NIST Technical Note 1910

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

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

by

Alexander Maranghides, Derek McNamara, Robert Vihnanek, Joseph Restaino, and Carrie Leland

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 and the United States Forest Service, Fire and Environmental Research Applications Team (USFS FERA) were invited by the Colorado Springs Fire Department (CSFD) to collect post incident data from the 2012 Colorado Waldo Canyon Fire (Waldo Canyon Fire). This case study is focused on the Mountain Shadows Community (MSC) in Colorado Springs. There were 1455 primary structures (refers to residences) in MSC, as classified in this report. Of these, 344 primary structures, as classified in this report, were completely destroyed and 85 had confirmed damaged, 14 had unconfirmed damage, and two had confirmed partial damage. This report on the Waldo Canyon Fire addresses the event timeline reconstruction and defensive actions. Additionally, the report documents identified science and engineering issues related to the WUI. Recommendations are also made on improving WUI data collection.

This work attempts to reconstruct the fire timeline in MSC with special focus on burning structures. The extent and type of defensive actions that were undertaken during the first ten hours after the Waldo Canyon Fire reached MSC are presented. An assessment of the quality, quantity and uncertainty related to data used to reconstruct the fire timeline and defensive actions is also conducted. The data collected and synthesized demonstrated the effectiveness of defensive actions as well as examined the extent of ignitions due to the wildland fire front. New concepts of defensible space are highlighted. The information presented in this report represents the first steps required for further examination of structure response to the fire exposure.

The information generated from this case study can provide input, together with additional research, to improve WUI building and landscaping (construction) codes and standards, and best practices. Extensive research is also needed to provide first responders with effective pre-fire, during-fire and post-fire tools and standard operating protocols to efficiently tackle WUI fires such as the Waldo Canyon Fire. Only then will hazard mitigation technologies for new and existing constructions together with improvements in firefighting response significantly reduce structural losses from WUI fires.

KEY WORDS: **Wildland Urban Interface, WUI, fire behavior, community, Waldo Canyon Fire, Waldo Fire, fire and ember exposure, WUI response, NIMS, ICS**

Executive Summary

Destruction of homes and businesses from Wildland-Urban Interface (WUI) fires has been steadily escalating, as have the fire suppression costs associated with them. Since 2000, in the U.S., over 3000 homes on average per year have been lost to WUI fires. This is compared to about 900 homes per year in the 1990s, and 400 homes per year in the 1970s. In 2011, in Texas alone, over 2000 homes were destroyed during WUI fires. In Colorado, from June 2012 to June 2013, three fires, the Waldo Canyon, the High Park and the Black Forest destroyed a total of 1103 homes and burned a total of 119 811 acres.

The WUI fire problem affects both existing communities and new construction. WUI fire construction codes and standards, test methods and best practices are in their technical infancy. While some codes address radiant heat flux, the science necessary to harden structures against ember assault is very limited, in part because quantifiable ember exposure data from wildfires and WUI fires is almost non-existent. Additionally, guidance on the efficient deployment of firefighting resources in the WUI is limited, and there is limited information on the effectiveness of defensive actions during WUI fires. Lastly, there is limited information on the effectiveness of WUI mitigation strategies from science based studies.

While the WUI structure fire problem is similar in principle to the urban structure fire problem of the US in the 1970s in that they both involve building fires, it is also significantly more complex because of the range of physical scales involved, the contributions of topography and local weather, the range of fuels involved, and the interdisciplinary nature of the problem. A significant body of research is necessary to improve construction codes, standards and best practices as well as provide first responders with effective tools and safe and efficient standard operating procedures (SOP) to address the WUI fire problem.

Smoke from the Waldo Canyon Fire was first observed on Friday, June 22, 2012 and the fire first reached the Cedar Heights Community in Colorado Springs, Colorado at approximately 22:00 SMT Fon Saturday, June 23. The fire crossed the topographic divide above Mountain Shadows Community (MSC) on Tuesday, June 26, sometime before 17:00. The fire progressed to the east up to and through MSC and to the north towards the Peregrine Community and the US Air Force Academy. The fire continued to impinge on Peregrine and the southern end of the Air Force Academy into Wednesday, June 27.

This work attempts to reconstruct the fire timeline and show where the fire was in MSC as a function of time, with an emphasis on structures. Additionally, the effectiveness and extent of defensive actions are documented in order to characterize effectiveness of extinguishment and containment at a parcel and structure level. Also included in this report are an overview of the WUI fire data collection conducted, the methods utilized in this case study to characterize fire behavior and first responder effectiveness, and assessments of data quality. Engineering and science issues related to the WUI are also identified and documented, and recommendations are made on improving WUI data collection. This report focuses on the following four primary objectives:

1. Reconstructing the fire timeline and showing where the fire was in MSC as a function of time while identifying locations with limited data.
2. Documenting the spatiotemporal extent and type of defensive actions that were undertaken during the first ten hours after the Waldo Canyon Fire reached MSC.
3. Assessing the quality, quantity and uncertainty associated with data collected for this study to guide further analysis and identify improvements to WUI pre-fire, during-fire and post-fire data collection efforts.
4. Documenting any discernible issues related to WUI mitigation strategies and first responder tactics and safety.

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. Integrating 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 responder's 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. [i]
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.
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.

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

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 loses.
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, therefore, 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 data collected and analyzed indicates that first responders were effective and extinguished 94 homes that had caught on fire, while only seven homes were potentially identified as damaged without any known defensive actions. Thirty two homes were unsuccessfully extinguished, yielding an extinguishment success rate of 75 %. Additionally, 154 structures were defended specifically to prevent structure ignition. Sixty burning homes were successfully contained, and sixteen were not, yielding a containment effectiveness rate of 79 %.

Overall, the first responders, when they arrived at the scene, were effective in saving structures and together with relatively favorable [ii] fire and ember exposure conditions, were able to "box in" and control the fire.

The extent of defensive actions executed directly on structures and parcels highlights the fact that the post-fire environment is the result of the complex interactions between local exposure, ignition potential and defensive actions. The extent of the identified defensive actions coupled with the almost ubiquitous lack of accounting for these actions in previous post-fire assessments calls into question almost all previous knowledge about the effectiveness of current hazard mitigation guidance and practices, particularly when defensive actions and local exposure conditions are not rigorously and extensively documented.

The Waldo Canyon Fire posed a significant challenge to first responders on June 26. The fire moved rapidly through the community. In the first hour after the wildland fire reached MSC,

[ii] Favorable in this context is only used in context of other locations such as Courtney Drive and the north end of Majestic Drive, where exposure was likely such that it was not possible for first responders to be on the street relatively early in the incident.

there were between 55 and 119 primary structures identified as ignited by the passage of the wildland fire front. Three hours after the wildfire reached MSC, there were between 248 and 286 primary structures identified as having been ignited. The existing tactics, while effective for wildland firefighting might have significant limitations for WUI fires with close structure spacing where very rapid deployment might be necessary to limit fire spread and structural losses, if possible at all, for situations found at the Waldo Canyon Fire.

The data shows the apparatus response to MSC using current standard operating procedures (SOPs) as peaking at 20:30, almost three hours after the main fire front first reached the community and when there were between 248 to 286 primary structures ignited (i.e., 83 to 95 structures per hour). A paradigm shift might be required to enable very rapid deployment of agile resources coupled with equipment with significant water to safely and effectively fight WUI fires. Additionally, there is a need for identification and possibly increased treatment extending beyond the Home Ignition Zone (HIZ) of these high density and/or low structure to structure separation distance locations found near or adjacent to wildlands.

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. The effective property protection and limited damage successes associated with the containment of the Peregrine area blowup on Wednesday, June 27 illustrate the potential benefits of rapid deployment of firefighting and hazard mitigation resources for fires of small geographic area. Larger fires, such as the Waldo Canyon Fire that affected MSC, require a better understanding of fire behavior and associated hazards to facilitate a safe and efficient during-fire situational response.

Rapid resource deployment to areas with established defensible space adequate for the exposure conditions are also illustrated in the Peregrine area blowup. The Peregrine area blowup was significantly smaller compared to that of MSC. Nonetheless, the importance of rapid deployment of resources for relatively less intense/smaller fires, is also demonstrated in MSC on Vanreen Drive, Darien Way, Huffman Court and other locations throughout MSC where fire spread was quickly contained.

Characterizing fire behavior, quantifying structure response, assessing exposure conditions and developing efficient and effective WUI mitigation strategies are processes that are in their infancy. It is thought that post-fire assessments alone, particularly given the current state of the art of the measurement science, will never be able to individually successfully perform the above characterizations, quantifications, and assessments. Integrated laboratory and field experiments, coupled with physics-based fire modeling and other new innovations are needed.

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 need 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.

The above activities would require integration of post-fire assessment data in the WUI and wildlands with lab and field experiments, coupled with validated computational fluid dynamics (CFD) fire models to gain a better understanding of exposure, structure vulnerabilities and fire behavior.

In summary, the information generated from this case study can provide input, together with additional research, to improve WUI building and landscaping (construction) codes and standards, and best practices. Extensive research is also needed to provide first responders with effective tools and SOPs, and continued advancements are also necessary in the field of data collection. Subsequent improvements to constructions and retrofitting techniques together with improvements in firefighting tactics should then reduce WUI fire structural losses and improve community resilience.

1.0 Background

Destruction of homes and businesses from Wildland Urban Interface (WUI) fires have been steadily escalating as have the fire suppression costs associated with them. [1] Since 2000, in the U.S., over 3000 homes on average per year are lost to WUI fire. [2] This is compared to about 900 homes per year in the 1990's and 400 homes per year in the 1970's.[3] In 2011, in Texas alone, over 2000 homes were destroyed from WUI fires. [4] The WUI fire problem affects both existing and new communities. [5] In Colorado, from June 2012 to June 2013, three fires, the Waldo Canyon, the High Park and the Black Forest destroyed 1103 homes and burned 119 811 acres.[6] In the U.S, the problem is most acute in the western and southern states; however, WUI fires recently have destroyed homes in the Mid-Atlantic States and the Pacific Northwest . [1]

WUI fires present a unique challenge to the firefighting, science and engineering communities. The scale of the events can be vast, spanning in many cases over 40 000 ha (100 000 acres). The moving fire perimeter can be tens of kilometers long with potentially thousands of structures at risk. The severity of the fire is dependent on vegetative (wildland and ornamental) and structural fuels, topography, and weather.

Complicating the above challenges is the interdisciplinary nature of a comprehensive WUI fire study. Collecting, organizing, analyzing, documenting and distributing WUI assessment data, particularly for a large incident, involves the use of relational databases, Geographic Information Systems (GIS), remote sensing, Global Positioning Systems (GPS), document management and many other geospatial science and technology applications. Knowledge and skills required to utilize the above technologies are not acquired through standard education and training in the firefighting, fire protection engineering or forestry fields. Conversely, those familiar with the above technologies are not typically trained in fire science.

Further complications arise from the fact that there are many WUI definitions based on different attributes, including vegetative fuels and population density. The Federal Registrar states that "the urban wildland interface community exists where humans and their development meet or intermix with wildland fuel." [7] Further WUI sub-characterizations include interface, intermix and occluded type communities. Attempts have been made to characterize the hazard as well as the risk. [2, 8, 9] Results have been mixed due primarily to the diverse nature of the objectives driving the definitions.

WUI community construction codes and standards, test methods and best practices are in their technical infancy. While some codes address radiant heat fluxes, the science necessary to harden structures against ember assaults is very limited [10, 11], in part because quantifiable ember exposure data from wildfires and WUI fires is almost non-existent. Guidance on the effective deployment of firefighting resources in the WUI, as well as the effectiveness of fuel treatments, is also limited. Additionally, there is limited information on the effectiveness of defensive actions during WUI fires. Finally, the effectiveness of WUI mitigation strategies in varying exposure conditions is not well understood.

2.0 Introduction

Smoke from the Waldo Canyon Fire was first observed on Friday, June 22, 2012. The fire first reached the Cedar Heights Community in Colorado Springs, Colorado at approximately 22:00 on Saturday, June 23. Fire progression for the Waldo Canyon Fire is shown in Map Figure 1. The fire crossed the topographic divide above MSC on Tuesday, June 26, before 17:00, resulting in destruction shown in Map Figure 2. The fire progressed to the east up to and through MSC and to the north towards the Peregrine Community and the US Air Force Academy. The fire impinged on Peregrine and the Air Force Academy on Wednesday, June 27.

The Waldo Canyon Fire affected three Colorado Springs communities shown in Map Figure 1. All of the destroyed structures were in Mountain Shadows Community (MSC). The main focus of this report is on MSC. Short narratives describing the overall fire event for Cedar Heights and Peregrine, the other two communities affected are also provided.

In Section 3, an overview of WUI Post Fire assessments is presented and is followed by the report objectives. The weather overview just prior and during the time the Waldo Canyon Fire reached MSC is described in Section 5. Sections 7 to 8 describe the data collection and analysis methodologies together with material on data integration and data categories. Assessments of data quantity, quality and uncertainty are presented and the resultant rules and assumptions used for this study are also detailed in Section 8. Section 9 of the report focuses on the MSC case study and starts with a general description of the community. Damage and destruction are then presented together with a fire behavior timeline. Details associated with a wind shift that occurred while the community was burning are also presented. Sections 10-13 of the report focus on timeline of burning structures. Analysis is presented starting with parcels defended and the tools used and then data on residential structures is presented. The analysis includes data on undamaged structures, structures damaged and successfully defended, and structures damaged and undefended. The effectiveness of defensive actions is then evaluated by examining sample populations of successfully or unsuccessfully extinguished and successfully or unsuccessfully contained structures. Defensive action tools used are also presented. Initial findings regarding defensible space concepts and locations with high densities of low separation distance structures are detailed. The first responders' deployment timeline is presented and ignition vulnerabilities are identified. Finally, in Sections 14-16, the technical findings are summarized, and the report concludes with a series of recommendations. Unless otherwise specified all tables and figures in this report are generated by NIST.

Appendix A contains data collection forms and Appendix B contains weather data. Appendices C and D list timelines for Cedar Heights and Peregrine respectively, while Appendix E contains sources of additional imagery used in this report. Appendix F lists the apparatus that was present in Mountain Shadows and when they arrived at the community. Lessons learned on WUI data collection are listed in Appendix G and an example of a technical discussion cross correlation can be found in Appendix H. Appendices J and K list the firefighting tools used to both prevent structure ignition and to extinguish damaged homes. Appendix L lists missed defensive actions in post fire assessments. Appendix M contains a list of damaged structures documented in this report. Lastly Appendix lists additional technical issues identified during technical discussions.

3.0 WUI Post-Fire Assessments

Post-fire WUI assessments are an important identified requirement in a recent National Fire Research Foundation (NFRF) funded study on fire prevention at the WUI. [1] WUI post fire assessments increase knowledge of WUI environments and thereby provide better protection of life and property in these environments. Assessments of post-fire WUI environments can be broken into the following four categories:

- **WUI 0/1**: These assessments occur at WUI incidents where structures are damaged or destroyed. The goal of these assessments is to respond to the incident both during, to facilitate allocation of resources, and after, to allow for safe re-entry into the community. Many protocols are used to perform WUI 0/1 assessments. A recommended scalable protocol is presented in Appendix A. An example of a WUI 0/1 type assessment would be the Colorado Springs Fire Department (CSFD) assessment of damage and destruction from the Waldo Canyon Fire.
- **WUI 2**: These types of assessments attempt to characterize fire behavior in the WUI, qualify/quantify exposure and assess structure response given the early nature of the study of the WUI and the state of the art of the measurement science. These assessments are data and labor intensive and suffer from a lack of available information to characterize the entire Fire Disturbance Continuum. [12] An example of a WUI 2 type assessment is described by Maranghides et al. [10]
- **Black Swan Assessment**: This type of assessment is introduced in this report and follows the belief put forth by Popper [12] which held that science cannot be founded on universal statements such as “all swans are white” (or “no additional research [to address the problem of wildland fire in the interface] was needed”). [5] Rather a falsification solution is proposed by Popper where a single universal observation such as “all swans are white” can be disproven by the identification of one swan that is not white as it would be impossible to observe every swan in nature. [iii] This type of assessment holds value in the WUI given the impossible task of proving the effectiveness of current mitigation strategies. WUI post-fire assessments that take a

[iii] Falsification as applied to WUI mitigation advice needs to be assessed in the context of exposure for an understanding of the conditions under which the respective mitigation advice failed and to ultimately understand the relative probability of such exposure conditions to exist in other WUI environments.

critical approach to potential shortcomings and can lead research and development in relevant directions applicable to the identified problem hold value for improving knowledge of the WUI. The examination of the Waldo Canyon Fire by the Colorado Springs Independent [14] is an example of a Black Swan Assessment.

- **Rapid Assessments**: These types of assessments typically require limited resources and are a result of larger scale (in terms of life and property) WUI disasters, which receive public attention or locally large disasters. These assessments attempt to go beyond identification of damage and destruction conducted in a WUI 0/1 assessment. Identification of selected information showing effectiveness of WUI mitigation strategies is conducted. Due to limited resources only a subset of data, typically not including during-fire and post-fire imagery, fire witness observations and signs of defensive actions[iv], is used. The limited resources also do not allow for gathering a statistically representative sample for assessment. An example of a rapid assessment is the Insurance Institute for Business and Home Safety (IBHS) report on the Waldo Canyon Fire. [15]

The assessment presented herein represents a Black Swan/WUI 2 Assessment, and will be referred to as a WUI 2 assessment in this report. This assessment identified previously unidentified issues in the WUI, as detailed below. Consequently, this Black Swan Assessment report was developed as a building block to a future WUI 2 assessment and to provide identification of well-defined issues associated with WUI mitigation and suppression tactics.

All of the above WUI assessments have their advantages and disadvantages. WUI 0/1 assessments are necessary to safely contain the incident, inform the public of the results of the incident and facilitate safe re-entry. A paradigm shift, however, is required in these assessments, particularly after the incident is contained, to fully exploit the potential for WUI 2 assessments and improve understanding of WUI fires. WUI 2 assessments [v] are the only assessments from which an understanding of fire behavior, structure response and exposure might be determined. These WUI 2 assessments are time and cost intensive, and typically suffer from a lack of available information.

Black Swan Assessments can help to lead WUI 2 type assessments in appropriate directions and are a natural consequence of a WUI 2 assessment. They are unlikely to provide solutions, except for obvious issues, without further research. It is important, as WUI hazard mitigation strategies are developed, to provide incentives for the public to implement the current recommended practices and rapid assessments are quick and efficient methods of

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[iv] The identification of signs of defensive action is new and it is understandable that historic assessments would miss these signs. Some signs are presented in this report.

[v] There are many protocols and measurement techniques that might be employed and a WUI 2 assessment does not imply in this case any specific protocol. WUI 2 assessments should make attempts to employ the scientific method to assessment of the WUI but must be careful of the "best available science" approach due to incomplete information leading to incorrect conclusions.

taking selected information to highlight potential successes. Rapid Assessments, however, have no possibility of moving WUI fire science forward except by coincidence or happenstance, and run the risk of perpetuating WUI mitigation strategies that are not effective for all conditions.

It is important to note that in this context, WUI 2 assessments do not imply any particular protocol implemented in previous NIST/USFS WUI Assessments. [2, 10] The measurement art/science is too young to propose a one size meets all assessment process. Rather it means the application of a process where information is collected relevant to the pertinent factors driving the Fire Disturbance Continuum. [12]

The idealized WUI 2 Post-Fire Assessment process is presented in Figure 1. At its core, the process is simple and involves assessment of the available data sets for the respective incident(s) to determine if enough information is available to draw conclusions based on information required to characterize well founded case studies. Conclusions are critically examined to ensure the first conclusions(s), and possibly desired conclusion(s), identified are well founded or if further analysis or information is required. An evaluation of improvements to the measurement science is conducted and recommendations for more efficient and effective future assessments are provided. Finally, the entire set of data is documented and made available for distribution.

A key component of the WUI Post-Fire Assessment methodology portrayed in Figure 1 is the level of data required in order to come to justifiable conclusions. Post-fire assessments that assume no defensive actions, [10, 16] provide no details on how exposure is calculated [17] and make no attempt to characterize burn times of features present, at best, questionable conclusions. [18]

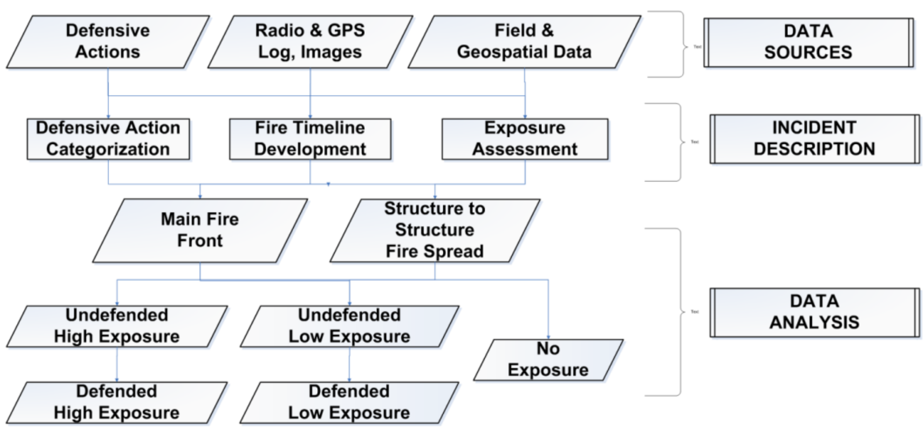

Figure 1 The NIST/USFS WUI Assessment Methodology with populations that will attempt to be assessed in future reports on the Waldo Canyon Fire.

The specifics of the methodology shown in Figure 1 can be implemented differently and improved as the measurement science progresses. As discussed and demonstrated in this report, post-fire assessments, both historic and future, should be viewed with caution. Future post-fire assessments should be guided by the collection of data sets listed in Figure 1 and detailed below. Fires where these data sets do not exist should not be attempted to be assessed by a WUI 2 assessment.

There can be a significant amount of time between the initiation of a WUI 2 assessment and the distribution of data. The amount of data being collected for quantification of fire environments, from prescribed burns [19, 20] to WUI post-fire assessments, is vast and involves numerous disciplines. Pre-fire collection, analysis, documenting and archiving this data to provide value to the discipline takes time. Without full documentation of post-fire WUI assessments the efforts will not conform to the scientific process as the repeatability of the efforts would not be possible because no one could assess the data and determine if the same conclusions might be drawn.

It is important to note that in many instances the WUI 2 process will determine that no conclusions can be drawn regarding structure response, exposure or improvements to WUI mitigation strategies or WUI firefighting tactics. Implementation of the process shown in Figure 1 provides identification of areas that do not contain adequate information from which conclusions might be drawn. The identification of well-founded case studies in post-fire WUI environments will also provide information for experiments and model development.

Regardless of the WUI assessment method utilized, the assessment of the WUI is in its infancy. Implementation of the WUI 2 Assessment Methodology, as generally shown in Figure 1, consequently allows for the building of the measurement science to help provide future direction to assess structure response, exposure, or improvements to WUI mitigation strategies or firefighting tactics.

It is thought that post-fire assessments alone, particularly given the current state of the art of the measurement sciences, will never be able to individually successfully quantify exposure and structure response. Integrated laboratory and field experiments coupled with physics based fire modeling and other new innovations are needed. That is not to say existing WUI mitigation strategies are not effective, only to hypothesize that WUI mitigation advice might not be effective enough in certain situations to prevent catastrophic WUI disasters. It is possible those situations might be identified as hazards and mitigated, given appropriate scientific advancement. The adoption of existing WUI mitigation strategies can lead to decreased destruction in the WUI.

4.0 Report Objectives

This report focuses on achieving the following four primary objectives:

1. Assessing the quality, quantity and uncertainty associated with data collected for this study to guide further analysis and identify improvements to WUI pre-fire, during-fire and post-fire data collection efforts.
2. Reconstructing the fire timeline in MSC while identifying locations with limited data.

3. Documenting the spatiotemporal extent and type of defensive actions that were undertaken during the first ten hours after the Waldo Canyon Fire reached MSC, during which 99 % of the destruction occurred.
4. Documenting any discernible issues related to WUI mitigation strategies and first responder tactics and safety identified through objectives one through three above.

5.0 Weather Overview

Recorded wind data was collected from the United States Air Force Academy sensors and the Colorado Springs Airport. The US Air Force Academy Mesonet (HWAS) and the Colorado Springs Airport (KCOS) recorded maximum gust values between 17:00 and 18:00 on June 26, as listed in Table 1. The winds were predominately from the west then the northwest, then moved briefly to the northeast and eventually around midnight moved back to the north. The US Air Force Academy is to the north of MSC and Colorado Springs Airport to the south and east. Distances from the water tower at Wilson Road and Alabaster Way (see Map Figure 2) are listed in Table 1.

Appendix B contains hourly weather data from the US Air Force Academy Airfield weather station (KAFF) for Tuesday, June 26 and Wednesday, June 27 and from the Colorado Springs Airport for Tuesday, June 26. Table 1 lists recorded wind gusts at seven locations in the Air Force Academy and gusts at Colorado Springs Airport. The distances of the different weather stations from the Wilson Road water tower are also listed. On Tuesday, June 26, the winds were sustained above 32 km/h (20 mph) nominally from 14:00 to 21:00.

Table 1 US Air Force Academy Mesonet (HWAS) and Colorado Springs Airport (KCOS) wind gusts between 17:00 and 18:00, June 26, 2012

Location	Maximum Gusts (km/h)	Distance from Water Tower at Wilson Road and Alabaster Way - km (miles)
USAFA Rampart	94	7.9 (4.9)
USAFA Cadet Area	94	9.5 (5.9)
USAFA North Gate	78	10.9 (6.8)
USAFA South Gate	72	7.4 (4.6)
USAFA Airfield	78	7.7 (4.8)
USAFA Community Center	87	7.2 (4.5)
USAFA Stadium	65	9.0 (5.6)
Colorado Springs Airport	46	16.7 (10.4)

The weather conditions that resulted in the fire plume lean or collapse are beyond the scope of this report and are discussed in more detail in Johnson et al. [21] In general, the fire plume leaned/collapsed between 17:20 and 17:25. The fire front and plume contacted MSC in the vicinity of the water tower near Wilson Road. The extent of the plume, once it leaned over, is not precisely known, as the smoke and embers did not cease abruptly at a specific location.

Technical discussions with firefighters indicate that initially, visibility was restricted to less than 10 m (30 ft) near the Wilson Road water tower. Visibility was less restricted as one got closer to Chuckwagon Road. With time, as the plume continued to lean/collapse and the fire front moved to the east, visibility was compromised to the south of Chuckwagon Road, along Flying W Ranch Road, all the way to Chipeta Elementary School and eventually to North 30th Street and Garden of the Gods Road. Smoke at ground level reached all the way to Centennial Boulevard. Visibility did not impair evacuation and vehicle movement on Centennial Boulevard.

A wind shift was observed from west to north at around 20:00 (also identified during a technical discussion) on Majestic Drive, which coincides with the weather data from the US Air Force Academy showing a wind direction shift between 19:00 and 21:00. A wind shift (also reported in the technical discussion), from the north to northeast on Darien Way between 22:00 and midnight together with an abatement of the wind. This is consistent with the wind measurements.

The wind shift identified from the technical discussion is also consistent with the weather data taken at the Colorado Springs Airport, which show a gradual veering of the wind from the west to the north and the wind abating, without any gusts being recorded at 20:00. This wind shift is also evident in numerous images of burning buildings, originally seen going to the east, changing direction and moving to the south (See Section 9.4 Fire Behavior Timeline and Observations [Wind Change]).

On Wednesday, June 27, at approximately 15:30, a westerly wind, possibly precipitated by a thunderstorm to the west, resulted in a down slope wind that, together with a spot fire, caused a fire front to reach the Peregrine area around Blodgett Drive. Sustained winds reached 66 km/h (41 mph), and gusts were recorded as high as 95 km/h (59 mph) at the US Air Force Academy. A short narrative of the impact of this weather event on the Peregrine Community can be found below. The June 27 wind event did not result in significant fire behavior in MSC or Cedar Heights.

6.0 Communities Affected

The section provides a brief overview of communities affected by the Waldo Fire. Maps illustrating the general progression of the Waldo fire can be found in Appendix B. Destruction to primary structures was limited to MSC. The sections below provide brief descriptions of the fire in the Cedar Heights Community and the Peregrine Community. Descriptions of MSC are provided in Section 10.0.

6.1 Cedar Heights Summary

The primary fire activity reached the community from the west on the night of Saturday, June 23 into the morning of Sunday, June 24. Exposure of structures to fire and embers was limited to low ember exposure on only one structure. The home at 3725 Outback Vista and its surroundings were actively defended during the ember assault. There were no reported ignitions on the structure or on that parcel and no structures were destroyed or identified as damaged in this community.

The Cedar Heights Community did receive exposure from the Waldo Canyon Fire but the fire at that time, in that area, was moving towards the northeast. The community was defended by a combination of hand crews, a double wide bulldozer, 1300 m (4200 ft) long fire break and fire retardant air drops. The existing fuel break was widened with bulldozers from 5m (16 ft) to 10 m (33 ft). The fire did jump the 10 m (33 ft) wide fuel break and spread on the other side (slop-over). The slop-over occurred between Saturday 22:00 and Sunday at 03:00.

The suppression of the slop-over was in the fuel treated area and was controlled and suppressed by hand crews. Suppression activities limited the slop-over to an area of less than 4000 m^2 (1 acre). Additionally, there were a number of small spot fires from ember showers that jumped the fuel break and were quickly suppressed. Fire and embers exposures did not result in the evacuation of any of the firefighting resources. Appendix C contains an abbreviated timeline reconstruction for Cedar Heights. The effectiveness of this fuel treatment was not studied in this report.

Between 22:00, June 23 and 03:00, June 24, wind speed ranged from 5km/h to 14 km/h at the US Air Force Academy. Temperature ranged from 15 °C to 21 °C. Relative humidity ranged from 21 % to 31 %. The weather conditions were measured at approximately 11.2 km from Outback Vista Point. While local conditions can significantly affect local weather, the US Air Force data is provided as a common weather source for general comparison with the event the next day, when the fire reached MSC.

6.2 Peregrine to Wolfe Ranch Summary

The Waldo Canyon Fire reached the area between Wolf Ranch Road and the Peregrine Community starting on Tuesday, June 26 in the evening. The neighborhoods between Wolf Ranch and Peregrine did not experience any structural ignitions. Bulldozer lines were created in several locations to create fuel discontinuities and at least two back burns were conducted to prevent or limit fire and ember exposure to structures in this area. One back burn occurred between Heartland Way and Ruststone Court in the evening of June 26, and one occurred between Blodgett Drive and Angelstone Point on June 27. Additional defensive actions, such as cutting down trees and fire suppression with water, in certain areas between Wolf Ranch Road and Peregrine were evident in the post-fire aerial imagery collected on June 28, 2012.

Peregrine received direct fire exposure on Wednesday, June 27 in the early morning on the north and northwest sides. Significant structure preparations had taken place in the previous 12 hours. No structures were lost, damaged or ignited from this fire activity. Ground and aerial fire suppression resources provided the necessary structure protection to control the approaching fire front. The pre-fire mitigation included moving propane cylinders to the curb and removal of combustibles from the structure vicinity. It was estimated that between 20 and 30 apparatus were available to provide the preparations prior to the local fire blowup on Wednesday afternoon.

A significant fire and ember exposure event occurred on Wednesday afternoon, June 27 as a result of wildland vegetation burning on the hill above and to the west of Blodgett Drive in the early morning hours of Wednesday. There was fire activity over an undetermined wildland area to the west of the Peregrine community. The area was monitored throughout the night and a request was placed for helicopter air drops at dawn. The helicopter air drops contained the fire but the fire was not completely extinguished.

At approximately 15:30 a developing thunder cell to the west started generating a significant down slope wind. The subsequent flare-up resulted in a rapidly descending fire front approximately 120 m (400 ft) wide. Flame lengths reached over 30 m (100 ft) in height. While the total front width was significantly smaller than what was experienced in MSC the previous day, the severe winds were possibly as strong, if not stronger[vi]. When the front arrived, first responders evacuated by going down Blodgett Drive then turning around and immediately re-engaging. The time for the process could not be determined from data available in this report as no Automatic Vehicle Locator (AVL) data was obtained for this event.

No structures were destroyed in Peregrine and structural damage was limited to deck and soffit ignitions on two primary structures[vii]. The pre-fire mitigation, the relative small width of the fire front, the limited number of structures ignited and the rapid response through the prepositioning of resources, illustrate the effectiveness of this combined approach to a fire of small to moderate size. Appendix D contains an abbreviated reconstruction.

7.0 Methodology

The data collection for this post-fire assessment was initiated in early July 2012, two weeks after the fire reached MSC and the fire was considered contained. A team was deployed to Colorado Springs and collected preliminary information on the fire. The focus of this effort was on testing of the electronic data collection systems. At the time, it was not anticipated that the effort would lead to a full study.

As time progressed it became apparent that the Waldo Canyon Fire, provided a unique set of pre-fire, during-fire and post-fire data that may be useful for understanding WUI fires and ultimately, help reduce the impact of these disasters. Consequently, a full study was initiated. Due to limited personnel availability, the majority of the field data collection could not begin until early 2013.

The focus of the Waldo Canyon Fire data collection effort was on recoding information obtained during discussions with first responders. A smaller, though still significant, effort was also initiated to gather other spatial, tabular and remote sensing data, representing pre-fire, during-fire, or post-fire conditions in and around MSC, to the extent practical. The data gathered for

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[vi] This is based on weather data collected at the US Air Force Academy, see section 6. It is important to note that local weather in MSC might have been significantly more intense then what was seen at nearby weather stations.
[vii] No extensive structural damage has been identified. Since Peregrine was not the main focus of this report, it is possible that additional structural damage occurred.

assessment of the Waldo Canyon Fire and used in this report can be classified into the following categories:

- **Field Data**: This type of data represents information gathered in the field before, during or after the Waldo Canyon Fire. Field data used in this report are shown in Table 2.
- **Remote Sensing Data**: This type of data represents information acquired remotely from a sensor before, during or after the Waldo Canyon Fire. Remote sensing data used in this report are shown in Table 3
- **Other Spatial Data**: This type of data represents information stored as GIS datasets, either raster or vector data. Other spatial data used in this report are shown in Table 4.

The data listed in Table 2 through Table 4 were integrated in an Environmental Systems Research Institute (ESRI) File Geodatabase for the assessment of the Waldo Canyon Fire. Additional images used for the fire timeline reconstruction are shown in Appendix E.

Table 2 Field Data used for this report.

Data Type	Source
Technical Discussions (TD)	First Responders
Location of CSFD Apparatus	Automatic Vehicle Location (AVL) system – CSFD
Radio Logs	Radio Logs – CSFD
Duty Reports and Damage Reports	CSFD
Post-Fire Damage Assessments	CSFD
911 Calls	CS Police Department (CSPD) Dispatch
Pre-Fire Defensible Space Ratings	CSFD

Table 3 Remote Sensing data used for this report.

Data Type	Source	Date	Characteristics
Oblique Imagery	Bing Maps	≈2007	Unknown
Multispectral Color Imagery	City of Colorado	Summer 2011	3-Band; 0.31 m spatial resolution
Multispectral Color Imagery	City of Colorado	Winter 2012	3-Band; 0.31 m spatial resolution
Light Detection and Ranging (LiDAR)	City of Colorado Springs	Summer 2011	~1m post-spacing; minimal information
Post-Fire Color-Infrared Imagery	The Sanborn Map Co, Inc.	6/28/2012, 7/13/2012	4-Band; 0.1 m spatial resolution
Pre-Fire Multispectral Imagery	Google Earth	Fall 2011	Unknown
Streetview Imagery	Google Earth Streetview	Sumer 2011	Unknown
Pre-Fire, During-Fire and Post-Fire Imagery	Fire Witnesses (First Responders, Public Citizens, etc…).	2/26/2012	Various videos and images representing conditions before, during and after the fire.
Post-Fire Oblique Imagery	USGS HDDS Colorado Civil Air Patrol	Summer, 2012	Oblique imagery of selected areas of MSC
Post-Fire Streetside	Microsoft Bing Maps	2014	After fire street level imagery.

Table 4 Other spatial data used for this report.

Data Type	Source
Parcels (Polygon)	City of Colorado Springs
Address Center Points	CSFD
Road Centerlines	CSFD
Waldo Canyon Fire Progression	Rocky Mountain Geographic Science Center

A major effort of the Waldo Canyon Fire data collection was the manual recording of information obtained from technical discussions (TD) with over 200 fire witnesses, largely first responders. The TD process took approximately eight months and 4500 person-hours to complete. In total, the process resulted in the tracking of 101 firefighting apparatus and command vehicles in MSC from 16:00 Tuesday, June 26, to 03:00 Wednesday, June 27. Appendix F lists the apparatus that were present, as well as when they engaged and when they disengaged from MSC.

TDs were the only data that identified shift changes. In many cases, TDs took place with more than one person on an apparatus. This effort was required to obtain a simple estimate of time to deployment, as discussed below, and to collect data to track 124 apparatus in order to identify that 101 were in MSC during the time of interest. Ultimately, all individuals on every apparatus were identified. The inability to quickly identify all apparatus and personnel at the fire was due to the complexity of the incident. Also, very little documentation existed on the staffing of the apparatuses. This was exasperated by selective[viii] personnel shift changes.

TDs, therefore, started with the Incident Commander and proceeded down the incident command chain to the apparatus level. The procedures conducted in the TD effort were as follows:

1. Met with the first responder (s) of interest, if there was a representative group (e.g. Brush Truck or Fire Engine) then discussed the incident with the first responder of interest.
2. Provided an open format for the first responders to describe what they saw at the incident in a chronological order, to the extent possible, with few questions actually asked.
3. Recorded the information spoken by the first responder using written notes with associated locations, if not representing an addressable structure, marked on a hard-copy map.
4. Two data recorders were often utilized. The first data recorder captured the overall narrative and the second recorder only documented defensive actions and observations.
5. Utilized geospatial technologies such as AVL, Bing Maps Birds Eye View, Google Street View and other geospatial technologies during TDs.

Key skills required for this effort were the ability to record written notes quickly and legibly, along with basic use of geospatial technologies (Web Map Services, Google Earth, Google Streetview, Bing Maps) to orient first responders . It should also be noted that the use of AVL,

[viii] Some apparatus had complete shift changes, some partial and some did not change crews at all.

Bing Maps Birds Eye View, Google Street View and other geospatial technologies did not occur until about one-third of the way through the TD process when it became apparent this was necessary.

Development of the fire timeline required the use of images and videos taken during the fire by witnesses and was not possible from the TDs alone. This was also shown in the 2011 Texas Tanglewood Fire Assessment [22]. Burning times of vegetation, residential and wildland, proved to be the most problematic features to develop a timeline. This report focuses on the ignition timeline for primary structures and the associated timeline of defensive actions. Burning times of combustibles, detached and attached, were also tracked when data was available.

As discussed in section 8.3.2.3 below, even with the use of AVL data, the TDs did not result in precise time estimates of burning features to allow adequate reconstruction of the fire timeline. Images taken during the fire were required to identify burning primary structures. Defensive actions did help in many cases and the defensive action discussions were the only way to associate defensive actions with specific properties or primary structures as few, if any, images portrayed the full extent of defensive actions taken. Lessons learned and improvements to the data collection methodology can be found in Appendix G.

Nonetheless, geolocating defensive actions often still required the use of images. It has not been uncommon in NIST/USFS post-fire assessments for first responders to be slightly off in the spatial location of actions. Consequently, pre-fire, during-fire and post-fire ground and aerial imagery were essential for proper location of many defensive actions both in space and time.

Integration of certain data, when images and videos were lacking, did allow for location of certain first responder actions in space and time in a few selected locations, with some uncertainty. An example of this integration is shown in Appendix H. The process shown in Appendix H requires the witness to accurately remember the chronology of events, which might not always occur. Cross-correlation was consequently a time consuming and, in many instances, ineffective means to assign time stamps to actions and observations.

Assigning during-fire images to a location in space also required the use of Google Streetview and a GIS. During-fire images were geolocated by comparing with pre-fire images shown in Google StreetView, as portrayed in Figure 2. Bing Maps Bird's Eye imagery was also useful in initial identification of locations of burning features with an example shown in Figure 3.

Additionally, orthorectified pre-fire and post-fire imagery covering MSC was instrumental in geolocating during fire images. Finally, it should be noted that in one case the respective image was of a backyard and the location could not be identified in a GIS. This case required a ground assessment, which could later be verified in the GIS, for proper location.

Figure 2 Example of locating during-fire images in space using Google Streetview.

Nonetheless, assigning locations of during fire images was generally very successful, even with images taken in the dark, if the features were burning. Though geolocation was a time consuming process, assigning during-fire imagery to a location in time was also challenging. Time stamps on imaging devices are sometimes not correct, have changes as a result of changes in time (e.g. daylight savings time) or otherwise might be in error. The protocol identified in the 2011 Tanglewood Study [22] was recommended to examine the time of images during the discussions to determine if, how, and why the images did not contain the correct time. This protocol was not followed during most TDs at this incident as in most cases the images were not collected during the TDs. In this study first responders were instructed to send their images and videos to the CSFD videographer. This did not happen in all cases. [ix]

[ix] It should be noted that this is no reflection on cooperation of any first responders. First responders had conflicting information regarding during-fire images and it is not their job to record images. This emphasizes the need for data collectors to obtain the images using the established protocol.

Figure 3 Using Bing Maps to geolocate burning features. The above image was compared to Bing Maps to help geolocated feature of interest.

In addition to ground images, post-fire imagery was also used to identify defensive actions and damage. The post-fire imagery also provided information on damage and was a key source for identification of damage and destruction to vegetation at this incident. The full integration of remote sensing with field data is not included in this report.

This collection of TDs and during-fire images were unprecedented efforts for a WUI fire investigation. Coupled with integration in a GIS, a comprehensive examination of a WUI fire is facilitated, initial results of which are described in this report. Also, many items identified in the 2011 Tanglewood Fire [22] to improve the collection of the defensive action information were implemented here for the Waldo Canyon Fire. Additional improvements have been identified for future WUI data collection efforts and are described in Appendix G.

It was determined that documenting of first responder actions privately 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 processes.

8.0 Data

8.1 Data Integration

There is a critical and necessary synergy among TDs, radio logs, during-fire images, GPS track logs, pre-fire and post-fire aerial imagery, and other pertinent data sets. It is only by integrating these different data sets that a precise and accurate reconstruction of the event might be developed. The integration of data also allows for assessment of the data quality as well. Each data set on its own can provide limited and potentially very misleading information.

This is the first effort of its kind that uses many data streams[x] to attempt to recreate the fire timeline and defensive actions for a large incident. It is expected that continued development of measurement science will improve this endeavor. Many skills are required for a WUI 2 Post-Fire Assessment. Recording of information obtained during TDs requires exceptional note taking skills and use of simple Geospatial Technologies, such as Google Streetview. Interpretation of integrated data requires skilled personnel with knowledge in fire sciences, fire protection engineering, landscape scale analysis, statistics, and other scientific and engineering disciplines.

In this project, data produced and gathered from TDs were initially integrated separately from the geospatial data gathering effort (i.e., post-fire imagery, all acquired during-fire images and landscape scale data). The partial integration was performed in an attempt to assess the WUI 2 methodology shown in Figure 1 and to determine if information could be derived using only partial data, as is common in a Rapid Post-Fire WUI Assessment. The combined data was then provided to the project GIS Analyst for review.

The partial integration in a spreadsheet was demonstrably less efficient compared to using a GIS coupled with relational database technology for data entry, data correction and data analysis. Additionally, integration of all data in a number of locations changed the interpretation of fire behavior and defensive action locations. Consequently, it was concluded that a GIS was the appropriate tool, given current technology, to use for integration of large spatial data sets such as those obtained and created for the Waldo Canyon Fire as opposed to a spreadsheet.

8.2 Data Categories

Regardless of how the data is integrated, it was required to develop categories for the various data subsets. This allowed for normalization of the data and provided a consistent integration of information. This section describes the data categories used.

The extent of damage to structures varied extensively and ranged from structures requiring complete rebuilds to minor cosmetic fixes. Additionally, it is possible that some structures identified as damaged in this report required rebuild. This report does not include a comprehensive list of damage to properties because no comprehensive list exists. Interior damage, specifically smoke damage, has not been systematically captured here.

The complete list of damaged structures contained in this report was compiled through TDs with first responders, post-fire damage assessments and aerial images. Corroboration was achieved though discussions with homeowners when possible. This task was undertaken by the Colorado Springs Office of the Fire Marshal. This information proved valuable; however, the lack of photographic documentation was an issue with these secondary assessments. Photographic documentation during initial local damage assessments was a critical step to capturing extent, type and location of damage in a WUI fire.

[x] Data streams are outlined in Section 8.3.1

Field observations in Table 5 were binned in the following two categories: structures and attached combustibles, and parcel and detached combustibles. Defensive actions were binned by action intent and tool used, as shown in Table 6. The data collected was binned in the categories listed in Table 5 and Table 6.

Table 5 Types of burning feature observations.

Observation	Type of Observation	
Structure and attached combustibles	• structure not on fire • structure on fire • structure ignition roof • structure ignition deck • structure ignition flame impingement • structure ignition garage • structure ignition other • structure standing fire extinguished	• structure standing fully involved • structure past peak • structure foundation • deck on fire • eaves on fire • no defensive action • prior defensive action
Parcel and detached combustibles	• parcel not on fire (veg) • parcel ignition (veg) • parcel ignition (detached combustible) • parcel on fire (veg) • detached combustibles on fire • detached combustibles not on fire • railroad ties (RR) on fire	• play sets on fire • fences on fire • smoking/melting/pre-ignition • no specific fire observation • no defensive action • prior defensive action

Table 6 Defensive action[xi] categories for objectives and tools/tactics.

Defensive Action Item	Type of Observation	
Defensive Action Objective	• prevent parcel ignition • prevent structure ignition • prevent detached combustible ignition • extinguish parcel • extinguish structure • extinguish detached combustible	• contain parcel • contain structure • pre-positioning of equipment • remove fences • vegetation removal • mop up
Defensive action tools/tactic used	• hand tools • garden hose • sprinklers • fire hose • foam • deckgun	• interior (going inside) • structure prep • back fire • bulldozer line • thermal imager • water curtain

8.3 Data Quantity, Quality and Uncertainty

This section discusses data quantity, quality and uncertainty associated with various data products produced or used for this report. Data quality is of particular concern in this study related to the following activities occurring on the wildland and built environments:

- Identifying damage and destruction.

[xi] Defensive actions refer to activities taken by first responders to prevent ignition, extinguish or contain the fire.

- Deriving the spatiotemporal extent of defensive actions.
- Constructing timeline information for burning features.
- Assessing exposure for pertinent populations of structures in time and space.

Quantification of exposure is outside of the state of the art of the measurement science related to post-fire assessments. Nonetheless, even for qualitative assessment of exposure, the quality and quantity of the data produced, along with resulting uncertainty, will provide guidance on assessing a WUI post-fire environment in a scientific manner.

Additionally, implementation of the NIST/USFS WUI Assessment Methodology outlined in Figure 1 provides potential to improve scientific understanding of the WUI. Implementation of the methodology shown in Figure 1 also provides the possibility of identifying enhanced exposure qualification and quantification techniques. Ultimately, sound observations regarding fire behavior, developed from fire assessments that attempt to quantify all aspects of the Fire Disturbance Continuum [12] are required to develop the measurement science such that standard test methods for WUI constructions are implemented and experiments representing conditions found in the WUI and the next-generation fire models are developed and tested.

Therefore, the assessment of data quality is an important process. The quality of fire timeline and defensive action data presented in this section also provides the foundation for qualitative assessments of exposure, and structure response. For example, if the initial structures ignited from the passage of the main wildland fire front cannot be determined, even qualitative assessment of exposure would be difficult and potentially misleading. The assessment of structure response would be almost impossible, except in individual case studies for select locations.

The rules and assumptions listed below were used for this study:

1. Categories of structure burning conditions portrayed by first responders, or viewed in the ground imagery were: structure condition unknown, structure not on fire, structure on fire. It should be noted that when images are available, a more definite progression in time might be reached, specifically in the context of primary structures burning adjacent to each other. Additionally, a primary structure observed not to be on fire does not imply that there was no fire anywhere on the structure. For analysis purposes, however, an observation of a primary structure not on fire is treated similarly to a definite statement that the structure is not on fire.
2. Structure or item (deck, roof, other) ignition observations are associated with statements or images where either ignition is actually observed or (relatively) small amounts of fire are present, and nothing else is on fire in the immediate surroundings. An example would be a small fire on the steps going to a deck without any other part of the structure on fire. If there were no confirmations (i.e., pictures, TDs) of the observation, then no ignition was recorded.

3. Damage and destruction were determined from a combination of local government field assessments, TDs, and aerial and ground imagery. All damaged structures independent of the extent of damage were documented as "damaged". The specific damage was recorded, when possible. The compiled list of damage is not a complete assessment of damage across the study area.
4. At a parcel level, numerous actions were taken to suppress fires or pre-wet vegetation. The term "contain parcel" was specifically reserved for defensive actions specific to the containment or redirecting of parcel fires, independent of any action directed at a structure itself. "Scratching fire line" is one example of an action taken specifically to contain or redirect a vegetative fire. A parcel can be initially defended to extinguish and subsequently to contain as the parcel fire becomes a direct threat to adjacent parcels or structures. A parcel is labeled as having both if both actions occurred.
5. On some streets in the study area, (i.e., Green Valley Circle, Regal View Road, Via Verona View), first responders activated watering devices (e.g. garden hose and sprinklers) on a row of primary structures with some primary structures not being activated for various reasons. First responders could not identify the specific primary structures, and all primary structures were marked as defended in the areas.
6. A first responder may have identified a specific fire observation and in the database no defensive action may have been associated with his observation. This does not necessarily indicate that no defensive action was taken, as frequently another first responder (also identified) would have taken the defensive action.
7. Time estimates with greater than ± 20 min of uncertainty were not used in reconstructing the event timeline of burning primary structures.
8. A structure ignited and suppressed represents a successful extinguishment effort. The extent of damage is not considered here.
9. Structure containment is defined as successful if a containment objective is explicitly identified in the defensive action(s) taken and the (identified) structure is saved. This rule applies even if the containment objective is not for an immediately adjacent structure. Successful containment does not apply to long range ember spotting (tens of meters, hundreds of feet). If there is failure in one direction and success in another, the actions for the structure will be assumed to have failed. This occurred very infrequently (less than five times). "Structure containment" only applies if containment or extinguishment actions were taken. Provided there was additional evidence of an exposure concern (i.e., pictures), containment includes mop-up as containment, as foundations were a concern for many hours after the majority of the fire activity ceased. Over the course of protecting a particular structure, defensive actions can transition from extinguishment to containment as the structure fire grows and the structure becomes un-savable. A failed extinguishment becomes a failed containment if fire spread continues beyond the defended structure.

10. All structures were deemed to be not on fire before 17:23 on Tuesday June 26, the first known structure ignition.
11. All decks are treated as attached combustibles. A deck on fire is therefore treated as a structure on fire.
12. The data analysis time intervals are finite in time. If a picture showed a house fully involved or destroyed at the first half of the time data analysis time interval (the first 30 min), the assumption was made that the primary structure was on fire in the previous time interval.

8.3.1 Damage Information

Damage information for the Waldo Canyon Fire came from the following five sources:

1. Local damage assessments from CSFD and cooperators consisting of spreadsheets with address and damage information as well as images of damage and destruction.
2. Project damage assessment from NIST/USFS consisting of field assessments of damage locations, not contained in the CSFD assessments, but identified during the TD process or the result of the first field assessment on 21 primary structures.
3. Post-fire aerial imagery collected by The Sanborn Mapping Co, Inc.
4. Various reports on the Waldo Canyon Fire. [15, 23]
5. Media sources: For example, http://gazette.com/waldo-canyon-fire-two-years-later-a-neighborhood-is-reborn/article/1521839. [24]

The identification of damage and destruction to the built and wildland environment is instrumental in locating defensive actions and fire behavior observations in space and time.

Damage information also provides the first building block for scientific assessment of a post-fire WUI environment. Any catastrophic incident such as the Waldo Canyon Fire results in a need to prioritize resources to finalize the response to the incident in the affected community.

During and/or shortly after an incident, the most effective use of limited damage assessment resources lays in the collection of structure damage data and not in the evaluation of hazard mitigation technologies as the latter requires a time commitment and resources that do not coincide with the rapid needs associated with post-fire after action reporting or damage assessment for public information. Additionally such efforts across multiple WUI fires would provide valuable information of structure ignition vulnerabilities.

Many post-fire assessments focus on documenting major damage and destruction to primary structures. The blistering of paint barely visible in Figure 4 demonstrates the missing of minor-scale damage prevalent in damage assessments of major WUI incidents. In many cases, this type of minor-scale damage was used to help geolocate first responder observations.

Figure 4 Ground image taken by local damage inspectors of a destroyed primary structure barely showing fire blistered paint on an adjacent primary structure in the background.

The focus on documentation of major damage and destruction is understandable in many post-fire environments due to the immediate needs resulting from the incident and the low priority of documenting minor damage such as fire blistered paint. Some assessments, however, skip documentation of minor-scale damage and move to selective gathering of partial incident data to highlight the effectiveness of current WUI mitigation strategies and data that supports previous findings of WUI post-fire assessments.

The information presented in the rest of Section 8 demonstrates the importance of not skipping steps when performing scientific post-fire assessments. If further post-fire analysis steps are taken beyond initial assessments of "major" and "visible" damage, complete documentation of damage should be conducted before moving onto other assessment steps. Scientifically based damage assessments will provide information to improve current WUI mitigation advice.

8.3.1.1 Local Damage Data

Local damage information was provided by CSFD and contained a list of 1100 properties in and around communities affected by the Waldo Canyon Fire. This list contained 341 destroyed primary structures. Additionally, there were 47 records in the spreadsheet with an inspection status of "Visible Damage", with one of these records having no address.

The 46 primary structures with addresses identified as damaged in the spreadsheet differs from the data identified by NIST, as discussed below. This is due to missing relatively minor damage such as that shown in Figure 4. Additionally, damage on property with locations not evident from the street might also be missed in rapid assessments. Furthermore, the convention used to record damage information might vary among damage collection protocols.

For example, Figure 5 portrays a primary structure with a damaged fence that might have been attached to the structure. The local damage collection protocol might include this type of damage as associated with the primary structure. The NIST data collection protocol used in this study considers fences as not attached, even if attached, to account for the common occurrence of the burning being relatively far from the structure. Data was not available to determine this distance. Additionally, the deck attached to the primary structure was damaged but with no evidence of the damage being from the fire directly. The NIST protocol is used in this report, and while the distinctions are arbitrary, they do point out the need for consistent protocols.

Figure 5 Image of a burned fence piece that appeared to have broken a deck post, which had no sign of fire damage.

8.3.1.2 TD Damage Data

The damage information collected from TDs was also provided in the initial spreadsheet and built from the local damage list described above. New damaged properties were identified through the TDs based on observations from first responders of properties with extinguished features. Though the specific amount of instances was not tracked, it was not uncommon for first responders to specify the area of the defensive action in an incorrect location (e.g. an adjacent primary structure). This was observed in the study of the 2011 Tanglewood Fire [22] as well. Correlation of damage information identified through TDs with confirmed damaged sources was used to confirm and adjust the spatial location of defensive action observations.

In most cases, initial incorrect geolocation of first responder actions was corrected through identification of damage information in the field. This sometimes required remote sensing data. For example, initial discussions with first responders identified defensive actions at 2225 Charing Court of defending a roof spot with a garden hose, putting out railroad ties and placing sprinklers at a gazebo. The first responders identified all of these actions occurring at 2225 Charing Court.

Examination of the post-fire imagery, however, identified roof damage at 2220 Charing Court as shown in Figure 6. Also shown in Figure 6 are a gazebo at 2225 Charing Court and the lack of a gazebo at 2220 Charing Court along with various unidentified burned and damaged features. Furthermore, discussions with homeowners at 2220 Charing Court confirming roof damage and damage to railroad ties along with identifying a heat damaged sliding glass door that required replacement. Finally, analysis of 2225 Charing Court in Bing Maps Streetside showed that 2225 Charing Court still had a wood roof as of 2014.

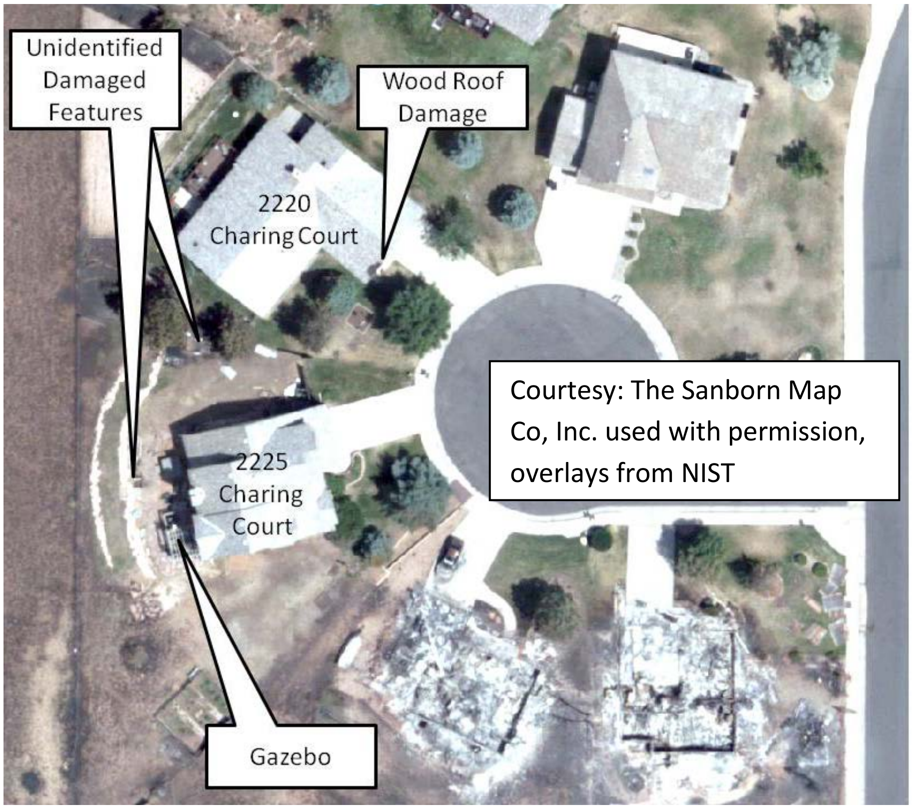

Figure 6 Damage on Charing Court used to geolocate first responder defensive action locations.

Based on the above described field and remote sensing data the defensive action for extinguishing the roof spot was moved to 2220 Charing Court. The above re-assignment of the spatial location of a defensive action from the initial spreadsheet occurred in a number of instances, resulting in moving certain defensive actions identified during the TDs to primary structures containing the damage, though all were not tracked. It was expected that first responders could not precisely geolocate all actions and observations based on memory alone, particularly given the long time span between the event and recording of the recollection. It is not the job of first responders to remember correctly all the events in space and time. This highlights the need to integrate all data before drawing conclusions from field assessments or discussions with first responders alone. Also highlighted is the need to have a means for first responders to record their recollection of events with associated images in an electronic format quickly after the incident.

In addition to post-fire ground imagery providing damage confirmation such as the image shown in Figure 4, [xii] post-fire aerial imagery also provided confirmation and/or identification of some damage such as that shown in Figure 7. This damage was not observable from the ground assessments conducted by CSFD due to damage on the roof and interior of the primary structures. However, aerial imagery could not directly identify damage to structure interiors.

Consequently, field visits were often required due to aerial imagery not identifying damaged features obscured by buildings or trees, or on the sides or insides of objects. Field visits also sometimes resulted in identification of damage not identified through other sources, including the TDs. Ultimately, the TD process resulted in 39 more confirmed damaged sources on primary structures compared to local field assessments.

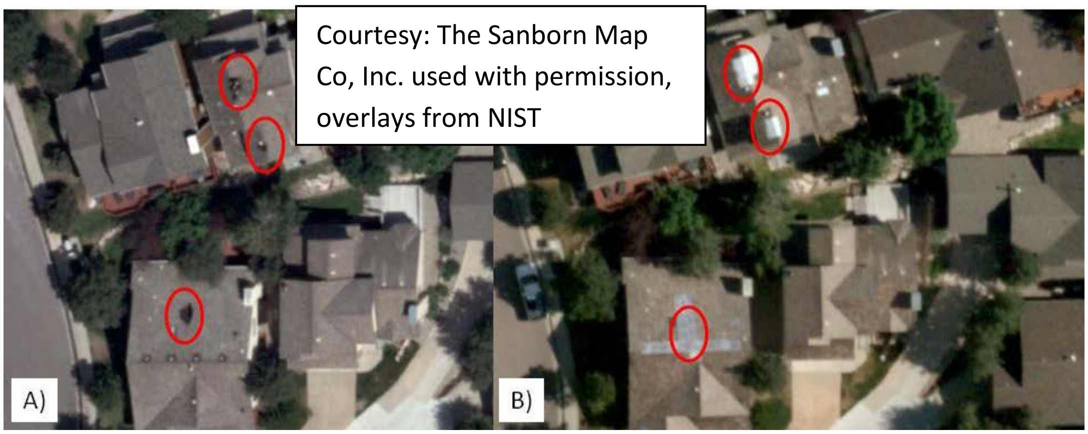

Figure 7 Post-fire aerial images of damaged wood roofs. A). Aerial image recorded on 6/28/2012 showing black marks on wood shake roofs. B). Aerial image recorded on 7/12/2012 showing initial repairs to roofs.

Discussions with homeowners alone regarding damage, however, were not used as a means to confirm damage. For example, Figure 8 highlights two primary structures, both of which were not identified as damaged in the local damage assessment. The two primary structures shown in Figure 8 were identified as a result of first responder accounts of roof extinguishment actions in the area. The first responders commonly could only identify the general location of actions in the area shown in Figure 8. Field visits identified spots on each roof through homeowner discussions. Additionally, imagery, as shown in Figure 8, clearly portrayed large damaged sections to the wood roof of the confirmed damaged primary structure, while damage to the asphalt shingle roof was not visible in the aerial imagery or any other imagery and consequently this primary structure damage was marked as unconfirmed damage.

[xii] The image shown in this figure was taken when documenting destruction to the neighboring house and was only coincidently recorded by damage assessors.

It is therefore important to note that unconfirmed damage does not mean there was no damage, and not all damage can be identified in aerial imagery. It also highlights the need for more science-based post-fire damage assessments in the future that attempt to record all damage with retrievable forensic evidence.

Figure 8 Two potentially fire damaged roofs. The primary structure circled in blue had anecdotal accounts of damage from the homeowner while the structure in red has clear visible evidence of damage.

The above described conservative approach to damage classification was used to highlight unknown damage such as the "spots" described for the asphalt shingle roof shown in Figure 8. This damage information, while potentially important, as asphalt roofs are not thought to ignite [25], needs to be quantified further to understand if these spots are results of debris on the roof or the roof covering being ignited due to some other factor. Again, the need for scientific documentation of data using ground and aerial imagery is highlighted. The need to provide homeowners the ability to document damage and provide this documentation to authorities having jurisdiction is also highlighted.

Some primary structures also had only partial confirmation of damage. For example, 2610 Rossmere Street was identified by first responders as being extinguished with a fire hose. First responders discussed the primary structure starting to smoke, the gutter melting and some "melting by the deck" from exposure caused by the primary structure to the northeast burning. The IBHS report [15] listed damage to two cracked windows at 2610 Rossmere Street. Field visits and discussions with homeowners indicated one cracked window and a damaged deck, but no visual evidence of either at 2610 Rossmere Street. Consequently, there is only partial confirmation, as defined in this report, of damage for this primary structure. The conflicting information described above highlights the need for established protocols to assess damage in the WUI that include the use of ground and aerial imagery.

It is also important to identify all apparatus at a particular incident, as illustrated in the two examples below. The first case that clearly illustrates the importance of tracking all apparatus is found in the examination of the structures that survived in Mirror Lake Court. For the first 150 TDs no first responder was aware that these structures had been defended. It was not until TD 151 that the first responders that successfully defended these structures were identified.

