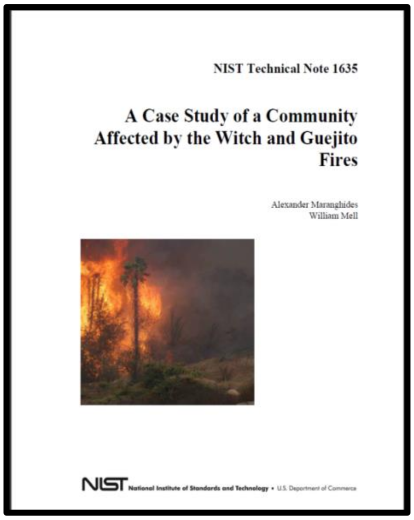
Evaluating the Effectiveness of Mitigations Activities in the Wildland Urban Interface, Final Report JFSP Project ID: 11-1-3-29

Alexander Maranghides

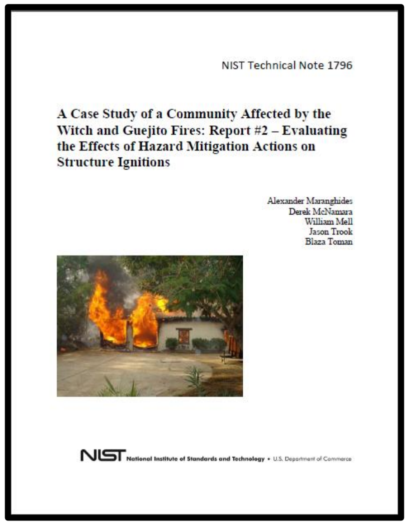


NIST Technical Note 1635

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

Alexander Maranghides
William Mell

NIST National Institute of Standards and Technology • U.S. Department of Commerce

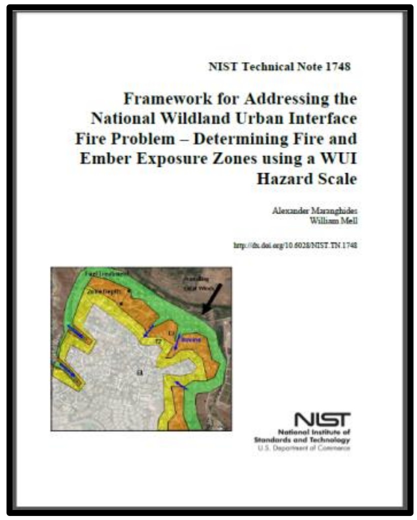


NIST Technical Note 1796

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

Alexander Maranghides
Derek McNamara
William Mell
Jason Trook
Blaza Toman

NIST National Institute of Standards and Technology • U.S. Department of Commerce



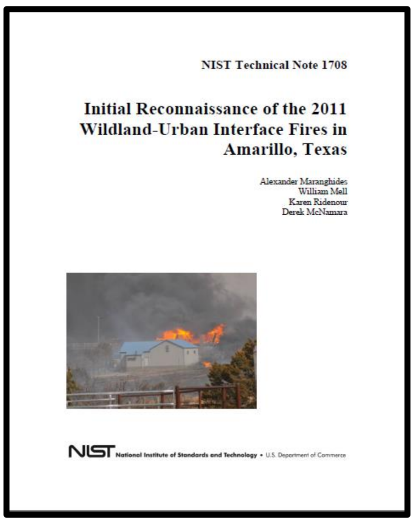
NIST Technical Note 1748

Framework for Addressing the National Wildland Urban Interface Fire Problem – Determining Fire and Ember Exposure Zones using a WUI Hazard Scale

Alexander Maranghides
William Mell

http://dx.doi.org/10.6028/NIST.TN.1748

NIST National Institute of Standards and Technology U.S. Department of Commerce

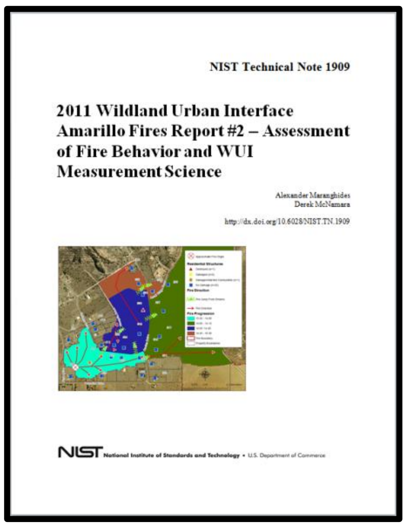


NIST Technical Note 1708

Initial Reconnaissance of the 2011 Wildland-Urban Interface Fires in Amarillo, Texas

Alexander Maranghides
William Mell
Karen Ridenour
Derek McNamara

NIST National Institute of Standards and Technology • U.S. Department of Commerce



NIST Technical Note 1909

2011 Wildland Urban Interface Amarillo Fires Report #2 – Assessment of Fire Behavior and WUI Measurement Science

Alexander Maranghides
Derek McNamara

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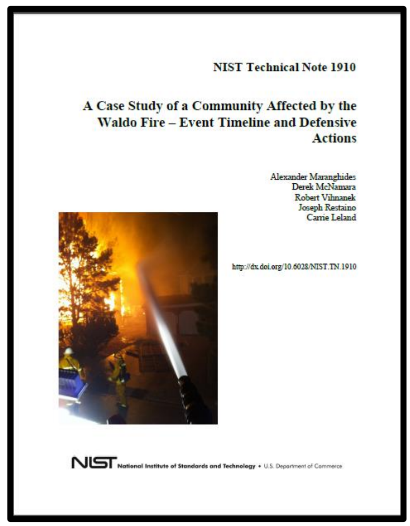

NIST Technical Note 1910

A Case Study of a Community Affected by the Waldo Fire – Event Timeline and Defensive Actions

Alexander Maranghides
Derek McNamara
Robert Vihnanek
Joseph Restaino
Carrie Leland

http://dx.doi.org/10.6028/NIST.TN.1910

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JOINT FIRE SCIENCE PROGRAM

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1. Project Overview

There has been relatively little research on Wildland-Urban Interface (WUI) fire spread, compared to fires within structures, despite the increasing frequency and losses from WUI fires. This is due, in part, to the fact that the subject of WUI fire research falls between traditional studies of building fires and forest fires, non-overlapping areas that in the past have been the responsibility of different government agencies. To date, no study that measures the effectiveness of current risk mitigation practices, whether through wildland fuel treatments or modification of residential fuels, has been conducted in the context of reducing WUI community hazards.

