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Why some homes survived: Learning from the Fort McMurray wildland/urban interface fire disaster

By Alan Westhaver, M.Sc.

March 2017

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The opinions expressed in this paper are those of the author and not necessarily those of the Institute for Catastrophic Loss Reduction.

Nothing in this report is intended to place blame or impart fault for home losses, nor should it be interpreted as doing so. The content of this report is solely to encourage improved preparedness for wildfires in the future by reducing the vulnerability of homes and other structures in the wildland/urban interface to igniting during a wildland fire event.

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Forward

Alan Westhaver

After surveying the ruins of vibrant and teeming neighbourhoods of Fort McMurray in mid-May, 2016 and searching for answers as to why some homes had survived, and others not, I wondered, is this a battlefield, a memorial, or a classroom? I saw it as a place of solemn learning, and believe that it held important lessons for all of us who live or work in the wildland/urban interface.

This report lays out the formal findings and recommendations of my investigation into aspects of how and why a wildland fire at Fort McMurray evolved into a wildland/urban interface fire disaster of such great magnitude. Although these results invite more forensic evaluation into some aspects of this particular disaster, they also show that the events at Fort McMurray repeated the well-known pattern of similar disasters elsewhere, and were predictable in the light of current scientific research.

Therefore, my personal thoughts are that results of this study also oblige immediate action. The present Canadian approach to the wildland/urban interface fire problem requires a radical and sweeping strategic shift that brings primary focus onto the root of the problem. That is, resolving this problem definitively and responsibly will require reducing the vulnerability of homes that are easily ignited by the inevitable showers of wind-driven embers from wildland fires. This can only be accomplished by mitigating known hazard factors at residential structures, and within ~30 metres of them. This re-orientation is essential because burning fragments of fuel from grassland, bush, and forest fires lofted and transported by the power of large wildland fires are able to surpass any possible man-made defense provided by fireguards and fuel modified areas[1] established at the margins of communities.

Today, with some queries answered and a few vital lessons learned, the most difficult challenge arises:

> *'Will the Fort McMurray disaster be the launching pad that causes us, as fire fighters and managers of public safety to pivot, shift our attention away from responding to and fighting fire (and fuel), and advance into an era of helping residents develop fire-resilient communities that can cope with the inconvenience of wildfires but are also prepared, and bounce back quickly from its impacts?'*

It is my belief that in order to achieve the vision of making fire-resilient communities the norm across Canada, the Federal Government must resolve the current impasse and move quickly by:

1. Providing decisive leadership and the sustained resources required to deal more effectively with this urgent, growing pan-Canadian issue.
2. Establishing a private/public partnership comprised of industry, governments, disaster relief organizations, and citizens with interests and abilities in community wildfire protection, and tasking them to deliver a single, consistent, and comprehensive *National FireSmart Initiative*.

This also necessitates that many of us as fire fighters, public safety officials, or municipal authorities facilitate that initiative by devoting a regular part of our duties to working with homeowners in ways that empower them with FireSmart information and support them with programs of risk reduction.

These are a few of my personal thoughts on what's needed to tackle the wildland/urban interface fire problem, responsibly and effectively. This is a solvable problem. Simple solutions that already exist must be put into place to mitigate hazards at the doorsteps and in the backyards of our neighbourhoods; applied by property owners to reduce the vulnerability of homes to ignition. That's where it counts the most, where the losses are piling up, and the only place where the sequence of wildfire disasters can be broken. The alternative is to stand by while it breaks us.

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[1] Fireguards and fuel modified areas are critical features of community wildfire protection that provide important advantages but they are incomplete solutions that cannot overcome the threat of home ignition by embers.

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Alan Westhaver held senior positions in the wildland fire program in Canada's National Park system for 27 years, and his involvement in the wildland/urban interface issue has spanned three decades. He was a member of the *Partners in Protection Association* Board of Directors 1992-2012, is a past president, and co-chaired the committee that developed and published the original FireSmart manual: *Protecting Your Community from Wildfire*. In conjunction with the Foothills Research Institute and the Municipality of Jasper Alan planned, managed, and implemented a unique community wildfire protection program for the Town of Jasper, Alberta between 1999 and 2012. Using the adaptive management approach, that project merged ecological restoration and wildfire protection objectives by melding knowledge from wildland fire behavior, forest ecology, wildlife biology with work experience as an ecosystem manager. It resulted in many innovations regarding communications, community engagement, and environmental best-practices. Aside from its practical benefits, the project also resulted in his 2006 M.Sc. thesis (Calgary) and a set of ecologically based fuel treatments that accommodate wildlife, habitat, and the aesthetic values of WUI residents. Since 'retirement', Alan continues to provide services in the fields of wildland fire behavior, community wildfire protection, FireSmart training, and environmental assessment through his Fernie-based consulting company. He is currently a faculty member of the RX-510: Advanced Fire Effects course at the National Fire Resource Institute, Tucson, AZ.

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Executive summary

In early May 2016 Fort McMurray, Alberta (population ~90,000) experienced the largest in a series of increasingly disastrous wildland/urban interface fires to recently occur in Western Canada. More than 2,400 structures were destroyed, insured losses approached $4 billion, and untold hardships now lay ahead for thousands of citizens of Fort McMurray who suffered displacement and disruption.

When the damage extent became apparent, the Institute for Catastrophic Loss Reduction sought permission for on-site access and tasked the author with conducting an investigation to answer the vital question: *'Why did some homes survive this wildland/urban interface fire with little or no damage, while others were vulnerable to ignition and destroyed?'* A methodology to evaluate the relative vulnerability or fire-resistance of homes was developed. Observations concentrated on homes near the edge of urban neighbourhoods where wildland fire first spread to, and established among, structures. Levels of hazard associated with 20 individual factors contributing to ignition potential of homes were evaluated. Sampling also occurred in country residential areas. Field investigations took place May 19 – 28, 2016.

The Fort McMurray wildland/urban interface fire disaster provided an unprecedented opportunity to learn firsthand about the survival and ignition of homes. Results of field evidence combined with observations regarding the arrangement of homes, forest fuels, and clearances between them led to the conclusion that the vast majority of initial home ignitions within this transition zone were most likely caused by embers of the forest fire. Based on sites visited, no instances were observed where home ignition could confidently be attributed to direct contact by flames of the burning forest, and there were very few observations where home ignition was likely due only to radiant heat from the forest.

Several analyses were used to compare conditions at surviving residences and respective ignition zones to that of nearby homes that were destroyed, across a range of home survival/loss situations. Overall, results demonstrated that surviving homes were generally rated with 'Low' to 'Moderate' hazard levels and exhibited many of the attributes promoted by recommended FireSmart guidelines. Conversely, a large proportion of homes destroyed by fire were rated with 'High' to 'Extreme' hazard levels, and mostly did not meet the criteria required to be deemed 'FireSmart'. Frequently, the magnitude of difference between ratings for surviving and burned homes was substantial. These relationships held true for both urban and country residential areas. When apparent anomalies or contradictions between home survival and assessed hazard levels were examined more closely, most were found to be artefacts of the FireSmart hazard assessment system itself, rather than failings in FireSmart principles. That is, they were explained either by critical vulnerabilities that are under-rated or by vegetation/fuel hazards further than 30 metres from homes which may be over-rated. Results also indicate that no single hazard factor, or category of factors, supersede all others to ensure home survival. Conversely, a single, critical weakness may result in home destruction, even though most other risk mitigations have been adopted.

Vegetation/fuel contributed the greatest proportion (i.e. 50 – 75%) of wildfire hazard scores in all home survival/loss situations, both for burned and surviving homes. Structural and ignition site hazard categories contributed the remainder, in about equal proportions. An analysis of the spatial distribution of vegetation/fuel hazards determined that 20 – 33% were located within 30m of surviving homes, whereas 59 – 67% were concentrated within 30m of homes which had ignited and been destroyed. In urban neighbourhoods, the large majority of un-treated, hazardous vegetation/fuel consisted of planted landscaping materials, not native forest vegetation. These and other results appear in section 4.

The most prominent positive attributes of surviving homes were: vegetation/ fuel conditions in accord with recommended FireSmart guidelines in Priority Zones 1 and 2; uncluttered yards with relatively few combustible objects and ignition sites[2], 'Low' to 'Moderate' ratings for structural hazard; and low-flammability surface fuel (i.e. partially greened lawn; restricted or no use of wood mulches). Other observations and discussions regarding individual hazard factors, additional vulnerabilities, and notable best practices are reported in section 5. Information regarding risk factors such as home adjacency, characteristics of the nearby forest and wildfire behavior, ember density, and pre-evacuation home protection actions by residents of Fort McMurray is also found in that section.

It seems clear that the survival of homes was a function of resistance to ignition, and not a random event or a matter of luck. Beyond doubt, risk mitigation (FireSmart) guidelines demonstrated their effectiveness in mitigating risk under the harshest of wildfire conditions. It is the opinion of the author that, had more homes exhibited 'Low' to 'Moderate' overall hazard ratings, the total number of homes surviving at Fort McMurray would likely have been significantly greater.

Overall, observations made during this investigation confirm that the Fort McMurray disaster followed a well-recognized pattern known as the 'wildland/urban interface disaster sequence' (see Figure 2-3). This progression can only be broken, and disaster avoided, by substantially increasing the proportion of homes that are resistant to ignition – especially by embers. Some encouraging evidence in support of halting the 'disaster sequence' was found at localized sites on the urban perimeter, but these were not numerous enough to deter the spread of fire from structure to structure towards the urban core, and eventual development of an urban conflagration. In these regards, the results of this investigation closely align with those from similar case studies and research conducted elsewhere.

The seven major recommendations generated by this study do not pertain specifically to disaster response, the Regional Municipality of Wood Buffalo, or to actions by Fort McMurray residents. Instead, they are intended to promote proactive approaches whereby entire communities become increasingly adapted to wildland fire events and bounce back more quickly, when they do occur. In summary, those recommendations are as follows:

1. Increased Emphasis on Reducing the Vulnerability of Homes – Breaking the Wildfire Disaster Cycle

Agencies and organizations with mandates or responsibility for public safety and/or fire protection need to shift their primary emphasis onto proactive initiatives that target the root cause of the wildland/urban interface problem – homes that are vulnerable to ignition by embers. This can be accomplished by accelerating development and implementation of programs[3] which empower and engage people to take risk reduction actions where they are most effective, in the home ignition zone.

[2] 'Ignition sites' include several hazard factors quantifying locations which accumulate fine fuels and are particularly susceptible to ignition by wind borne embers (i.e. litter accumulation on rooves, miscellaneous combustible objects, and 'nooks and crannies' resulting from structural design features).

[3] The pilot FireSmart Canada Community Recognition Program, based on the proven and highly successful *Firewise Communities* USA model, is a leading example of one such program but is struggling and in need of support.

2. Low-Risk Management of Residential Vegetation

Given the high relative proportion of hazard due to vegetation/fuel conditions within home ignition zones it is recommended that a range of new educational initiatives be developed specifically to raise awareness regarding hazards associated with natural and ornamental landscaping and risk reduction solutions among residents, landscape contractors, landscape retailers, and managers of urban parks and open spaces.

3. Further Study of the Fort McMurray Wildland/Urban Interface Fire Disaster

In order to extend the potential for learning beneficial lessons from the Fort McMurray wildland/urban interface disaster, it is recommended that further research be conducted:

- To assess the knowledge of Fort McMurray residents about wildfire risks and mitigations, pre-fire levels of risk mitigation, and attitudes towards risk mitigation prior to and following the disaster.
- Apply logistical regression to existing data collected and determine the contribution of individual hazard factors to the overall hazard rating of homes and the probability of home loss or survival.
- To identify/assess patterns of home survival in relation to wildfire behavior, attributes of wildland fuel, topographical location of homes, home density, fire arrival times and time structural ignitions.
- Explore potential correlations between the age of homes, the number and age of combustible home attachments (e.g. deck, patio, porch, balcony, fences) and home survival or destruction.
- Examine possible correlations between home loss and lot size, distance between homes, numbers of outbuildings, overlap of Priority Zones, and the number, hazard rating and survival of nearby homes.

4. 'Fire Pathways' for Better Communicating Wildfire Risk and Mitigations

It is recommended that a project be mounted to refine, deploy, and manage the novel *'fire pathway illustration'* system[4] for more effectively communicating wildfire risks, mechanisms of fire spread towards homes, and the logic of wildfire risk mitigations – so that this educational tool can be standardized, professionally produced, and made available across Canada and the USA as free-ware to all agencies, organizations, and other sponsors of wildland/urban interface risk or loss reduction.

5. FireSmart Hazard Assessment System

It is recommended that an expert panel be convened to assess, update, and upgrade the current FireSmart hazard assessment system (2003) in order to recognize additional hazards and incorporate new knowledge pertaining to structural ignition sources, fire resistance of building features and materials, all aspects of vegetation flammability, hazards posed by combustible ground cover, and 'Achilles' heel' hazards within the home ignition zone. As well, the panel should examine the relative weight placed on individual hazard factors and, in particular, the presence of vegetation/fuel in Priority Zone 3.

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[4] As described in Section 6 of this report.

6. Investigation of Future Wildland/Urban Interface Disasters

In order to maximize the benefit of future investigations it is recommended that a formal wildland/urban interface 'Disaster Analysis Team' be formed, adequately resourced, and readied in advance for quick deployment to future wildland/urban interface fire disasters anywhere in Canada.

7. Land Use Planning, Regulations, and Building Codes

In jurisdictions where it may be appropriate, it is recommended that strategic changes in urban land use planning, regulations, and building codes be considered to promote conditions on adjacent parcels of land that reinforce the mitigation efforts of homeowners, create synergy, and contribute to lowered potential for wildland/urban interface disasters.

Field investigations, such as this one at Fort McMurray, compliment more scientific, experimentally-based studies being conducted under controlled conditions and through simulation modelling. Collectively, they are essential in identifying and refining 'fire engineering' solutions to interface fire disasters. Regardless of how effective the potential physical solutions become, they are unlikely to be widely implemented until the 'human dimensions' of the wildland/urban interface fire problem are also wholly appreciated by fire protection and public safety agencies and organizations, and widely implemented by residents taking action in their backyards and neighbourhoods across Canada.

This is the collective challenge now facing fire and land managers, municipal administrators and residents of the wildland/urban interface. Preventing similar disasters in the future is a solvable problem. However, it requires that every stakeholder share the responsibility for facilitating or implementing wildfire risk mitigation actions – well before smoke is in the air. Much re-thinking and quantum shifts in the status quo are needed to achieve this objective.

[Photo credit: Alan Westhaver]

1. Introduction

1.1 The Fort McMurray disaster

On the afternoon of May 01, 2016 a wildland fire ignited southwest of Fort McMurray, Alberta in the Regional Municipality of Wood Buffalo, and its population of about 90,000 people. Low overwinter precipitation and early, summer-like weather had resulted in high fire danger. Despite immediate control efforts, the wildfire expanded quickly and spread towards urban areas as an intense crown fire burning in dense coniferous and mixedwood forest fuel types. Evacuation measures were initiated for outlying rural areas later that day. By about 3 pm on May 03 the fire grew to about 3,000 hectares, reached the western margins of Fort McMurray, and homes were reported to be burning. Serious losses occurred in the Abasand and Beacon Hill neighbourhoods later that evening, and continued overnight. At 10 am on May 04 it was reported that about 1,600 homes had been destroyed and the fire had grown to 10,000 hectares. Heavy losses continued in the neighbourhoods of Beacon Hill, Abasand, Waterways, Thickwood, Wood Buffalo, Timberlea, Saprae Creek, and others on May 05. By 6 pm that day the wildfire had reached 85,000 hectares, and it is probable that the bulk of structural losses had occurred.

Eventually, the 'Horse River' wildfire and the resulting wildland/urban interface fire disaster destroyed more than 2,400 structures, caused close to $4 billion in insured losses, and triggered the largest and most difficult disaster recovery in Canadian history.

1.2 The wildland/urban interface as an emerging issue in Canada

Wherever structures are located in places where topographical features, vegetation/fuel types, local weather conditions, and prevailing winds result in the potential for buildings to ignite from the flames and/or firebrands of a wildland fire, that location is called a 'wildland/urban interface' (NFPA, 2013) area.

The threat of wildfires, like the Horse River fire, spreading into populated areas and causing large-scale losses has been a growing concern among wildland fire managers, municipal officials, all agencies with responsibility for public safety, and other Canadians for many decades.

Wildland/urban interface fire disasters have periodically occurred in Canada for almost 200 years. While early fires, like the ones at Miramichi, NB in 1825 and Fernie, BC in 1908 were most notorious for their human fatalities, disasters of this type have persisted into the modern era of advanced wildland fire suppression but with far fewer losses of life. A study based on newspaper reports between 1980 and 2007 (Beverly and Bothwell, 2011) found that, despite their abundance and intensity, wildfires in

Figure 1-1: Typical wildfire behavior near Fort McMurray, May 2017

[Photo Courtesy of Alberta Agriculture and Forestry]

Canada annually displaced only a relatively small number of people (i.e. 3,600) and that more than 99% of evacuee homes survived. Most evacuations occurred in sparsely populated boreal regions, where annual area burned was greatest. In more densely populated regions, they considered wildfire disasters to be 'low-probability' but 'high-consequence' events.

Regardless of relatively low losses, prominence of the wildland/urban interface fire issue has grown steadily since the mid-1980s[5]. As early as 2004, some fire managers noted that losses appeared to be following a steeply rising curve. Costs of the new 'Worst' event were surpassing the previous record by a factor of three to five times (Fuglem, 2004). The escalating value of structural losses from the most recent interface disasters (i.e. 2003 Kelowna, BC ($200 million), 2011 Slave Lake, AB ($750 million), and 2016 Fort McMurray, AB (~$4 billion) appear to be following that trend, as are suppression costs. The Canadian Council of Forest Ministers (2016) also noted a "serious and sustained increase in extreme wildland fire behaviour and wildland-urban interface events" over the past 10 years.

