Institute for Catastrophic Loss Reduction

Building resilient communities

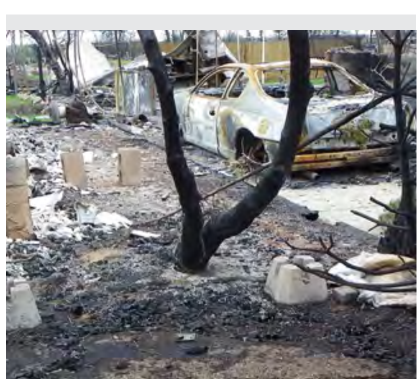
Developing a method for conducting wildland/urban interface fire case study research

A Foundational Document

Prepared by: Alan Westhaver, ForestWise Environmental Consulting Ltd.

Contributing author: Steve Taylor, NRCan-Canadian Forest Service

November 2020



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Established in 1997 by Canada's property and casualty insurers, the **Institute for Catastrophic Loss Reduction** is an independent, not-for-profit research institute based in Toronto and at Western University in London, Canada. The Institute is a founding member of the Global Alliance of Disaster Research Institutes. The Institute's research staff are internationally recognized for pioneering work in a number of fields including wind and seismic engineering, atmospheric sciences, water resources engineering and economics. Multi-disciplined research is a foundation for the Institute's work to build communities more resilient to disasters.

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- Mr. Paul Ward — Facilitator of the CIFFC Mitigation & Prevention Committee and members

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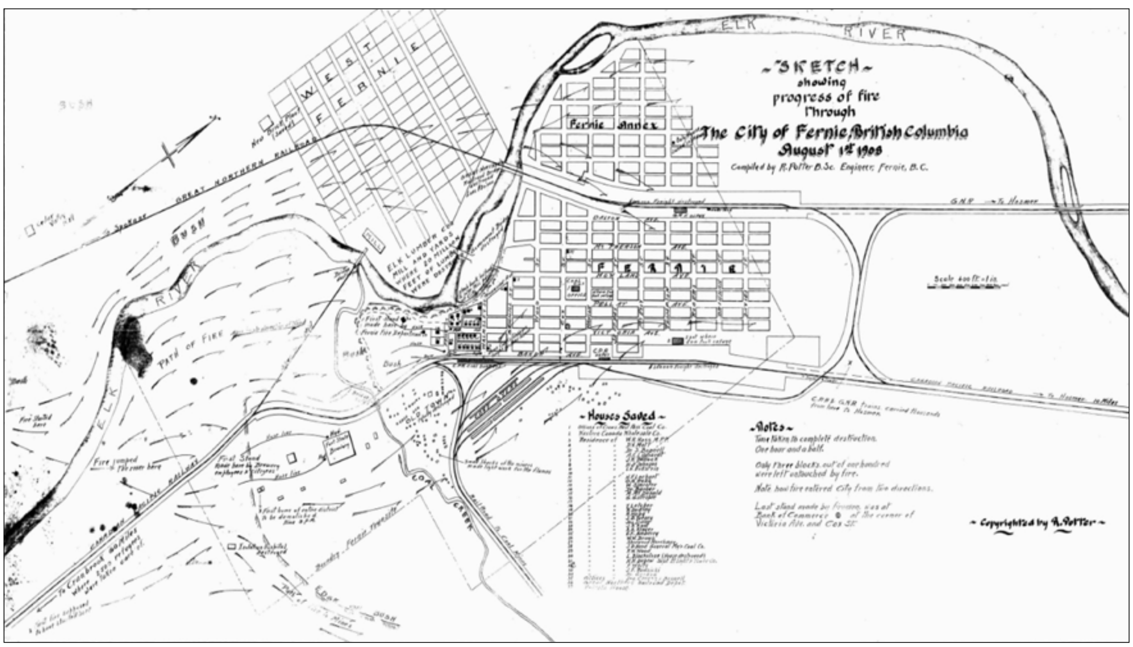
Foreword

Anyone with an interest in wildland/urban interface (WUI) fires should draw inspiration from the hand-drawn map below.[1] It was produced more than a century ago by Robert Potter, city engineer at Fernie, British Columbia, and may still be among the more illuminating studies of a Canadian wildfire disaster.

On one page he documented a wildfire that burned into and through the city of 5,000 people on August 1, 1908. His map traces the path of the wildfire as it converged on the town, the extent of losses (only 37 buildings survived) and the site of defensive actions during the fire's catastrophic 90-minute run.

Potter's work is an enduring record of a catastrophic WUI event. Over a century later, it is time to develop a standard protocol for documenting contemporary disasters in ways that provide better understanding of how such events evolve and knowledge needed to help avoid reoccurrences. It is noteworthy that, like many cities which experienced disastrous fires around the turn of the last century (including Vancouver in 1886 and Seattle in 1887), Fernie "built back better" using locally made brick.



Only recently did I appreciate the links between the 1908 map and my own flawed endeavours at Fort McMurray, Alberta, in May 2016. I was there to conduct one of Canada's few other WUI case studies and to attempt to understand why some homes survived a major WUI fire event, when others did not. On reflection, the outcomes of major WUI fire events don't seem to have changed much since 1908. Like other WUI fire researchers and responders, I also ponder what more might be learned about reducing WUI fire losses in the future if we are prepared and able to observe such events first-hand.
– AW

[1] Courtesy Fernie Historical Society. https://search-bcarchives.royalbcmuseum.bc.ca/sketch-showing-progress-of-fire-through-city-of-fernie-british-columbia-august-1-1908-compiled-by-r-potter-b-sc-engineer-fernie-bc

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Short forms

AHJ	Authority Having Jurisdiction
CCFM	Canadian Council of Forest Ministers
CFS	Canadian Forest Service
CIFFC	Canadian Interagency Forest Fire Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSRT	Case Study Research Team
CSWG	Case Study Working Group
IBHS	Insurance Institute for Business and Home Safety
ICFME	International Crown Fire Modelling Experiment
ICLR	Institute for Catastrophic Loss Reduction
ICS	Incident Command System
IMT	Incident Management Team
NIST	National Institute of Standards and Technology
NFPA	National Fire Protection Association
NRC	National Research Council
NSC	National Standard for Canada
SCC	Standards Council of Canada
SIZ	Structure Ignition Zone
TRP	Technical Review Panel
WUI	Wildland/Urban Interface

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Alan Westhaver served as a senior fire program manager for much of his 35-year career with Canada's national parks. His responsibilities included developing agency capability in operational and administrative aspects of modern fire management (i.e., fire suppression and fire use), and he was deployed many times as a Fire Behaviour Analyst on Incident Command Teams. His passion for the wildland/urban interface was kindled from the dual challenge of restoring the ecological role of fire to park ecosystems, while also protecting the park and nearby communities. Alan's long association with the Partners in Protection Association (also called FireSmart Canada) began in 1990. He served on its Board of Directors until 2013, co-chaired the working group responsible for creating the original *FireSmart* manual (1999) and co-authored the *FireSmart Canada Community Recognition Program* (2012). In Jasper, Alberta, he conceived and managed the collaborative *FireSmart – ForestWise Project* (2000–2012), which merged community wildfire protection, ecosystem restoration and resident values and was documented in his 2006 M.Sc. thesis (University of Calgary).

Alan conducted post–WUI fire case studies for the Institute for Catastrophic Loss Reduction at Slave Lake, Alberta and Kelowna, BC (2015) and Fort McMurray, Alberta (2016) (see www.iclr.org). He remains active in community wildfire protection and education through his Salmon Arm, BC, consulting company.

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Stephen Taylor is a research scientist with the Canadian Forest Service, Pacific Forestry Centre in Victoria, BC. He is active in several national advisory groups and is the author and co-author of a number of publications regarding wildland fire behaviour and its implications or applications in natural resource management, including the "Field Guide to the Canadian Forest Fire Behavior Prediction (FBP) System."

Executive summary

Wildland/urban interface (WUI) fires are now among the leading causes of natural disasters in Canada, and their impact on Canadian communities is trending upward. Several federal and provincial policies and programs recognize the need to adapt and become more resilient to increasing wildland fire. Scientific understanding has evolved to recognize WUI fire as largely a problem of structural vulnerability to ignition from wildfires reaching the built environment, rather than only of wildland fire control or landscape fuel management – meaning that risks can be mitigated by measures applied to structures and their immediate surroundings. This is consistent with the United Nations Sendai Framework (2015).

Effective disaster mitigation is driven by sound science, and assessing impacts and causation is an important part of the disaster management cycle. Canada has no formal process to monitor or follow WUI fire incidents with impact studies that may help to identify how future occurrences can be prevented or impacts reduced, unlike other natural hazards and disasters, and it is unclear who would have the mandate or authority for such assessments. Thus, very few field-based studies of WUI events have been conducted in Canada. Opportunities to learn from WUI events in Canada, which are both rare and fleeting, are being missed.

This Foundational Document, initiated by the Institute for Catastrophic Loss Reduction[2] (ICLR) and sponsored by the Standards Council of Canada (SCC), is a first step toward creating a comprehensive methodology (i.e., best practices) for WUI fire exposure and impact case studies in Canada. Such studies are vital to address outstanding knowledge deficiencies and improve mitigation measures that reduce structural vulnerability, ignition and loss. This document is not a prescriptive plan, but rather a backgrounder exploring what a comprehensive methodology might look like. It addresses scientific, operational and administrative aspects of implementing WUI fire case study research and provides a focal point for further discussion. In preparing this document, the authors clearly recognize that the trust and support of key stakeholders are required for such an initiative to move forward.

The Foundational Document draws heavily on the experience and knowledge of an international panel of experts, input from a wide array of Canadian stakeholders and a thorough literature review, all of which identified research questions, anticipated issues and informed recommendations. The document includes suggestions for collecting data, organizing a well-prepared research team and developing a functional system to safely access active WUI fires. These protocols may be applied across Canada. The scope of research includes the following areas of inquiry:

- exposure and vulnerability of hazard factors that contribute to the ignition potential of structures,
- pathways of fire progression within the Structure Ignition Zone (SIZ),
- spread of fire from one structure to another within the built environment, and
- conditions of the wildland fire environment correlating with ember flux.

[2] ICLR's mission is to reduce the loss of life and property caused by natural disasters through support of actions that improve society's capacity to adapt to, anticipate, mitigate, withstand and recover from natural disasters.

Many of these subjects can only be pursued with evidence gathered before the fire or from the fire's earliest stages. Therefore, rapid research response is an urgent priority to capture data that address many of the outstanding questions. WUI fire case study protocols have been adapted to ensure:

- optimal timing of research, and rapid mobilization and deployment of the research team,
- specialized sampling and data collection methods,
- coordination with Authorities Having Jurisdiction (AHJs)[3] and the Incident Management Team (IMT),
- prevention or minimizing of conflicts with fire operations,
- safety of a research team,
- competencies required within a research team and an approach to recruitment, and
- data management and communication of research results.

WUI fire case studies are operationally and technically challenging, but the problems are solvable. Concerns for safety and on-site coordination anticipated by stakeholders and expert reviewers can also be effectively addressed.

However, administrative challenges to achieving a functional WUI fire methodology remain. These are:

- obtaining the administrative and financial commitments necessary to support WUI research,
- assembling a cadre of structural fire engineers and WUI specialists to form a study team(s), and
- identifying a sponsoring body or "network hub" to coordinate Canadian WUI fire case studies.

Important work remains to be done to finalize a WUI case study methodology. We recommend that:

1. The procedures outlined in this document be developed into a National Technical Specification to manage and conduct future WUI fire case studies in Canada, under the auspices of SCC.
2. If SCC chooses not to pursue a standardized product further, then key stakeholders[4] should convene and arrange the creation of an independent Case Study Working Group[5] to finalize a comprehensive WUI fire case study methodology for implementation across Canada.
3. In either case, further engagement of key stakeholders is essential to finalizing a comprehensive WUI fire case study methodology. Therefore, we strongly urge that a facilitated forum of all key stakeholders be expedited to reach consensus on critical issues related to administering and managing WUI fire research.
4. Regardless of the process, a future comprehensive WUI fire case study methodology should be composed of the eight key elements noted in Section 13 (Recommendations).

[3] AHJs include provincial/territorial wildland fire agencies, as well as municipal/district/regional and First Nation governments.

[4] Key stakeholders include the Canadian Council of Forest Ministers – Wildland Fire Management Working Group, representatives of Canadian Council of Fire Marshals and Fire Commissioners, Public Safety Canada, Canadian Forest Service, National Research Council, Canada Wildfire, the Canadian Interagency Forest Fire Centre, Canadian Association of Fire Chiefs and leading fire researchers.

[5] The working group should consist of experts reflecting the composition of the proposed Case Study Research Team (CSRT) outlined in Section 8 (i.e., potential members of the CSRT).

Not surprisingly, WUI fires bring multiple diverse partners together into strong and efficient disaster response and recovery operations. However, a similar level of engagement regarding research to improve disaster prevention and risk mitigation efforts has not been seen.

We hope that this Foundational Document will stimulate the further discussion and collaborative actions needed to develop an effective path for conducting future WUI fire case study research that will inform all phases of the disaster management cycle and ultimately reduce wildfire impacts on Canadians.

In the meantime, as the Greek philosopher Theophrastus noted around 400 BC, "Fire is always hungry."

Part I: Environmental, policy and scientific drivers

This section reviews some of the environmental and policy drivers for this project, the project objectives and methods, and knowledge deficiencies that may be addressed by wildland/urban interface (WUI) fire case studies.

1.0 Introduction

Nearly 6% of Canada's forests and 60% of named communities lie within the WUI (Johnston 2016), containing about 15% of dwelling units in Canada (Taylor 2014). The number and impact of wildfires spreading from forests and grasslands into communities in the WUI have been increasing in Canada over the past two decades. Notably, several extreme WUI fire events since 2003 have resulted in the loss of hundreds to thousands of dwellings. Such wildfire impacts on communities have not been seen in Canada for many decades (Alexander et al. 2007). Furthermore, there is broad consensus (Coogan et al. 2019) that wildfire activity will increase in Canada in the coming decades, including:

- a 2-4 times increase in annual burn area across Canada (Flannigan 2005, Podur and Wotton 2010),
- increasing fire intensity and severity due to drier fuels (de Groot et al. 2013),
- increased numbers of rapid fire-spread days due to extreme weather (Wang et al. 2015),
- increasing fire season severity and length (Flannigan et al. 2013), and
- more days where head fire intensity precludes effective direct attack (Wotton et al. 2017).

More frequent and severe fire activity, combined with increasing WUI development in some regions, will result in higher WUI fire disaster losses in the coming decades (Canadian Council of Forest Ministers 2016).

Major loss events reported by insurance industry from 2000 to present (total losses exceeding $25 million)

Fire	Year	Insured loss, $millions (2017 CAD)	Number of homes or structures lost
Kelowna, BC	2003	$254	334 homes, many businesses
Slave Lake, AB	2011	$574	510
Fort McMurray, AB	2016	$3,811	1,595 structures containing 2,579 dwelling units
Thompson Nicola Regional District, BC	2017	$27	215
Areas surrounding Williams Lake, BC	2017	$100	107

Source: Adapted from National Research Council WUI Guide for Canada (Draft version, May 2020).

Canada has adopted the *Sendai Framework for Disaster Risk Reduction* (United Nations Office for Disaster Risk Reduction 2015), which emphasizes building disaster resilience over managing disasters. This direction, shifting toward proactive disaster risk management and away from managing disaster itself, has recently been reflected in three significant policy documents:

1) Public Safety Canada: Emergency Management Strategy for Canada (2019)

Promotes an all-hazard approach informed by evidence-based risk assessment with emphasis on expanded risk mitigation and building back better.

2) Canadian Wildland Fire Strategy (CWFS): A 10-Year Review and Renewed Call to Action (2016)

Promotes enhanced mitigation capability and commitment to FireSmart.®

3) Canadian Forest Service Blueprint for Fire Science in Canada: 2019–2029 (2018)

Promotes building fire-resilient communities and infrastructure, as well as improving risk reduction measures.

Each of these documents recognizes WUI fire as an increasing threat to the health and safety of Canadians and the need for research that supports wildland fire-related disaster resilience.

Furthermore, reviews of several extreme wildfires and wildfire seasons have been carried out in the past two decades including:

- BC Flood and Wildfire Review (Abbott and Chapman 2018)
- Horse River Fire, Fort McMurray, Alberta (MNP 2017)
- Wood Buffalo Wildfire Post-Incident Assessment Report (KPMG 2016)
- Early winter grass fires in southern Alberta (Alexander, Heathcott and Schwanke 2013)
- Flat Top Complex Review Committee: Slave Lake, Alberta (2012)
- Firestorm 2003, British Columbia (Filmon 2004)
- BC Auditor General Report: Managing Interface Fire Risks (2002)
- Chisholm, Alberta Fire Review Committee – Final Report (De Sorcy 2001)
- Garnet Fire Review (PricewaterhouseCoopers 1995)

Although these reviews focused on operational emergency management and fire response, they all identified the need for research relating to WUI fire loss reduction.

Current efforts to increase wildfire resilience in Canada include guidelines published by FireSmart Canada (Partners in Protection 2003 and others) and a WUI guideline for new development being prepared by the National Research Council. It is well recognized that there is need to increase the scientific basis of these guidelines in future iterations. Despite frequent calls for "lessons learned" and concern for reducing the susceptibility of communities to wildfire, there are few first-hand observations into and within the built environment, including knowledge about ember exposure, pathways of fire progression across individual properties and between adjacent structures, and the vulnerability of particular structural components, landscaping features and other combustible surroundings to ignition.

> **"A location is called a 'wildland/urban interface' area wherever structures are located in places where topographical features, vegetation/fuel types and local weather conditions result in the potential for those buildings to ignite from the flames, radiant heat and/or firebrands of a wildland fire."**
>
> **NFPA**

Several approaches can increase our understanding and ability to manage wildfire losses:

- laboratory experiments, which have been the standard method to evaluate the flammability of construction materials (e.g., current work by firebrand generator facilities),
- physical models, such as for radiant heat transfer (Cohen 1995), which provide predictive ability,
- field experiments, such as at the International Crown Fire Modelling Experiment (ICFME) project (Cohen 2004; Stocks et al. 2004), which have demonstrated that structures separated by about 30 m from a high intensity wildfire front are unlikely to ignite from radiant heat, and
- post-fire case studies (Cohen 2000; Cohen 2003; Blanchi et al. 2006, Moore et al. 2008, Quarles et al. 2012, Gibbons et al. 2012, Rissel and Ridenour 2013, Westhaver 2017), suggesting embers or firebrands lofted from a wildfire into a community are the primary cause of home ignitions.

While all of these methods contribute important knowledge, they are each carried out at a particular scale and with varying degrees of environmental control. A case study is the only method that examines the effect of full-scale, uncontrolled WUI fires. We believe that systematic observational studies documenting the progression of wildfires into the built environment, along with evidence of factors affecting structure vulnerability, have and will contribute to increased understanding of these events and will also suggest new avenues of research.

We also assert that we have missed many opportunities to learn from the WUI fire incidents that have occurred in Canada during the past two decades. This is, in part, because local emergency and fire services are wholly occupied during an incident, and wildland agencies don't have the jurisdictional authority over private property or a mandate to engage in detailed investigations outside of public land.[6] Because of the random element of wildfire occurrence and the brief window of opportunity as wildfire transitions into the built environment, researchers must be well-prepared in advance, able to respond quickly and have the trust of and support from agencies having jurisdiction over incidents to avoid losing these research opportunities.

Notwithstanding widespread support for lessons learned and disaster mitigation, Canada has no formal procedures or processes to study WUI fire incidents to gather knowledge to prevent future occurrences or reduce their impacts. This is in contrast to other natural hazards, where post-event damage assessments are often carried out, for example, tornadoes (Harrison et al. 2015), floods (Ahmari et al. 2016) and earthquakes (Mitchell et al. 1990, Bird et al. 2016).

1.1 Project Purpose and Objectives

This project was initiated in response to a need to learn more from disastrous WUI fire events in order to reduce the risk of future social and economic impacts. WUI fire disasters and their impacts are a pan-Canadian phenomenon, which require the public, the private sector and all levels government to share responsibilities to effectively address mitigation, preparedness, response and recovery actions.

Tornado damage surveys and construction guidance

Post-disaster damage surveys and consideration of damage survey findings in construction guidance are established for other types of hazards in Canada. For example, surveying of damage following tornado events is conducted to classify tornadoes using the Enhanced-Fujita scale (e.g., EF0 through EF5). Classification is based on observations of damage to different types of structures (barns, houses, schools, etc.) and other damaged objects (vehicles, trees, free-standing poles, etc.).

On-site investigations conducted in eastern Canada have revealed that buildings where more than 90% of occupants were killed or seriously injured had inadequate anchoring of the floors into foundations or anchoring of roofs to walls. The National Building Code of Canada includes building anchoring, as well as further commentary concerning anchoring of roofs to concrete block walls to accommodate tornado and high wind risk, reflecting these findings.

A National Standard of Canada (NSC) focused on increasing resistance of low-rise residential buildings in Canada to high wind and tornadoes is currently under development (CSA S520). The NSC was motivated by a Foundational Document citing findings from recent tornado damage surveys that revealed specific vulnerabilities of structures to tornado events.

For more detail, see: Sandink, D., Kopp, G., Stevenson, S., and Dale, N. (2019). Increasing High Wind Safety for Canadian Homes: A Foundational Document for Low-Rise Residential and Small Buildings. Toronto/Ottawa: Institute for Catastrophic Loss Reduction/Standards Council of Canada and citations therein.