This JFSP Grant was utilized, together with resources from US Forest Service (USFS) and National Institute of Standards and Technology (NIST), to deploy to two WUI fire events and conduct two detailed WUI case studies. Previous work conducted by NIST on the Witch/Guejito fire was also used to assess hazard mitigation effectiveness and is included here. Additionally, as a result of the Witch/Guejito fire case study, a framework was developed to quantify fire and ember exposure at the WUI and to link exposure to design and material guidance for structures in the WUI. The framework is outlined in NIST Technical Note 1748, Framework for Addressing the National Wildland Urban Interface Fire Problem – Determining Fire and Ember Exposure zones using a WUI Hazard Scale.

This JFSP project final report summarizes the technical findings and recommendations for reducing losses in the WUI through implementable hazard mitigation solutions and first responder response. Detailed information on the findings and research recommendations can be found in the five published reports. Reports on all three case studies can be found on the NIST website publication portal.[a] The primary technology transfer activities associated with this project are summarized in Appendix A. This project started on 10/01/2011 and was completed on 09/30/2015.

2. Primary Grant Efforts - Case Studies of three WUI Fires

Hazard mitigation in the WUI has been investigated in three fires: the Witch/Guejito (CA, 2007), the Tanglewood Complex (TX, 2011) and the Waldo (CO, 2013). Detailed investigations were conducted at each fire. The technical findings learned from all three case studies are summarized in section 4 of this report. All three case studies were done in partnership with local fire departments and other Federal, state and local agencies listed in Section 5 of this report.

2.1. Witch/Guejito Fires

The Witch/Guejito fire case study was initiated before this JFSP project, and the first report, NIST Technical Note 1635, *A Case Study of a Community Affected by the Witch and Guejito*

[a] http://www.nist.gov/publication-portal.cfm

Fires, was issued before this JFSP project was started. The second Witch/Guejito report, NIST Technical Note 1796, *A Case Study of a Community Affected by the Witch and Guejito Fires: Report #2* was issued after this JFSP effort was started. While the report was not funded by JFSP, due to timing, the work presented in this report is directly related to the JFSP funded research on evaluating the effectiveness of mitigation activities in the WUI. This case study was focused on a community affected by both fires, and the effort was the result of collaboration between NIST, California Department of Forestry and Fire Prevention (CALFIRE) and San Diego Fire and Rescue. The Witch/Guejito fire was responsible for two fatalities and for destroying 1650 structures. The Witch/Guejito case study focused on the Trails community of 283 residential lots with 274 residences at the time of the fires. There were 245 residences within the fire line, and these structures comprised the domain of the case study.

The Witch/Guejito case study identified three primary findings:

1. A data collection methodology was necessary to document the WUI fire scene.
2. The fire scene cannot be reliably interpreted without accounting for exposure and defensive actions.
3. A scale should be formulated to quantify fire and ember exposures.

As a result of the first Witch/Guejito report, and before work could be conducted to analyze the effectiveness of mitigation solutions in the second report, a framework for a WUI Exposure scale was articulated in NIST TN 1748, *Framework for Addressing the National Wildland Urban Interface Fire Problem – Determining Fire and Ember Exposure Zones using a WUI Hazard Scale.* Additionally, a data collection methodology was developed, data collection partners were identified and trained and equipment was forward deployed in anticipation of the next WUI fire case study in Texas. The findings from the Witch/Guejito Investigation are found in Appendix B.

2.2. Tanglewood Complex Fire

In 2010 Texas Forest Service (TFS) data collectors were trained in Bastrop, Texas on the NIST WUI 1 and WUI 2 data collection methodology. NIST WUI field data collection kits were then positioned in Bastrop, Texas in preparation for response to a WUI fire. On February 27, 2011, a series of fires destroyed homes in the WUI surrounding the City of Amarillo. Texas Forest Service (TFS) and NIST dispatched a joint WUI data collection task force to Amarillo. Data collection focused on two fires, the Tanglewood Complex and the Willow Creek fires. The Tanglewood Complex fire was responsible for the destruction of approximately 101 structures including 35 residences.

The NIST WUI field data collection method was used for the first time in a field deployment, where it was integrated into the Incident Command System (ICS), logistics and standard operating procedures (SOPs). Field measurements included structure particulars, specifically building construction materials, type of combustibles and proximity of combustibles to the structure, and damage to wildland and residential vegetation. Documentation included over 29 000 photographs. The data collection and initial analysis was conducted jointly with TFS. Soon after arriving in Amarillo, the Tanglewood Complex fire became the primary fire of interest and the focus of the data collection effort.

The Tanglewood Complex fire data collection and analysis processes were run continuously for 21 days. The daily safety brief was conducted at 07:00 am. The tablet PCs were subsequently loaded and field data collection was conducted during daylight hours. Post field work included data transfer and handling. Overnight work was conducted to check data into the database, check data out of the database, create field maps and perform a limited quality assurance/ quality control (QA/QC).

The Tanglewood Complex Fire case study identified five primary findings:

1. Data should be collected on all structures within the fire perimeter.
2. Data collection should be conducted in a standardized fashion.
3. An incident centric data repository is needed to document WUI losses and effectiveness of hazard mitigation at a national level.
4. Exposure to fire and embers can vary very significantly over very small scales (<5 m).
5. Pre-fire data is critical for assessing hazard mitigation effectiveness.

The full set of technical findings and recommendations from the Amarillo fires is presented in Appendix C.

2.3. Waldo Fire

The Waldo fire affected three Colorado Springs communities: Cedar Heights, Mountain Shadows and Peregrine. All 344 destroyed structures were in the Mountain Shadows community. The Cedar Heights community experienced no structural losses or damage,[b] while certain Peregrine homes experienced only relatively minor damage. The main focus of investigation was the Mountain Shadows community.

The primary objectives of the research were to reconstruct the fire timeline and show where the fire was in the community as a function of time, document the extent and type of defensive actions that were undertaken during the first ten hours after the Waldo Fire reached the Mountain Shadows community, quantify structural losses as related to local weather conditions and begin the characterization of fire and ember exposures from burning structures. 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.

The Waldo case study identified four primary findings:

1. Defensive actions were effective in suppressing burning structures and containing the Waldo Canyon fire.

[b] Damage here refers to fire and/or ember damage on a residential structure and does not include smoke damage, which could affect structures within as well as outside the fire perimeter.

2. Pre-fire planning is essential to enabling safe, effective, and rapid deployment of firefighting resources in WUI fires. Effective pre-fire planning requires a better understanding of exposure and vulnerabilities. This is necessary because of the very rapid spread of fire during WUI fires.
3. Current concepts of defensible space do not account for hazards of burning primary structures, hazards presented by embers and the hazards outside of the home ignition zone.
4. During and/or shortly after an incident, with limited damage assessment resources available, the collection of structure damage data will enable the identification of structure ignition vulnerabilities.