In the United States Caton et al. (2016) reported that the frequency and severity of fires in wildland/urban interface communities have rapidly increased in in the past few decades, and the number of structures burned per year has risen significantly.

First-ever mapping of pan-Canadian interface areas by Johnston (2016) helps to clarify and quantify the existing Canadian wildland/urban interface problem. It reveals that 3.8% of Canada's total land, or 5.8% of the countries forested area, lies within the wildland/urban interface (i.e. 32.8 million hectares). Almost three times that area lies within what Johnston labels as the 'wildland-industrial' and 'infrastructure' interface areas. In total, nearly 21% of Canada's wildland fuel is located within 2.4km of some type of human development. Quebec, Ontario, Alberta, and British Columbia lead with regards to total urban, industrial, and infrastructure interface area. However, Nova Scotia, New Brunswick and Prince Edward Island have the highest density of interface, as measured by percent of land area. Most importantly, this analysis shows that 60% of all named cities, towns, villages, and reserves in Canada have a substantial amount of wildland/urban interface around them (i.e. at least 500 hectares of wildland fuel within five kilometres).

The wildland/urban interface problem is also a dynamic one. First, the area of concern is expanding rapidly in many regions of Canada. This is due to population growth/re-distribution and encroaching recreational and industrial development. Second, the most sophisticated models forecast increased wildfire activity under climate warming, with added implications for wildland interface communities:

- Projections for 2 – 4x increased annual area burned across Canada (Flannigan et al. 2005)
- Increased fire intensity and severity in several fire regimes; increased crown fire and head fire intensity due to increased spring wind and summer fuel availability (de Groot et al., 2013)
- Increased fire season severity and length of fire season (e.g. 3x cumulative fire severity rating (Flannigan et al. 2013))
- Increased number of rapid fire spread days due to extreme weather (Wang et al., 2015)

[5] In addition to several disasters, there have been many 'close calls' at major population centres including Penticton, BC (2004), Salmon Arm, BC (1998), Halifax, NS (2009), Timmins, ON (2012), La Ronge, SK (2015).

Third, there are concerns that climate warming is resulting in more widespread outbreaks of forest insects and disease such as mountain pine beetle, which are causing increased tree mortality and exacerbating the fuel accumulation problem.

The cumulative effects of expanding interface areas, climate warming, and accumulating forest fuels converge to create an expectation of more frequent wildland/urban interface disasters and increasing losses in the future (Canadian Council of Forest Ministers, 2016).

Current (2005 and 2015) investments in FireSmart activities by Canadian wildland fire agencies reflect this concern, and are estimated to total $214 million (Canadian Council of Forest Ministers, 2016). No breakdown of this investment is available however it is presumed that the majority of these funds have been directed towards fuel modification/reduction treatments on public lands on the perimeter of fire-prone communities. These costs typically range from about $5,000 to $12,000-plus per hectare.

When implemented in accord with recommended FireSmart criteria[6], fuel modification treatments are effective in reducing fire intensity, increasing prospects for safe fire containment and control, and greatly reducing the threat of home ignition by flames and radiant heat of a wildland fire. However, due to the extraordinary ability of wildland fires to generate and transport myriad firebrands, fuel management is far less effective in countering the primary threat to interface structures (i.e. the ignition of homes and other structures by wind-driven embers as explained in section 2.4).

1.3 Study goals and objective

The ultimate goals of this investigation are to foster more widespread understanding of the wildland/urban interface problem, to convey knowledge about how homes ignite and ways to diminish their ignition potential, to encourage development and application of more effective approaches to wildfire risk mitigation for use by homeowners, planners, policy makers, and public safety and fire managers in the future, and to help avoid disasters like the one being endured by the people of Fort McMurray, Alberta. Overall, it is hoped that positive lessons can be learned from events at Fort McMurray.

The immediate objective of this investigation was to answer the important question posed by the Institute for Catastrophic Loss Reduction:

> *'Why did some homes survive this wildland/urban interface fire with little or no damage, while others were vulnerable to ignition and destroyed?'*

Alternatively, risk managers may have asked: 'Were the homes that survived less vulnerable to wildfire ignition than homes that were burned?'

To answer those questions the author investigated how known hazard factors, identified in recognized wildfire risk reduction standards and guidelines, may have contributed to the survival or ignition of homes at Fort McMurray.

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[6] See: *Fuel Reduction Standards for Crown Fire Hazard* – Appendix 2 and Recommended Guidelines on pages 3-9 to 3-18 in Partners in Protection (2003).

1.4 Scope of report

Section 2 of this report reviews the current understanding of structure loss in the wildland/urban interface and provides context for this investigation. Section 3 outlines procedures used to investigate structure vulnerability. Section 4 presents results of observations regarding home vulnerability and resistance to ignition made during the investigations; and these are discussed further in Section 5. A new concept for illustrating and communicating about pathways that spread fire to homes is presented in Section 6. Sections 7 and 8 summarize conclusions and recommendations of this study. Supporting material is included in the Appendix to this report.

It must be noted that this investigation was undertaken using a 'case study' approach with provision for collecting as much quantitative data as possible with available resources.

Figure 1-2: Typical wildland/urban interface scenario at Fort McMurray

2. Structure loss and hazard assessment in the wildland/urban interface

2.1 Wildland fire in the boreal forest

The area around Fort McMurray is located within the boreal forest. This vast region is characterized by high-intensity wind-driven crown fires and high intensity surface fires that are typically very large and occur on a cycle of about 100 years. Boreal wildland fire activity peaks in spring prior to green-up and again in summer as fuel dries with sustained heat; lightning and humans are the main ignition causes. Intense boreal fires typically generate towering convection columns that vent heated gases and burning fragments of fuel (e.g. cones, bark) many thousands of metres into the atmosphere. It is believed that the number of embers falling to the ground declines exponentially as distance from their source increases. However, embers (a.k.a. firebrands) are capable of igniting spot fires in receptive fuel beds several kilometres in advance of the main fire. Spotting occurs both in 'natural' forest fuel and structural 'urban' fuel such as landscaping or building materials. It appears that the 2016 wildfire at Fort McMurray was likely within the range of historical norms of boreal fires in terms of its size, intensity, and other aspects of fire behavior.

2.2 What is a wildland/urban interface fire?

A wildland/urban interface fire is neither a traditional forest fire, nor a typical structural fire event. This is because a wildland/urban interface fire involves both wildland fuel (e.g. fuels found in forests, brush, or grasslands) and man-made or structural fuels – simultaneously. Therefore, wildland/urban interface fires are a discrete and more complex type of fire emergency; they have unique challenges and dangers not known to either wildland or structural fire events. Moreover, wildland/urban interface fire disasters are not atypical of other types of natural disasters (Moritz and Knowles, 2016).

Given these distinctions, it is critical to accurately frame the problem and potential solutions. In the case of wildland/urban interface fire disasters, the consensus is that their root cause is the vulnerability of homes to ignition from the flames and embers of wildland fires. Fortunately, many of the conditions leading to home vulnerability are well-known, manageable, and can be readily addressed by residents working on their properties with guidance by knowledgeable local fire and public safety authorities. Collectively, the measures for reducing the risk of wildfire losses are known as FireSmart®.[7]

Figure 2-1: Wildland/urban interface fires initiate when wildland fire spreads into urban fuel

[Photo: Mark Missal]

[7] 'FireSmart' is a term developed by the non-profit Partners in Protection Association and is registered as a trademark to them. The term FireSmart simply means: actions to reduce wildfire losses.

2.3 Wildland/urban interface fire characteristics

Typically, wildland/urban interface fires occur under exceptional conditions of low relative humidity, high wind, and very dry fuel. These conditions enable extreme fire intensity and rates of spread and the potential for multiple home ignitions to overwhelm any conceivable response.

Aside from exhibiting extreme wildland fire behavior, the complexities that set wildland/urban interface fires apart from other municipal fire events are that:

- Multiple, even hundreds, of homes may ignite within hours, or even minutes.
- The fire 'front' is moving, not stationary.
- There may be very little warning or time to prepare and respond.
- Human life is at risk, and evacuations are ongoing.
- Concerns for firefighter safety are greatly heightened.
- Massive losses are typical, and home destruction is usually complete.

2.4 How homes ignite

The mechanisms for fire spread from forest, brush, or grassland vegetation to urban areas are widely misunderstood by the general public who often view fire an overpowering force that engulfs homes, like an avalanche buries structures. Better public awareness of the combustion process is required to resolve these myths, and create a foundation of understanding to promote meaningful risk reduction actions.

In reality, structures in the interface can only be ignited: 1) by contact with flames (called convection) from burning vegetation or adjacent homes; 2) by radiant heat transferred from burning vegetation or structures, and; 3) by smoldering or flaming particles of fuel (i.e. embers) generated by fire and transported into contact with other solid fuels by winds (WUI Working Team, 2006; Cohen, 2004). Regardless of the heat source, ignition of a home only occurs when sufficient heat is transferred to vulnerable parts of a structure to allow combustion to occur and be sustained.

2.4.1 Vegetation to structure ignition

Wildland fire spreads from vegetation to ignite homes directly due to flames and/or radiant heat, or indirectly due to embers (a.k.a. firebrands). Only recently[8] are the significance and complexities of the ember ignition mechanism becoming well known.

Direct ignition of structures from vegetation

The ignition of homes during a wildfire event is a dual function of the amount of heat being transferred at any given time and the length of time that heat exposure continues. Increasing the distance from flames or sources of radiant heat or decreasing the length of exposure, drastically cuts potential for ignition (Cohen, 2000). Since the burn-out time for forest fuels is usually less than 60 – 90 seconds (Butler et al., 2004) at the forest/urban interface, the distance between homes and forest vegetation (i.e. clearance) becomes the critical variable.

[8] Cutting edge work at ember-generating test facilities that expose homes and building materials to ember showers under controlled conditions by the Insurance Institute for Business & Home Safety and the National Institute of Standards & Technology.

Both simulation modelling and experimental fires have been used to verify adequate clearances. Using both techniques, Cohen (2004) demonstrated that wood walls exposed to intense boreal crown fire did not ignite at 20 – 30m, and that even slight scorching was rare. Walkinshaw et al. (2012) reported that 10m of cleared forest from vinyl/cedar-sided test buildings plus selective thinning and ladder fuel removal from 10 – 30m from the home was adequate to prevent structural ignition from intense crown (head) fire exposure. Hence, direct home ignitions by radiation or flame contact from a burning forest are not expected in urban interface areas where vegetation has been appropriately treated and adequate clearance between homes and wildland vegetation exists.

Case studies provide further corroborating evidence for establishing effective wildfire buffers. In a summary of existing research following the Fourmile Canyon fire in Colorado, Graham et al. (2011) stated categorically that the flames of burning objects beyond 33m do not ignite a home's combustible materials. Meeting recommended (i.e. FireSmart) fuel treatment guidelines in Priority Zones 1 and 2 (i.e. 0 – 30m) were endorsed as the best means of increasing structural survival (Walkinshaw et al., 2012; Scott and Reinhardt, 2001). Further support for proper clearances is provided by Cohen (2000) who noted approximately 90% survival rate for homes with non-combustible roofing and 10m of vegetation clearance based on several case studies, and prescribed a 10 – 40m treatment zone. Dittaro (2008) reported that of 238 homes destroyed during the 2003 Kelowna fire storm, only two were known to ignite by direct flame contact.

Indirect structural ignition by embers transported by wildfire

Historically, embers that enter or land upon structures have been considered as the main cause of home ignition and loss (Ellis and Sullivan, 2004). Embers generated by burning wildland vegetation may be glowing or flaming upon arrival; they may reach considerable size but are generally <2-3cm in diameter. Individual embers are highly efficient 'ignitors' and are especially effective when piled by the wind. Under very dry conditions, nearly 100% of embers can ignite spot fires (Forestry Canada Fire Danger Group, 1992). Ember densities are greatest within 100m of the fire front and can range from fewer than a dozen to several hundred per square metre; they may begin arriving in communities several hours prior to arrival of the actual fire front (WUI Working Team, 2006; Maranghides and Mell, 2009). Spot fires caused by embers are common at distances of 100-500m, occur at distances of more than five kilometres (Beverly, 2010; Rissel and Ridenour, 2013) and sometimes as much as nine kilometres (Maranghides and Mell, 2009).

Embers generated by burning vegetation are the indirect source of home ignition and reported to be, by far, the most common cause of home ignition. During the 2002 Hayman fire (Cohen and Stratton, 2003), the Cerro Grande fire (Cohen, 2000), and the Angora fire (Safford et al., 2009) it was estimated that nearly equal numbers of homes ignited from firebrands as from direct exposure. Two of the best documented interface fires to date, the Witch and Guejito fires near San Diego, CA., showed that at least two thirds of the 1,125 homes destroyed (and possibly all of those homes) had ignited as a direct or indirect result of embers (Maranghides and Mell, 2009; IBHS, 2007) with ember ignitions beginning as much as one hour in advance of fire front arrival in the urban area.

In many ways, ember ignition of homes mimics the way that individual spot fires ignite from embers blown downwind of the leading edge of a wildland (forest) fire, gradually increasing in size, and then eventually merging into a single organized fire front.

Figure 2-2: Spot fires ignited by embers effectively spread fire in both wildland (lower left) and urban fuels (lower right)

[Photo Credits: Bill Bereska] [John Gibbins/U-T San Diego/ZUMA Press]

2.4.2 Structure-to-structure ignition

Burning homes can also ignite adjacent homes because they burn with great intensity, duration, and release abundant embers. If separated by less than five metres, structures can become the principal ignition source for other nearby structures (Cohen, 1995).

2.5 The wildland/urban interface disaster sequence

Current research and other fire investigations consistently identify a pattern of events, known as the 'wildland/urban interface fire disaster sequence' (Calkin et al. 2014; Graham et al., 2011; Quarles et. al, 2010; Cohen and Stratton, 2008). The sequence (see Figure 2-2) begins when wildland fire occurs under conditions of severe fire danger leading to extreme fire behavior in forest, brush, or grassland fuels. When wildfire subsequently spreads towards an urban area multiple vulnerable homes quickly ignite and fire spreads to adjacent homes. Burning clusters of homes then coalesce into a continuous urban conflagration[9] which overwhelms the capability of any conceivable urban firefighting response.

Disastrous losses result but are often followed by re-building and recurring vulnerability to the next wildfire (National Wildland/Urban Interface Fire Program, 2006).

This model aptly encapsulates both the wildland/urban interface problem, and its ultimate solution. The weakness in this chain of events occurs in the top, right-hand panel of Figure 2-3 as indicated by the 'X'. This is the only practical means of breaking the disaster sequence and is accomplished by blocking the spread of the wildfire as it transitions into an urban area. That is, by making homes and their surroundings more resistant to ignition and thus depriving the interface fire of potential urban fuel.

[9] An urban conflagration is generally considered to be a large, destructive fire that spreads beyond natural or artificial barriers in an urban environment, causing large monetary losses.

We now know that home ignition by radiant heat and convective flames can be practically cancelled out by modifying forest fuels to reduce fire intensity and creating adequate separation. The remaining challenge is to reduce the vulnerability of homes to ignition by wind-driven embers which, like snowflakes in a blizzard, respect no boundaries.

2.6 Measuring vulnerability of homes to ignition by wildfire

The susceptibility to wildfire ignition can be evaluated by systematically examining a home and its immediate surroundings, an area collectively called the 'home ignition zone' (see Figure 2-4).

The home ignition zone consists of the home and three concentric Priority Zones. Hazard reduction criteria are most stringent closest to the home and relax as distance from the home increases. When urban development is dense, the Priority Zones of one home may overlap with those of others.

To reduce, or mitigate the risk of home ignition, deficiencies pertaining to each of the known hazard factors must be identified, and then addressed. Primarily, corrective actions are the responsibility of the homeowner.

Over the span of several decades, research into conditions that make homes vulnerable to ignition during a wildfire event has been compiled, evaluated, and translated into standards by the National Fire Protection Association (NFPA, 2013). As a result, these known hazard factors have become reliable measures of the potential for homes to ignite during a wildfire event. These hazard factors are listed in Table 2-1, and are the basis of the 'FireSmart wildfire hazard assessment system' developed by Partners in Protection[10] (2003).