Examination of the CSFD video, however, revealed this as a location with first responders present very quickly. Full videos and images obtained for this project clearly show first responders in the area. Three important concepts are highlighted by the above example:

1. Provision of all images taken by first responders during the incident would result in quicker identification of actions and burning features and greatly reduce the time taken for the TD process.
2. Examination of images available for the incident should be conducted before the TD process.
3. First responders require a mechanism to upload images and describe actions in an objective manner.

There are many current logistical constraints that might present problems to the seemingly simple concept presented above. The technology, however, is readily available. It is also important to note that the above is not suggested as a mechanism to replace the TD process, only to enhance the efficiency and effectiveness of the process.

The second case is found in examination of the structures that did not burn on the southern end of Majestic Drive, between Lions Gate Lane and Champagne Drive. Many believed that these structures received little exposure. It was not until TD 154 that the first responders who suppressed embers in this location were actually identified. Also, there was no identified damage in these locations. Two important concepts are highlighted by the above example:

1. Images will not capture all information due to shortage of devices on all first responders.
2. Accounts of actions are limited in determining structure response without associated damage information.

The above points confirm the need for efficient and effective TDs. Also, in some circumstances, without sensors on first responders, the information collected from descriptive accounts will be of limited value in directly assessing structure response and exposure conditions. Nonetheless, the information provided from more difficult to quantify exposure can help guide laboratory and field experiments and fire model development.

Regardless, it must be pointed out that in order to track the apparatus of interest, all apparatus involved must be identified. While this case study primarily focuses on MSC, all apparatus have to be tracked, including those that remained in Cedar Heights and Peregrine. This highlights the need, at the incident level, to have in place a mechanism to track all apparatus involved. This enhances safety and will enable post incident evaluations and after action reports. Furthermore, a crowd sourcing application that allows first responders to enter information about activities in an incident would, if ubiquitously used, result in tracking of all apparatus.

8.3.1.3 Remote Sensing Damage Data

Remote sensing, in terms of this report, includes both ground and aerial imagery. As discussed above, two sets of post-fire high resolution orthorectified image acquisitions occurred from flights conducted by The Sanborn Map Co., Inc. as listed in Table 3. Additionally, ground images taken by local authorities were provided with an example shown in Figure 4. The ground imagery was used in this study to search for primary structures identified as damaged during the TD process but not listed as damaged in the local spreadsheet. Further assessment of this imagery might yield additional information regarding damage and defensive actions.

Post-fire aerial imagery was the means used to identify destruction to primary structures in this study. The TD Damage Data did not have the observations for many destroyed structures. The CSFD Damage Data had 341 primary structures recorded as a "Total Loss". Additionally, the local damage assessment was updated to 346 [23] and the discrepancy between the 344 identified in this report has not been resolved. [xiii] The TD Damage Data used in this report is not intended to be the method to identify damage ubiquitously across a WUI incident.

Nonetheless, it is not uncommon for the homeowners to learn of the status of their primary structures through imagery provided by various sources after a fire. Full documentation of damage and destruction requires a synergistic approach between field data collection and remote sensing. This highlights the need for aerial assessments to be part of SOPs for moderate to large incidents, at least. These aerial assessments do not always have to produce industry standard orthorectified imagery but need to identify destruction, as would be common in many images taken by media sources after an incident, for example.

The remote sensing identified destruction in this report does not exclude primary structures that were completely replaced, such as 6465 Sandray Court where destruction was not evident from the aerial imagery. There was, however, a clear distinction between primary structures completely destroyed and those that were not completely destroyed in the post-fire imagery, even if demolition was eventually required due to extensive damage.

Post-fire aerial imagery was also used as a means to corroborate damage information to primary structures or other combustible features such as fences. In some instances, corroboration of damage from the homeowner was not possible due to difficulties in making contact. In other instances, discussions with homeowners identified a larger extent of damage compared to what was identified from other methods. Finally, in some cases, post-fire aerial imagery identified damage not identified through other methods.

Post-fire aerial imagery was also the major means to identify damage to vegetation, which is not studied in this report. Additionally, remote sensing was used to geolocate certain defensive actions as described in Section 8.3.2.2. Full integration of remote sensing with other Waldo

[xiii] One possible reason for the difference of 344 destroyed primary structures in this report and the 346 ultimately reported by CSFD might be the structures at Flying W Ranch. This report only counted one primary structure in this location, but many structures, which were considered as secondary in this report, were destroyed.

Canyon Fire Data is not conducted in this report. Evidence of defensive actions exists in the post-fire aerial imagery. These defensive actions are not included in this study.

For example, Figure 9 shows the locations where there were signs of defensive actions not recorded through the TD process but visible in the remote sensing data. Shown in Figure 9 are the locations where fences were on the ground and debris was in the yard that was not present in pre-fire imagery or in post-fire imagery recorded on 7/12/2012, after homeowners had returned. Also, shown in Figure 9, not captured in the TD process, is a location with possible evidence of containment actions through lack of white ash on destroyed primary structures compared to adjacent destroyed structures. It should be noted, however, that the presence of white ash does not indicate that no defensive actions had occurred. Some containment actions, such as those on Hearthstone Lane, focused on spraying water on primary structures adjacent to the burning structure and did not result in a blackened appearance, yet fire spread was still contained.

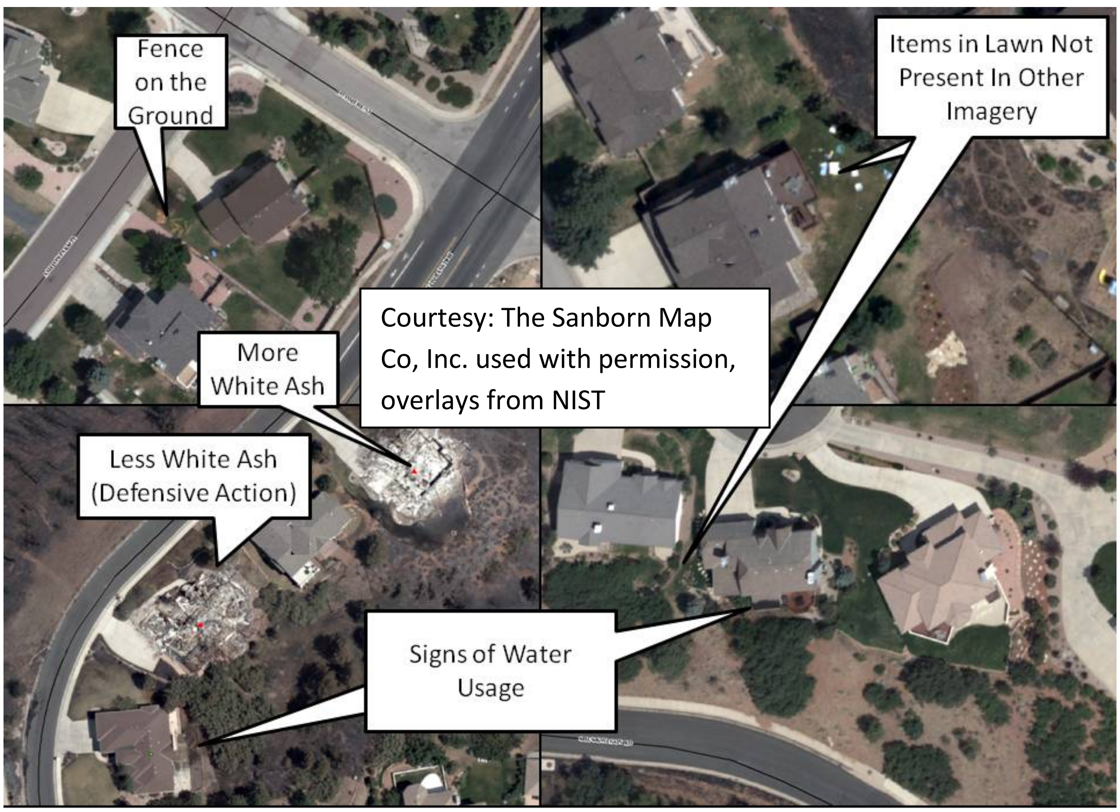

Figure 9 Examples of remote sensing identified defensive action signs not identified during the TD process.

Other examples of potentially missed defensive actions include defensive actions taken by video specialists on 2540 Rossmere Street and sprinklers on properties shown in the videos. Additionally, missed defensive actions are evident through examination of separate discussions by first responders on the same apparatus. This examination shows that sometimes one first responder would identify an action not identified by another responder on the same team. This in many cases is the result of the crew on the apparatus being split up and highlights the need for extensive data collection (TDs) at an apparatus level. Finally, mop-up actions were captured to a lesser extent compared to those occurring relatively shortly after the passage of the main wildland fire front (i.e. ≈ 10 hours after 17:30 on 6/26/2012).

The above highlights how it is impossible to capture all defensive actions through the TD process. This, coupled with the extensive time required to capture the first responder observations, emphasizes the need for a more efficient and effective method to record defensive action information. For example, not every first responder at the incident had a discussion due to time constraints. A crowd sourcing application might be more efficient, allowing for the capture of information from missed responders. Even with the above method it is likely that actions will still be missed and some discussions will always be required.

Regardless, it is believed that missing some defensive actions, as described above, has no repercussions on the findings in this report, where a conservative approach to geolocation of defensive actions was taken. This conservative approach was not to overextend defensive action locations. It is believed the defensive actions captured represent the general spatial location of actions occurring during the main burning of features in MSC. Future examination of exposure should attempt to account for missed defensive actions or at least potential locations where actions might have been missed.

In the context of exposure and structure response, remote sensing is used to categorize locations such as those shown in Figure 9, where there is evidence of containment actions, though these could be due to mop-up actions. These areas would need to be removed from the analysis of exposure and structure response, even if only qualitative analyses are employed. For example, the image shown in Figure 9 portraying varying levels of white ash present in destroyed primary structures provides evidence of defensive actions. Coupled with other signs of water usage in the area, the location should not be an area to assess structure response as it is possible the area was defended and simply not identified through the TD process presented in this report.

8.3.1.4 Media Sources

Handy [24] identified one damaged component on a primary structure. This damage consisted of a tile roof that had "piles of burned pine needles that had burned the roofing paper (beneath the tile)." It is important to note that there were also anecdotal observations collected during technical discussions of an additional unknown amount of primary structures with light scorching of objects but no ignitions recorded. There are no images or forensic evidence of these failed ignitions provided for this report. Again, this highlights the need for applications such as crowd sourcing applications to provide homeowners a means to document information not identified in local damage assessments.

8.3.2 Burning Feature and Defensive Action Timeline Data

Each data source used in the reconstruction of the fire timeline had uncertainties, with data quality varying over space and time. The data used to allocate time can be grouped into the following sources:

- Images/Videos (Images).
- Automatic Vehicle Locator (AVL)
- Radio Logs
- First Responders

Each observation must first be located in space to be of value for reconstructing the event timeline. Consequently, this section first examines the data quality aspects related to the geolocation of feature burning and defensive action observations. Next, this section assesses data quality related to burning and defensive action times, also across different spatial locations.

8.3.2.1 Images and Videos Spatial Data

Identification of the location of burning features and defensive actions is of paramount importance. Without proper geolocation of the observation, the account is of limited value for increasing scientific understanding of the incident. Burning features from images and videos were geolocated as described above using Microsoft Bing Maps and Google StreetView. Geolocation of burning vegetation and primary structures from videos and images with the burning feature in the foreground were almost ubiquitously geolocated successfully.

Figure 10 Image of primary structure burning in the back yard that required ground assessment to geolocate.

There was one image, shown in Figure 10, which required ground assessments to identify the location. Although even in this case, further confirmation was provided with Bing Maps and visual topographic analysis with the LidAR data (i.e., Line of Sight Analysis using the LP360 Extension to ArcGIS). Even in the dark, images of burning features were able to be geolocated if not blurry or over exposed. Nonetheless, the image shown in Figure 10 does highlight potential shortcomings of remote sensing technologies like Microsoft Bing Maps and Google StreetView for missing occluded features and features not viewable from the street.

The process of geolocating images in a GIS database also had potential for data entry errors. The main possible data entry error for image geolocation was that of incorrectly transcribing the location of the burning feature to a location in the GIS database. The high density of structures in many locations results in this data entry error being possible. There was no systematic assessment of this type of data entry error. Nonetheless, the image and video data has been examined extensively through the data integration conducted for this report. Consequently, this type of error is expected to occur in a small number of instances and, if present, is likely to result in only being off one or two primary structures.

There were, however, many images with burning features in the background, which could not always be precisely geolocated. In these cases, further evidence was required to confirm the location of the burning feature or the information was only generally used in this assessment. For example, there are a number of images that provide evidence of significant primary structure ignitions and burning on both the western side of Courtney Drive and Yankton Place before 20:00 as shown in Figure 11. These are not conclusive, and these areas remain as unknowns in this study with regards to burning time but there is some evidence of limited early ignitions in these locations based on the distant images showing primary structures as possibly foundations (this refers to structures totally destroyed and walls collapsed).

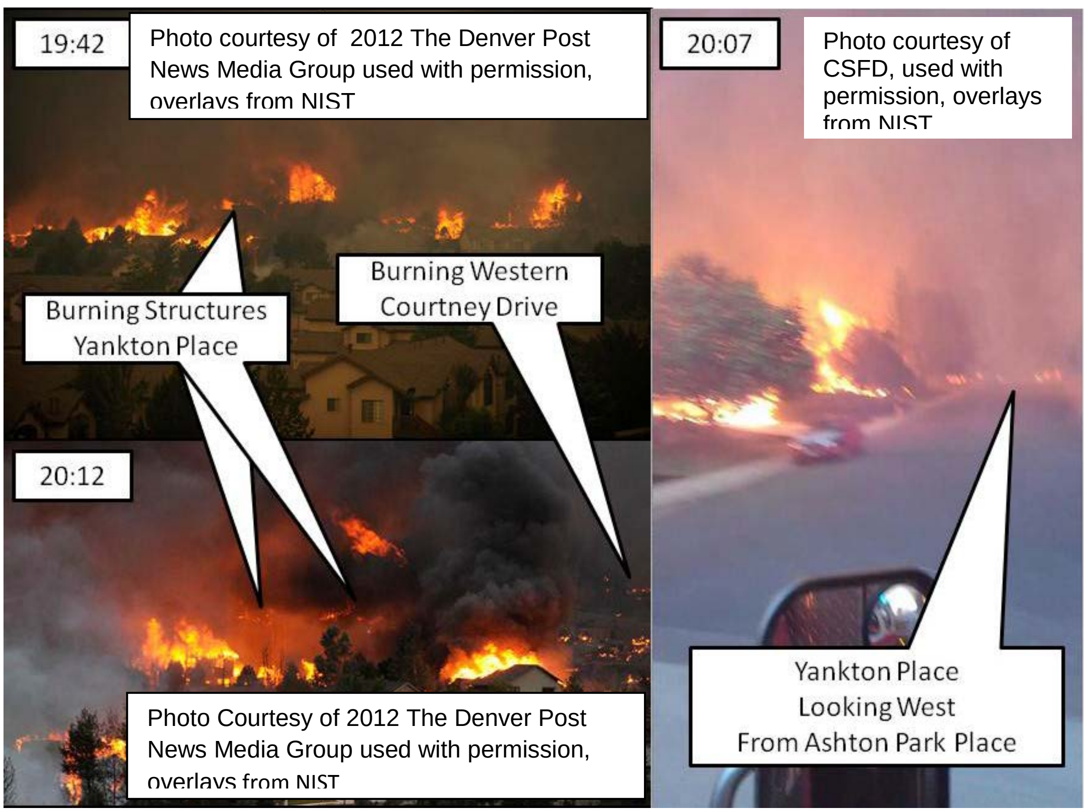

Figure 11 Evidence of early ignitions on Yankton Place and Western Courtney Drive through possible identification of primary structures as foundations.

Finally, it is important to note that images of all burning features were not captured. Images of burning features were obtained in locations where there were first responders or other fire observers (e.g., first responder video specialists, media and private citizens)who had safe vantage points. This is evidenced by the three different image sources available showing burning on the northern side of Courtney Drive and only distant views in the background of burning on the southeastern side of Courtney Drive and the western portion of Yankton Place, as shown in Figure 11.

8.3.2.2 Technical Discussion Spatial Data

The ability to locate defensive actions and first responder observations of burning features in space and time varied among the different TDs, the type of observation and the role played by the responder. In general, due to the correlation of defensive action observations with damaged features in the field, the geolocation of these defensive actions is believed to have occurred with a high degree of accuracy when damage was confirmed. These extinguishment defensive actions often occurred in areas where structure-to-structure fire spread was being contained and sometimes required multiple attempts at adjacent primary structures before containment was achieved, thereby allowing the geolocation of containment defensive actions to be simple and accurate.

Figure 12 Image showing first responder hand work associated with containment of a burning primary structure.

Automatic Vehicle Locator (AVL) information also provided a means to geolocate first responder burning observations and defensive actions. AVL allowed for identification of first responder's arrival on scene, thereby facilitating general geolocation of burning features through using ground images to identify the precise location of the actions, such as shown in Figure 12. Next, in conjunction with identified damage, defensive action locations of less obvious significance, though still essential to complete containment, compared to the engine work shown in Figure 13, could sometimes be geolocated.

Post-fire aerial imagery was not fully integrated into this assessment, but was used to more precisely geolocate some actions of importance to this study (e.g. containment actions). One example is shown in Map Figure 3 portraying AVL locations for a CSFD Engine Crew overlaid on post-fire aerial imagery. One observation available from several members of the Engine Crew defending this area originally placed the containment action on the western primary structure. In this case, subsequent TDs resulted in correct geolocation of the action to the eastern primary structure. Nonetheless, not all such errors were corrected through TDs alone.

Figure 13 Image showing significant engine work required to contain fire spread from burning primary structure.

This same primary structure was identified by the image data team as a likely primary structure where fire spread was contained due to some type of suppression, despite initial results from the TD team indicating containment on the western structure. As shown in Map Figure 3, the eastern primary structure shows lack of white ash evidenced through blackened appearance, indicating lack of complete combustion of features. The exact cause of the blackened appearance ascertained from the post-fire imagery requires ground validation and, in this case, appeared to be contained by first responders with significant water application identified through the TDs.

The location of the containment action to the eastern primary structure is further confirmed by AVL locations clustered around 6045 Wilson Road, as shown in Map Figure 3. The AVL time stamp also indicates the action occurring around 21:00, over two hours after the white ash primary structure is shown as fully involved, as shown in the image contained in Map Figure 3 from a video taken by first responders. This image indicates the ignition order of the two primary structures as west to east, evidenced by the state of involvement of the structures. Structure-to-structure fire spread is not confirmed in this case as evidenced by burning of mulch in the foreground of the image shown in Map Figure 3, which might have ignited the structure on 6045 Wilson Road. Though there is some evidence of structure-to-structure fire spread through the presence of more white ash on the western side of 6045 compared to the eastern side.

Not all observations contained as much data as the example above. It was also not uncommon for the locations portrayed in the observations spreadsheet to be initially geolocated improperly, as described in Section 8.3.1.2. There are also additional reasons for the potential imprecise geolocation of observations as shown in Table 7. The procedure used, before integration in a GIS environment, had four sources of error compared to one source of error in the image geolocation process. When examined in the context of expected data entry errors per operation (i.e., ≤10 %) it can be seen that the end result could be significant (i.e., ≤40 % of ultimate data if potential combined sources of error are identified).

In fact, the initial integration in a GIS environment discovered many errors, some of which could not be corrected despite multiple attempts outside a GIS, potentially due to difficulty in understanding the scene based on only discussions with first responders. Nonetheless, the GIS review and integration process is believed to have corrected major errors, but it is likely errors still exist. Again, the need for a less error prone process for the collection of first responder observations is highlighted.

Table 7 Sources of error present in the TD data collection process.

Technical Discussion Error Source	Potential Error Cause
First Responder Account	First responder incorrectly remembers some aspect of the burning feature or defensive action observation.
Transfer of First Responder Account	Data recorder incorrectly records information portrayed by the first responder (e.g. wrong address, wrong action, etc.).
Transfer of Recorded First Responder to Digital Media	Errors in transcription of information from handwritten notes to electronic media.
GIS Review Process	Cleanup between the image data collection team and the TD data collection team occurred with the TD data collection team attempting to make corrections in the spreadsheet resulting in potential for data entry errors.

There were also a number of observations that could not be located in space or time and were removed from the dataset. Additionally, there were 1036 observations that could only be located at the street level. Many of these observations, 916, are of logistical operations such as refueling, obtaining water or simply moving between locations. There were an additional 32 observations, which were related to general exposure conditions. The remaining 97 observations were related to features as shown in Figure 14.

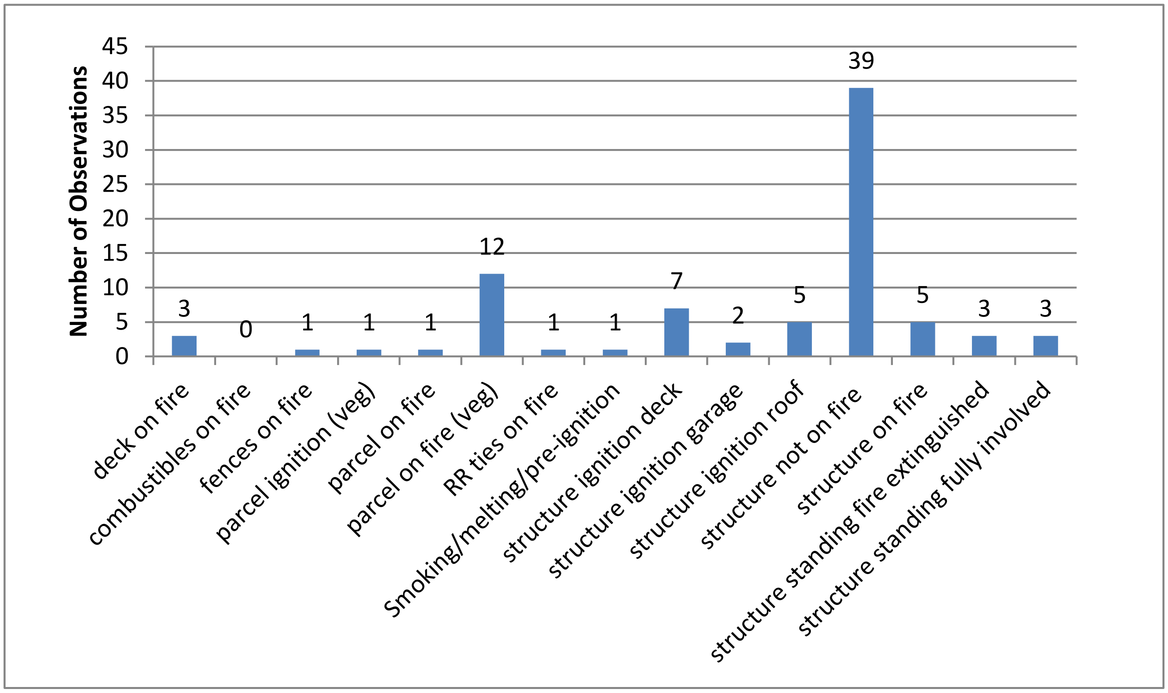

Figure 14 Counts of observations from TDs that could not be geolocated beyond the street.

As can be seen, the greatest percentage of burning feature observations at the street level belongs to observations of structures not on fire. The next greatest percentage of observations geolocated at the street level was of vegetation on fire, which was an important observation, but only 12 were recorded. It can also be seen that there were observations of decks on fire and igniting, railroad ties on fire and ignitions of garages and roofs.

It is sometimes difficult, even for eyewitness observers, to be able to precisely describe the ignition of a feature. For example, Figure 15 shows an ignition location in a re-entrant corner of a primary structure by a deck. The exact cause of ignition cannot be determined from the image in Figure 15, although closer inspection could indicate the ignition source. This shows that a fire observer's identification of an ignition location could be imprecise.

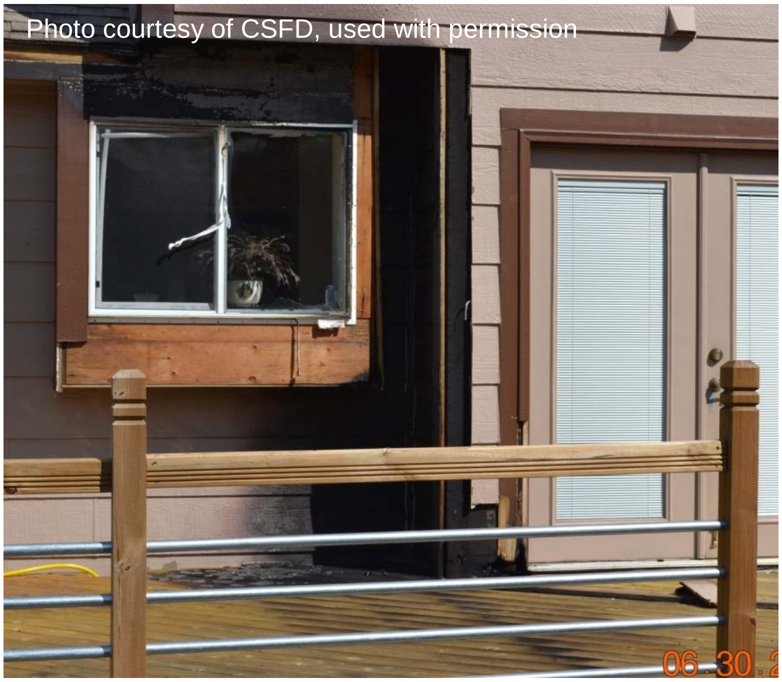

Figure 15 Ignition in a re-entrant corner area with precise ignition location not determined in this case.

Due to the GIS data integration that was conducted for this report, it is believed that the majority of incorrectly geolocated observations were identified and corrected. It is likely, however, that some errors still remain. Consequently, a conservative approach was taken for data analysis resulting in a classification of unknown for burning times when there was any reason to believe errors might exist for the particular data record.

Despite some shortcomings, geolocation of many of the primary types of actions described above, while difficult to independently assess, are believed to be accurate and adequately capture the spatial representations of actions for conclusions and findings derived from this report. It is known that not all defensive actions have been documented with examples described above. Additionally, as described above, some defensive actions likely occurred in other locations.

This was the first effort of its kind conducted for a large incident. Collection of observations from fire witnesses is the most difficult and error prone data collection procedures described in this report. Capturing of the general and often times precise location of defensive actions is possible within an integrated environment, particularly for major actions such as extinguishment and containment actions. There is no evidence that capturing this information accurately is possible in a non-integrated environment (e.g. tabular spreadsheet).

The number of error sources for recording of fire witness observations can be reduced. Solutions to improving the efficiency and effectiveness of recording first responder observations are possible. If any large error exists regarding the location of defensive actions described in this report, the evidence indicates that the error would be in underrepresenting the extent of defensive actions. Additionally, important spatial patterns are captured, as discussed below.

8.3.2.3 Images and Video Time Data

In total, there were 266 distinct images and videos [xiv] portraying burning conditions of primary structures. These images provided 681 observations on the ignition status of 290 primary structures. Of these observations, 33 did not have a time stamp beyond identification of day or night. This resulted in 284 primary structures with images portraying a time stamp of primary structure burning condition.

Figure 16 shows image counts by time stamp ranges. As can be seen, the majority of images were estimated to be within a narrow time range, as most devices had time stamps with the times occasionally being systematically in error due to seasonal time changes or time zone changes. These were adjusted accordingly based on cross correlation with other images and AVL. Time ranges of 0 min to 10 min or 10 min to 20 min were used to allocate ranges based on observations of burning structures from beginning to end as described in sections below.

The relatively small numbers of image observations with time ranges of 10 min to 20 min were largely from the Fox News Video and the YouTube Videos entitled “Mountain Shadows is Burning”, both shown in Appendix E. Additionally, a few other images and videos were missing time stamps and were assigned times and ranges based on co-occurrence of burning objects and observed burning time of objects in other time stamped images. These images were essential to the determination of burn times and were in some cases the only information available, as was the case for Trevor Lane. This highlights the importance of having imaging devices correctly enabled and configured to record time of images for during-fire photography.

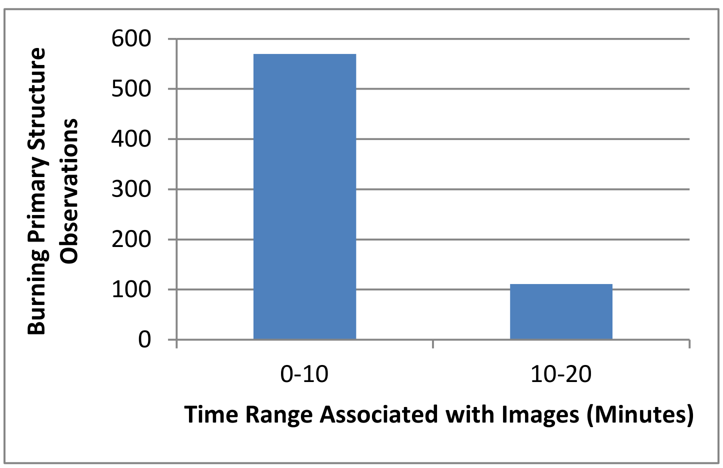

Figure 16 Counts of burning primary structure observations from images by range (±) associated with time stamp.

The observations of burning primary structures came from image sets from 31 distinct sources as shown in Figure 17. The two largest sources of observations came from the CSFD videographer and a scout truck, which had a first responder who collected time lapse images of many locations, when safe to do so. TD 41 and TD 165 both had GoPro cameras, allowing recording of many burning condition observations. This highlights how a small number of individuals can provide a great deal of information through photographing WUI

[xiv] There were over 4010 images provided representing pre-fire, during-fire and post-fire conditions. Of these at least 565 contained images of structure burning, 266 were used to prescribe locations to burning structures. Many of the 565 images were duplicates of the 266 used and were not recorded if no new information was discerned. This data will reside in a database at NIST.

incidents during the fire, when it is safe to do so, and how imaging devices like GoPro cameras can collect a great deal of information in a unobtrusive manner.

The availability of images also varied in both space and time. Map Figure 4 shows the locations of the 290 primary structures of which images exist to portray some form of burning features between the time of the incident reaching MSC and June 27, 2012 01:30. Sixty-five percent of the damaged or destroyed primary structures had images of burning or complete destruction. There were, consequently, 157 destroyed or damaged primary structures for which time estimates from images were not available.

Of the 157 primary structures with no images of burning, 73 had confirmed damage, 14 had unconfirmed damage, and two had partial damage confirmation. Information from TDs was available on the remaining 68 destroyed primary structures for most areas except for Flying W Ranch. The group of primary structures shown in Map Figure 4 in the interior of Majestic Drive also has no specific observations from images, other than on Hot Springs Court, but primary structure burn times can be inferred from these images, videos, and TDs as described below.

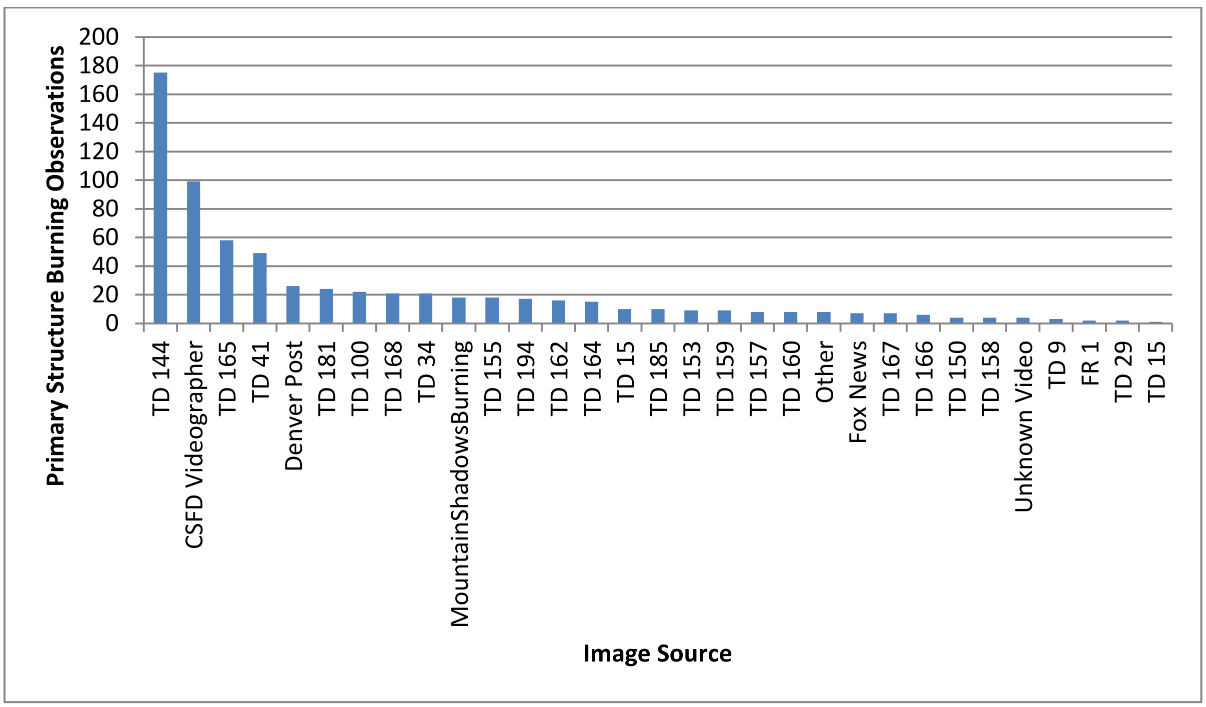

Figure 17 Counts of primary structure burning observations by source.

The number of images available during one hour time periods increased with each time interval until 20:30 when they began to decrease. This pattern is shown in Figure 18, which also portrays a slight increase on June 27 at about 0:30. This increase is due to one video from a first responder showing burning foundations or completely destroyed primary structures along the eastern side of Majestic Drive, almost from Lions Gate Lane to the northern part of Majestic Drive, where the road begins to curve to the west, representing a total of 37 primary structures.

This video comprises almost all information, other than anecdotal, for the northeastern area of Majestic Drive, available for this report.

The peak image acquisition at 20:30 is likely due to several factors. First, the steady increase in images available is partly due to an increased number of witnesses as the incident progressed. As discussed in the sections below, this peak also roughly coincides with deployment of resources. Many images were taken as first responders first deployed and those not driving were assessing the situation and imaging features. The imaging did not continue once first responders were deployed, except during breaks or by those tasked with documenting the incident.

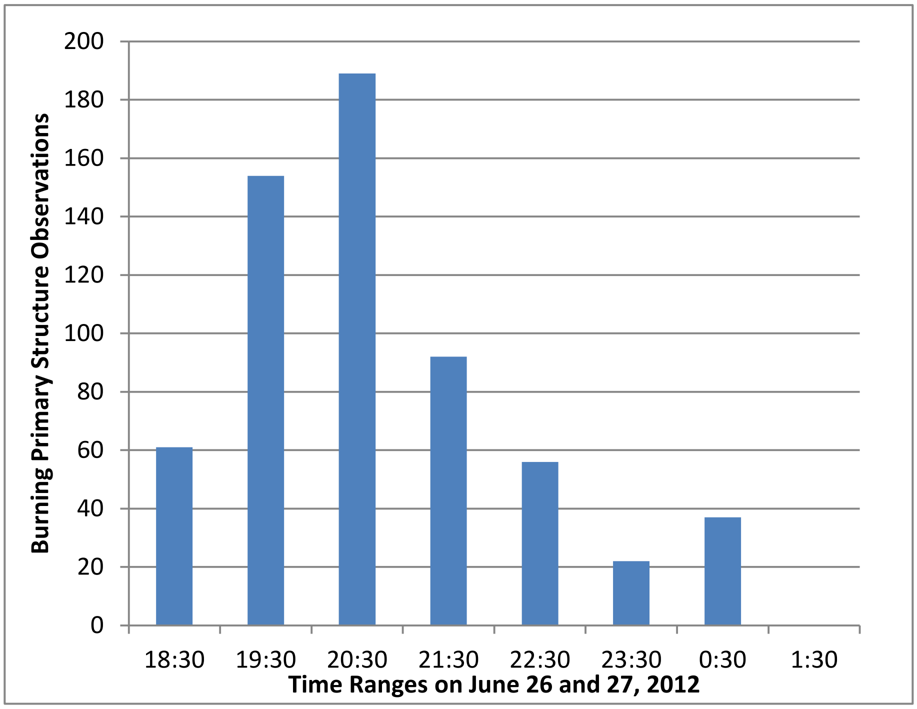

Figure 18 Counts of primary structure burning observations from images by time range.

The spike of images at 20:30 is also likely due to the increased visibility, which appeared to have coincided with the wind change and also allowed the imaging of the scene by observers on the periphery of the fire and in topographically convenient areas safe from the incident. These areas facilitated imaging of burning primary structures and vegetation for the southern portion of Wilson Road and areas east such as Trevor Lane, Courtney Drive and Jenner Court. Finally, the setting of the sun around 20:30 reduced some imaging. Many later images were also instrumental in determining the fire timeline on southern Majestic Drive and Lions Gate Lane as well as Ashton Park Place and other locations.

Regardless of the cause, the general increase and spike around 20:30 of burning observations from images also represented a peak of understanding of the fire timeline related to structures burning, and, possibly, a convergence with defensive action peak deployment of resources. This time also appeared to coincide with the beginning of the large majority of successful containments of structure-to-structure fire spread and other flare-ups. Additionally, given the time for apparatus deployment coupled with burn time and defensive action integration presented below, the fact that it took time for resources to reach effectiveness is highlighted.

Images portrayed varying degree of information regarding burning times. For example, some images only portrayed structures in a complete state of destruction with minimal flames present in images taken at night. Other images portrayed structure ignitions or early burning clearly seen during the day or full involvement at night, thereby illuminating surrounding features. Figure 19 provides counts of primary structure observations showing burning structures grouped by burning categories.

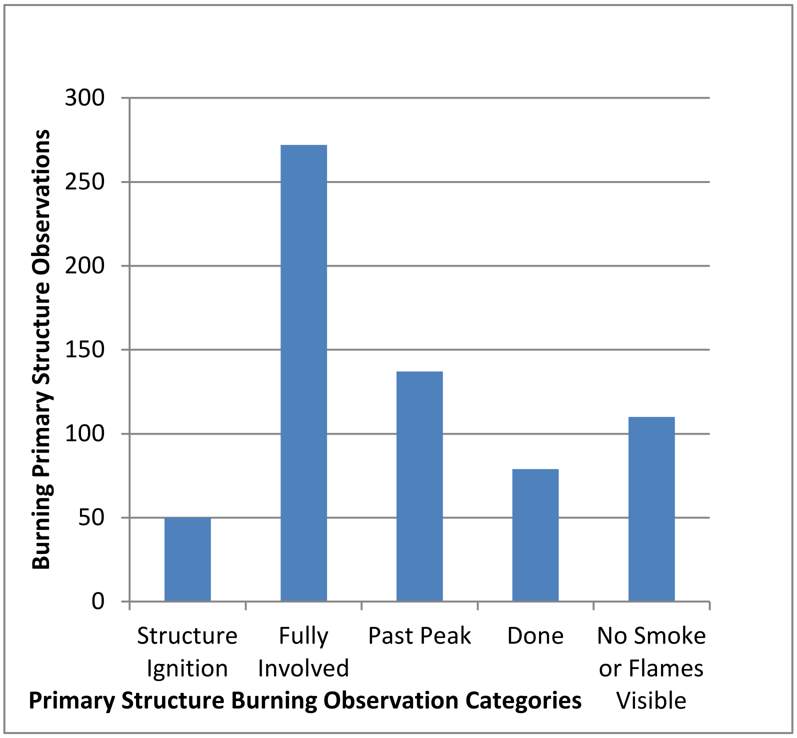

Figure 19 Structure burning observation counts by burning category.

The images were initially grouped into the categories shown in Figure 19 but normalized to "burning" or "not burning" to coincide with burning descriptions from TDs, which could not generally be precisely classified based on lack of a quantitative measure. It should also be noted that 50 structures were identified in the images as in the process of igniting and placed in the "structure ignition" category. In most cases this delineation was conducted to identify fire progression and possible structure-to-structure fire spread. The ignition categorization was not used in tabulations for the Waldo Canon Fire studies beyond those shown in Figure 19, unless ignition was also confirmed by eyewitness observers and a field assessment or image of damage.

All images showing some state of burning, or lack thereof, provide some information for timeline development. The locations of primary structures with image observations only coinciding with the "Done" category also identify certain gaps in image information regarding burning primary structures, such as the east side of Majestic Drive. Map Figure 5 shows the location of these images, which in some cases portray a general lack of information. Nonetheless, in some cases, even images portraying "Done" burning primary structures such as on Trevor Lane, Courtney Drive and Hot Springs Court, when available in the context of other burning images, might also portray valuable information.

For example, the videos shown in Appendix E titled, "Mountain Shadows is Burning" show primary structures "Done" burning in conjunction with other neighboring structures in a more involved state of burning. This provides information on the extent of fire spread in the area of Trevor Lane. Map Figure 5 also highlights the lack of images on the eastern side of Majestic

Drive. This, coupled with the areas shown in Map Figure 4 not having any images, portray the general areas where limited information from images regarding burning times of primary structures are located (i.e., east side of Northern Majestic Drive, Brogan's Bluff between Wilson and Rossmere Road, Karamy Court and interior portions of Yankton Place).

Counts of primary structures by number of image observations in each burn condition category available for respective structures summarized in Figure 19, are portrayed in Figure 20. Primary structures counted as having one observation category in Figure 20 might have had multiple images in the same category. As can be seen in Figure 20, the number decreases dramatically with an increase in the number of burning observation types. Also shown in Figure 20 are 191 primary structures having image observations portraying only one state of burning conditions of the 284 (67 %) structures with images showing burn condition from a time stamped image.

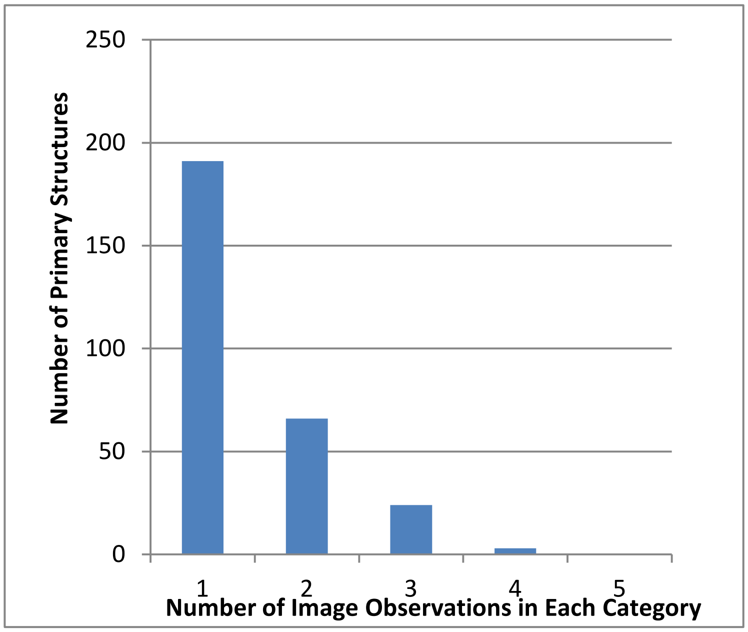

Figure 20 Counts of primary structures by number of image observations in each burn condition category.

There were only 44 distinct images that provided 108 observations on the ignition status of vegetation and detached combustibles on 64 parcels, as shown in Map Figure 6. Time patterns generally follow those described above, with the peak amount of images occurring between 19:30 and 20:30 on June 26, and only three images not having time stamps. Figure 21 shows the number of images per combustible feature category.

Images of burning features on the parcel covered less features compared to those of burning primary structures. For example, of the 840 mapped parcels within MSC containing a mapped fire perimeter, only 64 (i.e. ≈ 8 %), as shown in Map Figure 6, had images of parcel burning features. This is compared to 65 % of the damaged and destroyed primary structures having images showing some state of burning.

There might be several reasons for this, including that some significant percentage of the wildlands burned shortly after the passage of the main fire front while first responders were evacuated. Also, images might have focused on burning structures as they were a more significant phenomenon. Nonetheless, there were locations with multiple images portraying different states of burning vegetation and detached combustibles, which provided valuable information, particularly regarding consequences of a wind change after the passage of the main wildland fire front. These specific cases are discussed in more detail below.

Images portrayed relatively little information on specifics of defensive actions. The above described images, however, were useful in determining time of defensive actions. Specific details of defensive actions were obtained from TDs. It should be noted that images did contain evidence of defensive actions, which were not recorded by the TD process, with an example shown in Figure 22.

Figure 22 provides evidence of a possible defensive action around Wilson Road by a CSFD apparatus at 18:29. Although it is not conclusive that any action took place in this location, there is evidence that a defensive action might have occurred at this location based on the image of the first responder with equipment at the ready and the deployed hose. Ultimately, no defensive action was recorded at this location and time by the apparatus shown in Figure 22.

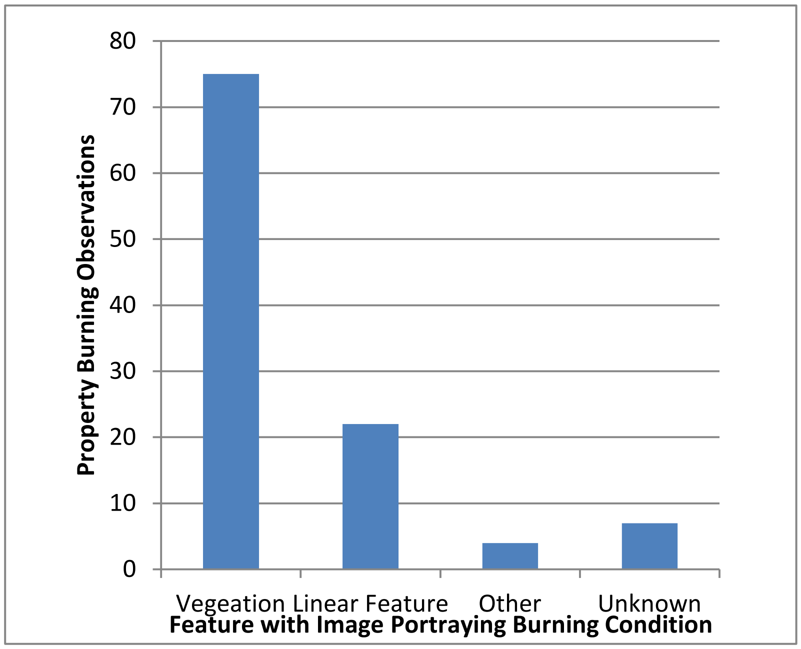

Figure 21 Counts of properties with images of burning features or lack thereof.

The potentially missed defensive action described above demonstrates the importance of integrating all data. Also, highlighted is the need to improve techniques for recording defensive action information. For example, if a crowd sourcing method was available to gather information from first responders, the image shown in Figure 22 could have been used before the TDs began. This would have allowed data recorders the opportunity to present the image to first responders on the apparatus, which might have refreshed the memory of the responder to the action that took place.

The area shown in Figure 22, which was geolocated due to Google Streetview imagery of the same location, is important to overall analysis of the Waldo Canyon Fire. Ideally, it is important to know what locations, built and wildland, received spotting potentially from the main wildland fire front. Aside from the image shown in Figure 22, there was no evidence of ignitions in this area after the passage of the main wildland fire front, though there was evidence of ignitions in areas to the south of this location. Consequently, uncertainty of ignitions is present based on the image shown in Figure 22, and the lack of a recorded defensive action in this location at the respective time.

8.3.2.4 Technical Discussion Timeline Data

The 208 TDs provided timeline information on burning features and defensive actions. TDs occurred with varying members of particular fire suppression resources (e.g., Engines, Brush Trucks, Hot Shot Crews, etc…) with an effort made to have discussions with at least one member of each apparatus or hand crew. Additionally, TDs occurred with individuals who directed defensive actions and made observations of burning features and other defensive actions, but might not have conducted the defensive actions. These actions were in theory marked in the spreadsheet as "prior defensive action", and are considered anecdotal information in this report.

Figure 22 Image taken at 18:29 on Wilson Road to the east of Vantage Vista Drive showing an unconfirmed defensive action.

It should also be noted that the TD spreadsheet essentially has two records for some observations. For example, a first responder extinguishing a deck would result in two records. One record would contain information related to the primary structure burning condition (e.g., "deck on fire") and the second record would contain information related to the defensive action (e.g. "extinguish structure"). For this and other reasons, care must be taken when "counting" observations of burning features or defensive actions in the TD spreadsheet.

Also, the defensive action data and burning feature observations, whether from images or other sources are biased because they required human presence. Some areas, including many wildland areas, did burn with no documented accounts in this study. The assessments presented in this section aim at identifying those locations of known activity, based on post-fire information, but no observations of burning features or defensive actions in addition to assessing other items of data quality.

Many records of primary structures burning (950) had coincidental observations of defensive actions. Consequently, the population of TD burning primary structure observations with time stamps (1872 as described below), was used to assess distributions of observations in the TD data without the double counting that would have occurred if both defensive action and burning feature observations were included.

Figure 23 shows the number of burning primary structure observations by TD number. Only those observations with greater than 20 observations are examined to look at those discussions with a larger than average number of observations. The average number of burning primary structure observations per discussion was about eleven with a standard deviation of about ten. For this population, there were 28 discussions that accounted for 742 of the 1872 observations or 27 % of the discussions accounted for 40 % of the observations of burning primary structures.

There might be many reasons for the relatively small number of discussion numbers having a disproportionate amount of observations of burning primary structures. First, the majority of apparatus were local CSFD apparatus, which were on the fire scene for the entire time period being studied, requiring duplicate discussions to cover the extent of the incident. Observers with images sometimes resulted in numerous observations, as evidenced by TD 41 having the most observations, many of which were a result of a GoPro video early in the incident. There might be other reasons.

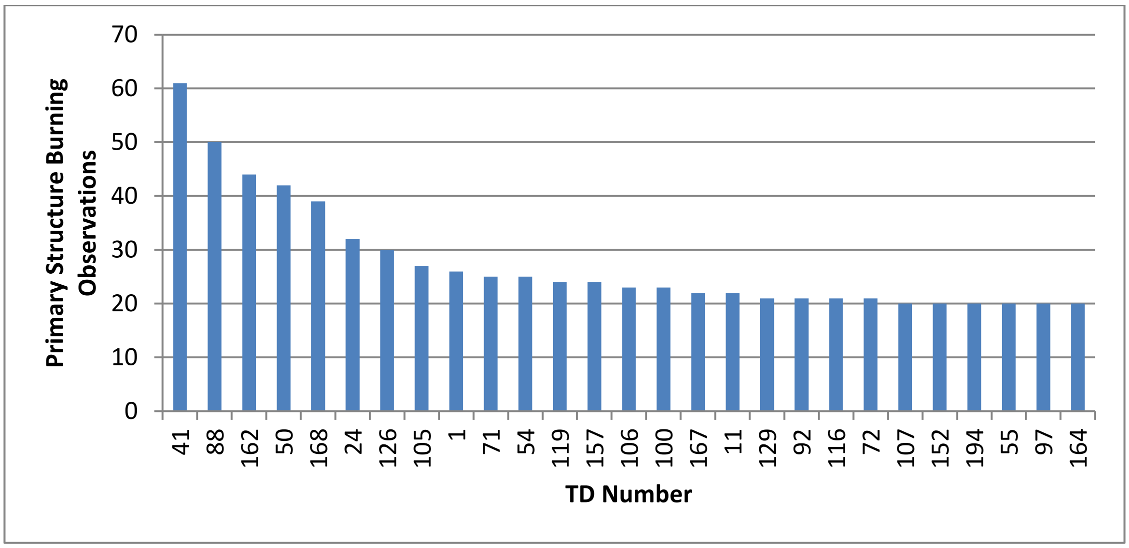

Figure 23 Counts of observations of burning primary structures by TD number for those discussions that contained greater than 20 observations.

There were 1996 observations from TDs related to burning conditions of primary structures of which 124 had no time estimate. The remaining 1872 observations all had time sources, either from images, AVL or radio logs, often correlated in the context of related first responder events. Additionally, the above sources were often used to bound observation times. Ultimately, the TDs provided time stamped information on 365 of the 455 (82 %) destroyed or damaged primary structures as shown in Map Figure 7. Only small areas on the northeastern side of Majestic Drive and Yankton Park Place had no observations.

Some locations had contradicting information regarding burning conditions from uncorroborated accounts. For example, one first responder stated that he, “could see all the framing” of all the primary structures on the southern side of the interior of Brogans Bluff Road early on June 27. Discussions with a homeowner on Karamy Street provide descriptions of the primary structures, “going up like dominoes” on Brogans Bluff Road before sunset on June 26. The above discrepancies highlight the difficulties of obtaining primary structure burning observations from anecdotal accounts with no imagery.

Figure 24 shows the counts of TD observations of burning primary structures by time source listed in the TD spreadsheet. It should be noted that some of these estimates had multiple confirmations of time from AVLs, images and/or radio logs, which are not reflected in Figure 24 as only one source was listed. And, as discussed above, observations from a particular team (e.g. engine) might be counted twice and represent only one burning feature or defensive action. Consequently, it is difficult to provide exact "counts" of observations from TDs and the data contained below is presented to assess basic trends in the data regarding quality and uncertainty.

As can be seen in Figure 24, the largest number of time stamped TD observations came from AVLs, followed by cross-correlation, images and radio logs. It is also important to note that while there is some overlap with the images listed in section 8.3.2.3, many of the fire behavior observations found in the images described above are not included in Figure 24. That is to say that not all images were integrated with observations from TDs.

The contribution of each time source to providing observations on burning primary structures across time ranges on the evening of June 26 into June 27 are shown in Figure 25. AVLs, images, and radio logs mostly surpass cross-correlation in regards to amount of time stamped observations obtained for the first three hours of the incident. Cross-correlation as a time source then begins to become more prevalent between 20:30 and 21:30 on June 26 and eventually surpasses or equals the number of observations from other time sources, between 23:30 to 1:30. Then AVL proceeds to have the most observations, relatively, as this became the main time source and no more images were available.

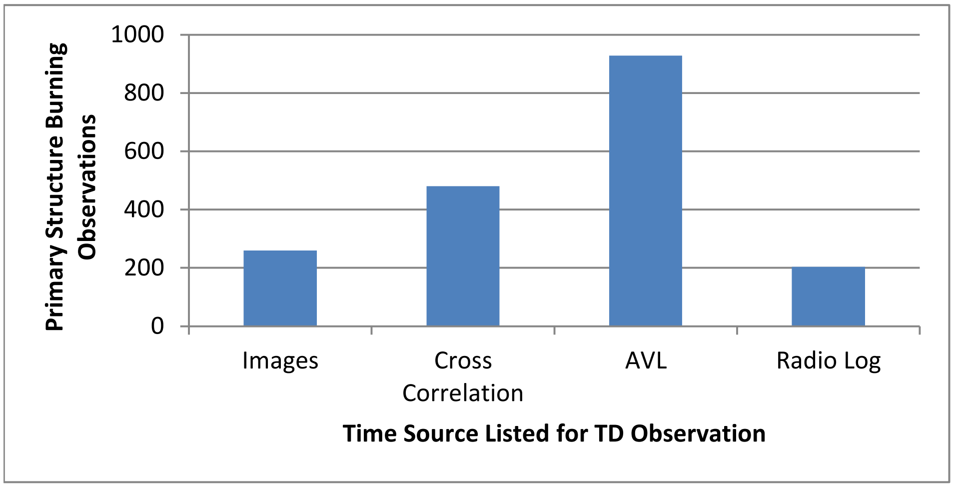

Figure 24 Counts of TD observations of burning primary structures by time source listed in the TD spreadsheet.

The increased number of observations from the cross-correlation time source around 21:30, shown in Figure 25, is also, in part a consequence of the large time ranges associated with this time source method. There were a number of observations of burning primary structures with time ranges greater than 20 min with significant numbers greater than ± 60 min, as shown in Figure 26.

These observations often had a time estimate assigned later during the incident to account for the large uncertainty in the time. The increase is also due to the occurrence of a number of defensive actions, which began during the 21:30 time period, or shortly before. The spike of primary structure burning observations shown in Figure 25 around 0:30 on June 27 is also due in part to increases in deployment of mutual aid resources at this time along with mop-up actions and defensive actions at the southern end of Majestic Drive and Lions Gate Lane.

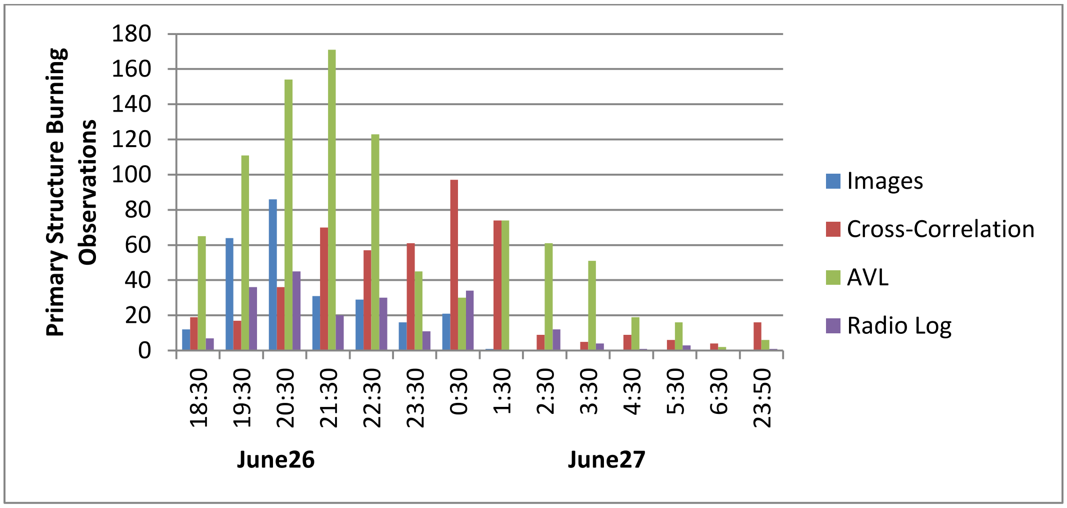

Figure 25 Counts of burning primary structure observations from TD by time on June 26-27, 2012 associated with each time stamp for each time source.

Consequences of large time ranges associated with TD observations can also be seen when comparing the distribution of burning primary structure observations from TDs shown in Figure 25 to the distribution of burning primary structure observations from images shown in Figure 18. This comparison of the time ranges for the two observation sources indicates that observations from TDs peak about one hour later than observations from images (21:30 versus 20:30). In part, this is due to the increased time range associated with observations from TDs, as shown in Figure 26, compared to time ranges associated with observations from images, as shown in Figure 16, resulting in TD observations with greater than about ± 20 min time ranges sometimes being binned an hour different than when the burning actually occurred. Also, this is a consequence of the time it took from initial deployment to actions.

Figure 27 shows the contribution of each time source to the dataset on observations of burning primary structures across time ranges on the evening of June 26 into June 27 for those observations with uncertainty in the time range of ± 20 min. The contribution of images becomes more prevalent for observations between 19:00 and 21:00, but AVLs are equally as important for TD observations. The effect of large time range in the peak of AVL time stamped observations at 21:30 is reduced and there is a more even distribution of images. Also, comparison with Figure 18 highlights the missing contribution of primary structure burning observations from images.

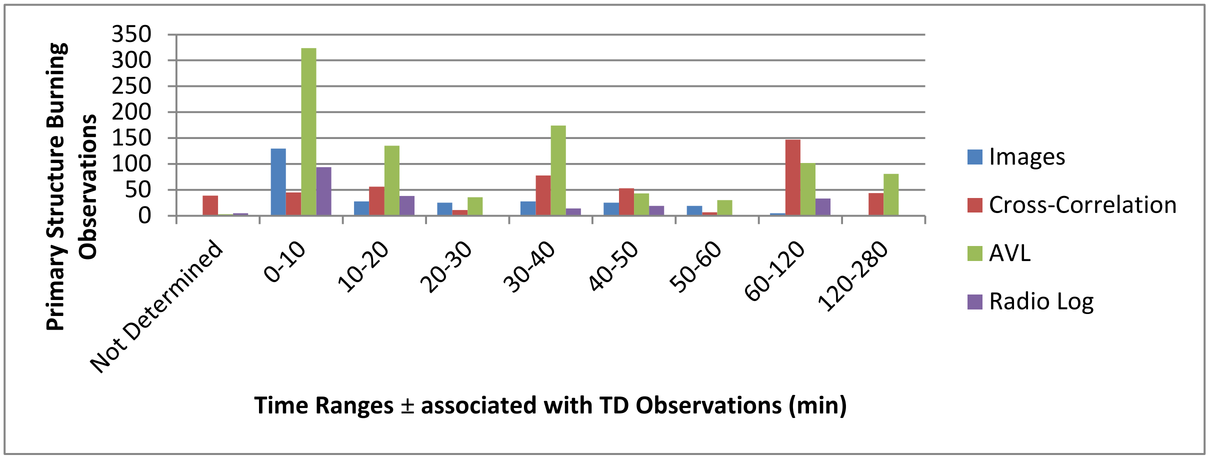

Figure 26 Counts of burning primary structure observations from TDs by range in minutes (±) associated with time stamp for each time source.

The number of primary structure burning observations by time range estimates is shown in Figure 28. The effect of those observations with large time range estimates around the single estimate is seen in Figure 28 with the majority of the time ranges with estimates greater than 60 min occurring during the 21:30 time interval or later. The distribution from time ranges of 0 min to 20 min likely represents the population of TD burning primary structure observations with time estimates useful for this study. These 859 observations represent time stamp observations with uncertainty in the time range of ± 20 min on 290 primary structures in some state of burning, or lack thereof, as shown in Map Figure 8.

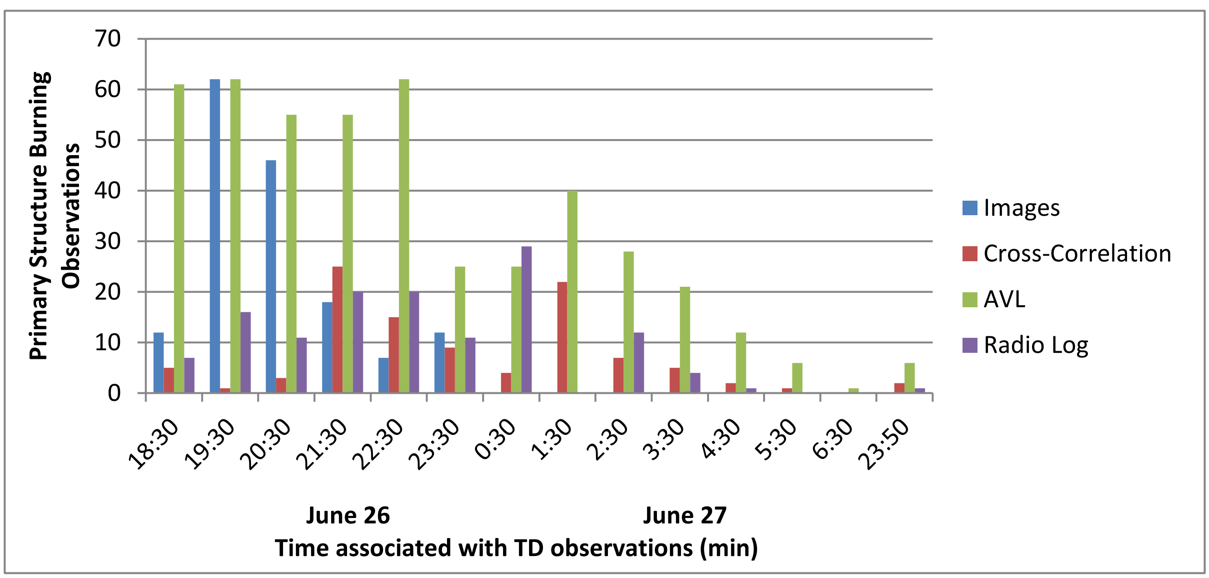

Figure 27 Counts of burning primary structure observations from TD by time ranges on June 26 -27, 2012 for each time source with a time range less than or equal to ± 20 min.