The full set of technical findings and recommendations from the Waldo fire is presented in Appendix D.

2.4. Overview of Three Case Studies

The Witch/Guejito case study focused on the Trails community in San Diego. The Trails community was almost entirely affected by the Witch and Guejito fires and had significant structural losses.[c] The data collection, conducted in partnership with CALFIRE and San Diego Fire and Rescue, and the subsequent data analysis highlighted the need for a WUI data collection methodology, and such a methodology was developed. The next case study was conducted in Amarillo Texas in partnership with the Texas Forest Service (TFS). TFS was trained on the data collection methodology and teams were deployed to investigate the Tanglewood Complex fire. The size of the fire enabled the response teams to investigate the entire fire. While the fire was a relatively small WUI fire, looking at the entire incident provided technical information that was not available during the Witch/Guejito case study, both in the context of exposure and defensive actions. The third case study, the Waldo fire in Colorado Springs, CO, also investigated the entire fire. While resources had not been trained to respond rapidly and collect field data right after the incident, significant data was available in the form of photographic and video documentation of the fire. This information together with data from the Automatic Vehicle Location (AVL)[d] system of the Colorado Springs Fire Department (CSFD) and the CSFD radio logs was able to provide a clear picture of what occurred across the majority of the incident. As in Amarillo, the Waldo fire investigation focused on the entire fire, which in Colorado Springs destroyed 346 destroyed homes. Table 1 provides a summary of all three investigations.

[c] It was necessary to select a community as the Witch/Guejito fires resulted in 1650 destroyed structures and encompassed approximately 10 000 structures within the fire line. The scale of the entire incident was beyond the resources available to conduct the investigation.

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

	Witch/Guejito – Trails Community	Tanglewood Complex	Waldo – Mountain Shadows Community	Waldo – Peregrine Community
Structures within fire perimeter (approximate numbers)	10 000	200	1700	1700
Fatalities	2	0	2	0
Destroyed structures within fire perimeter	1650	35	344	0
Structures within study domain (Exposed structures)	245	183	1204	50
Destroyed structures within study domain	74	35	344	0
Damaged	16	13	99	3
Damaged and Defended/ Damaged structures (fraction) within study domain	15/16 (0.94)	11/13 (0.85)	90/99(.93)	3/3 (1.0)
Damaged and Destroyed/Exposed fraction within study domain	0.37	0.26	0.37	0.06
Type of community	Interface	Interface	Interface	Interface
Structures Defended	85	82	170	50
Max. Apparatus on Location	6	21	69	15
Wind (km/hr)	50 gusting to 80	65 gusting to 100	50 gusting to 65	65 gusting to 100
Defended/Exposed within Study Domain	0.35	0.45	0.14	1
Max. Apparatus/Damaged and Destroyed Structures	0.07	0.44	0.16	5.00
Apparatus/Exposed Structures	0.02	0.11	0.06	0.30
Defended/(Destroyed+ Damaged)	0.9	1.7	0.4	16.7
Relative Humidity	<10%	<10 %	<10 % increasing to 30%	20% increasing to 30%
Terrain	Complex	Complex	Complex	Complex
Ignition Location	Outside community	Inside Community	Outside Community	Outside Community
Initial Exposure to Community	Fire Front	Point source	Fire Front	Fire Front

Table 1: Summary of Three Case Studies

3. Hazard Mitigation in the Three Studied Communities

None of the three communities evaluated had a complete community wide hazard reduction system implemented. At the Trails community in CA, while there was no formal hazard reduction system implemented, many properties had well irrigated and maintained landscaping. At the Tanglewood Complex fire, at least one community affected by the fire has a WUI fire hazard evaluation conducted by first responders, and hazard mitigation material was distributed to the community. This evaluation had taken place in the year prior to the fire. In Colorado, the Colorado Springs Fire Department has an active hazard mitigation program. The program is voluntary. Like in the Trails in CA, in the Mountain Shadows community in CO many homes had well irrigated and maintained lots.

The primary technical challenge with assessing the effectiveness of hazard mitigation solutions, identified during the Witch/Guejito fire data analysis, was that an evaluation could not be reliably conducted in the absence of data on fire and ember exposure and defensive actions. In order to analyze the data collected during the Witch/Guejito fire, therefore, a methodology had to be developed to quantify exposure at a parcel level. While this was demonstrated at the Trails community, it was determined that extensive work needs to be conducted to quantify exposure from both embers and fire.

Exposure quantification needs to be conducted both in controlled environments, such as prescribed burns, and in wildfire/WUI fire settings. Only then can this exposure data, together with defensive actions during the event as well as pre-fire and post-fire data, be used to look at specific hazard mitigation failures as well as successes. This part of the WUI fire problem reduction cannot be further simplified, and the above technical plan is necessary to ensure reliable guidance for homeowners and first responders.

The second Witch/Guejito fire report, NIST Technical Note 1796, demonstrated at a parcel level the positive (statistically significant) contributions of several hazard mitigation technologies. The report, however, also identified potentially significant implementation issues of current hazard mitigation practices, such as fuel displacement and the creation of high fuel corridors within the community. For additional information, because of the complexities associated with that data analysis and interpretation, the reader is directed to NIST Technical Note 1796.

Until reliable exposure data is available and mitigation solutions are evaluated under realistic exposures, hazard mitigation should focus on the overall reduction of combustibles. The three case studies demonstrated that timeline reconstruction is essential in deciphering the fire scene, as the end product is a result of many different factors such as multiple fire fronts, wind shifts and defensive actions. In order to reconstruct the event timeline, aerial imagery (pre, during and post-fire), video and pictures, automatic vehicle location systems, radio logs and technical discussions[e] can provide critical insight when integrated into a Geographic Information System

[e] Technical discussions with homeowners who stayed and defended as well as first responders should be complete and inclusive of all personnel on the fire scene during the time of interest. This is necessary as it has been determined that observations and actions can vary significantly in both space and time.

(GIS) database. Such a database enables data storage at a parcel level and provides the ability to link and cross reference data. It was also determined that pre-fire data is critical, and that the absence of such data significantly limits the findings of a detailed case study. This points to the need for a paradigm shift in rapid data collection,[f] where the focus on damaged homes (compared to destroyed) can yield valuable insights into structure vulnerabilities.

The case studies also identified that current hazard mitigation guidance is frequently based on very limited science, and that the information presented to the public can be frequently confusing and occasionally contradicting. Additionally, many building codes/standards and associated test methods are not adequately accounting for the need to harden structures for protection against embers.