Figure 2-3: The wildland/urban interface disaster sequence (after Calkin et al. 2014)

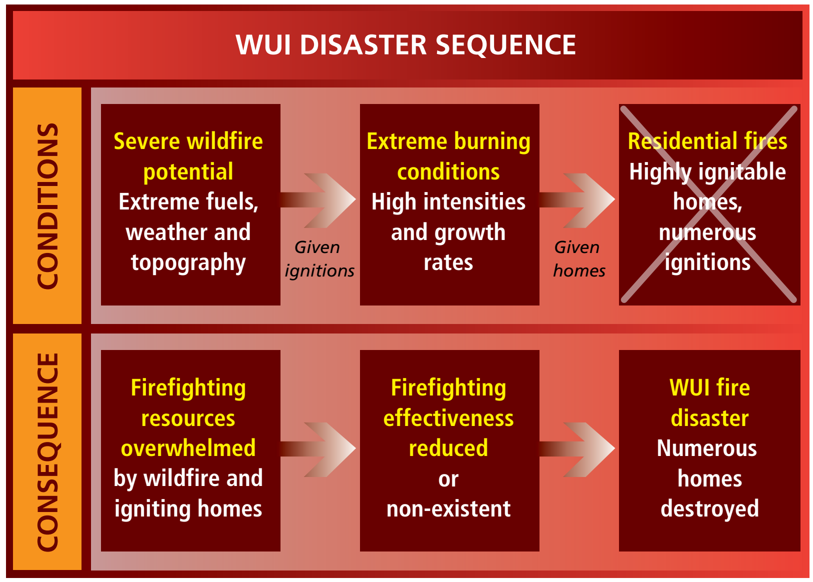
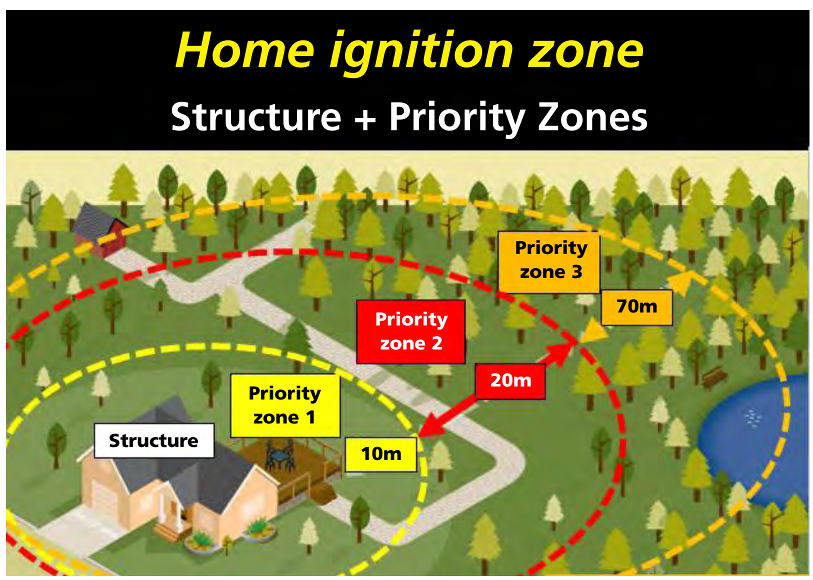


Figure 2-4: The home ignition zone



[Graphic modified with permission from NFPA Wildland Fire Operations Division]

[10] See chapter 2 of *'FireSmart: Protecting Your Community from Wildfire'* (Partners in Protection, 2003).

Individual hazard factors are quantifiably described by assigning a numeric value[11] then all hazard factors are summed to produce an overall hazard point rating and 'FireSmart hazard level' for each individual home (see Table 2-2). Only hazard levels of 'Low' and 'Moderate' qualify a home to be considered FireSmart.

In Canada, the corrective actions or 'risk mitigations' for bringing each hazard factor to the prescribed condition are properly called 'recommended FireSmart guidelines' and are described in Chapter 3 of the manual *'FireSmart: Protecting Your Community from Wildfire'* (Partners in Protection, 2003). As noted in a recent two-part review of fire spread in the wildland urban interface, knowledge about wildland/urban interface hazards is still improving and further research is ongoing to strengthen reliability of risk mitigations (Caton et al., 2016; Hakas et al., 2016). These reviews emphasize uncertainty and should not deter residents and agencies from actively engaging or promoting risk mitigation initiatives.

Table 2-1: Listing of FireSmart hazard factors (20) by category

Hazard factors grouped into major hazard categories			
Structural	**Vegetation/Fuel**	**Topographic**	**Ignition sites**
1. Roofing material 2. Building exterior 3. Eaves, vent, openings 4. Balcony, deck, porch 5. Windows and doors	6. Surface fuel in PZ-1 7. Ladder fuel in PZ-1 8. Canopy fuel in PZ-1 9. Surface fuel in PZ-2 10. Ladder fuel in PZ-2 11. Canopy fuel in PZ-2 12. Surface fuel in PZ-3 13. Ladder fuel in PZ-3 14. Canopy fuel in PZ-3	15. Setback from slope 16. Slope percent 17. Slope position	18. Roof cleanliness 19. Location of combustibles 20. Ember accumulators

Table 2-2: Hazard levels of the FireSmart assessment system

	FireSmart hazard point values			
Hazard point range	**0 – 42**	**43 – 58**	**59 – 70**	**>70**
FireSmart hazard level	Low	Moderate	High	Extreme
Degree of FireSmart adoption	Excellent	Good	Fair	Poor

[11] Each hazard factor is 'weighted' according to its relative importance and influence on structural ignition.

Figure 2-5: Scenes from the Fort McMurray fire

[Photo credits: Alan Westhaver]

Upper left: Home destroyed at interface between urban area and adjacent forest.

Bottom left: Ember ignition on deck resulted in a rare 'partial loss' of a home.

Upper right: Fire spread from home to home towards centre of community (urban conflagration).

Bottom right: FireSmart homes survived even in hard-hit Saprae Creek Estates area.

3. Investigative procedures

The Institute for Catastrophic Loss Reduction (ICLR) appreciates the importance of addressing the root causes of natural disasters. It also recognized the unprecedented opportunity that the Fort McMurray fire held for firsthand learning and contributions towards lowering wildfire losses and limiting the socio-economic after-shocks that follow wildfire disasters. With this in mind, ICLR sought permission to investigate impacted Fort McMurray neighbourhoods prior to any major recovery efforts. Consequently they commissioned the author to investigate the circumstances regarding ignition and survival of Fort McMurray homes. This study was carried out by the author from May 19 to 28, 2016.

Being on-scene immediately following the Fort McMurray fire provided unique opportunities to observe and interpret first-hand evidence about the spread of fire into residential areas, the vulnerability of homes and home ignition zones to ignition forces of the wildfire, and to examine conditions related to known hazard factors which allowed some homes to be more resistant to fire than others. The ability to witness where fire started and stopped, what burned or did not, damage to surviving homes, and the arrangement and continuity of man-made and forest fuel provided invaluable insights into the susceptibility of homes in the wildland/urban interface and the process of home ignition. Timing of the field investigations was critical, and took place before the visual signs and signals of ignition and fire spread disappeared or were obscured by rain, wind, new growth, or recovery efforts.

While the scientific and grey literatures contain several examples of well-documented wildland/urban interface disasters from the United States and Australia, few such studies are available from Canada.

3.1 Study location

In order to answer the questions posed by the Institute, it was essential to differentiate between homes ignited by fire spreading from vegetation-to-homes during the early stage of the disaster, versus subsequent stages of the disaster sequence when fire spread directly from structure-to-structure. Therefore, this study was carried out in portions of urban neighbourhoods at the forested 'interface' fringe of the city[12], and on forested acreages nearby. Care was taken to avoid areas where evidence was likely to have been confounded by the effects of multiple adjacent burning homes.

As a result, in all but a few situations observations took place at or near the 'front line' of homes immediately adjacent to, or within two to four city blocks of, forested areas on the urban fringe. This is where urban areas were first, and most severely, affected by heat transfer from the wildland fire and where the wildland fire began its transition to consuming 'urban' fuels. In some neighbourhoods, several rows of apparently fire-resistant homes survived near the forest edge, before homes further into the community began to ignite. Sampling also took place in these situations.

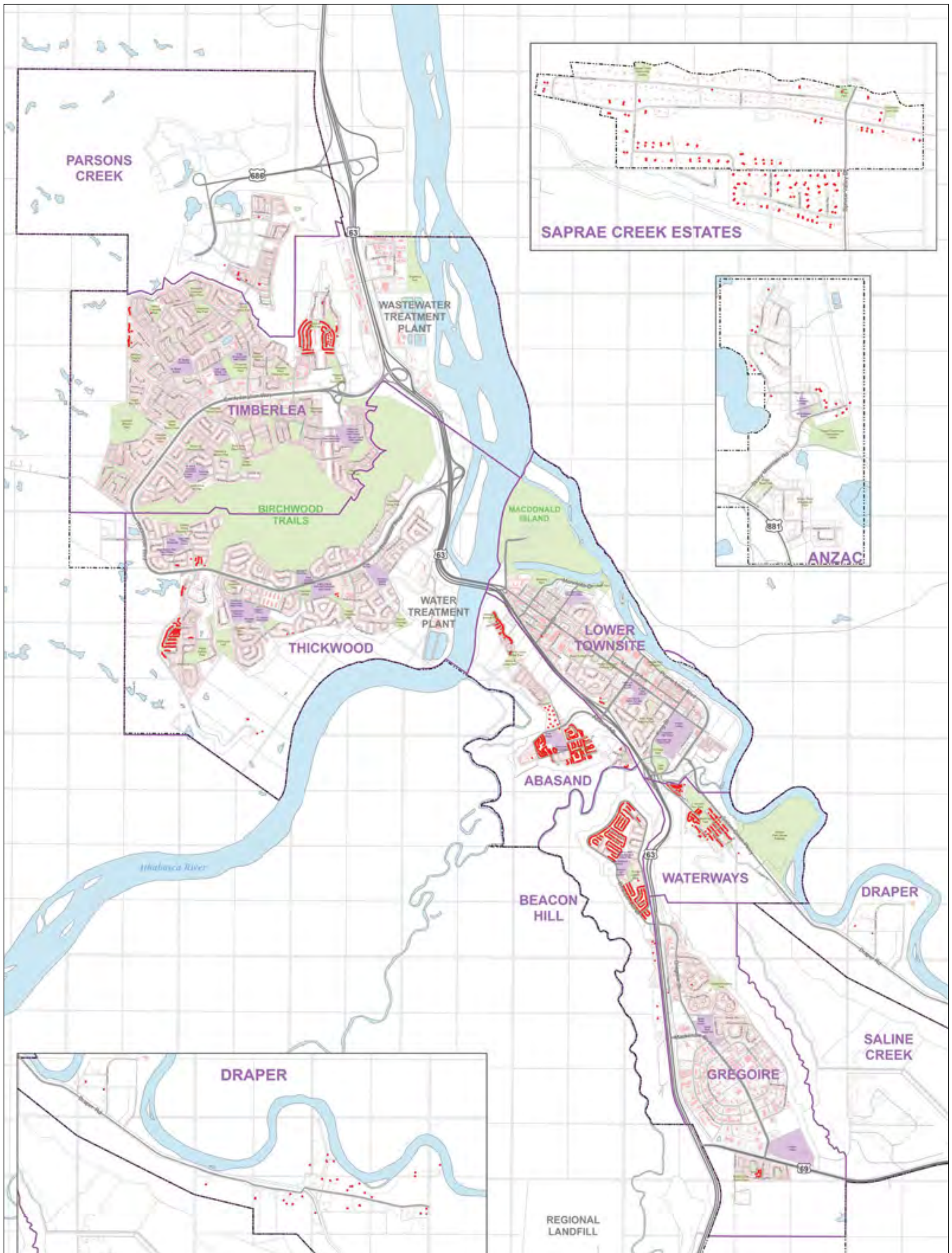
[12] Technically, Fort McMurray is an "urban service area" within the Province of Alberta.

Figure 3-1: Investigations focused on homes near the ‘front line’ adjacent to forested areas

The majority of observations made during this study were within the heavily damaged urban neighbourhoods of Beacon Hill, Abasand, Wood Buffalo Estates, and Timberlea. These urban neighbourhoods were widely separated, but each was located on relatively level upland areas adjacent to expanses of boreal forest. Some neighbourhoods were bordered by steeply forested terrain sloping towards valley-bottom riparian areas. See Figure 3-2 for the general location of these neighbourhoods. Homes assessed were standard built, single-family dwellings of varied ages built on average-sized urban lots. A smaller number of homes were investigated in the country residential area of Saprae Creek Estates, located about 10 kilometres southeast of Fort McMurray. These homes were generally larger single-family homes, located on 1 – 3 hectare lots amidst dense black spruce and mixedwood forests.

In districts where manufactured homes were the dominant construction mode, sampling was limited to informal observations. No manufactured homes are included in the analyses that follow.

Figure 3-2: Areas with high concentrations of home loss (red) were chosen for investigation in this study



3.2 Sampling strategy

In general, this investigation followed a ‘case study’ approach. An initial reconnaissance of Fort McMurray was undertaken to assess the range of circumstances where home ignitions had occurred near the urban perimeter and to match the study objectives with its limited capacity for statistical sampling. Subsequently it was decided to focus sampling within the Regional Municipality of Wood Buffalo on two main scenarios:

- Urban neighbourhoods comprised of medium density, standard built, single family dwellings.
- Low density country residential homes constructed on acreage lots within a forested matrix.

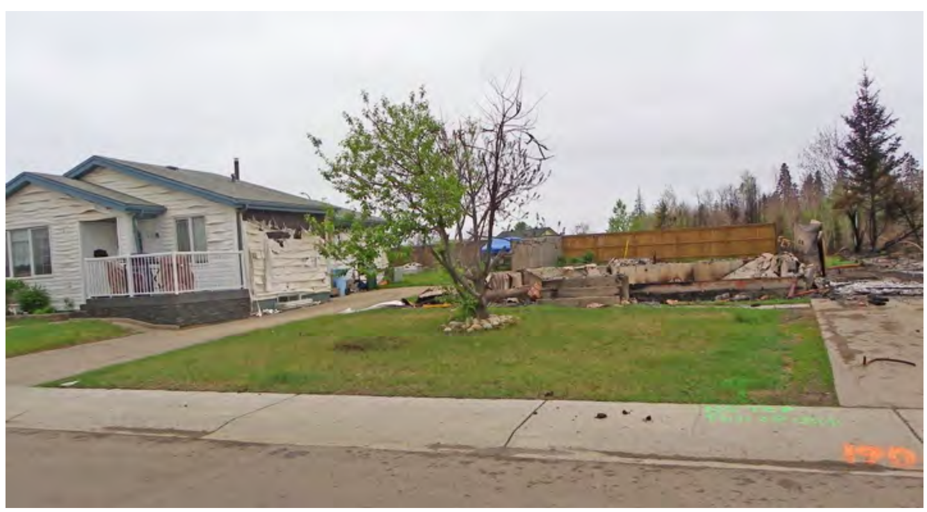
Although other important scenarios, such as neighbourhoods comprised of multi-family structures or manufactured homes were also heavily damaged, the scope of this study could not be extended to include them.

Wherever possible, an attempt was made to match pairs of adjacent urban and country residential homes (i.e. one that survived and another that ignited and was destroyed) that appeared to be of similar construction and age, and had been subjected to similar forces of ignition from adjacent forest and urban heat sources.

In some instances (e.g. strata developments comprised of virtually identical single-family or duplex homes) multiple dwellings with equivalent hazard factor ratings were assessed collectively, on the same hazard assessment form. Therefore, the number of forms does not equal the number of individual homes assessed.

During the initial reconnaissance, it was also noted that home survival and ignition had occurred across a variety of circumstances. In a more intensive study, these may have been used to stratify the sample and to discover potential differences or similarities between circumstances. However, the limited capacity of this study for sampling precluded that approach. Nevertheless, limited observations were made in these, less common, circumstances and relevant tables are included in Appendix 2.

Figure 3-3: Adjacent homes with similar fire exposure were not always affected equally



The less common but distinctive situations of home survival/loss identified at Fort McMurray were:

- Urban neighbourhoods where groups of homes received substantial wildfire heat exposure, sustained damage, but did not ignite
- Isolated homes that ignited and were destroyed well within the perimeter of urban neighbourhoods that were otherwise not impinged or penetrated by forces of the wildfire
- Isolated homes that survived amid urban neighbourhoods mostly destroyed by fire

Pairs of comparable single family homes and individual homes in each of these situations were sought out however sampling was not equal in each district or in all home survival situations. Sampling took place in each of the major urban Fort McMurray districts most heavily impacted by the fire (i.e. Beacon Hill, Abasand, Wood Buffalo Estates, Timberlea, and Dickinsfield).

Figure 3-4: Representative images from typical home survival/loss situations at Fort McMurray

Top left: Paired comparison of surviving and burned homes.

Upper right: Isolated home ignitions.

Middle left: Substantial exposure but no Ignition.

Middle right: Isolated survivor homes.

Bottom left and right: Pairs of comparable country residential homes.

[Photo credits: Alan Westhaver]

3.3 Quantifying home survivability

Survivability of a home was judged to be best quantified by describing its degree of vulnerability and/or resistance to ignition. Consequently, known wildfire hazard factors (see Table 2-1) were examined at each of the homes sampled, and within their respective home ignition zones. A similar method was used by Cohen and Stratton (2008). Nineteen factors from the standard wildfire hazard assessment system (Partners in Protection, 1993) and one additional factor recognizing the significance of 'ember accumulator sites' were condensed into a one-page format (Appendix 1).

Unique to this investigation was the necessity for conducting hazard assessments retroactively, after the home had burned. This required an understanding of home construction and deductive investigative skills to identify the presence, arrangement, and character of structural features, woody vegetation, and miscellaneous combustibles within home ignition zones – based on charred remnants and non-combustible debris. The Regional Municipality of Wood Buffalo on-line mapping tool, which provides large scale "before and after" aerial photography of every home, was utilized to verify and augment field interpretations regarding the pre-fire condition of properties destroyed by fire.

In addition to the hazard assessment an additional two-page form was developed to capture other potentially relevant data. This included additional details of home construction; attributes of forest and landscaped fuel; behavior of the adjacent wildland fire; the number and distance of adjacent homes; and evidence of ember abundance and ignition effects. In all, more than eighty home ignition zones[13] were assessed using the resultant three-page data collection form (see Appendix 1). Photographs were taken and supplemental information, including site diagrams, was recorded in a notebook.

Ellis and Sullivan (2004) deemed it possible to deduce causes of home loss from causes of damage on surviving homes, or draw inferences by comparing characteristics of destroyed and surviving homes.

3.4 Study authorization and limitations

Study authorization

Initial arrangements for this study were made at the request of the Institute for Catastrophic Loss Reduction through authorities with jurisdiction in the Province of Alberta. Full security clearances were obtained, and security, health, and safety protocols were followed throughout.

Further authorizations were received from Incident Command at the Regional Emergency Operations Centre prior to visiting affected Fort McMurray neighbourhoods, and hourly contact with on-site security personnel was maintained during observation periods. Field observations took place while the city was still subject to evacuation and full security lock-down.

The utmost consideration was given to respecting the people whose properties were visited during this study. Only careful visual observation, prior knowledge of fire behavior and home construction, and use of the Regional Municipality of Wood Buffalo on-line mapping tool was required to reconstruct pre-fire conditions. No probing or collection of material was undertaken to conduct this study. Observations were made at a distance from sidewalks, pavement, and lawns. No homes or structures were entered.