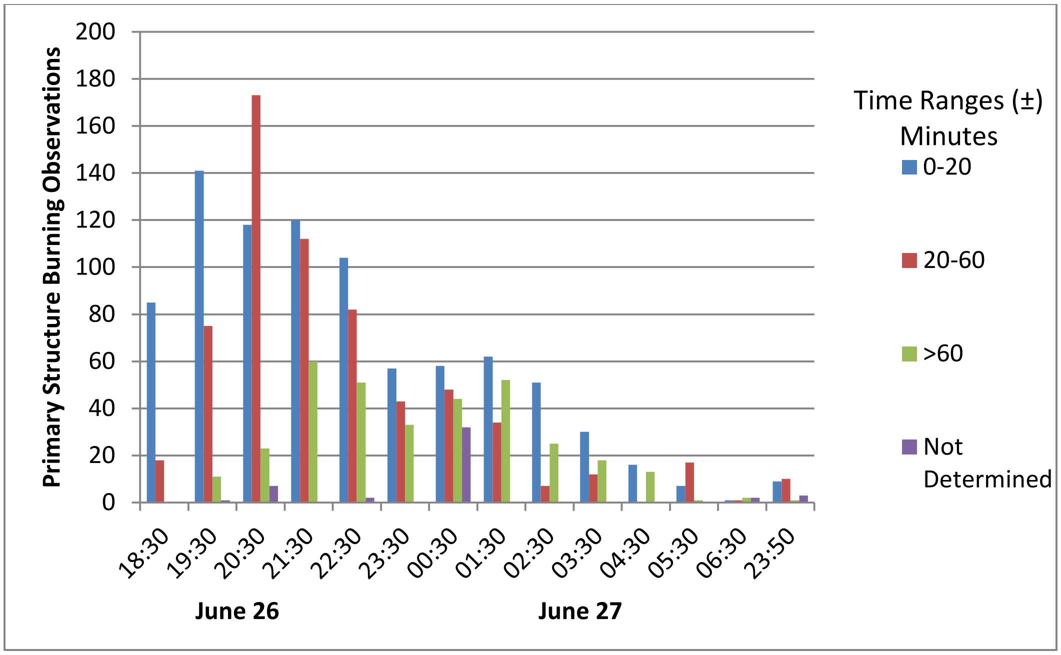

Figure 28 Counts of burning primary structure observations from TDs by time intervals on June 26-27, 2012 displayed by time range estimates associated with burning primary structure observation.

This shows that about 35 % of the primary structure burning observations from TDs with a time range between 0 min and 20 min occurred late in the incident (i.e., after 21:30 on June 26) and had low time ranges because of the late state of burning as described above. It should also be noted that observations of burning features might be from different observers viewing the same burning object. Therefore the observations of decks, garages, roofs and other items burning or ignited, in Figure 31, can only be used to indicate that these items were burning and not to quantify the amount of burning of each feature type at the Waldo Canyon Fire.

There were only 201 observations of detached combustibles or vegetation on parcels in some state of burning. These had similar patterns to those described above for primary structure burning observations. There were, however, more observations from cross-correlation (84), and then AVL (71) followed by radio log (24) and images (22). There were 62 or about 31 % of the observations with uncertainty in time stamps of less than ± 20 min. There were 117 observations occurring before 21:30 on June 26, or about 58 %. The distribution of observations among the various burn condition categories assigned as shown in Figure 30.

TDs were the primary source used for determination of the time of defensive actions. There were 1921 observations related to some specific defensive action, of these 51 had no time stamp. Consequently, there were 1870 time stamped defensive action observations on 487 properties.

Many of these 1870 coincided with observations regarding time estimates of burning features described above. Similar time range issues, as described above, for burning features occur with defensive actions. The images could not be used to fill in the missing information of defensive actions with large time ranges in this report. Consequently, all defensive action records are assessed below.

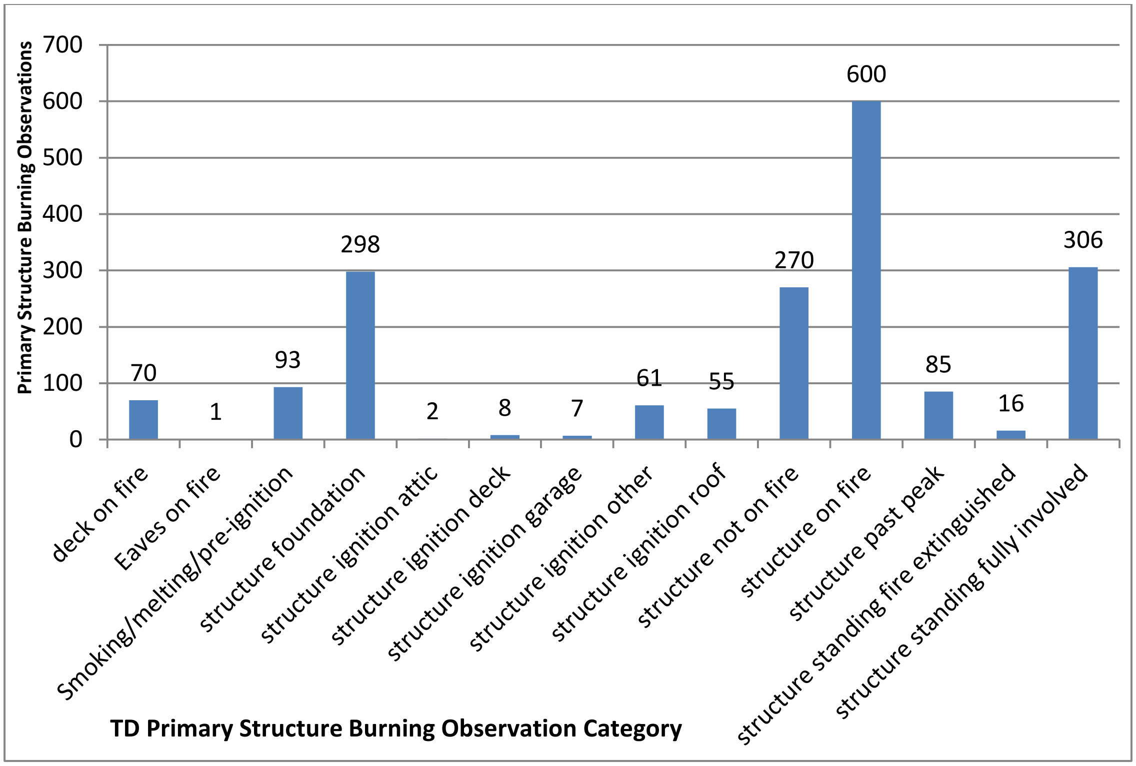

Figure 29 Counts of burning primary structure observations from TDs by observation category.

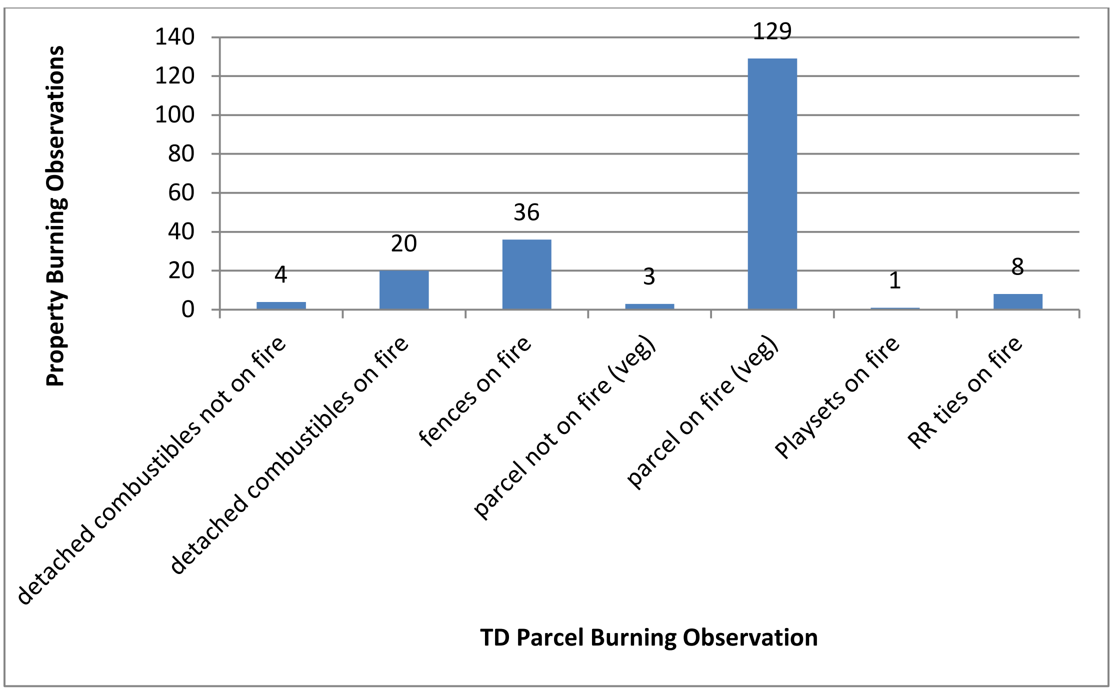

Figure 30 Counts of TD parcel burning observations.

Defensive action observations from TDs across one hour time intervals for various defensive action observation categories are shown in Figure 31 through Figure 34. Figure 31 shows defensive actions observations related to primary structures. Figure 31 indicates “preventing structure ignitions" had the most occurrences followed by "extinguishing structures" and then "contain structures". There is an increase of actions to "prevent structure ignitions" coinciding with an increase in time up until 22:30.

This increase is in part due to the increased number of burning structures during this time period and the consequential containing or "boxing in" of burning structures. Map Figure 9 portrays this "boxing in" of burning areas by preventing structure ignitions and shows defensive actions conducted to "prevent structure ignitions" between 19:30 and 22:30 and the spatial relationship of these structures to other primary structures, many of which have burned or are burning during the specified time. Also shown in Map Figure 9 are a large number of defensive actions to "prevent structure ignitions" around Chase Point Circle and Regal View Drive, which are a result of first responders turning sprinklers on in this area to prevent ember ignitions.

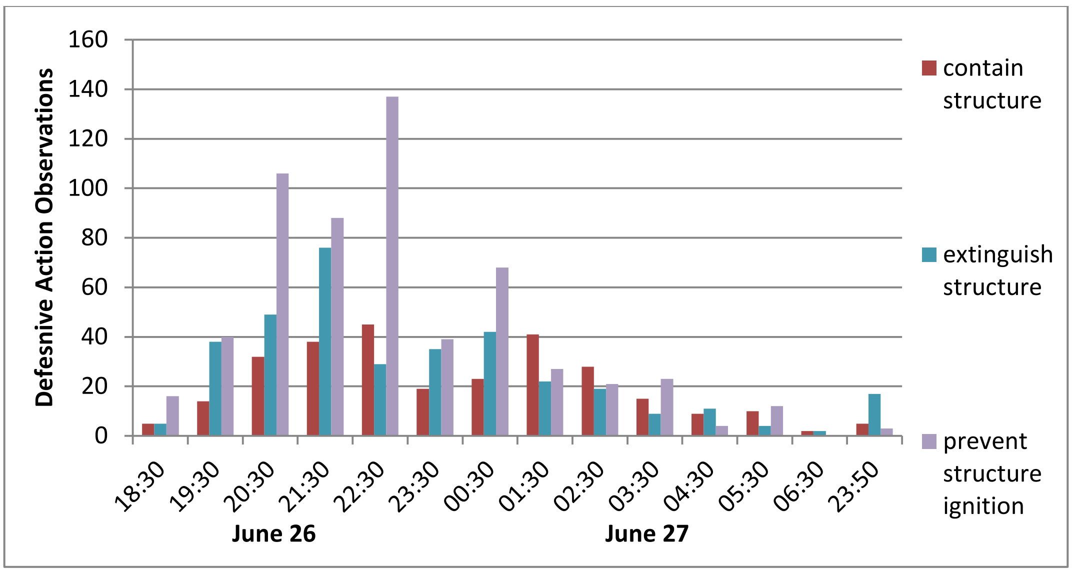

Figure 31 Counts of defensive action observations from TDs by time for each primary structure observation category from June 26-27, 2012.

The turning on of sprinklers also accounts for some of the spike in defensive actions to "prevent structure ignitions" at the 22:30 time interval on June 26. Additionally, Figure 31 indicates a second spike in actions related to primary structures occurring at the 00:30 June 27 time interval and a gradual decrease until about 06:30. This again, represents a "boxing-in" of the fire as also portrayed in Map Figure 10.

It should also be noted that the spike in structure related defensive actions occurring at 00:30 and continuing until 06:30 consists of records where only 148 of 388 (38%) have uncertainty in the time range of than $\pm$ 20 min. Consequently, some of these observations do represent burning and ignitions likely occurring sometime earlier than what are portrayed in Figure 31, or observations of primary structures largely done burning, but with embers still being produced and actions required. The deployment of mutual aid resources likely contributed to the second spike of "prevent structure ignition" actions at 00:30 on June 27.

Figure 31 also indicates a significant number of actions to "extinguish structures" peaking at 21:30 but continuing into June 27. These extinguishment actions recorded as occurring later in the incident is a result of, in part, the large time range associated with some TD observations. The "extinguish structure" actions are also a result of certain features reigniting. Also, a significant portion of these "extinguish structure" actions are to the south of Majestic Drive, Lions Gate Lane and Courtney Drive, and represent final containment actions in these areas.

The containment of structures peaks at 22:30, coinciding with major containment actions at the south of Majestic Drive, Lions Gate Lane and Courtney Drive. Increases in action shown in Figure 31 are, in part, due to the large time range associated with many of these defensive action observations. Also, actions did continue until June 27 in many areas on Majestic Drive, Lions Gate Lane and Courtney Drive. Some of these actions might have transitioned to mop-up and it was difficult to discern between containment and mop-up actions.

Figure 32 shows defensive actions related to detached combustibles. Again, defensive actions on properties increased until the 20:30 time interval. The most frequent actions were "extinguish detached combustibles" followed by "remove fences" and "prevent detached combustible". Extinguishing detached combustibles consisted largely of extinguishing fences relatively early (< 20:30), primarily to the south of Stoneridge Drive, on Moorfield Avenue, and on the southern end of Ashton Park Place, both along Flying W Ranch Road as shown in Map Figure 11.

Removing fences started to peak at 20:30, coinciding with structure to structure fire spread around Courtney Drive and Ashton Park Place and was a consequence of fire spreading to fences and igniting, causing more embers in locations shown in Map Figure 11. The demarcation between fence removal as a preventative measure or as extinguishment action is difficult to discern. Some locations, such as Moorfield Avenue, saw both extinguishment of fences and the removal of fences.

It is known that the extent of fence removal is underestimated in Map Figure 11, as the TDs did not use the post-fire imagery to identify locations of downed fences. Nonetheless, the removal of fences emphasizes the use of a combination of suppression resources to stop structure fire spread. Engines with water were required to contain burning primary structures from spreading to adjacent structures, and hand tools and low water applications were necessary to prevent ignition of and extinguish exposed features from the structures burning further away.

Figure 33 shows similar patterns as described above for defensive actions related to parcel features. Figure 34 shows other defensive actions such as pre-positioning of equipment, mop-up actions, and anecdotal defensive actions. As seen in Figure 34, pre-positioning of some equipment occurred early before the passage of the main wildland fire front resulting in the later boxing-in of the fire around Courtney and Majestic Drives.

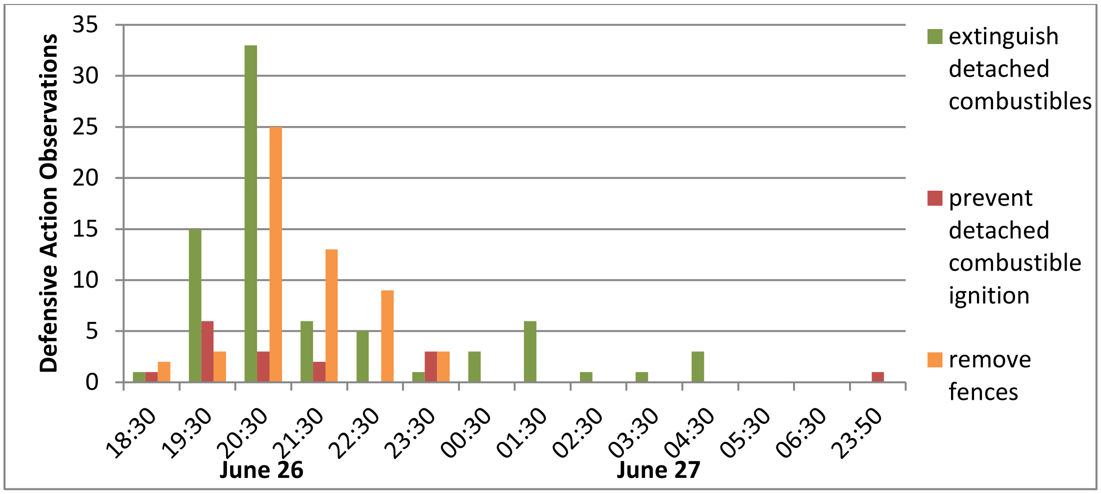

Figure 32 Counts of defensive action observations from TDs by time for each detached combustible observation category from June 26-27, 2012.

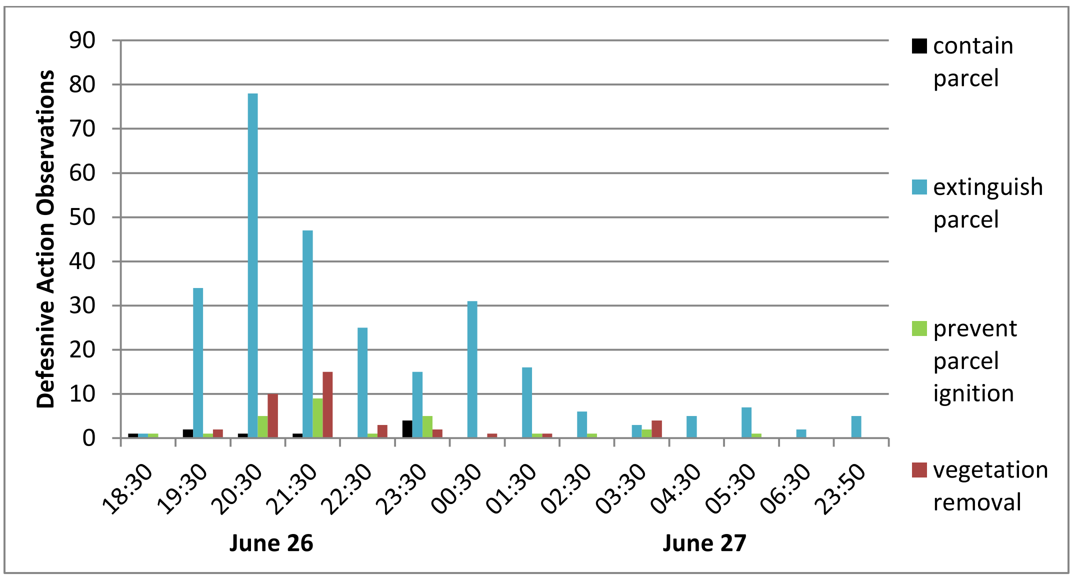

Figure 33 Counts of defensive action observations from TDs by time for each parcel or vegetation observation category from June 26-27, 2012.

Mop-up actions occurred later during the event, peaking on June 27. It should be noted that extensive mop-up actions were required for days after the incident. The decline in recorded mop-up actions on the 27 is a reflection of not focusing on documenting these actions. It is likely Figure 34 does not represent the true amount of mop-up actions occurring on or after June 27.

The tracking of the apparatus deployment times was also achieved by integrating multiple data sources. AVL was used when available and AVL dropout (associated with AVL GPS signal loss or loss of communication link) was addressed by integrating apparatus location information with images, video, radio communications and first responder TDs. Dispatch information was used for mutual aid when it was available. TD times were often the least accurate with images and AVL providing the most accurate apparatus deployment time information. Partial information was available when an apparatus went to refuel. Data was also collected from TDs on crew changes. Both refueling and crew changes were not utilized in documenting the apparatus engaged at any one time in MSC, as both activities removed the apparatus from the scene for only a brief period of time.

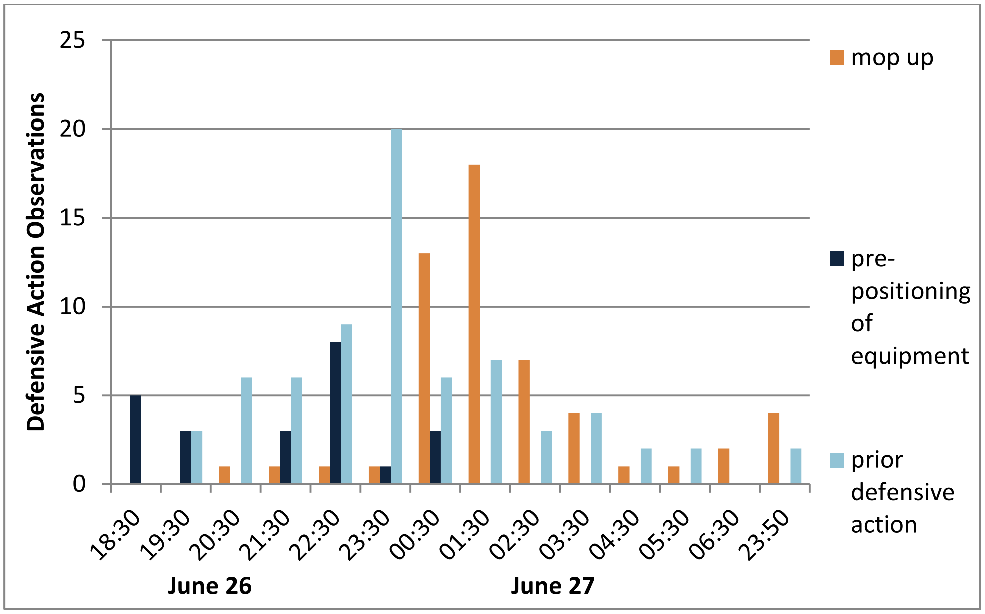

Figure 34 Counts of defensive action observations from TDs by time for each mop-up, pre-positioning of equipment and prior defensive action observation category from June 26-27, 2012.

9.0 Data Quality Summary, Resultant Rules, and Assumptions

All data gathered and compiled for this study has not been integrated in this report across all locations. This report focuses on integration of information related to damage and destruction, defensive actions, and the timeline of events for burning in and around MSC, with an emphasis on TD information. Described above are quantity, quality and uncertainty related to integration of damage and destruction, defensive actions and timeline data.

Even with the integration effort described herein, it is expected that new damage, defensive actions and burning observations might be identified. Consequently, the examination of data quality conducted in this report is required to understand where well-founded case studies exist to derive pertinent information. A finding of this report is that data should be collected with an eye towards complete integration from the start. This includes data collected from various organizations or studies that might occur, even if independent from each other.

The integration of data also provides potential for introducing error, which is why the number of steps for the TD process shown in Table 7 should be reduced. It is difficult to quantify errors resulting from the full data integration process. Although versions of the spreadsheet provided during each cleanup step were retained and could be compared, this step was not conducted as it was shown that integration in a spreadsheet was inefficient and ineffective, and resulted in a large effort to cleanup discrepancies as a result of partial data integration.

Data has been checked for gross errors when transferring spreadsheet data to a GIS database using automated techniques. Comparisons were made against the GIS database and the original spreadsheet and numbers of records and data were retained for random checks. No errors were found in the final transfer. Potential errors with the full integration process lie largely with incorrect assumptions or interpretations. Again, the process described above was employed to provide an understanding of data quality in space and time so that appropriate assumptions could be made, resulting in defensible conclusions from the data.

It was not uncommon for the understanding of fire behavior in certain locations to be changed once all available data was integrated. In most cases, the result was a greater appreciation of the unknown areas regarding burning features and defensive actions in space and time, and the cause of the unknowns. Additionally, the process conducted above highlights key information required for well-founded case studies that might be used to assess exposure, vulnerabilities, and tactics.

Table 8 lists the specific data sources used in this report to produce the necessary building blocks to assess exposure, vulnerabilities, and tactics at the Waldo Canyon Fire. It is important to note that other specific technologies could also be used, and that Table 8 reflects the technologies used in this report. Also, for smaller incidents the geolocation of features might be simpler and not require as significant a number of pre-fire aerial image sources as used in this study.

Table 8 Data sources required to reconstruct the fire timeline.

Data Source[xv]	**Purpose**
Google Streetview	Pre-fire ground view of area for moderate to large incidents was used to geolocate burning features.
Microsoft Bing Maps	Pre-fire oblique aerial view of area for moderate to large incidents is required to geolocate burning features.
Colorado Springs Orthorectified Imagery	Pre-fire orthorectified aerial view of area for moderate to large incidents is required to geolocate burning features.
During Fire Imagery	Images are required to reconstruct the burning of features.
First Responder Recollection of Actions	First responder accounts of actions taken during the incident are required to document defensive actions.
Post-Fire Aerial Imagery	Post-fire aerial imagery, ideally orthorectified for full scientific post-fire assessments to provide situational awareness.
Post-Fire Ground Assessment	A detailed post-fire ground assessment, guided by assessment of the imagery should be conducted after the incident before collection of other data not pertinent to incident response.
Integrated Damage Assessment	All damage assessments conducted by various organizations should be made available and integrated.

An important point regarding Table 8 is the need to base conclusions on integration of all available data, also considering possible missing information. Conclusions based on limited data, aerial assessments alone, only field assessments, or just technical discussions often overlook key information and could be questionable. It is only through the characterization of well-founded case studies attempting to measure all aspects of the fire disturbance continuum [12]

[xv] These were the data sources used. Other sources may be available.

that proper guidance for field and laboratory experiments might be determined, and standard test methods developed for WUI constructions. Current methods of post-fire assessments focus largely on one aspect (e.g. field assessments or discussions with first responders) and not the full integration of all available data.

Table 9 describes the advantages and disadvantages of each of the above data sources for documenting damage information. For scientific assessments, a new approach to damage assessments is required to integrate aerial and ground images. Damage assessors should use standard technology in documenting damage, which involves image documentation of all damage in a linked electronic environment for distribution. Image documentation is required to provide an understanding of damage information, as is evidenced by the lack of images for potentially damaged asphalt roofs, and the inability to quantify that damage in this study.

Table 9 Advantages and disadvantages of various damage assessment data sources.

Data Type	Advantages	Disadvantages
1. Local Damage	1. Consistent data across large areas. 2. Ground imagery available after the fire for damage and destroyed primary structures. 3. Some damage locations tied to actions.	1. Only visible damage was documented. 2. Limited documentation of vegetation. 3. Not all damage linked to defensive actions. 4. Interior and roof damage missed.
2. TD Damage Data	1. Damage locations tied to defensive actions.	1. Partial assessment of damage. 2. No images of damage. 3. Some damage has only anecdotal accounts as identified damage was fixed.
3. Post-fire aerial imagery	1. Only method available that portrayed all primary structure destruction after fire. 2. Only method available for consistent vegetation damage information. 3. Identifies relatively significant damage to visible features from the air (e.g., roofs). 4. One data source for destruction assessment.	1. Does not identify damage to occluded features and sides of features or underneath features (e.g., deck and vegetation). 2. Not always easy to obtain though some aerial documentation is likely possible. 3. Interpretation might require knowledge and skills in aerial photo interpretation.
4. Other Reports	1. Selected in-depth damage assessments. 2. Selected images from reports.	1. Only partial assessment of damage. 2. No data available to all assessors. 3. Limited images of damage. 4. No attempt to assess all aspects of fire disturbance continuum.
5. Media	1. Highlights potential missing damage.	1. Information only available on one primary structure.

During-fire images of burning features and defensive actions would be an efficient and effective means to document a WUI event. Even though the technology exists for each first responder to have a camera mounted on them, there are logistical constraints which need to be overcome. Moreover, the mounting of cameras on first responders is not generally accepted among the fire response profession. Video devices mounted on apparatus with simple GPS devices would, and do, go far in providing documentation of an incident such as the Waldo Canyon Fire.

It should also be noted that unknown areas, during at least early time periods in the event (i.e., < 20:00) remained because no observers went to these locations until later. There were many reasons, not the least of which is safety. For example, radio logs record first responders commenting around 18:30 on Majestic Drive as follows:

"We're picking up our lines, that area is really hot"

There was one AVL of an apparatus heading to the north side of Majestic Drive around 18:26. The TD for this apparatus identified burning on both sides of the street, as evidenced in other images. The apparatus turned around after traveling 90 m into the north side of Majestic Drive because of uncertain exit conditions.

Other AVL time-stamped observations showed an apparatus driving through the north side of Majestic Drive and stopping south of Hot Springs Court around 16:55. A first responder on this apparatus identified burning primarily on the west side of Majestic Drive. Yet, less than one hour later, the north end of Majestic Drive was reported as impassable due to heat, flames, smoke and embers by the same first responder. Limited early observations also existed for Brogans Bluff Drive, Trevor Lane, Talleson Court and Courtney Drive because no first responders entered these areas until later, or the entry was limited. These limited entries, if documented with vehicle mounted cameras, would have provided more information in these unknown areas.

Some periphery areas were obscured by smoke, primary structures and topographic locations on Trevor Lane, Talleson Court and Courtney Drive. For example, a Colorado Springs Police Officer was recorded on the south side of Courtney Drive as early as 18:35 observing no structures on fire as described in Appendix H, yet at the same time saying the smoke was so thick the responder's eyes hurt. Images from locations upwind show significant burning in the interior of Courtney Drive earlier than 18:35, but some of the precise locations were observed as not burning by a responder to the south.

The above example demonstrates the uncertainty associated with cross-correlation of discussions to develop timelines. It is somewhat difficult to reconcile the two observations, though smoke obscuration is a possible reason. It is also possible the cross-correlation conducted in Appendix H was wrong because the first responder had the sequence of events wrong. Regardless, this highlights the uncertainties in areas lacking photo images. Even with available images, in numerous occasions it was necessary to calibrate thme to get the correct time stamp as demonstrated in Appendix I.

Trevor Lane and Talleson Court were also areas with no exits for first responders. Interior Brogans Bluff Road is the most interior road in the incident, with the earliest AVL recorded location at 19:28. This, along with information below, shows how the common parameter of response time used in WUI Mitigation assessments is more complicated than drive time from point A to point B. Limited ingress/egress is also an issue, but variables like distance from "major" road or visibility are possibly more important factors for determining response time for WUI disasters such as the Waldo Canyon Fire.

The assessment described above highlights advantages and disadvantages associated with the two general methods used in this report to obtain observations of burning features and defensive actions: 1) During-fire image acquisition and 2) Technical Discussions. Measuring phenomena in space and time are activities required for a scientific post-fire assessment. Table 10 lists the identified advantages and disadvantages associated with the two methods.

Table 10 Advantages and disadvantages of methods used in this report to document burning feature observations and defensive actions in space and time.

Method	Advantages	Disadvantages
During-Fire Video and Images.	1. Precise estimate of burn condition. 2. Most sensors explicitly have time information. 3. Time can be correlated relatively precisely based on other images if significant images exist such as at the Waldo Canyon Fire. 4. Lacking GPS information, location can typically be discerned from other methods. 5. In high density structure locations of moderate geographic extent, where adequate imagery exists, the geolocation process, while tedious, becomes readily achievable due to familiarity obtained of the area through repetitive viewing.	1. Not available for entire incident. 2. Requires (for some incidents) pre-fire ground and aerial imagery (e.g. Bing Maps™ and Streetview™). 3. Requires proficiency of use in basic geospatial science and technology. 4. Time stamps not always accurate. 5. Images recorded from the street only portray partial defensive action information, which could be easily misinterpreted. 6. Miss occluded areas.
Technical Discussions	1. Provides detailed accounts of first responder activities. 2. Discussions are believed to have allowed for an increased transfer of knowledge compared to manually recording activities by first responder. 3. Provides a real-life accounting of events for post-fire assessors as compared to electronic media. 4. Involves first responders in the process, which is a key step to educating responders and homeowners, and improving mitigation advice.	1. Labor and time consuming to obtain. 2. Several sources of error. 3. Large time lag between first responder recollection of event and event. 4. Difficult to discern between anecdotal and direct observations. 5. Not possible to have discussions with all fire observers at large incidents. 6. Recording activities and observations in space and time is error prone without pre-fire, during-fire and post-fire geolocated images and damage.

The TD process implemented at this incident was also implemented at the 2007 California Witch Fire and the 2011 Texas Tanglewood Fire. The amount of information collected from the Waldo Canyon Fire TDs was much larger than the 2011 Texas Tanglewood Fire, which had 203 defensive action records. For these smaller incidents, integration of data sources did not result in as significant an effort. Similar errors in integration have been present and corrected though.

In all cases, the relative amounts of records are trivial from a data management perspective. From a data uncertainty perspective, the increased records and lack of initial full data integration at the Waldo Canyon Fire produced significantly more discrepancies, which took significant time to resolve. The integration issues were not foreseen until after partial integration occurred.

A key improvement regarding the collection of information from fire witnesses was identified. Crowd sourcing technology should be examined due to its potential to rapidly provide post-fire assessors with an overview of the incident. A crowd sourcing application is not intended to replace the TD process, only enhance it. This type of application would also help first responders to evaluate and improve their activities.

An initial integration of all data will provide assessors with a basic awareness of the incident. If this information is contained in technology applications, such as a GIS, it can be readily retrieved during the TD process. This would reduce the time required to obtain information from first responders, and the data integration process, dramatically. Additionally, anecdotal accounts, which were sometimes in error, would be more readily identified during the TD process.

Figure 35 Image of primary structure on Talleson Court taken at 19:11 on June 26, which allowed time stamp observations for other primary structures not shown to be obtained.

Also, full integration of observations with images during the discussion is ideal, as observations beyond the area of the image can be time-stamped. For example, Figure 35 shows a primary structure burning on Talleson Court. First responders also observed other primary structures involved in this location at the same time but there were no images. The one image allowed prescribing a time stamp to the other observations. Having this image geolocated before discussion would save resources for all parties involved.

Finally, the TD process can have the number of steps shown in Table 7 reduced by not initially entering data into a spreadsheet and taking the information recorded on hard copy notes from the TD process directly into a GIS database. A crowd sourcing application would also directly enter data into a GIS database. Additionally, for TDs, more appropriate data structures can be employed that will facilitate data integration and analysis and remove issues with duplicate records and difficulties with maintaining integrity of data in tools such as a spreadsheet. As this was the first effort of its kind at such a large incident, improvements to the process are expected, and detailed in Appendix G.

In addition to the above, important new concepts regarding WUI post-fire data collection and integration are:

- During-fire imaging, obtained in a safe and effective manner, is necessary to reconstruct the timeline of events to an extent necessary to assess exposure and vulnerabilities.
- First responder recording of actions, taken along with images recorded during the event, should occur shortly after the event in a standardized electronic manner.
- Damage assessment should involve ground and aerial techniques with complete data integration before assessing WUI mitigation effectiveness or other items.

Additional information, such as in-situ sensors, would likely be required to quantify exposure during an event such as the Waldo Canyon Fire.

The assessment described above also highlights locations with unknown burn times as follows:

- **Northeastern Majestic Drive**: this area had limited observations of burning and it was primarily unknown what was burning in this area before 20:00.
- **Interior Brogans Bluff Drive**: this area had limited observations of burning before 20:00. Other limited observations present some contradictory information.
- **Trevor Lane**: this area had limited observations of burning before about 20:20 (± 20 min).
- **Midwestern Courtney Drive**: this general area had an image observation of burning of unknown features at 18:23, but exact locations and magnitude of burning were unknown.

Other smaller areas have some individual primary structure unknowns or uncertainties, which are addressed as appropriate, below.

10.0 Mountain Shadows Case Study

This section provides a general description of MSC. Next, an overview of damage and destruction to primary structures is presented. After that, fire observations and timelines associated with the passage of the main fire front are described. This is followed by descriptions of fire observations and timelines occurring around the time a change in wind direction was observed (≈20:00, June 26). Finally, this section provides an overview of burning structures. Highlights of the defensive action timeline reconstruction are listed in Table 11.

Table 11 Highlights of defensive action timeline reconstruction in MSC.

Time	Activity or Observation	Source
6/26	Evacuated MSC residents requesting to go into primary structures to collect information and medications	AAR
15:00	All call issued to all CSFD firefighters	TD
17:08	CSFD personnel located near Wilson Water Tank moved to hard pavement on Spector Way and Wilson Road.	AAR, Radio Log
17:19	Air Attack reported that the column had collapsed	Radio Log
17:20	Power tripped to Wilson Water Pump Station	CSFD duty report 1C1A
17:23	Evacuation of CSFD to Chipeta Elementary First CSFD observed structure on fire at Brogans Bluff Road	TD 41, AAR Radio Log Command 6,
17:58	First recon sent back into MSC	Radio Log Command 6
18:16	First CSFD apparatus enters MSC	AVL
	Visibility improves around Wilson Road. There is visible blue sky	TD, Video
	Numerous primary structures observed ignited within 15 min	TD, Video, Radio Log
17:40-18:16	USFS task forces enter MSC	TD, Picture
18:37	Second evacuation of CSFD to MCI building [xvi]	TD 41, Radio Log Command 6
18:56	Utilities shut off gas and electric west of Centennial between Flying W and 30th Street.	PIO, Twitter
20:00	Local evacuation for wind shift and anticipated second flame front	Radio Log TAC 7
19:54	Power restored to Wilson Pump Station	CSFD Duty report 1C1A
	Mutual aid task forces starts entering MSC	TD, Radio Log
20:28	Sunset	

[xvi] Not all CSFD evacuated Mountain Shadows the second time.

21:00	County resources leave MSC and move north to Peregrine	TD, Radio Log
21:00-22:00	Wind abated	KAFF Weather Station
	CSFD personnel begin shift change on apparatus [xvii]	TD, ALV
6/27 08:30	Last observed structure ignition – structure saved	TD

10.1 General Description

The MSC, as described in this report and shown in Map Figure 2, is a neighborhood extending from North 30th Street at the southern end to a drainage ditch on the northern end. The neighborhood starts at Centennial Boulevard on the eastern side and directly abuts the wildlands extending into the Rocky Mountains to the west. There are occluded wildland areas and recreational parks within MSC. The majority of primary structures are residential structures, but within the community are three schools, commercial buildings, a well-known tourist ranch, as well as other types of primary structures. [xviii]

MSC is bordered by a canyon to the north where elevations at the water tower are approximately 2166 meters (7105 ft) and elevations at the bottom of the northern canyon at 2109 meters (6920 ft). A significant canyon is also found to the south of the water tower, extending down into a high structure density portion of the community to the east of Flying W Ranch Road (i.e. Majestic Drive). Throughout the community are smaller canyons and other topographic features of various configurations.

The 2001 Colorado Springs Community Wildfire Protection Plan (CWPP) [26] lists the wildland vegetation around MSC as consisting of predominantly Ponderosa Pine (*Pinus ponderosa* Lawson & C. Lawson), Gambel Oak (*Quercus gambelii* Nutt.), pinyon-juniper (*Pinus monophylla* Torr. & Frém, *Juniperus osteosperma* (Torr.) Little) stands and other mixed conifer stands. The Colorado Springs CWPP [26] also lists other vegetation types in and around Colorado Springs as shortgrass prairie with *Yucca* spp. L. and prickly pear-cactus (*Opuntia* spp. Mill.). Additionally, the Colorado Springs CWPP [26] describes isolated pockets of beetle-kill and mistletoe (*Arceuthobium* spp. M. Bieb) in Colorado Springs, though this was not evident in pre-fire imagery around MSC. High stand densities of 300 stems per acre compared to traditional densities of 75 to 150 stems per acre are also found in Colorado Springs. [26]

In this report, wildland vegetation was mapped as those vegetation species believed to consist of Ponderosa Pine (*Pinus ponderosa* Lawson & C. Lawson), Gambel Oak (*Quercus gambelii* Nutt.), pinyon-juniper (*Pinus monophylla* Torr. & Frém, *Juniperus osteosperma* (Torr.) Little), shortgrass prairie with *Yucca* spp. L. and prickly pear-cactus (*Opuntia* spp. Mill.). Unknown grass vegetation species found along walking paths and road edges were also delineated as wildlands. These vegetative species had the characteristic of not being watered.

[xvii] Crews were not replaced on all apparatus.

[xviii] There were many structures located on the Flying W Ranch. Only one structure was marked as a primary structure in this report, but most structures on the property were destroyed.

Vegetation was delineated into wildlands versus residential vegetation as shown in Map Figure 12, based on aerial photo interpretation of the various remote sensing data sets listed. The various wildland vegetation species listed above were all observed in and around MSC both during field visits and in ground images. The area was delineated as wildland versus residential vegetation based on various geolocated ground images available. Wildlands were labeled as occluded if surrounded by residential vegetation.

Generally, areas mapped as residential vegetation represent vegetated locations comprised of many different vegetation species, but characterized by well-watered vegetation and actively maintained landscapes or the presence of other non-combustible landscapes (e.g. rock). There were, however, clear distinctions between watering levels based on photo interpretations of vegetation greenness and the assumption that these differences were due to watering.

Primary structure density across MSC is shown in Map Figure 13. Primary structure separation distance across MSC is shown in Map Figure 14. Both primary structure density and separation distance are portrayed in 5 classes using the Jenks natural breaks classification method as implemented in ArcGIS 10.2. Highest density structure locations are found in the interior of neighborhoods with many structures with relatively low separation distance. The hazard of a high primary structure density with low structure separation distance is highlighted in Map Figure 13 and Map Figure 14.

Majestic Drive highlights this potential hazard of high density and low separation distance, particularly when adjacent to wildlands and dangerous topographic configurations. Lower primary structure density areas with low structure separation distance, such as Trevor Lane, interior Brogans Bluff Drive to the north of Karamy Court and southern Ashton Park Place, are also hazardous areas with high potential for conflagrations due to topographic and vegetative characteristics. This, coupled with the evident structure-to-structure fire spread described below, provides evidence that it is not solely structure density which effects structure response but the spatial arrangement of structures both within the community and to nearby flammable vegetation, topographic features, geology and the prevailing weather characteristics at the time of the fire. Additionally, structure density may impact defensive actions as discussed below.

10.2 Damage and Destruction

This report identified 344 structures with known addresses destroyed. One of these addressable structures, the Flying W Ranch, had numerous destroyed structures, some of which were certainly outbuildings, and these set of structures were counted as one destroyed primary structure. Other primary structures also had destroyed outbuildings. Of the 344 structures with known addresses, 12 represented multi-family residences with two units per structure. Consequently, there were technically 338 (what are termed in this report as) primary structures, destroyed by the Waldo Canyon Fire. However, since 344 is the number of primary structures/residences displaced due to destruction from the Waldo Canyon Fire, it is the number used in this report.

Additionally, there were 85 primary structures with confirmed damage through ground or aerial assessments, and 14 structures with damage identified through TDs but not confirmed by ground assessment. There were also 2 primary structures identified as having damage, only some of which was confirmed by field or aerial assessments. All of the damage and destruction took place on June 26, or early in the morning of June 27, with the exception of two primary structures in the Peregrine Community which were damaged on June 28.

Map Figure 1 shows damage and destruction to primary structures across the entire Waldo Canyon Fire. Map Figure 2 shows damage and destruction to primary structures in MSC. This report does not represent a complete assessment of damage across the entire Waldo Canyon Fire as no complete assessment of damage was ever conducted.

10.3 Fire Behavior Timeline and Observations (Main Fire)

The Waldo Canyon Fire crossed the mountain ridge to the west of MSC sometime in the afternoon of June 26, 2012. Images taken in and around MSC indicate spotting over the ridge produced fires to the west of MSC as shown in Map Figure 15. These spot fires then had main fire fronts that traveled uphill or in a north to north west direction as portrayed in images in Map Figure 15.

Additionally, there appeared to be intense fire behavior in the canyon area to the west of MSC with a pyrocumulus cloud moving along this canyon generally from west to east, as shown in Figure 36. The images in Figure 36 were recorded by first responders assessing the fire as it was approaching Cedar Heights and show the smoke plume as the fire travels down the canyon to the west of MSC. There are no images, available for this report, of fire in the canyon to the west of MSC.

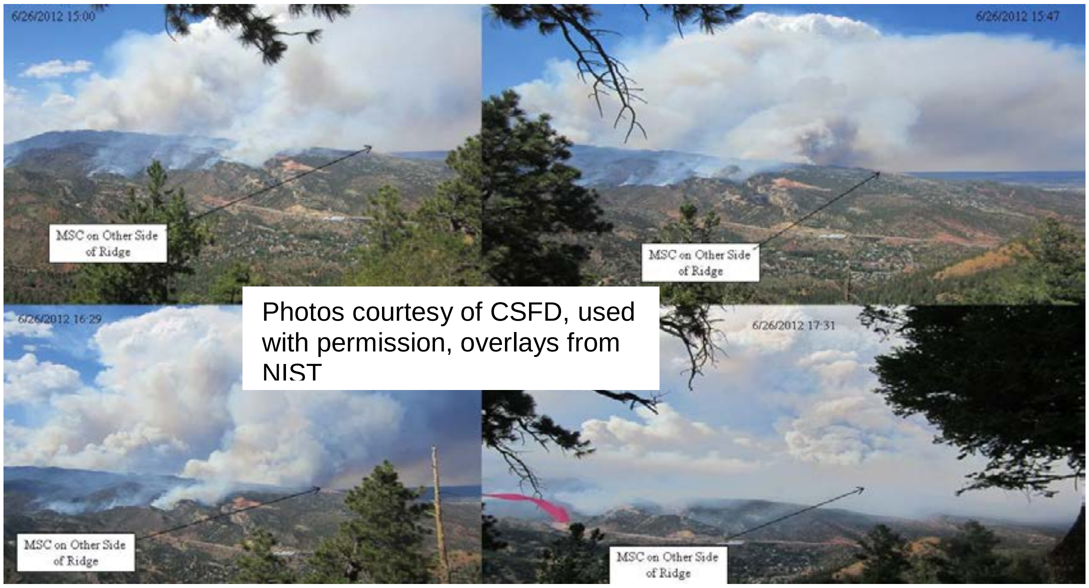

Figure 36 Pyrocumulus cloud as it approaches MSC from the west. Observed from south of Cedar Heights Community on June 26 at approximately 17:00.

The plume approached MSC from the west, then started leaning or collapsing in the vicinity of the Wilson Road water tower between 17:20 and 17:25. First responders were evacuated from MSC at 17:23 when the fire was approaching various locations along the MSC wildland interface. Visibility near the water tower was reduced to less than 10 m (33 ft) with strong winds and heavy ember showers. Table 12 summarizes the first responder observations from just prior to right after the evacuation to Chipeta Elementary. Embers reported from TDs were up to “fist” size from the Water Tower off Wilson Road all the Way to Chipeta Elementary. During the first stage of the evacuation to Chipeta Elementary, visibility improved near Flying W Ranch Road.

At Chipeta Elementary, while resources were arriving, the visibility decreased and ash started falling. There was a significant range in the observations and local conditions, depending on the exact location of the first responder, with respect to the elementary school structure. First responders on Flying W Ranch Road reported significantly reduced visibility compared to first responders located to the south and east of the elementary school building. The visibility near the school continued to decrease and the evacuation continued to North 30th Street and Garden of the Gods Road, where smoke and ash were also present.

Within less than 15 min of arriving at the new staging location at North 30th Street and Garden of the Gods Road, a CSFD scout was dispatched to assess re-entry into MSC. Flying W Ranch Road, just to the north of Lanagan Street and to the south of Majestic Drive was impassable due to very high heat. The fire exposure (convective and radiative) was so severe that face shields were necessary inside the command vehicle, and the heat melted the window gasket on the driver side (the vehicle was stopped on Flying W and facing north between Lanagan Street and Champagne Drive). Embers varied in size; many being of “fist” size that bounced off the vehicle. The extensive exposure lasted approximately 10 min to 15 min.

Table 12 Observations near Wilson Road Water Tower from 17:15 to 17:28, June 26, 2012.

Time (±2 min)	TD	Observation
17:15 -17:23	6	Wind 10 to 15 km/h (5 to 10 mph) from the west. Within 10 min winds go from 10 to 15 km/h (5 to10 mph) to 80-100 km/h (50 to 60 mph) from the same direction. Wind picks up, then extensive ember showers. Smoke starts getting very thick.
17:15 - 17:23	6	Fire front flames estimated at 2 to 3 times tree height, 25 m to 30 m (80 ft to 90 ft).
17:23	4	Visual contact with helicopter pilots signaling to leave.
17:23	4	Visibility drops to 10 m (30 ft). Dark smoke noted down by Flying W Ranch.
	51	Flame front about 250 m (750 ft) observed north and south of water tower. Wall of flames above tower. Embers raining down. Extreme winds. Residents leaving Wilson Road /Sceptor Way north of Rossmere Street. Then traffic clears.
17:23	20	300' wide wall of fire observed, wind direction is down Alabaster.
17:23	14	Wind breezy 10 to 15 km/h (5 to 10 mph) -- suddenly goes to (50 to 60) km/h (30 to 40 mph). Wind is initially not hot then starts heating up -- fire is crowning. Wind peeled door back on truck, like being in a tornado 100 km/h (60 mph gusts).
17:23	14	Citizens still present in Wilson area. CSPD still are coming up the street (Wilson).
17:23	6	Visibility down to 2.5 m (8 ft).
17:23	6	Visibility improving as they drive out (west of Karamy Court cul-de-sac).
17:24	34	Hot air blast before CSFD leaves the water tower area (personnel couldn't breathe).
17:24	34	Evacuation call due to wall of flames behind water tower.
17:25	34	Major traffic jam at Wilson Road /Rossmere Street. Wind, dry air, then smoke and embers, worse than thick fog. Had to use AVL to navigate out.
17:28	34	Drive out by Linger Way, nothing on fire, visibility had improved.
17:24-17:29	105	Wall of flames visible in rear view mirror. Visibility 67 m (225 ft) at 2945 Brogans Bluff. Strong winds from west to east. Within 3 to 4 min, visibility down to 15 m (50 ft) on Rossmere Street near Linger Way/Chuckwagon Road.

Eighteen minutes after the reconnaissance team was dispatched, the first CSFD engine arrived at MSC. The dashboard video showed that the plume had cleared and that blue sky was visible. A limited number of primary structures were on fire. The number of structures increased with time.

As more primary structures were ignited and burned, a second plume was formed and MSC became, in part, blanketed by smoke. A second evacuation was triggered. The plume was interpreted as the arrival of a second fire front. The second evacuation, triggered 21 min after the first CSFD apparatus re-entered MSC, was partial and some engines remained in areas of MSC that were not in heavy smoke. Some parts of MSC were still under a blue sky, highlighting the limited situational awareness frequently associated with large and complex WUI fire scenes.

The wildland area to the east of Wilson Road and south of Flying W Ranch Road is shown to be partly burned before 20:00. A new fire in the interior of these wildlands to the east of Wilson Road, thought to be a result of a change in wind direction, was observed, as shown in Map Figure 16. The consequence of this fire is discussed below. Other wildland areas east of Wilson Road, visible in the image, had burned at this time, though various small fires were observed burning in these areas after 20:00. At least one structure ignition (5345 Chambrey Ct) was identified as igniting in the general location of the middle image shown in Map Figure 16, shortly after the middle image shown in Map Figure 16 was taken.

At 18:31, after first responders re-entered the community, the fire could be seen at one of its most eastern extents along Centennial Boulevard, with flanking fires traveling to the south and north, as shown in Map Figure 17. Fire spotting in this location was first observed and defended by first responders at around 18:44, based on AVL locations. The southern end of the fire was defended by first responders after they re-entered MSC at approximately 18:44, as shown in Map Figure 16. This southern defense occurred off Alpine Meadows Lane in the wildlands to the south where most of the primary structures in MSC (4975 Braeburn Way) were destroyed.

First responders could also be seen containing the northern edge of the fire along Wolfe Ranch Road, at around 20:00 on June 26, as shown in Map Figure 17. Fire was shown in this location as early as 17:30. Fire witness observations corroborated that defensive actions occurred in these locations. The main Waldo Canyon Fire front had already passed through MSC at this time and this was a flanking or backing fire along the northern edge of MSC.

10.4 Fire Behavior Timeline and Observations (Wind Change)

There is evidence that the main fire front traveled relatively quickly through major portions of MSC as shown in Map Figure 17. There are also anecdotal accounts of first responders identifying flare-ups and possible small fire fronts in various locations after the main fire front moved through MSC. Additionally, identified in various time lapse images is at least one area of wildland vegetation not burning after the passage of the main fire front, but burning later as shown in Map Figure 18.

Some of the anecdotal accounts and the images had burn times corresponding to a shift in wind direction occurring around 20:00. The wind shift was observed in during-fire images and video. Not all images and videos portrayed wind direction but some clearly showed wind direction and were useful when a confident time stamp was included. The series of images taken by CSFD videographer, shown in Figure 37, demonstrate a wind shift from generally coming from the east to northeast (for a short time around 19:52), then from the north around 20:00. Identification or comparison of wind magnitude was not possible from the images and videos.

Changes in wind direction also corresponded to ignition of the primary structures shown in Map Figure 19. These primary structures were ignited around the time of the wind change and coincident with the image shown in Map Figure 16 around Chambrey Court. The ignition locations of 5350 and 5410 Chambrey Court were unknown, but both had wood roofs. If ignited from the wildland fire shown in the middle image in Map Figure 16, these structures would have had to have been ignited from embers. This is due to the presence of roads and green vegetation around the residences. It is, however, possible that these two primary structures were ignited earlier, before the change in wind direction, from vegetation or primary structures burning between these primary structures and Wilson Road to the west.

The approximate ignition location for 5345 Chambrey Court is seen in the image contained within Map Figure 19 and also in the Fox News video referenced in Appendix E. The general location of the ignition was identified but the exact ignition source (deck, re-entrant corner, debris under deck or other item) could not be determined. Also, note the deposition of white ash in areas to the north/northeast, and upwind from the re-entrant corner of 5345 Chambrey Court, compared to lack of white ash and more green vegetation to the north/northeast of 5345 Chambrey Court. Finally, the Fox News video shows active burning in the area to the north/northwest of 5345 Chambrey Court.

At around 20:00, at the time of the wind change, ignitions on Vantage Vista Road and Huffman Court were observed. The ignitions on Vantage Vista Road occurred around the same time as the wind change. The ignition on 5775 Huffman Court, however, appeared to have occurred before the wind change and coincided with burning vegetation behind the house. The destroyed Huffman Court primary structure was extinguished by first responders and then reignited, shortly after being extinguished. First responders contained the burning residence after re-ignition.

Figure 37 Time lapse imagery portraying change in wind direction on Courtney Drive. Images are looking south.

Coinciding with changes in wind were also ignitions on Jenner Court, as shown in Map Figure 21. Images from the Denver Post clearly show 2450 Jenner Court fully involved around the time of the wind shift and 2470 Jenner Court with fire around it and possibly ignited. The video screen shot of 2485 Jenner Court fully involved, as shown in Map Figure 21, was not time stamped, but it was after the wind change as can be seen from smoke direction seen in the video. 2460 Jenner Court could not be seen burning in any of the images, but was also in a topographic depression relative to other primary structures.

There were other primary structures ignited sometime after the change in wind direction, which were not clearly identified as structure to structure fire spread. These primary structures still might have been ignited from far afield structure-to-structure fire spread, or from structure-to-structure to vegetation fire spread. Finally, changes in structure to structure fire spread were also observed to coincide with changes in wind direction, as discussed in detail in the sections below.

Most of the primary structures discussed and shown in Map Figure 18 through Map Figure 21 were defended by first responders. 2470 Jenner Court showed clear evidence of containment action through the lack of white ash (i.e., black ash) present in the building debris. The primary structure at 5548 Vantage Vista Drive was not defended, but 5542 and 5560 Vantage Vista Dr were defended to contain further fire spread. The primary structure at 5560 Vantage Vista Dr also showed clear evidence of containment action seen through the identification of black ash. Numerous other structures were also ignited on Majestic Drive, Lions Gate and Ashton Park Place after the wind change, as a result of structure to structure fire spread, and discussed in more detail below.

10.5 Fire Extent and Spotting

Ember or fire brands caused spot fires throughout large sections of the MSC. Spotting was continuous across a range of distances and was a function of the type of embers (size, density, shape, and material), the local conditions (plume dynamics, updraft, local weather and topography), and the ignition potential of the area where the ember(s) landed. Spotting, in the presence of wind, is a process that occurs across a range of physical scales. Consequently, it is important to assess the distribution of embers and therefore their potential hazard as a function of distance from the source.

Spotting distance varied throughout the Waldo Canyon Fire, including some spotting and potential spotting which traveled across many fuel breaks (e.g. roads and bulldozer lines), other combustible items (e.g. wood roofs), and occluded wildland areas (e.g. Ute Valley Park). This far field spotting was limited at the Waldo to a handful of locations listed in Table 13. Minimum distances are determined by identifying what was burning upwind of the spotting location at the time the spot fires were identified. The locations of these potential far field spotting are shown in Map Figure 22.

It should be noted, however, that there was also a potential spotting location at Woodman Court. It was undetermined if it was spotting from the Waldo Canyon Fire. This study did not assess the Woodman Court location. The spotting was questionable, in part, because the ignition time was so much later than the passage of the main wildland fire front and after the change in wind direction. It was possible, however, that the spotting might have smoldered for some time before ignition. Eventually, the spotting location was extinguished by first responders.

Table 13 Locations of far field spotting to vegetation at the Waldo Canyon Fire along with distance downwind from burning features and defensive action status.

Spotting Location	Fuel Type	Date/Time	Minimum Distance (downwind) form closest possible burning feature	Defended
Utte Valley Park (west of ridge)	Wildland Vegetation	6/26/2012 18:58	~515 m (1700 ft)	Yes
Utte Valley Park (east of ridge)	Wildland Vegetation	6/26/2012 19:00[xix]	~360 m (1200 ft)	Yes
Mule Deer Drive	Wildland Vegetation	6/26/2012 17:44	Unknown	Yes

The spotting on Mule Deer Drive was also uncertain as to the distance of the spotting. There is evidence that defensive actions occurred at the Mule Deer Drive location based on AVL time-stamped observations. It is less clear if the defensive action at Mule Deer Drive shown in Map Figure 22, is a consequence of the fire having traveled through the wildlands to the east of this area or if it is a consequence of spotting over this entire occluded wildland area.

It was possible the Mule Deer spotting might have been a result of the fire spotting over Flying W Ranch Road, burning through the occluded wildland area between Vantage Ridge Court and Majestic Drive, and then jumping Wilson Road and traveling down to the spotting location shown at Mule Deer Drive in Map Figure 22. It was also possible the embers were produced from the wildlands west of Flying W Ranch Road and traveled to the Mule Deer Drive spotting location. The specific scenario was not clear from first responder accounts.

Spotting also occurred over shorter distances and resulted in early ignitions of some structures, including those listed in Table 14. The locations of these structures are shown in Map Figure 23. Other closer spotting also occurred throughout the Waldo Canyon Fire, some of which is discussed in sections below.

Table 14 Locations of far field spotting to structures at the Waldo Canyon Fire along with distance downwind from burning features and defensive action status.

Spotting Location	Fuel Type	Date/Time	Distance (downwind) form closest burning feature	Defended
5445 Wilson Road	Structure (wood roof)	6/26/2012 18:15	325 m (1100 ft)	Yes
5140 Champagne Drive	Structure (wood roof)	6/26/2012 19:33	Unknown	Yes
5765 Huffman Court	Structure (eave) or Vegetation	Unknown	Unknown	Yes
5745 Regal View Road	Structure or vegetation	Unknown	Unknown	Yes
6030 Moorfield Avenue	Fence (wood)	6/26/2012 18:29	Unknown	Yes
6020 Moorfield Avenue	Fence (wood)	6/26/2012 18:29	Unknown	Yes
2185 Wickes Road	Structure (wood roof)	Unknown	Unknown	Yes
1605 Manning Way	Structure or vegetation	6/26/2012 18:13	Unknown	Yes

10.6 Summary of Structures Burning

As shown in Map Figure 2, a potential population for analysis of the Waldo Canyon Fire regarding exposure includes the primary structures ignited from the passage of the main wildland

[xix] Time is estimated from TD. Defensive actions took place between 17:50 and 19:00.

fire front (not from structure to structure fire spread) west of Wilson Road, southeast of Flying W Ranch Road. Additionally, the time of peak observations of burning primary structures (≈20:30), which coincides with peak first responder resource deployment, is another key time period to identify ignited structures and examine structure to structure and structure to vegetation fire spread.

Consequently, this section attempts to identify the structures ignited from the passage of the main fire front around 18:30 and those structures ignited around 20:30 on June 26, 2012, and the identified time of peak information available on burning primary structures. Then, somewhat arbitrarily, the 23:00 and the June 27 00:30 times are examined for ignited primary structures. From this point forward in this report all text, figures, tables and map figures referenced will assume times on June 26, unless otherwise specified.

Map Figure 24 displays estimated ignition status of primary structures at or shortly before 18:30 on June 26. Three sets of known ignitions are shown in Map Figure 24: 1) The first set includes those primary structures known to be ignited, mostly through images, by about 18:30. 2) The second set includes those primary structure known to be ignited, again mostly through images, by about 18:30 but with some evidence the ignition might have been from structure to structure fire spread. 3) The third set includes those primary structures known not to be ignited based on observations of burning later. It should be noted that there is likely some percentage in the third set displaying those primary structures known not to be ignited, which could have ultimately ignited from embers, flames or radiant heat produced from the passage of the main wildland fire front, but smoldering resulted in the structures igniting later. It is believed this percentage is relatively small based on evidence of structure-to-structure fire spread or other ignition sources. 4) The last set of ignition categories are those structures with an unknown ignition status around 18:30.

As described above, most of these primary structures have an unknown ignition status at 18:30 because of limited first responder activity in the areas. As described above and below, there is little evidence that all 103 of these structures were ignited by the passage of the main wildland fire front.

It is sometimes difficult to determine if the ignition was caused by passage of the main wildland fire front or from structure-to-structure fire spread. For example, Figure 38 shows an image taken at 18:38 of four primary structures on fire on Vantage Vista Drive. Figure 38, in conjunction with other imagery and observations described below, provides evidence that structure to structure fire spread occurred in this area.

Figure 38 Image showing structure to structure fire spread on primary structures ignited by 18:38.

Figure 38 shows the primary structure at 5610 Vantage Vista Drive as partially involved on the side closest to 5620 Vantage Vista Drive. The primary structure at 5620 Vantage Vista Drive is shown as completely involved as evidenced by the outline of the building material, which also provides evidence of collapse of some parts of the material on the side next to 5630. The flame heights of 5620 are also higher on the side closest to 5610. Finally, it is clear 5640 and 5630 Vantage Visa Drive are on fire at 18:38, as shown in the image in Figure 38, as little vegetation was present in front of these structures to account for the flame heights portrayed in the image.

It is, however, less conclusive to compare flame heights and state of involvement to determine burn times for 5630 and 5640 Vantage Vista Drive in relation to other primary structures shown in Figure 38 as it is possible 5630 and 5640 had collapsed and no building material outlines are visible in the image. This would indicate 5630 and/or 5640 ignited before 5610 and 5620. The smoke might have obscured the view of 5630 and 5640 building components, which might not have been ignited yet. This would indicate that 5620 ignited before 5630 and 5640. In this case, the state of burning in relation to other structures shown in Figure 38 for 5630 and 5640 is unknown. There is evidence of other structure to structure fire spread from 5620 to 5610.

In the above case, one primary structure is marked as a known ignition on Vantage Vista Drive from the passage of the main wildland fire front with the other three marked as possible structure to structure fire spread. Similar logic was used in the other locations shown in Map Figure 24 to classify structures as possible structure-to-structure fire spread. In some cases, such as the primary structure on northern Wilson Road, there are both images such as those shown in Figure 38 and eyewitness accounts of structure to structure fire spread.

