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A review of post-incident studies for wildland-urban interface fires

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ABSTRACT

Post-incident studies provide direct and valuable information to further the scientific understanding of Wildland-Urban Interface (WUI) fires. Most post-incident studies involve data collection in the field (i.e. a “research field deployment”). In this review, technical reports of post-incident studies for WUI fire and other natural disasters were analyzed and professionals directly involved in WUI fire research field deployments were interviewed. The goal of this review is to provide a resource for future WUI studies regarding the development of safe and effective fieldwork procedures, the collection and integration of accurate and relevant data, and the establishment of practical lessons learned. Three main stages of WUI fire post-incident studies are identified and described in detail. Data collection methodologies, data attributes, logistical practices and lessons-learned were compiled from various past studies and are presented here in the context of application to WUI fire.

Introduction and background

Wildland-Urban Interface (WUI) fire events occur when fires ignited in the wildlands spread into populated areas [1]. Fire spread from the wildlands into and throughout the WUI is governed by three mechanisms: direct flame contact, flame radiation, and firebrands (hot or flaming debris) [1]. Studies have indicated that ignition of structures due to firebrands carried by prevailing winds and the convective currents produced by fires is a primary means of fire spread both from vegetation to nearby structures and from structure to structure [2,3]. Local topography, weather and fuel loading are major factors that drive the likelihood and the severity of WUI fires. For instance, steep slopes that favor flame spread, high temperatures, prolonged periods of drought and dense wildland vegetation in proximity to structures all increase WUI fire hazard [2,4]. The aspects of structures and parcels of land within a WUI area, such as the degree of fire-resistant construction and fuel management practices, also contribute to the risk of home ignition [4]. In the event of a severe fire, the emergency response, evacuation response and event preparedness of a WUI community greatly influence the outcome [5,6].

Wildland fires and WUI fire events have been increasing in severity, frequency and impact. A 2017 economic report places the total annualized costs and losses of wildland and WUI fires in the United States between “low” and “high” estimates of US$71.1 billion and US$347.8 billion, respectively [7]. Within the last fifteen years, several WUI fire events have incurred unprecedented costs and are indicative of the destructive potential of WUI fires as natural disasters. In Australia, the 2009 Black Saturday bushfires claimed 173 lives and cost US$4 billion equivalent [8]. More recently, the 2019–2020 wildfire season resulted in an area burned near the size of Syria [9,10]. In Canada, the WUI fire disaster at Fort McMurray in May 2016 destroyed over 2400 structures and is estimated to have cost over CA$10 billion in insured property damages and other indirect costs [11]. It is considered the costliest natural disaster in Canadian history [12]. The deadliest and costliest fire in US history, the Camp Fire, occurred in November of 2018, resulted in 85 lives lost and accrued an overall loss of approximately US$17 billion [13,14]. Also in 2018, the Mendocino Complex Fire began as two individual events that merged to create the largest wildfire event by geographical area in California history. By the time of full containment, the fire had burned an area over half the size of the state of Rhode Island [13,14]. Local climate change, fuel management policies and increases in urban sprawl have been recognized as primary reasons for escalating trends in WUI fires. The consequences of WUI and wildland fire are diverse. These include “loss of life and injuries, health impacts through smoke exposure, property and infrastructure loss, business interruption, ecosystem degradation and soil erosion, all despite significant efforts to

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Table 1
WUI fire and other natural disaster studies reviewed.

Reports published by NIST
- Witch-Guejito Fire (Report 1) [18]
- Witch-Guejito Fire (Report 2) [19]
- Tanglewood Fire (Report 1) [20]
- Tanglewood Fire (Report 2) [21]
- Waldo Fire [22]
- Joplin Tornado [23]

Hurricane studies conducted or funded by the University of Colorado Boulder Natural Hazard Center
- Hurricane Matthew Evacuation [27]
- Hurricane Irma Evacuation [28]
- Hurricane Ivan Community Impacts [29]
- Hurricane Sandy Maritime Responders [30]

“Black Saturday” Australian Bushfire Reports
- Bushfire CRC Fire Behavior [24]
- Bushfire CRC Human Response [25]
- Bushfire CRC Structure Response and Planning [26]

Other WUI fire studies
- Fort McMurray Fire [11]
- Hidden Pines Bastrop Fire [31]
- Cross Plains Fire [32]
- Thomas Fire [33]

address the problem and associated firefighting costs” [15]. As the number and severity of WUI fires escalates, there is a need to understand and extract information from these events (e.g. information pertaining to the fire dynamics, impact on the built environment and human response). The most direct way to analyze a WUI fire event, short of collecting information during the event itself, is a post-incident study. Information from these studies is used to improve evacuation and emergency response practices, anticipate the pathways of fire spread within an at-risk community, and improve fire resilience of these communities on the scales of structures, land parcels, and the community itself.