[13] In several situations, groups of identical single-family strata homes exposed to very similar ignition forces and displaying similar fire impacts, were assessed collectively rather than using individual forms.

Study limitations

Timing of the investigations, conditions brought about by the disaster itself, and finite resources available for sampling each placed minor limitations on this study. Although evidence of the burning forest abounded and millions of cold embers were observed throughout the study area, real-time behavior of the wildland fire and the ignition of homes were not observed, nor was the actual spread of fire between objects within home ignition zones, or between homes. Therefore, surrogate forms of evidence regarding home ignition, damage, and fire spread were gathered and evaluated. Constraints on sampling resources limited the number of homes that could be assessed in detail.

Figure 3-5: Observations were made remotely; no homes or structures were entered

In areas where structure-to-structure fire spread predominated, extraordinary fire intensity and tremendous amounts of firebrand material from building materials obscured evidence of pre-fire conditions, forest embers and fire spread. Therefore, to avoid potential limitations or misinterpretations, hazard assessments and observations generally focused on homes within the first three rows, where the wildland fire transitioned into a wildland/urban interface fire and not within the urban conflagration zone[14]. Within that zone forest embers were readily observed and fire severity generally allowed survival of enough remnants of shrubs and trees to allow them to be located and identified, at least at the genus level.

Finally, it was not possible to gain access to roof tops, to closely view the condition of vent screening at all surviving homes, or to evaluate roof litter conditions at homes that were destroyed. These limitations produced a minor but consistent bias across the entire sample.

Altogether, it is estimated that the net effect of these limitations would have been to under-estimate assessed hazard ratings, particularly for burned homes, by 10 – 15%. No attempt to correct or compensate for this bias was made.

[14] It is believed that the great majority of homes destroyed in this disaster were ignited due to structure-to-structure fire spread during the urban conflagration phase of the fire.

4. Results

Key results of this investigation are presented in Section 4 and address the differences between homes that survived in comparison to those that ignited and burned. They also include an evaluation of the causes of home ignition at Fort McMurray, analyses of FireSmart home hazard assessments in several home survival/loss situations, analyses of home survival in relation to particular hazards, observations regarding forest and man-made fuels, and remarks on the exposure of Fort McMurray homes to embers.

Although the sample size was necessarily small, distinct patterns and trends regarding home survival and destruction emerged from the data. Analysis also yielded some apparent anomalies which required further examination in order to be explained.

4.1 Radiant heat, flames, and embers as causes of home ignition at Fort McMurray

Home ignition by embers

The observations and results of this investigation align with the findings of case studies conducted elsewhere (e.g. as noted in sections 2.3 and 2.4 of this report). That is, the majority of home ignitions (and eventual losses) occurring at the outer edges of urban neighbourhoods and in the country residential area were most likely caused by embers of the forest fire that attacked vulnerabilities in residential structures and their immediate surroundings.

Ignition by radiant heat and flames

Forested wildland areas on the outskirts of heavily impacted neighbourhoods investigated during this study were a patchwork of various forest types and stand ages, typical of the boreal forest. With respect to the Canadian Forest Fire Behavior Prediction System, these forest types corresponded to several standard fuel types (i.e. leafless aspen, D-1; boreal mixedwood, M-1; and boreal spruce, C-2). Given the prevailing weather and fuel moisture conditions these fuel types supported very high intensity surface fire, intermittent crown fire, and extremely intense crown fire, or combinations thereof. That is, fire that appeared to burn in the upper categories (i.e. 5 and 6) of the wildfire intensity rank system.

As a rule, urban Fort McMurray neighbourhoods first impinged upon by the wildfire (e.g. Beacon Hill, Abasand, Wood Buffalo Estates, and Timberlea) were physically separated from surrounding dense coniferous and mixedwood forests by substantial buffer areas (a.k.a. fireguards). These buffers consisted of linear 'non-fuel' and 'light-fuel' zones located at the outer edge of urban neighbourhoods. Non-fuel zones consisted of features such as paved roads, gravelled road shoulders, and sidewalks or footpaths arranged parallel to each other – and incapable of sustaining combustion. Light-fuel zones were also linear, contiguous with non-fuel zones within the buffer, and comprised primarily of contiguous grassy or gravelled verges, grassed or bare ditches, maintained boulevards and residential front-lawns. Light fuel zones were capable of supporting low-intensity surface fire but were non-threatening in terms of causing direct home ignition by radiant heat. In some cases, added clearance was provided by public hiking/ski trails, and manicured grassy green spaces.

The width of clearances (i.e. open space) provided by non-fuel and light-fuel buffer zones between forest fuels and urban neighbourhoods at Fort McMurray generally ranged from 45 to 55-plus metres, and occasionally narrowed to ~35 metres. These clearances exceed distances prescribed by current standards, recommended FireSmart guidelines (Partners in Protection, 2003) and related research on structural ignition (Walkinshaw et. al, 2012; Cohen, 2004).

Figure 4-1: Typical separation of homes from forest fuel at Fort McMurray

Given these buffers and the presence of expanses of unburned fuel and other combustible materials between the forest and urban developments, it was judged that forest/home clearances at perimeter areas of Fort McMurray were sufficient to ameliorate the heat requirements for structural ignition from flames and radiant heat of the forest fire, even when wildland fire intensities reaches extreme levels[15] (i.e. intensity ranks 5 and 6). Consequently, 'big' flames were eliminated as the cause of home ignitions in all but a very few localities.

While ignitions due to flames and radiant heat can be considered negligible, it is certain that neighbourhoods opposite and downwind of burning forest areas would have been subjected to an intense, and sustained, 'blizzard' of burning and smoldering embers. The physical evidence for this was documented at every home, in the form of abundant cold embers which accumulated in home ignition zones at densities ranging from dozens to hundreds per square metre[16], and also as ember burns on combustible surfaces. Ember transport and ignition of homes were also inadvertently documented in 'dash-cam' videos taken by Fort McMurray residents during their evacuation. Firebrands, consisting of fragments of fuel (e.g. cones, branches, bark, and needles), would have been lofted far ahead of the fire front by strong convective and

Figure 4-2: Occasionally, grassy wildland fuels connected forest areas with urban and landscaped fuel

[15] Heat transferred towards structures declines almost exponentially because of the duel effect of increasing distance and the short duration (i.e. 60 – 90 seconds) of peak energy production as forest fuel burns out.

[16] Maximum ember density observed by the author, as measured by burn-hole counts on fabric, was 600/M².

general winds, and landing in home ignition zones for a considerable time prior to arrival of the flame front at the urban perimeter. It is also highly probable that wind-driven embers travelled hundreds, if not thousands, of metres in advance of the fire front.

Even though fuel buffers at the margin of neighbourhoods investigated all but eliminated the potential for home ignitions due to flames and radiated heat of the wildland fire, mass ember production and long-distance transport by strong winds subjected neighbourhoods to intense ember showers. Neither the existing buffers nor any practicable firebreak would have been effective in preventing a large number of ember-caused home ignitions at Fort McMurray. All things considered, it appears that embers were the proximate cause of the vast majority of early home ignitions at the outer edges of Fort McMurray.

4.2 Wildfire hazard ratings for homes that survived, compared to those that did not

Hazard assessment data for Fort Mc Murray homes was analysed in order to determine significant differences between homes that survived and those that were destroyed. Analysis began with a general comparison of the overall wildfire ratings for homes that survived versus homes that burned, then narrowed to investigate differences in hazard ratings for individual categories of hazard, and the spatial distribution of vegetation/fuel hazards. This was done for both urban and country residential homes. Limited analysis was done to make comparisons within and between the five different home survival/loss situations observed at Fort McMurray.

4.2.1 Analysis of home hazard assessments for pairs of comparable homes

In this analysis, the home hazard assessments for matched pairs of burned and unburned homes located adjacent to each other in urban and country residential areas were pooled to see if, and how, assessments for surviving homes varied from those of homes destroyed (see Table 4-1).

Table 4-1: Hazard ratings for comparable pairs of surviving and destroyed homes

Hazard ratings for comparable pairs of surviving and destroyed homes		
Urban homes (N = 13)	**Surviving homes**	**Destroyed homes**
Average hazard points	29	56
Range of hazard point values	10 - 65	12 - 103
Average hazard level	Low	Moderate/High*
Average difference between surviving & destroyed homes	27 points	
Frequency that surviving homes rated < destroyed homes	12/13 (92%)	
Country residential homes (N = 5)	**Surviving homes**	**Destroyed homes**
Average hazard points	47	87
Range of hazard point values	26 – 63	66 – 120
Average hazard level	Moderate	Extreme
Average difference between surviving & destroyed homes	40 points	
Frequency that surviving homes rated < destroyed homes	5/5 (100%)	

* The division between "Moderate" and "High" FireSmart hazard levels is at 58 points.

In paired comparisons of urban and country residential homes, 17 out of 18 times (94%) the surviving home was assessed as having lower risk than the home located next door which had been destroyed by fire. This was true 92% of the time for pairs of urban homes and 100% of the time for pairs of country residential homes. Furthermore, the average difference in point ratings between surviving and burned homes was 27 and 40 points respectively for urban and country residential areas. This represents a substantial difference in the relative vulnerability of homes that survived and those that were destroyed.

This analysis shows that, on average, surviving homes in urban neighbourhoods were assessed as being FireSmart, and well within the 'Low' hazard level. That is, conditions in those home ignition zones resulted in them being relatively resistant to ignition, with few vulnerabilities. In stark contrast, adjacent homes destroyed by fire were assessed as having, on average, borderline 'High' hazard levels.

Similarly, in country residential areas, the average rating of surviving homes was at the lower range of 'Moderate' (which also qualifies them as FireSmart). On average, nearby homes destroyed by fire were assessed as being at 'Extreme' risk.

4.2.2 Pooled analysis of hazard levels for homes assessed in each home survival/loss situation

A second, pooled analysis was performed by examining the frequency of surviving and burned homes assessed with 'Low', 'Moderate', 'High' and 'Extreme' FireSmart hazard ratings, across all observations. This was another means of relating home survival to the presence and condition of hazard factors that contribute to the ignition potential of homes. Results of this analysis are summarized in Table 4-2.

Table 4-2: Pooled analysis of wildfire hazard rating for all homes assessed at Fort McMurray

FireSmart Hazard Level for all Homes Assessed in all Situations								
	Low (0-42 points)		Moderate (43-58 points)		High (59-70 points)		Extreme (71+ points)	
	'FireSmart' rated				Not 'FireSmart' rated			
	#	%	#	%	#	%	#	%
Paired Urban Homes – Survived	10	77	2	15	1	8	0	0
Paired Urban Homes – Destroyed	4	31	4	31	1	7	4	31
High Heat Exposure – Survived	3	100	0	0	1	0	1	0
Isolated Urban Ignitions – Destroyed	2	40	1	20	0	0	2	40
Isolated Urban Survivors	2	40	0	0	1	40	0	20
Paired C. R.[17] Homes– Survived	1	20	3	60	1	20	0	0
Paired C. R.13 Homes – Destroyed	0	0	0	0	2	40	3	60
Surviving Homes by Haz. Level (N = 26)	16	62%	5	19%	4	15%	1	4%
Homes Destroyed by Haz Level (N = 23)	6	26%	5	22%	3	13%	9	39%

[17] Country Residential

Overall, the pooled analysis of all homes, across all situations, showed that 21 out of 26 times or a total of 81% of the surviving homes were rated as being 'FireSmart'. Respectively, 62% were rated 'Low' hazard and 19% rated 'Moderate' hazard. This correlates well with the analysis for comparable pairs of homes shown in Table 4-1.

However, the linkage between assessed hazard levels and home destruction was less clear. Two seemingly contradictory results were obtained.

The first apparent contradiction arose when the analysis revealed 5 out of 26 surviving homes rated as not being FireSmart (i.e. 4 homes rated with 'High' hazard and 1 home rated as 'Extreme') had actually survived. Further examination of the data for these homes showed that high hazard ratings had been assigned primarily due to the presence of untreated overstory forest vegetation in Priority Zone 3. Several experimental studies (Butler et al. 2004, Walkinshaw et al. 2012) conducted since development of the original FireSmart wildfire assessment system have downplayed the importance of forest conditions greater than 30m from the home on ignition potential. This is the suspected source of the anomalous results. In other words, actual hazard is systematically overestimated by the current system in cases where untreated forest is present in Priority Zone 3. If this, potentially discounted, hazard factor were set aside, the hazard rating for each of these surviving homes would drop to 'Low', congruent with the observed survival of these homes.

In the second apparent anomaly, the analysis shows that 11 out of 23 homes that were destroyed were actually assessed as being 'FireSmart' (i.e. 6 rated 'Low' and 5 rated 'Moderate'). This is almost as many as the number of burned homes rated at 'High' and 'Extreme' hazard levels (12) and seemed highly contradictory. A more detailed analysis of hazard distribution found three potential reasons for this contradiction:

- Some evidence of hazard factors was likely overlooked or underestimated due to the obscuring effect of fire damage (i.e. 10 – 15% as noted in section 3.4, Study Limitations).
- The present hazard assessment system does not adequately identify critical weaknesses (i.e. Achilles' heel factors described in Section 4.4.4) that result in high probability of home ignition despite 'Low' assessed hazard levels.
- The unmeasured effect of burning adjacent homes on the ignition of assessed homes.

The following observations were made, specific to each of the home survival/loss situations:

Paired comparisons in urban neighbourhoods

Tabulation by hazard level shows that 94% of paired comparisons of all urban and country residential situations rated as having either 'Low' or 'Moderate' hazard levels, survived the wildfire. This yielded a very strong, and encouraging, correlation between the absence or limited presence of known FireSmart hazard factors and home survival. It is also significant that more than three-quarters of the paired homes in this subset that survived the fire were assessed as having 'Low' hazard.

Substantial exposure but no home ignition (survived)

This situation was encountered and sampled at three locations, each involving multiple homes that survived extreme exposure to intense heat from the adjacent wildfire, adjacent homes, or both. In addition, these homes were also exposed to intensive ember storms. Each group of homes rated with very 'Low' hazard levels and were exemplary with regards to low occurrence and degree of hazard factors. These results provide further evidence to corroborate the effectiveness of FireSmart mitigations in reducing risk of wildfire losses, and the potential value in establishing FireSmart neighbourhoods.

Isolated ignition of homes in otherwise undamaged neighbourhoods

This subset was comprised of five isolated homes that ignited and burned well within neighbourhoods otherwise free of wildfire losses. On average these homes rated with 'High' hazard. However, this is misleading since three of these homes were rated at 'Low' or 'Moderate" hazard levels. On-site observations revealed that each of those homes had a critical weakness or 'Achilles' heel' that made them immediately susceptible to ember ignitions, and that these were the likely causes of ignition.

Isolated surviving homes

The two most dramatic examples of 'miracle' survivor homes were both rated with 'Low' hazard. Both homes were subject to massive forces of ignition, particularly embers from the adjacent forest and to a significant degree, also from nearby homes. In all instances, the surviving homes were either located on the outer edge of the neighbourhood, close to the surrounding forest on the upwind exposure, and therefore only exposed to the heat of burning homes on three sides.

There was one apparent anomaly within the 'isolated survivor' category. This involved a single home rated with 'High' hazard. After more critical examination, it appeared the fortuitous presence of a plastic covered arch-rib structure and a small copse of early-leafing deciduous trees shielded the home and other combustibles, at least temporarily, from radiant heat on two exposures and likely prevented ignition of the home. This beneficial 'shielding' effect was also documented by Cohen (2004).

Paired comparisons in a country residential neighbourhood

Most homes in the country residential neighbourhood were located in areas of very dense, mature black spruce forest that was largely untreated in terms of recommended FireSmart guidelines for crown fire reduction (Partners in Protection, Appendix 2, 2003). Four of five surviving homes in this situation rated with 'Low' or 'Moderate' hazard levels, with one home edging into 'High'. Overall, hazard factors had been noticeably well addressed by the owners of surviving homes in this neighbourhood. In contrast, all paired homes that ignited and burned in this situation were rated at 'Extreme' or 'High' hazard.

In summary, the pooled analysis of data found that the overall frequency of survival, across all home survival/loss situations, was 81% for homes rated with 'Low' or 'Moderate' hazard levels – and thus considered to be 'FireSmart'. This demonstrates a close correlation between low assessed hazard and home survival. However, only 56% of the homes destroyed were rated at 'High' to 'Extreme' hazard levels. Therefore, a further breakdown of the data seemed warranted to seek explanations for this apparent contradiction.

4.3 Home survival in relation to three major hazard categories

The overall FireSmart rating for a home ignition zone is the sum of rating values for multiple hazard factors within several categories of hazard. Therefore, it was anticipated that breaking the overall hazard rating down into the three most pertinent categories[18] (e.g. structural, vegetation/fuel characteristics, and ignition sites) might yield important insights into the fire resistance of surviving homes and/or details of the particular vulnerabilities of homes that ignited and were destroyed.

4.3.1 Urban neighbourhoods

Information summarized in Table 4-3 pertains to thirteen pairs of similar homes assessed in urban neighbourhoods.

Table 4-3: Breakdown of hazard points assessed to pairs of urban homes by hazard category

	Major hazard category		
	Structural	**Vegetation/ Fuel**	**Ignition sites**
Surviving homes			
Average Value for Surviving Homes	10	14	5
Range of Values for Surviving Homes	5 – 16	0 – 47	1 – 8
% of Total Hazard assessed to Surviving Homes	34%	49%	17%
Homes destroyed			
Average Value for Homes Destroyed	13	37	10
Range of Values for Homes Destroyed	2 – 23	0 – 84	6 – 14
% of Total Hazard assessed to Homes Destroyed	22%	62%	16%
Avg. Point Difference between Surviving & Burned Homes	3.5	24	5

This analysis of hazard distribution by category reveals, in general, that vegetation/fuel conditions are the leading contributor to hazard rating and hence, to home vulnerability. This was true regardless of whether or not the home survived. Vegetation/fuel hazards were prominent in all three Priority Zones surrounding homes, in each vertical layer (i.e. canopy, ladder, and surface fuel), and involved both native vegetation and ornamental landscaping materials.