Detailed case studies enable a quantitative understanding of hazard mitigation failures, together with the identification of ignition vulnerabilities in the context of fire and ember exposure and defensive actions. Additionally, the extensive data on defensive actions is providing initial insights into defensive action effectiveness. This type of information cannot be reliably collected without the in-depth type reconstructions as conducted in the three investigations discussed here.

The Waldo case study has identified that vegetative fuel treatments guidance, like building and parcel hazard mitigation, should have specific hazard reduction goals and should be tied to the availability of defensive actions. There is a significant difference if a fuel treatment or hazard mitigation solution is designed to work in the presence of defensive actions or if it can operate as a standalone. Fuels reduction, as an example, could have a goal of making the environment tenable for first responders. This goal is very different from one where a specific ember flux is achieved at a given downwind distance in order to reduce the ignition potential of certain fuels by a given fraction.

Lastly, the case studies together with the exposure scale framework have identified a critical disconnect between the way urban building fires and exterior WUI fire are addressed. Interior fires, for the most part, are addressed through the implementation of building codes/standards and test methods. A new commercial building frequently will have sprinklers installed for fire protection. The sprinkler system is the product of sprinkler experiments and developed test methods, which are incorporated into building & fire codes and standards. Furthermore, the system is designed by an accredited fire protection engineer and is reviewed by an accredited building official. Finally, the system is installed by a certified installer. The building tenant is not intimately involved in this process. In essence, a series of professional disciplines are interconnected and together ensure a reliable and quantifiable level of hazard reduction.

In contrast, in the WUI the limited connection between exposure and buildings codes/standards and test methods results in building assemblies that frequently cannot successfully mitigate or survive fire and ember exposures during WUI fires. Additionally, in the WUI the homeowner or

[f] Rapid data collection refers here to activities conducted during and shortly after the WUI fire incident to support the needs of the Public Information Officer and the local residents.

resident may be tasked with reducing their hazard. As a result there is a shift from a professional response infrastructure to one where residents with limited knowledge are given the responsibility to implement hazard mitigation solutions. This responsibility shift is confounded by the fact that in many cases the hazard mitigation guidance may be incomplete and often lacks scientific foundation. A technical approach, as outlined in NIST Technical Note 1748, is aimed at creating a science-based and professionally implemented infrastructure to manage and reduce WUI hazards. Such a professional system, together with clear, consistent and science-based guidance for the public, can significantly improve the built environment in the WUI and reduce long term WUI losses.

4. Future WUI Hazard Mitigation Recommendations– How to Reduce WUI Fire Losses

WUI structural losses due to WUI fires will continue to increase in new and existing construction until science-based/implementable hazard mitigation guidance is developed and provided to the engineers, designers, building officials and first responders. The following needs are aimed at providing an overview on the state of WUI hazard mitigation and ways to reliably reduce future WUI loses. During the transition to a professional infrastructure, additional research needs to be completed to improve the science-based foundation for improving existing homeowner checklists. The following needs are aimed at providing an overview on the state of WUI hazard mitigation and ways to reliably reduce future WUI losses. The source of this information is provided in parentheses.

4.1. Hazard Mitigation

- Additional field data collection studies need to be conducted to provide insight into structural response in both high and low exposure environments (Witch/Guejito).
- The exposure characteristics need to be further developed to enable valid comparisons of structural response within and across incidents (Witch/Guejito).
- The relationship of exposure and structure vulnerability needs to incorporate additional science-based understanding. This will lead to improved testing standards for new construction and improved guidance for retrofit (Witch/Guejito).
- Until a professional infrastructure can be implemented, a science-based checklist needs to be developed to facilitate the implementation of hazard reduction techniques by homeowners. New checklists are required for different scenarios, e.g. intermix[g] versus interface communities; existing construction versus new construction (Witch/Guejito).
- The concept of structure vulnerability needs to be further developed. When coupled with exposure, this approach will yield improved tools for predicting structure destruction (Witch/Guejito).

[g] 2001 Federal Register, 66 FR 753: *The Interface Community exists where structures directly abut wildland fuels.* There is a clear line of demarcation between residential, business, and public structures and wildland fuels. *The Intermix Community exists where structures are scattered throughout a wildland area.* There is no clear line of demarcation; wildland fuels are continuous outside of and within the developed area.

- Building standards and test methods need to be updated to capture representative fire and ember exposures. Adoption of these improved test methods and building codes and standards will reduce WUI losses in new construction (Exposure Scale).
- Hazard mitigation guidance needs to be developed to help reduce hazards in and around existing high risk WUI communities (Waldo).
- Wildland fuel treatment standards needs to be developed that quantify exposure reduction for different topographical and weather conditions (Waldo).
- Ignition vulnerabilities of structures from adjacent combustibles, specifically fences and decks (Amarillo), need to be quantified.

4.2. Hazard Assessment and WUI Data

- Hazard mitigation assessments of limited scope, "drive by" [h]studies, should be be undertaken with caution, as they can generate very erroneous data (Waldo).
- Post-fire damage assessments need to focus on damaged structures and identification of first item(s) ignited in order to gain further insight into construction vulnerabilities (Amarillo, Waldo).
- Pre-fire hazard assessments need to focus on identifying hazards and not prioritizing them. The identification of hazards will aid both homeowners and first responders. Quantification should factor in fuels, topography and local weather. Fuels should include (vegetative) and urban/interface fuels such wood roofs, fences and combustible decks (Exposure Scale, Amarillo, Waldo).
- A standardized WUI data collection system can generate consistent national WUI data. (Amarillo).
- A national incident centric WUI fire repository needs to be implemented to capture the scale of the WUI problem and monitor nationwide trends and losses (Amarillo).
- Detailed case studies need to be undertaken in the wildland urban intermix (Amarillo).

4.3. Defensive Actions

- First responder tactics, equipment and training need to be developed for the WUI, to bridge the gap between structural and wildland firefighting. (Waldo).
- Standard Operating Procedures (SOPs) need to be developed for the rapid deployment of first responder resources to WUI fires. First responders need to be trained in the new SOPs and practice rapid fire department response to WUI fires. SOPs need to account for responding, in the event of a specific WUI scenario, to both high and low exposure areas (Waldo). SOPs need to be science based and should be developed to enhance first responder safety.
- A science-based response time threshold needs to be developed for WUI fires the same way urban fire departments have response thresholds for responding to building fires (Waldo).

[h] Drive by studies are defined here as studies that involve minimal data collection, and exclude pre and post-fire imagery, timeline reconstruction and the quantification of defensive actions. Such studies can generate potentially dangerously misleading conclusions about hazard mitigation and structure survivability.