A review was performed that 1) analyzed post-incident natural disaster research studies carried out or funded by organizations such as the National Institute of Standards and Technology (NIST), Bushfire Cooperative Research Center (CRC) and University of Colorado Boulder Natural Hazards Center, and 2) interviewed professionals involved in these studies. All studies except one involved a deployment of research staff to the event location to collect data in the field (i.e. a “research field deployment”). The data collection methodologies, data attributes and logistical practices from these deployments were compiled in the context of application to WUI fire. The goal of this review is to provide a resource for future WUI fire studies regarding the development of safe fieldwork procedures, the collection of accurate and relevant data, and the establishment of practical lessons learned. This review is not intended as a manual of best practices since the methods of studying WUI fires are constantly changing.

The original motivation for this study was the Fort McMurray fire in Alberta, Canada. In the wake of the disaster, the National Research Council Canada (NRCC) initiated a climate change resilience project, including an initiative to develop a blueprint for studying WUI fire events in hopes of reducing future losses [16]. The original technical report is publicly available [17].

Methodology

Seventeen technical reports pertaining to both WUI fire events and other natural disasters were analyzed. The technical reports are listed in Table 1. In addition, eight professionals in fields related to WUI fire and other disaster field studies were interviewed. All the interviewees were research staff employed by NIST and several were directly involved in research field deployments. The focus on NIST stems from the fact that they have been at the forefront of studying WUI fire events in the US and have been developing methodologies for conducting WUI fire research deployments over the past decade.[1]

Two instruments were developed to collect and organize information from interviews and the sources in Table 1:

1. A technical report review template
2. A qualitative semi-structured interview script

The review template was used to organize details of the data collection effort from the body of each report in Table 1. The report template included a variety of fields ranging from the types of data being collected to the personal protective equipment used by data collectors. The goal of the template was to identify the processes, methodologies, resources and data attributes relevant to data collection. The template included five main sections: general document information (i.e. author, date of publication, etc.), cooperation with other organizations, pre-data-collection planning, data collection, and subjects addressed (i.e. topics and information covered in the report).

Eight interviews were conducted. All interviewees were employees of NIST; therefore, their input is influenced by NIST’s methods and protocols. The interview protocol contained a structured list of questions focused on the logistical and practical details of a research field deployment. The protocol also included an open-ended section that allowed interviewees to give additional recommendations or other information that they felt was important and previously unreported. The structured portion of the protocol consisted of four sections: incident awareness, pre-deployment planning, deployment, and post-deployment analysis. Questions in the protocol covered a range of information from overarching points such as “what are the objectives of the deployment?” to logistical details such as “how do staff stay in contact in the field?”. The review template and the interview protocol can be found in the original report.

Results

A WUI fire post-incident study can be divided into three main stages as shown in Fig. 1. Descriptions of each stage and sub-area are presented in sections below. The group or organization conducting the research deployment/study is referred to as the “researcher”.

Stage 1: planning and initiating a research study

Incident awareness and the decision to act

As a WUI fire is unfolding or immediately after, the researcher’s professional connections and media sources are the primary means of becoming aware of the event and gathering information. Given the potential range and quality of information sources that are available, information obtained from official incident authorities such as the California Department of Forestry and Fire Protection (CAL FIRE) or the Federal Emergency Management Agency (FEMA) are considered most credible. This includes information taken from direct contact with the incident authorities, from mass notification systems, or from official social media accounts. Information from regular reporting media and general social media is also considered. Overall, a diverse set of information sources is exploited to ensure the broadest understanding of the event as possible.

Once the researcher has become aware of an event, a decision is made on whether the event merits a field deployment in the context of the available resources to do so. The primary criterion for this decision is the fulfillment of research goals and answering meaningful questions that advance understanding of WUI fire phenomena. Understanding of the long-term effects of a fire on the community, understanding typical patterns of life and property loss, determining the primary mechanisms

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[1] It should be acknowledged that several WUI fire post-incident and field studies have been conducted in multiple areas around the world. However, the focus of this work is North America and Australia.