Collectively, vegetation/fuel conditions accounted for 49% of the total hazard rating at homes which survived and 62% of total hazard at homes which failed to survive. With regards to the actual allocation of hazard points, surviving homes were awarded only 14 points (on average) for non-conforming vegetation/fuel conditions, whereas homes that were destroyed accumulated an average of 37 points. These are substantial differences. Most notably, vegetation/fuel hazard allocated to the burned home was greater in every paired comparison, and by a factor of up to 3 times in some cases.

[18] Topography, the fourth major hazard category, was not included in this section of the analysis because it was largely a constant at Fort McMurray, and therefore deemed to affect all homes about equally.

Incidental observations indicate that a majority of non-conforming vegetation (i.e. trees, shrubs, ladder fuels, surface fuels) were due to landscaping material planted by residents, not residual native forest.

Structural features encompass building material used in home construction as well as important home features such as eaves, vents, balconies, and decks. Analysis shows that structural features of the home ranked second in the proportional contribution to total hazard, both to homes that survived (34%) and homes that ignited and burned (22%). However, the difference between the average hazard points ascribed to structural features was small (i.e. 3 points) but consistently (66%) lower for surviving homes.

Figure 4-3: Flammable decks and porches were common examples of structural hazard factors

The relative proportion of hazard allocated to ignition sites ranked third, contributing 16% and 17% respectively to total hazard rating assessed to surviving and burned homes. More importantly, the average points assessed to burned homes was double the amount ascribed to surviving homes (i.e. 10 versus 5 points), thus identifying the abundance of ignition sites as a potential characteristic for differentiating between the vulnerability of homes.

4.3.2 Country residential neighbourhoods

The same types of information were summarized in Table 4-4 for five pairs of similar homes assessed in the country residential neighbourhood of Saprae Creek Estates.

Table 4-4: Breakdown of hazard points assessed to pairs of country homes by hazard category

	Major hazard category		
	Structural	**Vegetation/ Fuel**	**Ignition sites**
Surviving homes			
Average Point Value for Surviving Homes	8	35	3
Range of Point Values for Surviving Homes	4 – 12	3 – 53	0 – 11
% of Total Hazard by Category at Surviving Homes	17%	76%	7%
Homes destroyed			
Average Point Value for Homes Destroyed	11	64	15
Range of Point Values for Homes Destroyed	7 – 13	40 – 100	13 – 16
% of Total Hazard by Category at Homes Destroyed	12%	71%	17%
Avg. Point Difference between Surviving & Burned Homes	3	29	12

Surviving country residential homes consistently had lower hazard ratings in each major hazard category in comparison to adjacent homes which had been destroyed. This is similar to results for urban homes.

Again, vegetation/fuel was the leading contributor to total hazard ratings, both at surviving homes (an average of 35 points, or 76% of all hazard) and burned homes (an average of 64 points, or 71%). It is noteworthy that vegetation accounted for about three-quarters of the total hazard assessed. On average, the magnitude of difference between vegetation/fuel hazard allocations to surviving and burned homes was also meaningful (i.e. 29 points).

Regarding structural and ignition site hazard ratings, the points awarded were much smaller in proportion to vegetation and marginally lower at Saprae Creek Estates than in urban Fort McMurray settings. As expected, point ratings were somewhat lower for homes that survived versus homes that ignited and burned. Most notably, ignition sites garnered five times more hazard points at country residential homes that were destroyed, than at homes which survived.

4.3.3 Hazard by category for situations of high exposure, isolated ignition, and isolated survivors

See Appendix 2 for this analysis and results.

4.4 Home survival in relation to spatial distribution of vegetation/fuel hazard

Given the disproportionately large amount of the total hazard rating ascribed to vegetation/fuel, further analysis of its spatial distribution within the three concentric Priority Zones was conducted. Results are presented in Tables 4-5 and 4-6 for pairs of comparable homes in urban and country settings, and in Appendix 2 for the remaining situations. Results of these analyses revealed important patterns and correlations between the proximity of vegetation/fuel to homes and their survival or destruction.

4.4.1 Vegetation/Fuel hazard distribution by Priority Zone – urban

Data for 13 sets of paired urban homes is summarized below.

Table 4-5: Distribution of vegetation/fuel hazard by Priority Zone in urban neighbourhoods

	Vegetation/Fuel Priority Zones		
	Priority Zone 1	**Priority Zone 2**	**Priority Zone 3**
Surviving homes			
Average Point Value for Surviving Homes	2	3	10
Range of Vegetation/Fuel Point Values for Surviving Homes	0 - 22	0 – 11	0 - 35
% of Vegetation/Fuel Hazard by Priority Zone	16%	17%	67%
Homes destroyed			
Average Point Value for Homes Destroyed	12	12	12
Range of Vegetation/Fuel Point Values for Homes Destroyed	0-50	0 - 47	0 - 37
% of Vegetation/Fuel Hazard by Priority Zone	35%	32%	33%
Avg. Difference between Surviving and Burned Homes	10	9	2

4.4.2 Vegetation/Fuel hazard distribution by Priority Zone – country residential

Data for five sets of paired homes in similar urban situations is summarized below.

Table 4-6: Distribution of vegetation/fuel hazard by priority zone in country residential areas

	Vegetation/Fuel Priority Zones		
	Priority Zone 1	**Priority Zone 2**	**Priority Zone 3**
Surviving homes			
Average Point Value for Surviving Homes	0	7	28
Range of Vegetation/Fuel Point Values for Surviving Homes	0	0 - 23	0 - 42
% of Vegetation/Fuel Hazard by Priority Zone	0%	20%	80%
Homes destroyed			
Average Point Value for Homes Destroyed	12	27	27
Range of Vegetation/Fuel Point Values for Homes Destroyed	0 – 25	0 - 55	15 – 45
% of Vegetation/Fuel Hazard by Priority Zone	18%	41%	41%
Avg. Difference between Surviving and Burned Homes	12	20	-1

The spatial distribution of vegetation/fuel hazard ratings was both striking and consistent across urban and country residential neighbourhoods. That pattern shows that between 59 and 67% of all hazard within Priority Zones 1 and 2 (i.e. 30m) of homes that were destroyed was attributed to vegetation/fuel conditions, while that figure dropped to 20 – 33% for homes that survived. In other words, vegetation/fuel hazards were concentrated much more closely to homes which had been destroyed by fire. Thus, a strong, positive correlation exists between home destruction during wildfire events and untreated vegetation within 30 metres of homes. The implications of this pattern become more serious when it is recalled that vegetation/fuel also accounted for half to three-quarters of all assessed hazard. Therefore, proper selection and treatment of vegetation emerges as being crucial to home survival.

What isn't evident in the data but was consistently observed is that more than half of the hazard accruing from vegetation/fuel within Priority Zones 1 and 2 resulted from landscaping materials chosen and planted by the residents or landscape contractors and not from residual native (i.e. forest) vegetation in urban neighbourhoods.

Figure 4-4: Vegetation/Fuel near to homes accounted for the majority of hazard assessed

4.4.3 Hazard by Priority Zone for situations of high exposure, isolated ignition, and isolated survivor

See Appendix 2 for these results and analysis.

4.4.4 Vegetation/Fuel anomalies

The Achilles' heel

Analysis in previous sections noted that a number of homes rated with low hazard and considered to be "FireSmart" had ignited and were destroyed. Review of these apparent contradictions reveals that, aside from being at risk due to the overall accumulation of hazard factors, homes are at risk from the presence of 'fatal flaws' or an 'Achilles' heel.' That is, a single, overriding weakness yielding a high probability that a home will ignite, regardless of other good practices. Examples of such weaknesses are:

- Bulky, high flammability[19] ornamental shrubs (usually juniper, cedar, arbour vitae, or mugo pine) placed within 1 – 3m of windows, walls or eaves.
- Substantial, easily ignited fuel sources such as garden sheds, ATVs, petroleum products and firewood or construction materials located within 5m of the home or under combustible elements of the home.

Such fuel sources burn with high intensity and long duration and are capable of sustaining ignition of nearby homes.

Figure 4-5: Homes surviving extreme exposure had uniformly low vegetation/fuel hazard within 30m

Significance of untreated vegetation 30+ metres from the home

Another consistent trend was apparent with regards to vegetation/fuel hazard ratings but in Priority Zone 3. Point allocations indicate that large amounts of untreated vegetation were present in the Priority Zone 3s of urban and country residential homes, in roughly equal amounts surrounding homes which survived and those destroyed. Consequently, there did not appear to be a solid correlation between home survival and the amount of vegetation in Priority Zone 3. This gives rise to further speculation regarding the relative importance of untreated forest vegetation beyond 30m from homes in regards to structural vulnerability and home survival.

[19] Flammability refers to plants that are easily ignited, burn with high rates of spread and energy release, burn for long duration, and burn until completely consumed.

5. Discussion of hazard factors and associated characteristics affecting home ignition potential

Hazard factors affecting the ignition of structures encompass all aspects of the structure, nearby vegetation/fuel, and ignition sites. Aside from individually rating these factors to determine the overall vulnerability of the homes investigated, the Fort McMurray disaster provided unparalleled opportunities for making less structured, first-hand observations regarding well recognized hazard factors, other less well-known hazards, and the roles each played in allowing fire to spread or making homes resistant to ignition.

Discussion of vulnerabilities and best practices related to formal hazard factors follows in Sections 5.1 to 5.3 and mirrors the organizational pattern of the hazard assessment system. Section 5.4 presents observations and discussion regarding less well-established risk factors such as home adjacency, characteristics of the nearby forest and wildfire behavior, ember density, and pre-evacuation home protection actions by residents of Fort McMurray.

5.1 Structural hazard factors

Given the wide range of building styles, ages, and fire exposures encountered at Fort McMurray there were ample opportunities for observing the response of structural elements of homes to fire. In general, it was perceived that newer homes rated with lower structural hazard than older homes. This is believed to be because they feature more fire resistant materials, have design features with fewer opportunities for ember accumulation, and have far fewer openings to allow entry by wind-driven embers.

5.1.1 Roofing

The vast majority of homes examined were fitted with asphalt roofing, and this was true of both surviving and burned homes. Virtually all had been exposed to varied intensities of ember showers, and many had been exposed to intense radiant heat or subjected to short-lived flames from adjacent vegetation. However, all remained intact and there were no indications of fire starts on asphalt roofs of surviving homes. Only one structure inspected was observed to have a wood shake roof, probably unrated, and that building was destroyed by fire even though it was separated from forest vegetation and other homes by at least 40m on all sides. A number of situations were observed where the edges of asphalt roofs had been exposed to extreme heat, enough to cause layered shingles to droop and curl downward towards the eave, but in all cases they resisted ignition and continued to protect the combustible decking beneath.

5.1.2 Building exterior

Vinyl siding was, by far, the most common home siding material observed, followed by various forms of stucco, wood paneling, and timbers[20]. Of these, only stucco and aluminum/steel are considered to be fire resistant by the FireSmart hazard assessment system (Partners in Protection, 2003), so nearly all homes received a poor rating. The vulnerability of vinyl siding to radiant heat and subsequent sagging and peeling, or to ignition when contacted by flames is well known. Regardless, hundreds of vinyl-sided homes survived the Fort McMurray fire, even in areas exposed to significant heat flux.

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[20] Use of fire resistant cement fibre board was uncommon.

More specifically, about 73% of all surviving urban homes in the study had vinyl siding. Among the subset of matched pairs of homes, 50% of the surviving homes in urban areas had vinyl siding and 50% had non-combustible stucco or other siding; that 50:50 ratio was about the same for matched pairs that had burned. Consequently, within this limited sample, vinyl siding did not appear to be a factor that (alone) differentiated surviving from burned homes. What is not known, are the materials beneath vinyl siding and their role in fire resistance. This invites further investigation.

Figure 5-1: A significant proportion of Fort McMurray homes had exterior vinyl siding

Observations indicated a positive correlation between surviving vinyl-sided homes and strong adherence to recommended FireSmart guidelines pertaining to vegetation/fuel conditions and ignition sites. From this, homeowners should be encouraged that vinyl siding may not be an overwhelming handicap, if other risk mitigations are carefully applied. As well, older homes renovated by layering vinyl siding over original stucco or rock composite siding proved to be highly resistant to ignition from intense radiant heat.

Planed wooden siding was observed on several homes adjacent to others destroyed by fire, but did not display signs of scorch or flaming. In numerous locations, it was observed that various types of fences, tarped arch-rib storage structures, and deciduous trees or hedges (some of which eventually burned) appeared to provide vital ‘shielding’ to homes with fire-susceptible siding; apparently enough to reduce duration and/or intensity of radiant heat from adjacent burning homes or vegetation and to prevent ignition.

Traditional vinyl was less common in country residential areas however a number of homes had been sided with a novel type of flexible textured sheeting that mimics a plaster finish. This material was observed to stretch, loosen and begin to peel due to radiant heat exposure but was not observed to ignite or completely shed from the home as vinyl strip siding often did.

Best practices and innovations that appeared to increase the resistance of siding to ignition and associated with surviving homes included: a) adequate clearance to prevent flame contact from combustible vegetation; b) adequate clearance to limit radiant heat exposure from large combustible objects, storage bins, parked vehicles, RVs, ATVs, and stored petroleum products; c) the presence (even temporary) of shielding barriers to diffuse or block radiant heat; d) separation of siding from the ground by exposed concrete foundations, brickwork, or ornamental stone stub walls.

5.1.3 Eaves, vents, and openings

Given limited access, it appeared that eaves, vents and openings contributed little to overall hazard and were mostly rated low. However, it was rarely possible to reliably verify the adequacy of vent screen mesh size in preventing entry by fine embers.

The majority of homes assessed appeared to be forty years of age or younger, and constructed with modern techniques and materials intended for reducing energy waste and air leakage. These advances inadvertently also serve to prevent embers from penetrating into homes. In older homes, features like open eaves, gable vents, and other openings were more common and may have served to permit increased entry points for ember invasion.

Two important locations for ember entry, frequently observed but not noted in manuals, were: 1) old-style 'whirly-bird' roof vents (generally unscreened) and, 2) gaps surrounding panelled garage doors.

Positive attributes of surviving homes were: a) smooth or finely slotted aluminum soffits; b) low profile, finely screened roof vents; c) newer and retrofitted homes with far fewer vents, and layered or non-combustible siding; d) tightly fitting garage door gaskets that block ember entry on all 4 sides of the door; e) finely screened soffit and gable end vents.

5.1.4 Decks, patios, porches, and balconies

Combustible external attachments to homes such as decks, balconies, and fences were popular features at the majority of urban homes, and contributed to the overall vulnerability of these homes. On average, homes that survived had <1.8 combustible attachments while urban homes destroyed had an average of 2.0. Most were constructed of combustible wood, and therefore are inherently susceptible to ignition by embers or easily ignited by dense, ornamental shrubbery. That risk was often compounded by designs that tended to trap and accumulate embers. Danger is frequently enhanced by placement of other combustible objects[21], storage items, or accumulations of plant debris on, under, or beside these surfaces. Design features of decks, balconies, and porches that add inside corners, steps, and more locations where vertical and horizontal surfaces meet also increased opportunities for embers to accumulate and foster ignitions.

It was observed that spot ignitions by embers on wooden decks were more common and smoldered more extensively on older decks, decking with micro-sites showing signs of decay or rot, and decks with narrow (i.e. less than 6mm) spaces between planks clogged with fine debris and providing added fine fuel to support combustion.

It was observed that spot ignitions by embers on wooden decks were more common and smoldered more extensively on older decks, decking with micro-sites showing signs of decay or rot, and decks with narrow (i.e. less than 6mm) spaces between planks clogged with fine debris and providing added fine fuel to support combustion.

Figure 5-2: Example of decks exhibiting low-risk features in area exposed to high ember density

[21] Furniture, outdoor cooking devices and fuel, firewood, construction material, planters, recycling, etc.

Best practices and innovations observed, and that may have reduced the vulnerability of wooden outdoor surfaces at surviving homes, included: a) an absence or low total surface area of deck and balcony features; b) a minimalist approach to the amount of combustible objects attached to, or placed upon them; c) completely non-combustible surfaces (e.g. gravel) beneath decks and patios; d) the absence of below-deck storage, e) fully closed-in sides; f) non-combustible support legs, or placement of wooden deck supports on pedestals that are non-combustible and raised above the ground surface (e.g. pre-cast concrete bases, metal sleeves); g) non-combustible furniture and storage boxes; h) an absence of firewood; i) 2m clearance from any coniferous shrub/tree vegetation or combustible hedge; j) application of highly ember-resistant coverings such as hard-surface composite "planks" or flexible sheeting over wood decking; k) application of tiles or metal flashing at wall/deck junctions; l) non-combustible stairs or stair stringers in ground contact.

5.1.5 Window and door glazing

Virtually all surviving homes observed were fitted with standard double glazed windows, mostly with vinyl frames, and the degree of fire resistance they provided appeared to be consistently high. Although many hundreds of windows, of all sizes, were observed (on surviving homes) to have cracked due to heat exposure, fewer than five were observed to have failed completely such that embers could move freely into a home. While vinyl trim strips frequently peeled away, no structural or frame failures or openings resulted even when 80 – 90% of the surrounding vinyl siding had weakened and fallen away. In one instance, a single-glazed door fractured and failed due to heat from a smoldering, possibly flaming, deck and door frame, allowing fire into the home.

Figure 5-3: Double-pane vinyl mounted windows routinely survived extensive heat exposure

Although timing of the study did not allow first-hand observation of window failure, numerous situations were observed where placement of bulky, highly-combustible ornamental cedars or conifer trees within 1 – 3m of windows was likely to have been the trigger for ignition of the home.