5. Acknowledgments

The Witch/Guejito case study would not have been possible without the critical contributions from CALFIRE Chief Ernylee Chamblee, San Diego Fire Department Chief Tracy Jarman, and San Diego Police Department Chief William Lansdowne. Additionally, the authors would like to acknowledge Mr. Steve Arnold, President of The Trails Home Owners Association, for his critical contributions in organizing the data collection efforts with The Trails residents and Jimmy Zurenko for his data collection support. Lastly, the authors of the Witch/Guejito reports would like to thank residents of The Trails and of the city of Poway.

The Tanglewood Complex Fire Case study would not have been possible without the support of the Texas Forest Service. The authors would like to acknowledge the contributions of the Mayors and Home Owners Associations of the Timber Creek, Palisades and Tanglewood communities, as well as the numerous homeowners that provided critical information on both the Willow Creek and the Tanglewood Complex fires. Lastly, the authors of the Amarillo reports would like to acknowledge the contributions of Bruce Woods from the TFS for enabling this deployment and Wanda Duffin and Eric Letvin from NIST for facilitating the deployment logistics. The Coeur d'Alene Tribe is also acknowledged for their assistance with data entry and data collection. The City of Amarillo and Potter-Randall County 911 are gratefully acknowledged for their extensive cooperation in providing vector and raster data for this analysis.

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Appendix A - Technology Transfer Selected Activities 2012-2015

Presentations and Lectures

1. February 3, 2012: WUI Problem and Solutions, Advanced Fire Dynamics Graduate Course, Lecture 1, WPI, Worcester, MA
2. February 20, 2012 WUI Problem and Solutions, Firehouse Conference, San Diego, CA
3. March 31, 2012: WUI Problem and Solutions, Advanced Fire Dynamics Graduate Course, Lecture 2, WPI, Worcester, MA
4. September 10, 2012: Wildland and WUI Fires, Impact Through Exposure Quantification, National Science and Technology Council, Subcommittee on Infrastructure, White House
5. January 22, 2013: Wildland and WUI Fires, Impact Through Exposure Quantification, International Code Council WUI Meeting, Washington, DC
6. March 12, 2013: WUI Problem and Solutions, Advanced Fire Dynamics Graduate Course, Lecture 1, WPI, Worcester, MA
7. March 31, 2013: WUI Problem and Solutions, Advanced Fire Dynamics Graduate Course, Lecture 2, WPI, Worcester, MA
8. April 30, 2013: NIST WUI Program Presentation, NIST Yearly Review
9. May 23, 2013: WUI Exposure Scale and Problem Overview Presentation, NFPA WUI Committee meeting, San Diego, CA
10. May 31, 2013: WUI Exposure Scale Presentation, CAL FIRE, Sacramento, CA
11. June 19, 2013: WUI Exposure Scale Presentation, JFSP, teleconference
12. July 6, 2013: WUI Problem Overview Presentation, DHS, NIST, MD
13. July 16, 2013: WUI Problem Overview Presentation, USGS UAV Operations, Boulder, CO
14. October 21, 2013: America Still Burning Presentation, International Smoke Symposium, College Park, MD
15. October 21, 2013: NIST WUI UAV Application and Data Collection Poster, International Smoke Symposium, College Park, MD
16. January 6, 2014: Hosted NIST WUI workshop. Participants included NIST Contractors, NIST Grantees, Academia, USFS, DHS, NFPA, White House
17. March 26, 2014: WUI Data Collection Needs and NIST Methodologies Presentation, NFPA Fire Data Workshop, NIST, MD
18. April 16, 2014: WUI Program Review Presentation, NIST Yearly Review
19. May 8, 2014: WUI Problem Overview Presentation at Brazilian Government WUI Conference, Brasilia, Brazil
20. May 18, 2014: WUI Problem and Waldo Fire Data Presentation, Subcommittee on Disaster Reduction, White House.
21. June 10, 2014: Evaluating the effectiveness of mitigation activities in the wildland urban interface, JFSP Project 11-1-3-29, Presentation to JFSP Board, teleconference
22. July 23, 2014: WUI Problem and Waldo Fire Data, National Research Council, NIST
23. August 21, 2014: WUI Problem Overview, Solutions and Waldo Fire Data Presentation to USFA Senior Management
24. August 27, 2014: WUI Problem Overview, Solutions and Waldo Fire Data Presentation to IAFF Senior Management
25. September 15, 2014: WUI and UAV field day hosted by CSU. Presented WUI Problem Overview, Solutions and UAV Operations Overview to a total of 39 individuals representing 14 different agencies/organizations (Colorado State University (including the Dean of the Warner College of Natural Resources), members of the Public/Private sector, Colorado State Forest Service, Non Profit organizations, Colorado Department Fire Prevention and Control, City of Ft Collins, USFS, City of Boulder, Senator Bennet's

Office Staff, NRCS (State Forester), Jefferson County Parks and Open Spaces, City of Greely, City of Loveland, Boulder County Parks and Open Spaces)

26. January 6, 2015: 3rd Annual WUI Seminar Series Webcast. Forty remote participants from Academia, Federal, State and Local Agencies and 30 participants in person at NIST Gaithersburg. This year the webinar focused on WUI fire research first responders. Day long webinar is available on line at http://www.nist.gov/el/fire_research/wildland/wildland-urban-interface-hazard-reduction-webcast.cfm
27. January 27, 2015: NIST – National Fire Protection Association WUI Research Foundation Data meeting. Focus on WUI data collection and hazard mitigation and technology transfer specifically for hazard reduction.
28. August 26, 2015: IAFF John P. Redmond Symposium/Dominick F. Barbera EMS Conference, Keynote presentation, The National Wildland Urban Interface Fire Problem: Engineering and Response Solutions
29. November 11, 2015: Fire Chiefs' White House Roundtable, Climate Impacts in the Wildland Urban Interface; https://www.whitehouse.gov/the-press-office/2015/11/09/fact-sheet-administration-and-fire-chiefs-around-country-take-action
30. January 25, 2016: National Fire Protection Association Webinar
31. February 4, 2016: California Fire Science Consortium Webinar
32. February 11, 2016: Western Region Wildfire Council Webinar

Committees – Selective Technical Findings Dissemination based on Committee Mission

NFPA –Wildland and Rural Fire Protection (member)
National Cohesive Strategy Subcommittee on Data (member)
Office of the Federal Coordinator for Meteorology Wildland Fire Weather Committee (member)
White House Sub-Committee on Resilience (alternate/presenter) 2014
White House National Security Council Sub-Interagency Policy Committee on WUI (member)
White House Climate Change impact of WUI Fires Roundtable (presenter) 2015
White House Sub-Committee on Resilience (alternate/presenter) 2016