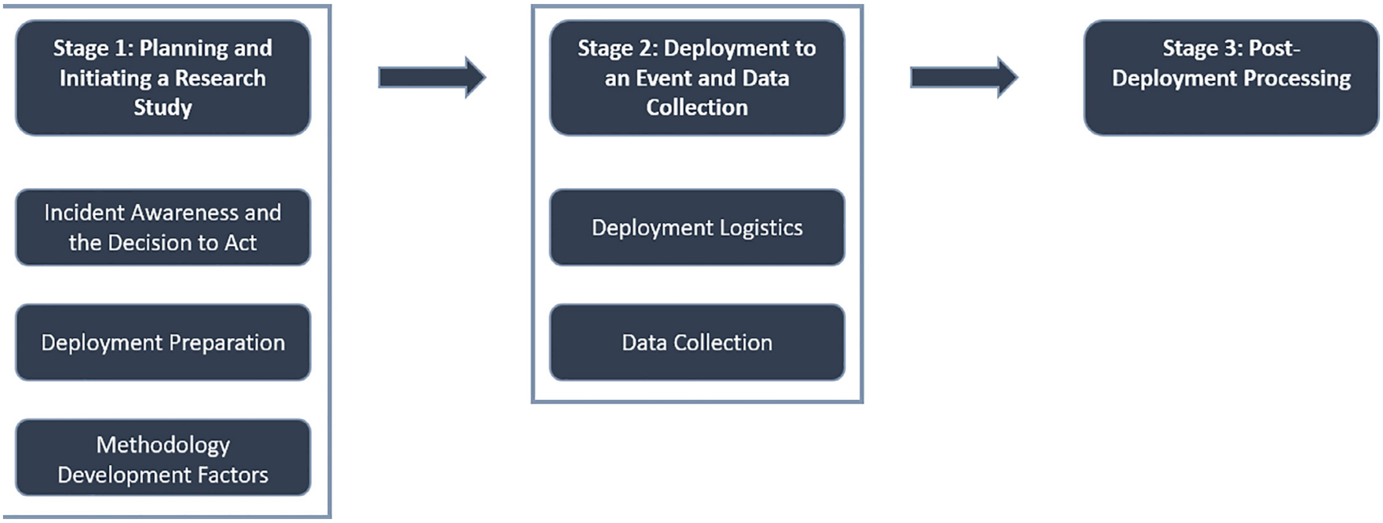

Fig. 1. Stages of a WUI fire post-incident study.

of fire spread, and influencing improvements of codes and standards are all major goals of WUI research. The question is asked whether the event being considered can produce data that fills knowledge gaps related to these goals and, more broadly, the fire dynamics and human impact of WUI fires. Careful consideration of this question is critical when many fires can occur across multiple areas during a wildfire season and resources may only permit a single full-fledged field study. Other considerations for initiating a research field deployment include whether deployment to the field would interfere with emergency response efforts, if residents and authorities accept the presence of the researcher and if conditions on the ground are safe.

Two methods for assisting the decision to study a fire event include a reconnaissance trip or “initial deployment” to the event location and the use of a quantitative checklist for objective decision making. A reconnaissance trip is advantageous if the decision to study an event cannot be made only based on information available remote from the event location. The studies of the Tanglewood Fire and Fort McMurray Fire both used this method. The objective of an initial deployment is to confirm information about the event, determine if the event could produce data that meets research objectives, identify areas for data sampling, and identify any potential drawbacks or dangers associated with a full deployment. A form of quantitative checklist or similar tool is used to compile criteria for justifying a full deployment/study and gives a baseline for objective reasoning. For example, disaster response studies at NIST utilize a “score card” for this purpose.

If the decision to initiate a deployment is made, the timeframe between the event and the beginning of data collection is ideally 2–3 days or no more than one week. The perishable nature of WUI fire data requires that collection begins as soon as possible. Burn patterns, structure damage, and accounts of the fire from first responders and residents are examples of data types that can change or fade with time or be otherwise altered by the effort to rebuild following the fire.