The burn pattern portrayed in Figure 38 and described above, possibly indicating structure to structure fire spread, was verified as a burn pattern where structure to structure fire spread was confirmed to have occurred through both eyewitness observation and multiple time lapse images on Courtney Drive. Figure 39 demonstrates this validation process through a series of time lapse images taken mostly by the CSFD videographer. The first image of the area shown in Figure 39 is obscured by smoke but shows a possible ignition at 2280 Courtney Drive.

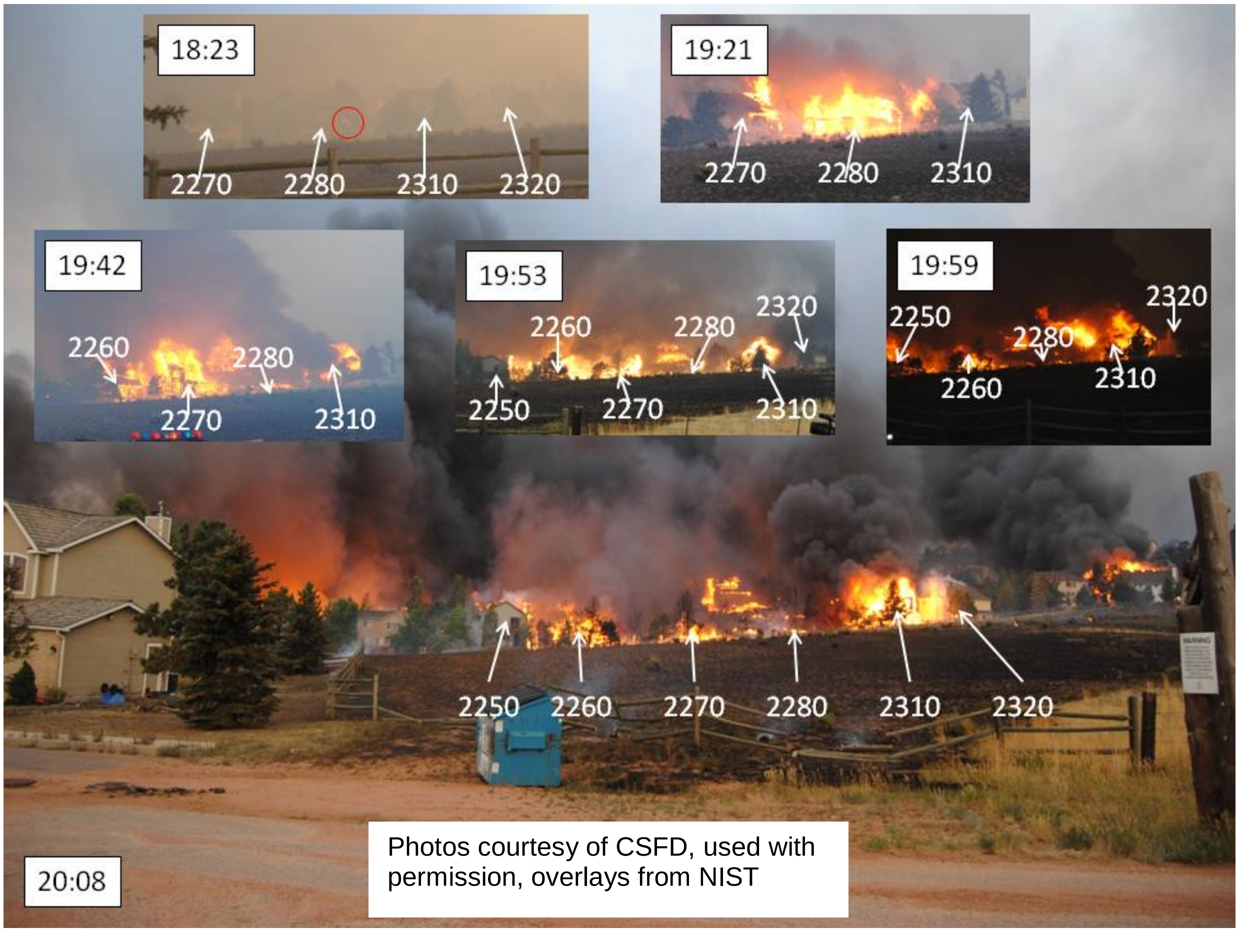

Figure 39 Time lapse images of burning on the northern side of Courtney Drive. White text boxes with black outlines portray burning times. White text portrays addresses of continuously adjacent primary structures from 2250 and 2320. All images are oriented to the south.

It is, however, believed the flames observed in the image were from a primary structure on Courtney Drive to the south of 2280 Courtney Drive, though it is not conclusive. Also, if 2280 Courtney Drive was ignited at 18:23, it seems unlikely it would have taken an hour to spread to the adjacent primary structures based on fire progression observed between 19:21 and 20:08 shown in Figure 39 and assuming no large change in wind direction and magnitude during 18:23 and 19:21. There were no images or observations between 18:23 and 19:21 of this area.

It should also be noted that the careful examination of this area of Figure 39 provides additional data points for analysis, beyond other burning structures not discussed here. These other structures, shown in Figure 41, were used for the development of the timeline For example, the image with a time stamp of 19:53, which also provides evidence of a wind shift to the northeast as shown in Figure 37, portrays no flames or smoke visible on 2320 Courtney Drive. The subsequent image at 19:59 in Figure 39 also shows no flames or smoke visible on 2320 with wind direction being undetermined. Finally, the background image in Figure 39 at 20:08 shows flames coming out of the eaves of 2320 and wind direction to the south.

This provides evidence for the dynamic nature of exposure in relation to structure to structure fire spread. Figure 39 clearly demonstrates the difference in spread distance in the downwind direction compared to the upwind. This information shows how the effects of structure spacing, in regards to burning of adjacent structures, are dependent on exposure and can vary considerably within a small spatiotemporal extent. Also demonstrated is the fact that burn time of structures is dependent on wind magnitude and direction, among other factors.

Also, shown in the background image displayed in Figure 39 is the one undestroyed primary structure found in the northwest corner of Courtney Drive, along with the adjacent primary structure to the north, fully involved. Fire was believed to have spread from one of the unknown ignitions shown on the western side of Courtney Drive in Map Figure 24 to the north and south, resulting in this most northwestern primary structure on Courtney Drive (2340) being one of the last structures to burn on the western side of Courtney Drive and contained by first responders.

Using images with patterns similar to those validated above and eyewitness observations of structure-to-structure fire spread there is evidence that 26 of the primary structures shown as ignited in Map Figure 24 might have been a result of structure to structure fire spread and not passage of the main wildland fire front. It should also be noted that the evidence indicates a relatively minor number of ignitions were probable to have occurred in the unknown locations compared to the overall amount of unknown ignitions portrayed in Map Figure 24.

For example, observations of first responders confirmed in the radio log describe 8 to 10 ignitions on Majestic Drive at 18:15. Other TD observations stated few ignitions on the east side of Majestic Drive. Also, a homeowner on Karamy Court who was present and defending properties during the incident described the primary structures burning on Brogans Bluff as burning west to east like torches after the fire was burning, possibly indicating a limited number of early ignitions and structure-to-structure fire spread, though there is also some contradictory accounts in this area. Though not conclusive, accounts indicated that most destroyed and damaged primary structures burning on Karamy Court and Tamora Way also burned later, indicating the possibility of structure to structure, or structure to vegetation fire spread from Brogans Bluff Drive.

Furthermore, while there is limited information on early burning on Trevor Lane, “Mountain Shadows is Burning” videos, referenced in Appendix E, indicate burn patterns representing possible structure to structure fire spread, providing evidence for a limited number of ignitions in this area. It is believed at least three ignitions must have occurred on Trevor Lane from the passage of the main wildland fire front based on analysis of the "Mountain Shadows is Burning" videos. There was also a smoke obscured image associated with an eyewitness account of only one structure on fire in the general vicinity of Trevor Lane at 18:00.

The image documentation for primary structures burning on and around Courtney Drive indicate a limited number of ignitions, likely less than the total number of primary structures with an unknown ignition status portrayed in Map Figure 24 for this area. One first responder was shown defending the most southern property, with a damaged primary structure, on the west side of Courtney Drive, by extinguishing a burning wheel barrow. Visibility was obscured, but this first responder did not see any primary structures burning as early as 18:35, though there was some uncertainty associated with this time estimate. It is assumed this observation extended to the six most southern primary structures, on the east and west sides of Courtney Drive based on observations of these primary structures burning later. These six primary structures were also observed as being defended and ignited as early as 20:00 for the most northern of these primary structures, providing evidence of no early ignitions in this area.

Another first responder also took images of the Courtney Area shown in Figure 40. Figure 40a shows large flame heights in the general vicinity of the primary structures with an unknown ignition status shown in Map Figure 24. Figure 40b also shows evidence of primary structures burning on Courtney Drive. This burning is only seen on the east side of Courtney Drive in the section of the street that goes north to south, but it is possible primary structures were ignited on the west side of Courtney Drive also at this time.

Some of the evidence that the initial burning did not extend to the east of the primary structures with an unknown ignition status on and around Courtney Drive shown in Map Figure 24, is also demonstrated in Figure 40c. Figure 40c shows burning behind the northern side of Majestic Drive at 19:42 again providing evidence these primary structures were likely not ignited early, but from structure to structure fire spread. Additionally, Figure 40d shows primary structures as foundations in the vicinity of the structures portrayed with an ignition status of unknown in Map Figure 24, at 20:14, indicating the possibility of earlier ignitions of structures in this vicinity.

Furthermore, there was one account of a first responder observing the fire spreading from Courtney Drive to Yankton Place between 19:00 and 20:00, where the fire spread was described as going from Courtney Drive to the north side of Yankton Place and then to the south side of Yankton Place. Finally, the two primary structures shown in Map Figure 24 with an unknown ignition status, one on Vanreen Drive and the other on Regal View Road, while inconclusive, do have some burning time information (images and observation) that indicates later ignitions, possibly from burning structures in and around Linger Way. These observations are not conclusive.

Primary structures shown with an ignition status of not burning in Map Figure 24 were classified as such due to observations and/or images of the structures burning later. It is possible a certain percentage of these were the results of ignitions from the main wildland fire front and subsequent smoldering of combustibles on or near the respective primary structure, for a relatively long period, and ignited at a later time. It is, however, believed this number of smoldering ignitions would be relatively small based on the analysis of images, videos and observations obtained for burning at most of these locations.

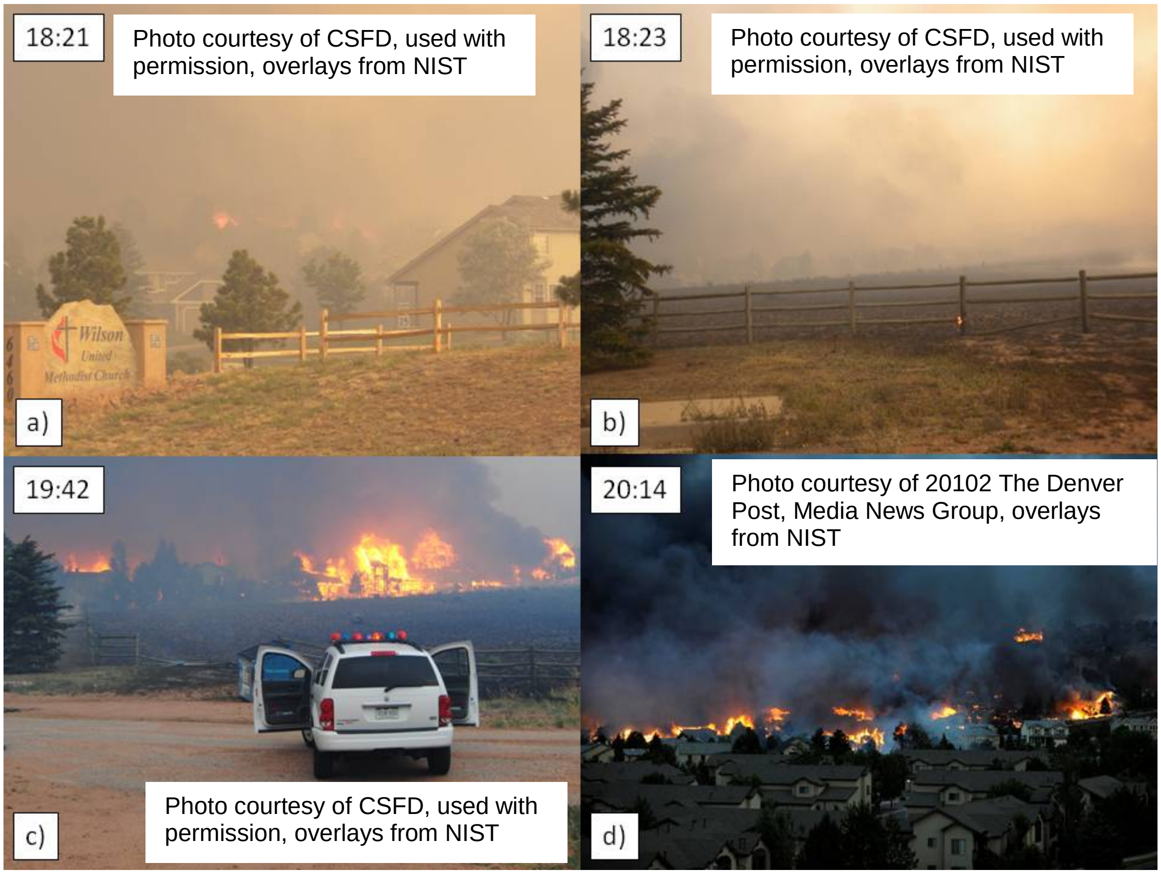

Figure 40 Evidence of limited number of early ignitions on Courtney Drive. a) Image looking to the west showing high flame heights on the east side of Courtney Drive, near the bend in the street. b) Image looking to the south showing flames either on 2280 Courtney Drive or behind it. C) Image looking to the south showing primary structures involved on the south side of Courtney Drive. D) Image looking to west showing foundations on the west and east side of Courtney Drive and Yankton Place.

Map Figure 25 displays the ignition status of primary structures on or approximately before 20:30. The structures listed with an ignition status of unknown, shown in Map Figure 25, on Courtney Drive and Yankton Place are believed to have mostly been destroyed or ignited by 20:30, based on known burning primary structures surrounding these structures and the information described in Figure 11 and Figure 40. The structures listed with an unknown ignition status, shown in Map Figure 25 on Rossmere Street south of Courtney Drive were not known to have ignited by 20:30, but were shown to be defended from the burning structures on Courtney Drive by at least 21:30.

The destroyed primary structures classified as not ignited in Map Figure 25 east of Yankton Place and on Ashton Park Place were shown to have ignited by 20:50, except 6455 Ashton Park

Place, which had either ignited or was close to ignition based on upwind burning of structures. The damaged primary structures in this area, including the one damaged primary structure on Savannah Way were ignited sometime after 20:30 from embers, radiant heat or flames from these ignited structures on Ashton Park Place. All damaged primary structures were identified as being defended, and containment locations are portrayed in the sections below.

As shown in Map Figure 25, there are a number of unknown ignitions at 20:30 in interior Brogans Bluff Drive. This is due to lack of time stamped observations and some contradictory information. The other primary structures west of Wilson Road, southeast of Flying W Ranch Road, were all damaged and defended from structure to structure fire spread sometime after the adjacent primary structures were ignited, based on observations of first responders defending these structures.

Figure 41 Image looking west into Majestic Drive from its northern entrance showing significant burning in the second cul de sac on the north side at 19:23.

The primary structures with an unknown ignitions status in Map Figure 25 north of the four ignited primary structures on the east side of Majestic Drive (directly north of the two most northern primary structures identified as not ignited in Map Figure 25) are believed to have mostly been destroyed or ignited by 20:30. There is evidence for this in the image shown in Figure 41 portraying significant burning on the northern end of Majestic Drive at 19:23. This burning could not be precisely geolocated beyond the second cul de sac on the north side from the northern Majestic Drive entrance.

Figure 42 portrays a single screen shot from a video showing the structures on the north end of Majestic Drive as foundations sometime between 20:45 and 21:15. This is further evidence that the primary structures on the northern end of Majestic Drive were destroyed or ignited before 20:30. Additional evidence is also provided in Figure 43, which highlights various burning and non-burning areas. Also shown in Figure 43 are multiple ignitions in the northwestern area of Vantage Vista Drive, labeled as unknown ignition status in Map Figure 25.

The image labeled 20:20, and shown in Figure 43, does not provide sufficient detail to identify individual primary structures ignited, but general locations of burning structures can be seen given the topographic configuration of streets, such as Vantage Ridge Road and Majestic Drive. Images of foundations and ignitions, shown later than 20:20 on both the east and west sides of Vantage Ridge Road, also support the locations portrayed in Figure 43. Finally, Figure 43 shows little burning between the area of full involvement on the north side of Hot Springs Court and the northern end of Majestic Drive, close to Harbor Pine Point. This provides evidence that most of the structures on northern Majestic Drive area were ignited or destroyed by 20:30. Both Figure 43 and Figure 44 portray 3D representations of the earth's surface from Light Detection and Ranging (LiDAR), overlaid on pre-fire 2011 City of Colorado Springs orthoimagery.

The southern end of Majestic Drive shows a number of primary structures identified as not ignited in Map Figure 25, based on images and videos of the area between 20:00 and 22:00. As seen in Map Figure 25, the two southernmost ignited primary structures are separated by structures with an ignition status of unknown or not ignited. As shown in Figure 44, there is evidence that 2539 Hot Springs Court, the one primary structure off Majestic Drive and backing to Flying W Ranch Road ignited at 20:20.

Figure 42 Destruction on the north end of Majestic Drive observed between 20:45 and 21:15.

The location of the ignition portrayed in Figure 44 was identified through assessment of Bing Maps, as shown in Figure 3. In conjunction with this initial image of ignition at 2539 Hot Springs Court, there is a subsequent image showing a structure to structure burn pattern at 21:01, as shown in Figure 44, indicating 2539 Hot Springs Court burning first. The above two pieces of information provide evidence of an ignition at 2539, which appeared to be caused by embers from burning structures on the north side of Hot Springs Court.

Also shown in Figure 44 is an image of burning on, or to the south of, 5450 Majestic Drive sometime after 20:00. Both this image in Figure 44, and other images, show burning on the most southwestern part of Majestic Drive, separated by primary structures which were not burning. This indicates another ember jump location, again presumably from burning primary structures on Majestic Drive to the north. Finally, Figure 44 shows an unidentified ignition somewhere around Majestic Drive, separated by areas of no burning.

This unidentified ember jump location could be on the east or west side of Majestic Drive. A video taken at 21:47 shows the most southeastern primary structures on Hot Springs Court in various stages of involvement, and the most southeastern destroyed primary structure on Lions Gate Lane is shown as ignited by 21:17, indicating both locations were possibilities for the general area of the unknown ember ignition, showing that there were multiple paths of fire spread from the structures on the northern side of Hot Springs Court to primary structures on the southern and western side of Majestic Drive. The primary structures portrayed with an ignition status of unknown in Map Figure 25, off Lions Gate Lane, were defended after the burning of the southernmost destroyed primary structures on Lions Gate Lane occurred (i.e., < 21:30).

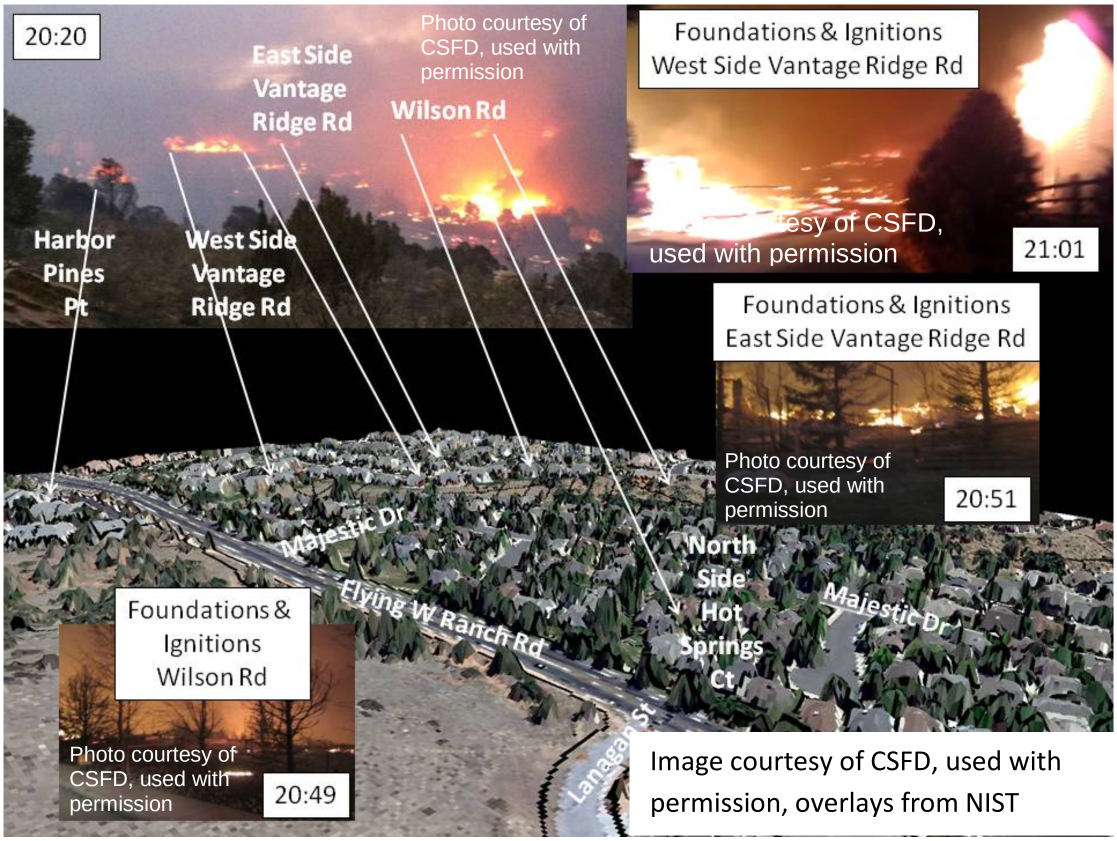

Figure 43 Selected images of burning primary structures around Majestic Drive.

Map Figure 26 shows ignition status of primary structures around 23:00. There are no primary structures classified as not burning at this time, with 316 known primary structures burning, and 129 primary structures with an unknown ignition status. Of these 129 unknown structures, 73 were found off Majestic Drive and Lion Gate Lane. Images taken by a first responder of this area at 11:55 are shown in Map Figure 27.

As seen in Map Figure 27, the entire southern section of destroyed primary structures on Majestic Drive and Lions Gate Lane are shown as ignited within 55 min after 23:00, with many being foundations. Also shown in shown in Map Figure 27 is the correlation between white ash, or lack thereof, and ignition status at the time of the images. The primary structures shown in Map Figure 27 that are foundations have higher presence of white ash relative to structures shown in a more involved state of burning and contained at 23:55. This, coupled with the images of first responders defending these areas, provides evidence for the lack of white ash on primary structures being correlated with defensive actions or some form of suppression.

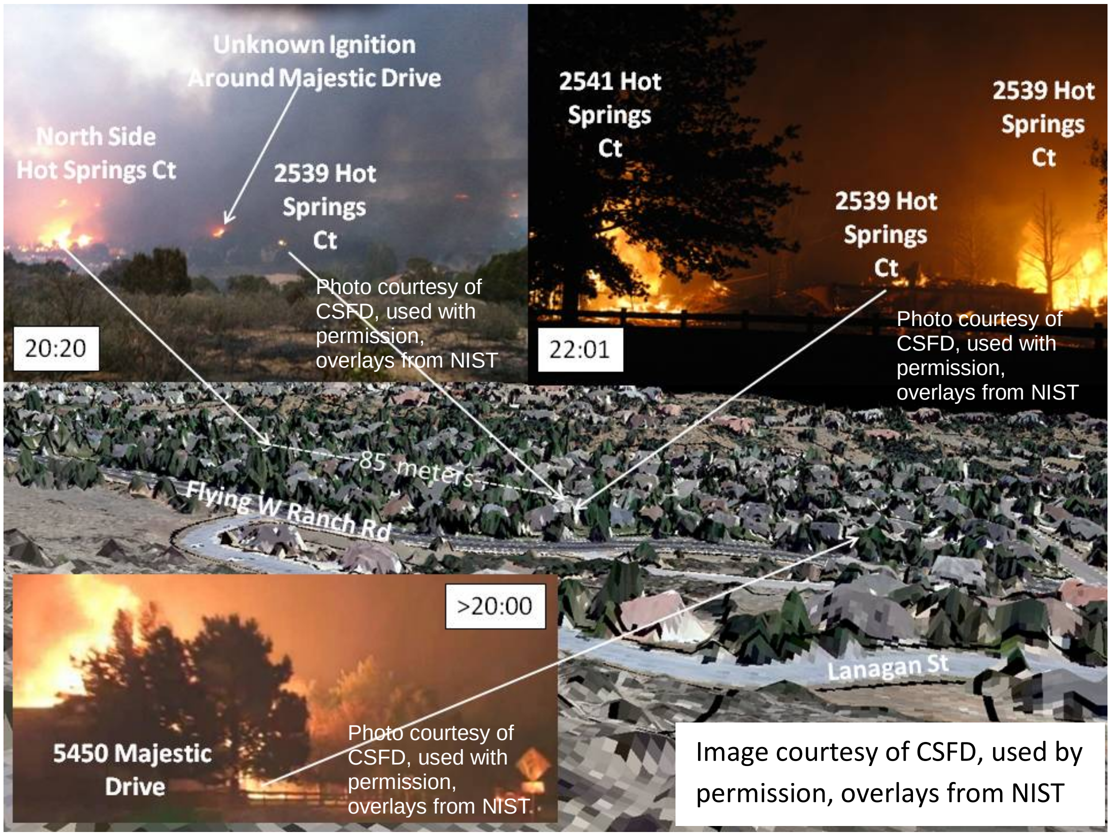

Figure 44 Additional selected images of burning primary structures around Majestic Drive.

There were about 40 primary structures with unknown ignition status off Majestic Drive located north of Hot Springs Court and the intersection of Lanagan Street and Flying W Ranch Road that were assumed to mostly have been destroyed by 23:00 with some additional evidence shown in Figure 45. As shown in Figure 45, at 23:01 several primary structures along the eastern side of Majestic Drive were fully involved. A latter image shown in Figure 45, taken at 01:07 on June 27 shows the same primary structure in a state of involvement more than those to the east, providing evidence that the primary structures to the east of 5535 Majestic Drive were ignited.

The remaining 56 primary structures with unknown ignition statuses around 23:00 were found in various locations, with 36 of them damaged primary structures. These damaged primary structures had large time ranges associated with the defensive actions and, consequently, are listed as unknowns. Assuming these occurred around the time of associated burning of adjacent primary structures, these damaged primary structures were also ignited, or close to being ignited, by 23:00. The 20 destroyed primary structures found on Yankton Park Place and Brogans Bluff Drive (north of Karamy Court) were assumed to be destroyed by 23:00, but represented unknown locations. Two of the 20 destroyed were found on Linger Way, with images of full involvement at 23:44. In short, by 23:00 there were only a handful of structures with unknown ignition statuses on the southern end of Majestic Drive, which likely did not ignite by 23:00, as identified in Map Figure 27. Additionally, there was one ignition extinguished on the morning of June 27 on Lions Gate Lane, and one on Lanagan Street around the same time.

As mentioned above, there were also numerous other mop-up actions occurring for days after the incident. It is difficult to exactly quantify the defensive actions and burning conditions during the mop-up stage.

The rate of burning of structures appeared to vary considerably, even on the same street, as shown in Figure 39. This makes a rate of structure burning between time intervals shown in Map Figure 24 through Map Figure 26 potentially misleading. Nonetheless, it is useful as a coarse measure, particularly when viewed in conjunction with apparatus deployment, as discussed below.

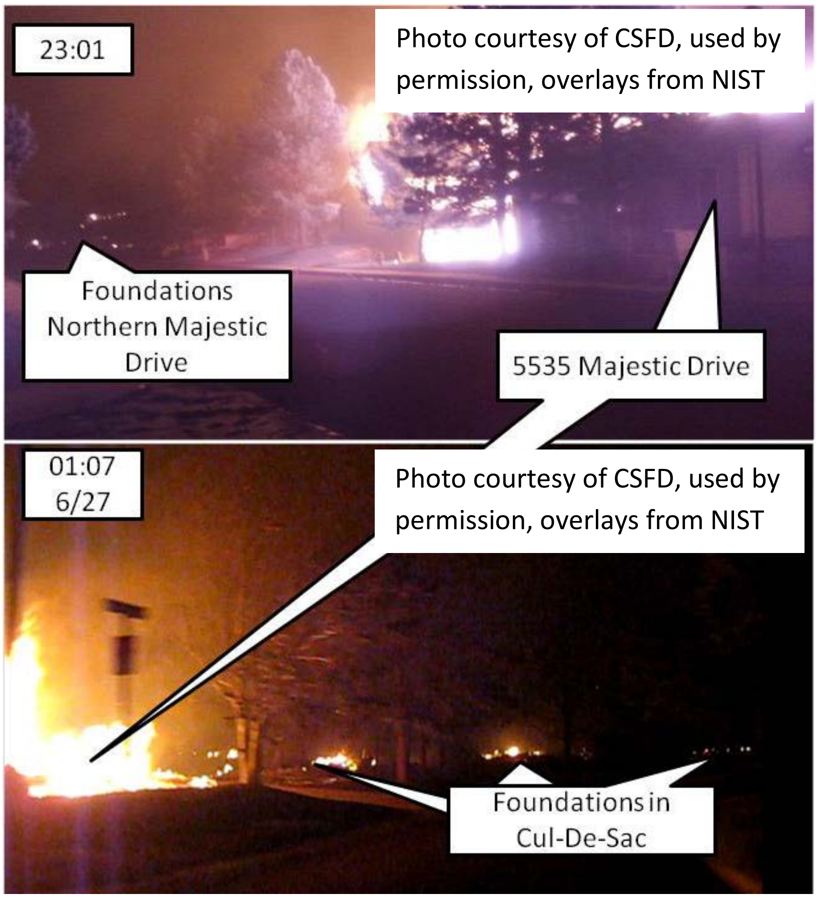

Figure 45 Ignitions on Majestic Drive providing evidence for majority of primary structures on east side ignited or destroyed by 23:00.

Examination of Map Figure 24 shows that there were at least 48 ignitions of primary structures by 18:30. Table 15 provides minimum and maximum estimates for the various streets with unknown primary structure ignitions after the passage of the main Waldo Canyon Fire Front. The number of primary structures ignited from the passage of the wildland fire front ranged from 55 (48 as shown in Map Figure 24 plus the minimum shown in Table 5) to 113 (48 + 26, as shown in Map Figure 24, plus the maximum shown in Table 5).

Examination of Map Figure 25 shows that there were 217 primary structures ignited by 20:30. Additionally, there were 198 structures with an unknown ignition status. Table 16 provides minimum and maximum estimates for the various streets with unknown primary structure ignitions around 20:30. The number of primary structures ignited at 20:30 ranged from 248 (217 as shown in Map Figure 25 plus the minimum shown in Table 15) to 286 (217 as shown in Map Figure 25 plus the maximum shown in Table 15). Finally, the number of primary structures ignited at 01:00 on June 27 ranged from 435 to 445.

Table 15 Estimates of the minimum and maximum number of primary structures ignited on streets with unknown primary structures ignitions after the passage of the main Waldo Canyon Fire Front.

Street	Maximum	Minimum
Majestic Drive	7	0
Tamora Way	1	0
Ravina Court	1	0
Brogans Bluff Drive	4	0
Trevor Lane	6	3
Talleson Court	5	1
Courtney Drive	6	1
Yankton Place	2	0
Ashton Park Place	1	1
Regal View Road	1	0
Huffman Court	1	0
Linger Way	2	1
Harbor Pines Point	2	0
Sandray Court	1	0
TOTALS	**39**	**7**

The data has shown that because burning (non-savable) structures can generate embers for several hours, early structure ignitions enhance and accelerate fire spread. Ignited structures not only affect nearby structures by radiation and convection, but also create a significant ember exposure hazard downwind for tens of meters (hundreds of feet). If fuels are present, this ember exposure is then responsible for the potential ignition of vegetation and structures downwind. It is this fire spread potential, or multiplier effect, that makes it advantageous to limit early structure ignitions.

Table 16 Estimates of the minimum and maximum number of primary structures ignited on streets with unknown primary structures ignitions after 20:30.

Street	Maximum	Minimum
Majestic Drive	36	18
Aubrey Way	1	1
Stoneridge	2	0
Hearthstone	1	0
Darien Way	1	0
Harbor Pines Point	2	0
Linger Way	1	1
Ravina Way	1	0
Brogans Bluff Road	8	4
Trevor Lane	1	0
Courtney Drive	6	3
Yankton Place	7	3
Ashton Park Place	2	1
TOTALS	**69**	**31**

It should also be noted that the ember jump locations shown in Figure 44 also occurred after the change in wind direction. There were no known ignitions south of the general canyon area to the west of Majestic Drive before the wind change. This highlights that even at peak apparatus deployment, which first responders were at by 20:20, as discussed in sections below, fire can easily become embedded in high density/low structure separation distance neighborhoods, and first responders are not aware of this due to situational awareness limitations in a dark, smoke-filled environment. This also highlights the need for prevention of ignitions through effective pre-fire actions taken on WUI constructions and surrounding vegetation.

11.0 Defensive Actions

By documenting defensive actions in both space and time, critical information can be collected on structural vulnerabilities and fire and ember exposure data. The spatiotemporal extent of defensive actions is required for any scientific assessment of WUI fires. Collecting defensive actions in large multijurisdictional events requires significant resources. It is important to identify all apparatus at a particular incident, as demonstrated in Section 8.3.1.2 of this report. Efficient and effective defensive action information collection, however, is in its infancy.

Defensive actions were attributed to two primary categories, parcel and structure actions. Defensive actions were further divided into pre-fire, fire extinguishment and fire containment actions. At the parcel level, actions were taken to prevent ignition, extinguish the fire, or contain the fire. Structures were defended in the following possible scenarios:

- Successfully before ignition (structure undamaged)
- Unsuccessfully defended before ignition (structure ignites – structure damaged)
- Successfully extinguished after ignition (structure saved)
- Unsuccessfully extinguished after ignition (structure destroyed)
- Successfully contained (fire did not spread beyond structure of origin)
- Unsuccessfully contained (fire spread beyond structure of origin to adjacent structure)

It should be noted that not all types of defensive actions were taken on every structure. In some cases, structures were too far along to extinguish, and defensive actions were immediately aimed at containing the fire. Re-ignitions represent a scenario where extinguishment was originally thought to be effective by first responders, but ultimately required additional actions to extinguish or contain.

11.1 Residential Parcels

Residential parcels, as described in this report, include wildland and ornamental vegetation, as well as other detached combustibles such as railroad ties and fences. In both cases, due to limited resources, no attempt was made to identify if fences or railroad ties were connected to the main structure and were by default treated as detached combustibles. Defensive actions on parcels included pre-fire parcel prepping, which might include pre-wetting or fuel removal. When fire was present, defensive actions included fire extinguishment and fire containment. In the latter case, this term was used when a fire line was scratched specifically to contain or redirect a vegetative fire. Defensive actions on other detached combustibles are also included in this section. Map Figure 28 displays parcels for which defensive actions were identified.

Figure 46 shows counts of parcels by action type. It should be noted that the TDs only identified some of the total parcels which had fire behavior in vegetation. Over 500 parcels that were identified as having fire affected vegetation in the post-fire imagery and were not identified as burning through the TD process. Identification of defensive actions on vegetation has proven one of the most difficult tasks to identify, possibly due to the fact that the vegetation does not make as distinct an impression on first responders memory as burning primary structures. Additionally, if a parcel was on fire and did not directly threaten a structure, when resources were limited, it received lower attention than vegetative fires directly threatening structures.

Nonetheless, in a number of cases, fire suppression actions at a parcel level reduced fire and ember exposure to the structure on that parcel. The response of individual structures to variation in fire and ember exposures is beyond the scope of this report. Additionally, the limited amount of information regarding building characteristics available for structures in MSC will likely limit the analysis of structure response to roof cover and siding type.

As shown in Figure 46, the majority of the actions taken were aimed at extinguishing the fire on the parcel, followed by entinguishment of detached combustibles. It is likely the number of fences removed were underestimated, as there were known areas with knocked down fences observed in pre-fire imagery not tabulated in Figure 46. This highlights the difficulty in identifying every single action and the need to integrate all data.

Table 17 contains a summary of the bulldozer lines that where placed to protect the MSC. Both the lines from the Wilson Road water tower to the quarry and the line from the Autism Center to the Flying W Ranch were breached. It is estimated that one third to one half of all parcels/structures affected by fire were defended. The uncertainty in this value is related to the fact that a large fraction of parcel level defensive actions were not captured during technical discussions.

11.2 Residential Structures

Defensive actions on structures, like on parcels, include pre-fire mitigation and post ignition defensive actions. In some cases structures were pre-wetted; water was applied prior to any ignition, whereas in other cases, water application took place after the structure was on fire. If the water or foam application was successful, the structure was just damaged. If the fire was not successfully extinguished, then in many cases, defensive actions were transitioned to containment.

At the structure level, containment was intended to prevent the burning structure from igniting other structures on fire. Successful containment was achieved if a containment objective was explicitly identified in the defensive action(s) taken and the (identified) structure is saved. This rule applies even if the containment objective is not for an immediately adjacent structure.

Successful containment does not apply to long range ember spotting tens of meters (hundreds of feet). If there is failure in one direction and success in another (e.g. North or South), the containment actions for the structure have failed. It is critical to analyze defensive actions both in space and time, as successful containment may have been achieved and the adjacent structure(s) may have been destroyed as a result of a different exposure.

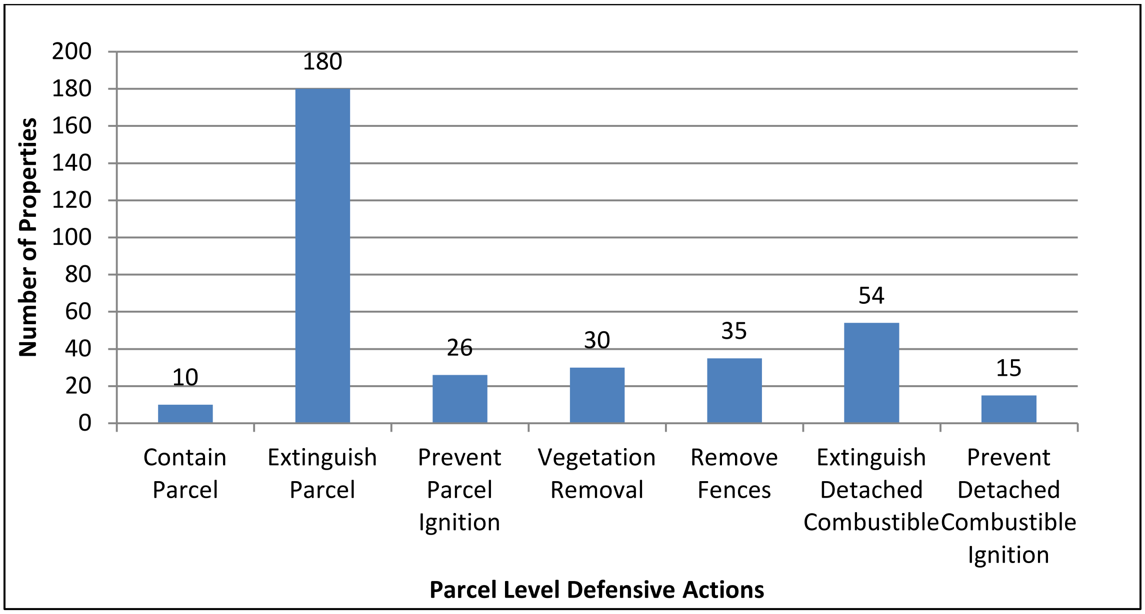

Figure 46 Counts of properties by parcel level action. Individual properties might have seen multiple actions.

11.2.1 Undamaged Structures Defended to Prevent Ignition

Map Figure 29 portrays the locations of 154 primary structures that were identified as being defended to prevent structure ignitions and were not identified as being damaged. Figure 48 shows the number of properties where each identified suppression tool was used. It is difficult to exactly quantify the magnitude of each action across the entire incident. It can, however, be observed that in a majority of cases where containment occurred, both a combination of significant water suppression, coupled with low water and hand tool applications were required to prevent/extinguish spotting down wind.

The majority of recorded defensive actions on undamaged properties were taken with fire hoses. Deck guns, structure preparation, and garden hoses were recorded as being equally used. Each tool was only counted once per structure but might have been used multiple times. Additionally, a structure might have received multiple types of defensive actions, such as a combination of fuel removal and cooling by fire hose. For this reason, the number of defensive actions listed in Figure 48 exceeds 154, the identified number of structures defended to prevent ignition. Appendix J contains the list of tools used to prevent structure ignitions by address.

Finally, Figure 47 shows a histogram displaying the count of undamaged and defended structures, based on distance to the nearest destroyed structure. It is important to note that some of the defended structures were not defended from fire produced by burning structures, but rather from fire produced from burning vegetation or detached combustibles. The utilization of sprinklers was likely exaggerated, as in multiple cases first responders were not absolutely certain on which properties they had activated the sprinklers. For recording purposes, all the potential primary structures at Chase Point Circle and Regal View Court received sprinklers as defensive actions.

Table 17 Bulldozer line summaries.

Name	Distance (km)	Approximate time constructed	Description
Cedar Heights	1.6	6/24/2012 morning	TDs 36-38, 90. Bulldozer line in Cedar Heights constructed from Outback Vista Point (near Monitor Rock Lane/Cedar Heights Dr) to near Silver Spruce Way/Cedar Heights Dr. Bulldozer line length was approximately 1.6 km. Hand crews dug line down into the canyon from the bulldozer line. At 14:00, a large increase in downslope wind velocity caused a flare up around the south side of the bulldozer line.
The Navigators to the Flying W Ranch	3.2	6/25/2012 all day	TD 36. Monday (all day). Created a bulldozer line from The Navigators (3820 N 30th St, Colorado Springs CO) to the Flying W Ranch (approximately 1.6 to 3.2 km). Two, 20 person hand crews connected a hand line to the Autism Center from the bulldozer line. Bulldozer boss TD 90, with USFS and CSU. 2 bulldozers, 1 water tender. Instructed to build it "wide enough to light with fusees, and hold with a hand pump." TD 90, Tuesday AM. Re-engage with bulldozer line, finish bulldozer line by 12:00 in front of the Flying W Ranch. Flame spotted on hillside, resources fall back. Observed fire coming over the ridge at the Flying W Ranch. Vorteces dump over the ridge, dropping into the grass, column collapses, and pulls surface fire to canopies. Column spinning over the Flying W Ranch. Bulldozers parked in green patch. Burned over. Survived.
The Flying W Ranch to Wilson Tower	0.4	6/26/2012 morning	Created a bulldozer line from the Flying W Ranch to the Wilson water tower (approximately 0.4 km). TD 36. Tuesday AM. Used the bulldozer to knock down trees on the NW side of the Wilson water tower and then built bulldozer lines by Wilson water tower Monday afternoon (2 blade-widths, 4.9 m (16 ft) total width). Patrol bulldozer line into Tuesday.
Wilson Tower to Wolfe Ranch	0.8	6/26/2012 morning	Created a bulldozer line from the Wilson water tower to the east, downhill to Wolfe Ranch (approximately 0.8 km).
Wolfe Ranch to Pikeview Quarry	1.6	6/26/2012 afternoon	TD 36-38. Tuesday (12:00 – 16:00). Created a bulldozer line from Wolfe Ranch to Pikeview Quarry (4.3 m (14 ft) wide) (approximately 1.6 km). From TD 90. CSU Brush and bulldozer rode out fire (collumn collapse) at Pikeview Quarry, never evacuated.
Pikeview Quarry to Peregrine	0.8	6/26/2012 evening	TD 38, Tuesday 22:30. Created a bulldozer line from the Pikeview Quarry to Hollandale St. (Peregrine) (approximately 0.8 km).

11.2.2 Damaged Structures Successfully Extinguished

This section summarizes the successful defensive actions on structures that were damaged. The definition of damaged includes structures or attached combustibles, excluding fences, that ignited as well as structures that were in pre-ignition mode with documented damage. Not included in this category are structures listed as smoking/melting/pre-ignition, if no confirmed damage was identified. As mentioned above, the damage list provided in this report cannot be viewed as complete because a systematic assessment of all structures within and around the fire perimeter was not conducted.

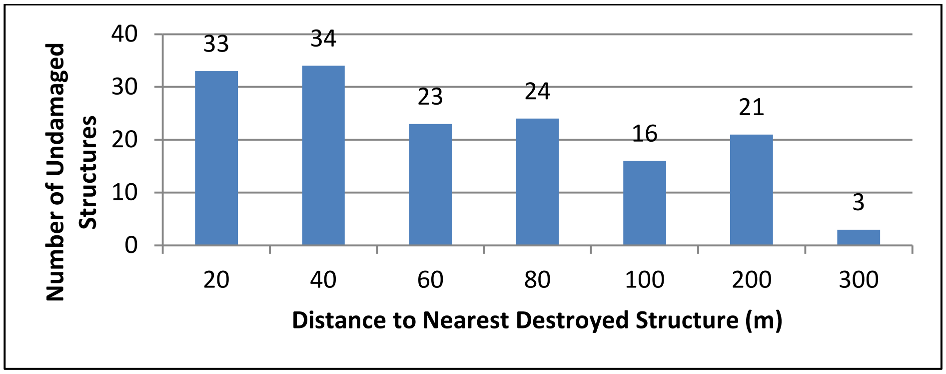

Figure 47 Counts of undamaged structures based on distance to the nearest destroyed structure.

Also, as discussed above, many of the categorizations presented below are somewhat arbitrary due to the lack of complete documentation. Classifications of "structure ignition deck", as shown in Figure 15, do not necessarily correctly identify the ignition source. This highlights the importance of assessments on damage to primary structures such as partial damage assessments conducted for the IBHS report on the Waldo Canyon Fire. Also highlighted is the need for complete photographic documentation of the respective scene to capture all damage.

Map Figure 30 portrays damaged structures that were known to be defended. In total, there were 94 damaged structures known to be defended out of a total of 101 identified potentially damaged primary structures. Consequently, 93 % of the damaged primary structures were identified as being extinguished or having radiant heat and flames reduced from adjacent burning objects as a consequence of first responder actions.

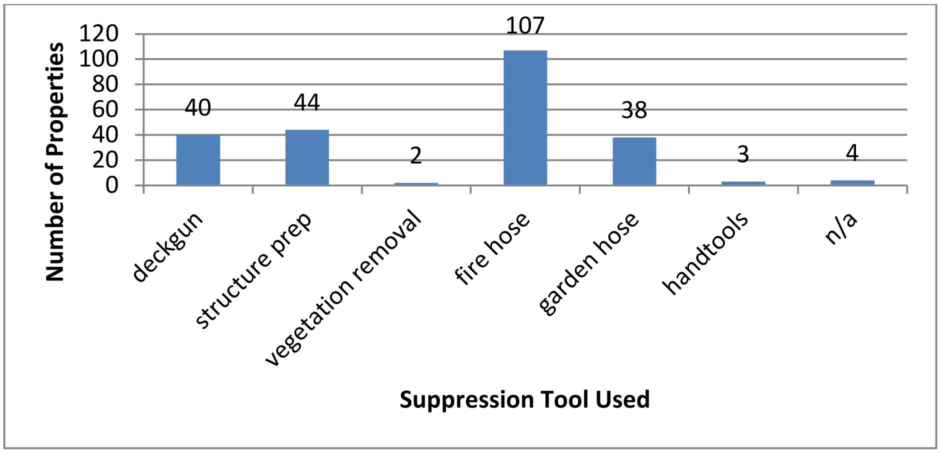

Figure 48 Counts of undamaged structures defended with various suppression tools.

Figure 49 shows the count of suppression tools used by property and represents suppression tools used on 63 of the 94 properties found to be defended. Fire hose, garden hose and hand tools were the three primary tools used with interior access ranking fourth. The remaining 31 properties did not have any specific suppression tool identified as some were a result of containment of an adjacent structure. Appendix K describes the tools used to extinguish the structures.

Figure 49 highlights the fact that structure extinguishment required both significant water application and implementation of low water and hand tool applications. Also, some damaged primary structures were extinguished with more than one tool. Multiple types of apparatus, required for successful containment/extinguishment, is further demonstrated in Figure 50, showing the distance to the nearest destroyed primary structure from each damaged and extinguished primary structure. The spike of extinguished primary structures greater than 100 m from a destroyed structure is in part due to primary structures in low density and high separation distance areas, typically damaged by the passage of a wildland fire front.

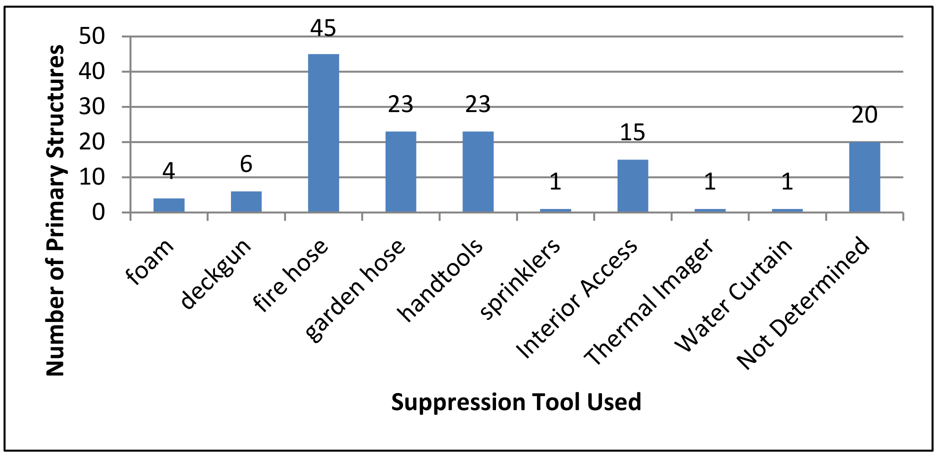

Figure 49 Counts of extinguished primary structures per suppression tool. Each tool is counted once per property and might have been used multiple times.

These primary structures potentially damaged by the wildland fire were found on Langan Street, Wilson Road and Sandray Court. Primary structures found on Moorfield Avenue and Rossmere Street south of Courtney Drive might also have been damaged from wildland fire fronts or structure-to-structure ignitions. The majority of the other extinguished primary structures were the

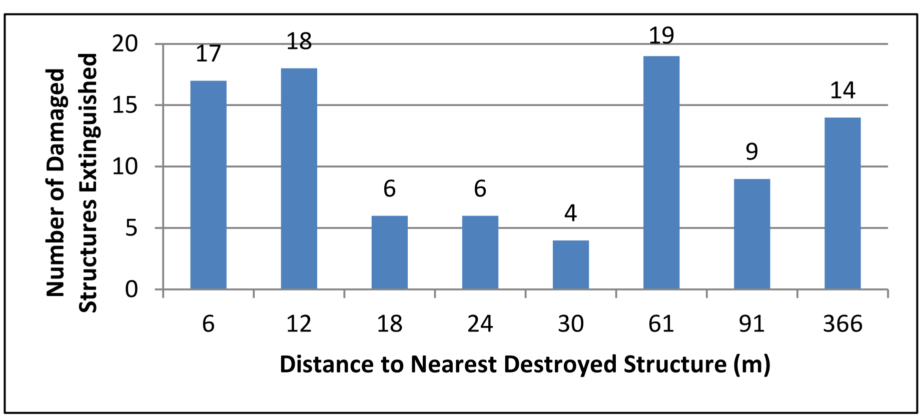

Figure 50 Counts of damaged structures based on distance to the nearest destroyed structure.

result of structure-to-structure fire spread, often requiring hand tools or low water applications to extinguish. Consequently, there was some evidence structure to structure fire spread might have occurred from structures greater than 300 m apart. There was video evidence of structure to structure fire spread occurring between structures greater than 80 m apart.

11.2.3 Damaged Structures – Undefended

The seven structures identified as damaged with no identified defensive actions are shown in Table 18. It is important to remember that lack of identifying a defensive action does not indicate a defensive action did not occur. The fact that 93 % of the damaged primary structures were defended leads to the conclusion that it is more prudent to assume a defense action occurred when considering damage to structures compared to not assuming this, if one is to assume anything. There are, however, cases of no defensive actions, such as at 2580 Brogans Bluff Drive, but no documentation of damage, beyond anecdotal. This highlights the need for homeowners to have the ability to provide authorities with documentation of damage.

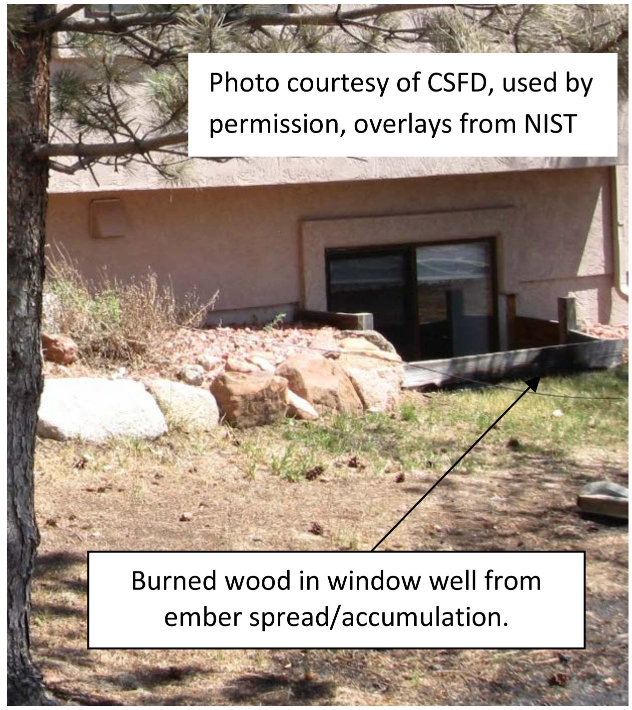

Figure 51 Damage to wooden window well. Note the damage was not from continuous fire spread as evidenced by the green vegetation.

Table 18 Potentially damaged structures with no specific defensive action identified.

Address	Damage Location
5265 CHAMPAGNE DR	This primary structure was identified in the field as having possible roof damage but was not confirmed.
5430 WILSON RD	Minor roof damage identified in the damage assessment by CSFD. There were defensive actions in the area.
5530 DARIEN WAY	This primary structure was identified in the field as having possible roof damage and confirmed as roof damage by a field visit and post-fire imagery. There were defensive actions in the area.
5760 LINGER WAY	Damage to wooden window well as shown in Figure 51 identified in NIST/USFS assessment.
5020 LANAGAN ST	Anecdotally seen as defended early in the morning of June 27 but actual responder not identified. The damage was confirmed in a subsequent field visit.
2580 BROGANS BLUFF DR	Burned tar paper under a tile roof was identified in (http://gazette.com/waldo-canyon-fire-two-years-later-a-neighborhood-is-reborn/article/1521839). There was no defensive action identified on this structure.
2340 ROSSMERE ST	Field visit identified the deck was replaced. Numerous defensive actions occurred around this area.

11.2.4 Destroyed Structures Unsuccessfully Extinguished and Successfully Contained

There were 24 primary structures for which fire extinguishment actions were unsuccessful and tactics were transitioned to containment which were successful. These primary structures are portrayed in Map Figure 31. Out of 24 primary structures that were unsuccessfully extinguished and successfully contained, 18 were adjacent to destroyed primary structures and 6 were not: 2380 Rossmere Street, 2645 Stoneridge Drive, 2320 Vanreen Drive, 4975 Braeburn Way, 1605 Manning Way and 5775 Huffman Court. The primary structure at 2320 Vanreen Drive was ignited around 20:00, sometime after the passage of the main fire front coinciding with the change in wind direction. The primary structure, likely on Huffman Court, ignited before the wind shift. The remainder of the primary structures were ignited shortly after the passage of the main fire front (< 18:30, with 2680 Rossmere Street being no later than 19:00). All six of these primary structures had defensive actions occurring relatively shortly after identified ignition.

The majority of the other primary structure destructions were the result of structure-to-structure fire spread as evidenced in imagery and/or fire witness observations. It should be noted, however, that 5175 Lanagan Street and 2470 Jenner Court might have been ignited by the wildland fire. The primary structure at 5175 Lanagan Street had a deck ignition identified and suppressed, which might have been a result of the fire at 5155 Lanagan Street, or the result of the passage of the main wildland fire.

The primary structure at 2470 Jenner Court has images from the CSFD videographer of ignitions shortly before the wind shift (19:30 to 19:50). Unidentified features attached or near to 2470 Jenner Court are also shown in Figure 52 as possibly ignited at about 20:00. The relationship between the burning condition at 2470 Jenner Ct and 2450 Jenner Ct also indicates the possibility of structure to structure fire spread that occurred after the wind shift. The destroyed primary structure at 2460 Jenner Court between the above two primary structures is not shown burning in Figure 52, but 2460 Jenner Ct is also in a topographic depression compared to 2470 and 2450 Jenner Ct.

When containment occurred, as specified in this section and the sections below, water (e.g. fire hose or deckgun) was used to contain the fire. In many cases, containment also involved actions in the down wind direction to other primary structures and combustibles. Quantification of the containment tools used is, consequently, not presented in this section and sections below.

11.2.5 Destroyed Structures Unsuccessfully Extinguished and Unsuccessfully Contained

Table 19 displays the structures that were unsuccessfully defended to extinguish the fire, subsequent containment attempts failed and an adjacent primary structure(s) was destroyed from the resulting exposure. The information was provided by first responders. Unless otherwise stated, defensive actions on an ignited structure were assumed to be for fire extinguishment and not containment. The cases shown in Table 19 are for structures where fire spread was of concern, and specific containment actions were taken and reported.

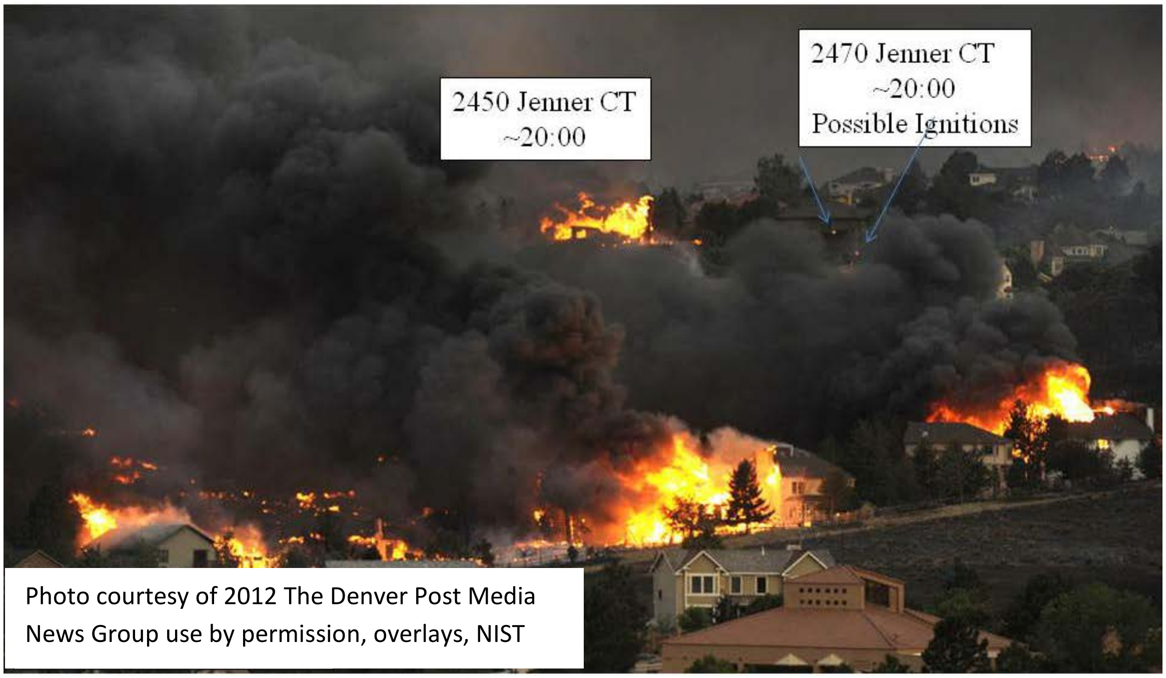

Figure 52 Possible ignitions at 2470 Jenner Ct in relation to burning at 2450 Jenner Ct.

Table 19 also describes the specific defensive action related to unsuccessful extinguishment, unsuccessful containment, and the tool used. Six out of the eight containment failures were attributable to high exposures during structure-to-structure fire spread in high density and low structure separation distance areas.

11.2.6 Destroyed Structures Successfully Contained

Map Figure 32 portrays the locations of the 60 structures where defensive actions were directly aimed at containing the structure of origin. There were no attempts to extinguish the structure on fire, but instead the focus was directly on containment. These containment actions, when viewed across the incident, demonstrate the first responder effectiveness in "boxing in" the fire. Structures on fire that were not savable could consume significant personnel and water resources to cool down or suppress. First responder observations identified that in some cases, resources could be effectively used to contain ember exposure and limit fire and ember spread by cooling adjacent combustibles and not putting water on the burning structure.[xx] As evident by the extensive lack of white ash on most successfully contained primary structures, water application to structures was also required in certain locations.

[xx] Direct high flow water application on fully involved structures can enhance ember generation as the pressure from the water can dislodge burning materials that are then lofted by the fire plume and help propagate fire downwind.

Table 19 Destroyed structures unsuccessfully extinguished and unsuccessfully contained.

Address	Failure of Containment	Defensive Action Description
5448 Majestic Dr.	Structure-to-structure fire spread with high exposure	Fire hoses were used to attempt extinguishment/ containment by two different engines.
5450 Majestic Dr.	Structure-to-structure fire spread with high exposure	Fire hose used by single engine late on June 26.
5683 Majestic Dr.	Evacuation of resources	Fire hose used by a single brush truck around 18:23 before the second evacuation.
5432 Majestic Dr.	Structure-to-structure fire spread with high exposure	Actions were taken to prevent ignition and extinguish/contain structure with a fire hose.
5430 Majestic Dr.	Structure-to-structure fire spread with high exposure	Actions were taken to prevent ignition and extinguish/contain structure with a fire hose.
5445 Wilson Rd.	Unknown	An engine on ember patrol observed the shake roof on fire at this address at a time when nothing else in the immediate vicinity (lower Wilson) was burning. The engine extinguished the roof fire, but upon doing so, observed that fire was already inside the house.
5554 Vantage Vista Dr.	Structure-to-structure fire spread with high exposure	The neighboring primary structure immediately to the east, 5548 Vantage Vista Drive, had ignited prior to 5554 Vantage Vista Dr and was an exposure concern for 5554 Vantage Drive. First responders tried to defend and contain the exposure, but were unsuccessful. 5554 Vantage Vista Drive was "too far gone," as 5548 Vantage Vista Drive was in the process of collapsing.
6445 Ashton Park Pl.	Structure-to-structure fire spread with high exposure	The exposure from 6455 Ashton Park Place caused smoking on the north side of the house. First responders attached to a hydrant, attempting to defend 6445 Ashton Park Place with fire hoses but were unsuccessful.

11.2.7 Containing or "Boxing in" the Fire

The defensive actions identified were very successful in containing or "boxing in" the fire around identified boundaries. Smoke inhalation by first responders from burning of urban fuels, particularly primary structures and their contents, was identified as an issue. In the northern end of MSC, the fire was prevented from spreading to the east of Flying W Ranch Road between Manning Way and Moorfield Avenue. In that area, fence ignitions were contained, and ignited structures contained or extinguished.

Similarly, the fire was prevented from spreading to the neighborhood south of Chipeta Elementary. The fire was also contained to the west of Centennial Boulevard through extinguishment of at least two known spotting locations. Additionally, the fire was also contained at Courtney Drive, Rossmere Street, Kirby Court, and Flying W Ranch Road. The "boxing in" through first responder actions can also be seen in examination of Map Figure 28 through Map Figure 33.

