NIST Field Data Collection Used for Assessing 168 Non-Destroyed Structures

ADDRESS: ________________________ **DATE:** _______ **TEAM #:**_____

Pictures First to Last	**Issue**	**Yes, No, N/A**	**Comments**
Zone 1 is closest to the structure; Zones 2-4 move progressively further away			
	Zone 1. This well-irrigated area encircles the structure for at least 30' on all sides. *(If one side or section does not meet this it is a "No")*	**Yes, No, N/A**	
	Zone 1. Provide space for fire suppression equipment in the event of an emergency.	**Yes, No, N/A**	
	Zone 1. Plantings should be limited to carefully spaced low flammability species.	**Yes, No, N/A**	
	Zone 2. Low flammability plant materials should be used here. Plants should be low-growing, and the irrigation system should extend into this section.	**Yes, No, N/A**	
	Zone 3. Place low-growing plants and well-spaced trees in this area, remembering to keep the volume of vegetation (fuel) low.	**Yes, No, N/A**	
	Zone 4. This furthest zone from the structure is a natural area. Selectively prune and thin all plants and remove highly flammable vegetation.	**Yes, No, N/A**	
	Take out the "ladder fuels" — vegetation that serves as a link between grass and tree tops.	**Yes, No, N/A**	
	Provide added protection with "fuel breaks" like driveways, gravel walkways, and lawns.	**Yes, No, N/A**	
Maintaining a landscape:			
	Keep trees and shrubs properly pruned. Prune all trees so the lowest limbs are 6' to 10' from the ground.	**Yes, No, N/A**	
	Remove leaf clutter and dead and overhanging branches.	**Yes, No, N/A**	
	Store firewood away from the house.	**Yes, No, N/A**	

NIST FIELD DATA COLLECTION FORM (PAGE 2)

Selecting a firewise location:			
	Slope of terrain; be sure to build on the most level portion of the land	**Yes, No, N/A**	
	Set your single-story structure at least 30 feet back from any ridge or cliff; increase distance if your home will be higher than one story.	**Yes, No, N/A** **If Yes Specify Setback:___ ft**	
In designing and building your firewise structure, the primary goals are fuel and exposure reduction			
	Use construction materials that are fire-resistant or non-combustible whenever possible. (*Any wood (deck/pergola, fence) within 30 ft is a "No")*		
	For roof construction, consider using materials such as Class-A asphalt shingles, slate or clay tile, metal, cement and concrete products, or terra-cotta tiles.		
	On exterior wall facing, fire resistive materials such as stucco or masonry are much better choices than vinyl which can soften and melt.		
	Driveway that is 12 feet wide with a vertical clearance of 15 feet and a slope that is less than 5 percent and include ample turnaround space near the house.		
Any structures attached to the house, such as decks, porches, fences, and outbuildings should be considered part of the house. These structures can act as fuel bridges, particularly if constructed from flammable materials.			
	Periodically inspect your property, clearing dead wood and dense vegetation at distance of at least 30 feet from your house.		
	Move firewood away from the house or attachments like fences or decks.		
	If you wish to attach an all-wood fence to your house, use masonry or metal as protective barriers between the fence and house.		
	Prevent combustible materials and debris from accumulating beneath patio decks or elevated porches.		
	Screen or box-in areas below patios and decks with wire screen no larger than 1/8 inch mesh.		
	Make sure an elevated wooden deck is not located at the top of a hill where it will be in direct line of a fire moving up slope.		

Appendix E

Derivation of dNDVI Data Set

Change in greenness can be derived from the remote sensing image sources listed above by exploiting the difference between the spectral response of healthy green vegetation in the near infrared and red portions of the electromagnetic spectrum. The individual bands of imagery collected in the NAIP and post-fire imagery can be manipulated through the derivation of the Normalized Difference Vegetation Index (NDVI) as shown in equation A.

$$NDVI = \left(\frac{Near\ Infrared\ Band\ \text{-}\ Red\ Band}{Near\ Infrared\ Band + Red\ Band}\right) \qquad \textbf{Equation A}$$

Near Infrared Band is the spectral response in the near infrared portion of the electromagnetic spectrum as recorded by the respective sensor. *Red Band* is the spectral response in the red portion of the electromagnetic spectrum as recorded by the respective sensor.