Best practices observed with regards to reducing window vulnerability included: a) closing windows tightly during a wildfire and, b) ensuring adequate clearances between windows and vegetation or outbuildings.

5.1.6 Fences

By virtue of being attached to homes, fences were also considered to be a part of the home. Wooden fences played a significant role as 'wicks' and 'connectors' to help fire spread horizontally along pathways between various fuel sources, between homes, and through neighbourhoods. Burning fences were observed to directly scorch homes they were attached to and to ignite more substantial fuel sources such as hedges, decorative juniper/cedars, wood and lumber piles, recycling bins, ATVs and outbuildings. It was also observed that older, poorly maintained fences affected by rot or weathering seemed more susceptible to ignition by embers. Similarly, fences were frequently subject to scorching or ignition when underlain by accumulations of light fuel like untrimmed grass and leaf litter.

Fencing innovations and best practices observed to reduce the vulnerability of homes included: a) use of non-combustible fencing alternatives; b) inserting a single section of non-combustible fencing between the last section of wood fence and the home; c) installing a metal gate and end-post between the fence and home; d) lacing metal frost fencing with plastic staves to create privacy, and a radiant heat 'shield', between homes or other large heat sources at risk; e) constructing wood fence with adequate clearance beneath to allow for grass trimming and removal of litter; f) leaving adequate space between fences and structures to permit routine removal of leaf-litter.

5.1.6 Storage buildings/outbuildings

Overall, it appeared that the condition of outbuildings (i.e. their vulnerability to ignition) was more important than their presence, as a factor contributing to home ignition. Although not formally assessed, about two-thirds of all surviving outbuildings were judged to be vulnerable to ember ignition.

On average, urban homes had ~1.0 outbuilding on the property. At surviving urban homes the average distance between outbuildings and the home was 7.0m and 4 of 13 outbuildings had burned. For urban homes which had been destroyed, the average distance between home and outbuilding was 5.6m but 8 out of 9 outbuildings also burned. It could not be determined in which direction the fire spread, or if the outbuilding and nearby home had ignited independently.

Figure 5-4: Vulnerable outbuildings were a heat source capable of igniting homes

Outbuildings such as garages, garden sheds, and play-houses that are elevated above ground or supported on skids appeared to be common locations for structural fire to take root from embers, and spread to adjacent homes. These smaller structures are particularly problematic because they are most often constructed of wood, located <10m from the home, and large enough to generate long-lasting sources of extreme heat. Observations show them to be prime locations for build-up of fine and medium fuels (e.g. grass, leaf litter, garbage, paper), either under or around them, as well as sites that easily trap wind-driven embers and allow fire to become established. Miscellaneous combustible items were frequently stored or stacked close to outbuildings thus compounding risk.

Innovations and best practices for increasing fire-resistance of outbuildings and reducing the risk they pose to homes included: a) attachment of tight, non-combustible skirting around the base to seal out embers and prevent accumulation of vegetation and litter beneath the outbuilding; b) application of fire resistant siding; c) installation of a rated roof; d) ensuring adequate clearance from other combustibles.

5.2 Vegetation/Fuel hazard factors

This section examines some of the qualitative properties of vegetation and natural fuel that were observed in relation to home survival or ignition. In most cases the residual evidence of plants, visible following the fire, was sufficient to determine the abundance, form, and even the species of problematic vegetation/fuel – and to discern its role in home ignition and losses.

5.2.1 Surface fuel

Residential lawns

The timing of this fire, prior to early season green-up, allowed cured residential lawns to act as highly receptive fuel beds. Lawns provided a medium for embers to smolder, kindle, and propagate spreading spot fires. Conversely, it was clear that homeowners who had applied water encouraged early-season greening of lawns, and that this greatly reduced the density and size of successful ember ignitions around their homes.

Evidence was abundant that increasingly drier lawns allowed for correspondingly greater expansion of spot fires (either flaming on the surface, or smoldering deep in the sod). Spot fires merged in some locations, thus spreading radially to encompass and potentially ignite, more combustible objects located within the home ignition zone.

It was also observed that well-trimmed (shorter) grass appeared to retard fire spread and infrequently provided enough fuel to ignite more substantial fuel such as fences, stacked lumber and firewood.

To the contrary, untended grass areas (i.e. taller or matted grass) often augmented with leaves or needles appeared to be more effective in spreading fire and igniting heavier fuels, thus extending fire pathways towards nearby structures. The generally 'patchy' pattern of burning in lawns, the dominant ground cover in suburban and country residential home ignition zones, was interpreted as further evidence that homes were not engulfed by a continuous wall of flames emanating from nearby forests.

Overwinter accumulations of leaf litter occasionally supported discontinuous fire spread in fine fuels whereas heavy or multi-year leaf accumulations were continuous and generated the heat required to kindle heavier fuels such as firewood piles and garden sheds.

Figure 5-5: Parched lawns allowed ember-caused spot fires to merge and spread towards homes

Wood chips and bark flakes (mulch)

Organic landscaping materials (i.e. wood chips and bark flakes) of varying particle size, colour, and degrees of decay were common elements of landscaping in private yards and on municipal lands at Fort McMurray. Overall, they ignited and burned in the large majority of these locations, and appeared to play frequent and very prominent roles in the spread of fire towards homes and other buildings, and in eventual ignition of structures. In about half of the locations observed, beds of wood chips or bark flakes burned completely; in the other half, burning was confined to a portion of the bed.

Figure 5-6: Combustible wood chip/bark mulch was easily kindled by embers and readily spread fire

The high frequency of wood mulch ignition was likely due to combined effects of the high density of incoming embers, strong ventilating winds, and low fuel moisture due to sustained drying conditions. Regardless of watering frequency, chipped wood and bark behave like all fine woody fuel and lose moisture quickly to the atmosphere when temperatures rise and humidity dips. Much as kindling is to a campfire, mulched or chipped wood materials appeared to feed fire spread and were common elements of fire pathways.

Aside from appearing to be easily ignited, wood chips and bark flakes also gave indications of being effective ember accumulators, sustaining smoldering fire and effectively transferring enough heat to ignite adjacent fine, medium, and heavy fuels. Consequently, these materials were judged to very effectively enable fire spread to nearby vegetation, landscaping timbers, other combustibles, and home or deck components.

The author observed a number of locations where beds of wood chips or bark flakes had been fitted with underground drip irrigation systems, but had burned regardless. It is interpreted that the irrigation systems had either failed due to loss of power or water, or that the systems were not yet functional due to the time of year and thus had not been effective in mitigating fire risk.

5.2.2 Shrubs, tall shrubs, and trees

Mature coniferous trees were uncommon in urban neighbourhoods, rarely found in groups, and were only occasionally involved in pathways leading to home ignition.

Conversely, ornamental evergreen shrubs (i.e. mostly introduced junipers, cedars, and arbor vitae) of short to medium (<8m) stature were present on many urban lots. Frequently, they were planted in clusters or formed dense, linear hedges. These ornamentals combine virtually all the characteristics of extremely flammable vegetation (i.e. high fuel volume, easily ignited, chemical volatility, and high-intensity long duration burning). They are surface, ladder, and canopy fuel combined into a single plant and are capable of igniting decks, wood walls, vinyl siding and fences. As well, they generate enough heat to break windows and melt aluminum soffits allowing flames to enter homes. Consequently, juniper/cedars were observed to play leading roles in scores of fire pathways discerned during this investigation, and are believed to have triggered the ignition of many homes.

Figure 5-7: Volatile ornamental junipers/cedars figured prominently in many fire pathways to homes

Prevailing conditions (i.e. high ember density, high winds, low humidity and low fuel moisture) would have raised the probability of ember-ignition of juniper/cedar shrubs to near-certain levels. Aside from embers themselves, ornamental evergreen shrubs were judged to be among the more common heat sources causing early ignitions of Fort McMurray homes. Video dash-cam footage taken by a Fort McMurray resident during the evacuation on May 04 provides vivid evidence of the capacity of ornamental shrubbery as a source of home ignition; the sequence of events leading from ember > mulch bed > cedar/juniper > full home ignition took place in the elapsed time of approximately 40 seconds. See Figure 6-1 for a photograph of this location, and Figure 6-2, Fire Pathway #2 for a diagrammatic representation of this sequence.

5.3 Ignition site hazard factors

This group of factors encompasses locations, objects, and conditions that facilitate ignition by embers. This includes rated factors that address roof cleanliness, the presence of miscellaneous combustibles on the property, and the frequency of locations that allow embers to accumulate. Roof cleanliness did not appear to be an issue at surviving homes but could not be evaluated at those destroyed, and is not addressed further in this section.

5.3.1 Miscellaneous combustibles

This hazard factor accounts for combustible materials of any kind located outside of the home, within the home ignition zone, and susceptible to ignition by embers. The abundance of 'combustibles' was observed to be a more problematic issue in older neighbourhoods and in neighbourhoods with smaller lot sizes – but not always. Overall, there appeared to be a positive correlation between home survival and properties that had minimum amounts of materials, machinery, and general "clutter" stored in open areas and accessible to wind-driven embers. The most common and significant sources of combustibles were general yard 'clutter', firewood, construction materials, recycling and compost storage, machinery and recreational vehicles, petroleum products, and patio furniture or amenities.

Tidiness, diligent property management, and provision of ember-proof storage containers or sheds were prominent best practices for minimizing the ignition of miscellaneous objects by embers.

Landscaping timbers

The use of milled landscaping timbers or rough-sawn logs in residential landscaping was a common practice at Fort McMurray. They were utilized as patio and deck borders, retaining walls for flower beds and raised gardens, to demarcate property or sub-division boundaries, and other purposes. However, they were also observed to be surprisingly effective conduits for fire spread (flaming or smoldering) and were frequently connected to combustible portions of homes or nearby outbuildings such as deck supports, siding, garages, or other combustibles. Hold-over fires associated with landscaping timbers appeared to have persisted above and below ground for days following passage of the main fire. They are suspected of being long-lasting and insidious sources of home ignition.

Figure 5-8: Landscaping timbers smoldered persistently and spread fire into contact with structures

Ensuring that landscaping timbers are not physically connected to elements of the home, used only in beds that are otherwise isolated from homes and other large fuel sources, and not used in association with wood chips or bark or other forms of highly volatile vegetation/fuel were observed to be best practices reducing home vulnerability.

5.3.2 Ember accumulators

Ember accumulators are best described as sites that allow or encourage wind-borne embers to pile up and become concentrated sources of heat transfer causing the ignition of other combustible objects. Building design features such as inside corners, junctions between horizontal surfaces, and depressions such as stairwells are examples of 'nooks and crannies' that trap and allow light, wind-transported objects to pile up. In general, it was found that older and renovated homes with more complex roof lines, dormers, inside corners, and multiple levels possessed more ember accumulator sites than newer homes. Local winds and lee-side eddies carry and deposit embers at these locations. The best proxy for anticipating ember accumulation sites is to take note where wind-driven snow tends to accumulate.

Strategies for mitigating ember accumulators included: a) leaving wide clearances between homes and outbuildings; b) screening in porches and decks; c) adding fire resistant or non-combustible surfacing to inside corners, deck/wall junctions, and flat surfaces; d) utilizing steep-pitched roofs on garden sheds.

5.4 Other characteristics affecting home ignition potential

Aside from the standard home assessment hazard factors, observations were made regarding other characteristics of neighbourhoods, adjacent forests, forest fire behavior, ember density, and pre-evacuation home protection actions by residents that affected the ignition potential of homes at Fort McMurray. These too, provide insights into risk factors that may have affected the survival or loss of individual homes.

5.4.1 Home adjacency

Aside from hazard factors that are inherent to an individual property, this investigation also documented information regarding attributes of adjacent homes considered to have potential for affecting home survival. Some of these are discussed briefly below.

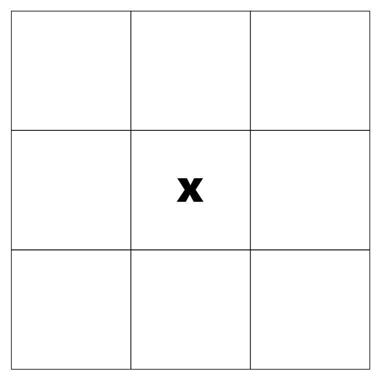
Lot size and neighbourhood planning

Based on these investigations, it was observed that numerous homes with very 'Low' hazard rating had likely ignited and burned because of critical deficiencies in recommended FireSmart guidelines that occurred on adjacent properties but within the 10m radius of Priority Zone 1. Most commonly, this involved the presence of untreated vegetation or of improperly stored combustibles vulnerable to ember ignition within the shared (i.e. overlapping) Priority Zone 1.

Figure 5-9: Hazards on one property can be a threat to the Priority Zones of several homes

Previously, it has been widely recognized by fire officials that the Priority Zone 2 of adjacent homes sometimes overlaps and that conditions in both affect the net hazard ratings and ignition potentials of homes. Now, with the advent of smaller urban lots and infilling projects, it appears that this issue is also pervasive in Priority Zone 1, thereby creating more widespread concerns.

Figure 5-10: Diagrammatic view of nearest-neighbour grid surrounding subject home (X)



Number of adjacent homes and average distances between homes

According to the Institute for Business & Home Safety (2007), homes within a radius of 10m from each other are capable of damaging each other if ignited. Therefore, the number and distance of immediately adjacent homes was recorded for each home that was formally assessed. This was done by imagining the maximum number of nearest-neighbour homes to be eight, with each home being centred in the midst of a 3 x 3 grid of surrounding home ignition zones (see Figure 5-10). Homes to the immediate left and right were generally the closest neighbours and separated only by narrow side-lots, whereas homes to the front and rear were generally separated by streets, sidewalks, alley ways and wider front and back yards.

By applying this grid concept, the average number of homes located immediately adjacent to surviving paired urban homes was 5.5. The average distance to the closest homes on the right and left sides was 7.9m. The shortest distance between the subject home and any of its neighbours was 4.0m.

For comparable urban homes that had burned, the average number of homes located immediately adjacent was 5.4 and the average distance to the closest homes on the right and left sides was 6.7m.

The shortest distance between the subject home and any of its neighbours was 3.0m.

In country residential areas, the average distance between neighbouring homes located next to surviving homes was about 65m, which reflects the larger lot sizes.

Number of adjacent homes surviving and burned

The average number of adjacent homes that burned next to a surviving urban home was 2.64, whereas this average increased to 3.45 next to homes that had burned. It is unknown if this difference is significant or approaching some threshold. It could either be an indicator that a burning home pre-disposes neighbouring homes to ignite, or that a single problematic fuel source (e.g. an ornamental cedar hedge, a wood pile, a vulnerable garden shed, or stored combustibles) located between two homes provided a common source of ignition.

In country residential areas the average number of adjacent homes that burned next to a surviving home was 3.5. Given the large distance between homes in this setting, this relatively large value is more likely to reflect the presence of known FireSmart hazard factors and the tremendous intensity of ember showers generated by adjacent spruce forests than the influence of one burning home on another.

5.4.2 Characteristics of adjacent forests

Data describing several physical attributes of the forest adjacent to assessed homes was gathered for the purpose of linking it with subsequent but separate fire behavior studies in relation to home survival. That information is outlined below and available for future analysis.

Forest type

Boreal mixedwood forest (with aspen in leafless condition), boreal black spruce (evergreen) forest, and deciduous (leafless) aspen forest were present around the perimeter of Fort McMurray and as small, mostly linear, enclaves within urban areas. These correspond to the M1, C-2 and D1 fuel types of the Canadian Forest Fire Danger Rating System. Forests at the perimeter of country residential homes were generally continuous boreal spruce but forest stands were highly fragmented within the residential area itself.

Forests beyond the perimeter of urban neighbourhoods were more varied in type, and subject to more disturbances, like road building. The breakdown between forest types was approximately 70% mixedwood, 10% spruce, and 20% deciduous adjacent to surviving urban homes, and approximately 85% mixedwood and 15% spruce near burned homes.

Distance between forest and homes

For 13 pairs of comparable urban homes, both burned and surviving, the average estimated distance from forest to homes was 71m, and average estimated distance from all unburned homes in all home survival/loss situations was 69m. For burned homes in cases of isolated ignitions, the average distance was 226m.

Figure 5-11: Non/low flammability buffer zones adequately separated most homes and forest cover

All of these distances are well beyond the capability of flames or radiant heat of a forest fire to ignite combustible materials, leaving embers as the sole potential ignition source.

Forest density

Overall, the average estimated density of the mostly mixedwood forest canopy cover[22] adjacent to burned and unburned urban homes was about 58%, which is considered to be a fairly dense forest. In the country residential area adjacent to surviving homes the forest canopy cover averaged 48%. In only a very few cases did the dense forest canopy extend into the outer edges of Priority Zone 2 of urban or country residential homes, and not at all into Priority Zone 1.

Size of nearest forest patch

For urban homes that survived, the average estimated size of the nearest continuous forest patch at the urban perimeter was estimated to be 49 hectares, while the average estimated size of the nearest continuous forest patch to urban homes that burned was 29 hectares. Consequently, there did not appear to be a correlation between the size of the nearest adjacent forest patch and home survival.

For country residential areas, the average estimated size of the nearest continuous forest patch was 12 hectares where homes had survived. Although there was more forested area nearby than in urban neighbourhoods, it was extensively fragmented.

5.4.3 Characteristics of adjacent forest fire behavior

Forest fire type

For urban homes that survived, the predominant type of forest fire behavior nearest to homes was crown fire. It was estimated that 57% of all adjacent forest fire was of the crown fire type, and the remaining 43% was high intensity surface fire accompanied by intermittent crown fire. For surviving homes in country residential areas, 95% of the adjacent forest appeared to have burned in crown fire; a significantly higher proportion than in urban neighbourhoods.