Media - Select NIST/JFSP WUI Project Research in the media

- Waldo Fire Research, Colorado Springs Gazette http://www.csindy.com/coloradosprings/waldo-canyon-fire-spreads-in-the-scientific-community/Content?oid=2637860
- WUI Hazard Mitigation Research, NBC, KXAN Austin, TX
- Exposure Scale, Weather Channel
- Exposure Scale, NPR All Things Considered Weekend Edition http://www.kunc.org/post/living-extreme-wildfires-new-normal
- Exposure Scale, Associated Press http://bigstory.ap.org/article/feds-developing-richter-scale-wildfires
- NFPA Wildfire Blog http://wildfire.blog.nfpa.org/2012/10/csi-fire-analyzing-a-scene-of-wildfire-destruction.html
- WUI Hazard Mitigation, Discovery Channel Canada http://watch.discoverychannel.ca/#clip1063601

Appendix B – Witch/Guejito Fires Trails Community - Technical Findings and Recommendations

General Fire Behavior (NIST Technical Note 1635)

- 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 (NIST Technical Note 1635)

- 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 ember 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 of the sixteen damaged homes were successfully defended. No defensive actions have been identified on the sixteenth damaged home.
- Impact of defensive actions was significant, and probably reduced losses from over 37 % down to 30 %.

Hazard Mitigation (NIST Technical Note 1796)

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. Detailed information on the effectiveness of specific treatments can be found in the Technical Note.

Appendix C – Amarillo Fires - Technical Findings and Recommendations

Preliminary findings (NIST Technical Note 1708)

Likely technical factors responsible for the damage, failure, and/or successful performance of buildings and/or infrastructure in the aftermath of the Amarillo fires

- Extreme weather, in the form of severe wind and very low humidity, resulted in very rapid fire spread.
- Buffalo grass, even when mowed, carried fire over residential yards and in the wild.
- Statewide pre-deployment of firefighting resources using the Texas Intrastate Fire Mutual Aid System (TIFMAS) was effective in rapidly getting resources to the fires.
- Extensive defensive actions were identified in the Tanglewood Complex fire. The defensive actions will be factored in the evaluation of the response of structures to the WUI fire in the detailed technical report.
- Certain foundation constructions (pier and beam) as well as modular/mobile homes may exhibit certain ignition vulnerabilities.
- Pre-fire and post-fire aerial imagery, particularly oblique imagery such as that found on Microsoft™ Bing Maps, was found to be essential for efficient and accurate delineation of the total number of damaged/destroyed structures.
- The local wind direction and speed and the topography had a significant impact on fire behavior; however, limited weather observation equipment was located in the bottom of the canyon and along the creek beds.

Specific improvements to standards, codes, and practices as well as any further research and other appropriate actions based on study findings

- The multijurisdictional aspects of this event posed a significant challenge to the accurate documentation of the damage and performance of the buildings.
- In the absence of a national standardized data collection framework, the NIST-developed WUI 1 and WUI 2 systems enabled the documentation and analysis of structural losses from the Amarillo WUI fire.
- Collecting data from undamaged as well as from the damaged/destroyed structures provided for meaningful assessment of the data.
- There is no scale to characterize the severity of WUI events, like the scales used to rate tornadoes, hurricanes or earthquakes.
- Additional weather observational equipment in numerous locations in the bottom of the canyon and along the creek beds would significantly help NWS forecasters, and also help local fire officials understand the potential behavior of the fire. Additional Remote Automated Weather Stations (RAWS) or West Texas MesoNet stations would be extremely helpful in cases of wildfires in these areas.

Findings and Recommendations (NIST Technical Note 1909)

The five primary findings are listed here:

1. Information collected from detailed post-fire case studies is more useful for assessing hazard mitigation technology failures than for quantifying successes (data collection and analysis methodologies).
2. Damaged structures provided more useful information compared to destroyed structures, as building materials and ignition location were more reliably identified (structure ignition and hazard mitigation).
3. Damaged structures, which were defended, in many cases did not show direct signs of defensive actions. Without the collection of defensive action data, the effectiveness of hazard treatments can be wrongly interpreted (defensive actions).
4. Remote sensing combined with field assessments presents the best means to obtain pre-fire and post-fire vegetation information (data collection and analysis methodologies).
5. Mapping of existing hazards in WUI communities without the use of weighted attributes[i] provides a means for identification of existing hazards (manmade and natural). This will provide potential for removal of hazards by homeowners and land managers, and recognition by first responders during fires (structure ignition and hazard mitigation).

The specific findings on structure ignition and hazard mitigation areas include:

1. Out of the 183 structures documented in this case study, 35 homes were destroyed, and 13 were damaged.
2. Secondary structures such as sheds, garages, etc., when ignited, generated a significant amount of embers, exposing primary residences under certain conditions to increased hazardous conditions.
3. Mapping of existing hazards in WUI communities without the use of weighted attributes provides a means of identification of existing hazards (manmade and natural), thereby providing potential for removal of hazards by homeowners and land managers, and recognition by first responders during fires.
4. Ember and fire generating combustibles, both detached and attached to residential structures, include fences, decks, railroad ties, mulch beds, attached stairs and piles of firewood.
5. Detached combustibles, in numerous cases, ignited prior to the primary structure and were then responsible for the ignition of the structure.
6. Damaged structures, which were defended, in many cases did not show direct signs of defensive actions. Without evidence and documentation of defensive action data, the effectiveness of hazard treatments can be wrongly interpreted.
7. The exposure from a fire burning up to or near a structure varied significantly across the incident. In some cases, a very low intensity fire reached the structure walls, while in other cases very severe fire exposure was experienced by the structure even without fuel reaching all the way to the structure walls.

The findings on defensive actions include:

[i] Current WUI Fire hazard rating systems rely on very limited technical information to develop weighted ratings. Due to this limited technical information such weighted systems can provide erroneous assessments of actual hazards.

8. Out of the 183 structures in the study, 82 (45%) were identified through technical discussions as having been defended during the fire.
9. The lack of evidence of a defensive action around a particular structure or feature does not mean that a defensive action did not occur on that feature. This implies that due diligence in collecting data from first responders is necessary.
10. Same as technical finding #6 (above).
11. Many features including fences and railroad ties were recorded as being defended multiple times by different first responders. This is consistent with the features' long lasting potential to generate flames and embers. These items increased the hazard to nearby unburned structures.
12. Relatively recent technologies such as AVL systems, mobile phones, GPS and imaging technologies allow for recording of real time fire information that could help better understand fire timeline information.