Most of the studies in Table 1 are reactive studies, meaning that were only initiated after and in response to an event. For example, the Bushfire CRC research taskforce was established following the Black Saturday bushfires in Victoria as a reaction to their unprecedented impact. The Fort McMurray Fire study and early NIST WUI fire studies were also reactive. The reactive studies conducted by the Natural Hazards Center following multiple hurricane disasters are referred to as “quick-response” studies. An alternative approach is to use a proactive response protocol. While a reactive study begins most planning and preparations once an event has occurred, a proactive study begins planning and establishes resources in an area at high risk of WUI fire prior to an event occurring. A proactive study typically involves partnering with local authorities or organizations and storing essential equipment near the area of interest. With these preparations, response to an event can be enhanced relative to a reactive study.

Deployment preparation

After enough initial information has been collected about the event, preparation for deployment involves organizing a team, acquiring permissions to access the incident site and addressing the logistical details of the deployment effort. The authorities overseeing emergency response to the fire – e.g. local police and fire departments, state authorities such as CAL FIRE, or other incident command structures unique to the event – have significant input as to whether a research field deployment will proceed. These authorities would have criteria about the invasiveness and additional burden imposed by a field deployment on the emergency response effort.

The size and structure of the research team may vary depending on the study. All WUI studies, the Joplin Tornado study and three out of four hurricane studies listed in Table 1 utilized field data collection teams. The Bushfire CRC taskforce also included extensive support structures in addition to field data collectors. A team structure utilized by NIST for studies of WUI fire spread and structure response consists of two halves: 1) a field deployment group that actively collects data at the incident site, and 2) a secondary group that works remotely to compile data on a daily basis and provide logistical, analytical and technical support. Overall, a team would be organized so that members cover the required range of experience, skill sets and subject matter expertise relevant to the study. Important skill sets for team members involved in data collection in the field include safety training (e.g. CPR or med-tech training), awareness or training in wildland firefighting and emergency response protocols, and proper physical conditioning. Examples of important areas of expertise among the team members both in the field and working remotely include fire dynamics, local wildland ecology, building construction, human behavior relevant to the social impacts of disasters, and geographic information systems (GIS). Although the field of GIS is not directly related to WUI fires, integration of WUI fire data on geographic maps was essential to the NIST WUI fire studies, Bushfire CRC studies and Hidden Planes Bastrop Fire study.

With a team in place, organizational meetings are held to distribute information to team members, solidify team roles and prepare deployment logistics. The goal of these meetings is to ensure that when team members arrive at the incident site, they are prepared and aware of the situation. This preparedness reduces burdens on local authorities when briefing researchers on the details of the event. Standard operating procedures (SOPs) for data collection, lists of necessary equipment, and safety protocols are also established. Safety measures include personal protective equipment (PPE) and consideration of local health hazards such as asbestos products in older buildings. Typical equipment used in the WUI studies listed in the Table 1 includes GPS units, data recording medium (e.g. voice recorders, cameras and a data collection app for a tablet computer), measurement devices, communication devices (e.g. walkie-talkies, cell phones, satellite phones) and power supplies (battery packs, chargers).

Methodology development factors

A single wildland fire has the potential to produce numerous WUI incidents as it spreads and interacts with different communities. Once an event occurs, the sample to be studied (e.g., the community, group of first responders, cluster of structures, interviewees, etc.) is chosen based on whether it meets criteria to satisfy research objectives. The criteria may include the number and layout of damaged and destroyed buildings; the types of wildlands surrounding the community; the number of evacuees, injuries or deaths; and/or the presence of unique outcomes. The research objectives for WUI fire studies are broadly grouped into two categories: social and physical. Social research objectives focus on the human factors of a WUI fire event such as evacuation behavior and the psychological and economic impacts the fire has on the people who experience it. Physical research objectives, on the other hand, focus on the dynamics of fire spread and the vulnerabilities/resilience of affected buildings. Data collection methods are based on whether research objectives are physical or social (or both) and the level and type of detail required.

Information from human sources via surveys and interviews was utilized in each study in Table 1. WUI studies with both socially- and physically-centric research objectives benefitted from the use of human data sources. Studies focused on the human response to an event used both surveys that collect quantitative information about the sample population as well as semi-structured interviews that ask eyewitnesses about their experiences. Studies aimed at understanding the physical aspects of a fire event utilized not only forensic evidence obtained from examining structures, vegetation and land parcels but also interviews with first responders and residents regarding their actions and observations. These accounts are central to reconstructing the event timeline, the path of fire spread, and the actions of people in response to the fire.