The NDVI equation produces a range of values between -1 and 1. Generally speaking, values below zero represent areas where there is little photosynthetically active vegetation. Values above 0.2 typically represent areas with photosynthetically active vegetation. Values between -0.1 and 0.2 might represent features such as soil, rock and water. Assuming that the near infrared reflectance of burned vegetation decreases after a fire; pre- and post-fire NDVI data sets can be differenced to derive a change in NDVI product (dNDVI). The NDVI also helps to compensate for both in scene variations in imagery based on topography and between scene variation based on differences in flight season and time of day. The assumption of near infrared reflectance decreasing after a vegetation fire, however, is not always true when complete combustion occurs and is evidenced by white ash (Smith et al. 2005) [xxiii]. The wildlands surrounding the Trails also contained alkaline areas that experienced stand replacing fires where white areas might have been white ash but could have been exposed mineral soils. NDVI can also be influenced by shadows and/or clouds. Phenological differences in vegetation between image acquisition dates can also affect changes in NDVI. Finally, image differencing and calibration techniques might introduce errors.

Appendix F

Two-way Contingency Tables for Firewise Treatments with No Association Between Structure Survivability and Treatment Presence

Treatment 1c: Plantings should be limited to carefully spaced low flammability species for at least 30'.

	Undamaged Structures	Damaged/ Destroyed Structures	Total
Fail	121	70	191
Pass	31	11	42
Total	152	81	233
Firewise Treatment 1c: p-value = 0.1975			

Treatment 6: Take out the "ladder fuels" — vegetation that serves as a link between grass and tree tops.

	Undamaged Structures	Damaged/ Destroyed Structures	Total
Fail	114	67	181
Pass	33	12	45
Total	147	79	226
Firewise Treatment 6: p-value = 0.224			

Treatment 11: Slope of terrain; be sure to build on the most level portion of the land.

	Undamaged Structures	Damaged/ Destroyed Structures	Total
Fail	9	1	10
Pass	144	90	234
Total	153	91	244
Firewise Treatment 11: p-value = 0.096			

Treatment 14: For roof construction, consider using materials such as Class-A asphalt shingles, slate or clay tile, metal, cement and concrete products, or terra-cotta tiles.

	Undamaged Structures	Damaged/ Destroyed Structures	Total
Fail	0	13	13
Pass	152	77	229
Total	152	90	242
Firewise Treatment 11: No p-value exists			

Treatment 15: On exterior wall facing, fire resistive materials such as stucco or masonry are much better choices than vinyl which can soften and melt.

	Undamaged Structures	Damaged/ Destroyed Structures	Total
Fail	30	16	46
Pass	122	67	189
Total	152	83	235
Firewise Treatment 15: p-value = 0.9323			

Treatment 18: Move firewood away from the house or attachments like fences or decks.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	20	39	59
Pass	21	31	52
Total	41	70	111
Firewise Treatment 18: p-value = 0.556			

Treatment 20: Prevent combustible materials and debris from accumulating beneath patio decks or elevated porches.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	27	9	36
Pass	47	6	53
Total	74	15	89
Firewise Treatment 20: p-value = 0.0906			

Treatment 21: Screen or box-in areas below patios and decks with wire screen no larger than 1/8 inch mesh.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	48	23	71
Pass	6	4	10
Total	54	27	81
Firewise Treatment 21: p-value = 0.6329			

Treatment 22: Make sure an elevated wooden deck is not located at the top of a hill where it will be in direct line of a fire moving up slope.

	Undamaged Structures	**Damaged/ Destroyed Structures**	**Total**
Fail	22	22	44
Pass	11	2	13
Total	33	24	57
Firewise Treatment 22: p-value = 0.02635			

Appendix G

Three-way Contingency Tables for Firewise Treatments with No Association between Structure Survivability and Exposure Delineation, and Treatment Presence

Treatment 1c: Plantings should be limited to carefully spaced low flammability species for at least 30’.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	27 (46%)	32 (54%)	59	**Fail**	94 (71%)	38 (29%)	132
Pass	31 (84%)	6 (16%)	37	**Pass**	31 (86%)	5 (14%)	36
Total	58 (60%)	38 (40%)	96	**Total**	125 (74%)	43 (26%)	168
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	7 (21%)	26 (79%)	33	**Fail**	114 (72%)	44 (28%)	158
Pass	31 (94%)	2 (6%)	33	**Pass**	31 (78%)	9 (23%)	40
Total	31 (58%)	28 (42%)	66	**Total**	145 (73%)	53 (27%)	198