11.2.8 Destroyed Structures Unsuccessfully Contained

This category of defensive actions refers to structures where containment efforts were unsuccessful and fire spread and destroyed adjacent primary structures. A total of 16 primary structures were identified in this sub-category and are portrayed in Map Figure 33. These 16 primary structures include the eight outlined in Table 19. Out of the 16 primary structures that were unsuccessfully contained, failures in 12 cases were associated with structure-to-structure fire spread and high exposures associated with high structure densities.

11.2.9 Mop-up (cooling down foundations)

Mop-up operations started in the late hours of Tuesday, June 26, and continued for several days after the fire moved through MSC. It is difficult to discern between containment and mop-up as the two defensive actions have similar objectives in preventing fire spread. It should be noted, however, that two primary structures were identified as being on fire in the morning of June 27.

At 08:30 on June 27, 5437 Lions Gate Lane had an attic fire that was successfully extinguished. Similarly, at 08:00 on June 27, the deck posts on the back deck of 5020 Lanagan Street were observed to be on fire. The observation was made by a mutual aid engine leaving the incident and was reported to the CSFD structural task force. It is not known when these two structures ignited. These two incidents illustrated that structures remained vulnerable to ignition in the WUI over twelve hours after the initial wildland fire front had moved through the community.

11.3 Defensive Actions Summary

The data collected and analyzed from MSC has identified the spatial representations of defensive actions at a parcel and structure level. Table 20 summarizes the defensive actions in MSC. In total, from the TDs, defensive actions were identified on 324 structures in this report.

It is impossible to give an exact estimate of the percentage of defensive actions captured through this effort, compared to the total actions conducted. Nonetheless, the spatial representations present in Map Figure 28 through Map Figure 33 are believed to portray the general extent of actions and efforts required to stop structure-to-structure fire spread at the Waldo Canyon Fire. The list of defended structures will increase as additional analysis of images and video are conducted in the future. It should also be emphasized that the data discussed in this report does not emphasize mop-up activities.

At a parcel level, 245 parcels were identified as defended, with 180 of them specifically identified as having received parcel level fire suppression activities. The uncertainty associated with parcel level defensive actions are expected to be significantly larger, due to issues identified above, and cannot be quantified given the data available. This is based on the amount of cross correlated data provided and the known gaps in the information provided.

Table 20 Defended and undefended structures by damage status.

Status and Defensive Action	Structures
Undamaged and Defended	154
Damaged and Defended	94 (93 %)
Damaged and Undefended	7 (7 %)
Extinguished Successfully	94 (75%)
Extinguished Unsuccessfully	32 (8 UE&SC + 24 UE&UC) (25 %)
Contained Successfully	60 (79 %)
Contained Unsuccessfully	16 (21 %)

Defensive actions on damaged primary structures were identified with 93 of them identified as defended. There were 24 unsuccessful extinguishments of structures that occurred where the fire was successfully contained yielding an extinguishment success rate of 75 % (94/126). Additionally, 154 structures were defended to prevent structure ignition.

Containment of a structural fire is a function of resources available, exposure, ignition potential of the surrounding structures, structure separation, vegetative and other fuels, and environmental conditions. Sixty structure fires were successfully contained and 16 were not, yielding a containment success rate of 79 % (60/76). The first responders, therefore, stopped the fire from spreading beyond fully involved structures at 60 different locations, at least.

Without the above information, evaluation of hazard mitigation effectiveness at a structure level would be unreliable if the assumption was made that structures were undefended. Assessment of hazard mitigation effectiveness at the parcel level is difficult due to the lack of burning time information for vegetation, compared to primary structures. Two structures were identified as being on fire in the early morning of June 27, and hotspots remained an issue well past that time. In order to address the re-ignition/flaring up potential across MSC, patrolling and cooling of foundations lasted for several days after the last structural ignitions.

The data collected demonstrated that the overall containment objectives were achieved, and fire was “boxed in” both around Courtney Drive and Ashton Park Place and around Majestic Drive. Changes in wind both helped and hindered the containment actions in these areas. Wind negatively impacted fire containment in two ways. First, it enhanced the burning of the structures on fire and enhanced ember transport and possibly ember generation and secondly it impacted fire suppression by affecting hose stream reach. First responders observed that against the wind, fire hoses and deck guns had much reduced reach, thereby affecting what could effectively be defended.

Changes in wind speed also reduced structure to structure fire spread. This is evident in many locations including northern Courtney Drive, as shown in Figure 39. On this northern side of Courtney Drive structure-to-structure fire spread occurred very rapidly before the wind change. After the wind change, only two structures were ignited in over 1.5 h. Also, fire became embedded in Southern Majestic Drive a second time, as shown in Figure 44, in three separate locations after the wind change. Additionally, it took over an hour before any defensive actions were initiated on southern Majestic Drive, even when the apparatus were at peak deployment. The above highlights three important concepts:

1. It is extremely difficult to respond rapidly and safely to moderate to large fires such as the Waldo Canyon Fire.
2. Even at full deployment, fire can become embedded in a high density, low structure separation distance community before first responders are aware and capable of mounting a safe defense.
3. Methods to increase situational awareness are required to improve the response time to initial ignitions in WUI communities.

It should be noted that for all three concepts above, additional research is needed to safely implement any changes in existing defensive action and tactics.

The extent of defensive actions directly on structures and parcels highlights the fact that the post-fire environment, as also seen during the Witch/Guejito [27] and Amarillo [20] fires case studies, is the result of the interactions between local exposure, ignition potential, and defensive actions. The fact that defensive actions are almost ubiquitously ignored or assumed to not happen in historic post-fire assessments puts into question almost all previous knowledge about the effectiveness of current hazard mitigation guidance derived from post fire assessments. This is particularly the case when extensive documentation of defensive actions and local exposure conditions are not rigorously and extensively documented as seen in Table 21.

The absence of indicators, such as of white or burn patterns, and confirmed containment actions is evidence that post-fire assessors may not be capturing certain defensive actions. Table 21 shows reports and post-fire examination recommendations that demonstrate post-fire assessors missing defensive actions. Most of these missing defensive actions appear to be in post-fire assessments that are based on conclusions of field assessments or discussions with first responders alone. It is strongly recommended that scientific post-fire assessments focus on integration of all available data and assess the available data in context of its ability to produce conclusions based on well-founded case studies with adequate data.

Table 21 Examples of studies and training materials where defensive actions were missed.

Study or Training Material	Description of Missed Defensive Actions
Lessons Learned from Waldo Canyon: Fire Adapted Communities Mitigation Assessment Team Findings[15]	In cases examined, it was assumed no defensive actions occurred. Defensive actions are identified at every location as shown in Map Figure 28 through Map Figure 33.
MEGA FIRES: The Case for Mitigation [28]	Defensive actions are not mentioned in this report. Post-fire imagery shows clear evidence of lack of white ash in locations where the fire stopped, as shown in Appendix L.
Examining Home Destruction by Wildfire in The Wildland Urban Interface [29]	Though not conclusive, there is potential evidence of defensive actions being missed in this video as shown in Appendix L.

11.4 Defensible Space and High Density Primary Structures

The basics of defensible space and the primary structure ignition zone outline structure protection using the Home Ignition Zone (HIZ) concept, with the first zone encircling the structure and all its attachments for at least 9 m (30 ft). [30] The Firewise community fire hazard mitigation program states that the 9 m (30 ft) [30] number comes from the minimum distance, on flat ground, that a wood wall can be separated from the radiant heat of large flames without igniting. In California, the California Department of Forestry and Fire Protection (CAL FIRE) recommends a 30.5 m (100 ft) defensible space, "Creating and maintaining defensible space around your home can dramatically increase your home's chance of surviving a wildfire and improves the safety of firefighters defending your property." [31]

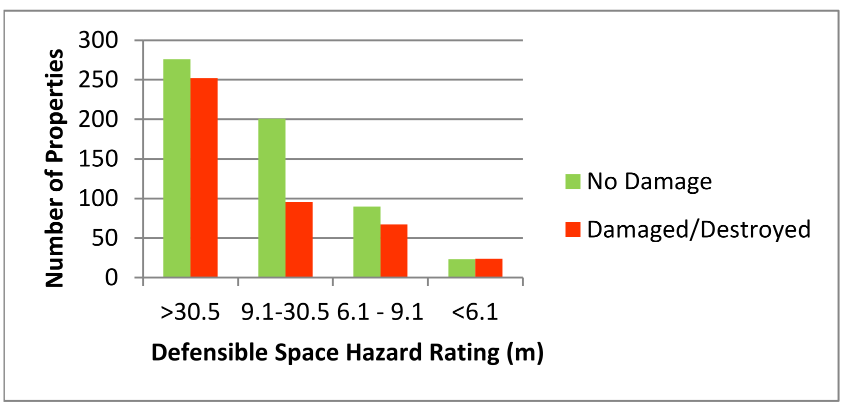

Figure 53 Counts of select properties with primary structures by hazard rating and structure response.

According to CSFD, "Defensible space refers to that area between a house and an oncoming wildfire where the vegetation has been modified to reduce the wildfire threat and to provide an opportunity for firefighters to effectively defend the house. Sometimes, defensible space is simply a homeowner's properly maintained yard." [32]

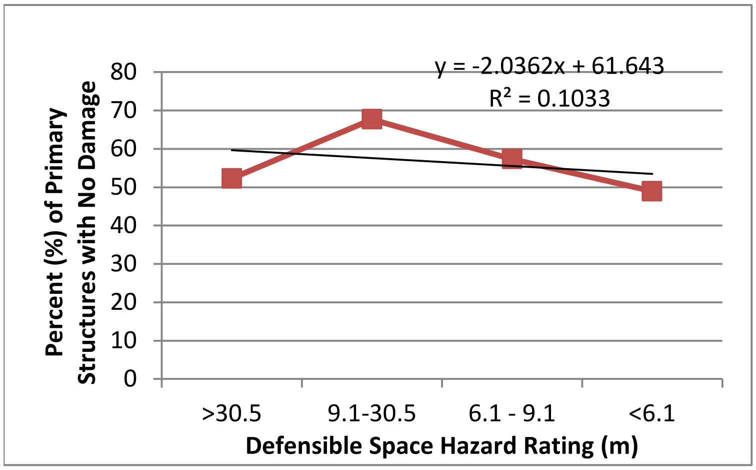

Figure 54 Percent primary structures with no damage by defensible space rating for select properties with a primary structure and a rating.

In all three cases, the defensible space approach attempts to reduce fuels and enable first responders to safely access areas around structures. Additionally, it should be noted that reducing fuels reduces the fire intensity and can alter fire behavior, under certain conditions, from a crown fire to a slow creeping fire that is easier to defend. Map Figure 34 portrays defensible space pre-fire ratings from the Colorado Springs WUI Mitigation Advice. [33] [xxi] Figure 53 shows the distribution of pre-fire defensible space hazard ratings of primary structures in response to the Waldo Canyon Fire. Figure 54 shows the percentage of primary structures not damaged or destroyed by the Waldo Canyon Fire by hazard rating category.

Examination of Map Figure 34, Figure 53 and Figure 54 demonstrates the failure of current concepts of defensible space at certain areas affected by the Waldo Canyon Fire and the failure of the HIZ concept. The figures and tables referenced above do show an expected relationship for primary structures with "No Damage", in that, as the defensible space goes down, the number with "No Damage" also goes down. The relationship between hazard rating and damaged/destroyed primary structures is not anticipated, as the number of damaged/destroyed primary structures would be expected to increase as the defensible space was reduced. Viewed in combination, as would be appropriate, Figure 54 shows a general pattern of decreased survivability as defensible space becomes less, except at the "> 30.5 m (100 ft") category, though the relationship is not strong.

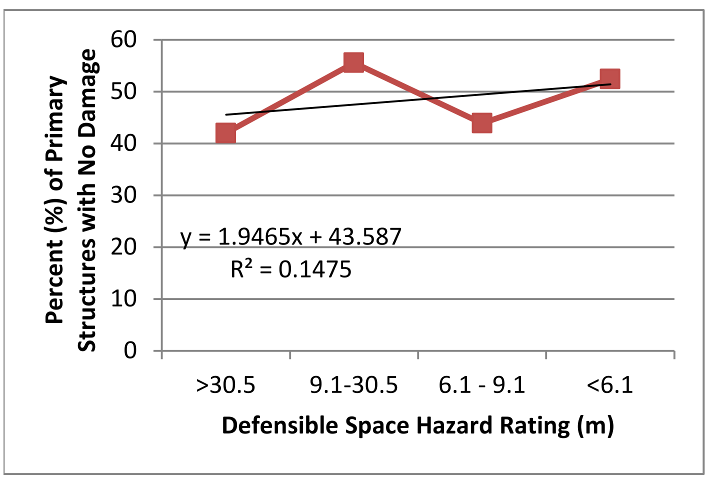

Figure 55 Percent primary structures with no damage from the Waldo Canyon Fire by defensible space rating for all properties with a primary structure, a rating and no defensive actions as identified in this report.

[xxi] Not all properties had hazard data provided.

The reason for the decreased percentage of primary structures with no damage in the "best" defensible space rating category is the destruction on Majestic Drive and Courtney Drive. These areas did not have defensible space evaluations that considered the hazard and consequences of the fire becoming embedded in the community. The information presented in Map Figure 34, Figure 53 and Figure 54, however, does not account for defensive actions or exposure, which might change the results shown in Figure 54, possibly resulting in an inverse or flat relationship between defensible space, as rated pre-fire using the CSFD protocol, and structure response to the Waldo Canyon Fire. This type analysis will be conducted in a follow on report, similar to the second Witch/Guejito report. [10]

This is demonstrated through a simple exercise where those properties with defensive actions are removed from the populations, shown in Map Figure 34, Figure 53 and Figure 54. The percent of primary structures with no damage are then plotted by defensible space rating, as shown in Figure 55. Next, the set of properties with defensive actions is examined and the percent of primary structures with no damage from the Waldo Canyon Fire are plotted by defensible space rating, as shown in Figure 56.

As can be seen in Figure 55 and Figure 56, the relationship between increased defensible space and primary structure response to the Waldo Canyon Fire when only considering those primary structures that were not defended or only those defended, is the opposite of what would be expected. Again, there is not a strong relationship, but even a flat relationship is not anticipated given current beliefs in the HIZ and defensible space concepts. Further analysis is required, but certain points are evident from examination of Map Figure 34 and Figure 53 through Figure 56.

To begin, as mentioned above, there is an obvious limitation of the defensible space concept in accounting for the hazard to primary structures of other burning primary structure(s). There was video evidence of burning structures igniting other burning primary structures over 80 m (262 ft) away, though in a down slope direction, and some evidence of burning primary structures igniting other structures up to 300 m (984 ft) away. The inability of first responders to defend large conflagrations in high density areas is also clearly not recognized in current definitions of defensible space.

As described above, the ability to defend high density primary structure areas is dependent on wind direction and magnitude, among other things (i.e., exposure). Also highlighted above is how rapid the fire could become embedded in high density primary structure areas, such as southern Majestic Drive, even at peak deployment of resources, thereby resulting in new concepts of defensible space with focus on defense of structural fuels. Less obvious from the above information is the failure of current definitions of defensible space to account for hazards beyond the traditional 9.1 m (30 ft) to 30.5 m (100 ft).

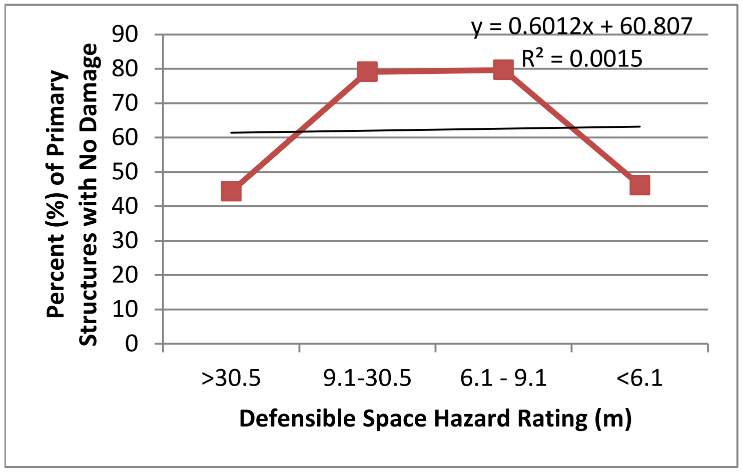

Figure 56 Percent primary structures with no damage from the Waldo Canyon Fire by defensible space rating for all properties with a primary structure, a rating and a defensive action.

For example, Map Figure 35 shows pre-fire defensible space ratings overlaid on slope for northwestern MSC. In this area many of the defensible space ratings reflected the fact that steep slopes (>20°, as shown in Map Figure 35) approached close to the primary structure, thereby resulting in a small area for defense. Early ignitions could be seen in some of these locations, with steep slopes and low amounts of defensible space, such as on Wilson Road, Jenner Court. Conditions were also similar on Trevor Lane and Talleson Court, where at least one early ignition was known. In these locations defensible space was difficult to create due to steeper slopes beyond a relatively short distance around the primary structure.

Locations on Wilson Road, Trevor Lane, Talleson Court, and Jenner Court demonstrate areas of poor defensible space due to higher potential fire and ember exposures. These high exposures were in part due to the arrangement of fuels and slopes. While a number of these factors and conditions were identified by CSFD pre-fire mitigation assessment, early ignitions in these areas made these areas more difficult to defend.

As shown in Map Figure 35, the lack of accounting for hazards beyond 9.1 m (30 ft) or 30.5 m (100 ft) from the primary structures is evident on Majestic Drive. Northern Majestic Drive, particularly those areas adjacent to Flying W Ranch Road, had defensible space ratings greater than 30.5 m (100 ft), (i.e., the "best" rating possible). The slopes to the west of this Majestic Drive area were relatively small, within 150 m (500 ft) of the closest primary structures on Majestic Drive. The topographic and fuel configuration coupled with the prevailing winds at the time of the fire resulted in the changes in exposure (higher exposures in northern Majestic compared to the area north of it) as seen in scorched vegetation as shown in Figure 57.

In areas directly downwind of the canyon, the vegetation along the east side of Flying W Ranch Road was scorched while adjacent areas on either side of the canyon were not scorched, except those downwind of the destroyed structures. The severe exposure shown in Figure 57 was witnessed by a first responder parked somewhere south of Lanagan Street at the approximate time the fire moved through the canyon and described as a "gigantic gas torch coming across the road (Flying W Ranch Road)". This highlights how conditions greater than 45.7 m (150 ft) from the primary structure can have consequences for structure response to wildland fire and the ability of first responders to defend the primary structure.

Furthermore, the above provides evidence on how fire behavior can be affected by topographic conditions other than steep slopes. In high structure density settings such as those found on Majestic Drive, adjacent to wildlands, with topographic configurations that can generate high exposures, the Fire Adapted Communities [34, 35] use of fuel breaks external to the community might be necessary to prevent the fire from reaching the community. This may be necessary as the approach of allowing the fire to enter the community might yield unacceptable losses.

There are many types of defensible space. A location might be defensible from far field ember spotting but not adjacent wildland burning. This was evident in locations off of Regal View Road that had a defensible space of less than 6.1 m (20 ft). These areas had steep slopes to the south, which would have resulted in space that was not defensible if fire spread came from this direction. These areas were defensible from ember attack as evidenced by the numerous defensive actions in this location as shown in Map Figure 29. Finally, it must be pointed out that ultimately, that TDs with first responders confirmed that not all of MSC was defendable from the passage of the main Waldo Canyon Fire front due to severe fire, ember and smoke exposures.

11.5 Defending High Density Primary Structures

High densities of low separation distance primary structures located adjacent to wildlands with dangerous topographic configurations posed significant threats at the Waldo Canyon Fire. As evidenced by ignitions in some locations on Majestic Drive, these areas were prone to higher densities of early ignitions from the passage of the main fire front. Also, these areas basically had no defensible space during the passage of the main fire front allowing no possible defense by first responders. Subsequently, these high density areas of low separation distance primary structures also presented significant challenges to first responders.

In the Waldo Canyon Fire, containment failures occurred primarily in two areas, Majestic Drive and Courtney Drive/Ashton Park Place. These two general areas contained the highest densities of primary structures with the lowest separation distance of any of the areas in MSC affected by the Waldo Canyon Fire. The difficulty of containing fire spread once it became embedded in these areas is evident in Map Figure 33, showing 11 (69 %) of the failed containment actions occurred in these two areas. Eight failed containment actions occurred in the southern end of Majestic Drive, where the high density of low separation distance primary structures was evident.

The initial failed containment in these two neighborhoods resulted in success in adjacent properties only when additional resources were added. In all cases, the containment actions occurred after the change in wind direction, which caused the fire direction to begin moving in the direction where containment actions ultimately occurred. Without the change in wind direction, the fire would likely have not spread as quickly.

The change in wind direction also appeared to be accompanied by a reduction in wind magnitude. It was possible this reduction in wind magnitude resulted in the ability of first responders to contain the event in areas such as southern Courtney Drive and Ashton Park Place adjacent to Yankton Place, compared to inability to contain the event on eastern Courtney Drive when wind direction was from the west and wind speeds were thought to be higher. This cannot be directly compared, however, because no containment actions on Courtney/Ashton Park Place occurred before the change in wind direction. Furthermore, there was evidence that the change in wind direction caused significantly more destruction on Majestic Drive than would have occurred without the change in wind direction, even with a reduction in wind magnitude.

Successful operations in high density housing also occurred at Via Verona, Regal View Court, Chase Point Circle, Moorfield Avenue, Savannah Way, Manning Way, and other locations. At least in Via Verona, some of the ember exposure occurred late in the night, and first responder resources were on the scene successfully preventing any ignitions of structures.

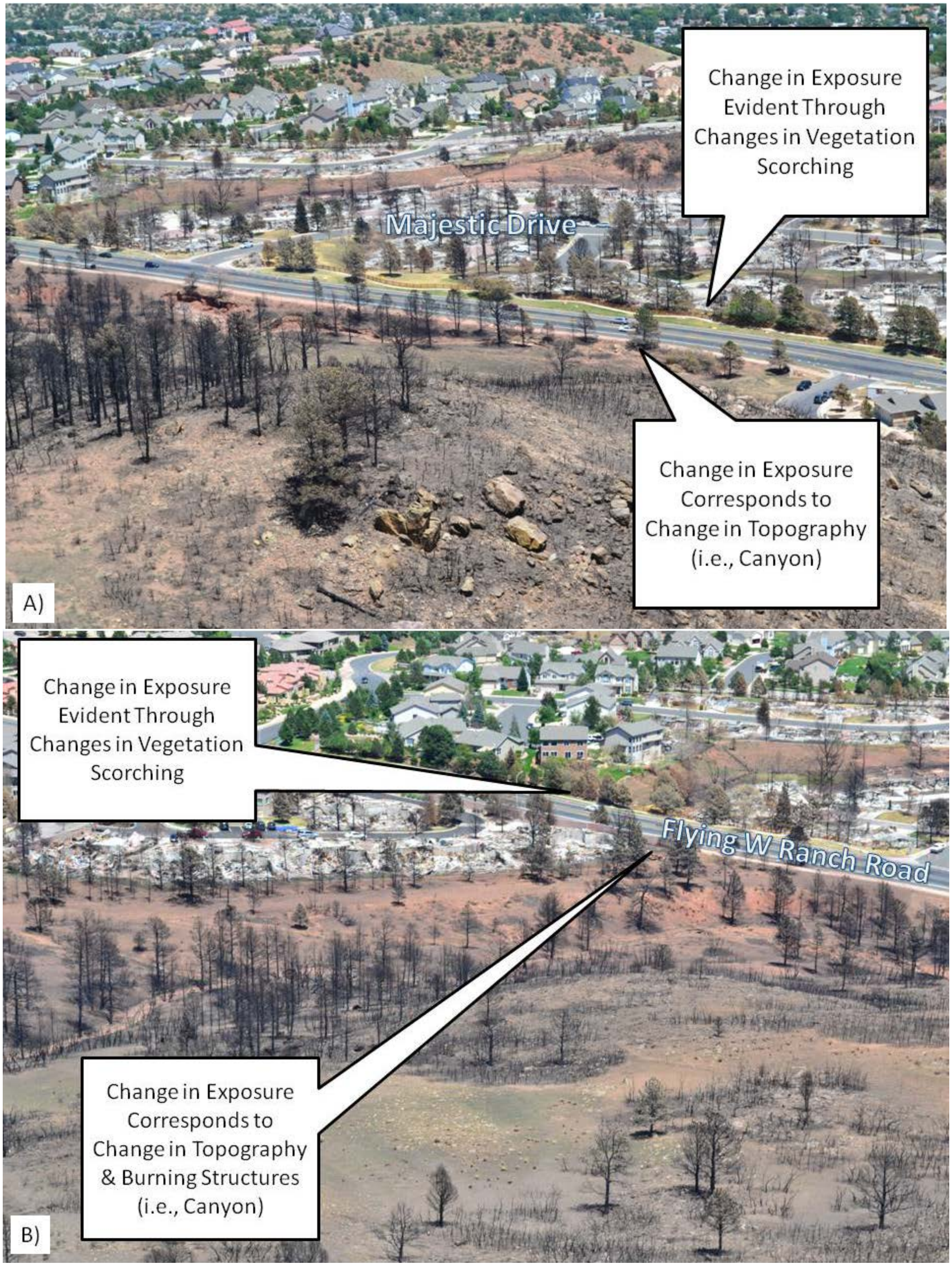

Figure 57 Changes in exposure conditions evident through changes in scorching to vegetation corresponding to areas across from a canyon and burning structures. Looking east to northeast. NIST Photos

Though ember exposures could not be directly compared, it should be noted that the Flying W Ranch Road side of the Via Verona structures had a metal fence resting on a masonry wall limiting the potential impacts of embers from the west side of Flying W Ranch Road, as compared to the combustible fences along the structures between Moorefield Avenue and Manning Way. Nonetheless, these high density locations of low separation distance between primary structures, where limited numbers of primary structures were damaged/destroyed, all saw early suppression of ignitions with a combination of high water applications and low water or hand tools applications.

There are two primary reasons ignited structures are not defended in a WUI scenario. Structures are not extinguished because insufficient resources are available, or structures are not extinguished because of the very high fire and/or ember exposure they receive. A possible solution to the first issue is more rapid and effective safe response (see section 12.0 of this report). It was not clear this was possible at the Waldo Canyon Fire, except maybe in hindsight, knowing what the fire would do. A second solution is reduction of hazards and removal of vulnerabilities. Understanding WUI hazards and vulnerabilities is in its infancy.

The very high exposure can be associated with three primary and possibly interrelated components. Local high exposure can be a result of extensive exposure from a combination of fuels, topography, and local weather. When looking at the fuel component of high exposure, vegetative fuels burn relatively quickly compared to residential structures that can generate high exposures (particularly in a high wind environment) for a long duration. In high wind scenarios, defensive actions in high exposure environments become ineffective and in some cases dangerous for first responders. The two potential approaches to limit high exposure conditions are to:

1. Prevent fire from getting into environments that will yield high exposures by either creating fuel breaks or fuel treatments around high structure density areas, coupled with reduction of vulnerabilities.
2. Prevent fire from starting structure to structure fire spread when it is safe to do so.

Obviously, a combined approach that has correct information on exposure risks and vulnerabilities would be ideal.

Effective fuel treatments [xxii], when implementable, around these high structure density areas, can address the above needs by:

1. Reducing fire and ember exposures to the community.
2. Making the environment tenable for first responders. This can enable first responders to remain (not evacuate) and rapidly suppress any ignitions (both structural and vegetative) early, therefore preventing fire from becoming deep seated and eliminating/limiting the hazards associated with multiple structures burning in close proximity.

[xxii] Performance standards are needed for the quantification of effectiveness of fuel treatments.

This approach represents a paradigm shift from the approach of accepting that fire will burn through the community. [xxiii] Research is needed to further define the above described exposure scenarios and create safe, reliable and implementable WUI mitigation strategies and firefighting SOPs to reduce structural loses.

12.0 First Responder Deployment Timeline and Structure Ignitions

It was identified that seven separate staging areas were assembled as the fire approached and entered MSC. These staging areas, along with other event coordination centers, are listed in Table 22. CSFD activated Fire Department Operations Center (FDOC), whose primary mission was to back fill the City's fire stations. Additionally, the City activated the Emergency Operation Center, whose primary mission, along with Colorado Springs Police Department, was to develop evacuation zones and management action points, based on fire behavior.

Mutual Aid was coordinated both through the CSFD and El Paso County. County resources and County activated Mutual Aid were staged at the County Fire Station on Cimarron Street, while mutual aid responding to the City's request staged at the other staging areas. Communications between CSFD and mutual aid about needing or accepting mutual aid resources were hindered by situational awareness. Table 23 summarizes the number of primary structures known to be on fire and the number of apparatus in MSC at 18:30, 20:30,and 23:00; one, three hours and four and a half hours after the arrival of the wildland fire front.

Table 22 Command posts, staging and IC posts.

Location	Date Started	Date Ended
Safeway Colorado Blvd and 31st Street	6/23/12	6/24/2012
Verizon(MCI) Garden of the Gods and 30th Street	6/26/12	7/1/2012
Fire Station 9 622 W Garden of the Gods	6/26/12	7/1/2012
Fire Station 18 6830 Hadler View	6/26/12	7/1/2012
Tiffany Square I-25 and Woodmen Road	6/26/12	6/27/2012
Holmes Middle School mobile command	6/23/12	7/1/2012
Coronado High School staging and accountability	6/24/12	6/29/2012
University of Colorado, Colorado Springs (UCCS)	6/24/12	6/25/2012
Cheyenne Mountain High School Cedar Heights shelter	6/23/12	7/1/2012

At 18:30, 74 structures were identified as ignited or burning, 268 identified as not burning and an additional 104 with an unknown burn status. The number of burning structures ranged from 55 to 119 (see Table 23), and given all the available data, it was estimated that the actual number of burning primary structures at 18:30 was close to or less than 91. In contrast, 120 min later, there were 217 confirmed structures on fire, 30 not burning and an additional 167 of unknown status. Similarly, given all the data available, it was estimated that the number of burning primary

[xxiii] Preparing structures using Firewise or similar principles may not yield all the benefits necessary to limit fire spread in high structure density areas.

structures at 20:30 was above 277. By 23:00, the number of ignited and/or burning structures ranged from 435 to 445. The above structure ignition values indicate that in this case, there was a 4.9:1 (91/445) multiplier between the estimated structures ignited in the first hour and the total number of known structure ignitions. If the high density structural losses of Majestic Drive and Ashton Park Place/Courtney Drive are removed, the multiplier between early ignitions and total ignitions was reduced to 2.7:1. [xxiv]

Table 23 Primary structures burning and apparatus in MSC as a function of time.

Time	18:30	20:30	23:00
Ignited/burning	55-119	248-286	435-445
Not burning	267	30	0-10
Ignition Unknown	64-96	129-167	0-10
Apparatus in MSC	37	63	64

Figure 58 depicts the number of first responder apparatus in MSC from 15:40 June 26 to 04:00 June 27. The lines represent the total apparatus that entered the community (in red) and the net apparatus (in blue) that was in the community at any time. The difference between total and net apparatus is in part associated with equipment moving to the north towards the Peregrine area and equipment that was dispatched to scout, in order to enhance situational awareness. The dip in the blue line at 17:20 represents the evacuation of first responders when the fire reached the community and the plume leaned/collapsed. The figure illustrates that it took until 19:20, or two hours for the apparatus count to reach 60. The apparatus peaked at 78 early in the morning of June 27, with the arrival of the last mutual aid task force. One hour after the fire reached MSC, there were 37 first responder apparatus in the community, and two hours after the fire reached the community, there were 63.

Figure 58, as constructed, does not account for departures of apparatus from the community for refueling and crew swapping purposes. Additionally, the values presented included all apparatus, such as trucks and command vehicles, and were not limited to firefighting engines and brush trucks. Appendix F contains the apparatus identifiers, and when each specific apparatus arrived and left Mountain Shadows. The partial second evaluation only affected two apparatus and is identifiable in the appendix.

[xxiv] 445 total number of ignited primary structures, 195 destroyed in the two listed areas resulting in 91/250 multiplier.

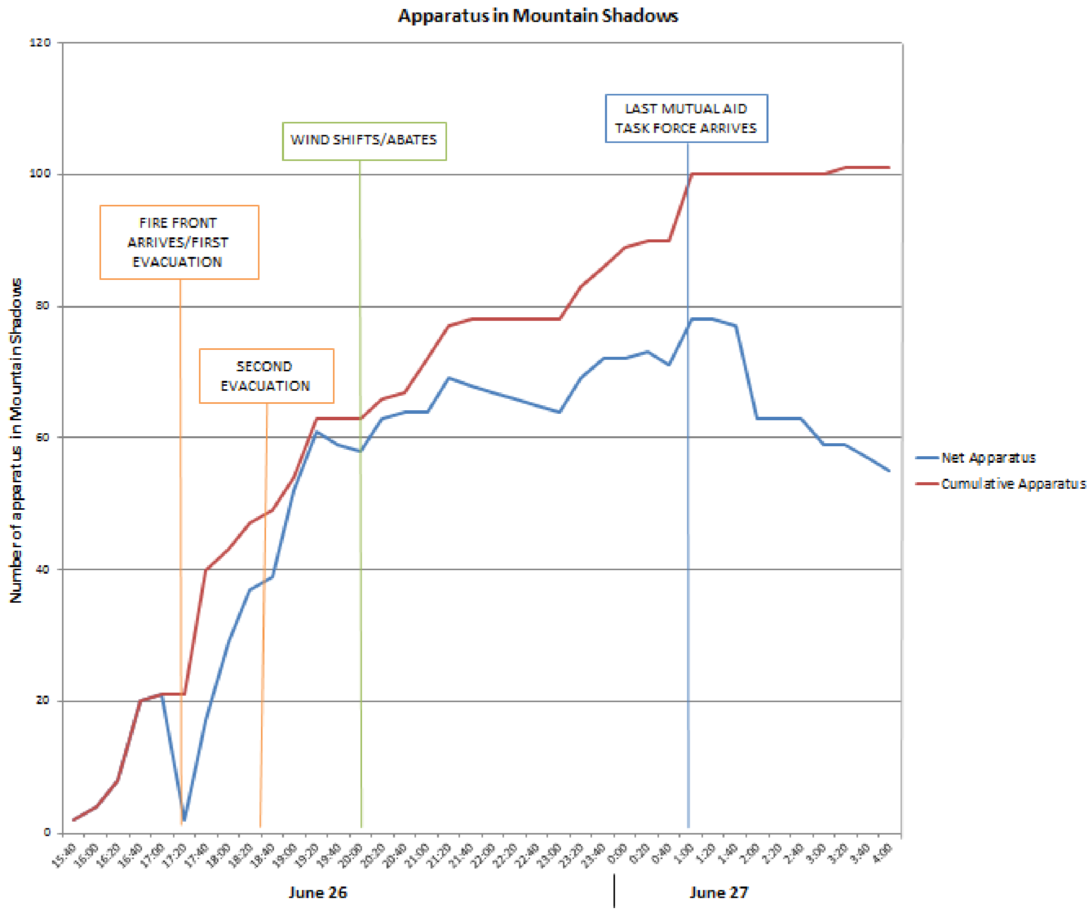

Figure 58 Apparatus in Mountain Shadows Community from 15:40 June 26 to 04:00 June 27

13.0 National Incident Management System and Incident Command System

The infrastructure framework for the response to the Waldo Canyon Fire at a Federal, State and Local level was NIMS (National Incident Management System) and Incident Command System (ICS). ICS has its origins in the "1970 California Fire Siege" when, during a course of 13 days, 773 wildfires destroyed over 700 primary structures and killed 16 people. [xxv] Three fires, the Clampitt, Wright, and Agua Dulce fires burned a combined total of 157 058 acres and destroyed 183 out of the 700 total primary structures. The Laguna fire, which started the next day, destroyed another 382 primary structures, killing eight civilians and burning 175 425 acres.

[xxv] The concept of ICS was developed more than fourty years ago, in the aftermath of a devastating wildfire in California. Although all of the responding agencies cooperated to the best of their ability, numerous problems with communication and coordination hampered their effectiveness. As a result, the Congress mandated that the U.S. Forest Service design a system that would "make a quantum jump in the capabilities of Southern California wildland fire protection agencies to effectively coordinate interagency action and to allocate suppression resources in dynamic, multiple-fire situations." - Source http://www.fema.gov/txt/nims/nims_ics_position_paper.txt

NIFC [xxvi] reports that the Laguna fire burned 366 primary structures in 6 h. In comparison, the Waldo Canyon Fire burned at least 435 primary structures in 5.5 h.

The Laguna Fire Analysis demonstrates the first component of fire resources, namely availability. The Laguna report states that "manpower and equipment orders to meet predicted needs were slow in being filled due to the manpower and equipment drain caused by other fires in Southern California. Adequate resources were not fully mobilized until the morning of September 28th.[xxvii] This type of resource limitation can occur during fire sieges such as the 1970, 2003 and 2007 California Fire Sieges or the 2011 Texas Fires.

The second component of effective and efficient response is the utilization of resources, once the resources become available. The analysis of the Waldo Canyon Fire data suggests potential discontinuities of current National SOPs such as the lack of adequate preplanning and staging of resources and the identifications and prioritization of hazards. NIMS is designed to be able to respond to escalating events in terms of incident and response size but operates on a timescale that is commensurate with the behavior of wildland fires that can burn over days or weeks.

The data from the Waldo Canyon Fire show that while the wildland fire burned for many days, the urban losses occurred over a course of a few hours. This is also consistent with the data collected during the Witch/Guejito fires. [27] The data also shows that by following current SOPs critical time may have been lost, and that significant resources, while available at staging, did not get to the fire in a timely manner. The data demonstrates that because of the rapid spread of fire in the WUI, planning of resource deployment should be in place beforehand, as time spent planning during the incident can negatively impact the ability to rapidly contain the fire.

The Waldo data also illustrates the benefits of utilizing structural response Type 1 engines (see Section 11.2.2) , together with mobile readily deployable forces such as those brought to the incident by the USFS. Additionally, the data show that early ignitions (the first hour after the exposure was seen) can have a significant impact on fire behavior and can cause many other structures to burn through structure to structure fire spread. It is this multiplier effect that makes rapid response critical.

Quantifying fire and ember exposure, in absolute terms, from post-fire data, is very unreliable due to the lack of quantitative measurements during wildfire and WUI events. However, a simple two tiered approach is devised here to illustrate effectiveness of defensive actions. [xxviii] High exposure (both in terms of fire and embers) can be defined here as any flame impingement

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[xxvi] http://www.nifc.gov/fireInfo/fireInfo_stats_histSigFires.html

[xxvii] Regional Fire Analysis, Laguna Fire, September 26, 1970, Cleveland National Forest. http://www.wildfirelessons.net/Communities/Resources/ViewIncident/?DocumentKey=7eecfa9e-69d4-4bc3-91ef-ef613976a2e4

[xxviii] This two tiered exposure characterization is being used here to illustrate the effectiveness of first responders. Examples of high exposure are areas near burning wildlands and areas surrounding burning structures. Intentionally, no exact distances or flux values are provided here as they are scenario specific. Additional research is needed to quantify both fire and ember exposures. The high and low exposure approach presented here is a simplification of the NIST WUI exposure Scale.

or convective energy exposure that would cause thermal harm to first responders wearing wildland PPE (fire resistant pants and shirt; not bunker gear). Using the same approach, low exposure can then be defined as any exposure that would not cause any thermal harm.[xxix] It should be pointed out that exposure varies, not only with space, but also with time, and that the high/low definition provided above cannot be used at this time for building construction or any actual mapping of exposure.

Given these limited definitions of exposure, the data illustrates that there are cases, though not quantified in this report, in low exposure environments where small structure ignitions (typically caused by embers) were addressed by first responders with hand tools and/or limited water such as in lower Majestic Drive by the USFS. This finding indicates that in low exposure (as defined here); nimble and readily mobile resources can provide extinguishment of features. In contrast, high exposure environments (as defined here), while potentially more hazardous for first responders require significant resources, both in terms of personnel and water, necessary to control the fire such as on Ashton Park Place or Majestic Drive.

Situational awareness is essential to safely respond to large and multi-jurisdictional WUI incidents. Assessment of the first responder data illustrates that situational awareness was a significant factor in the redeployment of resources. A paradigm shift may be necessary to enable very rapid deployment of resources to safely and effectively fight interface fires, provided the appropriate situational awareness is available.

Data to enhance rapid situational awareness could be needed in order to accelerate the effective deployment of resources. Currently, data is often collected by the deployment of scouts and from lookouts. Remote sensing technologies such as unmanned sensors might provide additional valuable input in certain environments, and could potentially accelerate situational awareness. Communication between local and mutual aid resources was identified as limited, including the finite battery life of handheld radios. Mapping of hazards within and around a community, together with pre-planning for rapid and targeted deployment within the community can improve firefighter safety and provide homeowners with identification of these hazards and ability to possibly mitigate.

14.0 Structure Construction and Parcel Vulnerabilities

The information presented in this section identified recurring structure and parcel level vulnerabilities. As discussed in section 7.0, no detailed data collection was conducted at every parcel within the fire line, so there can be no statistics generated as to the relative performance of vulnerabilities, with the possible exception of roof cover and siding type, which are being examined, but are still limited due to lack of information on other confounding building treatments. For example, data is not available on how many primary structures (destroyed, damaged and undamaged) had wooden decks, so analysis cannot determine what percentage of

[xxix] Respiratory protection must also be addressed, but is not assessed here as limited data is available.

exposed wooden decks ignited, nor whether primary structures with wood roofs also had wood decks.

Additionally, the data presented is not all inclusive, but rather a collection of first responder observations and data extracted from images and video footage. The data presented in this report can be used to identify potential ignition vulnerabilities both at the parcel and structure level. The vulnerabilities presented here point to the need for test methods that utilize realistic exposures. A list of identified damage to building components is tabulated in Appendix K.

14.1 Decks

Three mechanisms of deck ignitions were identified. Decks were ignited by embers and/or fire exposure to their footers (at ground level or some distance above) and/or to their top surface (on the deck or steps), to their underside (deck or steps) or through accumulation of embers in re-entrant corners, for which the deck represents the floor. For most observations of decks on fire, there was some ambiguity in determining if the deck was the ignition source or some item on or around the deck ignited first. Additionally, it was not known for all decks what material and material finishing types were used. Finally, distance of the deck above the ground and amount/type of fuels present underneath the deck were also not known.

14.2 Roofs/Eaves/Attics

Roof assembly fires pose a significant challenge in terms of timeline analysis. Unless very detailed information is available on the fire progression, or only partial damage is present, it is very difficult to determine if a "roof fire" is actually an attic fire that has burned through the roof, a fire that started at the eves and progressed to the roof and possibly into the attic, or a fire caused by ignition of combustibles on the roof (e.g. pine needles). Unless otherwise noted, all roof, attic and eaves fires were recorded as structure on fire.

14.3 Garage Door and Utility Door Trim and Vinyl Window Frames

Some primary structures had confirmed garage door base/trim and utility door trim ignitions. All the identified ignitions were the result of embers accumulating in corners of combustible construction materials on a fine physical scale of centimeters (inches) not meters (ft). There was one reported occurrence of a vinyl window frame melting (the house was not on fire) due to exposure from an adjacent, fully involved structure. The melted frame released the window pane and exposed the interior of the structure to the exposure from the adjacent burning building. In this case the structure was defended and saved.

14.4 Fences

Combustible fences played a significant role in fire spread early in the fire. The area between the northern parking lot of the Verizon/MCI building and Cameo Way/Braeburn Way experienced very light fire exposure from the relatively limited wildland fuels burned in this location. The ignited fences posed a threat to the local structures. In this case, the fences on fire were suppressed by USFS crews using hand tools and small quantities of water.

Similar cases of burning fences threatening nearby structures were also observed in Charring Court, at the south end of Wilson Road, in the area between Moorefield Avenue and Flying W Ranch Road, along with Ashton Park Place. The burning fences not only caused a potential fire exposure threat to adjacent structures but also caused a potential ember exposure threat to downwind structures and other combustibles.

14.5 Railroad TFies

Railroad ties that were used as landscaping timbers were also identified as contributors to fire spread and retention of energy. [xxx] The creosote that is frequently used on these large pieces of wood makes their cooling down with water an intensive process that occupies firefighting resources for a significant amount of time. This was also observed at the Witch/Guejito [10, 27] and Amarillo fires. [22]

15.0 Summary of Technical Findings

The four primary findings from the Waldo Fire investigation 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. Additional issues identified during TDs are presented in Appendix N even though they did not affect the data analysis and primary findings of this report.

15.1 Primary Technical Findings

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

[xxx] In one case railroad ties were found to be smoldering over one week after the Waldo fire reached MSC.

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:
    - 8.1 Imaging of large numbers of burning structures in MSC.
    - 8.2 Documentation of practically all of the first responders' recollections of events in space and time.
    - 8.3 Imaging of MSC by Google Streetview, Bing Maps and the City of Colorado Springs prior to the fire.
    - 8.4 Imaging of MSC two days after the Waldo Canyon Fire affected the community.
    - 8.5 Integrating 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 responder's 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. [xxxi]
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.
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.

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

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 loses.
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, therefore, 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.

16.0 Recommendations

The following are the primary recommendations which are aimed at improving the safety and effectiveness of WUI fire response. An overall paradigm shift in responding to WUI fires is needed:

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.
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 need 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.

17.0 Summary and Conclusions

The primary purpose of this case study is to re-construct the event timeline for burning features and defensive actions in MSC from the Waldo Canyon Fire, describing the quality of data used to perform the reconstruction. Additionally, challenges with WUI mitigation strategies and tactics are highlighted. Improvements to WUI data collection are also highlighted.

The data collected and analyzed here indicates that first responders were effective and extinguished 94 primary structures that had actually caught on fire. Thirty-two primary structures were unsuccessfully extinguished, yielding an extinguishment success rate of 75 %. Seven primary structures were identified as damaged without any identified defensive actions. Additionally, 60 primary structures were successfully contained, and 16 were not, yielding a containment effectiveness rate of 79 %. Overall, the first responders were effective in saving structures and together with the abated wind, were able to “box in” and control the fire when they arrived at the scene.

Over 200 technical discussions with fire fighters captured the spatial extent of the defensive actions aimed at protecting structures. Fire spread and behavior during a WUI fire, and the subsequent loses, involves the interaction of multiple factors including pre-fire mitigation technologies, fire and ember exposure during the fire, and defensive actions. In order to adequately assess the effectiveness of hazard mitigation technologies and/or defensive actions, post fire assessment need to capture all these interactions.

Current concepts of defensible space do not consider hazards of nearby burning primary structures. Concepts of defensible space and the HIZ that only consider the environment within 9.1 m (30 ft) to 30.5 m (100 ft) of structures do not account for hazards present in MSC during the Waldo Canyon Fire up to 150 m from primary structures. High density primary structure areas adjacent to wildlands with topographic features that can increase fire and ember exposure are not considered in current concepts of defensible space. A particular location can be defensible from ember attack yet not defensible from direct fire spread.

The Waldo Canyon Fire posed a significant challenge to first responders on June 26. The fire moved rapidly through MSC. In the first hour after the wildland fire reached MSC, 55 to 119 primary structures were identified as ignited. In the first three hours, 248 to 286 primary structures were already on fire. The majority of destroyed primary structures were burned or ignited by midnight on the June 26.

Existing tactics, while effective for wildland firefighting, might have significant limitations for interface fires such as the Waldo Canyon Fire, where very rapid deployment might be necessary to limit fire spread and structural losses. The data captured the apparatus response timeline to MSC using current SOPs. A paradigm shift may be necessary to enable very rapid deployment of agile resources to safely and effectively fight interface fires. Mapping of hazards within and around a community, together with preplanning for rapid and targeted deployment within the community, can improve firefighter safety and in many cases reduce structural losses. Improved situational awareness is also required during an incident.

Characterizing fire behavior, quantifying structure response, assessing exposure conditions and developing efficient and effective WUI mitigation strategies are in their infancy. It is thought that post-fire assessments alone, particularly given the current state of the art will never be able to individually successfully perform the above characterizations, quantifications, and assessments. Laboratory and field experiments coupled with physics based fire modeling and other new innovations would ultimately be required with all activities integrated around representative fire and ember exposure values.

A new approach to post-fire assessments was used that involves integration of all data including aerial and ground imagery, radio logs , and AVLs and did not just draw conclusions based on field assessments or discussions with first responders. Post-fire assessments should consider defensive actions and attempt to map the spatiotemporal extent of these actions. Collection of all damage information from the fire before moving to assessment of fire behavior or effectiveness of tactics and mitigation would help scientific post-fire assessments in reconstructing the event timeline. The use of aerial and ground imagery with established post-fire assessment techniques would provide forensic evidence to help document post-fire environments in a more comprehensive manner. Mechanisms for first responders to document their activities and upload images of events are required.

In summary, the information generated from this case study can provide input, together with additional research, to improve WUI building and landscaping (construction) codes and standards, and best practices. Extensive research is also needed to provide first responders with effective tools and SOPs. Continued advancements are also necessary in the field of data collection and rapid situational awareness. Only then will hazard mitigation improvements for new constructions and retrofits, together with improvements in firefighting response, reduce WUI structural losses.

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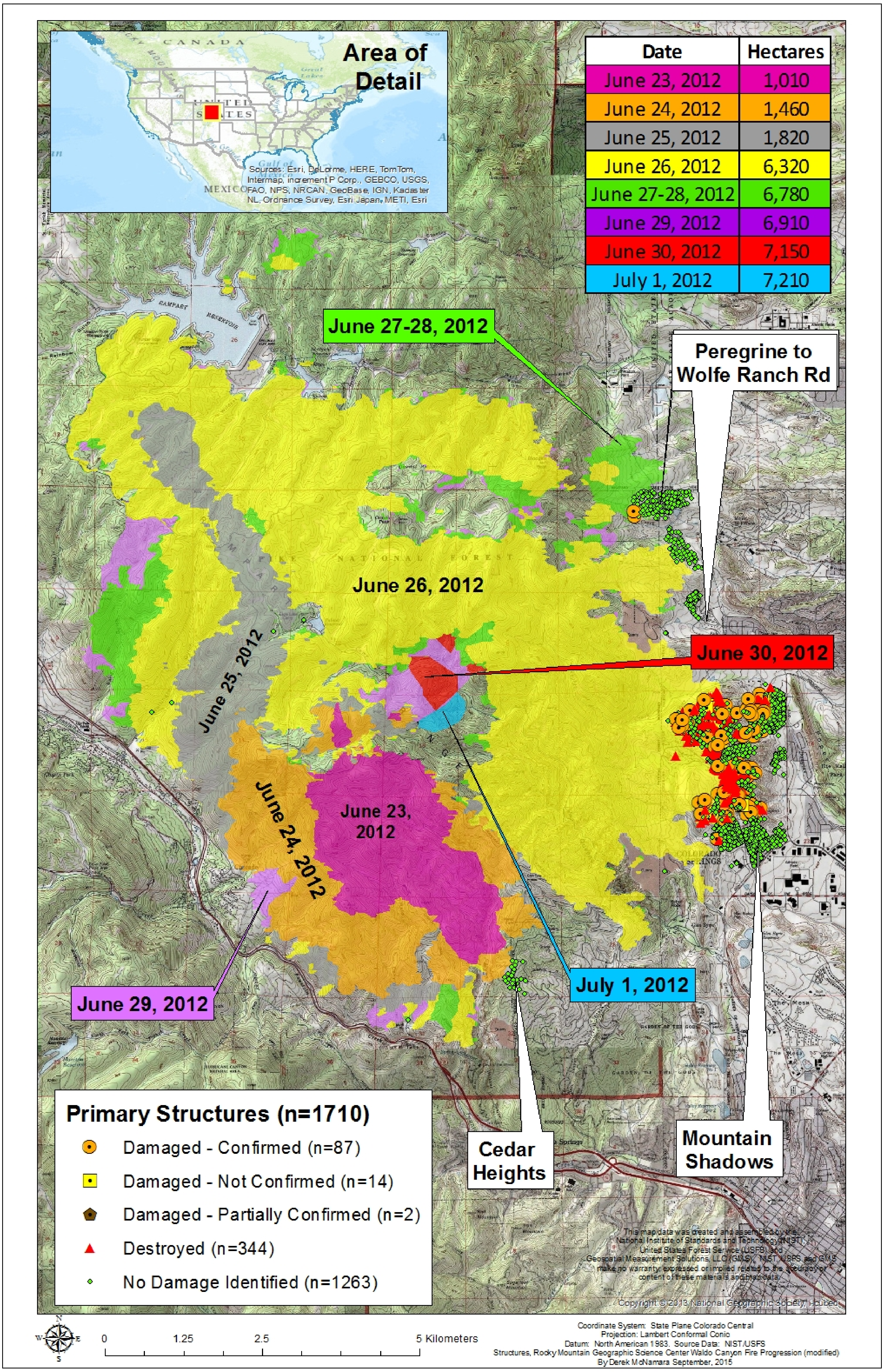
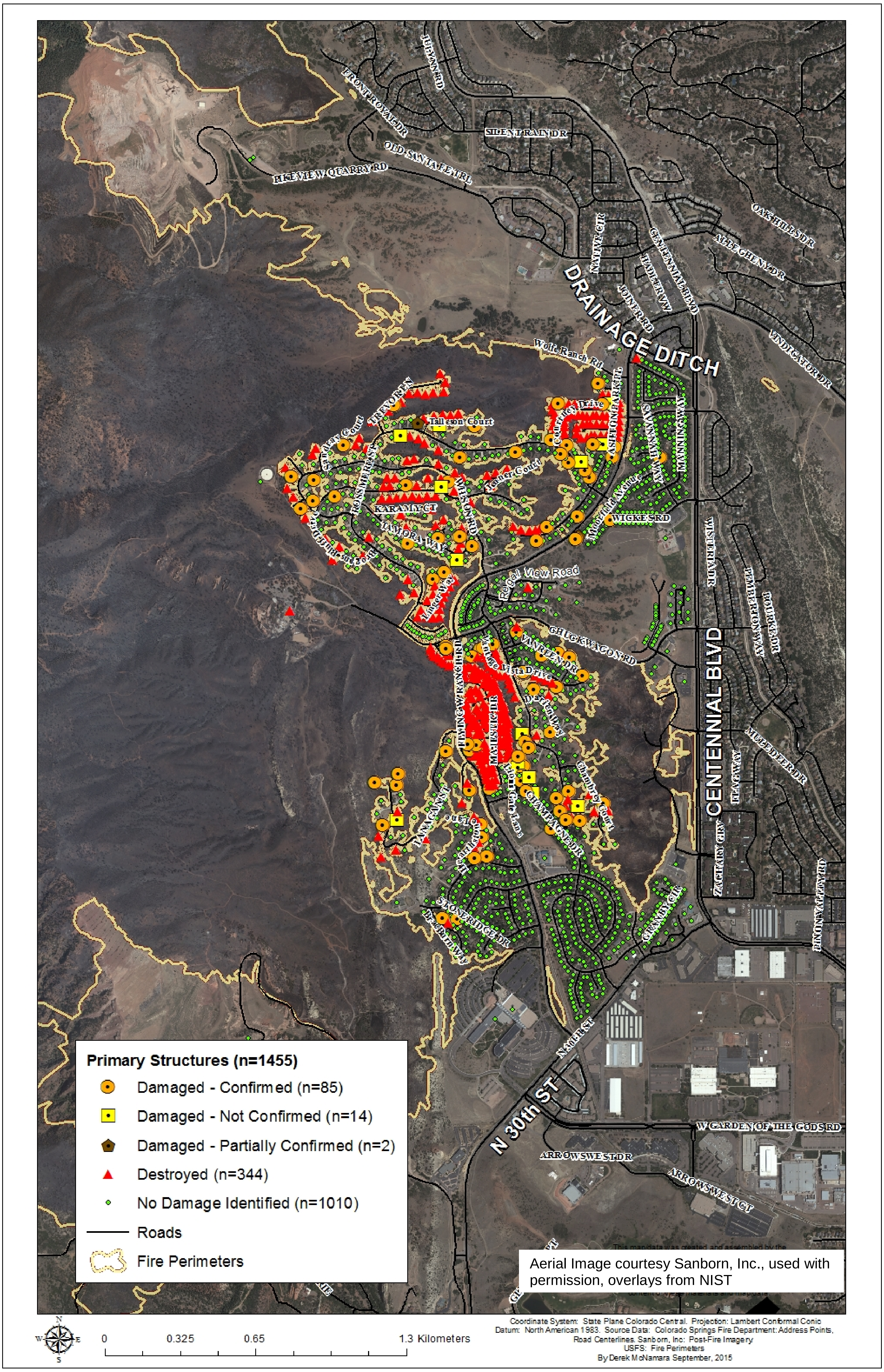
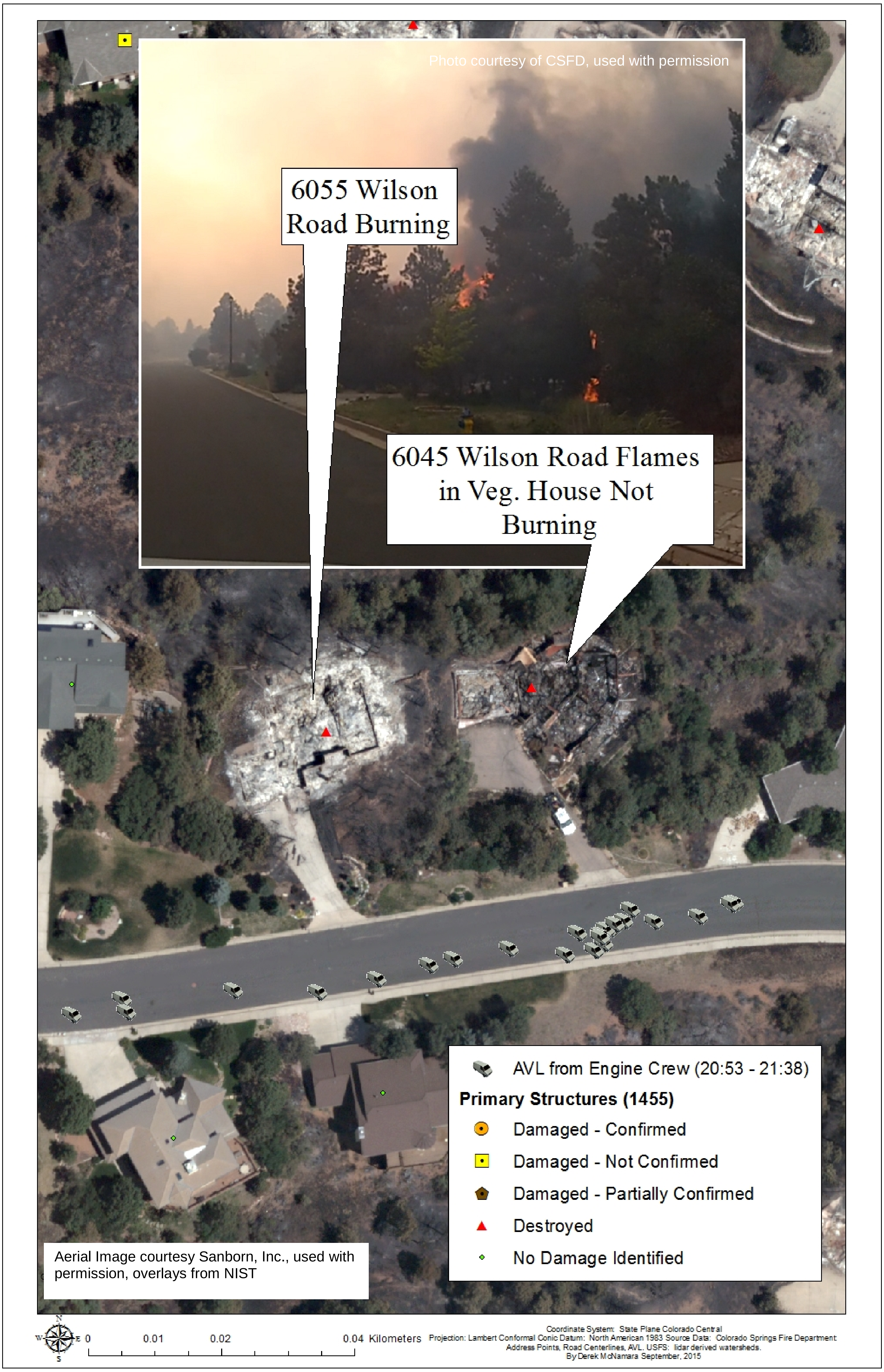
19.0 Map Figures



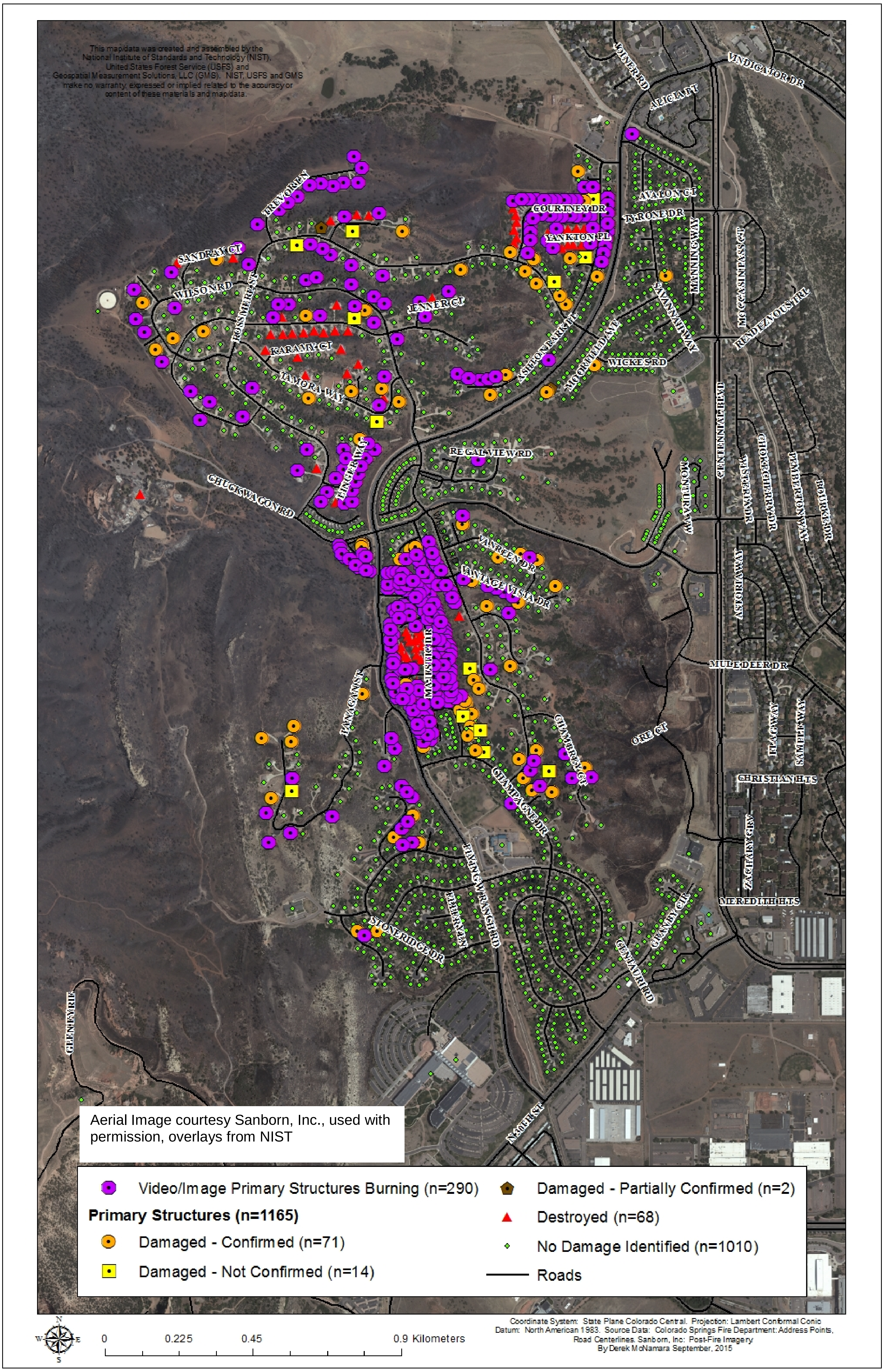
Map Figure 1 Fire progression of the 2012 Colorado Waldo Canyon Fire overlaid on structure response to the fire for primary structures in and around the fire.