Interviews included both targeted and open-ended questions. Open-ended formats provide an avenue for new lines of questioning and for interviewees to give information not anticipated by the interviewer. The interview structure use by the Bushfire CRC researchers embraced this concept and was designed to avoid shaping the responses of participants based on the assumptions of the interviewer and instead allowed the participants to recount their experiences in their own way. Visibility of the research study is also central to data collection from human sources. For example, the evacuation study of Hurricane Matthew funded by the Natural Hazard Center strategically placed researchers at rest-stops along primary evacuation highways. During the NIST study of the Joplin tornado, flyers and pamphlets were circulated through the city and the study was announced in local news coverage.

Data collection is rarely limited to the efforts of the researcher alone. The Fort McMurray Fire, Hidden Planes Bastrop Fire, Cross Planes Fire, Thomas Fire, NIST studies and Bushfire CRC reports all indicated involvement from several different organizations during various stages of operation. Partnering with other organizations can provide expertise, familiarity with the local region, and personnel support during a research endeavor that is, by nature, time sensitive and complicated. Both field data collection and procurement of pre-fire information about the local area are made possible with input from partner organizations. In the studies reviewed, information and data histories regarding the local vegetation, weather patterns, home construction, community layout and emergency response protocols were provided by partner organizations.

Other factors in developing a data collection methodology are data availability and instrument preparation. Availability involves not only the physical presence of forensic evidence – such as damaged structures and burn patterns – but also researcher safety and the willingness of first responders, residents and other eyewitnesses to give accounts of their experiences. Availability is also governed by time. The memory of subjective experiences recounted by eyewitnesses can change with time after the event occurs (a phenomenon called “memory decay”) while physical markers of fire spread are degraded by weather and the rebuilding effort that begins soon after the fire. Instrument preparation refers to calibration and debugging of measurement instruments, including surveys and interview protocols used to collect information from human sources. Surveys or interview protocols that are used to interview local first responders and residents must first be pilot tested and receive approval from established human subject review boards before being used in the field.

Lastly, the specific questions that a study is trying to answer will shape the methodology. As an example, the methodology of the Waldo Fire study was developed to determine structure exposure to flames, thermal radiation, and embers in the context of the defensive actions of first responders and residents. Information on the time-independent properties of the damaged and destroyed structures (e.g. structural materials, fuel loads and pathways of fire spread) was integrated with time-dependent information about the defensive actions. From this method of data selection and comparison, it was concluded that the end-result of damages to a community due to fire may not be always driven by fire-resistant qualities of structures but instead by whether people were present to fight the fire.

Stage 2: deployment to an event and data collection

Deployment logistics

In the case of the NIST WUI fire studies, data collected by the deployment team during the day is processed, integrated and assessed for quality by the support team working remotely. Data collected in the field is then backed up to both an online cloud storage location and physical drive locations on a nightly basis. Data related to the geographic layout, vegetation, and pre-fire conditions of the area are also collected by the support team before being integrated with data collected by the deployment group. This approach is intended to reduce the burden on the deployment group, improve data consistency, and reduce the time required to collect data.

The communication, safety and wellbeing of the data collectors are of foremost importance during a field deployment. NIST studies instituted daily safety briefings where new information is disseminated to the team, lessons-learned are discussed, adjustments to protocols or objectives are made, and contingency plans are established. The bushfire CRC and NIST studies both utilized a pairing system for individuals collecting data in the field. Data collectors did not work alone. To protect against burnout and to prevent mistakes that may result from prolonged exertion, it has been recommended that the length of a single deployment is limited to 2–3 weeks. However, an entire study may include multiple deployments with different team members over a prolonged time period in addition to extensive office work. For instance, the Bushfire CRC reports note that the entire Black Saturday fire study required “more than 2000 staff days of extensive data collection and analysis” over a period of two and a half months [8].

Data quality control includes the use of calibrated and validated instruments, the use of standardized data collection forms, and peer review. A standard paper form or a tablet computer user interface can be implemented to organize the input of information into a study database. In the case of analyzing damaged structures, standard forms require information for the same fields to be populated for every structure examined and, therefore, promote a consistent comparison across all samples. If possible, a data collection redundancy protocol can be implemented where two different data collector pairs analyze the same structure or land parcel and compare their results to ensure consistency.

Table 2
WUI Fire Data Attributes.