[6] The Fire Marshal or Fire Commissioner have this authority.

The purpose of the project was:

> *To develop a Foundational Document to assist in data collection from WUI fire events that can or have resulted in the loss of structures. The document will lead to the development of a functional system for having researchers access WUI fire–affected areas and for interpretation of collected data, as it relates to structure vulnerability and loss. It is expected that the development of this methodology will assist in field verification, improved understanding and assessment of hazard factors, fire spread characteristics, and structure ignition processes that affect structure vulnerability and loss, as outlined in WUI fire mitigation materials.*

The project objectives were to:

1. define critical knowledge gaps and research questions,
2. review and propose methods to obtain and manage critical data before, during and after WUI fire events,
3. anticipate technical, logistical and administrative issues,
4. recommend practicable solutions and best practices,
5. describe the attributes and deployment of an appropriate research team, and
6. outline outstanding issues and appropriate next steps.

We also recognize constraints on developing protocols and best practices for WUI fire research because:

- WUI fires vary greatly from each other; therefore, all aspects of *any* prescribed methodology will not be applicable to every individual fire event,
- research protocols must be based on an acknowledgement of inherent observer bias, and researchers must remain attentive to discovering and exploring unexpected observations likely to arise in WUI situations, and
- most, *but not all*, of the challenges to implementing WUI case study research can currently be anticipated and/or addressed.

Thus, methods and protocols are expected to be adapted as they are implemented and researchers gain experience with them; "learning by doing" is essential for success.

The anticipated benefits of developing this Foundational Document include:

- enabling SCC to decide on its options for development of a standardized product,
- allowing researchers to better prepare to be safely deployed at active WUI fire situations (under the auspices of the AHJ) and take advantage of the event to gather knowledge important to understand the dynamics of full-scale uncontrolled WUI events and inform practice to reduce WUI fire losses, and
- motivating broader interest, further discussions and collective actions toward creating research teams and an operational plan for organized WUI fire case study research.

Overall, the Foundational Document is intended to provide an anchor point for future development into a systematic methodology for learning from WUI fire disasters and to initiate future cross-disciplinary discussions and collaboration toward conducting such studies.

This document is intended for a wide range of Canadian audiences, from government policy bodies to citizen-led organizations, all of them stakeholders affected by the WUI fire issue. Key stakeholders include the Canadian Council of Forest Ministers – Wildland Fire Management Working Group, representatives of the Canadian Council of Fire Marshals and Fire Commissioners, Public Safety Canada, the Canadian Forest Service, the National Research Council, the Canadian Interagency Forest Fire Centre, the Canadian Association of Fire Chiefs, leading wildland fire researchers, the Union of British Columbia Municipalities, the Canadian Federation of Municipalities, and several other organizations, industries and institutions.

This report flows from problem description, project objectives, methods and knowledge requirements (Part I), to analysis of research opportunities and potential methods (Part II), to model protocols for deployment of a WUI research team (Part III), and finally, to conclusions and recommendations (Part IV).

2.0 Developing protocols for conducting WUI fire case study research

2.1 Introduction

The Standards Council of Canada (SCC), as part of the Pan-Canadian Framework on Clean Growth and Climate Change, is helping to better position the national standardization system to protect the health and safety of Canadians in the face of a changing climate. As part of this initiative, SCC is working with its partners and accredited Standards Development Organizations (SDO)[7] to ensure that infrastructure and construction standards are "climate ready" and that standardization is poised to help support the Canadian clean tech industry through accelerated commercialization.

Given nationwide concerns regarding the impact of WUI fires, SCC engaged the Institute for Catastrophic Loss Reduction (ICLR) to produce a "Foundational Document" to outline the components of a protocol to conduct and manage systematic science-based case studies of WUI events, potentially leading to development of a new standardized product. ICLR retained ForestWise Environmental Consulting Ltd., with assistance from the Canadian Forest Service, to draft the document.

The initiative to create a Foundational Document is responsive to and in keeping with the higher-level guidance of key federal agencies like Public Safety Canada (Emergency Management Strategy for Canada) and the Canadian Forest Service (Blueprint for Fire Science in Canada) and partnerships such as the Canadian Council of Forest Ministers (Canadian Wildland Fire Strategy). Furthermore, as outlined in the terms of reference for this project, several provincial and territorial government climate adaptation plans have highlighted the need to adjust codes and standards to increase resilience to extreme natural events and climate change, including those in Ontario, British Columbia, Quebec and Manitoba.

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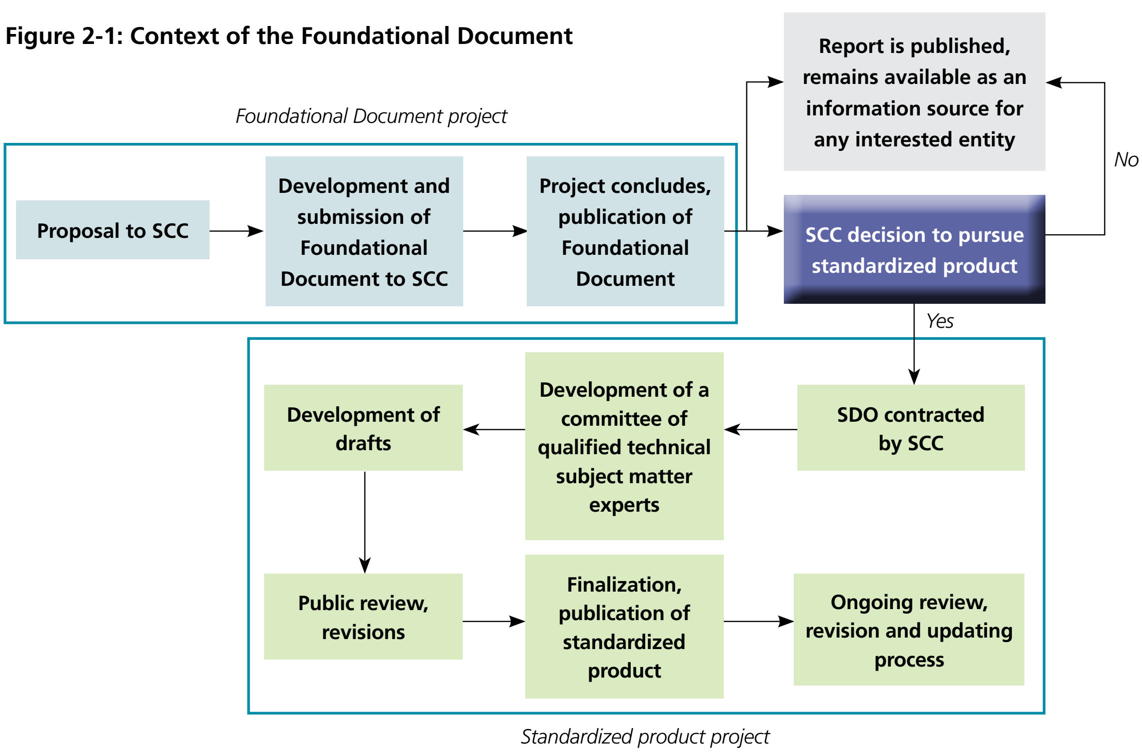
[7] SDOs in Canada are accredited by SCC to carry out standards development work. They develop a standard by consulting with a group of subject matter experts, who become members of a technical committee. Participants in these committees provide technical expertise and input. At the same time, they benefit by gaining professional knowledge in their field (Source: Standards Council of Canada).

This Foundational Document is intended to establish the groundwork of knowledge and stakeholder insights concerning WUI fire case study research. It has been written by and in consultation with subject matter experts to help others understand this complex issue, refine the research approach and make decisions regarding wildfire risk mitigation research going forward. Should development of a standardized product proceed, it would be a separate and distinct project, managed by SCC and informed by the Foundational Document (see Figure 2-1).

The appropriate type of standardized product depends on several factors, including the level of consensus and agreement that can be reached within the stakeholder community relating to the processes and practices that may be incorporated into the standardized product. Where a high degree of consensus can be achieved, a National Standard of Canada (NSC) may be pursued. Where consensus may not be possible or an NSC not fully developed, other products – such as a National Workshop Agreement, a National Community-Sourced Guidance, or a National Technical Specification – may be considered (see Appendix C).

The Foundational Document will be published as a public resource upon completion. If a decision is made not to pursue a standardized product, the document will remain available as a public resource (published by SCC and ICLR). While a Foundational Document may be used as a source of useful information, it should not be viewed as a regulatory or prescriptive document, and no part of the Foundational Document should be considered prescriptive or adopted as a vetted best practice by any agency.

Figure 2-1: Context of the Foundational Document



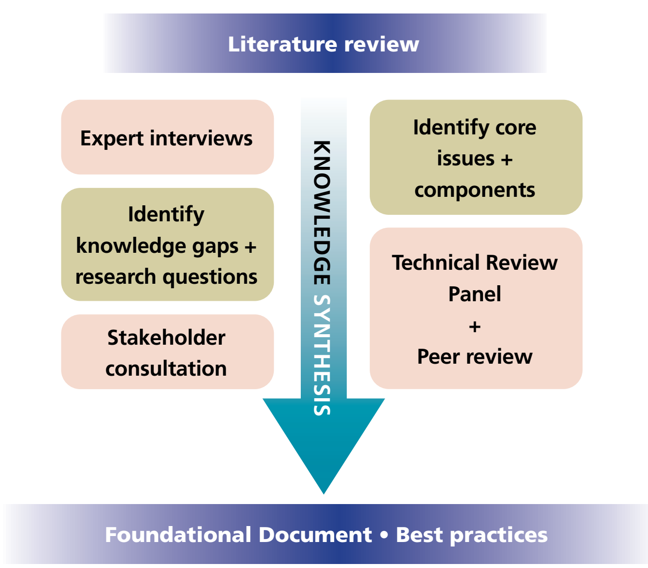
2.2 Methods for Creating the Foundational Document

The development of this Foundational Document was guided by general criteria provided by SCC, terms of reference established between SCC and ICLR, and processes for developing theory from case study research (Eisenhardt 1989). The Foundational Document process places strong emphasis on engaging people who may be participants in case study research, be affected by it or be potential users of the information produced. Importance was also placed on consulting with known experts in the field of interest. This project succeeded in involving both groups.

The primary methods to create the Foundational Document and meet project objectives were:

1. reviewing scientific, operational and popular literature related to WUI fire, research, structure vulnerability, ignition and loss,
2. engaging a panel of Canadian and international experts in WUI fire events and other disciplines (see Acknowledgements) to identify important research questions and elements of a methodology, seek their opinions and review drafts of the document,
3. seeking out and consulting with a broad range of stakeholders with interests in WUI fire response, prevention, mitigation, research and public education in order to understand and address problems, issues, concerns and opportunities perceived by them, and
4. developing questionnaires, polls and surveys to prompt discussion and feedback on specific questions and circulating draft documents for review and constructive criticism.

Figure 2-2: Methods for development of the WUI fire case study Foundational Document



3.0 Knowledge gaps regarding WUI fire structure loss mitigation

In keeping with practices set forth by Eisenhardt (1989), we reviewed existing WUI case studies and other relevant WUI fire studies to assess what has been learned from major WUI fire disasters of the past and identify knowledge gaps. We identified more than 30 published case studies of structure loss in WUI fires (Literature Cited and Appendix B) and a number of other reports.[8] The majority of case studies are from the United States and Australia. Westhaver's 2017 Fort McMurray report is the only related Canadian study. He applied a home hazard assessment matrix retrospectively to homes and acreages on the city margins and concluded that surviving homes were rated with low to moderate overall hazard, whereas homes that were destroyed were rated high to extreme. Vegetation contributed 50–75% of all hazard and was particularly problematic within 30 m of burned homes. Embers were flagged as the leading cause of structural ignitions. Although a number of properties in the 2003 Okanagan Mountain Park Fire were investigated, only a map[9] of structure loss was published (Beck and Simpson 2007). Other WUI fire case studies in Canada have focused on conditions in the fire environment and fire behaviour. Examples include 11 wildfires in Manitoba in 1987–89 that resulted in the evacuation of more than 32 communities and numerous home losses (Hirsch 1987, 1989, 1991) and work in Saskatchewan on the effect of fuel treatment on fire behaviour and effectiveness/difficulty of fire suppression on six fires (FP Innovations 2017; Govt. of Saskatchewan 2016).

Following extensive literature review, key findings of case studies and WUI reports include:

- Wildfires are inevitable. Agencies in Canada and the US routinely report that 95–98% are suppressed when very small. The remaining fraction (3–5%), which exhibit the most extreme behaviour, cannot be contained at a small size and account for about 90% of the annual forest area burned.
- These relatively rare but extreme wildfires are the principal cause of almost all disastrous WUI fire losses (Cohen 2010).
- Large WUI fire disasters follow a distinct pattern called the "WUI fire disaster sequence" (Cohen 2010, Calkin et al. 2014), in which disaster is precipitated when large numbers of near-simultaneous structure ignitions overwhelm responding resources. The sequence also reveals that creating ignition-resistant structures and properties is the most likely means of preventing WUI fire disasters.
- Most structure ignitions are caused either indirectly by embers/firebrands that ignite low-intensity surface fire next to a home or directly by ember ignitions on the home, not by direct flame heating (i.e., radiation or flame contact) from the advancing wildland fire (Menakis et al. 2003, IBHS 2007, Cohen and Stratton 2008, Sandink et al. 2017).
- Reducing structure ignitions depends primarily on managing conditions of the structure and the area within about 30 m of it (Stocks et. al 2004, Calkin et. al. 2014). These findings provide anchor points for future WUI case studies.

[8] An unpublished literature review is on file with Institute of Catastrophic Loss Reduction.

[9] Map prepared by the Canadian Forest Service.

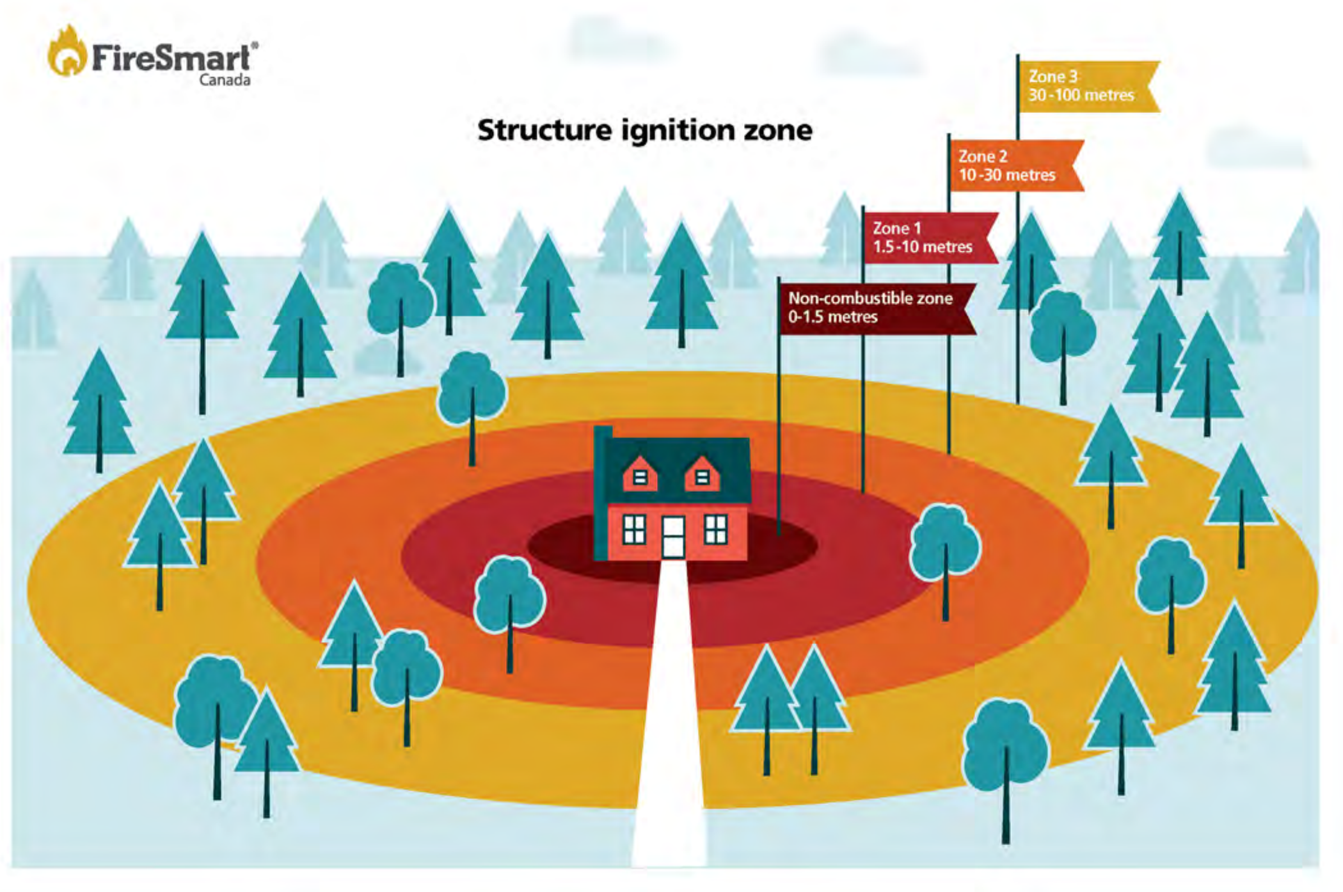
Similar views were recently echoed in a Canadian paper by Johnston et al. (2020), who summarized:

> **Wildland fires are inevitable but the ecological consequences and the susceptibility of human values (i.e., the built environment) are not inevitable … because management actions, like building or modifying structures for fire-resistance, can be undertaken to change the outcome.**

However, significant unknowns remain with regards to ignition points, heat exposure and ember ignition of materials and their respective vulnerabilities to ignition, and progression of fire in the built environment. The ultimate measure of success for future WUI fire case studies will be the degree to which homes and other structures become more resistive to ignition, controlled in part by the extent to which builders and owners adopt WUI fire mitigations.

Technical reviewers believe that the quality of WUI research and how it is presented to the public can also have strong, positive influences on the degree to which WUI fire mitigations are adopted.

Figure 3-1: Structure ignition zone[10]



[10] Retrieved from https://firesmartbc.ca/resource/firesmart-structure-ignition-zone-poster/

Photo credits: Alan Westhaver

Figure 3-2: Post-fire evidence, as above, is limited and constrains interpretation

3.1 Research Gaps and Questions

We grouped knowledge gaps into five categories. These are prioritized below in order of importance according to TRP responses with regard to relative significance and greatest potential to increase the understanding of WUI fire and ignition potential of structures in the WUI.

1. **Vulnerability:** Field observations of the characteristics or physical features of structural, vegetative or any other combustible material (i.e., hazard factors[11]) found within the SIZ that contribute to its individual ignition potential from wildfire.
2. **Exposure:** Field observations specifying the amount, location, duration and intensity of fire (i.e., heat effect) imposed by radiant heat, flames and particularly embers on structural components, vegetation or any other combustible material (i.e., hazard factors[11]) found within the SIZ that may affect structural ignition potential.
3. **Fire progression pathways in the SIZ[12]:** Documentation of the fire spread (including low flames, smouldering fire and ember spot ignitions) between all forms of combustible material across the SIZ toward the primary structure and ignition of the structure.
4. **Ember influx:** Identification of wildland fire environment conditions (e.g., weather, atmospheric instability, topography, wildland fuel types, fire intensity, rate of spread, convection column characteristics) that potentially influence the type, amount and distribution of live embers arriving in the built environment and their effectiveness in causing ignitions.
5. **Fire spread between structures:** Observations of the process of structure-to-structure fire spread, including factors related to building materials, clearances, type and continuity of fuel sources found between structures, density and other community characteristics, ember entrainment from adjacent structures and prevailing conditions of the fire environment, such as wind and slope.

Subsequently, based on the literature review (e.g., Mell et al. 2010 and others) and suggestions from the TRP and other experts, we constructed a list of 31 important research questions that could be informed by future case studies. A sample is provided below (see Appendix E for a complete list of nominated research questions).

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[11] In the terminology of the Canadian FireSmart® program, a "hazard factor" is one of many structural (components or design), vegetative or other combustible elements within a Home Ignition Zone that contributes to a structure's susceptibility to ignition during a WUI fire event. Typically, each hazard factor is evaluated and rated individually during a comprehensive structural hazard assessment.

[12] Alternately (historically) known as the Home Ignition Zone.