The findings on exposure and fire behavior include:

13. Fire moved from the fire origin, in the vicinity of 501 Pinto Drive, and crossed Cactus Road into the wildlands to the east of Timber Creek Canyon (a linear distance of approximately 500 m (1 640 ft.)) in about 30 min or less.
14. The post-fire scene represents the final product of the interactions between exposure, defensive actions and the response of fuels (vegetative or urban) to the actual received exposure. This was also identified in the Witch/Guejito case study.
15. Fire and ember exposure onto a target was a complex function of fuels, topography and the local weather. The interaction between topography and weather significantly affected local exposure conductions. Parcel aspect in combination with local prevailing winds sometimes had a significant impact on local exposure conditions.
16. The exposure, defensive actions, and weather vary with time. There were numerous fire fronts, wind shifts and multiple defensive actions all taking place at different times.
17. Fire burned more intensely along the leeward side of canyons and drainages.
18. Topographic features that significantly affected fire behavior were in many cases less than 40 m (130 ft) in length, such as terracing around a structure.
19. In numerous locations, steep slopes or cliffs appeared to stop fire spread in both the upward and downward directions.
20. Fire direction observations from the field were misleading without utilizing a detailed event timeline, as multiple fire fronts or changes in wind direction occurred during the fire incident.

The findings on data collection and analysis methodologies include:

21. Electronic data collection systems are essential in capturing the multidimensional data and interactions between topography, fuels, weather and defensive actions associated with WUI fires.
22. Same as technical finding #14 (above).
23. Complexities of collecting field data with sufficient temporal and spatial resolution make the quantification of exposure in the post-fire environment difficult. There is, however, great value in a qualitative assessment of exposure, as this information can be used, to first order, to determine how the event developed and which homes were exposed to significant fire and embers and which homes were not.
24. Information collected from detailed post-fire case studies is more useful for assessing hazard mitigation technology failures than for quantifying successes.

25. There is a lack of clear guidance provided to first responders for documenting incidents in real time, as well as collecting, sorting and storing incident images and video.
26. Data collected on vegetation both for the wildlands and in the community were important to understand the fire behavior.
27. There is currently no established post-fire data collection methodology to estimate vegetative fuel consumption.
28. Remote sensing combined with field assessments presents the best means to obtain pre-fire and post-fire vegetation information, as aerial imagery and LiDAR lacks the ability to identify understory conditions for both pre-fire and post-fire conditions.
29. Post fire data loss based on aerial imagery increased with time of acquisition after the fire.
30. Analysis of the effectiveness of structure treatments requires pre-fire data for comparison. This was also identified during the Witch/Guejito case study, NIST TN 1635.
31. Many structure treatments could confound the analysis/interpretation of structure performance during a WUI fire. For example, the destruction of a home with a wood roof does not mean the wood roof was the cause of the destruction. Without eyewitness accounts of the destruction, it is impossible to determine the ignition sequence.
32. Damaged structures provided more useful information compared to destroyed structures, as building materials and ignition location were more reliably identified.
33. There are no case studies similar to this one at the Wildland Urban Intermix, resulting in very limited understanding of how to effectively implement mitigation techniques in that environment.
34. Currently, there is no validated physics based fire model capable of providing a better understanding of appropriate scales for assessing and analyzing WUI environments.

As a result of this study, the following are the five primary technical recommendations:

1. Adequate technologies need to be developed and deployed to document the event including first responder actions. - Technical finding #12.
2. The coupling of wind and fire behavior needs to be better characterized, including the quantification of wind flow through topographically complex communities. This is necessary in order to quantify fire behavior at the WUI - Technical finding #15.
3. Standardized electronic data collection systems need to be implemented to capture post-fire data - Technical finding #21.
4. Clear guidance needs to be developed for first responders to document incidents in real time, as well as to collect, sort and store incident images and video - Technical finding #25.
5. Pre-fire WUI mitigation advice needs to involve vegetative sampling of wildlands in close proximity to residential structures using standardized plot based techniques -Technical finding #26.

Additionally there are three recommendations that will improve community resilience to WUI fires by conducting specific research activities as well as data collection. These are:

1. Heat fluxes and ember fluxes from wildland and urban interface fuels need to be quantified in both wildfire and controlled environments - Technical finding #3.
2. A methodology needs be developed to estimate vegetative fuel consumption in a post-fire environment. Collection of this information should not be limited to residential areas and should continue into the wildlands - Technical finding #27.
3. Case studies similar to this one need be conducted at the Wildland Urban Intermix – Technical finding #33.

Appendix D – Waldo Fire - Technical Findings and Recommendations

Technical Findings (NIST Technical Note 1910)

The four primary findings from the Waldo Fire case study are:

1. Defensive actions were effective in suppressing burning structures and containing the Waldo Canyon fire.
2. Pre-fire planning is essential to enabling safe, effective and rapid deployment of firefighting resources in WUI fires. Effective pre-fire planning requires a better understanding of exposure and vulnerabilities. This is necessary because of the very rapid development of WUI fires.
3. Current concepts of defensible space do not account for hazards of burning primary structures, hazards presented by embers and the hazards outside of the home ignition zone.
4. During and/or shortly after an incident, with limited damage assessment resources available, the collection of structure damage data will enable the identification of structure ignition vulnerabilities.

This case study identified a total of 37 technical findings, including 12 associated with field data collection and codes and standards, and 25 associated with fire behavior and defensive actions. As a result, 13 recommendations aimed at improving the fire resilience of WUI communities were developed.

Field Data Collection and Codes and Standards

1. Extensive data is required to create a detailed fire timeline and defensive action reconstruction, which is necessary to obtain a clear understanding of the incident fire behavior and structural response to the exposure conditions. This finding reaffirms what was found at the Witch/Guejito and Amarillo fires.
2. Clear identification of damage/destruction was a key mechanism for linking eyewitness accounts of defensive actions describing damage/destruction to a location on the ground.
3. WUI post-fire rapid assessments that focus on recording all damage and destruction to the WUI area would aid in identifying construction vulnerabilities.
4. Reliable technical data on WUI mitigation strategies and first responder tactics from post-fire assessments must account for the timeline of burning features, the human actions used to alter fire behavior (pre-fire and during-fire) and the exposure conditions experienced in the area from which the technical data is being collected.
5. During-fire observations might be very limited spatially (due to smoke or line of sight) and have a temporal limitation that makes them of limited value unless integrated both in space and time. This finding reaffirms what was found at the Witch/Guejito and Amarillo fires.
6. Fuel treatment effectiveness standards are needed; otherwise, the effectiveness of fuel treatments cannot be reliably assessed.
7. Collecting, organizing, analyzing, documenting and distributing post-fire WUI assessment data, particularly for a large incident, can be complex, involving the use of relational databases, remote sensing, Global Positioning Systems (GPS), document

management and many other geospatial and information technology applications to fully integrate all available data.