Treatment 6: Take out the “ladder fuels” — vegetation that serves as a link between grass and tree tops.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	114 (78%)	32 (22%)	146	**Fail**	114 (77%)	35 (23%)	149
Pass	33 (73%)	12 (27%)	45	**Pass**	33 (73%)	12 (27%)	45
Total	147 (77%)	44 (23%)	191	**Total**	147 (76%)	47 (24%)	194
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	114 (83%)	24 (17%)	138	**Fail**	114 (72%)	44 (28%)	158
Pass	33 (73%)	12 (27%)	45	**Pass**	33 (73%)	12 (27%)	45
Total	147 (80%)	36 (20%)	183	**Total**	147 (72%)	56 (28%)	203

Treatment 10: Storing firewood away from the house a minimum of 30 ft.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	5 (16 ± 12%)	27 (84 ± 12%)	32	**Fail**	14 (35 ± 14%)	26 (65 ± 14%)	40
Pass	5 (63 ± 35%)	3 (37 ± 35%)	8	**Pass**	12 (60 ± 20%)	8 (40 ± 20%)	20
Total	10 (25 ± 13%)	30 (75 ± 13%)	40	**Total**	26 (42 ± 12%)	34 (58 ± 12%)	60
FW10: p-value = 0.003 (**), perimeter: p-value = 0.14 – The perimeter is not significant for this attribute							
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	0	19	19	**Fail**	19 (36 ± 13%)	34 (64 ± 13%)	53
Pass	1 (20 ± 35%)	4 (80± 35%)	5	**Pass**	16 (70 ± 18%)	7 (30 ± 18%)	23
Total	1 (4 ± 8%)	23 (96 ± 8%)	24	**Total**	35 (46 ± 11%)	41 (54 ± 11%)	76
FW10: p-value = 0.002 (**), exposure: p-value = 0.004(**)							

Treatment 11: Slope of terrain; be sure to build on the most level portion of the land.

Property on Perimeter				Property in Interior			
	Undamaged	Damaged & Destroyed	Total		Undamaged	Damaged & Destroyed	Total
Fail	2 (100%)	0 (0%)	2	**Fail**	7 (88%)	1 (13%)	8
Pass	35 (45%)	43 (55%)	78	**Pass**	108 (70%)	46 (30%)	154
Total	37 (46%)	43 (54%)	180	**Total**	115 (71%)	47 (29%)	162
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	Damaged & Destroyed	Total		Undamaged	Damaged & Destroyed	Total
Fail	0 (--%)	0 (--%)	0	**Fail**	9 (90%)	1 (10%)	10
Pass	10 (77%)	33 (23%)	43	**Pass**	133 (70%)	56 (30%)	189
Total	10 (77%)	33 (23%)	43	**Total**	142 (71%)	57 (29%)	199

Treatment 13: Use construction materials that are fire-resistant or non-combustible whenever possible.

Property on Perimeter				Property in Interior			
	Undamaged	Damaged & Destroyed	Total		Undamaged	Damaged & Destroyed	Total
Fail	34 (45%)	41 (55%)	75	**Fail**	99 (72%)	39 (28%)	138
Pass	3 (60%)	2 (40%)	5	**Pass**	16 (94%)	1 (6%)	17
Total	37 (46%)	43 (54%)	80	**Total**	115 (74%)	40 (26%)	155
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	Damaged & Destroyed	Total		Undamaged	Damaged & Destroyed	Total
Fail	10 (24%)	31 (76%)	41	**Fail**	3 (50%)	3 (50%)	64
Pass	0 (0%)	1 (100%)	1	**Pass**	7 (78%)	2 (22%)	129
Total	10 (24%)	32 (76%)	42	**Total**	4 (44%)	5 (56%)	193

Treatment 14: For roof construction, consider using materials such as Class-A asphalt shingles, slate or clay tile, metal, cement and concrete products, or terra-cotta tiles.