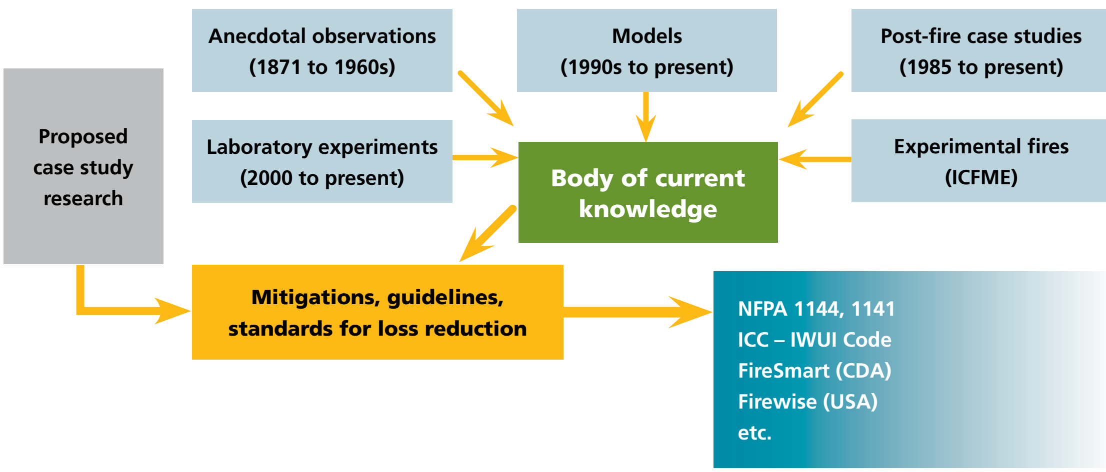
Table 3-1: Examples of important research questions for WUI fire case study

1. Vulnerability
Q1: What structural elements and which aspects of them are most susceptible to ignition from embers?
Q2: When elements of a structure (e.g., walls, deck, roof) are exposed to extreme radiant heat causing ignition, where does the fire spread and/or enter the structure to sustain ignition?
Q3: What principle combustibles found in the SIZ and specific characteristics of those objects provide sites for sustained ignition from embers or heat flux from wildland fires?
2. Exposure
Q1: What are the physical characteristics (e.g., type of material, size, number/density, accumulation patterns) of live embers arriving on structures and other combustibles in the SIZ?
Q2: What is the critical number or mass flux of embers sufficient to result in building ignition?
Q3: Is there a "heat shielding" effect from vegetation or other features with the SIZ? What are the qualities of effective heat shielding objects resulting in reduced exposure?
3. Fire progression pathways
Q1: Are existing FireSmart fuel reduction standards for crown fire hazard (i.e., 1–3 crown width spacing) effective at breaking the fire spread pathway between tree canopies in the SIZ?
Q2: For creeping surface fire, where specifically did fire first enter the property? What objects or fuels comprised the pathway across the SIZ leading to ignition of the structure?
Q3: How effective is the 1.5 m "non-combustible" zone at preventing ignition of the primary structure? Is it adequate or excessive?
4. Ember influx
Q1: To what degree do fire environment conditions and fire behaviour characteristics influence the types, amounts, sizes, transportation distance, distribution pattern and efficacy of embers?
Q2: For what period of time, and at what distance is the built environment impacted by incoming embers from the advancing wildfire? Is this constant for all forest fuel types?
Q3: Is there a correlation between the rate of structural ignitions in the WUI and known characteristics of extreme wildland fire behaviour (e.g., column, instability, high rate of spread, fire whirls)?
5. Fire spread between structures
Q1: What are the primary means (e.g., flame, radiant heat, embers) of fire spread between structures?
Q2: How is structure-to-structure fire spread influenced by density of homes, type, age, slope, wind, building design and materials, intervening fuels, etc. under free-burning conditions?
Q3: Are current building codes adequate under conditions with little or no structure protection?

4.0 WUI fire research and case studies

A wide range of research approaches, methods, investigations and surveys have been used to study different aspects of WUI fire. Each has advantages and limitations due to the scale, timing or scope of observations. Thus, multiple complementary research approaches are needed to understand all the important dimensions of the WUI fire phenomena. Figure 4-1 depicts how these approaches, including case study, reinforce each other and contribute to the current body of knowledge about WUI fire. Collectively, results from each help to inform guidelines and standards meant to increase community resilience to wildland fire; they can also be combined to create an adaptive management feedback loop.

Figure 4-1: Contributions of varied research approaches to WUI fire mitigation



4.1 Characteristics of Case Study Research

We focus here on the case study approach to research, as it is core to the methodology being proposed. Case studies are conducted at the site of an event, as close as possible to real time, and provide unique opportunities for observing and learning about underlying principles and processes (Eisenhardt 1989). More heavily used in social sciences, they have also gained importance in physical science. Case studies are appropriate where the objective is exploratory (i.e., hypothesizing about a new or little-known topic), descriptive (i.e., communicates about a phenomenon) or explanatory (i.e., attempting to explain why things happened), and when it is not ethical or practical to carry out experiments. The terms “case study” and “case study research” are used interchangeably in this report.

Case study research:

- is highly appropriate to new topic areas (Eisenhardt 1989),
- offers flexibility,
- may combine qualitative *and* quantitative data collection methods,
- may embed multiple levels of analysis within a single study,
- focuses on understanding the dynamics present within a setting,
- generates theories and provides opportunities to test, challenge, or validate existing theories or models developed from other types of research,
- explores a single or multiple cases over time, through detailed data collection from multiple sources, for example direct or photographic observation, interviews and documents (Creswell 2007), and
- investigates contemporary phenomenon within its real-life context through empirical enquiry (Yin 2014).

Case study designs can involve single or multiple cases. Single case design is appropriate when a specific theory is to be tested, an individual case represents a situation that is either exceptional or extreme, or when the case may reveal an unexpected situation. Multiple case design is relevant for testing or replicating conclusions, eliminating extraneous variation and providing a larger view of a complex phenomenon through comparison (Yin 2014) and meta-analysis.

Case study research has some limitations, including:

- the results of a single case cannot be generalized to the wider population,
- causal inference from post-event observations is weak,
- researchers may be biased in selecting cases or observations, and
- replication is difficult, as each fire event (i.e., "treatment") likely has unique circumstances.

4.2 Anticipated Knowledge Contributions and Benefits of WUI Fire Case Studies

Over time, we expect observations and analysis stemming from case studies will generate knowledge and insights that will better inform strategies to improve WUI fire resilience. In general, WUI fire case studies are anticipated to provide knowledge about:

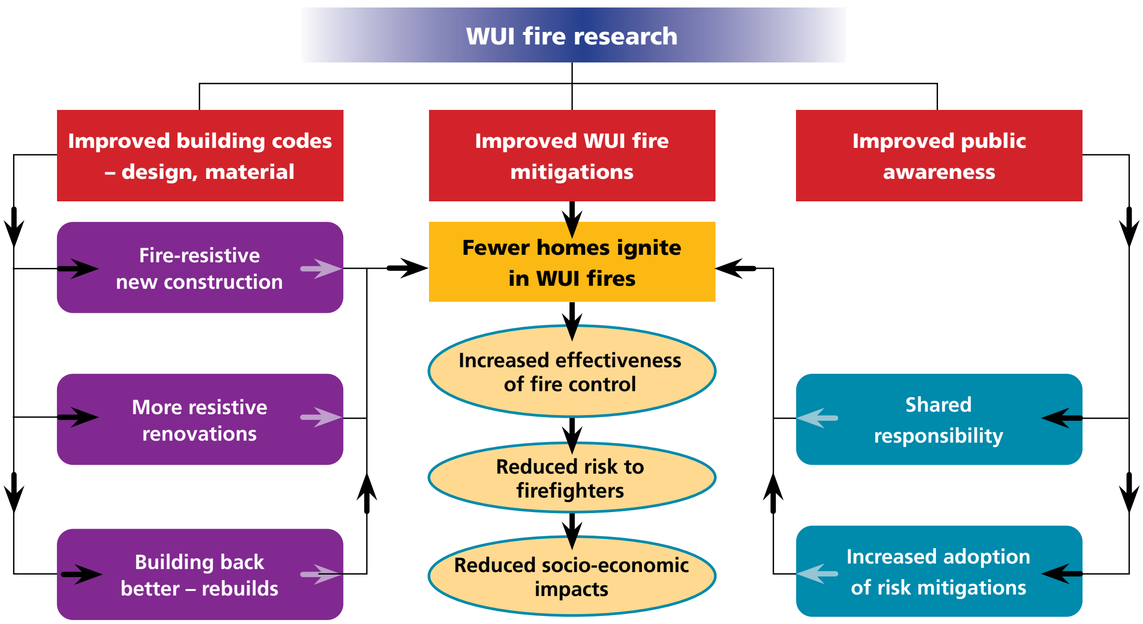
- the effects of real-time exposure to heat on combustible and other materials,
- the vulnerability or fire-resistive qualities of structural, vegetative and other fuels found within the built environment to full-scale uncontrolled fires,
- unexpected and extreme phenomena of WUI fire, leading to new research questions,
- opportunities to test, challenge or validate existing theories or models and focus future research, and
- the full context of fire progression from earliest ignitions to fire spread across properties to structures, and continued spread of fire as it burns freely between structures.

Given its inherent spirit of discovery, case study research is also likely to produce unanticipated observations and stimulate experimental research.

Figure 4-2 illustrates immediate, secondary and long-term benefits of case study research:

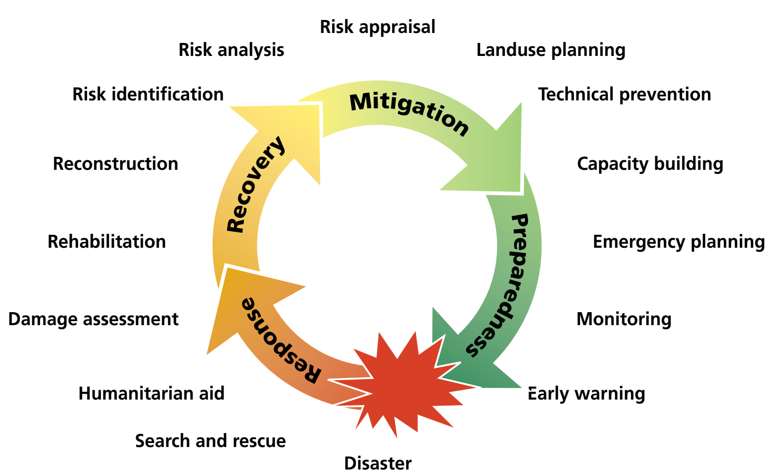
- **Immediate benefits:** results shown in squared boxes of the uppermost tier.
- **Secondary benefits:** results shown in rounded boxes of left and right columns.
- **Long-term benefits:** Fewer structural ignitions, and results shown in ellipses of middle column (inclusive of lowered economic costs and reduced social disruption [ICLR 2019][13] from WUI fires).

Figure 4-2: Model of anticipated benefits of WUI fire research



Consequently, when viewed in a wider context, we believe that a well-planned program of WUI case study research would make positive contributions to all four phases of the "disaster management cycle" (i.e., preparedness, response, recovery and mitigation) as portrayed in Figure 4-3.

Figure 4-3: Phases of the disaster management cycle (Harrison et al. 2015)



[13] It has been demonstrated that previously unmeasured costs of WUI fires to society far exceed insured losses.

Part II: Best practices: Preparing for WUI fire case study research

This section of the Foundational Document includes an assessment of background information essential to prepare for future WUI case studies, including guiding principles and scope, an analysis of the availability of prospective research opportunities to satisfy those needs (i.e., where and when), and an outline of potential field research methods deemed to be useful in gathering such information.

5.0 Applying and adapting the case study approach to WUI fire research in Canada

5.1 Guiding Principles

Principles that should guide WUI fire case studies include:

1. **Science-based:** Procedures and practices incorporate the best available knowledge, credible practices, rigorous data collection and management, expert opinion and peer review.
2. **A focus on health, safety and avoiding fire-ground conflicts:** The research team's activities must not impact the ability of the AHJ to prepare for fire or hinder efforts to manage the fire in progress; all necessary health and safety precautions will be taken.
3. **Flexibility:** Research protocols should be adaptable to ranges of geographic, fire and logistical conditions, and deployment times. Practicality should prevail: "one thing is what we desire, and another is what is feasible due to the circumstances."[14]
4. **Ethics:** Researchers must respect private property and community sensitivities. They will not enter buildings or disturb property and objects, and they will maintain privacy.
5. **Prioritization:** WUI case studies should focus on resolving priority knowledge deficiencies and research questions as evident in current literature and informed by subject matter experts.

5.2 Scope of WUI Fire Case Study Research

The potential scope of scientific inquiry regarding WUI fires extends well beyond the purpose of this project and includes other forms of enquiry (e.g., laboratory experiments) best suited to help answer related questions. While maintaining the importance of discovery as a central concept, case studies will address knowledge deficiencies related to the area and time period when wildland fire is transitioning from wildland fuels to those found in the urban environment (i.e., the SIZs) being exposed to radiant heat, convective/flame contact and airborne embers, and primarily located on the fringes of threatened communities.

The research subject areas within the scope of a case studies include:

- **Hazard factors:** How do characteristics of WUI fuel sources affect their susceptibility to ignition?
- **Mechanisms of fire spread:** How does fire progress across residential lots toward structures?
- **Processes of structural ignition:** How, when and where are structures ignited?
- **Fire spread between structures:** How does fire spread between structures?
- **New hypotheses:** Scrutiny of unexpected observations arising during the course of case studies.

Areas beyond the scope of proposed case study research are listed in Section 5.3 (Liability) to avoid duplication with other research programs and retain focus on primary knowledge gaps.

[14] Prof. Domingos Viegas, University of Coimbra, Portugal

5.3 Adapting WUI Fire Case Studies to Address Stakeholder Concerns and Scientific Needs

There is a compelling case for gathering information about the ignition potential of structures during all stages of a WUI fire event. Most previous WUI case studies have taken place after the fire, when exposure to fire heat and related losses have already transpired. Late arrival on scene precludes detailed assessment of the pre-disturbance condition of structures, vegetation and other hazard factors, as well as observations regarding exposure and ignition of combustible materials and structures. This has limited our current knowledge of WUI fire, fire losses and risk mitigation.

As determined by the analysis in Section 6.0, the arrival time at an evolving WUI incident is the most significant determinant of what can be observed, the types of data that can be collected and the quantity and value of that data. Also, it largely dictates the hypotheses that may be tested regarding WUI fire, and the breadth and degree of confidence in the ensuing conclusions, particularly with regard to causality.

However, the research and fire control communities also recognize that conducting research during an evolving WUI incident in an active WUI fire environment poses serious risks, including:

- the potential for research data to be used against fire agencies to argue liability for losses,
- confusion, conflicts and operational complexities for wildfire and fire-ground managers if researchers are present in the midst of an active fire suppression response, or
- researchers being exposed to personal dangers for which they are not well prepared.

During consultations, stakeholders reiterated these concerns. None of these situations are acceptable and, if not addressed effectively, could obstruct or completely preclude conducting future WUI fire case studies.

Vital research questions could go unanswered unless safe, unobtrusive ways of securing an effective research presence in the WUI are identified and successfully implemented.

Therefore, we propose the following strategies to mitigate or avoid the above risks; they have been woven into the overall approach and recommended protocols described throughout the remainder of this document.

> **"The benefits of a process like [case studies] are many; however, unless those involved in or engaged in managing a large-scale WUI fire have a very strong sense of trust, knowledge and awareness of what a case study practice and process is all about, they may not be at all happy, open and willing partners in any case study or investigation process."**
>
> Shayne Mintz (Canadian NFPA Representative)

Liability: Other forensic investigations associated with fire events may be conducted for the purposes of determining fire origin and cause, documenting damage or evaluating fire operations in search of improvement or to assign liability, responsibility or negligence. The proposed case study research is none of those and does not intentionally collect data likely to be useful for those purposes. This is because the scope of research is limited to subject areas described in Section 3.1. More specifically, *it is beyond the scope of proposed fire case study research to:*

- seek or assign blame or responsibility for losses,
- test or judge effectiveness of fire control strategies, tactics, equipment, products or personnel,
- investigate aspects of wildland fire behaviour, beyond its impact on exposure within the SIZ,
- develop predictive models of fire spread in wildland fuels or within urban areas, and
- undertake studies regarding human dimensions of WUI fire.

Forensic “fire origin and cause” techniques will only be applied to homes that have been saved from complete destruction by fire responders. Those structures are highly valued for learning how and where structural vulnerability and exposure led to initial ignition of the structure, with positive implications for loss mitigation.

Furthermore, in order to properly document and understand the evolution of a free-burning fire reaching the built environment, research will take place in areas that are not subject to intensive fire control activities, creating physical separation between fire control operations and research activities. These areas are very unlikely to overlap. Thus, research observations will have little relevance to after-action reviews or investigations.

Operational Conflicts: Maintaining physical separation (as above) will also be effective in preventing conflicts, confusion or concerns between operational and research activities. Additionally, there is an added element of *temporal* separation, since researchers will only be present before fire impingement/arrival to the community and after fires have been safely extinguished. Only heat-resistant sensing equipment will remain on site during the stages of ember attack and structural ignition, when fire responders are more likely to be present.

Safety: Researchers and drones will not be present in fire-impacted areas during times when dangerous levels of flame and radiant heat are present – only instrument-based observations will be gathered at those times. Additional health and safety protocols will be adopted to further reduce the potential for safety concerns, some of which are outlined below.

To summarize, research protocols will be employed to ensure safety of research personnel, prevent conflicts that could impact the ability of the AHJ or IMT to prepare for or manage the fire incident and preclude the use of research data for litigation purposes:

1. Research planning and protocols strive to ensure case study activities do not overlap spatially with fire suppression activities. Strong two-way communication and integration of research activity into the incident management structure increase confidence in these measures.
2. By design, *temporal overlap* of research and fire control operations will be avoided.
3. If fire control operations do shift into the study area, researchers will withdraw to other locations where research results will not be impacted by fire control activity.
4. Researchers will have appropriate personal protective equipment (PPE), will be accompanied by a qualified full-time Safety Manager during pre-fire dispatches, and (following the principles of LACES[15]) will withdraw if harmful exposure from the oncoming fire seems likely.
5. Data collected during dangerous phases of WUI fire events will be recorded using remotely controlled, insulated cameras and instruments placed prior to the fire by the research team (who will retreat in a timely way), thereby reducing safety risks and potential for conflicts with fire operations.

By mutual discussion, other protocols may be adapted to avoid or minimize temporal overlap to reduce the risk of clashes with the movement of residents or emergency responders.

[15] LACES summarizes all basic wildland fire safety rules: Lookouts, Anchor points, Communications, Escape routes and Safety zones.

Photo credit: Alan Westhaver, Fort McMurray neighbourhood (May 2016)

6.0 Opportunity analysis for WUI fire case study research

We analyzed the availability of opportunities to conduct WUI research and how it is affected by variables relating to the associated wildland fire, the built environment and time of arrival by researchers using an iterative four-step process. This analysis was helpful in developing potential research deployment scenarios, devising suitable research methods and evaluating the likelihood and benefits of research results to be obtained from deploying research teams to a range of differing WUI incident types. Steps in the analysis were:

1. Identify variables impacting availability of research opportunities (positive or negative).
2. Describe a realistic spectrum of incident complexity levels (WUI fire scenarios).
3. Develop a range of research deployment options (3) with consideration for research categories.
4. Rate the probability of conducting research in each category by time of arrival and complexity level.

Details regarding this analysis are found in Appendix F, and results are utilized throughout this report.

6.1 Variables Affecting Levels of WUI Incident Complexity and Case Study Research Opportunities

A number of variables were identified as affecting the complexity of individual WUI fire events and, ultimately, the potential for research opportunities.

Table 6-1: Characteristics and complexity level of representative WUI incidents

Characteristics affecting research opportunities	Levels of WUI incident complexity		
	Level 1: Low	**Level 2: Moderate**	**Level 3: High**
Fire duration	<3 days [hours to days]	3–14 days [days to weeks]	10–30 days [weeks to month]
Fire size	<100 Ha.	100–1,000 Ha.	1,000–10,000+ Ha.
Wildfire behaviour	Extreme; wind driven; single run	High to extreme; multi-fire scenarios; forecast predicts continued high fire danger	Extreme; multiple runs; sustained drought; regional complexes; mega-fire
Built environment	Low structure density in rural or remote settings; hamlets, villages or small towns	Towns less than 5,000 population of moderate to high density; scattered residential, recreational, country estate subdivisions with some low-density rural areas	Large town; cities; dense subdivisions plus satellite suburban neighbourhoods, country estate subdivisions, acreages with low density; regional situation
Probability of wildfire path intersecting built environment	Low – Moderate	Moderate – High	Highest
Properties/ Data collection points (number of structures)	Few SIZs, widely dispersed; anticipate up to 50 building assessments per deployment	Multiple SIZs, clustered into neighbourhoods, including densely packed and moderately separated structures; 100–250 building assessments possible per deployment	Many neighbourhoods, each with many SIZs, including tightly packed structures in adjacent neighbourhoods; 200–500 building assessments possible per deployment
Access	Rural/secondary roads or fly-in access	Rural/secondary roads and/or paved highways; airfield possible	Paved highways, good urban road network; airport
Vegetation/Fuel	Wildland fuels dominant in area	Mixed wildland/modified fuel types	Highly modified urban setting; some native vegetation
Examples	Chisholm AB 2001; Porter Lake NS 2008	Slave Lake AB 2011; La Ronge SK 2015; Halifax County NS 2009; Central BC 2018	South BC 2003; Ft. McMurray AB 2016; Timmins ON 2007

6.2 Case Study Arrival Time Scenarios

With regards to timing of research initiation, the three probable response scenarios for dispatch and arrival of a case study research team are summarized below.

Table 6-2: Summary of case study arrival time scenarios

	Arrival time	Research response
1	Early pre-exposure **Trigger:** Dispatched as/before "Evacuation Alert" declared.	Arrive *well* prior to exposure. Full pre-fire documentation; full instrumentation; observe exposure/ignitions/fire spread; full post-fire SIZ assessment. Fire origin as required.
2	Late pre-exposure **Trigger:** Dispatched on or about time of "Evacuation Order."	Arrive *just* prior to exposure. Limited pre-fire data collection. Some instrumentation installed; observe exposure/ignitions/fire spread; full post-fire SIZ assessments. Fire origin as required.
3	Post-fire (status quo) **Trigger:** Disastrous losses have occurred.	Arrival after passage of the fire. Minimal pre-fire data. No potential for instrumentation or direct observation of exposure, ignition or fire spread. Post-fire assessment only.