	Data Types	Data Sample	Data Collection Timeframe	Data Sources	Data Resolution	Data Representation
Spatio-temporal Fire Progression	Ignition instances, fire spread patterns and burn damage extent on structures, parcels, and wild-land/residential vegetation; locations of damaged, destroyed and undamaged structures; defensive actions; times of ignition of structures; times of ignition of vegetation and secondary combustibles	A single area affected by the fire (i.e. the entire event-affected area, a particular community, or a specific cluster of structures)	Beginning within one week post-incident and lasting up to several months	First responders; residents; local authorities; community businesses and organizations; LIDAR; aerial imagery (visible, infrared); fire model analyses; digital elevation models; community maps; time-stamped ground images and videos; first responder radio logs; first responder automatic vehicle location (AVL) logs; 911 call records; fire spread indicators; existing cause and origin reports	Timelines reconstructed on an hourly basis or less; GIS map 'pixel' resolution range of 2m-30 m or more depending on the size of the affected area	GIS maps; timelines; eyewitness account transcripts
Weather, Topography, and Wildland Environment	Wildland fuel types, densities and distributions; wildland fuel structure and height; ambient temperatures; fuel moisture content; wind speed, gust, and direction; humidity; terrain slope and aspect; drought indices; rainfall history; fuel lag time to ambient humidity	Affected residential area and the adjacent wildlands; area of wildfire initiation and spread towards the affected area	Beginning within one week post-incident and lasting up to several months	Local weather stations; LIDAR; digital elevation models; aerial imagery (visible, infrared); time-stamped ground and aerial images; land parcel delineations; fire service wildland fuel maps; national fire danger rating systems; national wildland fuel moisture databases; national weather databases	Point-source weather stations; 1 km – 10 km resolution weather maps; topography and vegetation map resolutions dependent on remote sensor technology	GIS maps; weather maps; tabulated information from weather stations; raster and vector maps (wind, temperature, humidity, etc.); wildland fuel maps; vegetation type and height maps; slope and aspect maps; percent change in greenness maps
Response of Structures, Land Parcels and Community Layout to the Fire	Structure damage severity; structure damage details; construction types; foundation types; roof types; modes of ignition; construction materials; fuel loads; attached structures; building openings and vents; secondary combustibles near or around main structures; available water supplies; presence and type of mitigation strategies	Several dozen to several hundred structures and land parcels; Several dozen to several hundred interviews. Depends on the size of the area affected	Beginning within one week post-incident and lasting up to several months	Residents; homeowners; first responders; local authority damage assessments; damaged structures; destroyed structures; undamaged structures; land parcels surrounding structures; tax-appraisal records; time-stamped ground and aerial images; Firewise or Firesmart survey records[a]	Per-structure basis; per-parcel basis	Damage forms and surveys; eyewitness account transcripts; tabulated structural detail summaries; formal damage assessments

(*continued on next page*)

Table 2 (*continued*)

	Data Types	Data Sample	Data Collection Timeframe	Data Sources	Data Resolution	Data Representation
Human and Community Response to the Fire	Resident demographics; resident vulnerabilities (physical ability, age, language barriers); community WUI preparation, adaptability and hazard reduction programs; Evacuee pre-fire experiences, training, preparedness, perceptions and mitigation actions; types, content and timing of emergency communications (warnings, alerts); resident threat and risk perception associated with the fire	Depends on the size of the community affected	Beginning within a few weeks post-incident and lasting up to several months	First responders; residents; homeowners; evacuees; individuals in charge of communicating with the public; victim's relatives and friends; casualty and demographic databases; existing evacuation protocols and emergency plans; media accounts; social media posts; local authority database of evacuation	Individual basis	Eyewitness /interviewee accounts and transcripts; survey responses
Emergency Response	first responder communications; first responder defensive actions; first responder protocols; firefighting tactics; first responder timelines	Depends on the size of emergency response force	Beginning within a few weeks post-incident and lasting up to several months.	First responders; individuals in charge of communicating with the public; local authorities; radio logs; first responder automatic vehicle location (AVL); fire service protocols	Individual or group basis	First responder account transcripts; first responder deployment timelines; fire and emergency service protocol documents

[a] 'Firewise' and 'Firesmart' are fire risk mitigation and community resilience programs used in areas of high wildland fire risk within the U.S. and Canada, respectively. Website links: https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Firewise-USA; https://firesmartcanada.ca/.