Property on Perimeter				Property in Interior			
	Undamaged	Damaged & Destroyed	Total		Undamaged	Damaged & Destroyed	Total
Fail	0 (0%)	3 (100%)	3	**Fail**	0 (0%)	10 (100%)	10
Pass	37 (48%)	40 (52%)	77	**Pass**	115 (76%)	37 (24%)	152
Total	37 (46%)	43 (54%)	80	**Total**	115 (71%)	47 (29%)	162
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	Damaged & Destroyed	Total		Undamaged	Damaged & Destroyed	Total
Fail	0 (0%)	4 (100%)	4	**Fail**	0 (0%)	9 (100%)	9
Pass	10 (26%)	29 (74%)	39	**Pass**	142 (75%)	48 (25%)	190
Total	10 (23%)	33 (77%)	43	**Total**	142 (71%)	57 (29%)	199

Treatment 15: On exterior wall facing, fire resistive materials such as stucco or masonry are much better choices than vinyl which can soften and melt.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	4 (50%)	4 (50%)	8	**Fail**	25 (66%)	13 (34%)	38
Pass	33 (49%)	35 (51%)	68	**Pass**	90 (74%)	31 (26%)	121
Total	37 (49%)	39 (51%)	76	**Total**	115 (72%)	44 (28%)	159
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	2 (33%)	4 (67%)	6	**Fail**	28 (70%)	12 (30%)	40
Pass	8 (24%)	25 (76%)	33	**Pass**	114 (73%)	42 (27%)	156
Total	10 (26%)	29 (74%)	39	**Total**	142 (72%)	54 (28%)	196

Treatment 20: Prevent combustible materials and debris from accumulating beneath patio decks or elevated porches.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	7 (64%)	4 (36%)	11	**Fail**	20 (80%)	5 (20%)	25
Pass	18 (82%)	4 (18%)	22	**Pass**	30 (97%)	1 (3%)	31
Total	25 (76%)	8 (24%)	33	**Total**	50 (89%)	6 (11%)	56
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged Structures	**Damaged & Destroyed**	**Total**		**Undamaged Structures**	**Damaged & Destroyed**	**Total**
Fail	2 (40%)	3 (60%)	5	**Fail**	25 (81%)	6 (19%)	31
Pass	6 (75%)	2 (25%)	8	**Pass**	41 (91%)	4 (9%)	45
Total	8 (62%)	5 (38%)	13	**Total**	66 (87%)	10 (13%)	76

Treatment 21: Screen or box-in areas below patios and decks with wire screen no larger than 1/8 inch mesh.

Property on Perimeter				**Property in Interior**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	18 (55%)	15 (45%)	33	**Fail**	30 (79%)	8 (21%)	38
Pass	1 (25%)	3 (75%)	4	**Pass**	5 (83%)	1 (17%)	6
Total	19 (51%)	18 (49%)	37	**Total**	35 (80%)	44 (20%)	44
Property with High Hazard Area				**Property with Low Hazard Area**			
	Undamaged	**Damaged & Destroyed**	**Total**		**Undamaged**	**Damaged & Destroyed**	**Total**
Fail	8 (38%)	13 (62%)	21	**Fail**	40 (80%)	10 (20%)	50
Pass	0 (0%)	2 (100%)	2	**Pass**	6 (75%)	2 (25%)	8
Total	8 (35%)	15 (65%)	23	**Total**	46 (79%)	12 (21%)	58

Treatment 22: Make sure an elevated wooden deck is not located at the top of a hill where it will be in direct line of a fire moving up slope.

Property on Perimeter			
	Undamaged	**Damaged & Destroyed**	**Total**
Fail	12 (43%)	16 (57%)	28
Pass	6 (75%)	2 (25%)	8
Total	18 (50%)	18 (50%)	36

Property in Interior			
	Undamaged	**Damaged & Destroyed**	**Total**
Fail	10 (63%)	6 (38%)	5
Pass	5 (100%)	0 (0%)	1
Total	15 (71%)	6 (29%)	6

Property with High Hazard Area			
	Undamaged	**Damaged & Destroyed**	**Total**
Fail	6 (29%)	15 (71%)	21
Pass	2 (67%)	1 (33%)	3
Total	8 (33%)	16 (67%)	24

Property with Low Hazard Area			
	Undamaged	**Damaged & Destroyed**	**Total**
Fail	16 (70%)	7 (30%)	23
Pass	9 (90%)	1 (10%)	10
Total	25 (76%)	8 (24%)	33

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