6.3 Estimating Availability of Research Opportunities

The matrix shown in Table 6-3 (page 24) estimates the probability of conducting studies for three of five major research categories (top row) during WUI incidents of increasing complexity given three different times of arrival at the incident. Probabilities are colour coded. The matrix is intended to be used to make strategic decisions about operation of a WUI research program and set expectations for planning and deployment preparations.

6.4 Summary

The availability of research opportunities is central to decisions regarding when and how to implement WUI case study research (see Appendix F for details). From this analysis, we conclude that:

- maximum research opportunity and data of greatest value accrue when "early arrival" is possible; this should become the urgent objective for future WUI fire case studies, and
- the scope of research opportunities is broader on fires of higher complexity.[16]

Although not the goal of this analysis, we also found that pre-fire data collection and equipment placement were likely to coincide with timing of evacuation and/or loss mitigation activities. We believe that the argument for gathering data regarding antecedent conditions and the evolution of a WUI fire event is analogous to hurricane researchers flying through the eye of a hurricane to obtain critical data on weather parameters. It can be done safely and without complications given proper preparation and coordination.

[16] However, this should not be construed as discouraging case study research in smaller communities or rural and remote areas. There are other compelling reasons to conduct WUI case studies in those communities as well.

Table 6-3: Anticipated availability of WUI research opportunities (selected research categories)

Complexity level	Arrival time at WUI fire	WUI FIRE RESEARCH CATEGORY		
		Exposure: **Heat effects imposed by WUI fire in SIZ that affect ignition potential**	***Vulnerability:*** **Hazard factors in SIZ contributing to ignition potential**	***Fire spread:*** **Between structures**
3 High – City	**Early pre-exposure**	Highly probable direct observations	Highly probable direct observations	Highly probable direct observations
	Late pre-exposure	Probable direct/indirect observations	Probable direct/indirect observations	Probable direct/indirect observations
	Post-fire	None (embers)	Unlikely	Unlikely
2 Moderate – Town	**Early pre-exposure**	Probable direct observations	Likely direct observations	Probable-possible direct observations
	Late pre-exposure	Possible – likely direct/ indirect observations	Likely – possible direct/ indirect	Possible indirect/direct
	Post-fire	None (embers)	Unlikely, deductive	None (embers)
1 Low – Intermix or village	**Early pre-exposure**	Possible direct/indirect observations	Possible direct observations	Possible – unlikely direct/ indirect
	Late pre-exposure	Unlikely direct/indirect observations	Unlikely, indirect	Possible – unlikely
	Post-fire	None (embers)	Possible – unlikely	Unlikely

Legend – Research opportunity:

High Research Opportunity

Moderate Research Opportunity

Low Research Opportunity

7.0 Wildland/urban interface fire case study methods

This document's central purposes are to assess, adapt and recommend research methods, as well as to apply the scientific method to WUI fire case study research. Methods that apply to each stage of a WUI fire event are identified below. They focus on providing empirical observations as a wildfire transitions into the built environment. Primarily, photographic and electronic data gathering techniques are suggested, allowing for safe data collection regardless of conditions. Several techniques may be applied to more than one research category (see Table 7-1), and all employ technology that is proven or readily adapted from other applications, including previous in situ wildland fire research.

In keeping with the intent of this Foundational Document, this section is not a prescriptive research design. Rather, it provides a menu of tools and approaches that can be evaluated and refined during future stages of methodology development and, potentially, creation of standardized products, prior to the initiation of field work. Ultimately, these will evolve into "best practices" for WUI fire case studies and data collection leading to stronger evidence-based WUI fire risk mitigations in the future.

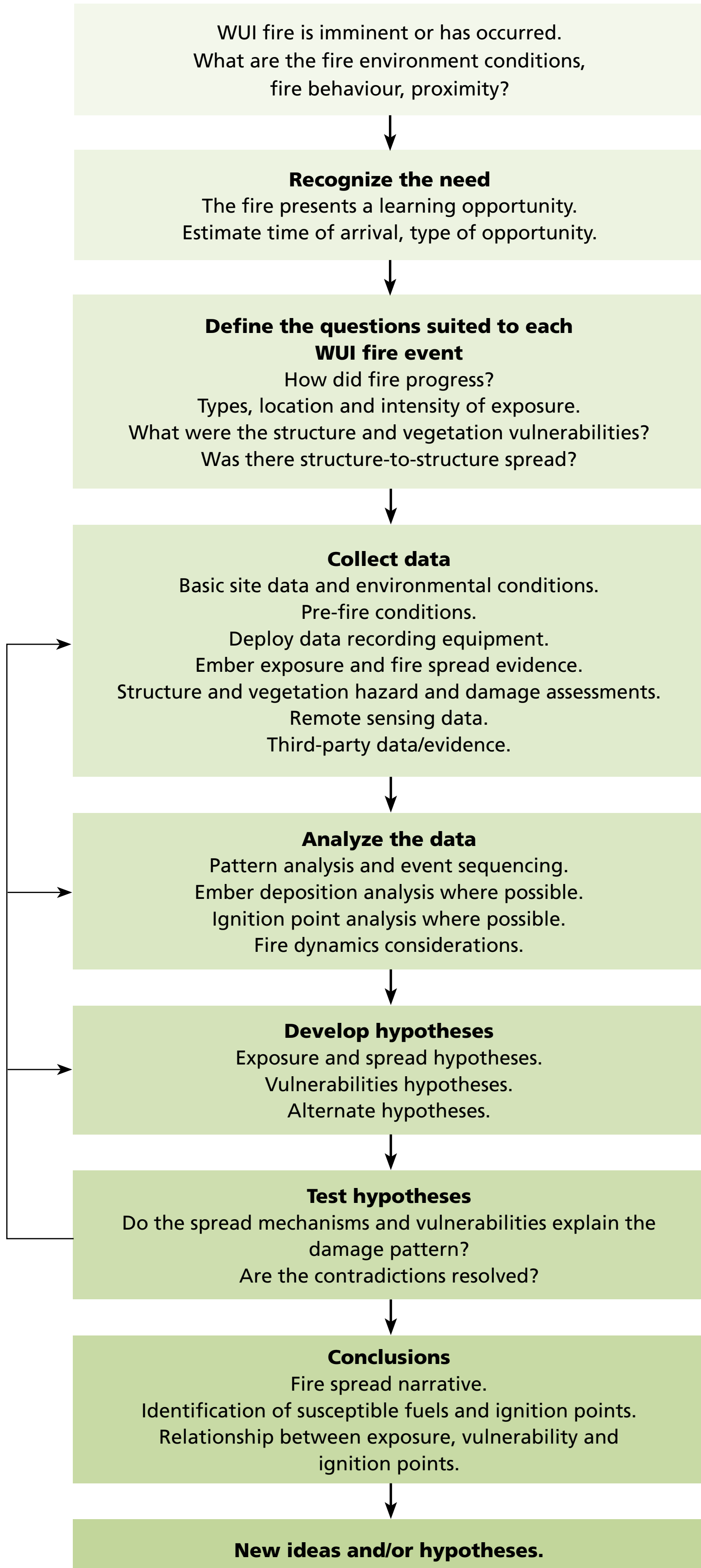
7.1 Study Design and Workflow

Despite promoting the spirit of discovery, the case study approach to WUI fire research must be guided by the need for scientific rigour and the publication of results in peer-reviewed journals. Therefore, the *scientific method* must be incorporated into study planning and workflow. Typically, the process for systematic pursuit of knowledge using the scientific method involves:

- recognition and definition of a problem,
- data collection,
- data analysis,
- hypothesis formulation, evaluation and testing,
- selection of a final hypothesis, and
- statement of confidence levels.

Some of the best examples of applying the scientific method to fire-related studies are found in Chapter 4 of NFPA 921 (Guide for Fire and Explosion Investigation) and in Gorbett and Chapdelaine (2014). Clearly, the WUI case studies proposed here are not "investigatory" in the sense of NFPA 921. However, we believe it provides a useful template for developing an experimental design for WUI fire case studies and accepting, discarding or developing new fire-related hypotheses. Consequently, we have adapted a model from it to illustrate a simple study workflow for WUI case studies in Figure 7-1, and we recommend these references for helpful discussions regarding application of the scientific method to the field of WUI fire studies.

Figure 7-1: Proposed application of scientific method to WUI case studies (adapted from NFPA 921)



7.2 Research Approaches

Harsh, rapidly changing environmental conditions and other constraints at WUI fires limit research design and data collection approaches, and some standard approaches are not feasible at all. Nevertheless, a range of investigative approaches from the literature and expert consultations remain available, including:

- use of drones to acquire high-resolution imagery documenting reference conditions in threatened neighbourhoods immediately prior to and soon after exposure, providing a permanent record for subsequent analysis of hazardous conditions, before/after comparisons, correlation to losses and evaluating fire progression;
- drone imagery (as above) that captures information at the scale of the SIZ, including detailed conditions of specific hazard factors (e.g., roof, deck details, surface fuels, ember accumulation sites, vegetation) vital for assessing vulnerability to ignition and fire-resistive traits;
- placement of heat sensors and cameras in areas subject to ember accumulation, radiant heat exposure from the wildfire or adjacent structures and/or low-intensity surface fire to document exposure and identify points or areas of ignition and subsequent fire spread;
- post-fire observations by WUI technicians to distinguish by elimination how home ignition could not have occurred, as a basis for deducing how homes could have been ignited;
- documenting and rating the condition of known hazard factors (i.e., structural, vegetative and other miscellaneous fuels or conditions) within the SIZ by trained technicians using the detailed purpose-built hazard assessment system, as recommended in this document;
- forensic study of homes that ignited and were damaged but were extinguished by the fire service, as well as homes that were damaged, but did not ignite; and
- documenting the pattern and association of burned/unburned homes in an urban conflagration in relation to topography, wind conditions and adjacent wildland fuels.

7.3 Detailed Method Descriptions

Research techniques described in Section 7.3 are recommended for addressing research gaps and questions outlined in Section 3. With refinement, each is a potential best practice for WUI fire case studies. Incident-specific conditions will determine which techniques are applicable, but multiple methods are intended to be combined into each research team deployment. Table 7-1 (page 34) summarizes which of these methods are applicable to each of three distinct deployment scenarios, and the research categories to which each method produces relevant data.

7.3.1 Colour video and/or single-frame imagery from pre-positioned, fixed insulated cameras

High-resolution, commercially available video cameras can be placed in custom-built insulated boxes similar to those adapted for use in documenting in situ wildland fire behaviour during the International Crown Fire Modelling Experiment (Stocks et al. 2004a). The boxes can be mounted prior to fire arrival onto metal or wooden utility poles at heights of 5–10 m at the edge of communities where wildfire impingement is expected to occur. Cameras can be positioned to provide broad street views of multiple structures facing onto wildland areas, close-up views of fewer structures, or views of specific structural components (e.g., siding, deck, landscaping). Such cameras are capable of operating continuously for 12 hours before overwriting data, and can be adapted to provide time-lapse images of the same scene every five seconds for up to 48 hours. Video quality is high (single-frame images are 8 MB), and all images are date and time-stamped. Camera positions on residential streets at or near the outer fringe of WUI communities judged to be in the path of an oncoming wildfire are preferred locations. The cameras would be left running until such time as latent or "hold-over" structure ignitions are no longer expected, then data recovered. True colour or black and white infrared video is available; adaptations to allow for solar recharging are possible.

Using this method, it is expected that images from before, during and after passage of the WUI fire event could be obtained. These would likely reveal important new insights into exposure, vulnerability, precise ignition locations and fire progression on properties and between buildings. In-fire imagery would be unique in WUI research. A camera aimed to reveal the sky and signs of an oncoming fire front could also reveal information regarding ember flux and associated environmental conditions. Images could be cross-referenced to data gathered before and/or after fire passage from structure hazard assessments or from heat-flux sensors placed in the camera's line of sight. Spatial coverage would be dependent on the number and distribution of cameras set up.

7.3.2 Use of pre-existing or near real-time aerial images or remotely sensed data

A growing number of local governments have adopted the practice of obtaining large-scale, high-resolution colour images of neighbourhoods and individual municipal properties for realty or other purposes. These images are very effective tools for understanding pre-fire conditions and interpreting post-fire hazard assessments of individual homes (Westhaver 2017). Municipal officials or technicians present at the Emergency Operations Centre can be queried about availability of existing imagery. In some cases, Google Street View may also provide helpful information. Image quality and interpretive value will vary. In addition, other existing remotely sensed images (or special ordered high-resolution imagery like "Torchlight") may be available or obtainable from federal agencies due to the disaster status of the WUI event.

7.3.3 Pre-exposure high-resolution colour aerial photography from unmanned aerial vehicles (UAVs)

GPS-guided commercial grade rotary-winged drones (unmanned aerial vehicles or UAVs) are capable of flying pre-programmed grids over front-line[17] urban neighbourhoods or entire small communities judged to be in the path of oncoming wildfire and taking high-resolution true colour stereo-photography – *in advance of exposure and onset of fire control activities*. Depending on the programmed parameters and camera type, drone imagery can capture details of objects smaller than an average cell phone in still images. Simultaneous video feed is also provided and downloaded to the operator's laptop and recorded for future analysis.

Like standard aerial photography, data from overlapping images along flight lines can be combined, processed and displayed in many formats (e.g., point cloud, ortho-mosaic, digital surface model, topographical map, digital terrain model) and even visualized into 3D models of individual homes, SIZs or groups of homes. Flying at normal speeds (e.g., 5–15 m/second) in moderate winds and at a height of 50–100 m above ground, a typical drone is capable of obtaining 100% coverage (with 50–60% side and forward overlap) of a 1 km long strip of homes, 3–4 blocks deep, in about 20 minutes (i.e., 1 battery charge). Battery changes take moments, and the drone is mission-ready again. This imagery would provide an accurate, high-resolution and permanent record of conditions within the overall community, in the area of wildfire transition into the built environment, and/or property-level conditions including the quantity and continuity of structural, vegetative and other combustible fuels.

[17] Homes immediately adjacent to, or within 2–4 blocks of forested areas on the urban fringe most severely exposed to all forms of heat transfer from the wildland fire as the transition to "urban" fuels takes place.

Figure 7-2: Typical commercial-grade drone with high-resolution cameras (below) and GPS (above)

Photo courtesy: Raven West Professional Drone Services

There are safety concerns, and restrictions apply to use of UAVs in the vicinity of active fire operations. However, drone applications can be limited to times and places that do not coincide with air attack or aircraft operations, and these can be enforced as in permit conditions set by AHJs.

UAV imagery could be cross-referenced with information on ember exposure and point ignitions obtained from fixed cameras, on-the-ground sensors and other sources (see 7.3.15) to reveal information about fuel continuity and vulnerability of structural and landscaping features, help with interpretation of pre- and post-burn home hazard assessments conducted by WUI technicians, and (being geo-referenced) provide baseline measurements that support study of structure-to-structure fire spread in the community and fire progression across individual SIZs.

NOTE: A Notice to Airmen (NOTAM) is a notice filed with an aviation authority and administered by Navigation Canada to alert aircraft pilots of potential hazards along a flight route or at a location that could affect the safety of the flight. NOTAMs are routinely filed in the vicinity of wildland fire operations by AHJs. Therefore, restrictions to ensure safety can be placed on the flight of UAVs near wildfires. Flights described in Section 7.3 may take place in “controlled airspace” and be considered “advanced operations” by Navigation Canada and Transport Canada, thereby being subject to obtaining written flight authorization from Navigation Canada and possibly other requirements. Further investigation into UAV use for research in the vicinity of WUI fire events is required. Several current UAV contractors are known to specialize and be experienced in conducting wildfire applications.

7.3.4 Post-fire aerial imagery, moderate resolution, true colour from UAV

Using methods similar to 7.3.3, a GPS-guided rotary-winged drone could be programmed to re-fly the same gridded pre-fire patterns to document post-fire conditions in all or portions of the impacted urban area (at smaller scales) post-fire, thus allowing comparison to pre-fire conditions. In this case, drones could also be flown at altitudes that would increase aerial coverage, which would be helpful in documenting structure-to-structure relationships and the overall pattern of structure loss and extent of fire damage. It may also be helpful in mapping progression and chronology of the fire in concert with other records.

7.3.5 Exposure and post-exposure, thermal/radiometric infrared, single-frame imagery from UAV

The same GPS-guided flight grids as in 7.3.3 and 7.3.4 could be duplicated using advanced infrared (IR) camera technology to capture differential heating signatures and hot spots indicating where firebrands are being deposited, accumulating, holding over or causing spot ignitions. IR imagery from about 50 m above ground level has a ground sampling distance of 6–8 cm (i.e., 1 pixel covers ~6–8 cm on the ground). Resulting ortho-photo mosaics are about 1/5 the resolution of true colour mosaics. All images are georeferenced, creating potential to overlay IR images onto true colour pre-burn images for later ground-truthing by WUI technicians, when it is safe to do so. In the WUI, temperature differences between ignition points and surrounding un-ignited materials are substantial. Therefore, ember accumulation sites and new, small fires on the ground and structures should be easily detected. Special approvals would be required for such flights.

7.3.6 Rapid-deploy heat flux sensors for in-fire use

The primary function of heat flux sensors in the WUI fire context is to obtain quantitative measures of exposure – a research topic of priority to the TRP. The technology required for measuring and recording extreme levels of heat flux was perfected in the dynamic environment of crown fire experiments in the Northwest Territories and is equally applicable for use in documenting heat exposure conditions inside WUI fires (Ackerman 2020). Heat flux sensors can quantitatively record the amount and duration of incoming energy from flames, embers or radiant sources to objects located anywhere within the built environment, as well as record changing temperature over time. Each heat flux sensor installation consists of a sensor bundle placed on a stand, an insulated conduit carrying the data cable to ground level, and an armoured cable connecting to a buried data logger. The unit survives extreme exposure. Installation time per unit is one to two minutes. The cost of sensors is not prohibitive, and multiple sensing units can be installed in combination.

Figure 7-3: Insulated colour video camera (right) paired with twin heat flux sensors (left)

Photo courtesy of: Mark Ackerman, MYAC Engineering

7.3.7 Installation of insulated cameras in tandem with rapid-deploy heat flux sensors

Insulated video cameras (as described in 7.3.1) may be deployed in tandem with one or more rapid deploy heat flux sensors (7.3.6) to visually document the ignition and/or spread/progression of fire in concert with exposure measurements at locations of special interest. For example, if suitable opportunities arose, multiple sensors and a camera could be placed to capture simultaneous information about incoming embers, fire spread and ignition of multiple hazard factors to reveal important relationships at an even finer scale (i.e., spread of fire between varied vegetative, miscellaneous and structural fuel sources on a given land parcel). Tandem installations could provide unique data on WUI exposures. As well, the combination of a visual record and simultaneous time-linked temperature profiles may allow insights into flammability of common WUI fuel sources and structure-to-structure fire spread. Privacy issues would have to be addressed beforehand.

7.3.8 Deployment of the US National Institute of Standards and Technology (NIST) "emberometer"

NIST has developed a unique device to aid in quantifying the threat of firebrand (ember) exposure from WUI fires on structures and structural materials (NIST 2020). Called an "emberometer," it captures data on critical characteristics of firebrand exposure (i.e., flux or temperature), based on their importance for solid fuel ignition and technical feasibility. Since firebrand exposure consists of firebrands in two states, dynamic (flying) and static (in a pile), Module 1 measures the dynamic or in-flight characteristics of firebrands (e.g., size, flux and temperature) and Module 2 measures the static or ground signature characteristics of a firebrand or firebrand pile (i.e., thermal signature and mass).

The device was designed for use in laboratory and field experiments, as well as actual WUI events. NIST indicates it is looking for opportunities to deploy this new technology at WUI fires, and Canadian case studies may be candidates. Information on the characteristics of "urban" embers should also be documented.

7.3.9 Enhanced SIZ hazard assessments

Conducting comprehensive quantitative SIZ hazard assessments for rating the *relative importance and contribution* of each of the approximately 20 known hazard factors and their particular attributes to the overall ignition potential (vulnerability to ignition) of structures in the WUI, in a manner that helps to *prioritize mitigations*, is essential to objectively answer many of the most pressing research questions. A hazard rating system based on current knowledge that meets the unique needs of WUI case study research is not known to exist. Therefore, one must be developed (see recommendation in Section 13). This hazard assessment system has applications both as a stand-alone assessment tool and in conjunction with data from other methods and may be used on properties before and after fire passage. Anticipated applications include:

a) *early pre-exposure deployments* to rate pre-fire conditions at large numbers of homes located in the presumed path of the oncoming wildfire,
b) *late pre-exposure deployments* to evaluate pre-fire conditions at a smaller number of homes,
c) *post-fire deployments* to evaluate conditions of homes sampled pre-fire, or sample pairs of adjacent and comparable burned[18] and surviving homes (Westhaver 2017),
d) evaluation of urban neighbourhoods where groups of homes received substantial exposure to wildfire heat sources and sustained damage, but did not ignite,
e) evaluation of isolated homes that ignited and were destroyed well within the perimeter of urban or lower-density acreage developments that were otherwise largely undamaged, and
f) evaluation of isolated homes that survived amid urban neighbourhoods or lower-density acreage developments that sustained heavy damages.