Data collection

Five main areas of interest in WUI fire studies are:

1. Progression of the fire in both time and space ('spatiotemporal progression')
2. Local weather, topography and wildland environment
3. Response of the structures, land parcels and community layout to the fire
4. Human and community response to the fire
5. Emergency response

Spatiotemporal progression refers to creating an event timeline that describes where and when the fire progressed. A completed timeline entails the path of fire movement from the point of origin in the wildlands, to fire spread from wildlands to urban structures, to fire spread from structure to structure. Local weather and environment data give context to fire spread and severity, while aspects of wildland vegetation (e.g. moisture content, density, height) and local topography (e.g. slope, aspect) are used to predict or explain fire exposure to structures. The response of structures and land parcels is studied to understand vulnerabilities to fire ignition and the effectiveness of fire mitigation measures in the context of fire exposure severity. NIST has published a framework to help determine expected fire exposure severity [34]. Mitigation measures include fuel load control, fire resistive construction, and control of fire spread pathways (e.g. fire spread from ignited mulch or decking to the primary structure). The assessment of fire damage to structures and land parcels must also be done in context of defensive actions [22]. Not doing so could give an incorrect context to the performance of fire mitigation strategies. Assessment of human response to the fire focuses on identifying factors that influence evacuation decision-making and behavior as well as understanding the social, psychological and economical effects on individuals, businesses, healthcare, education and other social functions after the fire [6,35,36]. Assessment of emergency response encompasses the actions, tactics and protocols of first responders before, during and after an event.

Data within these five areas is collected using the following overarching methods:

1. Field and office data collection at the level of structures, parcels (the land on which the structures are located) and landscapes (the surrounding wildlands)
2. Eyewitness interview and survey data collection
3. Aerial and remote-sensor data collection

Field data collection and eyewitness interviews/surveys require a field deployment to the event location. Aerial and remote-sensor data collection refers to information taken from satellite imagery, light detection and ranging (LIDAR) maps and other methods to give a broad view of the affected area and discern large-scale patterns of vegetation, structure clusters, community layouts and fire spread. "Office" data collection refers to information procured from online databases, local records, external organizations and other sources that gives context to the fire event. Table 2 describes examples of data attributes within the five WUI subject areas that are collected using one of the three methods listed above. The data attributes include the types of data collected, typical samples, data collection timeframe, data sources, data resolution, and data representation (formating and integration).

Stage 3: post-deployment processing

Integrating and cross-referencing multiple data sources and types is the primary technique by which conclusions are drawn. Data such as that described in Table 2 is integrated together to produce a "big picture" assessment of the incident and to discern findings. Development of an event timeline and utilization of a geographic information system (GIS) are two data integration methods used by the WUI fire studies in Table 1. Among other capabilities, GIS can integrate structural information, topographical information, wildland fuel information, damage assessments, fire spread indicators and evacuee travel behaviors onto a geographic map of the affected area. Event timelines put evacuation behavior, resident response to emergency cues, first responder actions, fire spread and structure damage into context of the timescale of the event. Event timelines, GIS maps of the affected areas and other methods of data integration reconstruct the event in both space and time and can be used to compare the event outcome (damage, fire spread, cost, injuries, casualties) to the presence of safety and fire resilience measures.

After the completion of a deployment, the field data collection team is debriefed, lessons learned are discussed, and alterations to future data collection methodologies are made accordingly. Those interviewed for this review emphasized that methodologies need to evolve with experience and allow for acknowledgement of failures and improvements.

Summary and key points

Main stages, details and points of interest of WUI fire post-incident studies were presented based on reviews of a selection of natural disaster and WUI fire reports and interviews with subject matter professionals. The study of WUI fires requires a multidisciplinary approach and integration of large quantities of information across multiple data sources and types. Dozens of data types from thousands of individual sources can be included in an analysis. In each study reviewed, interviews with first responders, residents and evacuees were key elements in the analysis regardless of whether the study was interested in the physical phenomena of the disaster or its impact on communities. In the case of physical-centric WUI fire studies, due to the large geographic area that encompasses most WUI fire events, analyses using GIS were instrumental in integrating the diverse data types collected both on the ground and remote from the incident. Logistical challenges and practices of conducting a WUI fire study were highlighted. In particular, researcher safety, efficient research team structures, the benefit of proactive planning prior to an event and in-depth cooperation with partner organizations were emphasized.

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