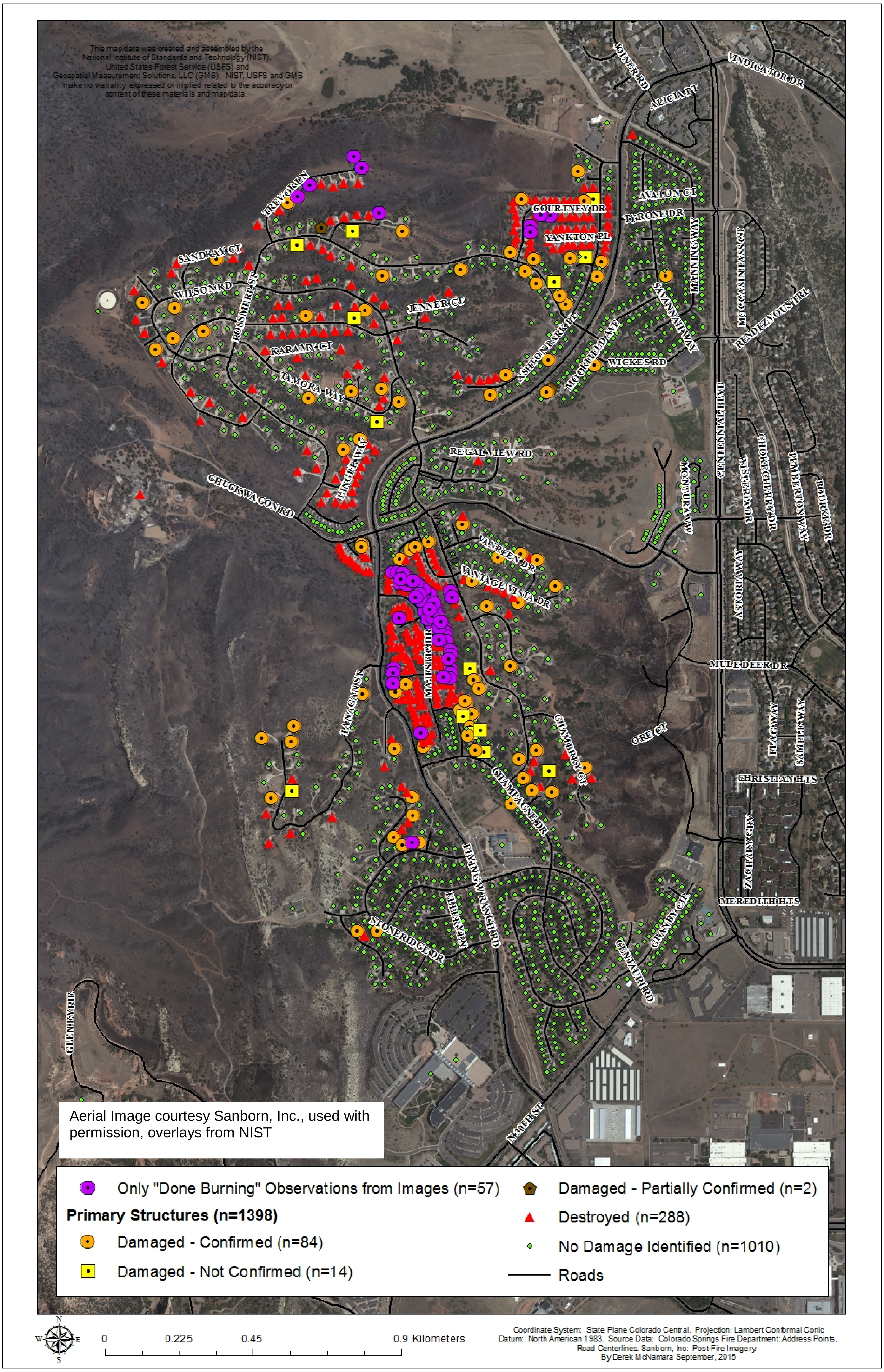
Map Figure 2 Overview of destruction to MSC by 2012 Waldo Canyon Fire.



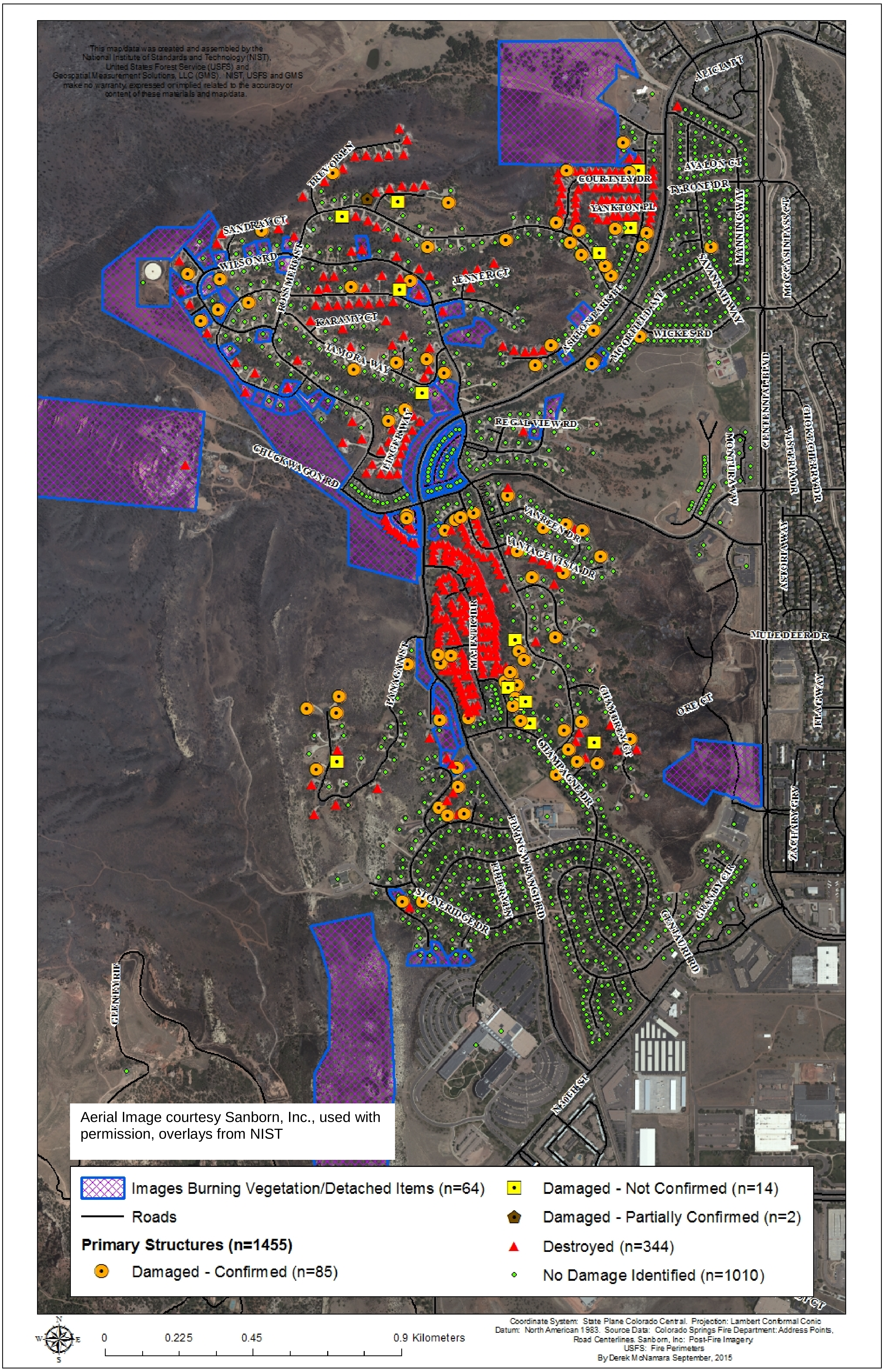
Map Figure 3 Location of two destroyed primary structures including images showing burning of western structure and locations of Engine from AVL clustered around primary structure with lack of white ash indicating lack of complete combustion of features.



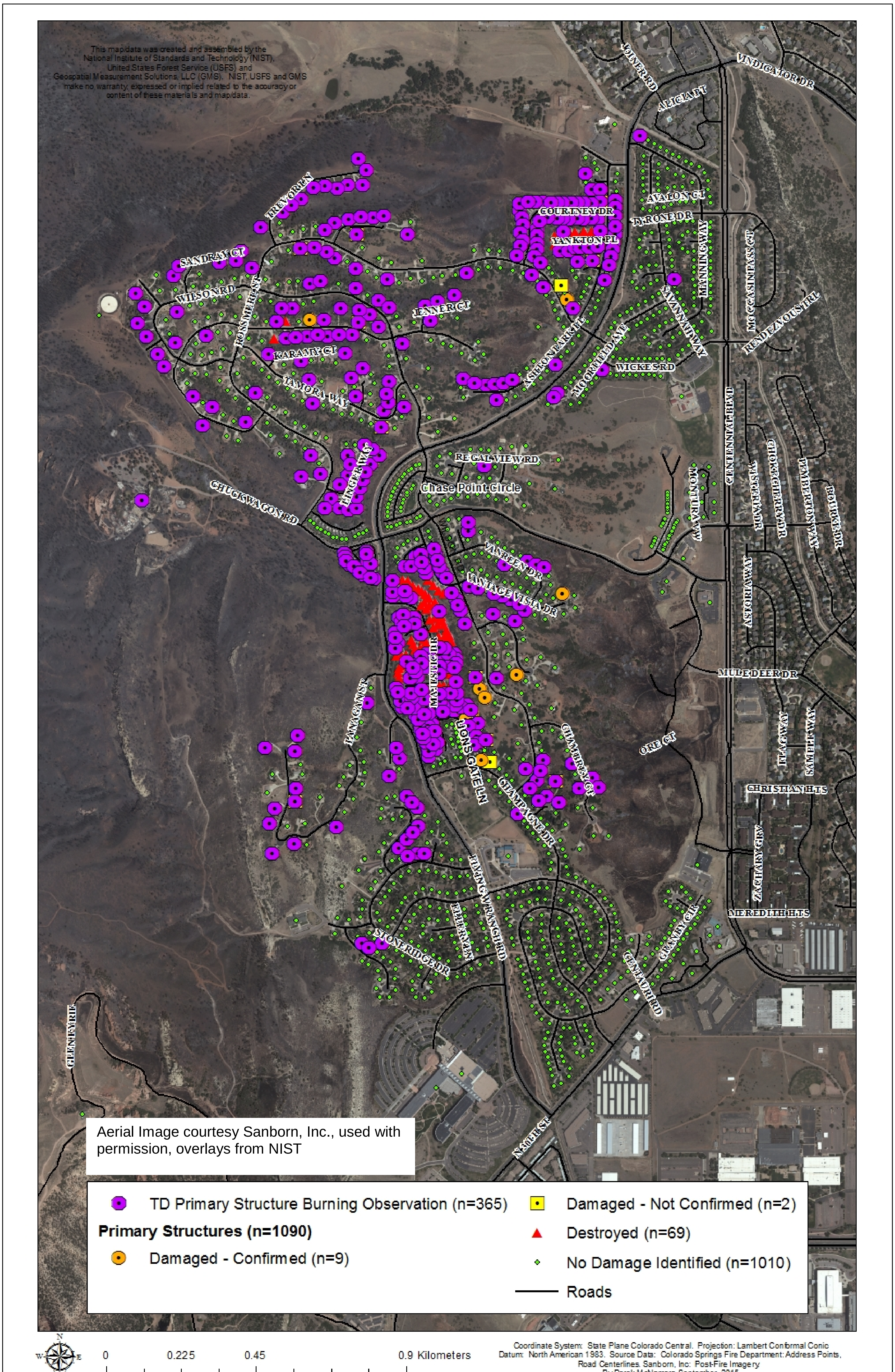
Map Figure 4 Destroyed and damaged structures with some video or image recorded of it in some state of burning, including complete destruction between 6/26/2012 17:59 to 6/27/2012 01:30.



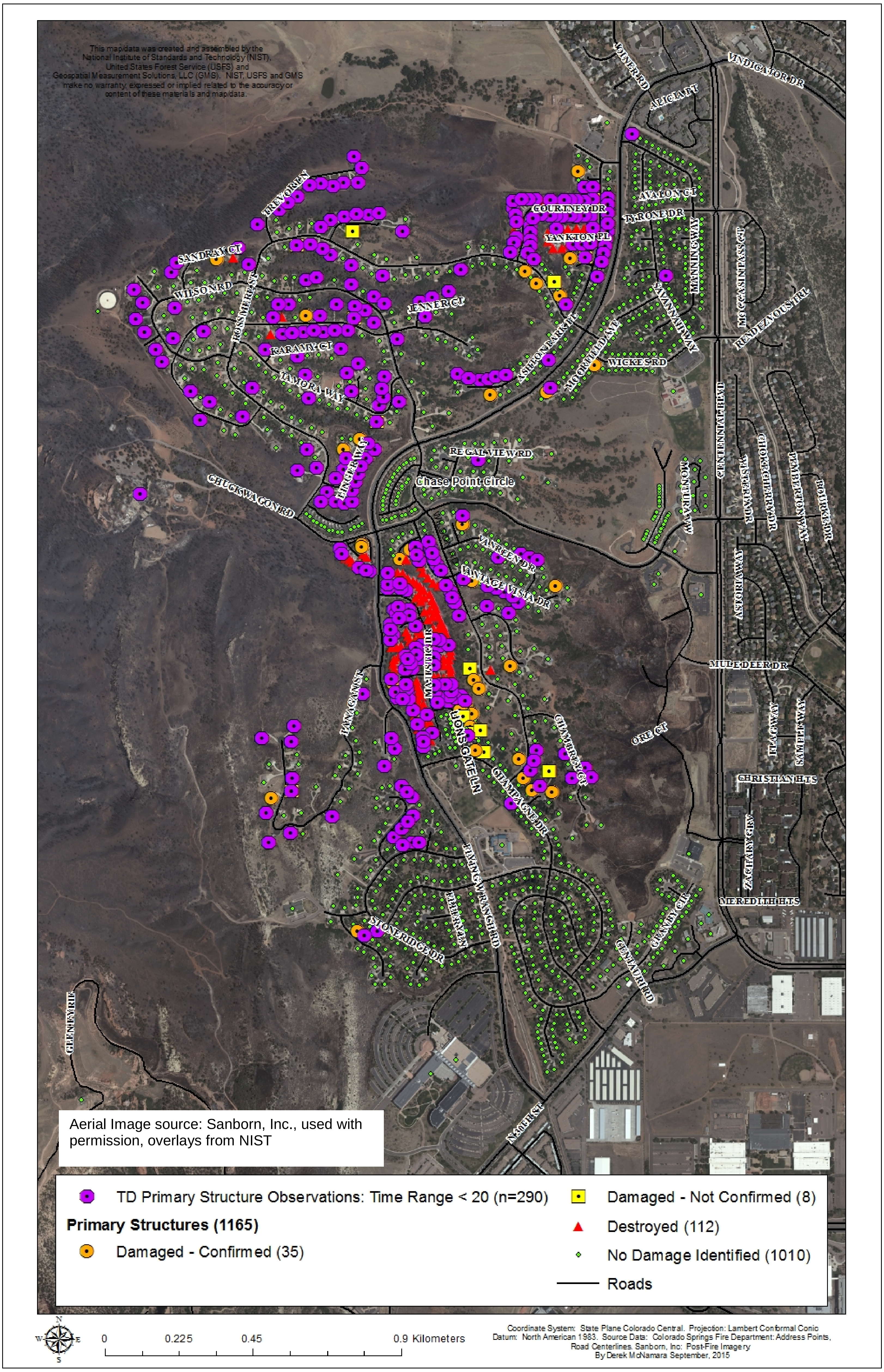
Map Figure 5 Primary structures with only "Done Burning" observations from images or videos overlaid on other primary structure damage categories.



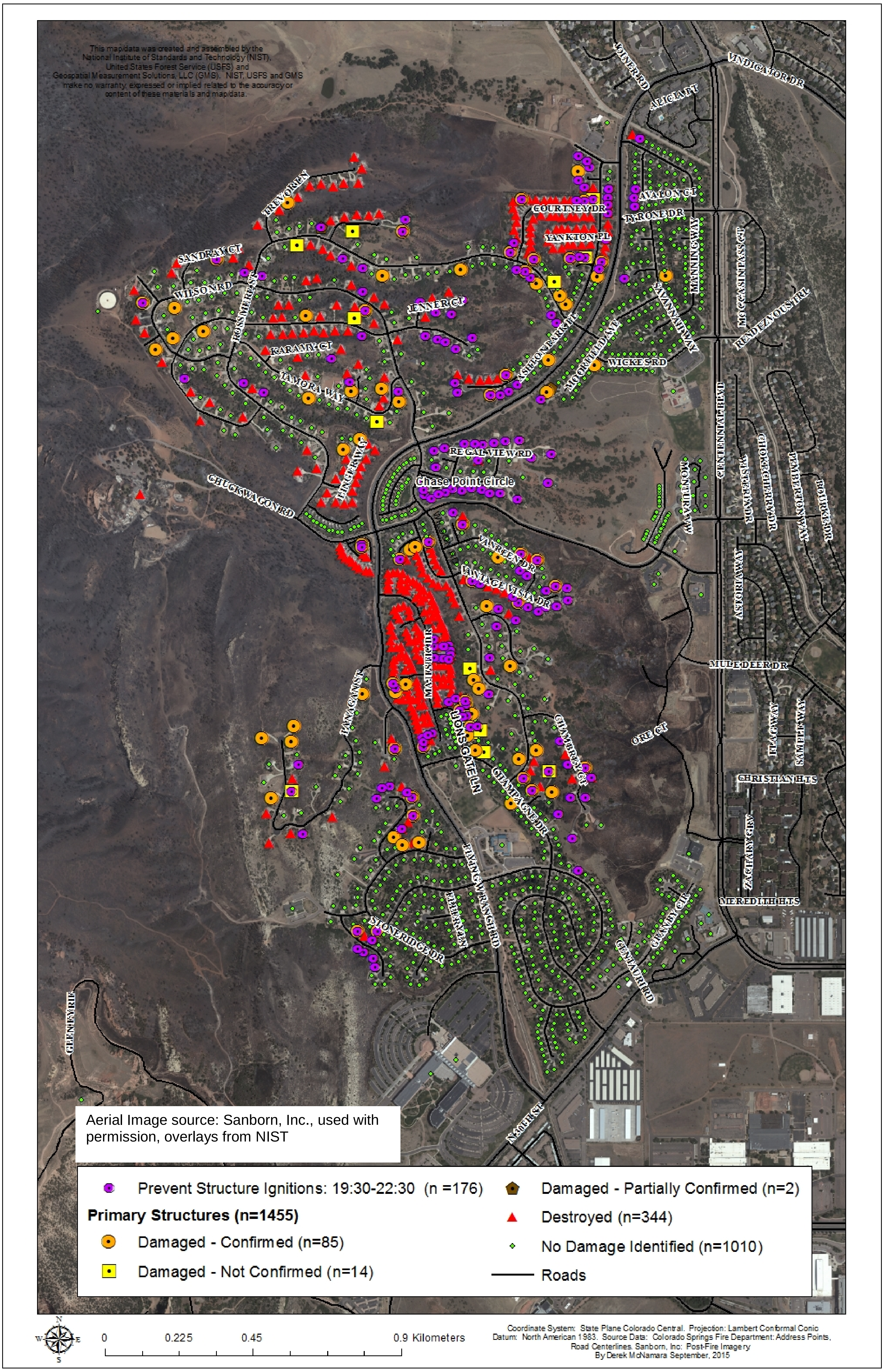
Map Figure 6 Parcels with some video or image recorded of vegetation or detached items such as fences or decks in some state of burning, including complete destruction between 6/26/2012 17:59 to 6/27/2012 01:30.



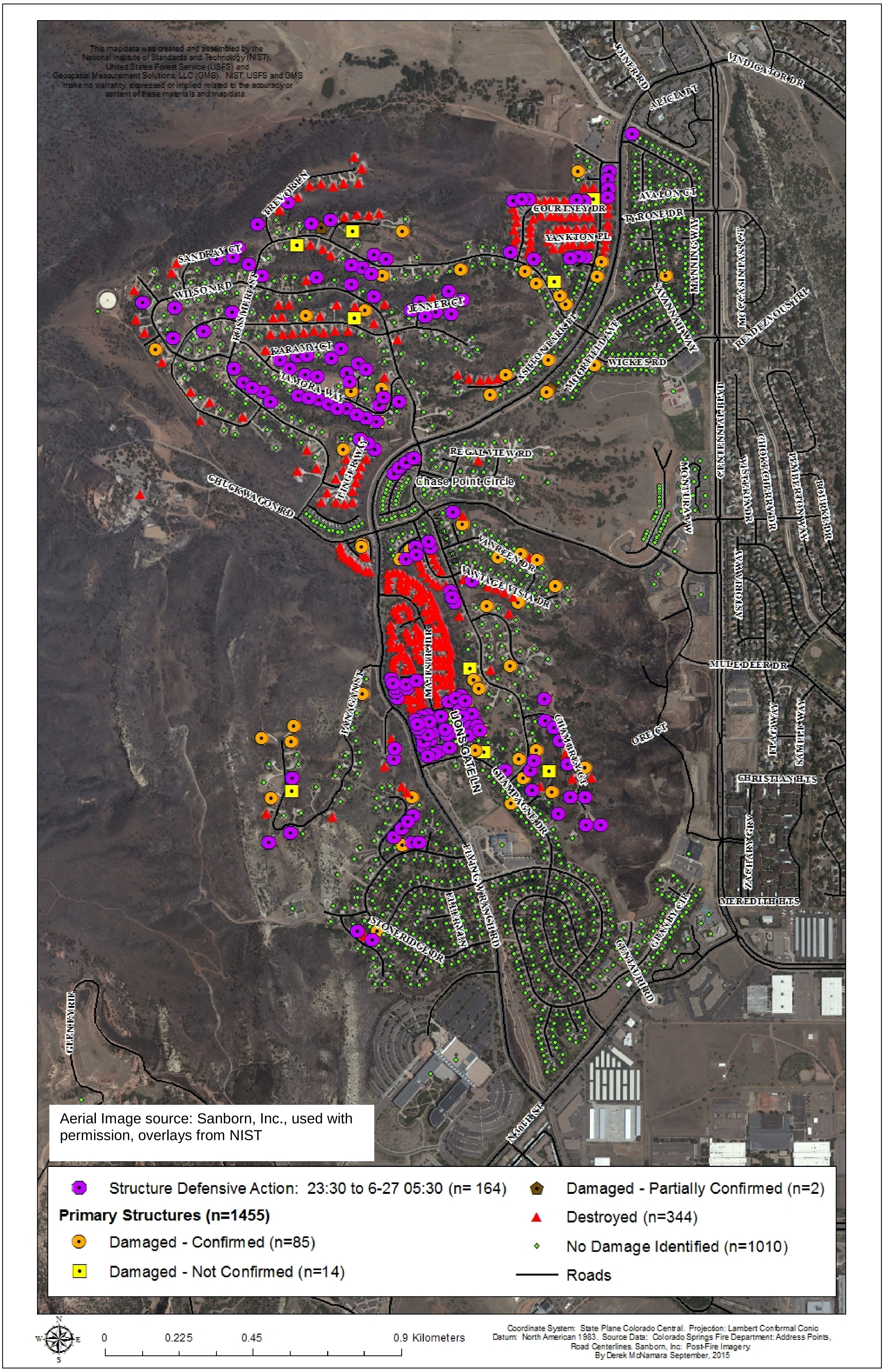
Map Figure 7 Primary structures with burning observation(s) from TDs overlaid on destroyed and damaged primary structures with no burning observations from TDs.



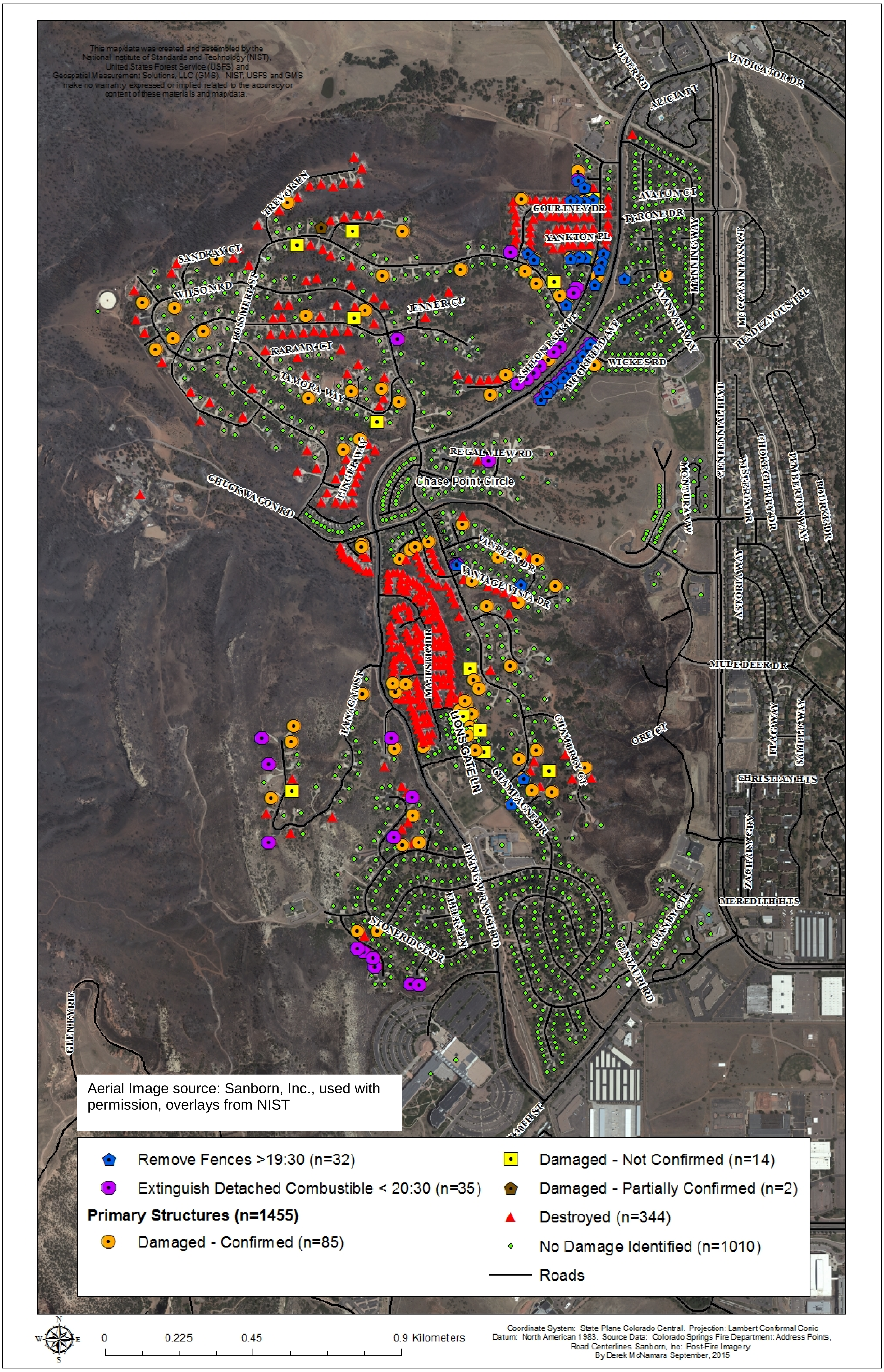
Map Figure 8 Primary structures with burn observations from TDs with time range estimates less than ± 20 min.



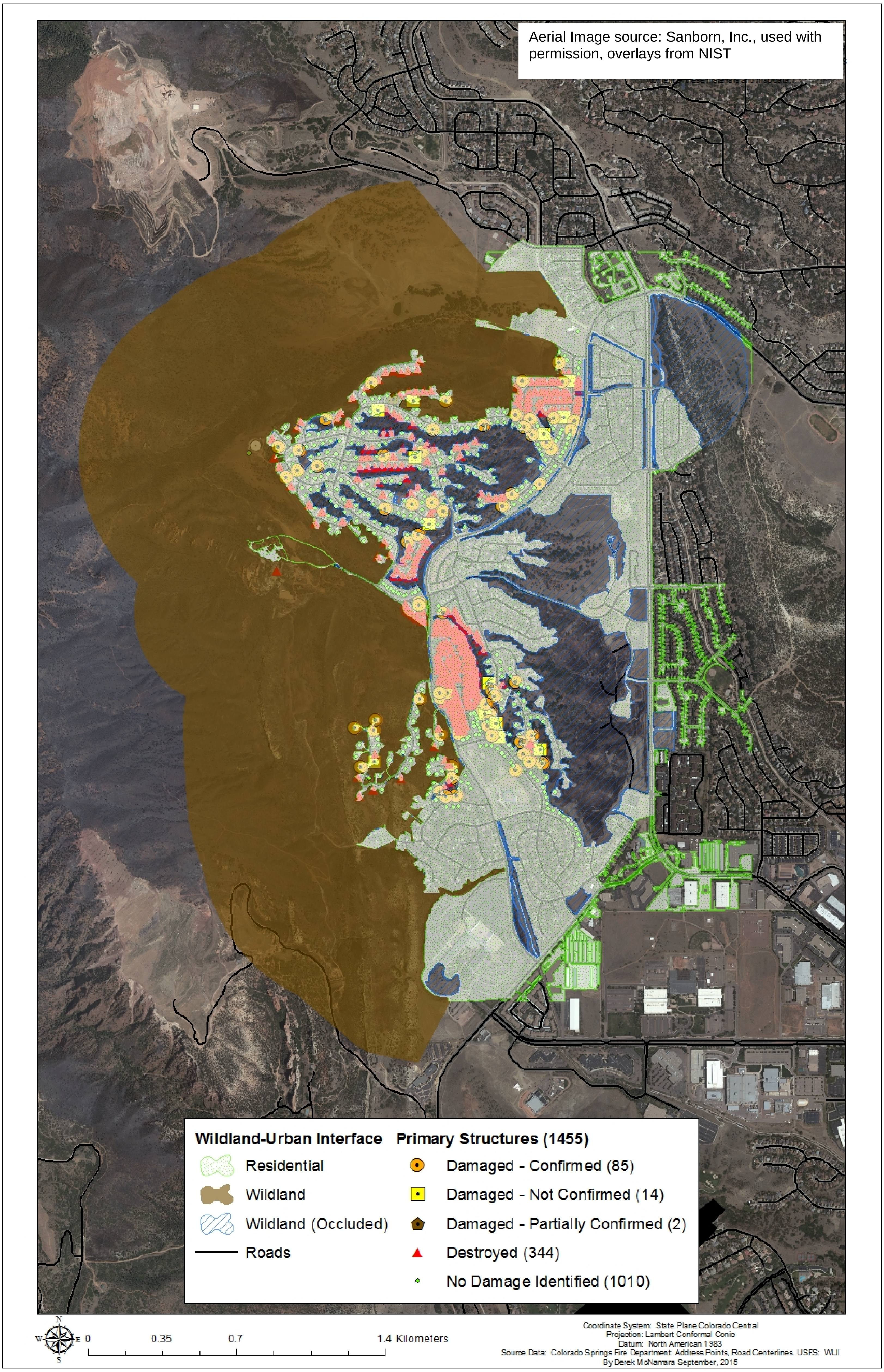
Map Figure 9 Primary structures identified as defended to "prevent structure ignition" between 19:30 and 22:30 overlaid on damage and destruction.



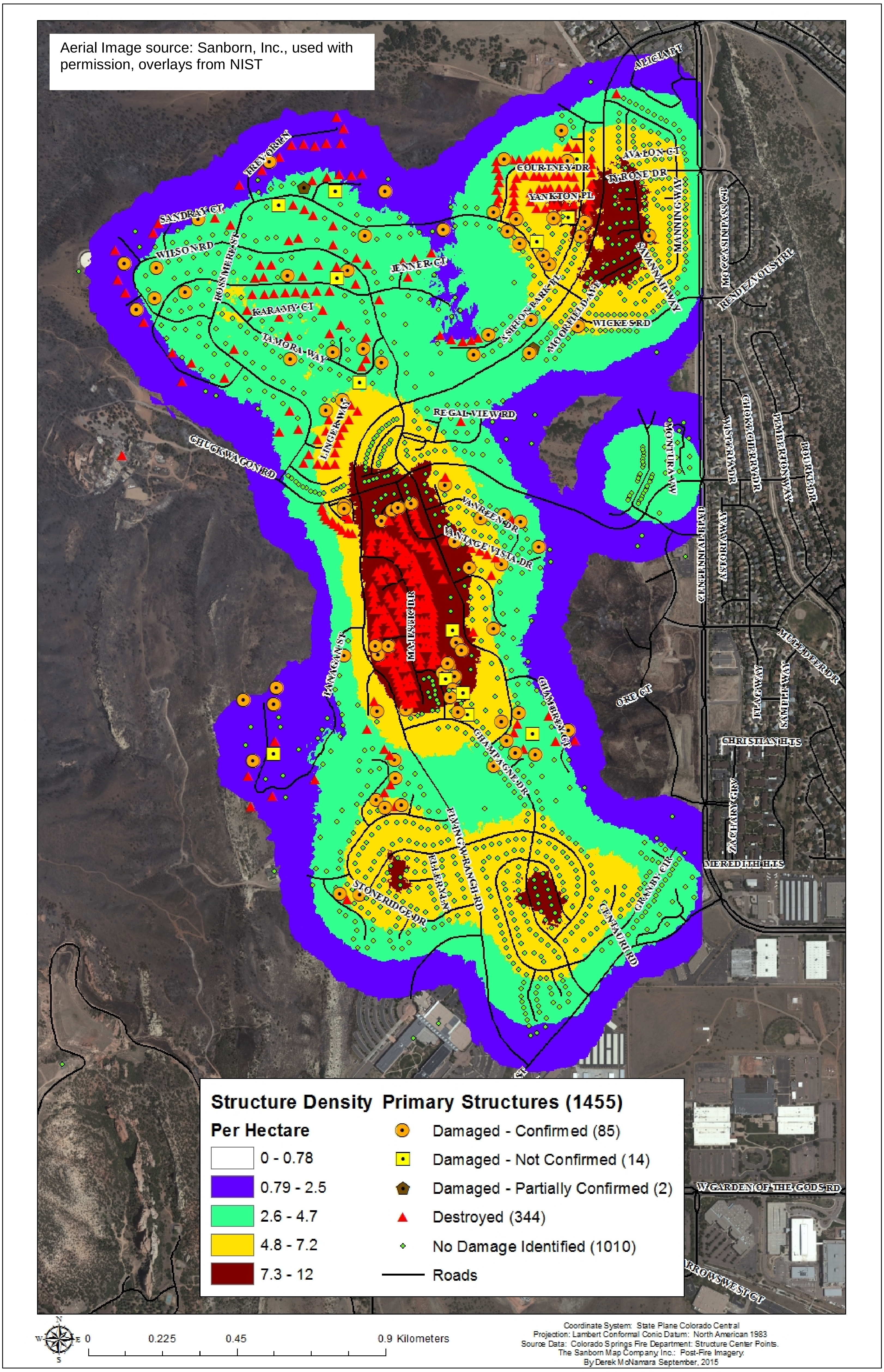
Map Figure 10 Primary structures identified as defended to "prevent structure ignition", "extinguish structure" or "contain structure" between 23:30 on June 26 and 05:30 on June 27 overlaid on damage and destruction.



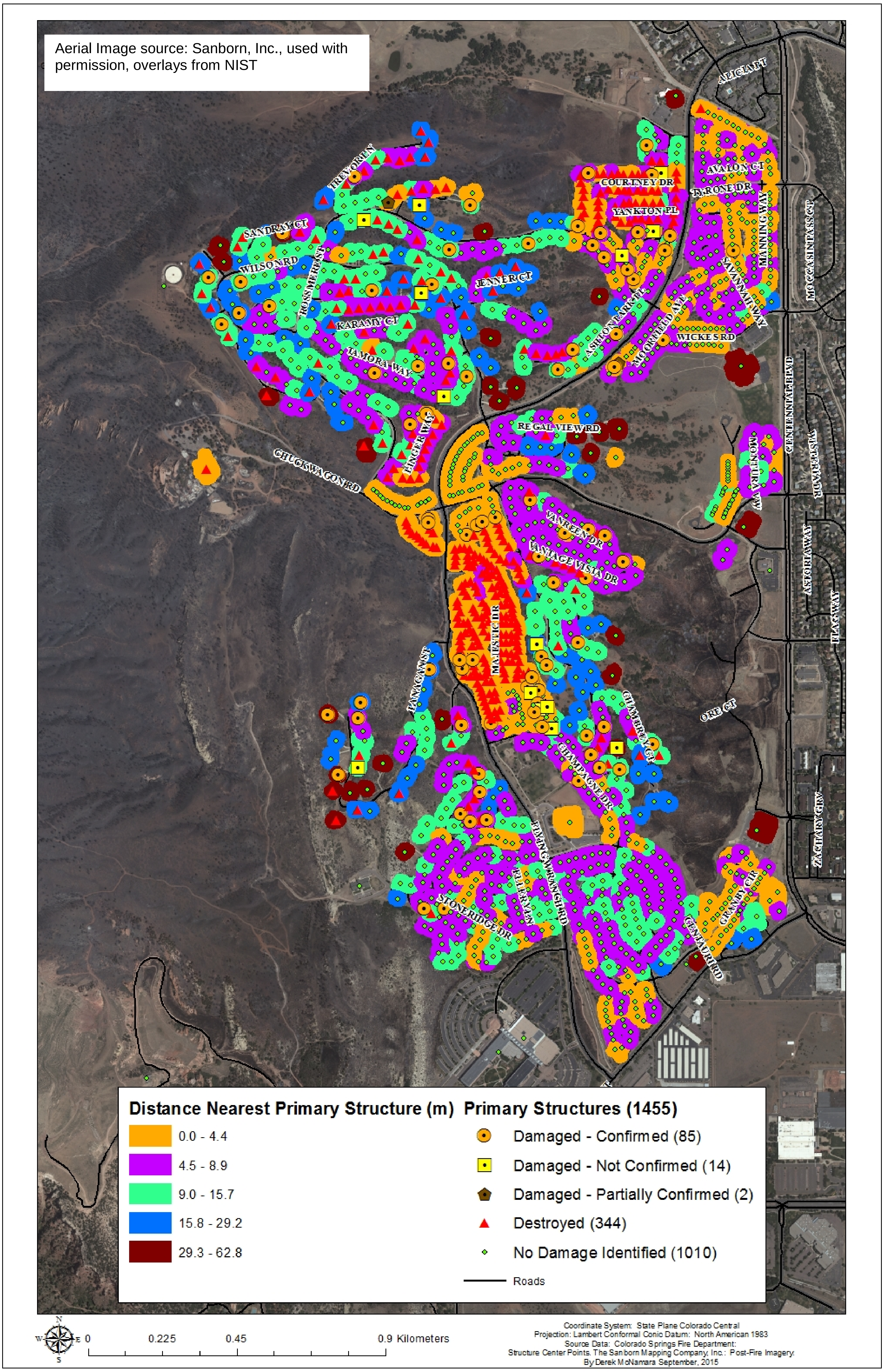
Map Figure 11 Properties with identified defensive action locations of extinguishing detached combustibles before 20:30 and properties with identified defensive actions of remove fences, burning or not, after 19:30, both on June 26.



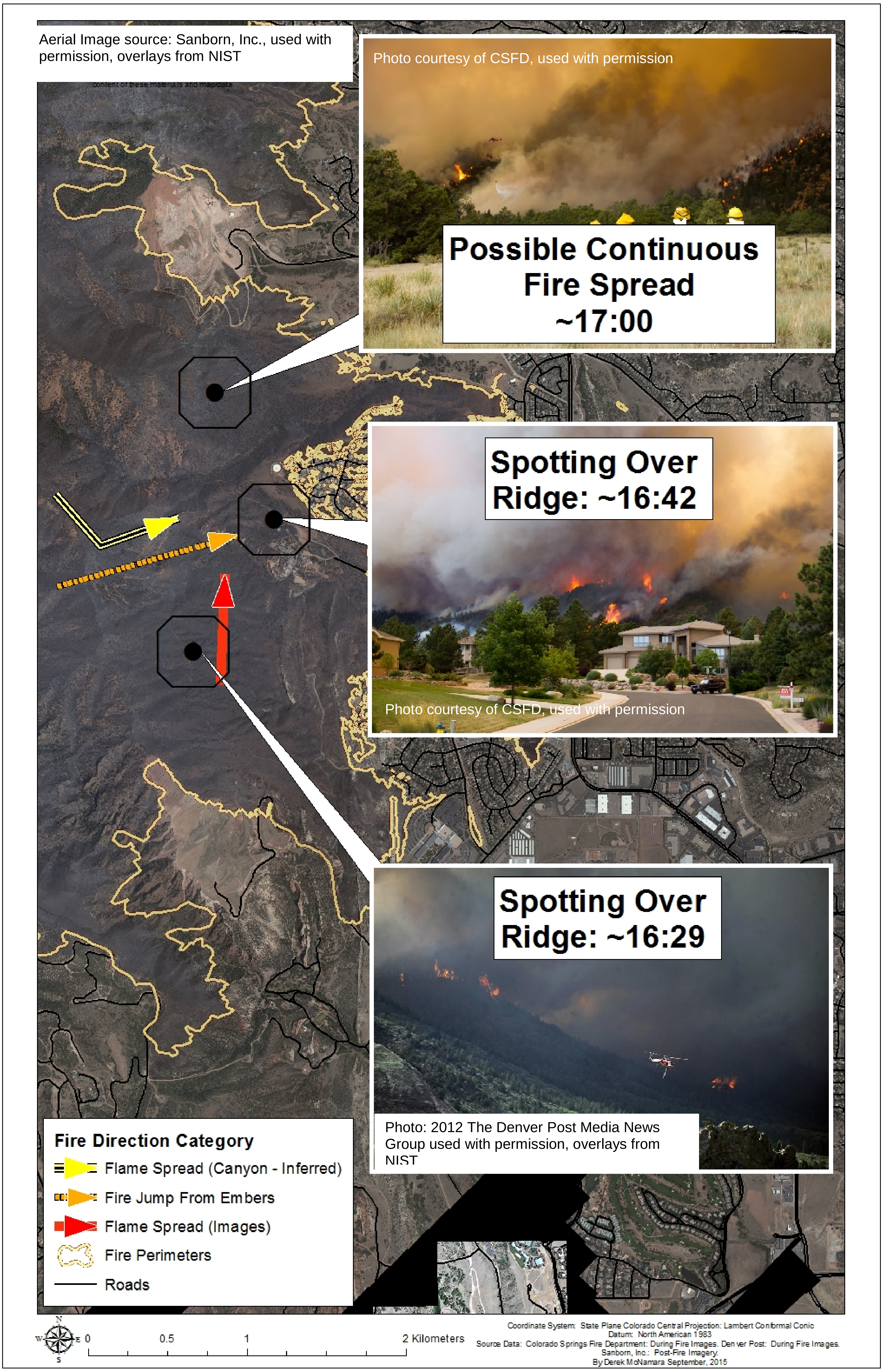
Map Figure 12 WUI area in and around MSC.



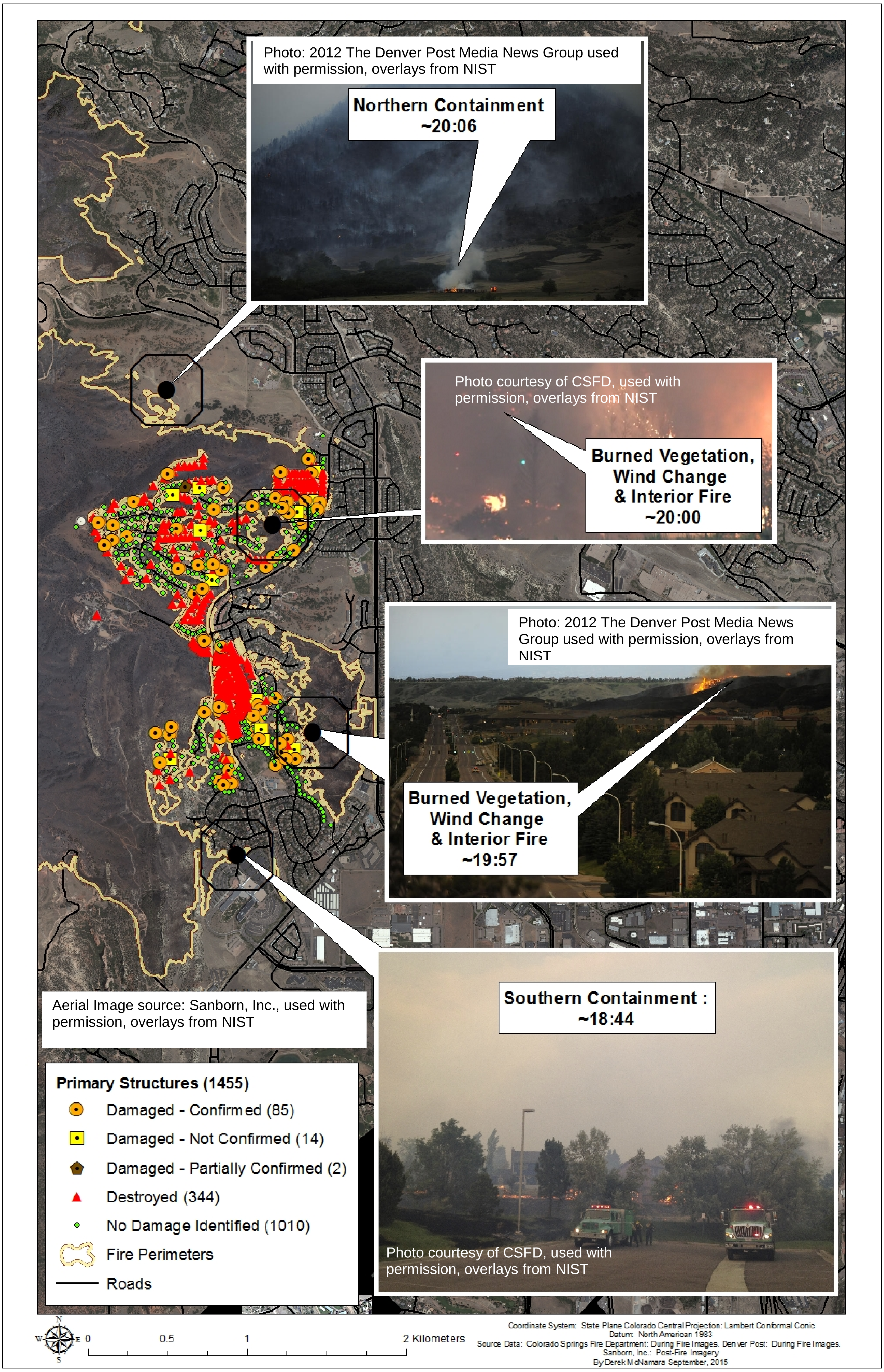
Map Figure 13 Structure density in and around Mountain Shadows. Derived using the ArcGIS™ Point Density Tool with a circle window having a radius of 200 m (660 ft) and an output cell size of 3 m (10ft).



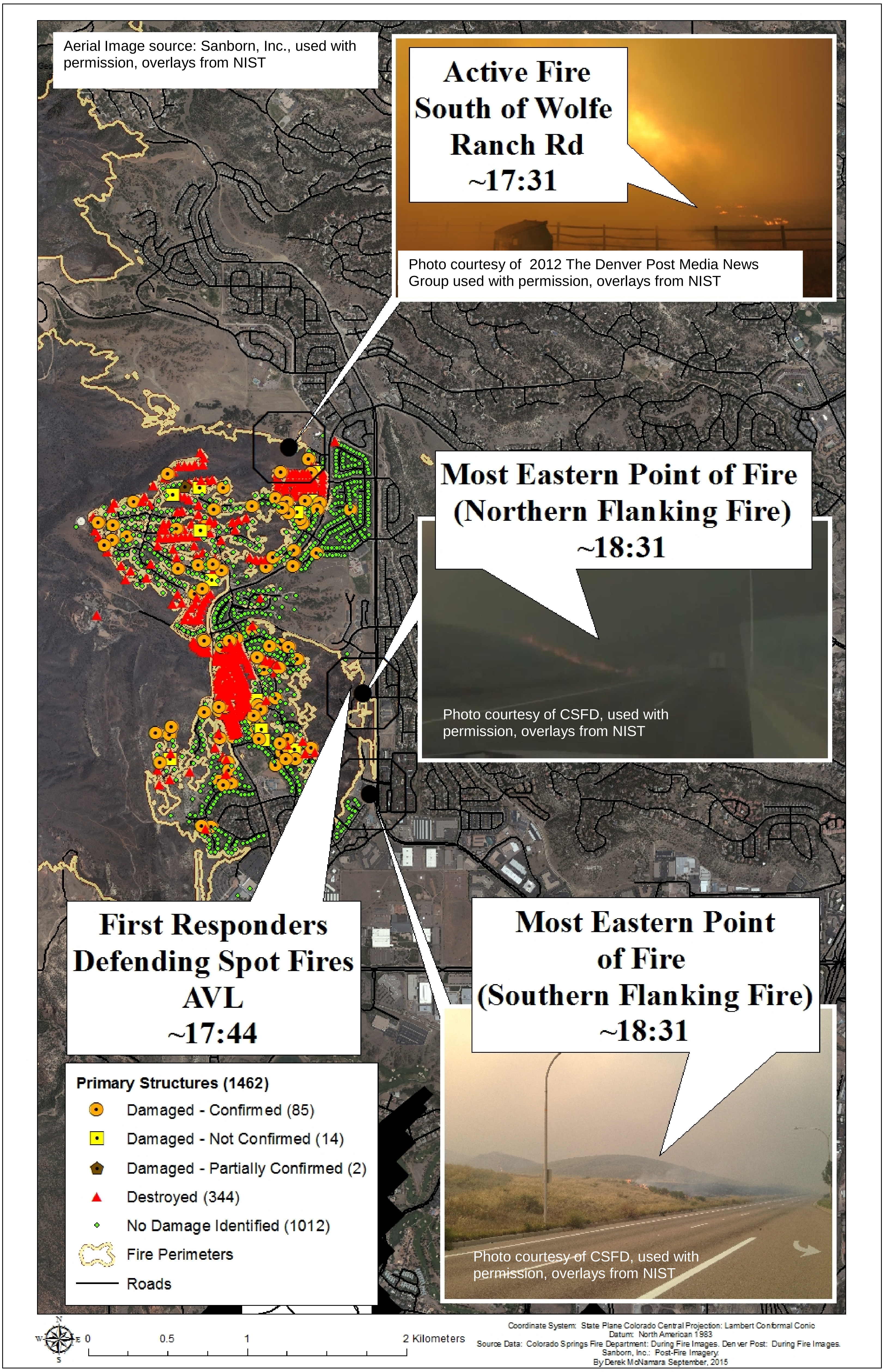
Map Figure 14 Distance to nearest primary structure in MSC.



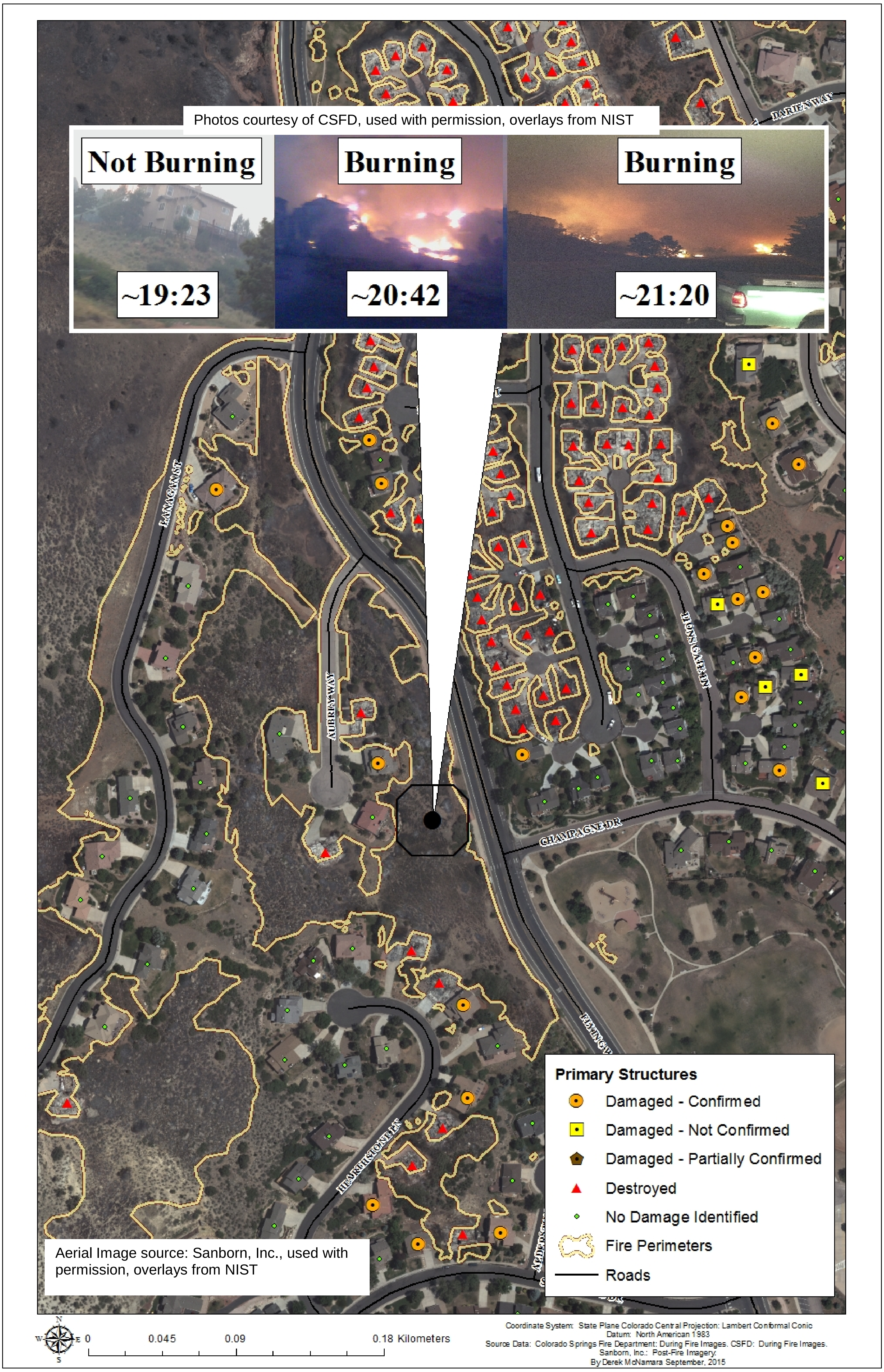
Map Figure 15 Spotting and possible continuous fire spread over the ridge above MSC occurring around 16:30 on June 26.



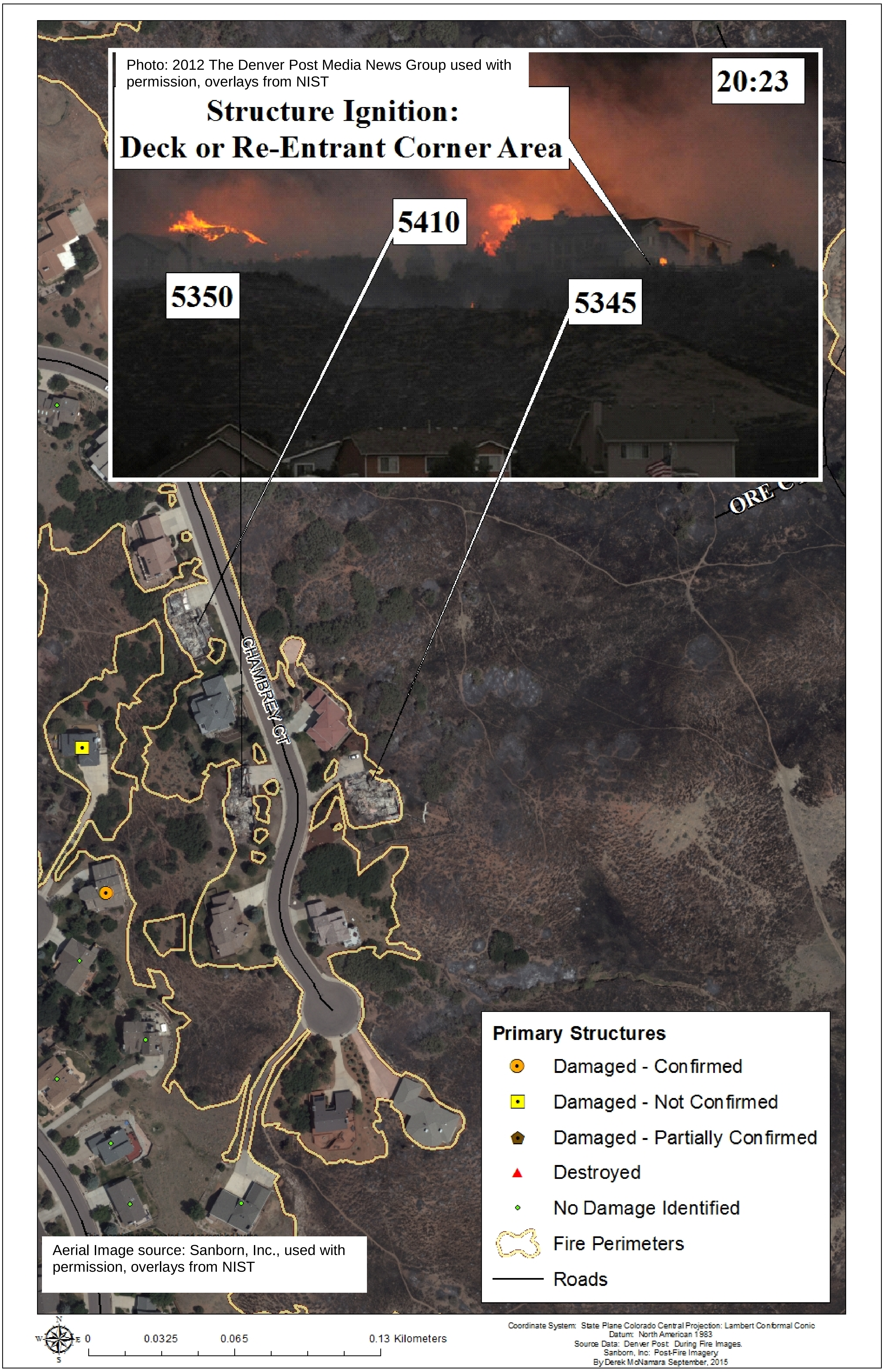
Map Figure 16 Burning times of wildlands around MSC.



Map Figure 17 Additional burning times of wildlands around MSC.



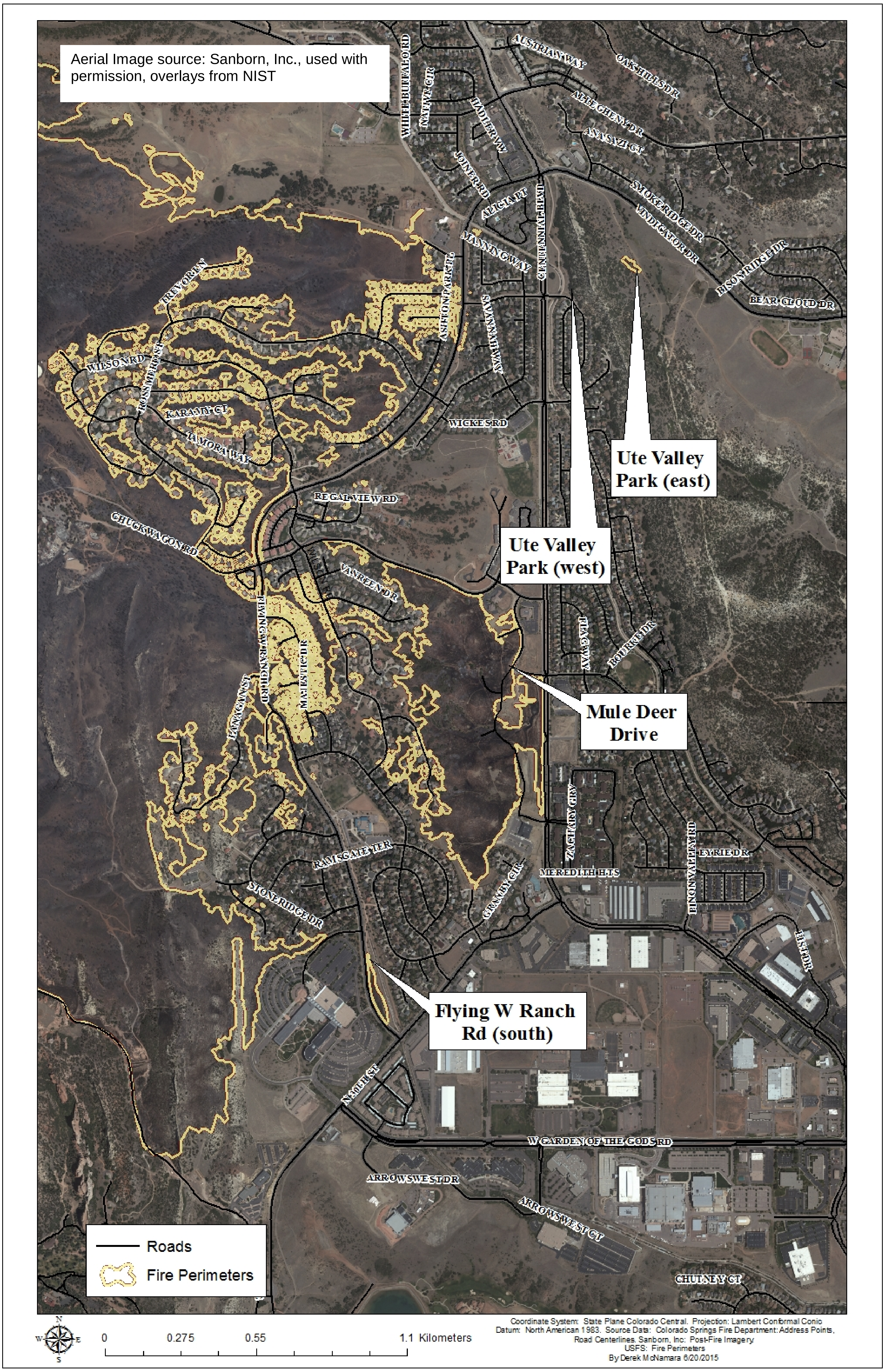
Map Figure 18 Time lapse images of vegetation along Flying W Ranch Road. The vegetation did not burn as part of the main fire front, as is evidenced in the image taken at 19:23. Later images show burning of vegetation and the destroyed primary structures as early as 20:42. The burning might have been a result of ember spread from primary structures burning on Hot Springs Court, corresponding to a change in wind direction.