Being careful to acknowledge inherent sampling bias and other limitations,[19] enhanced SIZ hazard assessments can be useful in evaluating vulnerabilities of structural and landscaping components in relation to fire exposure or the effectiveness of particular fire mitigation guidelines. For added credibility, two qualified technicians should perform the assessments and support them with photographs.

[18] Assessment of burned structures should be supported by best possible exposure data and pre-burn imagery.

[19] Given uncertainty of wildfire impingement on the community, it may be necessary to sample a variety of locations in order to obtain an adequate number of useful samples.

7.3.10 Post-fire ground-truthing of third-party information by Case Study Research Team (CSRT) specialists

Videos and photographs taken by fire responders or the public during the exposure and free-burning stages of WUI fire events have great potential to reveal aspects of fire activity (e.g., ember accumulation sites, ignitions points or areas, fuel sources, wind conditions). Some data will include GPS coordinates or time stamps. Photographed sites could be located again following the fire and further documented (i.e., ground-truthing) by technicians using the enhanced SIZ Hazard Assessment Form (see 7.3.9) to yield incremental observations. In turn, these assessments may provide insights into heat exposure during the WUI event, relationships between exposure and vulnerability or fire-resistive qualities, fire progression pathways, and effectiveness of existing risk mitigations – all leading to insights useful for developing new or improved mitigations. This technique also has the potential to lead to new discoveries.

7.3.11 Fire origin and cause investigation at homes ignited by wildfire but extinguished

Partially burned homes are relatively rare occurrences in WUI disasters. At locations where fire department suppression activities succeed, information regarding the ignition and spread of fire within the structure or between structures is "frozen" in the damage that has occurred. These situations provide valuable opportunities to gather important data, including information about fire exposure, structure vulnerability and fire progression. Standard fire origin and cause investigations[20] (as applied by structural fire departments) should be performed at such homes. All such data collection will require permission to access the structure and to ensure safety.

7.3.12 Pre-exposure "walk-around" inspection of individual properties with hand-held video camera

Using a hand-held video camera for stand-alone "rapid hazard SIZ assessments" or to support quantitative data gathered during augmented SIZ home hazard assessments (as in 7.3.9) is highly recommended for properties judged to be in the path of the oncoming wildfire. This technique provides a permanent visual record of conditions of designated hazard factors for future reference and correlation to other data sets (depending on home survival or loss). It may have particular value during "late pre-ignition phase" deployments, when time constraints preclude more detailed hazard assessments. A pair of qualified WUI technicians should perform these inspections, contribute to a running commentary of hazard factor conditions being observed and recorded on the video, and replicate the same systematic format for addressing each hazard factor listed within the standard hazard assessment data form.

7.3.13 Portable weather monitoring stations

One or more standard telemetered[21] portable fire weather stations, placed strategically in open areas within the built environment (e.g., parking lot) in the vicinity of the expected wildfire impingement (e.g., 500 m) would provide wind, temperature and relative humidity data useful to understanding and interpreting influences on ember distribution, aspects of fire progression, ignition potential of fine fuel and litter, etc. Portable stations can be set up in less than one hour and are able to measure conditions at pre-designated time intervals. Adapting the use of much smaller, less expensive hand-held weather meters is another option.

[20] References: NFPA 921. (2016). Guide to Wildland Fire Origin and Cause Determination. National Wildfire Coordinating Group/ PMS 412/ NFES 1874.

[21] Telemetry allows data to be sent to a central location away from the fire.

Figure 7-4: Example of a full-sized telemetered portable weather station

These data are the basic inputs required to predict wildland fire behaviour and are relevant to understanding the transition of glowing to flaming combustion, the probability of fine fuels to ignite, and insights into the location of ember accumulation sites and direction of fire spread within the built environment. Due to low density of the wildland fire weather station network, the nearest available weather data is often from locations more than 10 km from any given WUI.

7.3.14 Documentation of fire control activities within the study area

WUI case study literature warns that the location and nature of fire suppression activities (e.g., application of water) occurring within the study area, before or after arrival of researchers, either by residents or fire responders, must be carefully documented because of their impact on fire behaviour or ability for ignitions to occur. This information is essential to properly interpret the many forms of data collected during case study research.

7.3.15 Fire chronology and progression from volunteered data

New GPS-based "stitching" software is developing in ways that could allow volunteered geospatial data from multiple third-party sources to be gathered and merged to form a useful fire chronology and/or fire progression map. The types of information that could be combined include time-stamped photos and video from cellphones, social media, doorbells, air attack officers and fire responders; reports from dispatch logs and 9-1-1 calls; fire apparatus GPS data and many other sources. Other remotely sensed imagery may also be acquired.

Concurrent with wildland fire control activities, the CSRT leader should liaise with the IMT/Operations and request that air attack pilots record and submit still and video images of the WUI area and fire activity as much as possible while undertaking aircraft operations over the built environment and/or arrange dedicated photographic flights for this purpose. Similarly, pre-existing imagery gathered via method 7.3.2 should also be useful in assessing pre-fire hazards and fire spread potential at individual homes and neighbourhood scales.

7.3.16 Vehicle-based dash-cam photography

Video clips taken by a private citizen during the evacuation of Fort McMurray in 2016 and posted on the internet have proven the scientific value of dash-cam photography. This practice should be "formalized" by mounting front, rear and side window dash-cams onto a designated WUI patrol vehicle driven by a WUI technician in safe perimeter areas as they are exposed to firebrands from an approaching wildfire. The objectives would be to document the relative distribution, abundance, trajectory and accumulation of live and extinguished embers; the location, distribution and abundance of spot fires ignited by firebrands; the type of fuels ignited, progression of spot fires and their role in the ignition of structures; and information regarding structure-to-structure fire spread.

7.4 Applicability of Research Methods to Evaluation of Fire Processes and Arrival Time

The following table has been developed to help envision how the suggested case study methods could be applied and used for planning deployments.

Table 7-1 illustrates the degree to which each of the 16 methods produces data relevant to each of the major fire processes of interest (i.e., research categories), and how this varies with the time of research personnel arrival. For example, some methods produce data that is helpful in understanding multiple aspects of WUI fire and are productive before, during and after the fire, whereas other methods may only yield information about one aspect of the fire and only at certain times.

Table 7-1: Applicability of proposed methods to assess fire processes

Research methods		**Fire process / Research category**														
		Exposure			**Vulnerability**			**Fire progress**			**Structure to structure**			**Ember flux**		
Description	**#**	**Time of deployment**														
		EP	**LP**	**PF**	**EP**	**LP**	**PF**	**EP**	**LP**	**PF**	**EP**	**LP**	**PF**	**EP**	**LP**	**PF**
Fixed colour video – utility pole	7.3.1	✔	✔	–	✔	✔	–	✔	✔	–	✔	✔	–	✔	✔	–
Fixed time-lapse-frames-utility	7.3.1	✔	✔	–	✔	✔	–	✔	✔	–	✔	✔	–	✔	✔	–
Pre-existing aerial photos	7.3.2	–	–	–	✔	✔	✔	–	–	–	o	o	✔	–	–	–
UAV hi-res colour stereo pre only	7.3.3	–	–	–	✔	✔	–	–	–	–	–	–	–	–	–	–
UAV hi-res colour photos; pre + post	7.3.4	–	–	–	✔	✔	–	o	o	–	o	o	–	–	–	–
UAV lo-res IR photo; pre + post	7.3.5	✔	✔	–	✔	✔	–	✔	–	–	✔	✔	–	–	–	–
Heat flux sensors only	7.3.6	✔	✔	–	–	–	–	o	o	–	o	o	–	–	–	–
Heat flux sensor + in-fire camera	7.3.7	✔	✔	–	✔	✔	–	✔	✔	–	✔	✔	–	–	–	–
NIST emberometer	7.3.8	✔	✔	–	–	–	–	–	–	–	–	–	–	–	–	–
SIZ enhanced hazard assessment (pre)	7.3.9	–	–	–	✔	✔	–	o	o	–	o	o	–	–	–	–
SIZ enhanced hazard assessment (post)	7.3.9	–	–	–	o	o	o	o	o	o	–	–	–	–	–	–
Post-fire ground-truthing	7.3.10	o	o	o	o	o	o	o	o	o	o	o	o	–	–	–
Fire origin & cause – damaged homes	7.3.11	–	–	✔	–	–	✔	–	–	✔	–	–	✔	–	–	–
Pre-exposure video walk-around	7.3.12	–	–	o	✔	✔	–	o	o	–	o	o	–	✔	✔	–
Portable weather stations	7.3.13	o	o	–	✔	✔	–	o	o	–	–	–	–	✔	✔	–
Document fire control sites	7.3.14	–	–	o	–	–	o	–	–	o	–	–	o	–	–	–
Fire chronology and progression	7.3.15	–	–	o	–	–	o	–	–	✔	–	–	o	–	–	–
Mobile dash-cam photography	7.3.16	✔	✔	–	✔	✔	–	✔	✔	–	✔	✔	–	✔	✔	–

7.5 Summary

In addition to post-event assessments, 16 techniques – mostly reliant on unmanned, remotely controlled or pre-programmed sensors, fixed cameras and aerial vehicles shielded from disabling heat – are the primary methods recommended to document fire progression and exposure "first hand." These methods will minimize the potential for health and safety hazards to researchers and conflicts with fire operations personnel. Combining methods can provide added confirmation or insights.

	Legend	
✔	Method is fully applicable	Significant data results
o	Method has limited application	Data of limited value
–	Method not applicable	No data results
EP	Early pre-exposure deployment	
LP	Late pre-exposure deployment	
PF	Post-fire deployment	

Part III: Management and coordination of WUI fire case studies

Part III outlines management and coordination aspects of WUI fire case studies and suggests protocols for implementation. The aim is to create a competent, self-sufficient investigative body known as the Case Study Research Team or CSRT that works safely and independently without disrupting emergency fire operations and with a minimum of logistical support in order to maximize lessons learned from disastrous wildfires.[22]

This section discusses suggestions for securing site access, ensuring observer safety and engaging with key stakeholders toward methodology implementation. Recommended CSRT functions, competencies and composition are included based on a "cadre" approach. As much as possible, logistical, administrative and technical challenges have been anticipated. Many of these protocols are based on time-tested models for rapid-response incident management and research teams. This section also addresses data and information management components of WUI case study research. Development of more detailed standard operating procedures must await future decisions.

Part III closes with a discussion of opportunities and challenges for research implementation, potential partnerships, and suggestions for building essential collaboration among key stakeholders to facilitate future WUI fire case study research.

8.0 Deployment of a case study research team (CSRT)

Preliminary protocols to develop and deploy an organized, well-prepared team of researchers to evolving WUI fire events are outlined in this section; many of them are modelled after existing practices in emergency management. Protocols begin with monitoring of potential WUI fires and team dispatch, then progress through subsequent stages involving coordination with authorities, mobilization, arrival on scene and onset of data collection. This section closes with discussion of CSRT functions and suggestions for composition, training and competencies of team members. These protocols are intended to provide a general framework for future discussions leading to finalized procedures and dispatch of functional case study research teams.

8.1 Deployment Scenarios

Previous WUI case studies have taken place in the aftermath of the fire, precluding many important observations. As much as possible, the suggested protocols attempt to overcome this constraint by expediting the presence of research personnel at the event prior to transition of the wildland fire into the built environment, thereby expanding the observation window and the information available for analysis. The "opportunity analysis" in Section 6 resulted in three possible deployment scenarios, in order of preference: 1) Early pre-exposure, 2) Late pre-exposure, and 3) Post-fire. (See Table 6-2 for details.) Regardless of preferences, researchers may not always be able to arrive on scene within the optimal time frame.

8.1.1 Being alert to candidate WUI research fires and the decision to deploy

Candidate wildfires with WUI research potential must be identified in their early stages so timely dispatch and on-scene arrival can occur. This requires access to the best available intelligence on fire occurrence and subsequent predictions of fire expansion toward nearby communities. Fire occurrence data submitted daily by provincial/territorial fire centres to the Canadian Interagency Forest Fire Centre (CIFFC) and incorporated into the daily CIFFC situation report as "priority fires," combined with daily mapping of fire locations in the Canadian Wildland Fire Information System, are likely sources of information to signal candidate WUI fires.

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[22] In this sense, the goal is similar to successful initiatives to learn from wildfires that have resulted in firefighter fatalities or near misses, as advocated by Alexander (2002).

"False Starts" and "Misses"

Despite the best possible predictions regarding wildfire impingement onto WUI communities, the threat may not always materialize. There will be false starts and "misses" in cases where the wildfire does not reach the community, and CSRT deployment does not result in expected data collection. These situations are a risk of doing science and must be anticipated. At least initially, a "false start" may have some benefit for training and refining protocols.

Such fires draw quick attention at provincial and territorial fire centres and are often subject to additional forecasting analysis, another source of valued intelligence. Awareness and good rapport between wildland agency personnel and WUI researchers should allow candidate WUI fires to be flagged and a research team alerted early. Regardless, close collaboration and communication with wildland fire agencies and other public emergency warning systems is required. Ideally, a CSRT would need to be at some form of "alert" status throughout the Canadian fire season.

Following identification of a candidate fire, the final decision to deploy a CSRT must be made. A decision support tool is required to assist those decisions by evaluating possible outcomes, probabilities, benefits and value. Criteria cited in Tables 6-1 and 6-3 may be useful in developing such a tool, along with other logistical, operational and fiscal factors.

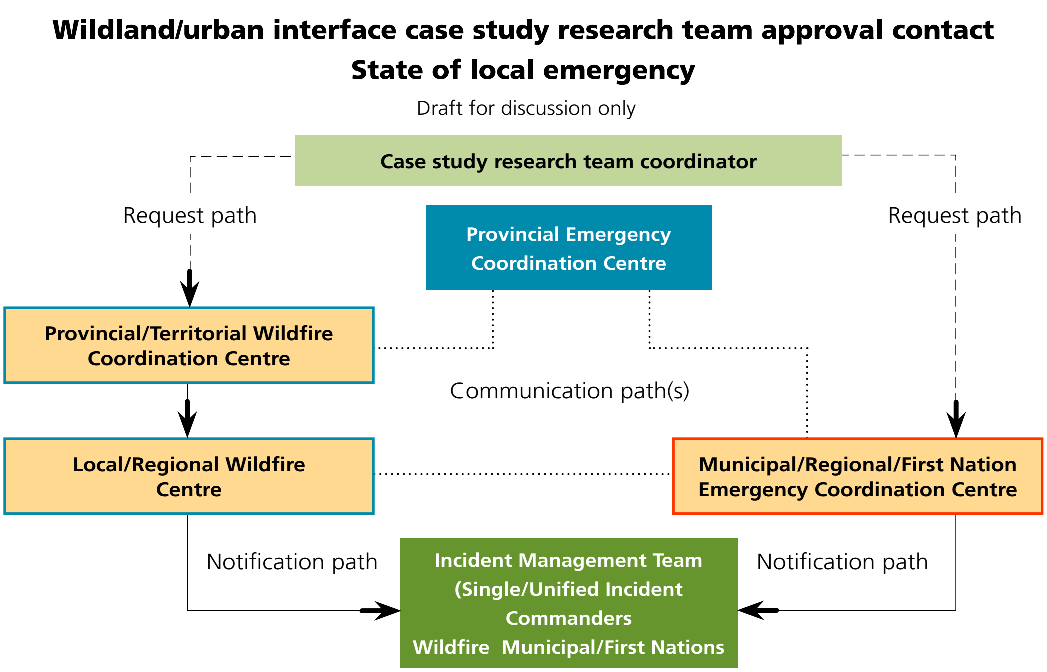
8.2 Obtaining Authorization to Attend a WUI Fire from the Authority Having Jurisdiction (AHJ)

Even though a CSRT may be aware of a candidate WUI fire, it cannot travel to or attend any WUI fire event without prior authorization and support of the AHJ. Dependent upon circumstances, the AHJ(s) will be a provincial or territorial *wildland fire management agency* and/or *a local emergency authority* (*i.e., municipal, district, regional or an Indigenous Nation, Band or community*). The Incident Management Team (IMT) may be operating under Unified Command, which combines AHJs.

A generalized process for gaining permission from the AHJ(s) for accessing a WUI fire event for research purposes is explained below and diagrammed in Figure 8-1:

Figure 8-1: CSRT approval pathway for contact with AHJ(s) to attend WUI fire[23]

*Dashed lines indicate contact path for requests; dotted lines indicate contacts between agencies; solid lines indicate notification path.



[23] Graphic provided by Stew Walkinshaw, Montane Forest Management.

The process is initiated when the CSRT Coordinator (or CSRT Operations Leader) contacts the AHJ(s) via the appropriate "Request Path" by contacting either the provincial/territorial wildfire coordination centre or the municipal/regional/Indigenous coordination centre to:

- request and obtain approvals to deploy a CSRT to the incident,
- request approval from AHJ(s) for support services required by the CSRT from the AHJ and/or IMT while attending the fire (e.g., accommodation, meals), and
- complete and submit all necessary deployment records prior to dispatch.

In response, the AHJ(s) would:

- approve or decline a CSRT request to deploy,
- provide deployment instructions to the CSRT Coordinator (Operations Leader), and
- communicate the approval and necessary information through the appropriate channels (i.e., the "Notification Path" shown on the diagram) to ensure that the IMT is aware of a CSRT deployment.

Upon arrival at the fire, a CSRT Operations Leader would:

- ensure check-in of all CSRT team members upon arrival,
- obtain a briefing from the assigned IMT supervisor (Planning Section Chief),
- brief CSRT members to ensure their effectiveness and safety, and
- follow Incident Command System (ICS) chain of command as required.

Application of ICS varies from one jurisdiction to another, and appropriate pathways may need to be verified for each province or territory. The common denominator in most situations is involvement of a wildland fire management agency.[24] Generally, it is the first responder to a wildland fire, usually before it gathers potential to become a WUI fire incident, and is operational throughout the fire season. Therefore, it is the "first call" AHJ and will be able to provide contact information for the partnering AHJ[25] if a Unified Command (or other) situation has evolved.

8.3 Mobilization of a CSRT

Once the decision to deploy has been made and subsequent permission(s) granted by the AHJ(s), a CSRT must be ready and prepared to depart to the WUI fire within a few hours.[26]

Well-tested preparedness and logistical protocols used for rapid deployment of past Canadian Incident Command Teams[27] and current IMTs are readily available and equally applicable to a CSRT mobilization. Those protocols and arrangements generally include:

- CSRT personnel roster or call-out/stand-by schedule,
- pre-approved personal travelling expenses for CSRT members and other operating expenses,
- personal "kits" prepared in advance by CSRT members (clothing and personal items),
- standing offer or reservations with regional charter air services[28] and national car rental companies,
- pre-packaged research equipment and data collection kits in shipping containers, and
- standing offers with technical research service providers (e.g., camera equipment, drone).

Field deployment procedures developed by NIST for WUI research purposes should also be reviewed (Maranghides et al. 2011) for relevance.

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[24] Exceptions include areas where wildland agencies do not have jurisdiction (e.g., non-forested areas/grasslands).

[25] In Ontario, Ministry of Natural Resources liaises first with the Provincial Coordination Centre, not the local AHJ.

[26] It is expected that 0.5 to 1.5 days may elapse between first notice of fire and AHJ approval to attend.

[27] As an example based on IMT deployments by Parks Canada: personnel from five locations in two provinces and equipment from the National Cache in Banff converged in Calgary, flew by charter aircraft to La Ronge, Saskatchewan, and took command of a wildfire in Prince Albert National Park within 12 hours of first notice.

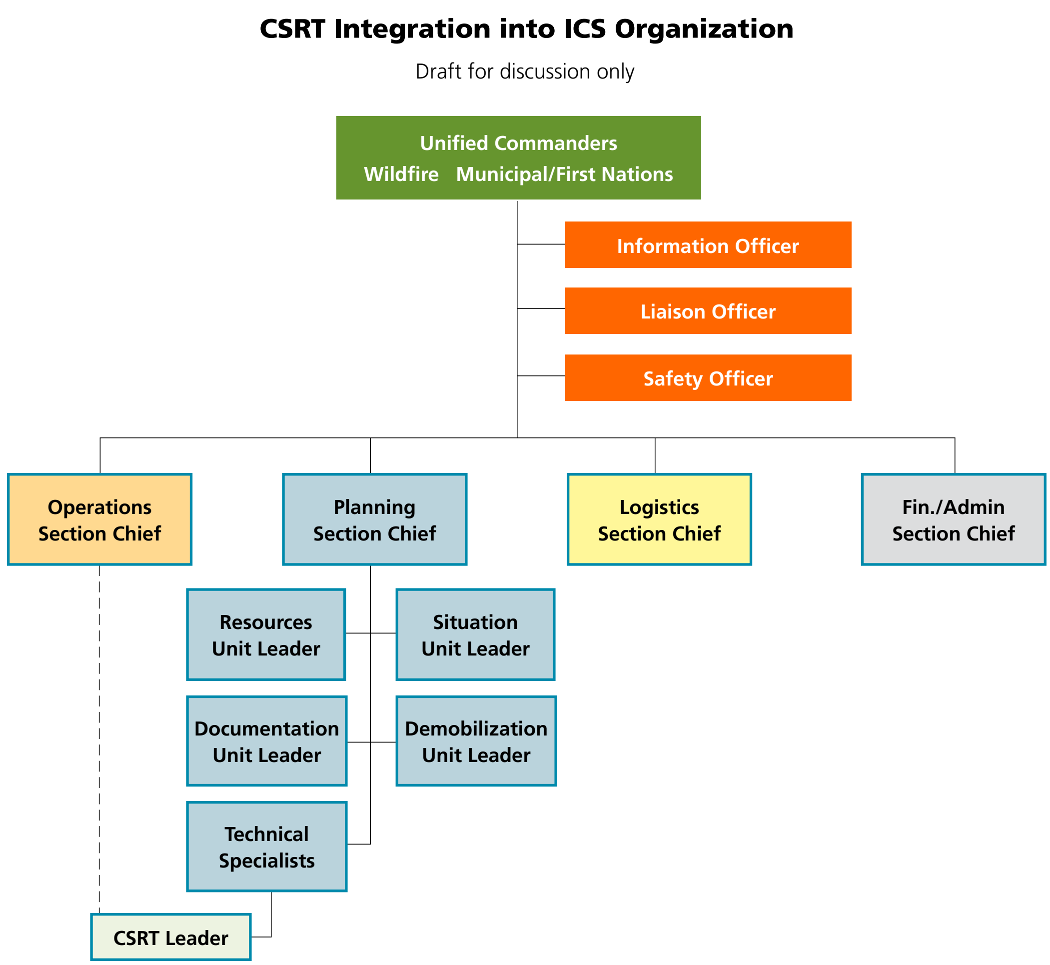
[28] For example, approximately 10-passenger Beechcraft King-Air or equivalent.