For urban areas where the home was destroyed, the predominant type of forest fire behavior was actually estimated to be lower, at about 33% crown fire and 66% high intensity surface fire with intermittent crown fire. It is believed that the ability of either type of fire to generate and transport massive amounts of embers would have been enormous.

Length of forest perimeter burned

The average length of forest perimeter that had burned nearest to surviving urban homes was estimated to be 182m, whereas it was 208m nearest to homes that had been destroyed. In country residential areas, the average length of forest perimeter that had burned nearest to surviving homes was similar, at about 179m.

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[22] Defined here as the proportion of the forest floor covered by the vertical projection of the tree crowns.

5.4.4 Ember characteristics

Although quantitative counts of ember density, ember scorch, and spot fire spread from embers would have been possible and highly informative, these proved to be too time-consuming for this study. Instead, a system of qualitative descriptors (e.g. Low, Moderate, High) was adopted during the course of the study. Even this proved difficult to perform consistently or accurately due to the level of scrutiny required to detect embers on varied surfaces and fuel beds ranging from driveways and decks to partially greened lawns, bare-soil and mulch-covered flower beds.

Overall, it was observed that the vast majority of forest-generated embers were 0.5cm in diameter or less, but commonly ranged up to 1.5cm. Sporadically, areas were encountered where the ember train included abundant charred black spruce cones measuring about 1.5cm x 3.5cm and 50-plus cm long segments of conifer branches. Some of the latter objects were deposited more than 150m from the nearest tree.

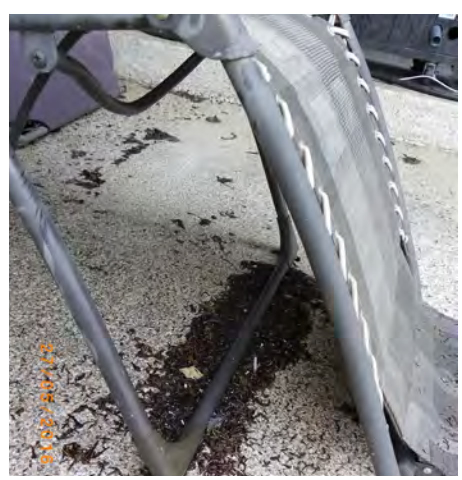
In terms of abundance, ember density appeared to vary significantly within and between urban neighbourhoods but the evidence indicates that all areas were subject to ember showers that rarely decreased below estimates of 10 embers per square metre on surfaces that retained embers. It was typical for embers to be piled 1 – 3cm in depth, often mixed with ash, in the majority of expected accumulation sites on and around homes (e.g. inside corners, the lee side of wind-exposed surfaces, window and stair wells, door steps, against vertical surfaces, against door mats). Such sites were present at most homes.

Based on informal observation, it is estimated that one third of all embers caused some sort of scorch or fire effect. Remaining embers appeared to extinguish without impact or to be cold upon landing.

The maximum actual ember count during this study occurred on a flat to convex shaped cloth seat cover measuring 57 x 59 cm (i.e. 0.3363m^2) resting on a patio chair observed at Saprae Creek Estates (see Figure 5-12). Extrapolated, the density of visible burns from embers in the seat cover was 604/m^2. This is equivalent to 6,040,000 embers per hectare. Similar ember densities were documented during the most destructive wildfire in Texas history (Rissel and Ridenour, 2013). Counts of ember burns on a tarp following a wildfire near the Hamlet of Chisholm, Alberta in 2001, limited to ember burn holes 1 cm^2 or greater, resulted in a measurement of 15 embers/m^2. Converted to a per hectare basis this yields 150,000 embers per hectare.

Figure 5-12: Indications of ember accumulation and density

603 ember burns/m^2 on seat cushion



Ember accumulation on lee side of deck chair

5.4.5 Effectiveness of pre-evacuation fire control actions by residents

For the most part, extreme behavior of the wildfire dictated almost immediate departure by Fort McMurray residents. Nonetheless, there was evidence that some residents had taken last minute efforts to reduce the vulnerability of their homes. In some locations, this may have impacted home survival. At a number of surviving homes it was obvious that:

- Combustible items normally found in back yards had been hastily gathered or scattered away from decks or external walls to eliminate them as potential ignition sites (e.g. stored firewood, deck furniture, BBQ and propane appliances, and wooden planters).
- Sprinklers had been positioned on the property and appeared to be left on to soak potential fuel sources such as decks, lawns, flower beds, firewood piles, and sheds located close to the home.
- Recycling containers, propane heaters, storage containers, and other combustibles appeared to have been hastily relocated to remote areas of the yard.
- Means for attaching garden sprinklers on top of (non-combustible) roofs had been improvised.

It is possible that these last minute efforts may have made a difference between home loss and survival on properties which were already substantially FireSmart.

In other locations it was evident that, had residents been more aware of the priorities for last-minute wildfire preparations, they could have been more effective in eliminating ignition sites or interrupting fire pathways. For example, some residents took precious time and great effort to fix sprinklers onto non-combustible asphalt roofs, while overlooking vulnerable fuel accumulations on, under, and against portions of the home at ground level.

6. The concept of 'Fire Pathways' for communicating wildfire risk and mitigation solutions

One of the unanticipated and potentially beneficial results of this study was to conceptualize a breakthrough model for use in risk communication. This novel concept offers the twin prospects of significantly raising levels of understanding about the problem of home ignition during wildfire events and motivating more widespread application of FireSmart risk mitigations among residents of the wildland/urban interface.

During this investigation hundreds of properties were scrutinized to detect how fire had ignited and spread to destroy homes – or why it had not. This required detecting and following telltale clues left along myriad routes that combustion followed from initial points of ignition, across backyards, to their ultimate destination whether it be extinction, or a blazing home. Embers were most often but not always the initiators of spreading fire. Beyond that, the trail of fire involved a surprising array of combustible objects that combined into dozens of sequences. These tracks were diagrammed and labelled as *'fire pathways'* in the investigators field notes and, soon, patterns began to emerge. It also became apparent that most often, these pathways were comprised of 'little things' that could have been easily modified, re-positioned, or eliminated by the homeowner to stop a spreading fire before it incurred serious damage.

The concept presented here is that *fire pathways* perceived at Fort McMurray could become teachable moments for all residents of the wildland/urban interface. Fire pathways can be visually represented in ways that would bring firsthand understanding to wildland/urban interface residents of all ages (i.e. from children to seniors) about wildfire threats, and would likely create increased motivation among the general public to take actions that greatly reduce the risk of fire losses.

Too often, *fire pathways* terminated with ignition and destruction of the home, but others were interrupted or terminated short of home ignition by basic FireSmart measures taken by residents. Some *fire pathways* were long, complex, and switched freely between multiple vegetation and man-made fuels, while others involved only one intermediate fuel source prior to ignition of the home. Occasionally, *fire pathways* persisted as slow-moving, smoldering fire covering distances of 30 – 40m between properties, while others flashed almost instantly.

All of these *fire pathways* can be visually portrayed in ways that convey virtually all complicated dynamics of combustion, wildland fire behavior, and structural ignition to ordinary people – but without the complexity. They also convey the simple logic of FireSmart risk mitigations (i.e. recommended guidelines).

The following *fire pathways*, using a small sample of prototype icons, were prepared especially for this report.[23] They provide a preliminary demonstration of the highly visual nature, flexibility, and simplicity of the fire pathway concept as an aid to more effective and educational fire prevention communication.

Figure 6-1: Photograph of an actual 'Fire Pathway': wood mulch > junipers > deck > home ignition

[23] By communication professionals at Book Services in Tucson, AZ.

Fire pathways replicate real and recurrent mechanisms of home ignition observed at Fort McMurray by the investigator. However, the primary reason for including the prototype pathways in this report is to gauge the level of support for further refining this concept[24] into a standardized tool for distribution as 'free-ware' for general use by agencies, organizations, and educators in all types of wildfire prevention and risk reduction applications.

Figure 6-2 includes six *fire pathways* representative of those observed at Fort McMurray; each is accompanied by a brief narrative. Note that fire pathway #6 depicts the ignition of a home that was captured live on video and published on the internet by a Fort McMurray evacuee at:

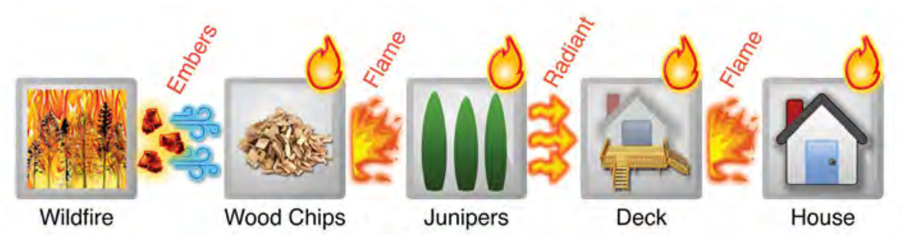
https://www.youtube.com/watch?v=PCc1FvZ3g0Q.

Elapsed time between landing of embers and home ignition is estimated to have been about 45 seconds. This is the same situation shown photographically in Figure 6-1 above.

Figure 6-2: Prototype illustrations of 'fire pathways' depicting sequences leading to home ignition

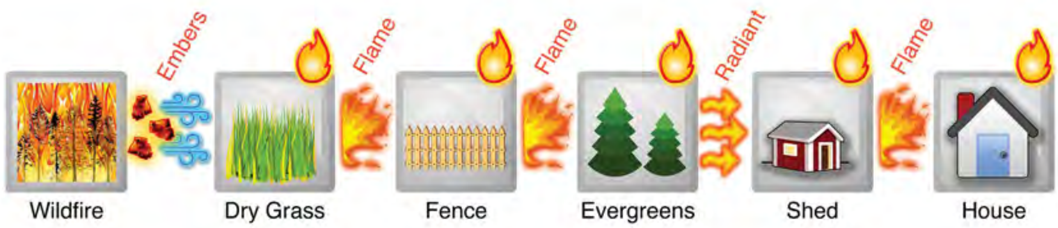
Fire Pathway #1: *Embers carried by the wind from wildfire, ignites fine leaves, spreads flames to evergreen trees, which ignites deck by radiant heat transfer, and spreads flames that ignite home.*

Fire Pathway #2: *Embers carried by the wind from wildfire, wood chip mulch smolders, flames climb into ornamental juniper/cedar, radiant heat ignites deck, and blazing deck ignites home.*

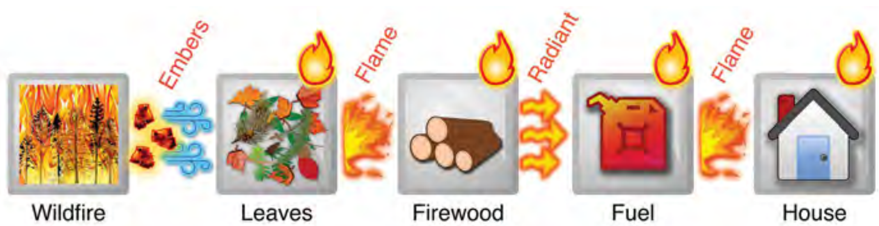


[24] Please direct enquiries or expressions of interest regarding use or further development of the Fire Pathway illustration symbol system to the author.

__Fire Pathway #3:__ Embers carried by the wind from wildfire, kindles dry grass, flames ignite fence, carries fire to evergreens, shed ignites by radiant heat transfer, and flames ignite home.

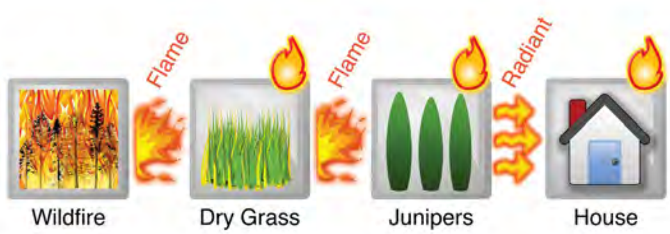


__Fire Pathway #4:__ Embers carried by the wind from wildfire, ignite fine leaves, flames spread to wood pile, mower gas ignites due to radiant heat, and flames ignite home.



__Fire Pathway #5:__ Embers carried by the wind from wildfire, flames kindle in wood chip mulch, fire spreads to lumber pile, radiant heat ignites garden shed, flames spread to deck, home ignites and burns.

__Fire Pathway #6:__ Embers carried by the wind from wildfire, flames kindle grass and litter at base of ornamental junipers/cedars, home ignites and is destroyed.



With very little additional explanation, these intuitive diagrams instantly convey an understanding and appreciation of how fire spreads, how homes ignite, and where and how people can take simple actions, or make better decisions which result in lowering the vulnerability of their home or neighbourhood to ignition and reducing the risk of wildfire losses.

If developed and perfected, this novel concept promises to effectively replace or enhance many of the too-technical or overly simplified explanations that prevail in current wildfire risk reduction information pieces.

Based on this study, and many others, it is obvious that a much greater proportion of people that live or work in the wildland/urban interface need to understand hazard factors contributing to the ignition of homes and FireSmart practices that could be adopted before the risk of future losses can begin to decline. This innovative communication technique would be helpful in achieving that desirable outcome.

7. Conclusions

This investigation into the reasons why some homes survived the wildland/urban interface fire at Fort McMurray, while others were vulnerable to ignition and destroyed led to a wide array of conclusions. While some conclusions are based solely on data gathered from a representative sample of home survival/loss situations using well-established criteria, others are based on insights gained during days of intensive field enquiry, and grounded in expert opinion and review of scientific literature.

Regardless, it is hoped that each of these conclusions will facilitate well-informed decisions by homeowners and building managers responsible for taking risk mitigations to limit wildfire hazards in home ignition zones, and also motivate productive discussions among authorities having jurisdiction over risk reduction as well as civic administrators, and managers with responsibilities regarding public safety and fire protection policy, standards, regulations, or programs.

7.1 Home survival versus home destruction during the Fort McMurray disaster

Every form of investigation and analysis conducted to evaluate and explain reasons for survival of homes at Fort McMurray, regardless of the neighbourhood, location, or particular situation, arrived at the same conclusion: Homes which survived the wildfire with little or no damage were less vulnerable to ignition by the embers and heat of the wildfire than homes that ignited and burned, and that this was due to the absence or low level of rated hazard factors that contribute to structural ignition potential (i.e. hazard factors pertaining to vegetation/fuel management, the abundance of ignition sites, and structural features of the home itself). Home survival was not random.

This is the confident answer to the primary question posed by the Institute for Catastrophic Loss Reduction: *'Why did some homes survive this wildland/urban interface fire with little or no damage, while others were vulnerable to ignition and destroyed?'*

Stated another way, diligent implementation of well-known wildfire risk mitigations (i.e. recommended FireSmart guidelines) by property owners acting within their respective home ignition zones would greatly increase the probability that many more homes would survive future wildfire events, and that disasters could be largely avoided.

Finally, the author concluded that when the few apparent anomalies in home survival or destruction versus rated hazards were examined more closely, they were generally determined to be caused by peculiarities of the FireSmart hazard assessment system which resulted in either omissions or under/over-estimation of various hazard factors, rather than in failings of FireSmart principles or ineffective risk mitigation guidelines.

As an important footnote, it is emphasized that this study did not investigate the level of awareness or understanding of recommended FireSmart guidelines among local homeowners. Therefore, it cannot be assumed that low hazard ratings and FireSmart conditions on properties were the result of conscious wildfire risk reduction decisions and/or actions by residents. Low risk structures, uncluttered yards, and fire-resistant landscaping could be the result of other influences or preferences that are, coincidentally, also FireSmart by nature.

7.2 Causes of home ignition during the Fort McMurray disaster

Ignition of homes by radiant heat of the forest fire

Despite the intense behavior of the wildland fire at Fort McMurray, based on the known short duration of wildfire at any given point and adequacy of clearances that existed between wildland vegetation and the urban neighbourhoods studied, it is confidently concluded that, with very few exceptions, homes observed near the edge of the community did not ignite due to radiant heat produced by the forest fire. However, radiant heat transfer was sufficient to cause, and did cause, substantial damage to many homes.

Regarding the country residential area of Saprae Creek Estates, it is concluded that the ignition of a small number of outbuildings and several homes by radiant heat of the forest fire was quite probable, since clearances were not adequate in all locations.

Ignition of homes by contact with flames of the forest fire

Analysis at the perimeter of urban neighbourhoods studied during this investigation revealed that the width of non-fuel and light-fuel buffers located between the forest and homes were sufficient, in almost all cases, to prevent the ignition of homes due to direct contact by flames of the forest fire. Again, this conclusion is made with strong confidence.

In the case of the Saprae Creek country residential area, clearances between homes and the surrounding forest matrix were more variable, yet it was concluded that only a small minority of the destroyed homes investigated had potential to be ignited by direct contact with flames of the forest fire.

Ignition of homes by embers of the forest fire

Given the wildfire behavior that occurred, the ability of embers to be transported, and direct evidence provided by the presence of embers observed in urban and rural neighbourhoods, it is concluded that:

a) Homes at and near the forest interface would have been subjected to glowing and flaming embers generated by the approaching wildfire that ranged in intensity from moderate showers to intense inundation.
b) Embers would have been lofted by fire updrafts and transported onto the community by prevailing winds for a considerable time prior to arrival of the fire front at the perimeter of neighbourhoods.
c) Embers would have been transported onto the community from distances of hundreds, if not thousands, of metres in advance of the main (flaming) wildfire front.
d) The intensity of ember showers would have increased with approach of the wildfire front, and peaked upon arrival of the wildfire at the edge of the forest opposite urban neighbourhoods.
e) Embers accumulated into ‘drifts’ or piles wherever micro-sites and wind currents around homes dictated, thereby increasing their effectiveness as ignitors.

Considering the above, and taking into account supplementary evidence gathered regarding the density of live embers, the author confidently concludes that embers generated by the wildland fire caused the ignition of the large majority of homes burned at the urban margins of Fort McMurray neighbourhoods during early stages of the disaster, and the majority of homes in the Saprae Creek Estates country residential area.