8. The reconstruction of the fire timeline and defensive actions could not have been accomplished without the following key activities:
   a. Imaging of large numbers of burning structures in MSC.
   b. Documentation of practically all of the first responders' recollections of events in space and time.
   c. Imaging of MSC by Google Streetview, Bing Maps and the City of Colorado Springs prior to the fire.
   d. Imaging of MSC two days after the Waldo Canyon Fire affected the community.
   e. Integration of all data in a Geographic Information Systems (GIS).
9. Documentation of first responder actions, in small groups, by the individuals conducting those actions in an electronic format, and allowing for incorporation of pertinent images, would increase the efficiency and effectiveness of the technical discussion (TD) data collection process.
10. Post-fire aerial imagery can provide indications of defensive actions, but not all defensive actions can be identified from aerial imagery, and first responders recording their activities in space and time is required.
11. Lack of judicious protocols for post-fire data collection can lead to loss of data and reduces the quality of scientific post-fire studies.
12. Post-fire assessors should not come to conclusions about fire behavior, tactics, or structure response based on field assessments or discussions with first responders alone. A full integration of all available data must first be conducted and then determinations made regarding the adequacy of the data before any conclusions are made.

Fire Behavior and Defensive Actions

13. Over 95% of the destroyed or damaged structures were ignited within five and a half hours after the fire reached the community, resulting in a structure ignition rate of 79 structures per hour or 1.3 structures/min, considering this entire time period.
14. One hour after the fire reached the MSC, there were 37 first responder apparatus in the community, and 2 h after the fire reached the community, there were 63 apparatus present.
15. The wildland fire front had passed and conditions were clear in the vicinity of the water tower at Wilson Road 60 min after the front reached the area. [j]
16. Large numbers of burning structures shortly after the passage of the main wildland fire front caused a second evacuation and slowed response to the fire due to the belief that a second fire front might be moving through the area.
17. There were 154 structures successfully defended to prevent structure ignition and defensive actions were documented on 245 parcels, with significantly more parcels likely defended.

[j] This information was collected from video footage. Conditions could have been clear even before the first responder captured the video footage.

18. There were 94 structures ignited that were saved by first responders.
19. First responders were effective in extinguishing ignited structures 75 % of the time.
20. Out of the 445 total ignited structures, there were 55 to 119 (12 % to 27 %) identified as burning within 60 min of the passage of the main wildland fire front.
21. First responders were effective in containing fully involved structures 79 % of the time.
22. Ninety-three percent of damaged structures were identified as defended.
23. The effects of structure spacing, with regard to burning of adjacent structures, are dependent on exposure and can vary considerably within a small spatiotemporal extent.
24. The effective and successful response to the Peregrine blowup on Wednesday, June 27 demonstrated the advantages of pre-fire mitigation and pre-positioning of resources for WUI fires of a small geographic extent.
25. Fire observations have to be interpreted in the context of the overall fire timeline. A structure can be observed to be "not on fire" when in fact it had ignited, was suppressed, and latter re-ignited, or was ignited in an unobserved location.
26. Features such as combustible decks, fences, railroad ties, secondary buildings, re-entrant corners, and readily ignitable roof coverings represent significant hazards to the structure and surrounding parcels. This finding reaffirms what was found at the Witch/Guejito and Amarillo fires.
27. There are currently no National Standard Operating Procedures for WUI firefighting response or resource deployment. SOPs for deploying resources in the WUI need to account for the extremely fast and safe response that might be required to stop fires in communities with high density and low structure separation distances before the fire becomes embedded in the neighborhood.
28. Fire can rapidly ignite multiple structures in high density, low structure separation distance communities even when first responders are at peak deployment of resources.
29. Rapid resource deployment strategies should be designed and rehearsed with mutual aid.
30. Rapid and safe deployments of firefighting resources would require an increased understanding of exposure and structure vulnerabilities.
31. Data to enhance rapid situational assessment is needed to enable rapid and effective deployment of resources.
32. Methodologies are needed to further define and map high and low exposure WUI areas.
33. Mapping of hazards to identify key community vulnerabilities in the context of fuels, topography and local weather is necessary in order to design effective response strategies.
34. Mapping of hazards within and around a community, together with preplanning for rapid and targeted deployment within the community, can improve firefighter safety and reduce structural losses.
35. Due to the limitations of the current state of knowledge, defensible space definitions do not consider defensibility from structure to structure fire spread or defensibility from dangerous topographic configurations.
36. Structure spacing and density affected exposure between adjacent structures and made certain locations untenable for first responders, thereby reducing their effectiveness and possibly their ability to respond quickly to stop early fire spread.

37. Smoke inhalation was identified as a key health concern by first responders.

The following are the primary recommendations made. The recommendations made here are aimed at creating an overall paradigm shift in responding to WUI fires:

1. Develop, plan, train and practice SOPs, based on better understanding of exposure and structure vulnerabilities, to enable rapid fire department response to WUI fires. SOPs need to account for responding, in the event of a specific WUI scenario, to both high and low exposure areas.
2. A response time threshold for WUI fire situations needs to be developed based on increased understanding of exposure and structure vulnerabilities, the same way city fire departments have response thresholds for responding to building fires.
3. Structure spatial arrangements in WUI areas where defensive actions are ineffective or unsafe need to be identified.
4. Response plans for high density WUI areas, with the objective of fire not reaching these areas, need to be designed.
5. Defensible space definitions need to be updated to emphasize that the main desired result is the ability for first responders to defend locations and recognize hazards of primary structures and dangerous configurations of topography and fuels outside the home ignition zone (HIZ).
6. Additional research is needed to fully characterize the relationships between the spatial arrangement of houses and defensive action
7. Hazards at the WUI, factoring in fuels, topography, and local weather need to be quantified. Fuels need to include wildland fuels and structural/residential fuels such as wood roofs, fences and combustible decks.
8. A better understanding of exposure and structure vulnerabilities needs to be developed, including definitions for high and low fire and ember exposure areas
9. Wildland fuel treatment standards to quantify exposure reduction for different topographical and weather conditions need to be developed.
10. Construction standards and test methods need to be updated to capture representative fire and ember exposures from fuel treatments.
11. Due to complexities associated with timeline reconstruction, exposure characterization and defensive actions, rapid post fire data collection is needed to identify/count destroyed homes, and focus on documenting damage and destruction to the WUI environment, using current technology and comprehensive methods for documentation.
12. Protocols for collection of ground and aerial imagery for pre-fire, during-fire and post-fire situations need to be developed.
13. Consistent protocols for collection of damage information in a WUI environment need to be developed.