8.4 Integration of CSRT into the Incident Command System (ICS)

The Incident Command System (ICS) is a universal system that has been generally adopted by all Canadian wildfire management agencies. Using ICS principles and terminology, this section outlines a preferred[29] approach for integrating activities of a CSRT into ICS and coordinating with the IMT.[30]

Figure 8-2: Integration of a CSRT into the Incident Management Team[31]

*Dashed lines indicate contact path for requests.



[29] Exact application of ICS may vary (e.g., a CSRT may be attached to Operations Section instead of Planning).

[30] It is presumed that WUI fires will continue operating under the Incident Command System, managed by ICSCanada.ca

[31] Graphic provided by Stew Walkinshaw, Montane Forest Management.

To operate effectively, safely and without conflicts with fire responders, a CSRT must function and communicate within the ICS, just as all other resources do. Consequently, it is recommended that:

- a CSRT be placed under the **Planning Section**[32] and *report to* the **Planning Section Chief** within the ICS organization chart,
- a CSRT be listed within the **Planning Section** as a **Technical Specialist – Mitigation Research Team**,
- in low and moderate complexity incidents, the CSRT Operations Leader acts as the sole spokesperson for the CSRT to the ICS organization/command staff,
- the CSRT Operations Leader determine the "boundaries" for **Formal and Informal Communication** between organizational elements upon arrival,
- in highly complex incidents, a CSRT *may* deploy an **Agency Representative** to provide support to the CSRT and liaise with IMT command/command staff as needed, and
- a CSRT should include a qualified Safety Manager who provides specific hazard and risk analysis and mitigation for the CSRT.

Although a CSRT should be well prepared to be self-sustaining in terms of research equipment, personal protective equipment, transportation and personal items, CSRT members will require fuel, commissary or other consumables and even medical services. These would have to be acquired via liaison between the CSRT Operations Leader and/or **Agency Representative** (if activated) and the IMT as determined and directed.

A CSRT's known requirements, such as accommodation and meals, should be pre-identified to the AHJ, concurrent with the original request to attend.

8.5 Suggested Configuration, Skills and Functions of a CSRT

Developing a CSRT with the appropriate combination of knowledge, skills and experience is critical to the success of WUI fire case studies, and establishing a CSRT should be an early goal during implementation of WUI case study research. This section presents conceptual team functions and desired skills and abilities, and suggests a pragmatic solution to "staffing" an operational CSRT.

Successful case study research is anticipated to require a sustained effort involving time commitments for coordinated preparation and pre-planning, data collection in the field, and follow-up analysis and reporting/publishing by CSRT members and their sponsors.

We believe that a range of scientific and technical skills, abilities and experience are essential to create an effective WUI research team. Primarily these attributes must come from structural fire engineering disciplines and secondarily from wildland fire backgrounds, and may be sourced from agencies and the private sector. Much of the proposed case study research is fire engineering in nature or uses specialized equipment, as emphasized by members of the TRP and subject matter experts. They also stressed that CSRT scientific leadership should have experience, insights and understanding of heat transfer and combustion processes, and an equal grasp of wildland fire behaviour in the context of the WUI.

[32] All bolded terms are as per proper ICS terminology.

Table 8-1: Positions and functions of case study research team members

Position*		Functions/Core Competencies
1	**CSRT Operations Leader** (Mandatory, all deployments)	Operational project co-leader; sole liaison with AHJ/IMT/command staff/ Incident Information Officer; attends IMT daily briefings; oversight responsibility for CSRT field operations, safety and communications with fire control operations; wildland fire and technical background
2	**CSRT Science Leader** (Mandatory, all deployments)	Scientific project co-leader; oversight responsibility for planning and implementation of research components, data management and analysis; fire engineering background. Assist with media/information
3	**CSRT Safety Manager** (Mandatory for pre-fire deployments; optional for post-fire deployments)	Lead responsibility for safety aspects during project planning, training and deployments prior to fire passage; reports to CSRT Operations Leader; liaises with IMT Safety Officer; qualifications outlined in Section 9.2
4	**UAV/Drone Operator** (Mandatory for all pre-exposure deployments; optional for post-fire deployments)	Prepare, program and operate aerial photography missions; UAV data processing (contracted service provider); wildfire background or awareness
5	**GIS/Data Coordinator** (Mandatory for all pre-exposure deployments; optional for post-fire deployments)	Responsible for data quality control; liaise with IMT Planning Section/ wildland fire behaviour section; conversant with forestry, remote sensing and realty/survey databases
6	**Photography/Sensor Equipment Specialist** (Mandatory for all pre-exposure deployments only)	Manage, maintain/repair, position, set up, and download fixed camera/video equipment and other specialized sensors (contracted service provider)
7	**Data Collection Technicians (2–4)** (2/4 on pre-exposure deployment; 2 on post-fire deployments)**	Assist in any aspect of data collection but primarily perform detailed pre- and post-home hazard assessments. Technicians should work in pairs of 1 fire engineer + 1 WUI fire specialist
8	**Transportation/Equipment/Logistics Technician** (Mandatory for all early deployments)	Team support and services role; planning, operational, mechanical and logistical jack-of-all-trades; electronics/instrumentation background; seconded from a supporting agency
9	**Fire Origin and Cause Specialist** (As required, on call)	Determine point(s) of origin, fire path and cause on partially burned homes; certified; seconded from agency or contracted service

* Positions best suited for contracted CSRT members are noted in shaded tone

** Wildland agency personnel with relevant hazard assessment backgrounds are available

To ensure safety within the WUI fire environment, all CSRT members, which may include contractors providing support services (e.g., drones and sensing equipment operators, technicians, Safety Manager), must have ingrained awareness of wildland and structural fire dangers, and at least one will require extensive experience, particularly the Safety Manager.

Overall, the research functions to be performed will define the configuration of a CSRT. Some team functions and positions are essential and remain constant, while others are variable depending on the timing of dispatch and fire complexity. Table 8-1 summarizes the recommended CSRT positions and functions.

The minimum CSRT response would be four people for a small-to-medium post-fire deployment, including an Operations Leader, Science Leader and two Data Collection Specialists.

The maximum CSRT response could be 9–11 people (possibly augmented by a Fire Origin and Cause Investigator) for the most complex incident with early dispatch deployment and both CSRT co-leaders. If the incident and extent of damage are at the scale of the 2003 Kelowna fire or larger, additional Data Collection Specialists could be requested to allow increased numbers of SIZ hazard assessments.

8.6 Deployment Variations

For practical and economic reasons, we suggest two variations on CSRT deployment to consider under unique circumstances.

First, in slow-developing wildfire situations when time is not of the essence and there is good research potential but much uncertainty, a "graduated deployment" could be exercised. This would involve dispatching the CSRT Operations Leader in advance to conduct a "reconnaissance" and to initiate contact with the AHJ, IMT and the Fire Behaviour Analyst of the attending wildland fire agency. If the research prospects prove worthwhile, then a more informed decision about whether the remaining team members will follow could still be made in time for early arrival. The Horse River (Fort McMurray, 2016) and Okanagan Mountain Provincial Park (Kelowna, 2003) WUI disasters are examples of where a graduated deployment would have applied. This concept mirrors the ICS, allowing a flexible organizational response to meet the needs of the event (CIFFC 2010).

Second, in relatively low complexity situations (i.e., where the community is remote or small or the values at risk are scattered or low density, as in rural areas), then the CSRT could be "right-sized" to fit with the actual functions needed and potential for reduced work load. Situations in rural or agricultural regions (e.g., central BC, 2018) or in remote northern communities are examples. Right-sizing is also valid when it is known that only post-fire sampling is expected, and data prospects are limited.

8.7 CSRT Recruitment and Staffing

No single agency is likely able to sponsor a full CSRT, and wildland agencies do not have a mandate or the capacity, especially during peak periods of fire activity coinciding with major WUI fire events (Ward 2020).

Consultations with stakeholders and professional experience point to the "cadre" approach as being the most practical, effective and probable means of gathering research teams from multiple sources. That is, federal, provincial and territorial agencies as well as the private sector[33] could be canvassed to identify participants to fulfill positions on a CSRT. The team would likely be rounded out with contracted service providers (e.g., drone and insulated instrumentation providers) and potentially staff from other organizations and institutions. Deployment of retired agency personnel as CSRT members should also be considered as a viable staffing option.

The cadre approach has resulted in important scientific advances in several instances where complex field-based fire research was required (Peterson and Hardy 2016). The International Crown Fire Modelling Experiment (ICFME) best exemplifies this team approach in Canada. In the US, federal fire agencies have developed and deployed inter-agency "Burned Area Emergency Response (BAER) and Rapid Assessment of Vegetation (RAVG) Teams" for more than a decade after wildfires to collect research data (Chappell 2020). As a result, the cadre approach has gained a reputation as being effective and efficient (Ottmar et al. 2016), and these deployments can number in the dozens per year.

Developing one national team would be an immediate goal. Development of regional teams, operating under consistent protocols with shared training, would be more feasible and likely more effective in the longer term. Assigning and training back-up (alternate) people for each team position is a proven best practice in emergency response and incident command.

[33] For example, FP Innovations specializes in and has extensive experience in closely related wildland fire research.

8.8 Simulations of a WUI Fire Case Study

To help envision a WUI fire case study in its entirety, but for illustration purposes only, Table 8-2 outlines prospective sequences of case study research activities as they could unfold during actual deployments to a WUI fire event – given differing times of arrival by a CSRT. Activities falling under the scientific, operational and collaborative aspects of each research deployment are included. These simulations are based on methods described in Section 7.3 and coordination/liaison activities recommended throughout Part III.

Table 8-2: Prospective chronology of WUI research activities during typical deployment scenarios

Table 8-2A: Early pre-exposure arrival activities	
1	Check in with AHJ and IMT; liaise with Operations/Planning Sections, Fire Behaviour Analyst (FBAN)
2	Gather relevant maps, geo-referenced database, GIS digital files from Planning Section
3	Employ CSRT safety plan; coordinate with IMT Safety Officer; communicate effectively
4	Conduct study area reconnaissance; consult wildland fire behaviour analyst; predict impingement areas
5	Begin gathering existing baseline imagery of homes and urban areas; gather geo-referenced maps
6	Record walking video with expert hazard assessment narrative of front-line homes, key areas only
7	Mount fixed cameras for video and time-lapse photography of streetscapes
8	Pre-place fixed time-lapse camera (facing fire/sky) to record wildland fire behaviour
9	Acquire full-coverage, high-resolution RBG & IR aerial imagery/mapping with GPS-guided UAV
10	Decide whether to summon remainder of CSRT; begin full operational mode
11	Pre-place fire/heat exposure instrumentation
12	Set up ember sampling experiments (traps, NIST emberometer site locations selected)
13	Pre-place portable, telemetered fire weather stations within built environment
14	Assess pre-burn hazards of representative SIZ (e.g., 50–250)
15	Characterize pre-burn wildland fuel (within 500 m) of urban areas
16	Determine and map areas affected by fire suppression activity; select sample sites to avoid them
17	Withdraw to safe location prior to fire impingement; shelter until safe to return
Passage of fire front – exposure phase of WUI fire	
Post-exposure phase of WUI fire	
18	Obtain periodic, higher elevation, overview photography of damaged areas (helicopter)
19	Monitor and document delayed ignitions, signs of latent fire in unburned homes, ignition points
20	Acquire duplicate set of high-resolution post-burn aerial imagery/mapping with GPS-guided UAV
21	Conduct post-burn hazard re-assessments of all pre-burn homes and SIZ (e.g., 50–250); check for other sources of home/hazard conditions (e.g., insurance, FireSmart evaluations)
22	Conduct post-burn hazard assessment of 50–250 additional burned/unburned paired homes/SIZ and others
23	Identify damaged homes where fire cause and origin investigations may be conducted (with permission)
24	Begin photographic documentation of damaged but not ignited homes

Table 8-2B: Late pre-exposure arrival research activities	
1	Check in with AHJ and IMT; liaise with Operations Section/Planning Section and FBAN
2	Gather relevant maps, geo-referenced database, GIS digital files from Planning Section
3	Employ CSRT safety plan; coordinate with IMT Safety Officer; communicate effectively
4	Conduct study area reconnaissance; consult wildland fire behaviour analyst; predict impingement areas
5	Determine areas affected by fire suppression activity; select sample sites to avoid them
6	Acquire partial coverage, high-resolution pre-burn aerial imagery/mapping with GPS-guided UAV
7	Mount minimal number of fixed cameras for video and time-lapse streetscape photography
8	Pre-place one fixed time-lapse camera (facing fire/sky) to record wildland fire behaviour
9	Photograph as many SIZ as possible in likely impingement areas
10	Record walking video with expert hazard assessment narrative of front-line homes, key areas only
11	Pre-place minimal fire/heat exposure instrumentation in optimal locations (optional)
12	Pre-place one portable fire weather station (telemetered) within built environment
13	Characterize pre-burn wildland fuel (within 200 m) of urban areas
Passage of fire front – exposure phase of WUI fire	
Post-exposure phase activities same as for Early Arrival (#18 – 24)	

Table 8-2C: Post-fire arrival research activities	
1	Check in with AHJ and IMT; liaise with Operations Section/Planning Section, FBAN
2	Gather relevant maps, geo-referenced database, GIS digital files from Planning Section
3	Employ CSRT safety plan; coordinate with IMT Safety Officer; communicate effectively
4	Conduct study area reconnaissance; obtain wildland fire behaviour summary from FBAN
5	Determine areas affected by fire suppression activity; select sample sites to avoid them
6	Employ safety plan; ensure situational awareness; maintain communication
7	Acquire full-coverage, high-resolution RBG aerial post-burn imagery/mapping with GPS-guided UAV
8	Assess post-burn hazards of 50–250 burned/unburned paired homes/SIZ and others
9	Characterize post-burn wildland fuel (within 200 m) of urban areas
10	Identify damaged homes where fire cause and origin investigations may be conducted (with permission)
11	Begin photographic documentation of damaged but not ignited homes

8.9 Summary

The preceding discussion and suggestions borrow extensively from existing, time-tested protocols and organizational systems to illustrate how a research team could be readied, obtain permission and mobilize to successfully conduct WUI fire case studies, as well as insights as to how a research team may be configured and staffed. Simulations in Table 8-2 provide a prospective view of research activities associated with various research team arrival times.

Still, the question of whether it is feasible that a team could arrive in time to set up and gather relevant pre-fire data collection remains. This question is addressed in Section 12.4.

9.0 CSRT training and preparations for deployment

Conducting research activities safely and effectively in an active WUI fire environment requires thorough preparation, appropriate training and practice to develop essential skills, teamwork and hazard awareness. The stress related to operating in this environment will complicate normal research tasks.

9.1 Objectives for Training and Preparation of a CSRT

Suggested objectives for preparing and training personnel working on a WUI case study team are:

1. clear definition of tasks, responsibilities and safety protocols,
2. ability to function efficiently, consistently and unobtrusively within an ongoing fire operation,
3. thorough understanding of ICS/IMT organization and ability to act in accordance with it, and
4. strong familiarity with the research plan, specific methods, equipment and data formats.

9.2 CSRT Training

CSRT members will require dedicated training sessions to meet these objectives. Training should span all aspects of team mobilization, equipment deployment, data collection methods, protocols for interactions with the IMT and fire responders, and workplace safety. Developing teamwork and efficiency will take time. Operational training should include tabletop simulations of mobilization and deployment scenarios, practical field exercises and supporting classroom sessions. Safety training should highlight "watch-out situations" in wildland and structural environments.

CSRT members should have the following basic safety competencies:

- Intermediate Wildland Fire Behaviour (CIFFC) or higher,
- internal and external radio protocols; operation of handheld radios,
- ICS-100 (Incident Command System),
- minimum of CIFFC Basic Certification in forest fire suppression/wildfire safety, and
- use of personal protective clothing and gear.

Operational training should focus on research protocols, equipment use, hazard assessment, knowledge of deployment process and on-site organization and protocols. CSRT members should have the following basic operational competencies:

- strong familiarity with the CSRT research plan,
- common theoretical understanding of fire in the WUI,
- practice in rapid deployment of photographic equipment, sensing devices, weather stations, etc.,
- knowledge of care, maintenance and troubleshooting of equipment, and preparation of checklists,
- review of administrative procedures, on-site logistics and communication protocols with AHJ/IMT,
- provision of support to UAV/drone operations and other specialists,
- data collection, recording and storage protocols,
- practice and training in making field observations and conducting SIZ hazard assessments, and
- expert-run, full tabletop simulations of WUI fire deployments based on actual past events (e.g., Fort McMurray, Kelowna, Timmins).

> **"Perhaps the greatest concern with conducting WUI case studies is the potential for placing a research team in harm's way, even though all possible means to mitigate this would be provided. Training and preparation are the most effective means of reducing the risk to the research team and minimizing impacts on the host authority."**
>
> Kimball Bailey, Technical Review Panel, Office of the Fire Marshal (Retired), Ontario

> **The Technical Review Panel strongly recommends that structural hazard assessments always be performed by a team of two highly competent assessors having considerable combined knowledge of wildland fire dynamics, fire engineering principles, and building design and materials. Functioning as a team increases the accuracy, completeness and perceptiveness of observations. Teams of assessors must train together to calibrate for consistency.**

9.3 CSRT Equipment

Equipment acquisition and management protocols cannot be established until important decisions regarding implementation and management of case studies are made.

Specialized equipment such as insulated imaging equipment and heat sensors should be anticipated to be outsourced (i.e., adapted and custom built) to a specialist from the private sector. Similarly, professional drone services (commercial-grade fire roto-wing surveillance drones and pilot) with data logging and processing capabilities are best acquired through contractors.

Data loggers should be purchased and pre-programmed internally with data collection forms to ensure 100% familiarity, custom functionality and automated cataloguing of related images. There is potential for interprovincial (or international) borrowing of specialized in-fire monitoring or sampling equipment. The team should be self-sufficient with their own programmable hand-held radio equipment.

CSRT members and others should anticipate the need for undertaking considerable pre-deployment preparations and training to ensure good performance during stressful field conditions.

10.0 Health and safety

Maintaining the health and safety of research personnel is paramount. During consultations, we heard valid concerns from stakeholders that the AHJ (and local fire services or agencies) must not feel burdened with responsibility for safety of researchers operating within their jurisdiction, and already scarce emergency resources should not be tied up in assisting or supervising researchers. Therefore, protocols and procedures must be part of a comprehensive research methodology for working in an active WUI fire situation. This section briefly outlines preventive health and safety measures.

The objectives are safety for research personnel, preserving scarce response resources for emergency fire-ground operations and allaying concerns of local (host) fire authorities.

10.1 Safety Strategies

In order to prevent a CSRT from being exposed to various hazards, fundamental safety strategies have been built directly into many aspects of recommended protocols for conducting WUI fire case studies:

- separation in time and space from exposure to the wildland fire front, radiant heat and heavy ember flux (i.e., maintaining safe clearance during pre- and post-exposure phases of the WUI fire event, planned withdrawal during the exposure phase),
- separation in time and space from active fire operations (as per Section 5.3),
- substitution of direct human observation of exposure of the built environment with automated imaging equipment techniques,
- provision of proper health and safety training along with personal protective clothing and equipment (including P-100 respirator masks and spare filters) to all CSRT members, and
- integration of a CSRT into the ICS organization and good communication with the IMT.

10.2 Safety Manager

Dynamic wildland fire conditions and other inherent workplace hazards (e.g., traffic, fire-weakened trees, fallen power lines, gas leaks, and toxic vapours and dust) are inherent elements of WUI fire research. Therefore, safety considerations must be thoroughly incorporated into all stages of planning, preparing and implementing WUI case study research. On-site considerations are only a portion of the essential safety duties to be performed.

All CSRT members are fully occupied by their duties. Therefore, ensuring a safe work environment requires the oversight and vigilance of a dedicated position on the team. It is recommended that a qualified, full-time Safety Manager (accountable to the CSRT Operations Leader) be a mandatory part of the CSRT during high-complexity (early) deployments. Under the ICS organization, the Safety Manager could be appointed as an **Assistant Safety Officer**.