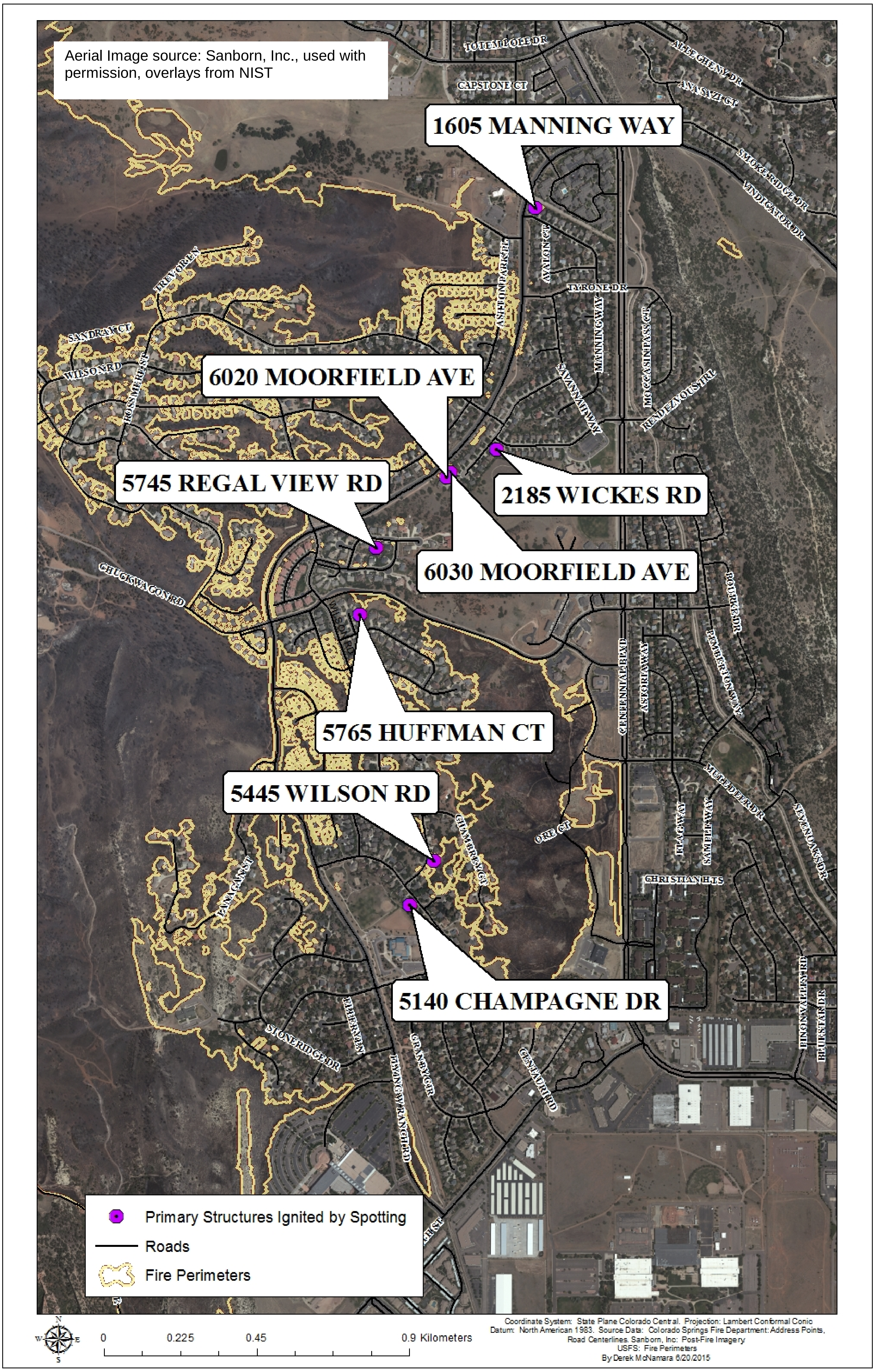
Map Figure 19 Ignitions occurring after the change in wind direction.

Map Figure 20 Ignitions occurring after 20:00.

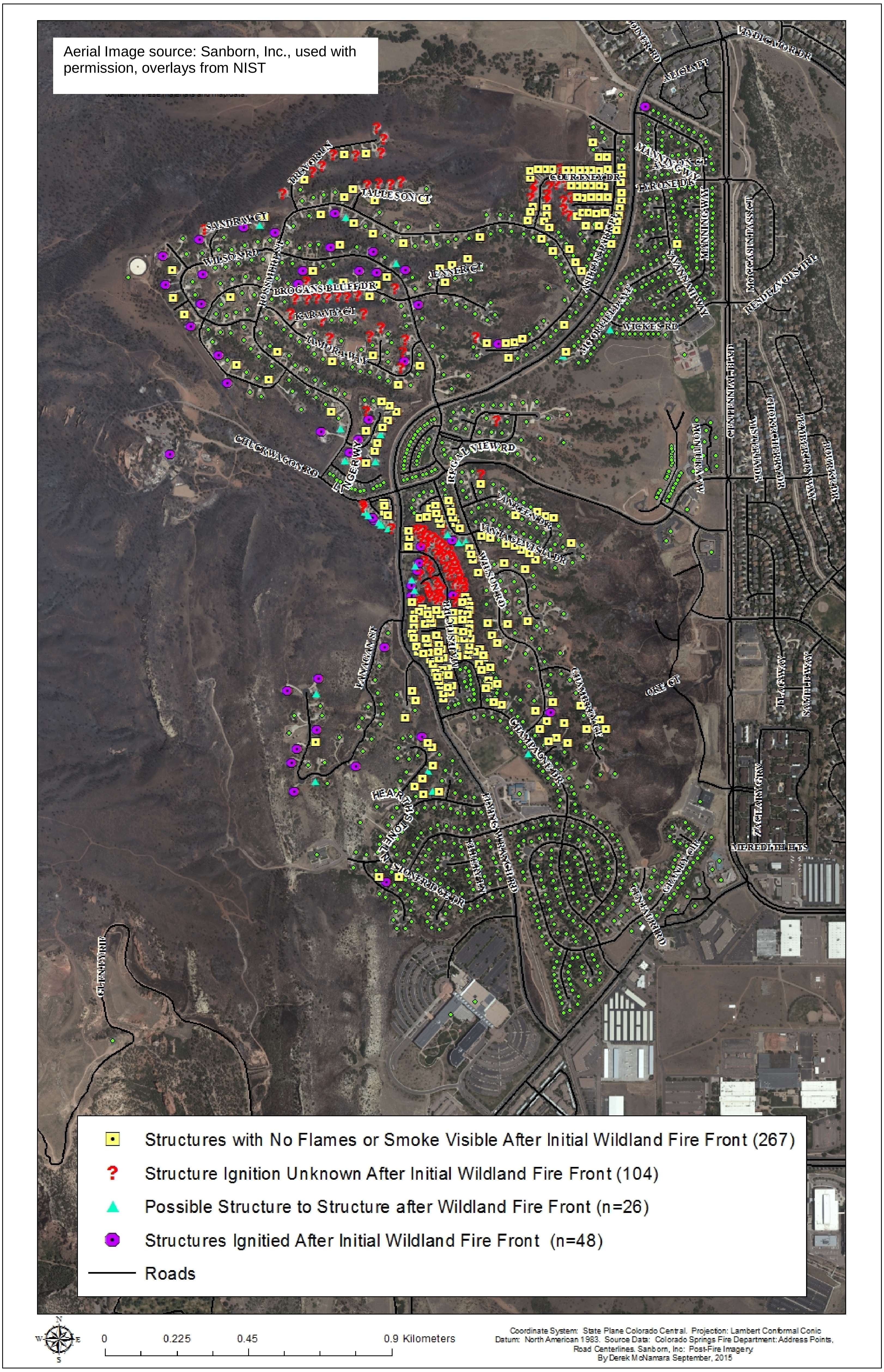
Map Figure 21 Structure ignitions on Jenner Court corresponding to changes in wind direction around 20:00.



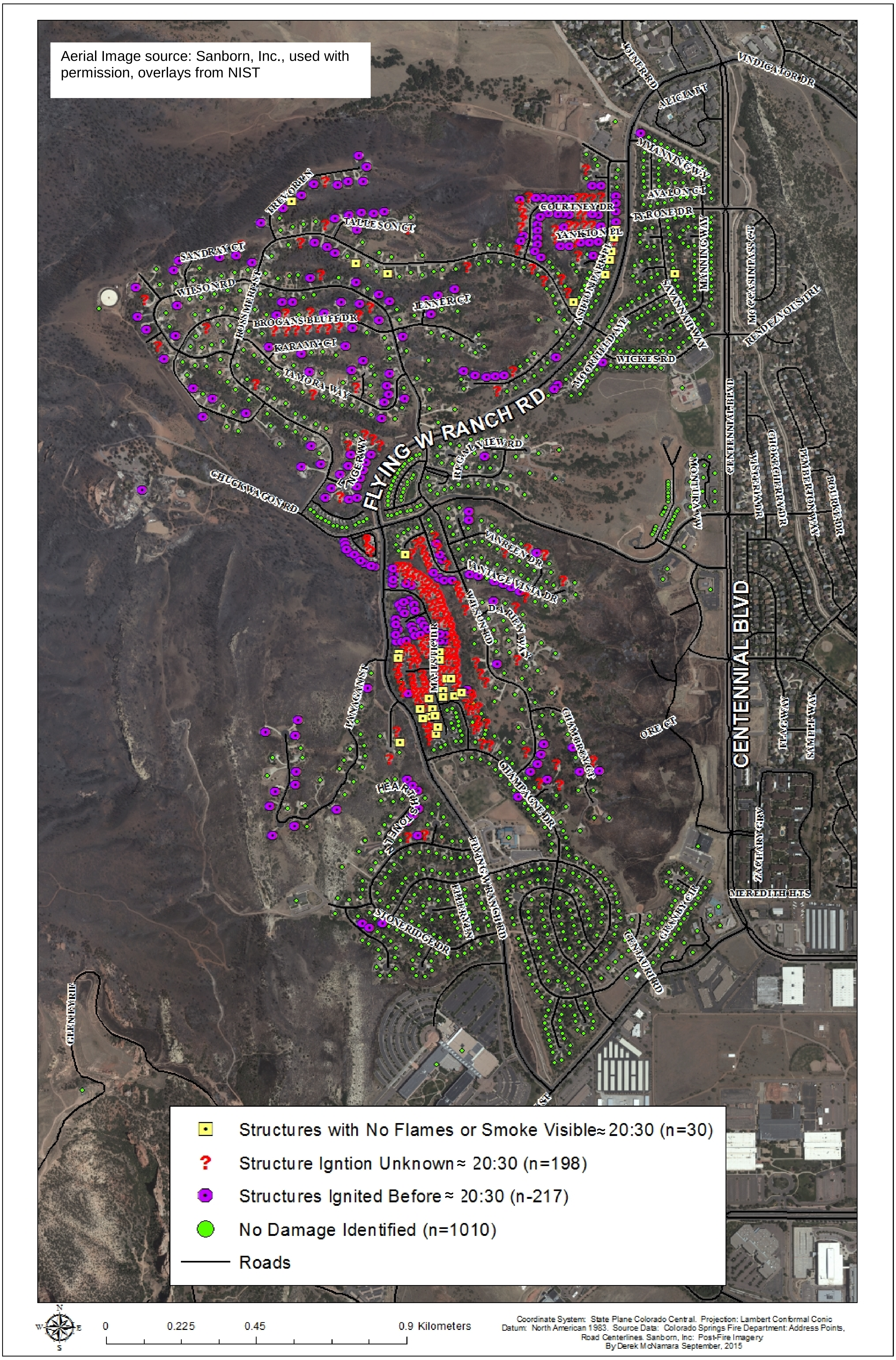
Map Figure 22 Spotting locations to wildland vegetation with potential farthest spotting locations highlighted.



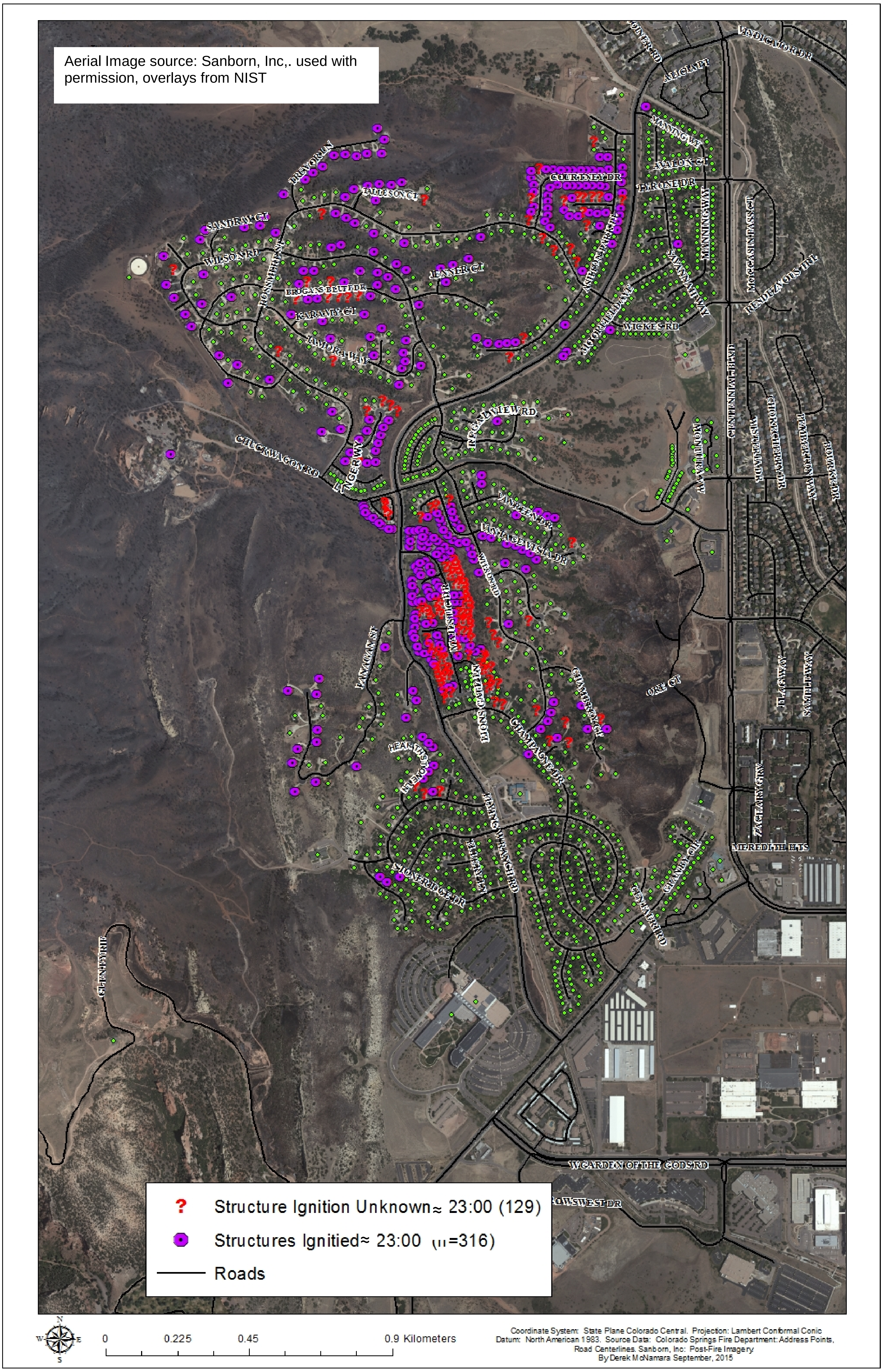
Map Figure 23 Potential spotting to structure locations, relatively early in the fire.



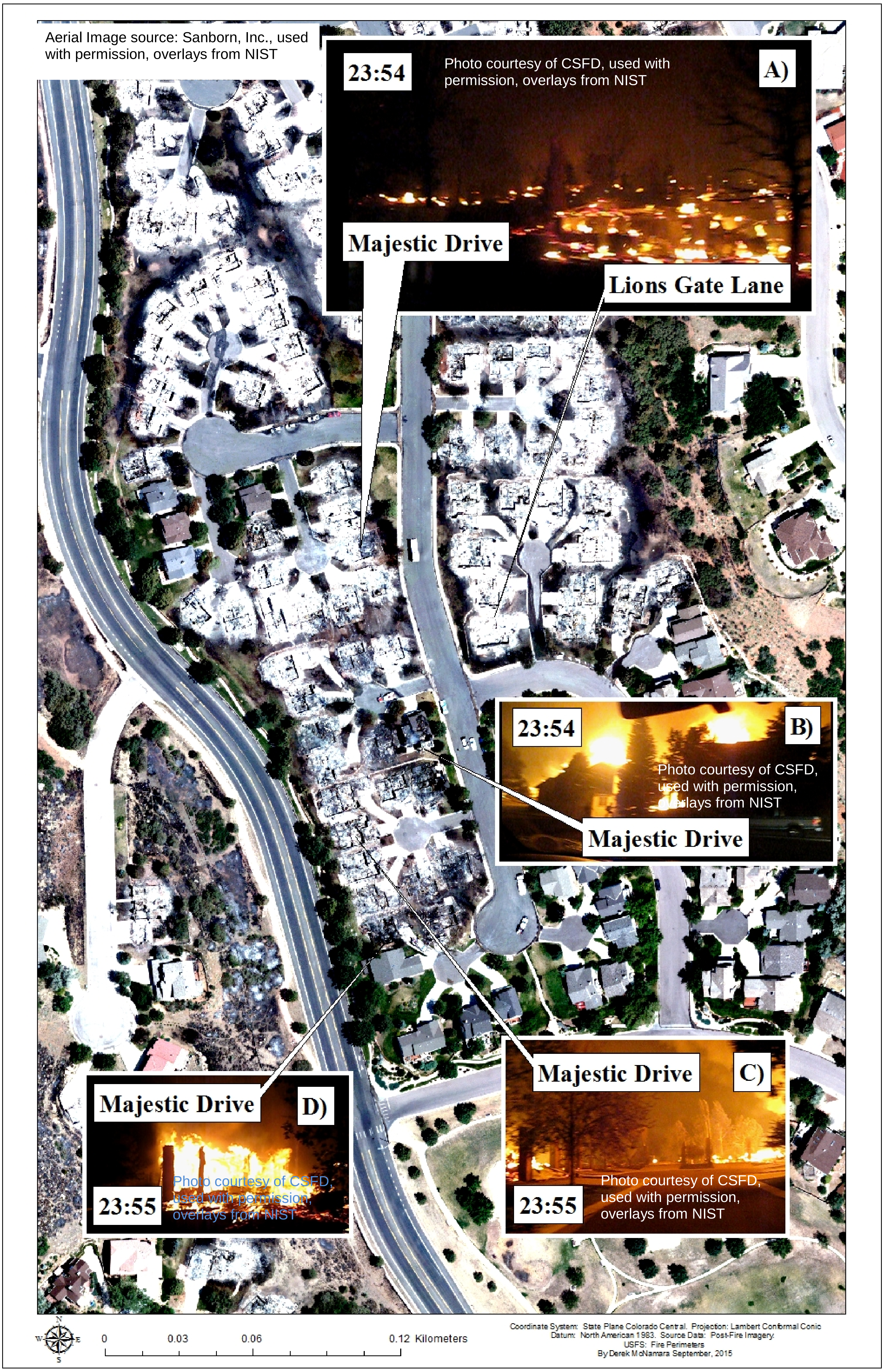
Map Figure 24 Ignition status of destroyed and damaged primary structures around 18:30 on June 26.



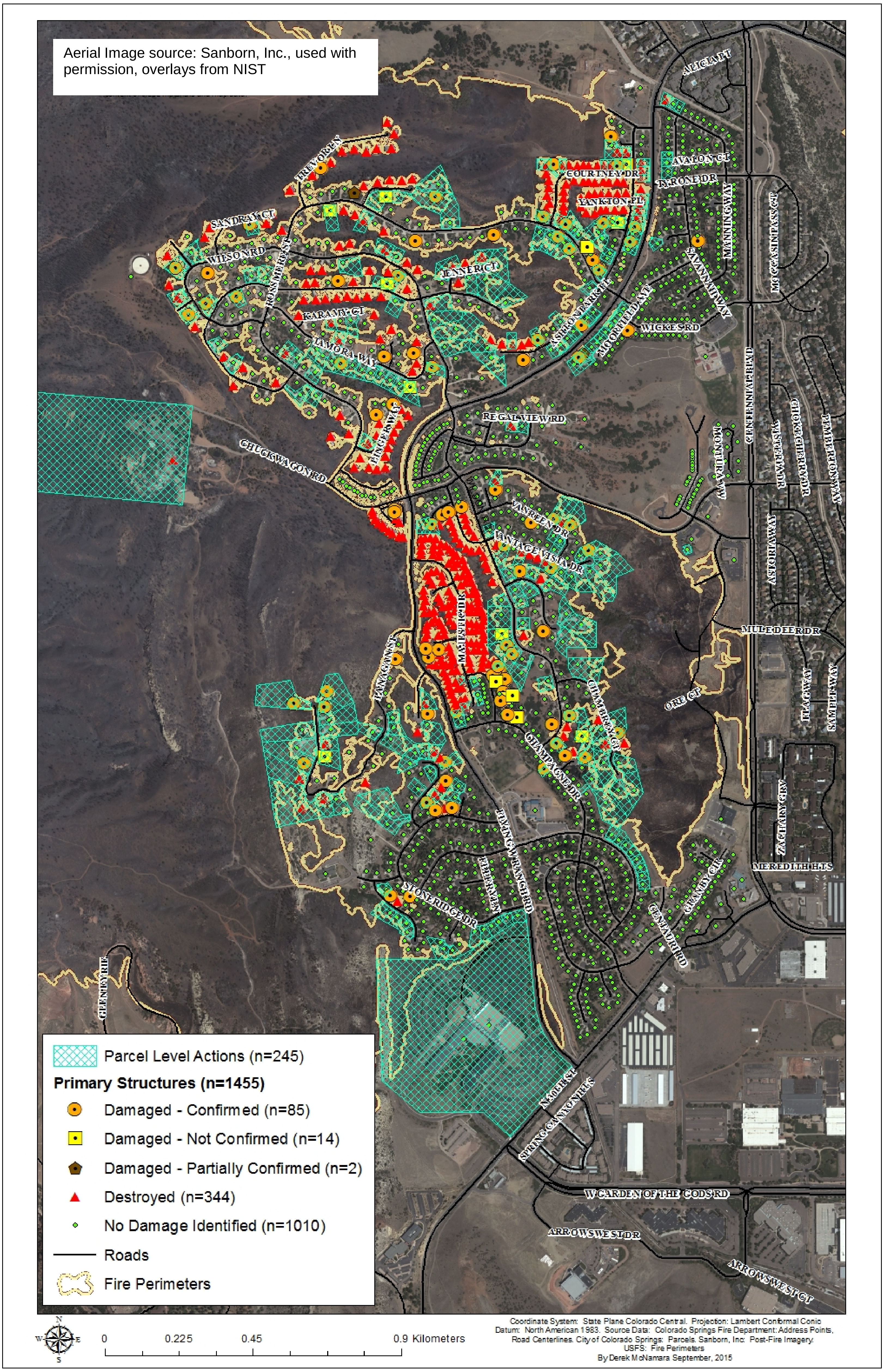
Map Figure 25 Ignition status of destroyed and damaged primary structures before ≈20:30 on June 26.



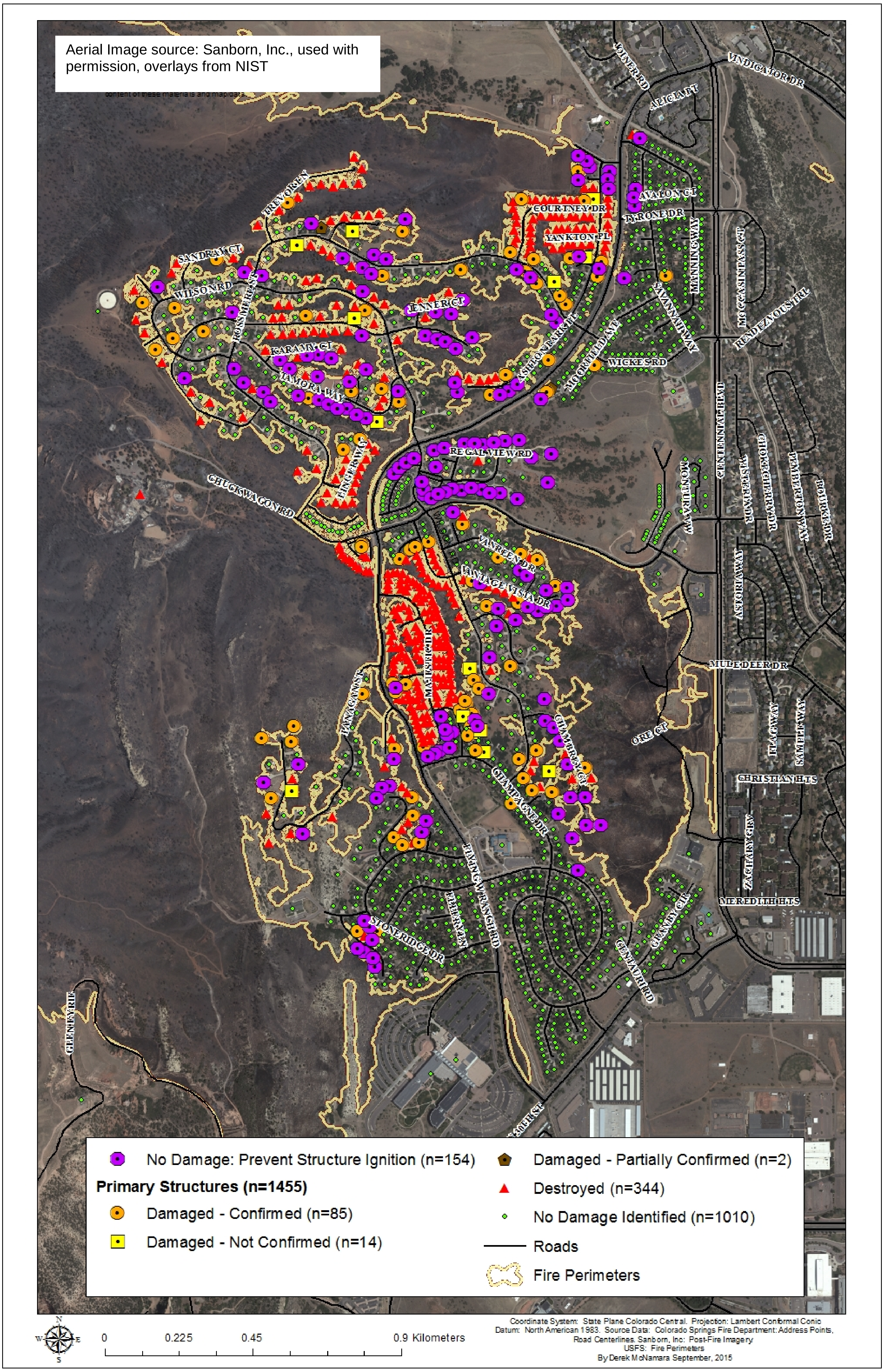
Map Figure 26 Ignition status of destroyed and damaged primary structures before ≈23:00 on June 26.



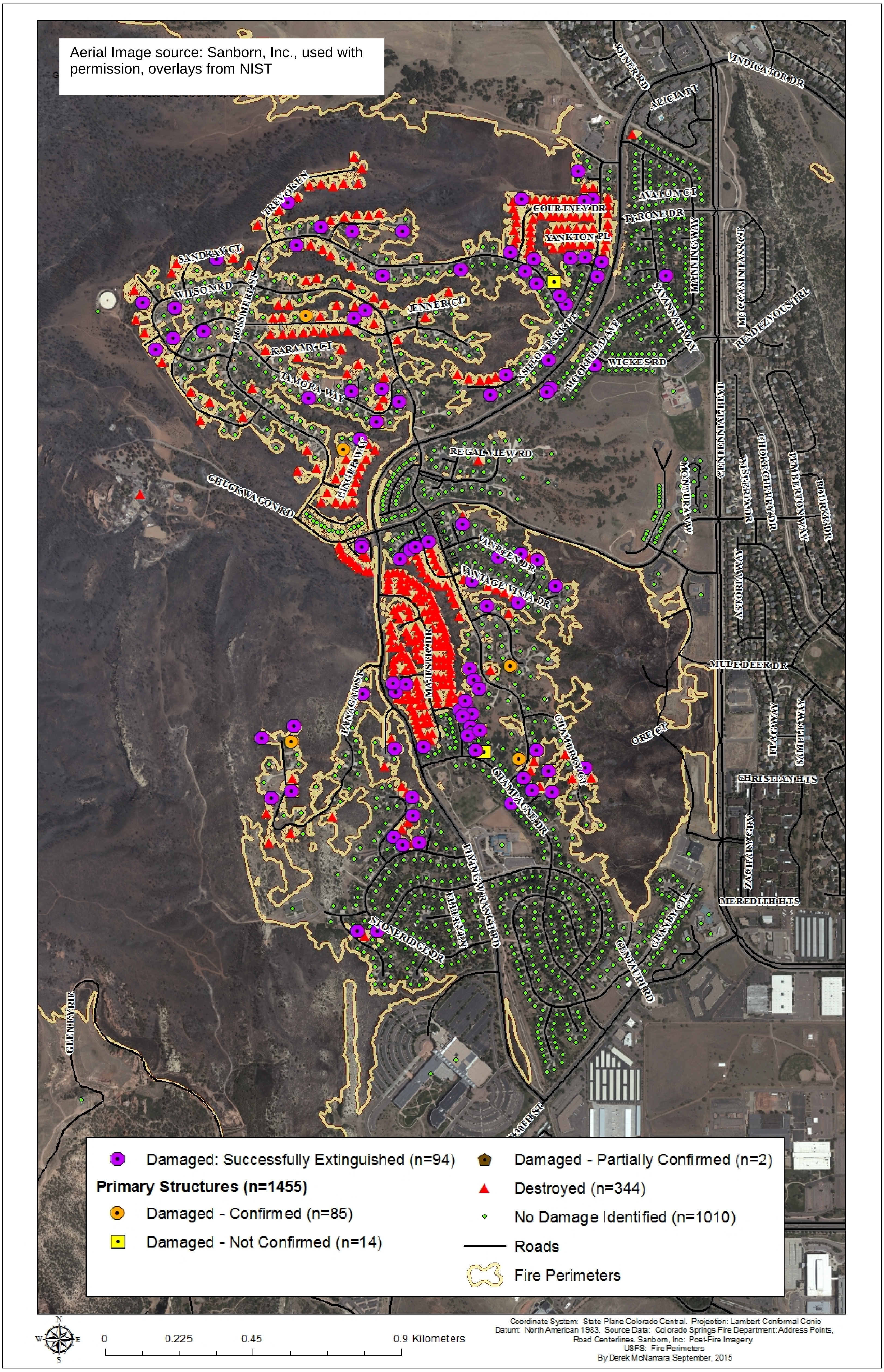
Map Figure 27 Images of structures as foundations or fully involved before 23:55. Image B and Image D show some of the last structures to burn in the area along with defensive actions. Defensive actions and burn order can also be deduced from areas with lack of white ash as shown in image C that indicates structures as foundations before successful containment actions occurred coinciding with structures containing white ash.



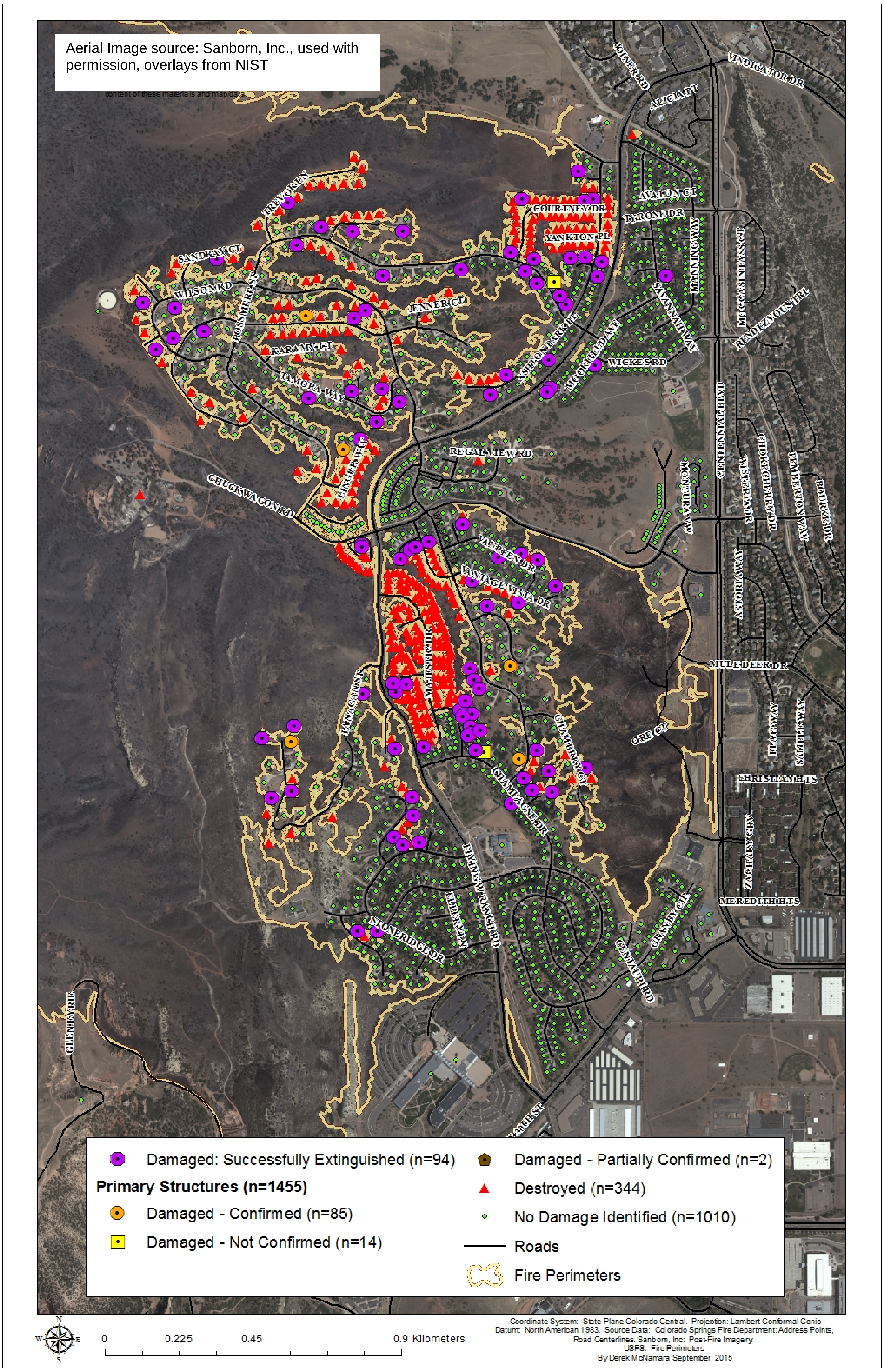
Map Figure 28 Properties that had parcel level defensive actions. Some properties had multiple defensive actions. The size of the parcel is not related to the quantity or quality of the defensive actions and defensive actions might not have occurred across the entire parcel.



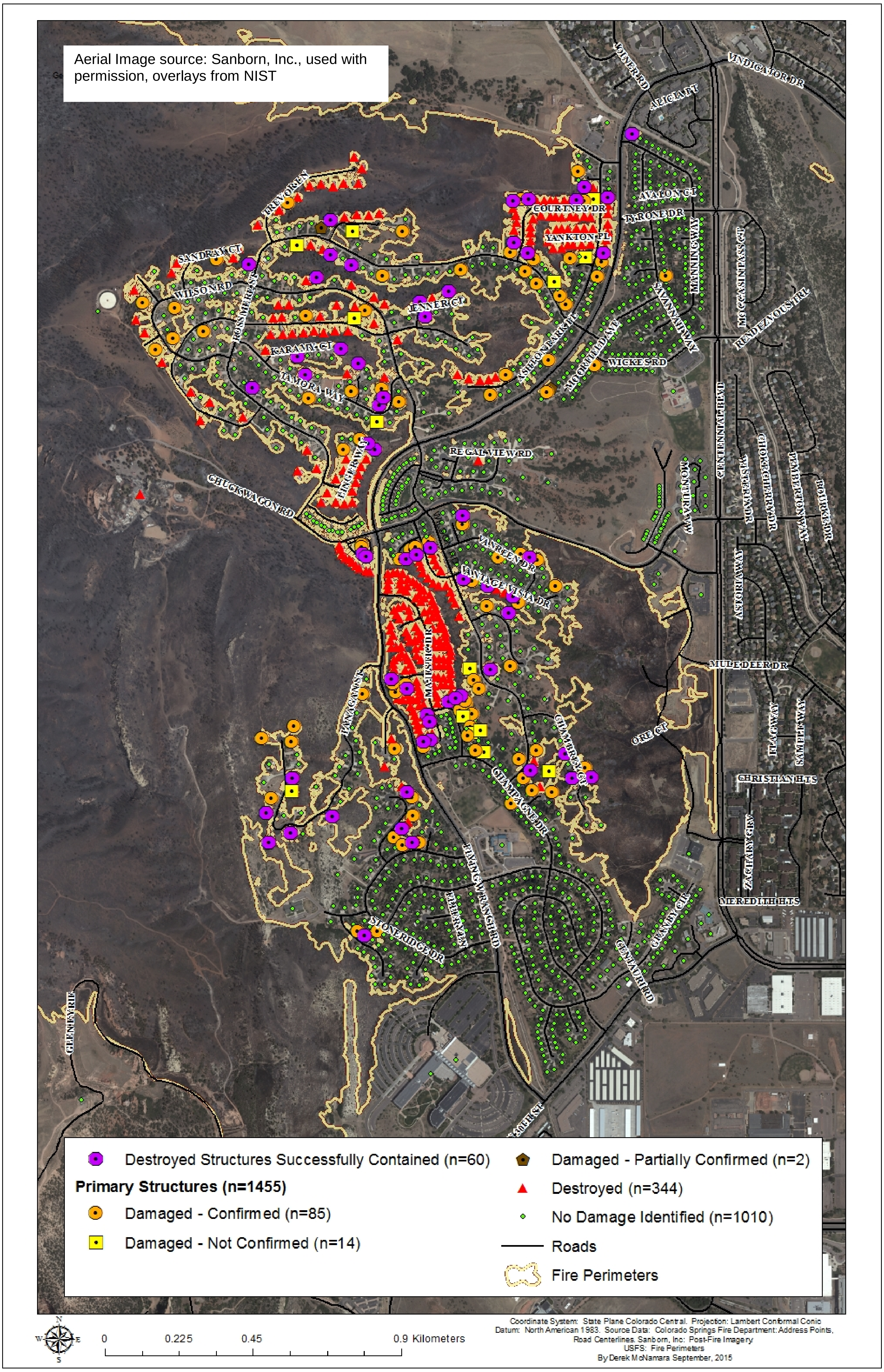
Map Figure 29 Structures with no damage, shown as purple hexagon with black dot, which were specifically identified by first responders as being defended to prevent structure ignition.



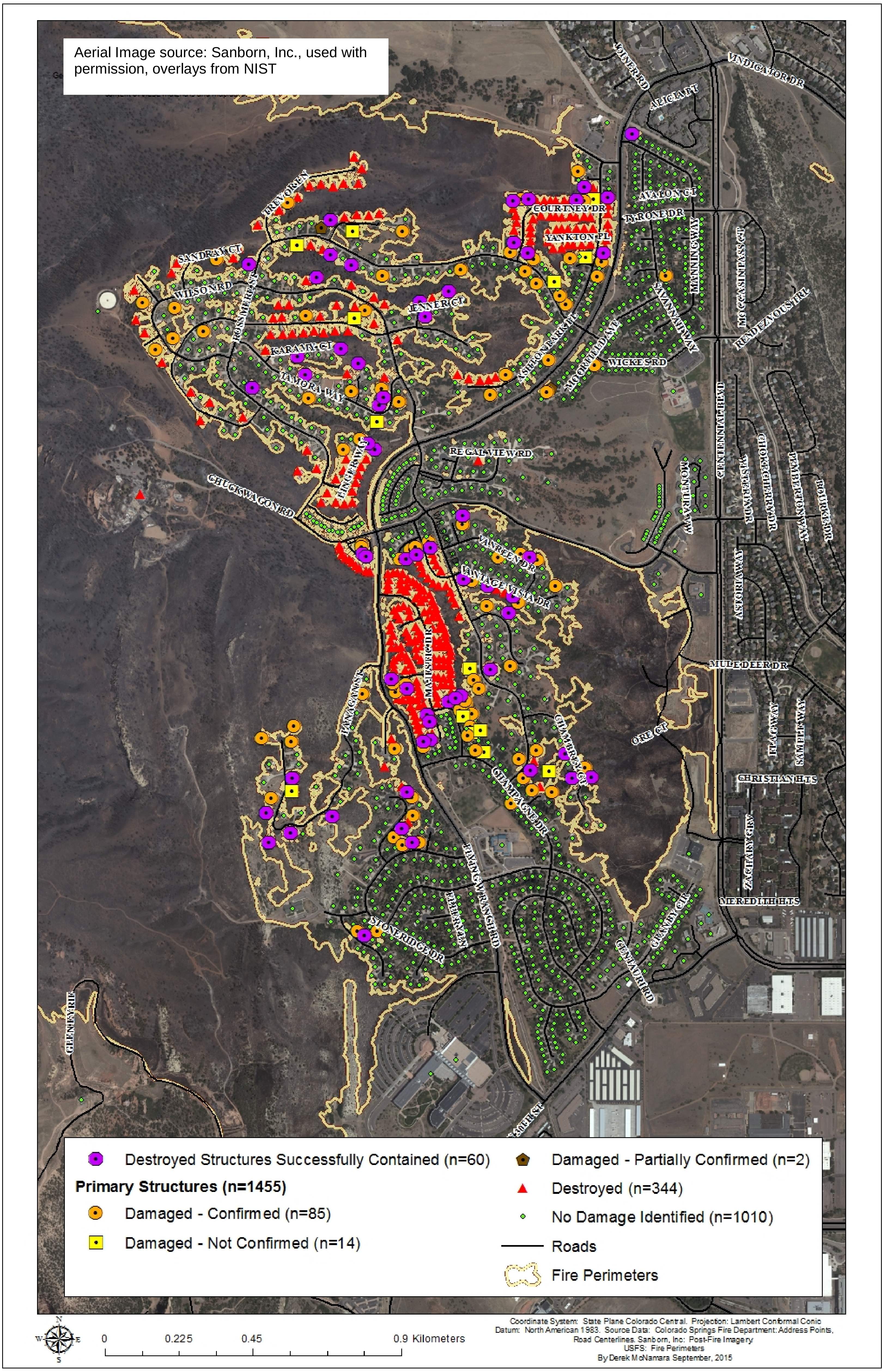
Map Figure 30 Structures with confirmed and possible damage, shown as purple hexagon with black dot, which were specifically identified by first responders as being extinguished (94/104 total or 93%).



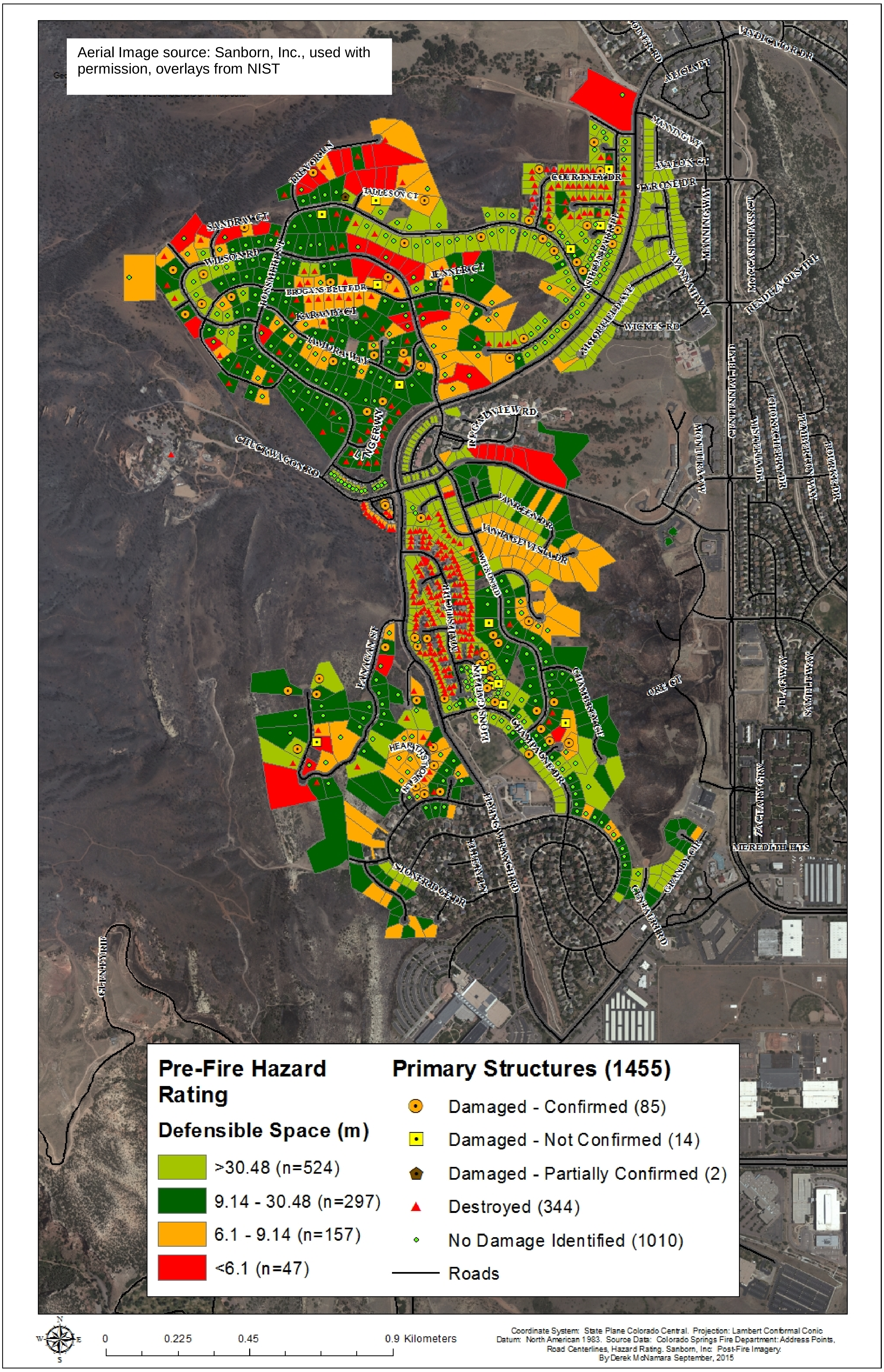
Map Figure 31 Destroyed structures, shown as purple hexagon with black dot, which were specifically identified by first responders as being attempted to be extinguished but were ultimately destroyed and also identified as first responders containing fire spread.



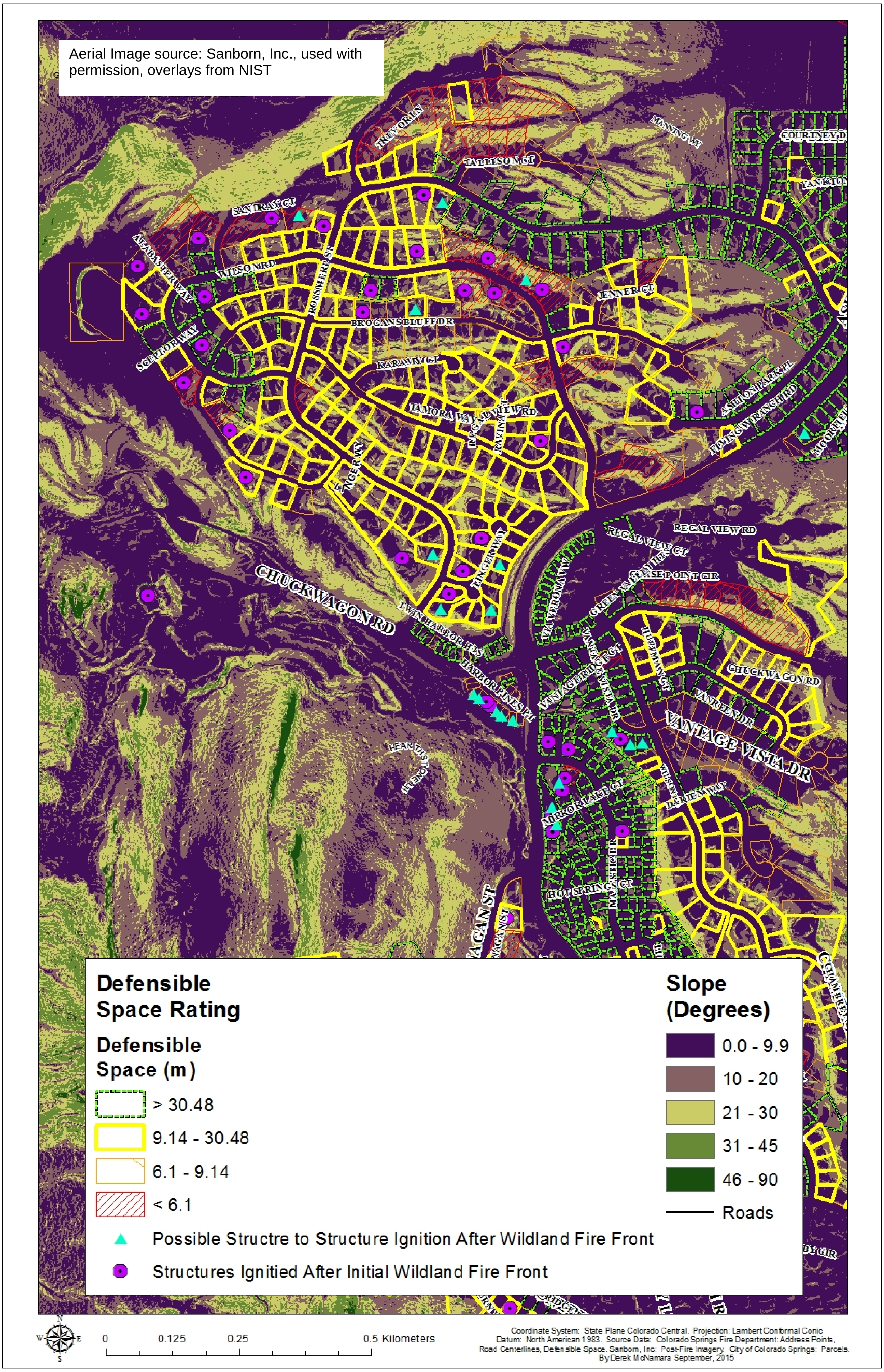
Map Figure 32 Destroyed structures, shown as purple hexagon with black dot, which were specifically identified by first responders as being attempted to be contained and fire spread did not continue to adjacent primary structures.



Map Figure 33 Destroyed structures, shown as purple hexagon with black dot, which were specifically identified by first responders as being attempted to be contained and fire spread did continue to adjacent primary structure(s), which were ultimately destroyed.



Map Figure 34 Defensible space ratings for select properties with primary structures in MSC overlaid with structure response to the Waldo Canyon Fire.



Map Figure 35 Hazard rating overlaid on slope for select areas of MSC.

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Appendix A – WUI 0 (Rapid) and WUI 1 (Complete) Data Collection Forms

NIST
National Institute of Standards and Technology

Organization: ______________
Department: ____________________

RAPID DAMAGE INSPECTION/ASSESSMENT

1	INCIDENT & FIELD DATA COLLECTOR INFORMATION						
	Event Type:	☐ Fire	☐ Flood	☐ Wind	☐ Earthquake	☐ Other: ______________	
	Incident Name: ________________			Incident Number: ________________			
	Incident Start Date: ____/____/____			Recording Date: ____/____/____		Time Recorded: __________	
	First Name:	Last Name:	Contact Phone:	Contact Email:	Camera Name:	GPS Name:	
2	SITE INFORMATION					Image Number(s):________	
	Street Number:	Street Pre-Direction: (e.g. North, South, Etc…):	Street Name:	Street Type: (e.g. RD, ST, etc….)	Unit Number:		
	City:	State	Zip ____ - ____				
	Site Assessment Method (Check All That Apply)	☐ Walked Built Property	☐ Walked Built Property & Spoke with Homeowner/Accessed Interior	☐ Spoke with Homeowner About Damage & Street Access	☐ Street Access Only	☐ Aerial Assessment	☐ Historical Records
	GPS Position:	Latitude (Decimal Degrees) ____ . ________		Longitude(Decimal Degrees) ____ . ________		Way Point # ____	
3	PRIMARY STRUCTURE DAMAGE INFORMATION					Image Number(s):________	
	Structure Landuse:	☐ Residential	☐ Business/Commercial	☐ Non-Profit	☐ Government	☐ N/D	
	Structure Type:	☐ Single Family Residence	☐ Multi-Family Residence (e.g. Apartment Complex)	☐ Guest Home	☐ Cabin	☐ Mobile Structure (e.g. Mobile Home)	
	☐ Business	☐ Educational	☐ Industrial	☐ Agricultural	☐ Fixed RV/Travel Trailer	☐ Other____	☐ Unknown (>=500 sq ft)
	Extent of Damage:	☐Destroyed	☐ Damaged	☐ No Damage	☐ N/D		
	Defensive Actions:	☐No Defensive Action	☐ Protected	☐ Saved	☐ N/D		
		☐Porch					
4	OTHER INFORMATION					Image Number(s):________	
	List Hazards Preventing Safe Building/Property Re-Entry:						
	List Other Pertinent Comments:						
	ESTIMATED VALUE OF DAMAGE/DESTRUCTION (Only Collect if Can Be Determined Accurately): $__________						

Damage Inspection Report Instructions

The Rapid Damage Assessment/Inspection (RDA) is designed to document damage and destruction to built environments from natural disasters with a focus on Wildland-Urban Interface Fires. The RDA is designed as a scalable data collection format with a full implementation documenting all of the information found below across some pertinent spatiotemporal extent. Modifications regarding extent of data to be collected and the geographic region and time period for which data is collected can be made depending on the purpose of the damage assessment/inspection.

Image Numbers: when applicable, record the image number(s) taken of the respective features in the appropriate text box. These are the names of the images as they appear in the respective camera. Certain repeating items such as leading 0's can be omitted. Recording these in conjunction with the device (camera name) will allow for linking of images to features in the office. Additionally, at a minimum, when using this form an image showing the structure address, if possible, along with explicit images of damage and destruction should be recorded. Multiple images can have the first and last image name recorded.

SECTION 1 INCIDENT & FIELD DATA RECORDER INFORMATION:

Event Type: record the type of event for which damage and destruction is being reported.
Incident Name: record the name assigned to the incident.
Time Information: record the date and time information was recorded.
Contact Information: record specific contact information for the individual recording the data being collected.
Camera/GPS Name: record the name of the camera and GPS used to record images and geographic locations respectively.

SECTION 2 SITE INFORMATION: *Each primary structure should have a site information section completed.*

Address Information: record the address information listed in the form or electronic system. Unit Number is recorded for multi-residential/commercial buildings. Each primary structure should have a site information section completed.
Site Assessment Method: record the type of access to the site used to complete the damage assessment. Identification of the method used to assess the property can provide information about the possibility of missed damage. In some cases, multiple methods might have been used.
GPS Position: record the GPS location of the respective structure. This should be recorded using a geographic coordinate system in units of decimal degrees. The way point number, can be record to save data entry time when using a hard copy form.

SECTION 3 PRIMARY STRUCTURE DAMAGE INFORMATION: *Primary structure information is recorded for each primary structure on the property. Primary structures are determined by landuse type. For example, a barn on an agricultural property might be considered the primary structure and assessed using this form. A small RV or mobile home on this agricultural property, used for temporary shelter, would be considered as a secondary structure and included in section 4 below. It is the landuse that determines the primary structure type not the size, secondary structures might be larger than primary structures.*

Structure Category: the structure category is determined by the landuse type. Primary structures with a use coinciding with the respective landuse type would have the corresponding structure category recorded.
Structure Type: record the type of primary structure.
Extent of Damage: record the damage based upon the following criteria: **Destroyed** – the structure is no longer habitable and what remains must be removed; **Damaged**: the structure received some type of damage from minor scorching to extensive damage; **No Damage** - the structure has not been damaged by the natural disaster. **N/D** - the extent of damage or destruction could not be determined.
Defensive Actions: record the damage based upon the following criteria: **No Defensive Action** – there are no known defensive actions occurring regarding the respective primary structure; **Protected**: the respective primary structure was protected against flames, radiant heat and embers produced by the WUI fire and it is unknown if the action saved the house; **Saved** - the structure was determined by assessors to have been saved by the actions of first responders. **N/D** - the extent of defensive actions conducted regarding the respective primary structure have not been determined.

SECTION 4 OTHER INFORMATION

Briefly describe hazards on the property, OTHER damage not listed in any of the above sections, other pertinent comments. Additionally, if known and calculated in a defensible manner the estimated cost of damage and destruction should be recorded.

Contact Info

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NIST National Institute of Standards and Technology

Organization: ____________________

Department: ________________________

COMPLETE DAMAGE INSPECTION/ASSESSMENT

1	INCIDENT & FIELD DATA COLLECTOR INFORMATION					
	Event Type:	☐ Fire	☐ Flood	☐ Wind	☐ Earthquake	☐ Other: ____________________
	Incident Name: ______________________			Incident Number: ______________________		
	Incident Start Date: ____/____/_____			Recording Date: ____/____/_____		Time Recorded: ______________
	First Name: ________	Last Name: ______________	Contact Phone: ____________	Contact Email: ____________	Camera Name: ____________	GPS Name: ____________

2	SITE INFORMATION					Image Number(s):__________
	Street Number: ______	Street Pre-Direction: (e.g. North, South, Etc…): ________	Street Name: ______________		Street Type: (e.g. RD, ST, etc….) ________	Unit Number: ________
	City: ______________		State ________		Zip _____-_____	
	Site Assessment Method (Check All That Apply)	☐ Walked Built Property	☐ Walked Built Property & Spoke with Homeowner/Accessed Interior	☐ Spoke with Homeowner About Damage & Street Access	☐ Street Access Only	☐ Aerial Assessment	☐ Historical Records
	GPS Position:	Latitude (Decimal Degrees) ______ . ____________		Longitude(Decimal Degrees) ______ . ____________		Way Point # ______

3	PRIMARY STRUCTURE DAMAGE INFORMATION								Image Number(s):__________		
	Structure Landuse:	☐ Residential	☐ Business/Commercial		☐ Non-Profit	☐ Government			☐ N/D		
	Structure Type:	☐ Single Family Residence	☐ Multi-Family Residence (e.g. Apartment Complex)		☐ Guest Home	☐ Cabin			☐ Mobile Structure (e.g. Mobile Home)		
	☐ Business	☐ Educational	☐ Industrial	☐ Agricultural	☐ Fixed RV/Travel Trailer	☐ Other______			☐ Unknown (>=500 sq ft)		
	Extent of Damage:	☐Destroyed	☐ Damaged		☐ No Damage				☐ N/D		
	Defensive Actions:	☐No Sign Defensive Action(s)	☐ Protected		☐ Saved	☐ Defensive Action Sign(s) ____________			☐ N/D		
	Damaged or Destroyed Features (Check All That Apply)	☐Roof	☐Siding	☐Soffit Eaves	☐Foundation	☐Windows	☐Doors	☐Garage Doors	☐Other ____	☐Not Determined	☐ None
	Damaged or Destroyed Attachments (Check All That Apply)	☐Deck ☐Porch	☐Pergola	☐Stairs	☐Fence	☐Retaining Wall	☐Car Port		☐Other ____	☐Not Determined	☐ None

4	VEGETATION DAMAGE INFORMATION					Image Number(s):__________	
	Fire Damaged Vegetation (Check All That Apply)	☐ 0-30 feet	☐ 30-60 feet	☐ 60-100 feet	☐ 100-200 feet	☐ 200-300 feet	☐ >300 feet

5	SECONDARY STRUCTURE DAMAGE INFORMATION (Structures with a landuse different from the primary landuse and typically OVER 100 SQ. FT. Destroyed structures were the use could not be determined should be recorded as secondary if less than 500 square feet)			Image Number(s):__________	
	Count of Damaged Structures:	Destroyed ____	Damaged ____	No Damage ____	N/D ____

6	VEHICLE DAMAGE INFORMATION		Image Number(s):__________
	Number of Vehicles Destroyed: _____	Number of Vehicles Damaged:______	Number of Vehicles No Damage: ______

7	DETACHED COMBUSTIBLE DAMAGE INFORMATION (List Counts in Blank Space by Type)				Image Number(s):__________	
	___Deck/Pergola	___Fence	___Retaining Wall	___Playground	___Wood Pile	___Other

8	OTHER INFORMATION	Image Number(s):__________
	List Hazards Preventing Safe Building/Property Re-Entry:	
	List Other Pertinent Comments:	
	ESTIMATED VALUE OF DAMAGE/DESTRUCTION (Only Collect if Can Be Determined Accurately): $______________	

Damage Inspection Report Instructions

The Complete Damage Assessment/Inspection (CDA) is designed to document damage and destruction to built environments from natural disasters with a focus on Wildland-Urban Interface Fires. The CDA is designed as a scalable data collection format with a full implementation documenting all of the information found below across some pertinent spatiotemporal extent. Modifications regarding extent of data to be collected and the geographic region and time period for which data is collected can be made depending on the purpose of the damage assessment/inspection.

Image Numbers: when applicable, record the image number(s) taken of the respective features in the appropriate text box. These are the names of the images as they appear in the respective camera. Certain repeating items such as leading 0's can be omitted. Recording these in conjunction with the device (camera name) will allow for linking of images to features in the office. Additionally, at a minimum, when using this form an image showing the structure address, if possible, along with explicit images of damage and destruction should be recorded. Multiple images can have the first and last image name recorded.

SECTION 1 INCIDENT & FIELD DATA RECORDER INFORMATION:

Event Type: record the type of event for which damage and destruction is being reported.
Incident Name: record the name assigned to the incident.
Time Information: record the date and time information was recorded.
Contact Information: record specific contact information for the individual recording the data being collected.
Camera/GPS Name: record the name of the camera and GPS used to record images and geographic locations respectively.

SECTION 2 SITE INFORMATION: *Each primary structure should have a site information section completed.*

Address Information: record the address information listed in the form or electronic system. Unit Number is recorded for multi-residential/commercial buildings. Each primary structure should have a site information section completed.
Site Assessment Method: record the type of access to the site used to complete the damage assessment. Identification of the method used to assess the property can provide information about the possibility of missed damage. In some cases, multiple methods might have been used.
GPS Position: record the GPS location of the respective structure. This should be recorded using a geographic coordinate system in units of decimal degrees. The way point number, can be record to save data entry time when using a hard copy form.

SECTION 3 PRIMARY STRUCTURE DAMAGE INFORMATION: *Primary structure information is recorded for each primary structure on the property. Primary structures are determined by landuse type. For example, a barn on an agricultural property might be considered the primary structure and assessed using this form. A small RV or mobile home on this agricultural property, used for temporary shelter, would be considered as a secondary structure and included in section 4 below. It is the landuse that determines the primary structure type not the size, secondary structures might be larger than primary structures.*

Structure Category: the structure category is determined by the landuse type. Primary structures with a use coinciding with the respective landuse type would have the corresponding structure category recorded.
Structure Type: record the type of primary structure.
Extent of Damage: record the damage based upon the following criteria: **Destroyed** – the structure is no longer habitable and what remains must be removed; **Damaged**: the structure received some type of damage from minor scorching to extensive damage; **No Damage** - the structure has not been damaged by the natural disaster. **N/D** - the extent of damage or destruction could not be determined.
Defensive Actions: record the damage based upon the following criteria: **No Defensive Action** – there are no known defensive actions occurring regarding the respective primary structure; **Protected**: the respective primary structure was protected against flames, radiant heat and embers produced by the WUI fire and it is unknown if the action saved the house; **Saved** - the structure was determined by assessors to have been saved by the actions of first responders. **N/D** - the extent of defensive actions conducted regarding the respective primary structure have not been determined.
Damaged Features: check all the features of the respective primary structure that have been identified as damaged or destroyed. If the primary structure was completely destroyed this would be record as N/D (not determined).
Damaged Attachments: check all the attachments on the primary structure that have been identified as damaged or destroyed. If the primary structure was completely destroyed this would be recorded as N/D (not determined).

SECTION 4 VEGETATION DAMAGE INFORMATION: *Fire damaged vegetation information is recorded.*

Fire Damaged Vegetation: check all distance categories that had some fire damaged vegetation (i.e., from scorched to complete consumption).