A CSRT Safety Manager's duties include:

- contributing directly to the safety and operational training of CSRT members,
- maintaining vigilance and full situational awareness of the local fire environment at all times,
- conducting daily safety/risk assessments reviews and briefings for a CSRT,
- obtaining daily (or more frequent as required) fire briefings and intelligence, and maintaining communications with the **Operations Section and Safety Officer**,
- ensuring PPE, first aid, respirators and other safety equipment are properly used and maintained,
- using specialized safety or environmental sensing equipment as required,
- making recommendations for withdrawal of a CSRT from the study area, and
- maintaining health and safety records and reports as required, on behalf of a CSRT.

The AHJ and workers' compensation organizations associated with each WUI incident may have additional safety-related expectations and reporting requirements. In some jurisdictions, the AHJ may assign a certified employee of their own to act as Assistant Safety Officer, attached to the CSRT.

A CSRT Safety Manager must be highly qualified in wildland fire operations, experienced and trained as a Safety Officer, and also be very familiar with structural fire operations, fire service protocols and workings of the ICS organization. Competent personnel with these qualifications are available in the private sector and in most wildland fire agencies.

10.3 Health Hazards

Fire in the built environment will be exacerbated or accelerated by hazardous materials, structures and outbuildings, stored fuels, motorized vehicles containing fuels and other highly flammable materials. These may produce noxious smoke, gases and hazardous dust. Leaking propane and natural gas lines present explosion hazards. Research personnel could suffer short- and longer-term health effects if awareness of hazards, vigilance for hazardous conditions and fitting precautions are not enacted.

Protocols will need to be developed to avoid hazardous exposure and ensure the health of researchers.

10.4 Personal Protective Equipment

Researchers must be outfitted with a complete set of approved wildland firefighting protective clothing and equipment, including protective garments, helmets, gloves and eyewear. P-100 breathing protection (respirator with spare filters) must also be supplied to guard against particulate inhalation.

10.5 Coordination with IMT, On-Site Reporting

A CSRT Safety Manager may be designated as an **Assistant Safety Officer** under ICS and, in that case, would report to the IMT **Safety Officer** at Unified Command (see Figure 8-2).

11.0 Information management

Management of the data created by this research and dissemination of public information are two critical elements of WUI case study research; they are addressed here in the broadest terms only. Both require more in-depth planning and development in conjunction with collaborating partners if WUI fire case study research is to be operationalized and achieve maximum impact.

Scientific data and educational information/public communications flowing from WUI fire case studies, in real time and in later publications, have potential to benefit other scientists working in the field of WUI research, as well as to influence and foster support and understanding among key WUI stakeholders and the general public.

11.1 Data Management

Sound data management protocols will optimize the value of case study research and facilitate benefits to the larger scientific community in the form of peer-reviewed articles, presentations in professional forums and exchanges of raw data. These are routine outcomes expected of researchers.

Given the diversity of research methods, case research managers must anticipate that the volume of data collected will be large, data formats will be highly varied and the effort required to properly manage it will be substantial. Some of most important data considerations identified during project investigations are highlighted below:

- Prior to entering the field, more specific case study objectives should be developed, leading to a formal research plan and detailed sampling procedures. In turn, objectives will identify and dictate the types and amount of data to be gathered. See Section 7.1 and Figure 7-1 for details.
- Since multiple aspects of WUI case studies depend on the sequence of events, data of all types (e.g., images, instrument measurements and technician observations) must be documented with precise locations and time-stamped.

  All observations must be recorded using standardized metadata, preferably electronic, that also identify the incident and observer. As backup, CSRT members should keep a daily activity log.

  Recent technological advances and the experiences of organizations such as the NIST and US Forest Service (US), CSIRO (Australia) and FireSmart Canada with the use of data loggers should be investigated further and adapted for use in WUI case studies.
- Case study proponents must also anticipate the need for substantial analytical capacity. Requirements for data input, integration and analysis will require the capacity of a geographic information system and a competent GIS specialist.

The scope of this Foundational Document *does not* include development of a refined experimental design or a data management plan. Both tasks should be done prior to undertaking field studies, once higher-level WUI research decisions are made.

TRP members and stakeholders caution that other challenges related to data management must be addressed. These include data ownership, archiving locations, protocols for sharing of data and procedures, and anticipating issues surrounding privacy and use of the data in litigation.

11.2 Public Information

WUI stakeholders (including the host agency and AHJs) and the general public (especially evacuees), must receive timely information about the research being conducted in order to foster trust and support and to avoid misunderstanding – particularly about the intent of the work.

Experience shows that the public's and media's interest in the WUI fire problem will peak at this time, and curiosity about the presence of researchers should be anticipated. Aside from being the ideal time for gathering scientific knowledge, WUI fire events are recognized by fire prevention personnel as the optimal window for raising understanding of WUI issues and motivating appropriate mitigation actions.

Public messaging around WUI research should:

- reinforce the shifting emphasis of emergency management toward risk mitigation, loss prevention and fire-adapted communities, which also allow firefighters to be safer and more effective, while reducing disruption and recovery to communities,
- raise awareness that research and assessment into WUI fire disasters are important parts of the disaster management cycle, and
- highlight findings in relation to home ignition and loss.

The TRP and stakeholders identified the following important public information considerations during this project:

- Many past WUI events are not only missed research opportunities, but also represent lost opportunities for highly effective public outreach and education. Researchers can have positive influences by relaying messages about their work "as it happens" to local AHJs and media. As well, images and video obtained from WUI methods have exceptional potential for educational impact.
- Information provided by WUI researchers must also contain an accurate contextual background about the problems of structural vulnerability and exposure causing home ignition, in order to counter prevailing myths about home ignition that are often perpetuated by the media.
- A CSRT should develop a pre-packaged communications kit that includes:
  - a one-page background document to provide upon first contact with AHJs when requesting permission to attend local WUI fire for research purposes,
  - draft media announcements explaining the research, as well as responses to anticipated media questions, and
  - a fact sheet specific to IMT members, and another for broader use by IMT media and public information specialists.

Overall, the CSRT should expect that fire and public safety communications specialists working for the local AHJs and agencies will want their cooperation to utilize the research being conducted (during and after the WUI event) as timely learning opportunities for local residents.

12.0 Additional high-level considerations

This section of the Foundational Document summarizes our findings regarding continued development and future implementation of a comprehensive methodology for conducting WUI fire case studies. Mostly, these arise from the insights, feedback and perspectives of the subject matter experts and stakeholders we have engaged, from WUI research program leaders in other countries to front-line fire managers experienced with WUI fire and its implications.

12.1 Potential for Implementation

Our analysis of the background material and the information provided by the TRP and stakeholders suggests that the none of the scientific, technical or operational challenges or issues identified during our investigations pose insurmountable barriers to implementation. The problems are tractable, and many can be avoided altogether by developing sound protocols and procedures. Others can be mitigated with solutions adapted from other aspects of emergency management and wildland fire research, or by maintaining strong communications and close collaboration among researchers, wildland and municipal fire agencies, and local AHJs.

Jack Cohen, PhD, Research Physical Scientist (Retired), US Forest Service Research, and member of the TRP, contributed the following opinion:

"There has been no serious discussion that identifies what can be known from post-fire examinations that is important for guiding the public and fire agencies, wildland and structure, to more effective approaches for preventing WUI fire disasters.

WUI fire examinations and case studies are valuable for personnel to gain insights to the patterns of destruction and the WUI fire disaster context that develop into questions and hypotheses leading to research questions and conclusions that are then checked/validated in part with additional case studies, or laboratory or field experiments. Questions should focus on "What do I need to know to identify a potential ignition problem? How critical is it given any sustained ignition can result in destruction? And what information do I need to accomplish an effective mitigation of the ignition factor?"

WUI fire disasters commonly occur during the first severe burning period after ignition. The primary pre-fire and during-the-fire data of benefit would be high-resolution aerial photos/video, with the recognition that there are relatively few chances to identify and reach a community before fire arrival, or that anticipated community fire involvement may not occur. For a post-fire examination, total destruction largely provides evidence of what could not have ignited the structure (e.g., burned structures in unburned surroundings suggest ignition by firebrands). Damaged but largely not destroyed homes offer the greatest evidence for determining where the ignition likely occurred and how, but not necessarily in sequential detail. However, even for these damaged structures, the exposure of each structure can't be reliably known. The underrepresented range of variability in the exposure, ignition conditions of the Home Ignition Zone (HIZ) and number of ignitions mean that while specific ignition details can provide insight on how homes can ignite, the information is largely anecdotal. In addition, detailed quantification of the physical exposure is not necessary to develop effective mitigation to ignition.

Our socio-political misconceptions of wildfire and specifically how WUI fire disasters occur are equally as important as current technical knowledge gaps. An agency-sanctioned, well-organized WUI fire case study effort (largely post-fire) could have the profound effect of changing the socio-political WUI fire perspective and thereby support a more effective alternative approach, recognize the need for specific subject matter expertise in operations and research, and close important technical knowledge gaps."

May 29, 2020

Sponsors of WUI fire research must also find effective ways of fostering awareness of research benefits and support among the general public, fire-impacted residents and the media.

As a result, we are confident that productive WUI fire case studies can be carried out in ways that are safe for researchers and compatible with fire-ground operations, although opinions differed about what can be taken from case studies. Jack Cohen (see feature panel on page 49) stated that enough is already known about the processes of structural ignition to guide more extensive (and effective) programs of WUI fire loss mitigation, but that case study research would be helpful in resolving current knowledge gaps and correcting public misconceptions of wildland fire. We felt it was important to share his counsel regarding the socio-political and technical challenges facing workers in this field and believe that his message should lend added resolve to forge ahead with case study research.

12.2 Alternative Modes of Obtaining Access to Conduct WUI Fire Case Study Research

Technical reviewers and stakeholders alike widely perceived two main modes for obtaining access to WUI fire scenes for research purposes. The first, as outlined in Figure 8-1, is for researchers to approach local authorities (i.e., AHJs) and *request permission* to access each individual WUI fire situation. The second mode is that concerned AHJ(s) would *invite* researchers as the incident begins to evolve.

These two alternatives were the subjects of considerable discussion among the TRP and stakeholder representatives, leading to the following conclusions:

1. There is agreement with the aspirational goal that, over time, being requested to attend a WUI fire by local authorities is the preferred pathway to attain access.
2. However, for this goal to be achieved, considerable time and sustained effort (perhaps years) are required to achieve the necessary levels of awareness, support and trust among host agencies and AHJs. These will develop as a result of successful research deployments and good communications and outreach by researchers.
3. In the interim, a formal process of seeking and obtaining permission to conduct research from agency and municipal authorities (AHJs) should be implemented, as adapted from Figure 8-1, but also accompanied by focused initiatives to develop trust and understanding of case study research.
4. Public safety agencies, fire departments and wildland fire agencies are prospective champions for WUI research, as well as essential mediators/bridges between the research community and municipal authorities (the latter being the ultimate hosts of research activity). Therefore, the process of building understanding, trust and support among municipal fire authorities, wildland fire directors and other key stakeholders should begin immediately – concurrent with further refinement of research protocols and potential standardization options.

12.3 Administrative Challenges to Implementation of WUI Fire Case Studies

In their responses to a written questionnaire on a wide range of WUI fire research aspects, TRP members were invited to offer views on alternatives for administering, managing and implementing a functional program of WUI case study research. Results included important insights regarding administrative challenges, summarized below:

1. All respondents favoured having a designated team(s) established with pre-determined functions and duties, good organization, pre-planning and logistical support, and pre-determined data collection protocols and equipment, as opposed to less formal approaches.

2. Respondents broadly agreed with implementing a national, centrally coordinated, multi-agency WUI fire case study team or teams.
3. All respondents rated the expected effectiveness of a centrally coordinated, multi-agency WUI fire case study team to be "very high" or "high."
4. A majority of respondents voiced strong preference for having the team led by a national agency. The remaining respondent declined to comment and instead chose to focus on the need to find quality personnel from a variety of backgrounds.
5. There was less uniformity in the responses regarding potential barriers, but two primary themes emerged:
    a. Maintaining funding levels from participating agencies and partners over a long period of time. No resolution was achieved; however, respondents acknowledged that there is potential for a high degree of resource-pooling amongst various government agencies, organizations and institutions having research interests and expertise. As well, respondents recognized that mounting a proactive program of WUI case study research would be costly, but fractional in relation to the expense of past fire suppression and recovery efforts or in comparison to expected cost savings from improved WUI fire mitigations.
    b. The possibility of legal hurdles regarding privacy, insurance and liability with regard to civilians, personnel and operating agencies.
6. The TRP highlighted the critical importance of developing trust through a close, fully collaborative working relationship with wildland fire management agencies and their coordinating bodies (i.e., the Canadian Council of Forest Ministers – Wildland Fire Management Working Group and CIFFC), as well as fully integrating and maintaining good communication with the incident management organization once on scene.

Numerous stakeholders from a wide range of professional and experiential backgrounds also emphasized these last sentiments.

12.4 Feasibility of Pre-Fire Data Collection

The WUI fire research approach in this document, advocating early dispatch and arrival to conduct on-site assessments, is untested and raises the questions:

> How feasible is it for researchers to arrive at a WUI event prior to transition of a wildfire to the built environment? Is it practicable to set up equipment and gather essential pre-fire data in advance of the oncoming exposure and widespread structural ignition?

Expert opinions on this question ranged widely. On balance, contributors with experience in Canadian situations and *forest fuel types* opined that a reasonable proportion of wildfires offer opportunities for pre- and post-fire data collection. Conversely, experts more familiar with wildfires burning in the southwestern United States fuel types were much less confident that pre-fire research opportunities would have been possible, given the expectation of short notice.

We believe this question could, and should, be addressed objectively. Specifically, this question could be answered by evaluating major Canadian WUI fire events (and near "misses") of the past, examining existing chronologies of these wildfires (e.g., Fort McMurray, Slave Lake and High Level, Alberta; Kelowna and Penticton, BC; Timmins, Ontario), and comparing those timelines against the estimated mobilization time of a well-prepared IMT or CSRT. Suitable fire chronologies are routinely included in post-fire operational reviews.

This analysis should also highlight "early signals" present in the Canadian wildfire occurrence reporting system, which may be useful triggers for alerting a WUI research team to a candidate fire.

12.5 International Collaboration

At least three important opportunities for international collaborations with respect to WUI fire case studies should be pursued during subsequent refinement to these preliminary protocols.

WUI Fire Data Collection on Parcel Vulnerabilities: US National Institute of Standards and Technology (NIST)

Although its objectives and technical approaches differ from the case study approach advocated in this Foundational Document, this NIST project is the most closely related WUI research project known to exist. As part of a much larger research program conducted at the NIST, this is a multi-year program to develop the measurement science needed to mitigate the effects of WUI fires by providing technical guidance on structures, landscaping elements and community designs that resist ignition and limit the spread of WUI fires. The two-tiered system is designed to gather pre- and post-fire data describing pre-fire conditions, defensive actions, chronological progression of fire through the community, scope of damage and identification of ignition vulnerabilities. The methodology, in development since 2011, has been applied by teams of researchers on several occasions, with a 2016 report providing preliminary results and recommendations for further refinement. NIST is collaborating with the US Department of Interior and the states of Colorado, California and Texas on this project.

Large Outdoor Fire and the Built Environment Working Group (LOF & BE)

A second initiative, known as LOF & BE, is in the early stages of building an international network focused on resolving current information deficiencies and initiating research on a global scale. It is spearheaded by the USDA Forest Service Intermountain Fire Sciences Laboratory and NIST, and sponsored by the International Association for Fire Safety Science (IAFSS).

The permanent Working Group intends to address shared characteristics relevant to urban fires, WUI fires, wildland fires and informal settlement fires. It is composed of three subgroups. Priorities of the Ignition Resistant Communities (IRC) subgroup are to determine the research done so far; the mechanisms that exist to protect communities from large outdoor fire exposures; the codes, standards and regulatory framework that apply; the knowledge garnered from actual large outdoor fires; and lessons learned from real fire events.

The Insurance Institute for Home and Business Safety (IBHS)

The Insurance Institute for Home and Business Safety is also undertaking extensive large-scale laboratory work using an ember generator at their research facility in South Carolina, and it is heavily involved in development of more effective wildfire risk mitigations.

12.6 Summary

The above insights and concepts have been integrated into the Foundational Document and subsequent recommendations.

Overall, members of the Technical Review Panel, subject matter experts and stakeholders strongly support moving ahead with WUI case study research. There is also a strong view that “now is the time,” and that the Foundational Document should be utilized as a means of maintaining and building continued momentum for collaborative solutions.

Part IV: Conclusions and recommendations

13.0 Conclusions and recommendations

The underlying premise for this Foundational Document is that rigorously examining factors within the built environment that contribute to the ignition potential of structures and property loss during WUI fires is a key part of the disaster management cycle and will lead to improved mitigation measures for loss reduction and more wildfire-resilient communities. Our background investigations and consultation resulted in the following conclusions and recommendations pertaining to WUI fire case studies.

13.1 Conclusions

1. Overall, it is our analysis that none of the scientific, technical or operational challenges or issues identified during our investigations pose insurmountable barriers to implementation of WUI fire case studies. The problems are tractable and rigorous case studies are feasible. With the proposed protocols and adaptations, we are confident that productive WUI fire case studies can be carried out in ways that are safe for researchers and compatible with fire-ground operations, thus addressing important concerns raised by stakeholders.
2. Investigating and assessing natural disasters are key parts of the disaster management cycle. However, few case studies on major WUI fires have been done in Canada. Rare WUI fire events provide brief but highly valuable opportunities for learning, but they are not being used to advantage.
3. Studies to advance current knowledge of WUI fires in Canada, the ignition potential of structures exposed to wildland fire and to address research questions are needed with regards to:
    - aspects of exposure and vulnerability contributing to ignition potential of structures within the built environment during WUI fire events,
    - pathways of fire progression in the SIZ (i.e., properties),
    - spread of fire from one structure to another within the built environment, and
    - conditions of the wildland fire environment correlating to ember flux.
4. Existing WUI fire case studies are relevant but have been carried out in fire environments that differ from Canada's. They also lack the benefit of direct observations gathered before the fire and in situ fire condition data safely gathered by instruments fitted with telemetry.
5. No comprehensive WUI case study research methodologies that could be readily adapted appear to exist. However, suitable components (i.e., methods, technologies and procedures) are available.
6. In order to meet the project purpose of developing the foundation needed to establish a systematic program of WUI case study research, it was essential to address several operational and administrative subject areas, as well as focus on technical and scientific components.
7. Early arrival of the CSRT, allowing for data collection before and during the fire event, is imperative to address the most critically important knowledge gaps and is most likely to be feasible.
8. In contrast to well-defined responsibilities for responses to wildland/WUI/structural fire events, it is unclear whether any Canadian agency, institution or professional body (or coalition of them) has or would assume responsibility for coordinating and/or conducting field-based WUI fire research.

9. The main challenges to developing a program of WUI fire case study research are administrative in nature, primarily:
   - obtaining the necessary administrative and financial commitments for implementation,
   - assembling a cadre of fire engineers and WUI fire specialists to form study team(s), and
   - identifying a sponsoring body or "network hub" to lead a Canadian WUI fire case study effort.
10. Key stakeholders[34] and prospective champions of WUI fire case study research need enhanced awareness, trust and collaboration (through accelerated consultation, outreach and facilitated discussions) to gain the widespread support and commitment necessary for implementation – and before further efforts to finalize best practices (i.e., comprehensive methodology) are undertaken.

13.2 Recommendations:[35]

Overall, and in light of previous conclusions, subject matter experts and stakeholders strongly support moving ahead quickly with WUI fire case study research and conducting the follow-up work needed to finalize a comprehensive approach for managing and implementing it. These experts also widely perceived that this Foundational Document provides a basis for continued momentum, discussions and collaborative actions to realize an effective program of WUI case study research.

As a result of our investigations and analysis into WUI case study research, we recommend that:

1. SCC considers proceeding with the development of a flexible but comprehensive methodology for conducting and managing future WUI fire case studies in Canada. In keeping with previous conclusions and following recommendations, it seems most appropriate this methodology be compiled initially in the format of a "National Technical Specification" (NTS) as described in Appendix C and the 2019 SCC circular, and based on this Foundational Document. Eventually, once the approach has been applied and protocols refined, a National Standard of Canada may be developed to guide WUI fire case study research.
2. If SCC does not pursue a standardized product, or if the development of a standardized product is otherwise considered to be impractical, key stakeholders should convene and arrange creation of a Case Study Working Group[36] to independently finalize a comprehensive WUI fire case study methodology to guide future work.

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[34] Key stakeholders include the CCFM – Wildland Fire Management Working Group, representatives of Canadian Council of Fire Marshals and Fire Commissioners, Public Safety Canada, the Canadian Forest Service, National Research Council, Canada Wildfire, the Canadian Interagency Forest Fire Centre, Canadian Association of Fire Chiefs and leading fire researchers.

[35] These recommendations hold regardless of whether subsequent steps toward a comprehensive methodology for WUI fire case studies proceeds under auspices of the Standards Council of Canada or under some other authority.

[36] The working group should consist of experts reflecting composition of the proposed Case Study Research Team outlined in Section 8 (i.e., be potential members of the CSRT).

3. In either case above, further engaging key stakeholders is an essential precursor to finalizing a comprehensive WUI fire case study methodology. Therefore, as the first priority for follow-up, we urge most strongly that a facilitated forum of all key stakeholders be convened to:
   a. examine and identify future means and sponsorship required to continue development of a comprehensive methodology for conducting WUI fire case study research,
   b. establish an administrative framework and commitments for implementing and managing subsequent WUI fire case studies,
   c. make recommendations for increasing project awareness, support, trust and commitment among other stakeholders, particularly municipal AHJs who ultimately provide permission (or invitations) for research access to communities exposed to WUI fires, and
   d. decide on a comprehensive WUI fire case study methodology and gather a cadre of qualified research personnel to implement it.
4. A supplementary analysis must be undertaken to further assess the feasibility of a CSRT team being mobilized and arriving on scene in time to set up and gather pre-fire data prior to the occurrence of catastrophic losses (i.e., wildland fire transitions into the built environment), as per the analysis outlined in Section 12.4.
5. A future comprehensive WUI fire case study methodology should be based on this Foundational Document and contain, at minimum, the following key elements:
   a. confirmation of the scope of WUI case study research (i.e., focus on the five categories identified in Section 3.1),
   b. a research plan designed to address specific research laid out here, outlining the scientific approach and specific guidelines for implementing chosen sampling methods,
   c. standard operating procedures for designating, preparing, training, mobilizing and deploying a CSRT – inclusive of agreed-upon "triggers" and procedures,
   d. guidelines for development, acquisition or contracting of necessary equipment and services,
   e. a comprehensive data acquisition and management plan,
   f. an enhanced SIZ hazard assessment system (see recommendation #7),
   g. a communications and outreach strategy outlining approaches and providing templates for enhanced awareness of WUI fire research efforts and results among the general public, AHJs, media, local fire authorities and residents, and
   h. a health and safety plan that includes requirements for procedures, personal protective equipment, training, on-site communications (within the team) and on-site liaison with the IMT.
6. A decision support tool should be developed to aid in making final decisions to deploy a CSRT to candidate wildfires having potential to develop into WUI fires.
7. A comprehensive, quantitative SIZ Hazard Assessment System should be developed to specifically apply to WUI fire case study research to rate the relative importance or contribution of known hazard factors and their particular attributes to the overall ignition potential of structures in a manner that helps to prioritize mitigations.
8. Staffing of a Case Study Working Group and/or subsequent CSRT(s) should employ the "cadre" approach to draw qualified personnel from agencies, organizations, the private sector and retirement – with concomitant resources and time allocations to fulfill identified tasks.

9. A single national CSRT should be established, at least initially. Long term, two regional CSRTs (i.e., in western and eastern Canada) are preferable. Annual training workshops should be held to develop and maintain skills and coordination.
10. Stakeholders and the CSRT should strive toward the aspirational goal that widespread awareness, support and trust regarding WUI research evolves to the point at which AHJs routinely invite teams to conduct WUI fire research when situations arise. However, in the interim, CSRTs will rigorously follow a defined protocol requesting AHJs for *permission to attend* a WUI fire prior to deployment. Outreach and trust-building toward that goal should begin now.
11. Recognizing the TRP's counsel that much of the value of case study research is in observation of the unexpected, the standardized product developed from this Foundational Document should be flexible and not so prescriptive that obvious or unexpected observations are overlooked.
12. Working relationships should be sought with the global *Large Outdoor Fire and the Built Environment Initiative*, the US National Institute of Standards and Technology and the Insurance Institute for Home and Business Safety.

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Appendix A: Glossary of key terms

Ember: A piece of flaming or smouldering material capable of acting as an ignition source (CIFFC 2017); usually lofted or transported by the wind or convection heating. Synonymous with firebrand.

Extreme fire behaviour: A level of fire behaviour that often precludes fire suppression action. It usually involves one or more of the following characteristics: high rate of spread and frontal fire intensity, crowning, prolific spotting, presence of large fire whirls and a well established convection column. Fires exhibiting such phenomena often behave in an erratic, sometimes dangerous, manner (CIFFC 2017).

Case study: A "research strategy which focuses on understanding the dynamics present within single settings" (Eisenhardt 1989, p.534) and employs multiple levels of analysis and multiple types of data collection.

Combustible: Any material that, in the form in which it is used and under the anticipated conditions, will ignite and burn. (NFPA, Firewise. Hazard Assessment Methodology. WUI Fire Working Team.)

Exposure: Incoming "thermal insult" experienced by a value based on its location irrespective of its resistance to the potential impacts of that exposure (Johnston et al. 2019). For example, exposure of a home depends on the magnitude and duration of heat flux represented by fire intensity and the potential for spotting.

Exposure level: The degree to which structures are exposed to embers, radiation or flame (NRC).

Firebrand: An airborne piece of flaming or smouldering material capable of acting as an ignition source (CIFFC 2017), usually lofted or transported by the wind or convection heating. Fuel particles carried by wind, convection currents or gravity into unburned fuel (USNWCG). Synonymous with ember.

Fire behaviour: The manner in which fuel ignites, flame develops, fire spreads and exhibits other related phenomena as determined by the interaction of fuels, weather and topography (CIFFC 2017).

Fire hazard: Any situation, process, material or condition that can cause a fire or explosion or that can provide a ready fuel supply to augment the spread or intensify a fire or explosion, all of which pose threats to life or property (NFPA 921, 2017). Alternatively, "a fuel complex, defined by kind, arrangement, volume, condition and location that determines the ease of ignition and/or resistance to fire control" (NFPA 1144, 2018).

Fire investigation: The process of determining the origin, cause and development of a fire or explosion (NFPA 921, 2017).

Fire resistant: Construction designed to provide reasonable protection against fire. (NFPA, Firewise. Hazard Assessment Methodology. WUI Fire Working Team.)

Fire resistive: Ignition-resistant construction methods using building materials and design features that reduce the vulnerabilities of buildings to ignite from wind-blown embers (firebrands) and other wildfire exposures (NFPA 1144, 2018).

First fuel ignited: That which first sustains combustion beyond the ignition source (NFPA 921, 2017).

Forest overstory: Layer of tallest or dominant trees in the forest, generally mature trees. Synonymous with canopy.

Fuel: Any living or dead organic or man-made material located in, on or above the ground that contributes to fire. This includes "urban" fuels (e.g., homes, businesses and industrial structures) and their associated combustible surroundings. More technically, fuel is the physical characteristics of live and dead biomass that contribute to wildland fire.

Fuel modification: Any manipulation or modification of fuels to reduce the likelihood of ignition or the resistance to fire control (NFPA).

Hazard assessment: Evaluation of hazards to determine risks. Assess the impact of each hazard in terms of potential loss, cost or strategic degradation based on probability and severity. (NFPA, Firewise. Hazard Assessment Methodology. WUI Fire Working Team.)

Hazard reduction: Any treatment of living and dead fuels to diminish the likelihood of a fire starting and lessen potential rate of spread and resistance to control (CIFFC 2017).

Home assessment: Evaluation of a dwelling and its immediate surrounding to determine its potential to escape damage by an approaching wildland fire. Includes the fuels and vegetation in the yard and adjacent to the home, roof environment, decking and siding materials, prevailing winds, topography, fire history, etc., with the intent of mitigating fire hazards and risks. (NFPA, Firewise. Hazard Assessment Methodology. WUI Fire Working Team.)

Ignition: The process of initiating self-sustaining combustion (NFPA 921, 2017).

Ignition-resistant building material: A type of building material that resists ignition or sustained flaming combustion (NFPA 1144, 2018). Alternatively, as above plus resists "sufficiently so as to reduce losses from wildland-urban interface conflagrations under worst case weather and fuel conditions with WUI fire exposure of burning embers and small flames" (ICC 2017).

Interface: A shortened term for wildland/urban interface.

Mitigation: An action that limits the severity of fire hazard or risk of loss, and is applied in a proactive, sustained manner. Mitigation capabilities include community-wide risk reduction projects, efforts to improve the resilience of critical infrastructure and key resource lifelines, risk reduction for specific vulnerabilities and initiatives to reduce future risks following a disaster (NFPA 2014).

Pre-fire observations: Research techniques applied prior to involvement of urban fuels in the SIZ.

Point of origin: Exact physical location within the area of ignition where a heat source and fuel first interact resulting in a fire or explosion (NFPA 921, 2017).

Post-fire observations: Research techniques applied following fire passage in the built environment.

Real-time observations: Research techniques applied or operational during the structural ignition phase period when structures are exposed to heat transfer from a wildland fire.

Resilience: The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions (NFPA 2014).

Recommended FireSmart guidelines: Criteria established and published by Partners in Protection (2003) to mitigate individual WUI hazards related to structural, vegetation, infrastructure and other elements of a home and its surroundings. FireSmart guidelines are founded in standards developed by the National Fire Protection Association, supplemented by research by the Canadian Forest Service pertaining to crown fire reduction.

Recommended Practice: A document similar to a standard that contains only non-mandatory recommendations using the word "should" (NFPA 921, 2017).

Risk: See Wildfire risk.

Spotting: A fire producing firebrands carried by the surface wind, a fire whirl and/or convection column that fall beyond the main fire perimeter and result in spot fires (CIFFC 2017).

Standard: "A document that provides a set of agreed-upon rules, guidelines or characteristics for activities or their results. Standards establish accepted practices, technical requirements and terminologies for diverse fields. They can be mandatory or voluntary and are distinct from Acts, regulations and codes, although standards can be referenced in those legal instruments" (SCC).

Structural fuel: Fuels composed of combustible building components and man-made materials.

Wildfire: An unplanned or unwanted natural or human-caused fire.

Wildfire risk: Product of potential impacts from wildland fire and the likelihood of those impacts occurring (Johnston et al. 2019). Alternatively, the measure of the probability and severity of adverse effects that result from an exposure to a wildland fire (direct flames, radiant heat or firebrands) (NFPA 1144).

Wildland fuel: Fuels composed of vegetation from forests, grasslands, shrub lands or other natural plant communities.

Wildland/urban interface: An area where structures are located in places where topographical features, vegetation/fuel types and local weather conditions result in the potential for those buildings to ignite from the flames, radiant heat and/or firebrands of a wildland fire (NFPA).

Wildland/urban interface (classic definition): An area where wildland fuels abut structures, with a clear line of demarcation between residential, business and public structure and wildland fuel (NFPA 1144, 2018).

Wildland/urban interface fire: Fire that involves buildings and wildland fuels or vegetation simultaneously. Wildland/urban interface fires can ignite within a building and spread to nearby forests, or more commonly, spread from burning vegetation to engulf homes, farms or industrial developments.

Appendix B: Partial bibliography of WUI fire case studies

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Appendix C: Examples of standardized products

Product type	Description
National Community-Sourced Guidance	A Community-Sourced deliverable is developed as a result of the collection of information using online platforms and allows for the continuous renewal of content. This process does not require the full consensus associated with the development of a National Standard of Canada (NSC).
National Workshop Agreement	A Workshop Agreement is a document that has been developed to begin the consensus process normally associated with a National Standard of Canada (NSC). A Workshop Agreement may be developed in any field where there are many unknowns and where speed of delivery, rather than full consensus, is of paramount importance. A Workshop Agreement is intended to: • bring thought leaders together on new and emerging issues to dialogue and reach general agreement on best practices, • enable market players to negotiate in an open workshop environment, • create understanding and coordination among various stakeholders, • help shape the future direction of the subject and influence any future standard, • improve quality and interoperability, • lead to national visibility, • allow the development of relationships within a profession or sector, and • give visibility to relevant professional practices.
Standard	A document, established by consensus and approved by a recognized body, that provides for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at achievement of the optimum degree of order in a given context. For the purpose of this document, this includes National Standards of Canada, adoptions and existing published Consensus SDO Standards.
National Technical Specification	A Technical Specification is a document that has been developed without using the full consensus process normally associated with a National Standard of Canada (NSC). A Technical Specification may be developed in a field where the technology or a related aspect, such as the regulatory environment, is rapidly changing and where speed of delivery, rather than full consensus, is of paramount importance. Another possible application may be where the required level of stakeholder consensus to support an NSC may not be possible; however, the national interest may be better served by providing the public with access to information that has achieved a certain degree of stakeholder agreement in a document that has a lesser status than a standard. A Technical Specification can fulfill this function. While it may include normative language, it does not purport to be a standard, and the title page contains information to this effect. In such cases, it would normally be expected that a National Standard of Canada would eventually be developed to supersede the Technical Specification.
Guide or Guideline	A publication developed through the consensus process that assists in decision-making by surveying relevant considerations and options but that does not require a specific course of action as a condition for claiming compliance.
National Standard of Canada	A standard developed by an SCC-accredited Standards Development Organization (SDO) compliant to SCC's requirements and guidance for accreditation of SDOs and for adoptions.

Appendix D: Details of methods for creation of the Foundational Document

As an addendum to Section 2.0, details of the primary information gathering and evaluation methods used in production of the report are summarized below.

Literature review

A literature review was undertaken at the project's outset and continued to expand throughout the project's duration. Its objectives were to identify current centres of excellence, WUI research efforts and existing and potential research methods, as well as to survey information relevant to WUI loss mitigation and pinpoint potential WUI fire and structural ignition knowledge gaps. It was also helpful in identifying professional contacts for project support.

To be thorough, and because of the lag time associated with peer-reviewed literature, a questionnaire seeking unpublished information and methodologies was also developed and distributed to the Technical Review Panel (TRP) and other subject matter experts.

Consultation with experts and stakeholders

This project drew heavily on the knowledge and experience of others. We consulted with the TRP's ten experts in wildland and municipal fire operations, fire physics and engineering, wildland fire behaviour, modelling and experimentation, and development of wildfire risk mitigations from Canada, United States, Europe and Australia (see member list in Acknowledgements section).

TRP members provided insights, ideas and comments in response to a written survey, provided written comments on the draft Foundational Document, and participated in introductory and post-draft webinar sessions and follow-up conversations and correspondence. We also carried out structured interviews with several other experts (see Acknowledgements), some of whom also completed the written survey. Meetings hosted by Jack Cohen at the US Forest Service Fire Lab in Missoula, Montana, were particularly informative.

We also consulted with a wide range of stakeholders (over 170 people), consisting of individuals and representatives from agencies, organizations, business and institutions who could be involved in or affected by WUI fire case studies, as well as potential users of the resulting information.

Stakeholders were gathered from municipal governments, wildland and fire engineering disciplines, and many other fields with potential interest in the project through calls, presentations at the Wildland Fire Canada 2019 conference and a series of three national webinars open to all interested parties. The stakeholder group grew to include people from every province and territory. Representation from wildland fire disciplines was strong, whereas participation from municipalities, Fire Commissioner/Marshal offices and fire engineering was less so. Two sub-committees of the Canadian Interagency Forest Fire Centre (Science and Mitigation/Prevention) provided important sounding boards for the project.

We especially want to recognize the interagency British Columbia FireSmart Committee (chaired by Kelsey Winter and Amanda Reynolds and championed by Chris Hodder), who have strongly promoted and tangibly supported the concept and implementation of learning via WUI fire case studies.

Appendix E: Important research questions for WUI fire case study

The literature review (e.g., Mell et al. 2010), as well as members of the TRP and other experts consulted, identified a number of research questions that could be informed by case studies. These have been organized by category.

Table E-1: Important research questions for WUI fire case study

1. Vulnerability
Q1: What structural elements and which aspects of them are most susceptible to ignition from embers?
Q2: When elements of a structure (e.g., walls, deck, roof) are exposed to extreme radiant heat causing ignition, where does the fire spread and/or enter the structure to sustain ignition?
Q3: What principle combustibles found in the SIZ and specific characteristics of those objects provide sites for sustained ignition from embers or heat flux from wildland fires?
Q4: What vulnerable elements of vehicles/RVs/ATVs and machinery lead to ignition?
Q5: How likely is fire from ignited combustibles to spread to and ignite the structure?
Q6: Why have some homes burned and others not?
2. Exposure
Q1: What are the physical characteristics (e.g., type of material, size, number/density, accumulation patterns) of live embers arriving on structures and other combustibles in the SIZ?
Q2: For each structure (burned and unburned) and its specific elements, what was the level of exposure to direct flame contact and/or radiant heat of the wildland fire? Is there a correlation between level of exposure and whether it burned?
Q3: What is the critical number or mass flux of embers sufficient to result in building ignition?
Q4: Is there a "heat shielding" effect from vegetation or other features with the SIZ? What are the qualities of effective heat shielding objects resulting in reduced exposure?
Q5: Is exposure to wildfire igniting vehicles, RVs, ATVs and other machinery? Or is this ignition caused by exposure from adjacent burning structures?
Q6: What are the relevant conditions (distance, duration, amount, etc.) when structures ignite from flame or radiant heat of wildland fire?
Q7: Are there differences in the exposure levels to embers between burned and unburned homes and ignited versus non-ignited fuels (structural, landscaping and vegetative materials)?
Q8: Is tempered glass required when heat exposure to adjacent burning homes is not a factor?
3. Fire progression pathways
Q1: Are existing FireSmart fuel reduction standards for crown fire hazard (i.e., 1–3 crown width spacing) effective at breaking the fire spread pathway between tree canopies in the SIZ?
Q2: Are existing FireSmart fuel reduction standards for crown fire hazard (i.e., 1–3 crown width spacing) effective at breaking the fire spread pathway between coniferous shrubs in the SIZ?
Q3: For creeping surface fire, where specifically did fire first enter the property? What objects or fuels comprised the pathway across the SIZ leading to ignition of the structure?
Q4: How effective is the 1.5 m "non-combustible" zone at preventing ignition of the primary structure? Is it adequate or excessive?
Q5: What roles do materials (e.g., landscaping timbers, mulch, dry sod) play in the spread of smouldering fire and eventual ignition of other, more flammable fuels in the SIZ?
Q6: Do motor and recreational vehicles and gas-powered machinery aid fire spread in the SIZ?

continued on next page

4. Ember influx
Q1: To what degree do fire environment conditions and fire behaviour characteristics influence the types, amounts, sizes, transportation distance, distribution pattern and efficacy of embers?
Q2: For what period of time, and at what distance is the built environment impacted by incoming embers from the advancing wildfire? Is this constant for all forest fuel types?
Q3: Is there a correlation between the rate of structural ignitions in the WUI and known characteristics of extreme wildland fire behaviour (e.g., column, instability, high rate of spread, fire whirls)?
5. Fire spread between structures
Q1: What are primary means (e.g., flame, radiant heat, embers) of fire spread between structures?
Q2: How is structure-to-structure fire spread influenced by density of homes, type, age, slope, wind, building design and materials, intervening fuels, etc. under free-burning conditions?
Q3: Are current building codes adequate under conditions with little or no structure protection?
Q4: What is the character of embers from burning structures? How do they sustain fire spread?
6. Others: Uncategorized
Q1: Within the entire built environment, does the pattern of fire spread/destruction correlate with structure density, ignition potential of homes, continuity of other fuels and fire weather?
Q2: Will factors affecting fire spread in vegetation or ignition potential of structures observed in WUI case studies be helpful in calibrating or testing other physical models relating to wildfire?
Q3: Can third-party information (e.g., images, video, dispatch records, 9-1-1 calls) be compiled to develop a fire chronology of the event?
Q4: Tree removal guidelines in the SIZ are not site-specific, raising resident concerns of being overly stringent?

Appendix F: Details of opportunity analysis for WUI fire case study research

The availability of research opportunities to case study investigators was examined via a four-step iterative analysis. This appendix displays the intermediate inputs and steps utilized in that analysis. Final results of the analysis are found in Table 6-3.

6.1 Levels of WUI Incident Complexity

In order to help plan and dispatch research responses appropriate to typical WUI scenarios, a cross-section of representative WUI "incident levels" was anticipated using Canadian examples. The primary attributes used to characterize an incident level included:

- expected duration of the fire event,
- large fire potential (hectares, intensity class, etc.),
- fire potential to encounter built environments (number, size, density of communities),
- number of potential data collection points (number of homes, structures), and
- potential to observe unimpeded fire growth in WUI.

Levels of incident complexity are shown in Table 6-1.

6.2 Case Study Deployment Scenarios

Three probable response scenarios for dispatch of a case study team are possible:

A. **Early pre-exposure case study research response**

   In this scenario, a CSRT is notified with adequate time for the team to mobilize, arrive on site, conduct all essential pre-fire preparations and (preferably) be fully readied for implementation upon evacuation of residents. Dispatch of a CSRT would coincide with declaration of an "Evacuation Alert," allowing 1–2 days of on-site preparation.

B. **Late pre-exposure case study research response**

   In this scenario, a case study is initiated in time for team mobilization and arrival on site prior to fire impingement, but *without adequate time to safely conduct all* essential research operations and equipment emplacements. Dispatch of a CSRT might coincide with an "Evacuation Order."

C. **Post-fire case study research response**

   In this scenario, the case study team arrives after passage of the fire in the built environment and all damages have occurred. The team does not take any pre-fire samples or observations.

These scenarios are illustrated in Table 6-2.

6.3 Estimating Availability of Research Opportunities

A final matrix was created to estimate the probability of conducting research across myriad combinations of variables created by differing research categories, time of arrival and incident complexity. Probabilities were assigned as objectively and consistently as possible. Matrix results are shown in Table 6-3, which is useful for planning purposes and setting research expectations.

6.4 Linkage to Factors Also Affecting WUI Fire Case Study Research

The analysis also affects a range of factors with bearing on decisions regarding methods and implementation of WUI research. Some of these factors are:

Operational, administrative and scientific factors	
• Time of arrival on site/timing of data collection	• Characteristics of the community or structures
• Health and safety considerations	• Potential for conflicts with fire operations
• The location of fire suppression actions	• Characteristics of the wildland fire and wildland fire environment
• Administrative or other logistical restrictions	• Difficulty of site access (distance, etc.)

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