SECTION 5 SECONDARY STRUCTURE DAMAGE INFORMATION: *Secondary structures are those that have a different purpose from the primary landuse type of the property. Multiple residential dwellings on a single parcel would be recorded individually on a separate form. Secondary structures are associated with only one primary building on the property. Situations might be encountered where a detached garage or other secondary structure is significantly larger than the dwelling. Remember, the use determines whether a structure is primary or secondary, not the relative size, location on the property or appearance.*

Count of Damaged Structures: record the number of secondary structures in the respective damaged category.
Data collectors should record -99 in the respective damage category if the information could not be determined.
Cumulative Size of Affected Secondary Structures: Sum the square footages of all affected secondary structures and enter in this field. Data collectors should record -99 if this cannot be determined.

SECTION 6 VEHICLE DAMAGE INFORMATION

Number of Vehicles Destroyed: record the number of vehicles that were left with no part undamaged.
Number of Vehicles Damaged: record the number of vehicles that received damage, even if the damage is minor.
Number of Vehicles No Damage: record the number of vehicles with no damage.
Cumulative Size of Affected Secondary Structures: Sum the square footages of all affected secondary structures and enter in this field. Data collectors should record -99 if this cannot be determined.

SECTION 7 Detached Combustible Damage Information

Damaged/Destroyed Detached Features: record the number of damaged and destroyed detached features by feature category.

SECTION 8 OTHER INFORMATION

Briefly describe hazards on the property, OTHER damage not listed in any of the above sections, other pertinent comments. Additionally, if known and calculated in a defensible manner the estimated cost of damage and destruction should be recorded.

Contact Info

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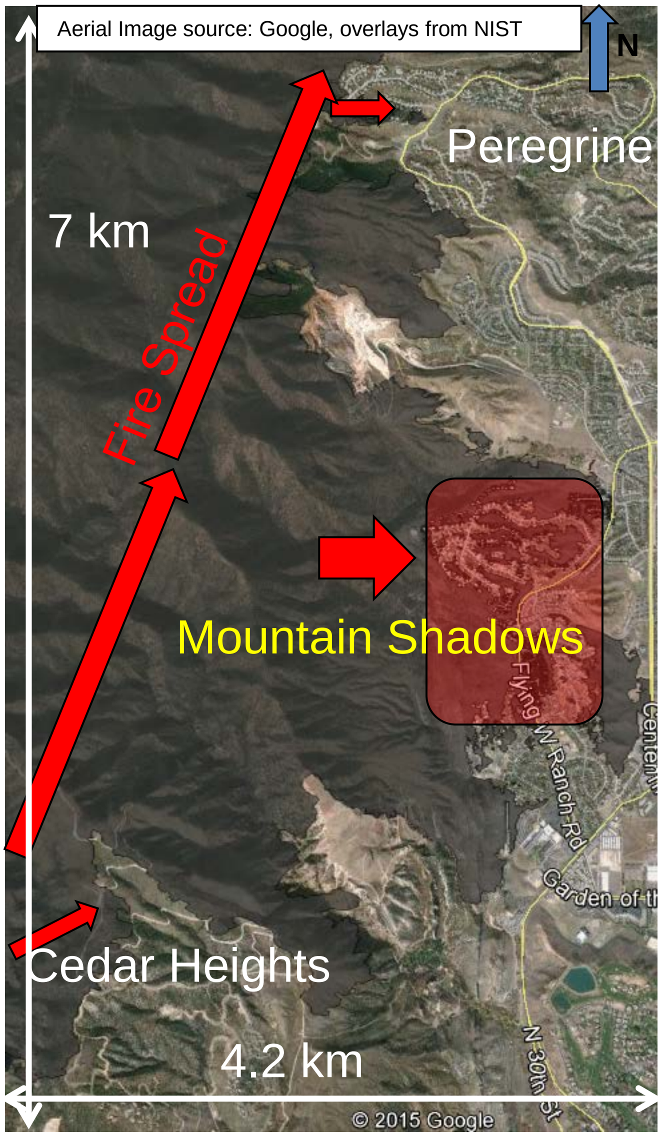
Appendix B – Fire Progression and Weather Data

Waldo Fire – General Fire Progression



Northern Mountain Shadows Community

Middle Mountain Shadows Community

Southern Mountain Shadows Community

Waldo Fire Weather Data

Source: KAFF Air Force Academy

June 26

Time (MDT)	Temp. (°C)	Dew Point (°C)	Humidity	Wind Dir	Wind Speed (km/h)	Gust Speed (km/h)	Conditions
12:55 AM	**15.00**	**-6.28**	23%	North	**13.0**	**-**	Clear
1:55 AM	**14.22**	**-5.00**	26%	North	**18.5**	**-**	Clear
2:55 AM	**15.89**	**-5.00**	24%	North	**20.4**	**-**	Clear
3:55 AM	**17.72**	**-3.89**	23%	NNE	**14.8**	**-**	Clear
4:55 AM	**17.89**	**-3.28**	24%	Variable	**7.4**	**-**	Clear
5:55 AM	**20.00**	**-2.89**	21%	WSW	**13.0**	**-**	Clear
6:55 AM	**26.22**	**-2.50**	15%	NE	**13.0**	**-**	Haze
7:55 AM	**28.72**	**-2.00**	13%	East	**7.4**	**-**	Clear
8:55 AM	**31.39**	**-1.89**	12%	SSW	**16.7**	**-**	Clear
9:55 AM	**32.89**	**-5.22**	8%	SW	**14.8**	**33.3**	Clear
10:55 AM	**33.11**	**-5.00**	8%	South	**5.6**	**-**	Clear
11:55 AM	**34.39**	**-6.22**	7%	SE	**25.9**	**35.2**	Partly Cloudy
12:55 PM	**34.72**	**-7.61**	6%	SSE	**16.7**	**38.9**	Partly Cloudy
1:55 PM	**34.50**	**-7.72**	6%	South	**35.2**	**57.5**	Scattered Clouds
2:55 PM	**34.50**	**-5.72**	7%	SSE	**37.0**	**55.5**	Partly Cloudy
3:55 PM	**33.78**	**-6.28**	7%	SSE	**25.9**	**42.6**	Partly Cloudy
4:55 PM	**32.89**	**-6.89**	7%	SE	**24.1**	**38.9**	Clear
5:13 PM	**33.00**	**-4.00**	9%	West	**44.4**	**64.9**	Clear
5:17 PM	**32.00**	**2.00**	15%	West	**38.9**	**64.9**	Clear
5:55 PM	**29.78**	**2.11**	17%	West	**27.8**	**57.5**	Partly Cloudy
6:55 PM	**29.72**	**1.11**	16%	NNW	**33.3**	**48.1**	Clear
8:55 PM	**25.11**	**2.89**	24%	NNE	**24.1**	**-**	Clear
9:55 PM	**21.78**	**2.78**	29%	NNW	**5.6**	**-**	Clear
10:55 PM	**20.11**	**2.72**	32%	NNW	**13.0**	**-**	Clear
11:55 PM	**19.89**	**1.39**	29%	Variable	**7.4**	**-**	Clear

June 27

Time (MDT)	Temp. (°C)	Dew Point (°C)	Humidity	Wind Dir	Wind Speed (km/h)	Gust Speed (km/h)	Conditions
12:55 AM	**20.28**	**1.61**	29%	North	**9.3**	**-**	Clear
1:55 AM	**18.50**	**2.50**	34%	North	**5.6**	**-**	Clear
2:55 AM	**17.61**	**2.28**	36%	North	**5.6**	**-**	Clear
3:55 AM	**15.61**	**2.89**	43%	NNW	**14.8**	**-**	Clear
4:50 AM	**16.00**	**3.00**	42%	North	**13.0**	**-**	Mostly Cloudy
4:55 AM	**15.39**	**3.28**	44%	North	**14.8**	**-**	Mostly Cloudy
5:25 AM	**16.00**	**3.00**	42%	NNW	**14.8**	**-**	Scattered Clouds
5:55 AM	**20.72**	**2.39**	30%	NW	**9.3**	**-**	Clear
6:55 AM	**24.28**	**3.50**	26%	Variable	**9.3**	**-**	Clear
7:55 AM	**27.11**	**3.28**	22%	Calm	**Calm**	**-**	Clear
8:55 AM	**29.39**	**3.22**	19%	SE	**11.1**	**-**	Clear
9:55 AM	**30.50**	**2.61**	17%	SE	**16.7**	**-**	Clear
10:55 AM	**30.72**	**3.28**	17%	West	**24.1**	**38.9**	Partly Cloudy
11:55 AM	**32.11**	**1.22**	14%	WNW	**22.2**	**48.1**	Partly Cloudy
12:55 PM	**30.50**	**0.61**	15%	West	**14.8**	**29.6**	Clear
1:55 PM	**30.22**	**0.22**	14%	North	**11.1**	**-**	Partly Cloudy
2:27 PM	**29.00**	**2.00**	18%	East	**13.0**	**-**	Clear
2:55 PM	**29.78**	**2.61**	18%	East	**9.3**	**-**	Scattered Clouds
3:26 PM	**28.00**	**4.00**	21%	WSW	**66.6**	**94.5**	Scattered Clouds
3:30 PM	**27.00**	**6.00**	26%	West	**44.4**	**94.5**	Haze
3:31 PM	**27.00**	**7.00**	28%	West	**42.6**	**94.5**	Haze
3:34 PM	**26.00**	**7.00**	30%	West	**66.6**	**94.5**	Haze
3:35 PM	**26.00**	**7.00**	30%	West	**61.2**	**94.5**	Haze
3:39 PM	**25.00**	**7.00**	32%	West	**51.8**	**85.1**	Haze
3:42 PM	**25.00**	**6.00**	29%	West	**59.2**	**85.1**	Haze
3:45 PM	**24.00**	**7.00**	34%	West	**55.5**	**79.7**	Haze
3:55 PM	**23.61**	**6.89**	34%	West	**50.1**	**74.0**	Scattered Clouds
4:55 PM	**25.11**	**5.72**	29%	North	**9.3**	**-**	Scattered Clouds
5:13 PM	**24.00**	**6.00**	31%	NE	**40.7**	**-**	Partly Cloudy
5:55 PM	**26.78**	**5.22**	25%	Calm	**Calm**	**-**	Clear
6:55 PM	**26.39**	**5.89**	27%	North	**14.8**	**-**	Clear
7:55 PM	**26.50**	**5.78**	27%	North	**13.0**	**-**	Partly Cloudy
8:55 PM	**24.28**	**6.61**	32%	ENE	**7.4**	**-**	Scattered Clouds
9:55 PM	**23.00**	**7.89**	38%	SSE	**16.7**	**-**	Partly Cloudy
10:55 PM	**24.00**	**4.72**	29%	Calm	**Calm**	**-**	Clear
11:55 PM	**20.61**	**6.72**	40%	NNW	**14.8**	**-**	Clear

Source KCOS – Colorado Springs Airport 38°48’21”N 104°42’03”W Weather Observations for June 26, 2012										
Time (MDT)	Temp (°C)	Dew Point (°C)	Humidity (%)	Pressure (mm)	Visibility (km)	Wind Dir	Wind Speed (km/h)	Gust speed (km/h)	Precip (mm)	Conditions
12:54	20.0	-6.0	17	754.4	16.1	NNE	7.4	-	-	Partly Cloudy
1:54	18.0	-5.0	21	754.1	16.1	NE	11.1	-	-	Partly Cloudy
2:54	19.0	-4.0	21	754.1	16.1	North	13.0	-	-	Partly Cloudy
3:54	22.0	-3.0	19	753.9	16.1	North	9.3	-	-	Partly Cloudy
4:54	19.0	-3.0	23	754.6	16.1	West	5.6	-	-	Partly Cloudy
5:54	18.9	-2.2	24	754.6	11.3	North	11.1	-	-	Partly Cloudy
6:54	22.8	0.6	23	754.4	16.1	NNE	7.4	-	-	Partly Cloudy
7:54	28.9	0.6	16	754.1	12.9	ENE	5.6	-	-	Partly Cloudy
8:54	31.1	-2.2	12	754.4	12.9	ESE	11.1	-	-	Scattered Clouds
9:54	32.8	-0.6	12	754.1	16.1	SE	5.6	-	-	Scattered Clouds
10:54	35.6	-5.6	7	753.9	16.1	SSW	29.6	50.1	-	Scattered Clouds
11:54	35.6	-6.7	6	753.6	16.1	South	25.9	44.4	-	Scattered Clouds
12:54	36.7	-4.4	7	753.1	16.1	South	35.2	51.8	-	Scattered Clouds
1:54	36.7	-4.4	7	753.1	16.1	South	24.1	53.8	-	Scattered Clouds
2:54	37.2	-4.4	7	752.3	16.1	South	16.7	33.3	-	Scattered Clouds
3:54	37.0	-6.0	6	751.8	16.1	South	24.1	31.5	-	Scattered Clouds
4:54	37.0	-9.0	5	751.6	16.1	South	33.3	46.3	-	Scattered Clouds
5:54	37.0	-1.0	9	751.6	16.1	WNW	14.8	44.4	-	Scattered Clouds
6:54	34.0	1.0	12	751.8	16.1	NW	31.5	44.4	-	Scattered Clouds
7:54	31.0	2.0	16	752.1	9.7	NNW	18.5	-	-	Smoke
8:54	29.0	2.0	18	752.3	4.8	North	29.6	-	-	Smoke
9:54	28.0	2.0	19	752.9	12.9	NNW	18.5	-	-	Scattered Clouds
10:54	27.0	2.0	20	752.6	16.1	North	18.5	-	-	Scattered Clouds
11:54	26.0	3.0	23	753.1	16.1	NW	9.3	-	-	Scattered Clouds

Appendix C – Cedar Heights Timeline

Event	Date	Time	TD	Note
Mobilized Station 13 and Station 5 to recon in Cedar Heights	6/23/12	12:15	3	
First Task Force on scene	6/23/12	12:35	3	W/L 9 prepped 7 primary structures
First Responders sent to the Quarry	6/23/12	12:35	3	E5 and W/L 9
Resident Evacuation order given	6/23/12	12:40		B5
Structure prepping started	6/23/12	12:40		20 primary structures prepped by B5
Water Tender requested to be sent to Cedar Heights	6/23/12	12:48		E5
Working on request for reverse 911 to Cedar Heights	6/23/12	12:55		Disptach CMD4
CSFD PIO tweets Cedar Heights evacauation begins	6/23/12	13:05		Twitter
Air Ops begin with helicopter with buckets	6/23/12	13:10		Disptach CMD4
Eagle Lake campground evacuation	6/23/12	13:18		B13
ENS sent to Cedar Heights residents	6/23/12	13:39		E911
Fire retardent drop comes into Cedar Heights	6/23/12	14:08		Dispatch on Command 4
Civilians Escorted out (from gun range)	6/23/12	14:33-14:42		W/L9 escorts out of gun range along with D1
Geocast for Voluntary Evac from Mountain Shadows S/E area 2	6/23/12	14:58		Police Report
All evacuations for Cedar Heights are mandatory	6/23/12	15:00		PIO on Twitter
Voluntary evacuation for 1000 people at Glen Eyrie		15:11		WEB EOC post 129
ENS message to Southern Mountain Shadows	6/23/12	15:12		PIO on Twitter
Mandatory evacuation all residents north of 30th to Chuckwagon	6/23/12	15:17		PIO on Twitter
Mandatory evacuation of Cedar Heights, Mountain Shadows and Glen Eyrie	6/23/12	15:21		WEB EOC post 131
Task Force to Cedar Heights	6/23/12	15:29		E5, B5, E18, B18, E2, WL9 CSU 1/2/3 TF1
Another ENS sent to Mountain Shadows Area 2	6/23/12	15:31		
First responders sent to Mountain Shadows	6/23/12	15:33		E7, B7, E13, B13, B9, WL4 Task Force 1
Structure prepping started in Mountain Shadows	6/23/12	15:35		E17, B17, E19, B19
Bulldozer line started widen fire break	6/23/12	15:41	15	Dispatch on Command 4
Flying W Ranch evacuation notification	6/23/12	15:51		PD CAD 12251014 line 49

Event	Date	Time	TD	Note
Voluntary evacuation for Mountain Shadows area west of 30th, north of Chuckwagon, Allegheny east to I-25, north to the Air Force Academy	6/23/12	16:02		PIO Twitter
Evacuation of Glen Eyrie 207 people	6/23/12	16:10-18:23		CSFD Duty report D2A
Evacuation of Verizon (MCI) building	6/23/12	16:14		PD CAD 12251110
Evacuation completed quarry down to upper Cedar Heights	6/23/12	16:23		PD CAD 12250775
Additional resources from outside city limits brought in for city coverage	6/23/16	17:57		
Air support finished for the night	6/23/16	20:24		CAD12250775
Structure Prep completed Cedar Heights	6/23/12	23:05		E20 B20 Duty report
Fire cresting at Cedar Heights	6/23/12	23:41		PD CAD 12250775
Fuel break getting bumped	6/23/12	22:00	3	last until 3:00am
Fire hits slurry lines	6/23/12	23:49		CAD12250775
Fire enters community behind fuel break	6/23/12	0:00	3	
Work done on slop over	6/24/12	0:30	41	
2nd Bulldozer line Outback Vista to Quarry	6/24/12	1:00		CSFD duty report TFL1N
Fire crossed into Cedar Heights near upper bulldozer trail	6/24/12	2:30		
Slop over contained, less than 1 acre (TD3), pulled crews off bulldozer line due to extreme fire conditions	6/24/12	4:00		CSFD duty report TFL1N
Bulldozer line to quarry started	6/24/12	9:00		CSFD duty report TFL5B
Air Tanker drops above bulldozer line in Cedar Heights	6/24/12	10:30		CSFD duty report TFL1N
Column 4 1/2 miles from Glen Eyrie Water tower	6/24/12	11:01		CAD 12250775
2nd ENS message sent to Cedar Heights	6/24/12	11:37		Web EOC post 174
Safety zone at Twisted Oak circle at north end of Cedar Heights	6/24/13	12:34	3	Duty report D1A
Air drops made around cell and repeater towers	6/24/12	12:34	3	
Fire reaches community at ridge above Cedar Heights	6/24/12	13:57		CAD 12250775
Fire bumps fuel break in fuel treated area(spots started between retardant and fuel break as well as beyond fuel break) Note: from TD3: summary, retardant, road widening, fuel mitigation and response resulted in controlled environment	6/25/12	0:00	3	
Fire on three sides of Cedar Heights	6/25/12	8:00		ICS 202 6/25

Event	**Date**	**Time**	**TD**	**Note**
Burn Ban enacted	6/25/12	18:00		PIO Twitter
Second fire front bumps northern edge of community	6/25/12	22:00-03:00	3	
Fire moves to the north (past Cedar Heights)	6/25/12	19:00-20:00	3	
Safety Zone information	6/26/12	6:00		CSFD duty report STPIN
First request to reassign from Cedar Heights to Mountain Shadows	6/26/12	18:00	45	CSFD Duty report TFL2N
Bulldozer line from water tower to quarry in Mountain Shadows	6/26/12	8:30	12	line never cut because fire is coming
Escorts begin for evacuees returning to Cedar Heights	6/26/12	9:00		CSPD
Escorts stop into Cedar Heights and all are pulled out	6/26/12	9:45		CSPD
Mountain Shadows residents allowed in for 30 min visits	6/26/12	10:56		Twitter
Voluntary Evacuation for Area 5 requested	6/26/12	11:00		CSPD unit log
Mountain Shadows escorts cancelled due to fire activity	6/26/12	11:32		City Press Release
Pre-evacuation notices being sent to areas 3 and 5	6/26/12	12:05		
Pre- Evac zone increased to include Centennial, Orchard Valley and USAFA up to the northern boundary	6/26/12	12:18		WEB EOC post 259
Pre-evacuation notice for Mountain Shadows and Peregrine	6/26/12	13:40		E911
Thunderstorm causes column collapse, fire pushed north and east at high rate of speed, bulldozer lines abandoned in Flying W ranch and Wolfe Ranch	6/26/12	16:00		CSFD duty report 1C1A
Fire enters the city limits	6/26/12	16:00		
Selected resources reassigned to Mountain Shadows	6/26/12	20:30		Task Forces 6 and 7
Request approved to move from Cedar Heights to Tiffany Square	6/26/12	20:30	45	13 engines moved, 3 Task Forces
Task Forces arrives from Cedar Heights to Tiffany Square	6/26/12	21:00		Task Forces 6 and 7

Appendix D – Peregrine Timeline

Peregrine Time Line	Date	Time	TD	Notes
EVENT				
Pre-evacuation for Peregrine under development Zone 3	6/26/2012	12:28		City After Action timeline
Pre-evacuation notice for Mountain Shadows and Peregrine	6/26/2012	13:30		E911
E103 assigned for spot fires, none found	6/26/2012	18:00		CSFD duty report
Mandatory evacuation for northern Mtn Shadows and Peregrine	6/26/2012	18:21		City After Action timeline
CSU shuts off utilities to Peregrine and other areas	6/26/2012	17:11		City After Action timeline
USAFA being evacuated	6/26/2012	18:47		WEB EOC post 303
ENS message sent to Rockrimmon loop	6/26/2012	19:40		WEB EOC post 312
Staging at Tiffany Square begins	6/26/2012	20:00	10	
Fire in wildlands, no structures involved	6/26/2012	20:00	11	
County puts in bulldozer line from water tower to Blodgett	6/26/2012	20:00	11	
Patrol of Coldwater, Hollandale by PPCC engine	6/26/2012	2:45	141	
Denver Task Force assigned to Peregrine	6/27/2012	3:00	11	
Bulldozer line from barn to trail some fire in field	6/27/2012	3:00	11	
Significant flare up to the northwest of Blodgett Dr.	6/27/2012	5:00		City After Action Timeline
Fire off Angelstone Pt, engines shelter in place	6/27/2012	11:30	11	
Fire along Woodman Road near Ruststone Ct identified. E3 and B6 crews attack and control spread prior to helicopter water bucket drops	6/27/2012	11:45	16	City After Action Timeline
Flame front blows through area near Blodgett WL 9 extinguishes small grass/spot fires, cut line and back burned hillside along Blodgett.	6/27/2012	14:00		City After Action Timeline
Fire making significant downhill run from Blodgett Peak. E8 engaged in fire that was in the undergrowth and brush, threatening 3 primary structures just below Angelstone Point. Stayed engaged 3-4 hours.	6/27/2012	15:00	11	
E8 prepped primary structures along Sawbuck. Increase in fire activity in Blodgett open space.	6/27/2012			
Fire controlled, no longer a threat to property	6/28/2012	17:00	67	

Appendix E – Additional Image and Video Sources from Used for Fire Timeline Creation and Fire Behavior Assessment

Appendix E Table 1 Pre-fire property information data sources.

Data Source	Link	Description
El Paso County Parcel Viewer	http://gis2.asr.elpasoco.com/	Web mapping service that contains pre-fire information about property owner, property size, building size, building value and property identifier.

Appendix E Table 2 Selected videos of the Waldo Canyon Fire.

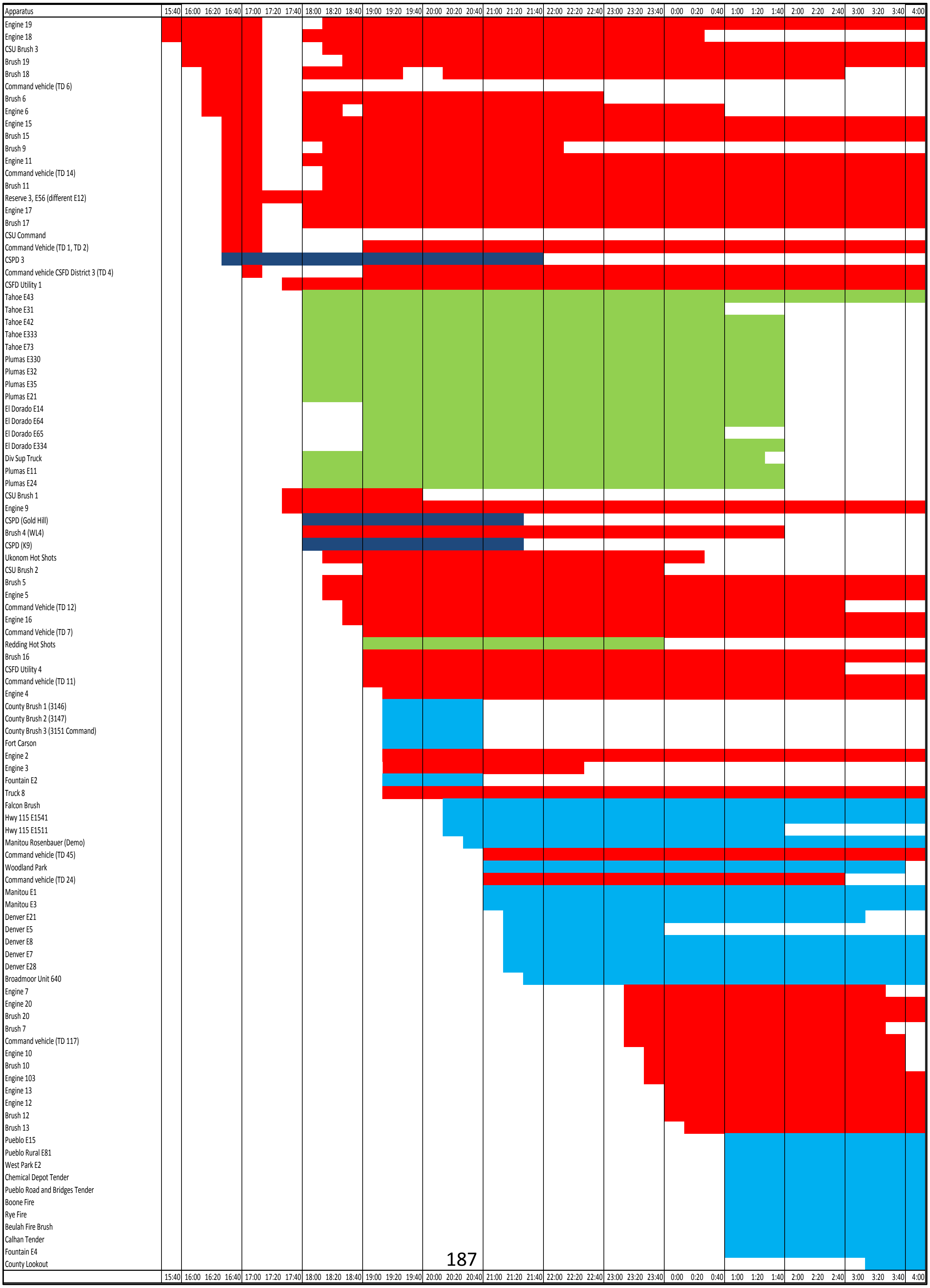
Image Video Description	Comments
Steve Moraco Five day time lapse of the Waldo Canyon taken from Monument Colorado.	Video shows buildup of smoke column and black smoke produced from destroyed primary structures.
Fox 21 News video showing primary structures burning in Colorado Springs at the most eastern area.	Time stamps are not shown. Correlation with the video allows for time identification. Video shows almost all primary structures in eastern portion.
KKTV news video taken at 8:32 pm showing most south easterly primary structure burning.	This video can be used to correlate time of burning primary structures to Fox 21 news footage
Mountain Shadows is Burning: Six videos showing burning along the northern most edge of destruction, taken by an unidentified camera man	These videos show the structure to structure fire spread along Courtney Drive. Additionally, general chronologies of burning primary structures on Trevor Lane can be ascertained from some of these videos.

Appendix E Table 3 Selected images of the Waldo Canyon Fire.

Image Video Description	Comments
Lee Roth photographed, and documented with verbal descriptions, the fire as it crested the ridge and traveled down into Mountain Shadows.	The location from which these images were taken is only generally known to be east of the fire. The narration describes the effects of the so called "collapse" of the smoke column.
Image from FLICKR showing last four primary structures on Linger Way burning, as well as primary structures to the west.	This image helps identify the chronological progression of burned primary structures for Linger Way. The image identifies primary structures that are not burning on the west side of Linger Way and other burning primary structures.
A set of 180 photographs and videos which show the fire traveling down the hill before it reached Mountain Shadows.	These images help to confirm and enhance interpretations of the images from Lee Roth.
Aerial images of various communities.	These images show areas that were defended, as interpreted from the lack of white ash, indicating water suppression on the structure.
Aerial Image of Water Suppression on Linger Way.	Image shows lack of complete combustion on two right most primary structures in the image, which were also shown to be the last to burn.

Appendix F – Apparatus in Mountain Shadows between 15:40 Tuesday June 26, 2012 and 04:00 Wednesday June 2, 2012

The following figure lists the arrival and departure times of the different apparatus that were involved in firefighting activities in MSC. The apparatus is color codes, red for CSFD, dark blue for CSPD, Green for USFS and light blue for mutual aid.


Apparatus
15:40
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2:00
2:20
2:40
3:00
3:20
3:40
4:00
Engine 19
Engine 18
CSU Brush 3
Brush 19
Brush 18
Command vehicle (TD 6)
Brush 6
Engine 6
Engine 15
Brush 15
Brush 9
Engine 11
Command vehicle (TD 14)
Brush 11
Reserve 3, E56 (different E12)
Engine 17
Brush 17
CSU Command
Command Vehicle (TD 1, TD 2)
CSPD 3
Command vehicle CSFD District 3 (TD 4)
CSFD Utility 1
Tahoe E43
Tahoe E31
Tahoe E42
Tahoe E333
Tahoe E73
Plumas E330
Plumas E32
Plumas E35
Plumas E21
El Dorado E14
El Dorado E64
El Dorado E65
El Dorado E334
Div Sup Truck
Plumas E11
Plumas E24
CSU Brush 1
Engine 9
CSPD (Gold Hill)
Brush 4 (WL4)
CSPD (K9)
Ukonom Hot Shots
CSU Brush 2
Brush 5
Engine 5
Command Vehicle (TD 12)
Engine 16
Command Vehicle (TD 7)
Redding Hot Shots
Brush 16
CSFD Utility 4
Command vehicle (TD 11)
Engine 4
County Brush 1 (3146)
County Brush 2 (3147)
County Brush 3 (3151 Command)
Fort Carson
Engine 2
Engine 3
Fountain E2
Truck 8
Falcon Brush
Hwy 115 E1541
Hwy 115 E1511
Manitou Rosenbauer (Demo)
Command vehicle (TD 45)
Woodland Park
Command vehicle (TD 24)
Manitou E1
Manitou E3
Denver E21
Denver E5
Denver E8
Denver E7
Denver E28
Broadmoor Unit 640
Engine 7
Engine 20
Brush 20
Brush 7
Command vehicle (TD 117)
Engine 10
Brush 10
Engine 103
Engine 13
Engine 12
Brush 12
Brush 13
Pueblo E15
Pueblo Rural E81
West Park E2
Chemical Depot Tender
Pueblo Road and Bridges Tender
Boone Fire
Rye Fire
Beulah Fire Brush
Calhan Tender
Fountain E4
County Lookout

Appendix G – WUI Data Collection Improvements

1. Data integration in GIS is critical in reducing errors associated with the evaluation of limited data sources.
2. Images and video taken by first responders are critical in developing the event timeline and in reconstructing the defensive actions.
3. First responder recollection of events in space and time is critical in developing the event timeline and in reconstructing the defensive actions.
4. Images and video taken by first responders should be collected before or during technical discussions (this was also identified during the Tanglewood complex fire case study).
5. Crowd sourcing applications should be developed to provide a means for first responders to initially record activity at an incident.
6. The crowd sourcing application is not intended as a means to replace technical discussions but will enhance them such that images can be provided to fire assessors before discussions and information is lost to memory over time. Properly developed applications would also provide first responders with internal mechanisms to evaluate what happened at the incident and improve safety and effectiveness at future incidents.
7. An effective data collection team would include the PI, a minimum of one note taker and a GIS specialist to handle AVLs, Bing Maps, Google Earth, images and other data.
8. Data collected during the day should be scanned to electronic format each night so that all team members have access to all information throughout the project. From there, records should objectively be entered into a GIS database.
9. Aerial imagery should be collected in the first two to four days after the fire. Cleanup and weather conditions can result in data loss if weeks go by before aerial imagery is collected (this was also identified during the Tanglewood complex fire case study).
10. The focus of the technical discussion process should be on observations related to actions taken by the first responders. Anecdotal accounts and observations of burning features as first responders drive between locations produced a lot of uncertainty and should not be the focus of data recording efforts.
11. It is necessary to cross correlate technical discussion observations with time sources from AVL or images. Cross correlation with other discussions or cross correlations with significant time uncertainties are of limited use to post-fire assessments, generally speaking. These less accurate sources from cross correlation should only be attempted in areas where little information is known or validation is required due to the extreme amounts of time required to perform these cross correlations and the resultant uncertainty.
12. Observations must take into account the point of view of the observer. An image of no burning does not mean the feature is not ignited if only viewed from one angle.
13. AVL drop out must be reconciled with other data, such as pictures, TD timeline, and/or radio log information.
14. Observations might not apply to the location the apparatus is on (e.g.: Apparatus was on Ravina Court but observation made was looking at 2505 Karamy Court).

15. Technical discussions must not begin before a solid and open-minded understanding of the incident is obtained from other sources, though it is acknowledged understandings might change after the technical discussion process. This implies obtaining a majority of the pre-fire, during-fire and post-fire imagery for the incident along with a complete damage assessment.
16. All project assessments of damage in the field must be recorded electronically with images taken of all damaged features.

Appendix H – Example of Technical Discussion Cross-Correlation

TD 182 Timeline Developments

The information presented below demonstrates how different data sources were used to link or correlate TD timeline information.

The timeline for TD 182 was based on three co-located actions/observations with other fire personnel:

- Engine 18 AVL at 1605 Manning
- Engine 16 AVL at the intersection of Rossmere/Moorfield/Flying W
- TD 165 PIC of 6155 Ashton Park Place on fire

The first observation that TD 182 makes upon entering Mountain Shadows from Station 18 is that 1605 Manning is on fire and 2 CSFD engines are there. Those 2 engines are Engine/Brush 18, who arrived to 1605 Manning at 18:19 (Engine 18 AVL). So, the logic is that 18:19 is the earliest possible anchor in time we have for TD 182.

A key time stamp came from TD 100, who mentioned giving a cop an extra firefighting hood near Flying W/Rossmere/Moorfield. TD 182 corroborates this statement, expressing gratitude for the gesture. This exchange must have occurred sometime between 19:15 and 19:33, while Engine 16 was in the area of the intersection (Engine 16 AVL).

Prior to this exchange, TD 182 briefly worked on putting out fences on Moorfield, walked up Rossmere from Flying W to 2420 Courtney (observed detached combustibles on fire), then drove "halfway up Rossmere --not much going on," and returned to Flying W/Moorfield. This must have all occurred sometime between 18:19 and 19:33 (Engine 16 AVL, Engine 18 AVL).

TD 182 later observes the ignition at 6155 Ashton Park. We know that 6155 Ashton Park had to have ignited before 20:21 (TD 165 PIC), and after 20:10 (TD 194). This is consistent with the timeline provided with TD 158/171 and TD 182.

We know from TD 182 that he was working for a total of 60 min during the night. Approximately 30 of those minutes were spent at 6155 Ashton Park, immediately following his observation of the ignition. There is corroboration from TD 171 that TD 182 worked with them at 6155 Ashton Park and also near Kirby/Yankton.

We know from examining the TDs from all 3 CSPD officers that they were instructed to leave Mountain Shadows at approximately 21:30-22:00.

So, to summarize more succinctly:

18:19 (no earlier), TD 182 arrives to Mountain Shadows

18:19 - 19:33 (no later), TD 182 works on Moorfield, scouts Rossmere, 2420 Courtney action

19:15 - 19:33, TD 100 gives TD 182 a fire hood at the corner of Rossmere/Moorfield/Flying W

19:15 (no earlier) - 20:20, TD 182 works on Moorfield (goes interior at 6020 Moorfield), works on fences on the W side of Flying W, breaks into garage to get tools, observes 6155 Ashton roof on fire.

20:20 - 20:50, TD 182 and TD 158/171 are at 6155 Ashton Park, TD 165 is also briefly present (PIC).

20:50 - end, TD 182 on Kirby/Yankton with TD 158/171.

Appendix I – Independent Picture Time Stamp Calibration

Camera clocks were checked for accurate time stamps using various methods described below. One method to check time stamps was the method used for TD144. Original images provided by the first responder were obtained during the first visit to Colorado Springs in July, 2012. The images provided by the first responder came from two cameras. At the time of acquiring the images, the dates and time were checked and it was found that both cameras had time as AM when it should have been PM, and that one camera had times stamps one hour early. This enabled accurate time stamping of the provided images, which were also checked against AVL time-stamped locations of first responders in certain images such as the image shown below.


Photo courtesy of CSFD, used with permission

Ideally, if the camera had a reasonable time stamp it was examined against other data to ensure correctness. For example, the images below show three images from three separate first responders portraying burning of the same primary structure. The center image is from TD144 and has a confirmed time stamp. The images to the left and right all fall within reasonable bounds and the time stamp is assumed to be correct within $\pm$ 10 min for both the left and right images.

Photos courtesy of CSFD, used with permission

AVLs were also a source used to calibrate time stamps for other images and videos. TD41 provided several MP4 videos taken from a GoPro. These videos had time stamps that were believed to be one hour early, which was confirmed based on examination of the AVL associated with the apparatus.

Appendix J – Tools Used to Prevent Structure Ignitions

Address	Tool
1615 MANNING WAY	deckgun, fire hose
1975 AVALON CT	fire hose
2005 AVALON CT	fire hose
2015 AVALON CT	fire hose
2050 TABOR CT	sprinklers
2210 CHARING CT	no data
2215 WOLFE RANCH RD	no data
2220 KIRBY CT	fire hose, sprinklers, structure prep
2225 CHARING CT	structure prep
2225 WOLFE RANCH RD	no data
2256 RAMSGATE TCE	structure prep
2285 VANREEN DR	structure prep
2315 ROSSMERE ST	deckgun, structure prep
2325 VANREEN DR	structure prep
2375 ROSSMERE ST	deckgun, ,structure prep
2395 ROSSMERE ST	deckgun
2405 GREEN VALLEY HTS	garden hose, ,sprinklers
2410 REGAL VIEW CT	garden hose, sprinklers
2415 REGAL VIEW CT	garden hose, sprinklers
2420 REGAL VIEW CT	garden hose, sprinklers
2425 GREEN VALLEY HTS	garden hose, sprinklers
2430 GREEN VALLEY HTS	garden hose, sprinklers
2445 GREEN VALLEY HTS	garden hose, sprinklers
2445 JENNER CT	deckgun, fire hose, garden hose
2450 BROGANS BLUFF DR	fire hose
2450 GREEN VALLEY HTS	garden hose, sprinklers
2455 BROGANS BLUFF DR	fire hose
2455 JENNER CT	fire hose, no data, sprinklers
2465 BROGANS BLUFF DR	fire hose
2465 GREEN VALLEY HTS	garden hose, sprinklers
2465 JENNER CT	fire hose, garden hose, no data, sprinklers
2475 BROGANS BLUFF DR	fire hose
2480 JENNER CT	fire hose
2485 BROGANS BLUFF DR	fire hose
2501 STONERIDGE DR	structure prep
2505 TAMORA WAY	structure prep

Address	Tool
2509 STONERIDGE DR	fire hose
2515 KARAMY CT	fire hose, garden hose, sprinklers, vegetation removal
2520 TALLESON CT	sprinklers, structure prep
2525 KARAMY CT	garden hose
2535 BROGANS BLUFF DR	structure prep
2535 KARAMY CT	fire hose, no data
2545 HOT SPRINGS CT	fire hose, no data
2550 ROSSMERE ST	fire hose
2555 KARAMY CT	fire hose
2555 ROSSMERE ST	fire hose
2555 TAMORA WAY	fire hose
2560 ROSSMERE ST	fire hose
2565 ROSSMERE ST	deckgun, fire hose
2565 TAMORA WAY	fire hose
2575 TAMORA WAY	fire hose
2585 ROSSMERE ST	fire hose
2585 TAMORA WAY	fire hose
2595 TAMORA WAY	fire hose
2605 TAMORA WAY	fire hose
2610 TAMORA WAY	no data
2620 ROSSMERE ST	sprinklers
2625 TAMORA WAY	fire hose
2630 TAMORA WAY	no data
2710 BROGANS BLUFF DR	sprinklers, structure prep
2785 ROSSMERE ST	sprinklers, structure prep
2795 ROSSMERE ST	deckgun, sprinklers, structure prep
2815 ROSSMERE ST	deckgun, sprinklers, structure prep
2825 BROGANS BLUFF DR	structure prep
2825 ROSSMERE ST	sprinklers, ,structure prep
4930 BRAEBURN WAY	structure prep
4940 BRAEBURN WAY	structure prep
4950 BRAEBURN WAY	structure prep
4965 BRAEBURN WAY	fire hose, ,garden hose, sprinklers
4970 BRAEBURN WAY	structure prep
5085 CHAMPAGNE DR	no data, structure prep
5120 ALDERSTONE WAY	structure prep
5120 LANAGAN ST	fire hose, structure prep
5125 LANAGAN ST	garden hose
5130 ALDERSTONE WAY	structure prep

Address	Tool
5180 HEARTHSTONE LANE	fire hose
5190 HEARTHSTONE LANE	fire hose
5195 HEARTHSTONE LANE	deckgun, fire hose
5195 LANAGAN ST	deckgun, ,no data
5310 CHAMBREY CT	fire hose
5315 AUBREY WAY	fire hose, structure prep
5315 CHAMBREY CT	fire hose
5320 CHAMBREY CT	fire hose, hand tools
5330 CHAMBREY CT	fire hose
5335 CHAMBREY CT	fire hose, no data
5370 CHAMBREY CT	fire hose
5410 MAJESTIC DR	deckgun, fire hose
5412 MAJESTIC DR	deckgun, fire hose
5414 MAJESTIC DR	fire hose, structure prep
5415 MAJESTIC DR	deckgun, fire hose
5423 MAJESTIC DR	fire hose
5425 MAJESTIC DR	fire hose
5429 MAJESTIC DR	fire hose
5430 CHAMBREY CT	fire hose, no data, structure prep
5439 LIONS GATE LANE	fire hose, garden hose
5439 MAJESTIC DR	fire hose
5441 LIONS GATE LANE	garden hose
5450 CHAMBREY CT	no data
5470 CHAMBREY CT	no data
5475 CHAMBREY CT	no data
5505 VANTAGE VISTA DR	structure prep
5506 VANTAGE VISTA DR	structure prep
5512 VANTAGE VISTA DR	structure prep
5517 VANTAGE VISTA DR	structure prep
5518 VANTAGE VISTA DR	sprinklers, structure prep
5520 WILSON RD	structure prep
5524 VANTAGE VISTA DR	structure prep
5530 VANTAGE VISTA DR	garden hose, sprinklers, structure prep
5555 DARIEN WAY	no data
5555 WILSON RD	garden hose, structure prep
5566 VANTAGE VISTA DR	fire hose

Address	**Tool**
5570 DARIEN WAY	deckgun
5575 DARIEN WAY	deckgun
5705 CHASE POINT CIR	garden hose, sprinklers
5715 CHASE POINT CIR	garden hose, sprinklers
5725 CHASE POINT CIR	garden hose, sprinklers
5730 REGAL VIEW RD	garden hose, sprinklers
5735 CHASE POINT CIR	garden hose, sprinklers
5740 REGAL VIEW RD	garden hose, sprinklers
5745 CHASE POINT CIR	garden hose, sprinklers
5750 REGAL VIEW RD	garden hose, sprinklers
5755 CHASE POINT CIR	garden hose, sprinklers
5760 REGAL VIEW RD	fire hose, garden hose, sprinklers
5765 CHASE POINT CIR	garden hose, sprinklers
5770 REGAL VIEW RD	fire hose, garden hose, sprinklers
5780 REGAL VIEW RD	fire hose, garden hose, sprinklers
5785 HUFFMAN CT	fire hose, no data
5785 REGAL VIEW RD	structure prep
5790 REGAL VIEW RD	structure prep
5795 REGAL VIEW RD	structure prep
5820 RAVINA CT	deckgun, ,fire hose
5835 RAVINA CT	deckgun
5888 VIA VERONA VIEW	deckgun, sprinklers
5896 VIA VERONA VIEW	deckgun, sprinklers
5904 VIA VERONA VIEW	deckgun, sprinklers
5912 VIA VERONA VIEW	deckgun, sprinklers
5920 VIA VERONA VIEW	deckgun, sprinklers
5928 VIA VERONA VIEW	deckgun, sprinklers
5965 WILSON RD	deckgun
6010 ASHTON PARK PL	garden hose, sprinklers
6010 MOORFIELD AVE	Sprinklers
6015 ASHTON PARK PL	garden hose, hand tools, sprinklers
6065 ASHTON PARK PL	garden hose, sprinklers
6075 ASHTON PARK PL	garden hose, sprinklers
6115 ASHTON PARK PL	garden hose, sprinklers
6155 WILSON RD	deckgun, fire hose
6205 WILSON RD	deckgun,, fire hose, no data, structure prep
6250 ASHTON PARK PL	deckgun, structure prep
6305 ALABASTER WAY	no data

Address	**Tool**
6375 ASHTON PARK PL	fire hose, hand tools
6535 ASHTON PARK PL	deckgun, , fire hose, structure prep, vegetation removal
6545 ASHTON PARK PL	no data

Appendix K – Tools Used To Extinguish Damaged Structures

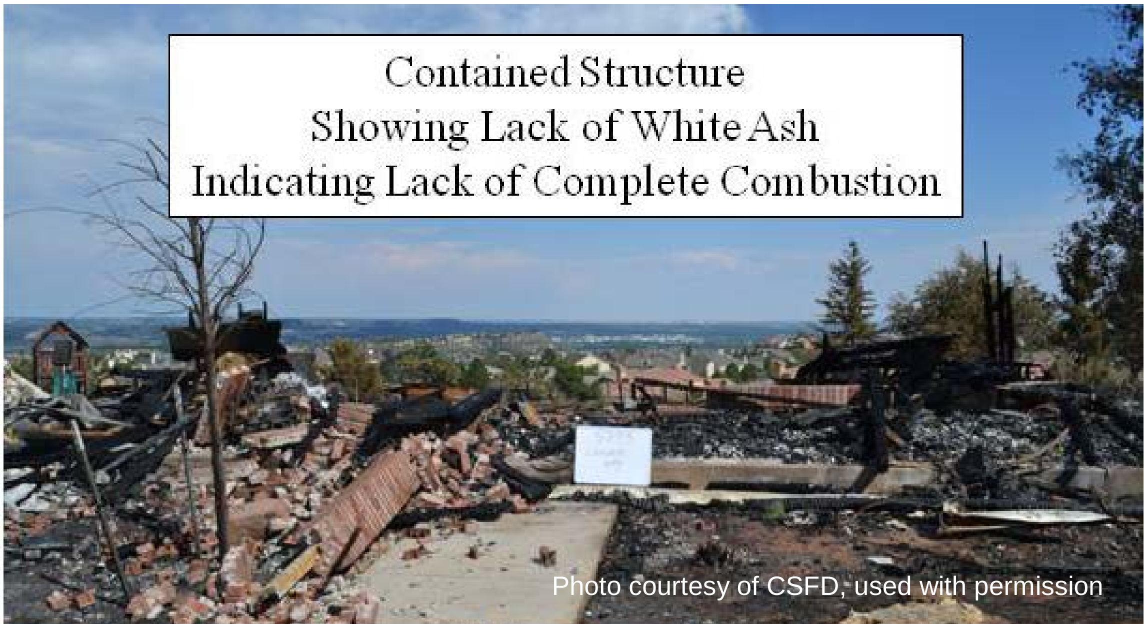
Address	Tool	Extinguishment
2185 WICKES RD	fire hose, garden hose	yes, when combined with other defensive actions
2210 CAPRA WAY	hand tools	yes
2210 KIRBY CT	fire hose, garden hose, hand tools, thermal imager	yes, when combined with other defensive actions
2215 CAPRA WAY	fire hose	yes, when combined with other defensive actions
2220 CHARING CT	garden hose	yes, when combined with other defensive actions
2230 CAPRA WAY	fire hose	yes, when combined with other defensive actions
2240 KIRBY CT	garden hose, hand tools	yes, when combined with other defensive actions
2310 ROSSMERE ST	deckgun, garden hose, interior, no data	yes, when combined with other defensive actions
2310 VANREEN DR	fire hose, no data	yes, when combined with other defensive actions
2355 ROSSMERE ST	fire hose, garden hose	yes, when combined with other defensive actions
2355 VANREEN DR	garden hose	yes
2380 ROSSMERE ST	deckgun, fire hose, hand tools, no data	yes, when combined with other defensive actions
2385 ROSSMERE ST	deckgun	yes, when combined with other defensive actions
2420 COURTNEY DR	no data	yes, when combined with other defensive actions
2455 ROSSMERE ST	fire hose	yes
2495 STONERIDGE DR	fire hose, hand tools	yes, when combined with other defensive actions
2515 TAMORA WAY	fire hose, garden hose, no data	yes, when combined with other defensive actions
2520 TAMORA WAY	fire hose, garden hose, no data	yes, when combined with other defensive actions
2540 BROGANS BLUFF DR	fire hose, interior	yes
2545 ROSSMERE ST	garden hose	yes, when combined with other defensive actions
2545 TAMORA WAY	no data	yes, when combined with other defensive actions
2549 HOT SPRINGS CT	fire hose	yes, when combined with other defensive actions
2555 TALLESON CT	garden hose	yes, when combined with other defensive actions
2565 VANTAGE RIDGE CT	garden hose, no data	yes, when combined with other defensive actions
2610 ROSSMERE ST	fire hose	yes
2625 TREVOR LANE	fire hose, garden hose, hand tools, interior	yes, when combined with other defensive actions
2635 STONERIDGE DR	hand tools	yes, when combined with other defensive actions

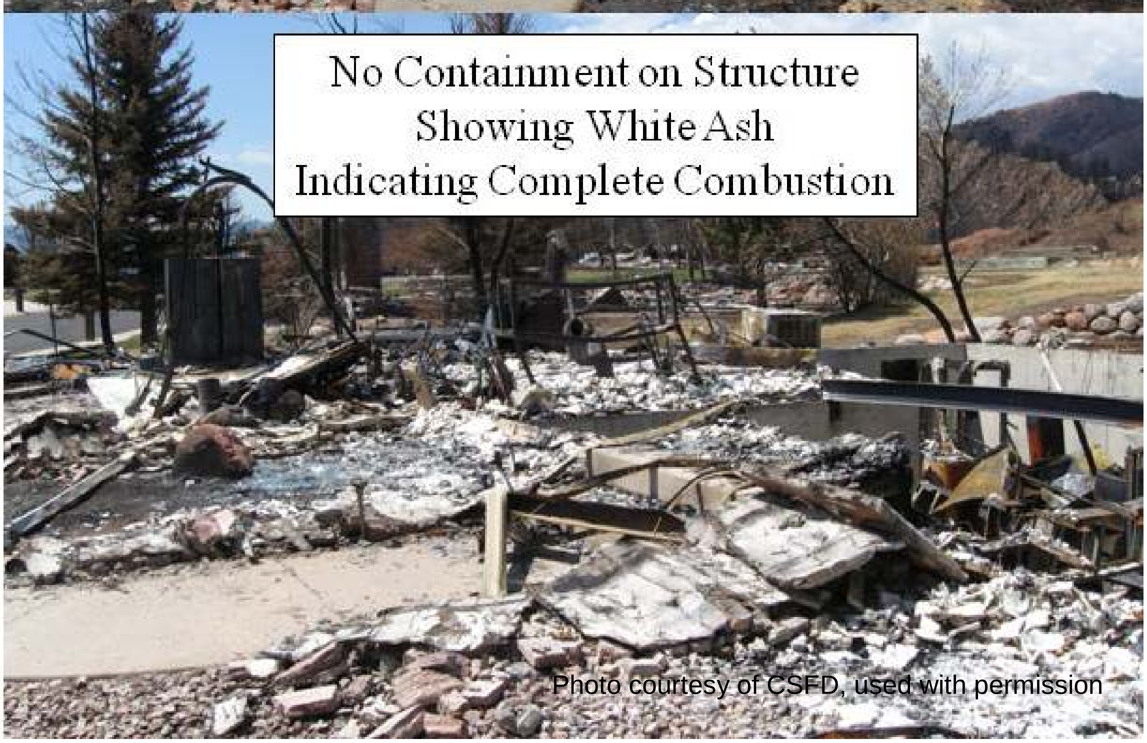
Address	Tool	Extinguishment
2655 STONERIDGE DR	fire hose, hand tools	yes, when combined with other defensive actions
2735 BROGANS BLUFF DR	fire hose, foam, hand tools, interior	yes, when combined with other defensive actions
2760 BROGANS BLUFF DR	fire hose, hand tools, interior, no data	yes, when combined with other defensive actions
5140 CHAMPAGNE DR	fire hose, no data	yes, when combined with other defensive actions
5145 HEARTHSTONE LANE	fire hose, hand tools, interior	yes, when combined with other defensive actions
5145 LANAGAN ST	fire hose, garden hose, hand tools	yes, when combined with other defensive actions
5325 AUBREY WAY	fire hose, hand tools, interior, no data	yes, when combined with other defensive actions
5425 LIONS GATE LANE	garden hose	yes, when combined with other defensive actions
5425 WILSON RD	fire hose, foam	yes, when combined with other defensive actions
5427 LIONS GATE LANE	garden hose	yes
5429 LIONS GATE LANE	fire hose, hand tools, interior, no data	yes, when combined with other defensive actions
5437 LIONS GATE LANE	fire hose, garden hose, hand tools, interior	yes, when combined with other defensive actions
5445 LIONS GATE LANE	fire hose, garden hose	yes, when combined with other defensive actions
5447 LIONS GATE LANE	fire hose, garden hose	yes, when combined with other defensive actions
5449 LIONS GATE LANE	fire hose, garden hose	yes, when combined with other defensive actions
5455 LANAGAN ST	fire hose, hand tools	yes, when combined with other defensive actions
5455 WILSON RD	fire hose, no data	yes, when combined with other defensive actions
5461 LIONS GATE LANE	fire hose	yes, when combined with other defensive actions
5536 VANTAGE VISTA DR	fire hose, hand tools, no data, water curtain	yes, when combined with other defensive actions
5550 WILSON RD	fire hose	yes, when combined with other defensive actions
5572 VANTAGE VISTA DR	fire hose	yes, when combined with other defensive actions
5585 DARIEN WAY	no data	yes, when combined with other defensive actions
5765 HUFFMAN CT	fire hose	yes, when combined with other defensive actions
5790 LINGER WAY	fire hose, hand tools, interior, no data	yes, when combined with other defensive actions
5810 RAVINA CT	deckgun	yes, when combined with other defensive actions
5950 WILSON RD	fire hose, interior	yes, when combined with other defensive actions

Address	Tool	Extinguishment
6020 MOORFIELD AVE	garden hose, hand tools, interior	yes, when combined with other defensive actions
6045 ASHTON PARK PL	fire hose	yes
6110 ASHTON PARK PL	garden hose, hand tools, sprinklers	yes
6155 ASHTON PARK PL	garden hose, interior	yes
6260 WILSON RD	fire hose, interior	yes, when combined with other defensive actions
6265 SAVANNAH WAY	no data	yes
6335 WILSON RD	fire hose, foam, hand tools, no data	yes, when combined with other defensive actions
6365 ASHTON PARK PL	deckgun, fire hose, hand tools, interior	yes, when combined with other defensive actions
6365 SANDRAY CT	fire hose, foam, hand tools, no data	yes, when combined with other defensive actions

Appendix L – Examples of Missed Defensive Actions in Post-Fire Assessments

Example of destroyed primary structure contained with significant water resources and resultant lack of white ash or blackened appearance, along with destroyed primary structure with no containment action and white ash present.





Appendix M – Revised List of Damaged Structures

Appendix K Table 1 provides a revised list of damaged structures, along with the identified damage and the confirmation of that damage. It is important to note that the damage identified below is not inclusive, nor is the identified damage necessarily an identification of the first item ignited in the location.

For example, the primary structure at 2549 HOT SPRINGS CT had two possible ignition mechanisms, which are not clearly identified by the simple list below. A firewood pile appeared to have ignited the composite lap siding causing a fire in the garage, which was extinguished by first responders, as shown in Appendix K Figure 1. The second ignition mechanism was direct flame contact and radiant heat from 2551 HOT SPRINGS CT, which was contained by first responders through application of water on 2551 HOT SPRINGS CT, as shown in Appendix K Figure 2, and application of water to the exposed side of 2549 HOT SPRINGS CT.

Appendix K Figure 1 Remnants of firewood pile, which appeared to have ignited and caused ignition of the composite lap siding and thereby entry into the garage. TDs identified first responders as breaking into garage and suppressing fire.

Another example is seen at 6260 WILSON RD, where TDs identified the damage as an attic ignition. The first NIST/USFS field visit, however, identified burned features as shown in Appendix K Figure 3. This identified other features than the attic as possible ignition mechanisms.

Appendix K Figure 2 Containment actions which resulted in successful containment of fire spread from 2551 HOT SPRINGS CT to 2549 HOT SPRINGS CT. Note multiple windows on exposed side of 2551 HOT SPRINGS CT, which could have helped spread fire if not contained by first responders.

Appendix K Figure 3 Possible first items ignited at X could have been a Juniper bush, which ignited the deck or the deck ignited the primary structure and the bushes. In either case there was green vegetation between the burned items shown above and other burned vegetation or features.

Appendix K Table 1 Possible damaged features identified on primary structures identified in this study.

Address	Damaged Feature(s)
2185 WICKES RD	roof
2210 CAPRA WAY	deck
2210 COURTNEY DR	siding
2210 KIRBY CT	siding, deck
2215 CAPRA WAY	roof
2220 CHARING CT	roof, door
2220 COURTNEY DR	siding
2230 CAPRA WAY	siding, window
2240 KIRBY CT	deck
2310 ROSSMERE ST	roof
2310 VANREEN DR	siding, eaves
2320 ROSSMERE ST	window
2330 COURTNEY DR	Window frame, satellite dish, roof
2330 VANREEN DR	siding, window
2340 ROSSMERE ST	deck, window
2355 ROSSMERE ST	roof
2355 VANREEN DR	window, deck, siding, roof
2380 ROSSMERE ST	door, deck, siding, roof
2385 ROSSMERE ST	roof, deck
2420 COURTNEY DR	siding, window
2455 ROSSMERE ST	garage, roof
2495 STONERIDGE DR	roof
2505 VANTAGE RIDGE CT	window, deck
2515 TAMORA WAY	deck
2520 TAMORA WAY	gutter
2525 VANTAGE RIDGE CT	deck, window
2533 HOT SPRINGS CT	siding
2535 TALLESON CT	deck
2540 BROGANS BLUFF DR	door
2543 HOT SPRINGS CT	window, gutter
2545 ROSSMERE ST	roof
2545 TAMORA WAY	doorframe
2549 HOT SPRINGS CT	garage, siding, window, eave
2555 TALLESON CT	deck
2565 VANTAGE RIDGE CT	siding, deck, window
2580 BROGANS BLUFF DR	roof
2610 ROSSMERE ST	window, deck, gutter
2615 TAMORA WAY	door, window
2625 TREVOR LANE	window, garage

Address	Damaged Feature(s)
2635 STONERIDGE DR	roof, deck
2655 STONERIDGE DR	eave, window, roof
2735 BROGANS BLUFF DR	deck, bump out
2760 BROGANS BLUFF DR	deck, chimney, siding, floor joist
3220 BLODGETT DR	unknown
3240 BLODGETT DR	unknown
4985 BRAEBURN WAY	siding
5010 LANAGAN ST	deck, siding
5020 LANAGAN ST	roof, deck
5025 LANAGAN ST	window
5115 HEARTHSTONE LANE	siding, eaves, window
5140 CHAMPAGNE DR	roof
5145 HEARTHSTONE LANE	window, deck, eave, roof
5145 LANAGAN ST	deck
5150 LANAGAN ST	window
5165 HEARTHSTONE LANE	siding
5265 CHAMPAGNE DR	roof
5325 AUBREY WAY	siding, deck
5375 CHAMBREY CT	roof
5417 LIONS GATE LANE	roof
5418 MAJESTIC DR	siding, window
5425 LIONS GATE LANE	roof, deck
5425 WILSON RD	window, roof, deck
5427 LIONS GATE LANE	roof
5429 LIONS GATE LANE	roof
5430 WILSON RD	siding, window, roof
5437 LIONS GATE LANE	roof
5445 LIONS GATE LANE	roof, deck
5447 LIONS GATE LANE	roof
5449 LIONS GATE LANE	roof, deck
5455 LANAGAN ST	garage, styrofoam pop-outs
5455 LIONS GATE LANE	roof
5455 WILSON RD	eave, deck
5459 LIONS GATE LANE	deck
5461 LIONS GATE LANE	siding
5511 VANTAGE VISTA DR	deck, window, siding
5530 DARIEN WAY	roof, window
5530 WILSON RD	siding, window, roof
5536 VANTAGE VISTA DR	deck, eave, roof, window, siding
5540 WILSON RD	roof, window, door, deck, skylight

Address	Damaged Feature(s)
5550 WILSON RD	roof
5572 VANTAGE VISTA DR	window
5585 DARIEN WAY	roof
5685 VANTAGE VISTA DR	siding, window, eave
5755 HARBOR PINES PT	window, eave
5760 LINGER WAY	other
5765 HARBOR PINES PT	eave, window
5765 HUFFMAN CT	siding
5790 LINGER WAY	eave
5810 RAVINA CT	roof
5950 WILSON RD	window
6020 MOORFIELD AVE	deck, siding, window
6030 MOORFIELD AVE	deck
6045 ASHTON PARK PL	roof, window frame
6110 ASHTON PARK PL	deck, window, siding
6155 ASHTON PARK PL	roof
6260 WILSON RD	eave, window, deck
6265 SAVANNAH WAY	roof
6305 WILSON RD	deck, eave, door frame
6335 WILSON RD	garage
6365 ASHTON PARK PL	roof
6365 SANDRAY CT	front and back deck, siding
6415 ASHTON PARK PL	Unknown, observed as catching in attic.

Appendix N - Additional Technical Issues Identified During TDs

Communications

1. Portable battery chargers (12V) for handheld radios can enable the charging of radios on mutual aid apparatus.
2. Communication between CSFD and mutual aid about needing or accepting mutual aid resources was hindered by situational awareness.
3. There was limited radio communication between air (Federal) and ground (City), between City and Mutual aid, and between USFS and all other resources.

Infrastructure

4. Reverse opening of hydrants and different fittings compared to what is used by many other jurisdictions, as developed by NFPA, 1961 Standard on Fire Hoses, caused confusion and delays during response. Multiple mutual aid apparatus experienced difficulties connecting to hydrants
5. Utility grids were not set up the same as street grid maps, slowing down decision making during the fire.
6. Underground power lines in most of MSC facilitated first responder access. The downed power lines to The Flying W Ranch temporarily limited local access.
7. The power grid feeding the residences in MSC supplied the CSU water pumps. When electricity was turned off, hydrant water pressure was compromised, and some automatic sprinkler systems also stopped functioning.
8. When the water pumps were on, very good water pressure was reported by first responders all across the MSC.
9. Multiple staging areas exacerbated communication and accountability challenges.
10. The watershed affected by the Waldo fire may take as many as twenty five years to recover.

Defensive Actions

11. Documentation during the event can be facilitated by having scribes for all task force leaders to capture personnel accountability, fire behavior observations and situational awareness.
12. Maps provided to mutual aid significantly improved situational awareness.
13. Images and video taken by first responders improved accountability.
14. Removal of bunker gear liner could reduce thermal stress to structural fire fighters during WUI operations.
15. Getting the engines to staging to swap crews removed them from the fire for significant periods of time.
16. There were preliminary indications that in high building density areas, defensive actions to "box in" the fire became more effective as the wind abated.
17. First responder awareness was limited both in space and time (e.g.: a Task Force Leader was unaware that the eastern part of lower Majestic (to the South of Lions gate Lane) had

experienced ember exposures that resulted in structure ignitions that were successfully defended by mutual aid).

18. Firefighting hoses experienced significant failures due to extensive wear both from heat and abrasion.