Vulnerable sites for ember ignitions that led to home destruction

After careful review of all evidence observed and gathered during this investigation, it is the opinion of the author that home ignitions caused by embers were, in order of greatest frequency, the result of embers that initially landed upon and ignited:

a) Fuel comprised of ornamental or native vegetation and organic ground covers (i.e. cured grass or wood chip/bark mulch) located within Priority Zones 1 and 2 of home ignition zones.
b) Miscellaneous combustible objects (e.g. construction material, firewood, outbuildings, machinery, petroleum products, compost, furniture, and other stored materials) located in backyards, on decks, porches, and balconies, or elsewhere in home ignition zones.
c) Combustible structural elements of the home (e.g. decks, balconies, porches, fences).

7.3 Effectiveness of FireSmart principles and guidelines for reducing the risk of wildfire losses

Lack of confidence in the effectiveness of FireSmart risk reduction measures is often cited by homeowners and administrators as a prime reason why people fail to implement or advocate for them. The Fort McMurray fire was an ultimate test of the efficacy of recommended FireSmart guidelines.

Based on results of this investigation the author has concluded, beyond doubt, that recommended FireSmart guidelines demonstrated their effectiveness in reducing known hazard factors and proved to be valid under the harshest of wildfire conditions; they can be confidently relied upon[25] to reduce the risk of wildfire losses. The author also concluded that recommended FireSmart guidelines functioned successfully across the wide range of urban and rural situations that occurred in this disastrous fire.

As testimony to these conclusions, investigations in Fort McMurray neighbourhoods showed that:

- 81% of all surviving homes assessed during the study were rated as being within the 'Low' to 'Moderate' hazard levels, three-quarters of these being 'Low' hazard.
- 94% of the time the surviving home in matched (side-by-side) pairs was rated as being at lower risk than its burned counterpart, and by a rating differential of more than 30 points.
- All of the isolated homes that survived amidst heavily damaged urban neighbourhoods rated with 'Low' hazard, when untreated vegetation further than 30m from the home was discounted.
- All of the isolated homes that ignited amidst otherwise undamaged neighbourhoods were either rated with 'Extreme' hazard, or had a critical weaknesses that made them immediately vulnerable.

Based on these correlations, the author concludes that the absence or low level of known FireSmart hazard factors contributing to wildfire vulnerability is the logical reason for the survival of most homes studied in the wildland/urban interface at Fort McMurray. The unfortunate corollary to this is that the total number of surviving homes at Fort McMurray could likely have been far greater if there had been more widespread application of FireSmart risk reduction practises in home ignition zones[26].

[25] Nonetheless, revisions to the 2003 hazard assessment system are required to reflect current research, to better acknowledge the proximal role of embers as ignitors, and to fully incorporate new hazard factors linked to these.

[26] As advocated by the FireSmart Canada Community Recognition Program.

7.4 The WUI fire disaster sequence as it applies to the Fort McMurray fire

It is the author's conclusion that the Fort McMurray fire followed the pattern called 'the wildland/urban interface disaster sequence' (Calkin et al. 2014) or alternatively, 'the wildfire disaster cycle' (National Wildland/Urban Interface Fire Program, 2006). This pattern is well-known and also described by other researchers (Quarles et. al, 2010; Cohen and Stratton, 2008).

At Fort McMurray, the author has concluded that the wildland fire transitioned into urban areas when multiple, scattered homes located near the forest/urban boundary ignited, primarily from embers, to become starting points or nuclei for subsequent fire spread towards the urban core. These homes, very intense and long-lasting sources of heat, would most likely have ignited adjacent homes. Fire then continued to spread downwind, burning from structure to structure with increasing intensity as it moved through dense urban areas, even without the support of forest fuels. These fires would have grown rapidly in force and size as more structures became involved, eventually merging to become a widespread urban conflagration; a large, destructive fire that spreads beyond natural or artificial barriers in an urban environment, causing large monetary losses. As the urban conflagration rolled deeper into the community core, it would have accounted for the majority of the 2,400-plus structures that were destroyed during this disaster.

Figure 7-1: Effects of urban conflagration as it spread towards the urban core

The author has also concluded that this pattern of events was replicated in several locations, remote from each other, such as at Beacon Hill, Abasand Heights, and Wood Buffalo. In this regard, the events at Fort McMurray followed the classic 'wildland/urban interface disaster sequence' (see Figure 2-3) recognized from past disasters, and described in technical risk management literature.

From this, and from observations of urban enclaves that did not burn, the author further concludes that breaking the wildfire disaster sequence at its weakest point, by addressing the vulnerability of homes to ignition (i.e. the root cause of these disasters) should be the focus of future efforts to resolve the wildland/urban interface fire problem.

7.5 Importance of a holistic approach to wildfire risk reduction for residential homes

The author concludes that home survival is a 'cumulative' issue, in that it relies on the net effect achieved by addressing the entire range of known FireSmart hazard factors. Mitigating each hazard factor contributes in a distinct way to a home's overall resistance to ignition by wildfire.

Conversely, the author also concludes that there is no single hazard factor, or subset of factors, that can override other vulnerabilities to ensure home survival during a wildfire event (i.e. a 'silver bullet'). The unfortunate consequence of this is that a single, critical weakness[27] (i.e. an Achilles' heel) can result in home destruction, even though all other FireSmart guidelines may have been adopted, and a home is rated at the 'Low' to 'Moderate' hazard level.

7.6 Relative significance of three categories of wildfire hazard

Vegetation/Fuel hazard categories

In this study, hazard factors in the vegetation/fuel category dominated as the most significant type of residential wildfire hazard. It was also noted, across the board, that the cumulative vegetation/fuel hazard points assessed against homes which survived averaged less than half the amount assessed to homes destroyed by fire.

From this, I conclude that up-scaled efforts to raise awareness and increase the motivation of wildland/urban interface residents to mitigate vegetation/fuel hazards are especially important, and likely to realize the greatest gains in reducing wildfire hazards in home ignition zones.

Ignition site and structural hazard categories

Whereas hazard ratings attributed to the structural features of the home were nearly equal for surviving and burned homes, it was observed that rated hazards in the ignition site category were noticeably greater for homes that ignited and were destroyed, than for surviving homes. While both hazard categories are vitally important, it was concluded that the general public must become more keenly aware of ignition sites and miscellaneous combustibles as crucial hazards, and that the profile of ignition sites should be raised among residents by organizations and agencies promoting wildfire risk reduction.

7.7 Spatial distribution of vegetation/fuel hazards with respect to homes

Priority Zones 1 and 2

Based on the results of this investigation, it is determined that between one-half and two-thirds of all hazard attributed to untreated vegetation/fuel was present within 30m of homes that were destroyed. It was also determined that ownership of this space is often shared between neighbours or by residents and adjacent land managers. This finding coincides with results of a recent study of homes rebuilt following wildfire/urban interface disasters at Kelowna, BC and at Slave Lake, AB (Westhaver, 2015) and similar American studies. Collectively, these investigations pinpoint the area within the home ignition zone where hazard is greatest and where risk reduction efforts by residents could be most effective.

Therefore it is concluded that, to be most effective, risk mitigation programs would place increased emphasis on urging residents to take actions to treat vegetation/fuel within the first 30m of homes (i.e. Priority Zones 1 & 2) and on facilitating cooperative action between neighbouring property owners to do the same.

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[27] Examples of critical weakness include ornamental juniper/cedar shrubs located within 5m of walls, eaves, windows, or decks; wood chip mulch against exterior wood siding or porches; vulnerable outbuildings near homes; firewood piled on or under decks.

Surface fuel

Regarding surface fuel, it was concluded that widespread presence of dried residential lawns and beds of wood chip and bark mulch provided highly receptive fuel beds, and that these sustained abundant ember ignitions resulting in significantly larger expanses of burned area within hundreds of home ignition zones. In turn, this exponentially increased opportunities for fire pathways leading to other, more concentrated sources of fuel, and eventual spread of fire to homes.

Priority Zone 3

Results of this investigation indicate that home survival and/or destruction does not correlate well with the amount or character of vegetation/fuel in Priority Zone 3 or to the degree of hazard attributed to it by the current hazard assessment system. Therefore, it was concluded that the FireSmart hazard assessment system (Partners in Protection, 2003) may be placing an inordinate amount of weight on vegetation hazard located within Priority Zone 3.

8. Recommendations

The following recommendations derive from findings of investigations conducted by the author at Fort McMurray, Alberta in May 2016. They do not pertain specifically to the disaster response, the Regional Municipality of Wood Buffalo, or to actions of Fort McMurray residents. Collectively, they are intended to promote more proactive approaches to the wildland/urban interface fire problem whereby homes, neighbourhoods and entire communities become increasingly adapted to wildland fire events and more resilient, when they do occur.

1. Increased emphasis on reducing the vulnerability of homes – Breaking the wildfire disaster cycle.

Three key conclusions from these investigations were that:

1) Very few homes were observed to ignite directly from the flames or radiant heat of the wildland fire due to sufficient clearance between the forest and homes.
2) Wind driven embers from the forest fire likely caused the majority of home ignitions near the urban perimeter which, in turn, likely triggered the massive urban conflagration and losses that followed.
3) Surviving homes near the urban perimeter were consistently rated with substantially lower wildfire hazard (i.e. exhibited FireSmart attributes) than nearby homes that ignited and were destroyed.

Therefore the leading recommendation of this report is that agencies and organizations with mandates or responsibility for public safety and/or fire protection shift their primary emphasis to proactive initiatives that target the root cause of the wildland/urban interface problem – homes that are vulnerable to ignition by embers. This should be accomplished by accelerating development and implementation of programs[28] which empower and engage home and property owners to take wildfire risk reduction actions where they are most effective, within the home ignition zone.

This is not to say that current approaches to community wildfire protection aimed at halting or extinguishing fire on public lands at or near the urban perimeter (i.e. fire response; development of fuel modification areas and fire guards) should be discontinued. These are essential tactics and must be continued. However, without precautionary actions by property owners to significantly reduce the vulnerability of structures to ignition, the likelihood of wildland/urban fire disasters is likely to continue.

2. Low-risk management of residential vegetation

Given the high relative proportion of hazard assessed or informally observed and attributed to factors linked to vegetation/fuel conditions within home ignition zones, it is recommended that a range of new educational initiatives and information products be developed specifically to raise the level of awareness regarding wildfire hazards associated with natural and ornamental landscaping and appropriate risk reduction solutions among residents of the wildland/urban interface, landscaping contractors, retail suppliers of landscape materials, and managers of urban parks and open spaces.

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[28] The fledgling FireSmart Canada Community Recognition Program, based on the proven and highly successful Firewise Communities USA program, is a leading example of one such program.

Furthermore, it is recommended that local municipalities and governments manage vegetation in public parks, green-belts, and around public buildings as 'demonstration sites' to model and promote low-risk landscaping alternatives to local residents.

3. Further study of the Fort McMurray wildland/urban interface fire disaster

The present investigation raised additional questions and identified the potential for learning other beneficial lessons from the Fort McMurray wildland/urban interface disaster. Therefore, it is recommended that:

- Research opportunities be provided for experts in social science and the human dimensions of wildland fire to conduct research assessing the state of knowledge of Fort McMurray residents about wildfire risks in urban areas and recommended FireSmart risk mitigations, levels of risk mitigation implemented prior to the fire, and attitudes towards these subjects prior to and following the disaster.
- Logistical regression techniques be applied to data collected during the present study to statistically determine the contribution of individual hazard factors to the overall hazard rating of homes and to the probability of loss or survival of homes.
- A wider scale spatial analysis be conducted to identify and correlate patterns of home survival and destruction with detailed information regarding behavior of the wildfire, attributes of adjacent wildland fuels, the location of homes in relation to topography and each other, known FireSmart hazard ratings, specific arrival times of the fire front at the perimeter of neighbourhoods, and known or estimated times of structural ignitions. This analysis may reveal more about the wildland/urban interface disaster sequence as it evolved at Fort McMurray, and nuanced tactics for interrupting it in the boreal region.
- Potential correlations between the age of homes, ages of combustible home attachments (e.g. deck, patio, porch, balcony, fences) and home survival or destruction be further explored.
- Possible correlations between home loss or survival and lot size, distance between adjacent homes, numbers of outbuildings on properties, overlap of Priority Zones on adjoining lots, and the number and location of adjacent homes that survived or were destroyed be investigated using existing aerial photographic information.

4. 'Fire Pathways' for better communicating wildfire risk and mitigations

The novel *'fire pathway'* approach for more effectively communicating wildfire risks, mechanisms of spread of fire towards homes, and the logic of wildfire risk mitigations was described in Section 6.

It is recommended that a project be mounted to refine, deploy, and manage the prototype 'fire pathway illustration' system so that this communication tool can be standardized, professionally produced, and made available across Canada and the United States as 'free-ware' to all government agencies, organizations, and other sponsors of wildland/urban interface education and risk reduction.

5. FireSmart Hazard Assessment System

Because it is possible that the current FireSmart hazard assessment system may be placing an inordinate amount of weight on vegetation/fuel in Priority Zone 3 (i.e. the area from 30m to 100m-plus from homes), it is recommended that more study be directed towards this issue and that the hazard assessment system be reviewed and revised accordingly.

More generally, it is recommended that an expert panel be convened to assess, update, and upgrade the current (2003) FireSmart hazard assessment system while retaining its original quantitative format, in order to incorporate new knowledge pertaining to:

1. The threat of ember ignitions and most recent knowledge of structural ignition mechanisms.
2. Critical clearances with regards to Priority Zone designations.
3. Flammability of exterior walls and building materials.
4. All aspects of vegetation flammability (e.g. ignitibility, combustibility, sustainability, consumability).
5. Hazards posed by the use of combustible ground cover (i.e. wood chips and bark mulch).
6. Risk posed by 'Achilles' heel' hazards within the home ignition zone.

6. Investigation of future wildland/urban interface disasters

This investigation resulted in important observations regarding home survival and destruction, and improved insights into reducing the vulnerability of homes to ignition.

In order to increase the effectiveness of future investigations it is recommended that a formal wildland/urban interface 'Disaster Analysis Team' be identified by April 2017, resourced, tasked to prepare investigative methods in advance, and readied for immediate deployment in the event that an authority having jurisdiction declares potential for a wildland/urban interface fire disaster anywhere in Canada. The Disaster Analysis Team should consist of 5 – 7 individuals with diverse expertise and experience spanning the disciplines of wildland fire behavior, structural ignition, WUI risk mitigation disciplines, data collection and analysis, and geographic information system technology.

7. Land Use planning, regulations, and building codes

It is believed that changes in land use planning, regulations, and building codes could help promote conditions on adjacent parcels of land that contribute to lowered potential for wildland/urban interface disasters – in some jurisdictions.

It is therefore recommended that Provincial and Municipal governments that administer lands within the wildland/urban interface[29] consider:

- Adjustments to land use planning and building development policy such that residential lot sizes are increased, amenities are arranged, and the amount of unoccupied 'open' space within new subdivisions is enhanced in order to reduce the potential for structure-to-structure fire spread, and to increase the ability for residents to appropriately manage their respective home ignition zones for low hazard rating.
- Enacting regulations to provide homeowners who have complied with recommended FireSmart guidelines on their own property but are placed at risk by wildfire hazards located on adjacent properties but within their Priority Zone 1 with some corrective recourse.

[29] Wherever fire-prone communities exist or high intensity surface fire or crown fire behavior can be anticipated.

- It is recommended that authorities responsible for national and provincial building codes and municipal bylaws acknowledge current research into structural vulnerability to ember ignition[30] and update building codes to strengthen requirements for increased resistance of homes and other residential structures to ignition by embers, radiant heat and flames of wildfire, and to decrease the potential for structure-to-structure fire spread and development of urban conflagrations – particularly in urban areas where structural densities are high.

All of the recommendations outlined above align with objectives expressed by the Federal Government and the Canadian Council of Forest Ministers in the original (2005) Canadian Wildland Fire Strategy and the subsequent 10-year update (2016).

[30] National Institute of Standards and Technology and the Insurance Institute for Business and Home Safety.

9. Summary

The outcomes of this investigation challenge many current misconceptions about the nature of wildland/urban interface fire, as well as past approaches to limiting its impact on our communities.

No, this fire was not, at least initially, an insurmountable force that rolled into, and over, an entire community like a smashing tidal wave. Primarily, it was millions of raisin-sized firebrands searching for places to carry on with combustion, and succeeding all too often. Yes, there are plenty of practical, easily applied remedies that ordinary residents can use to block the pathways that embers trigger; the vulnerable places where they take hold, and spread fire to our homes. Most certainly, a lot of homes did not ignite, and in the situations examined, survival was no accident. The means of making our homes and backyards less vulnerable to wildfire are codified as FireSmart® guidelines. This investigation showed again, that known solutions for reducing hazard do work – and that homeowners aren't helpless against wildfire.

Events at Fort McMurray displayed the classic phases of the 'wildland/urban interface disaster sequence'. Although they went mostly unnoticed, the fire also showed some promising signs of weakness but only locally, and too few. Those weaknesses were evident at homes, and groups of homes, where wildfire hazards had been dealt with well in advance making those properties more fire-resistant and allowing them to survive. This is a hopeful outcome.

In this regard and others, results of this investigation are in agreement with American case studies of wildland/urban interface disasters, and current scientific opinion pertaining to this problem. Today with many of the questions answered and a few pivotal lessons learned there is both evidence and optimism that the magnitude of future disasters can be reduced, if not avoided.

This investigation also came to conclusions about the importance of holistic solutions to wildfire risk reduction. For individual homeowners, this means addressing the full array of hazards that surround their home especially those relating to vegetation, not just structural attributes. In neighbourhoods, this means recognizing risk benefits adjacent fire-resistant homes can provide to each other.

These led to recommendations urging agencies and organizations with responsibility for public safety and/or fire protection to shift primary emphasis to proactive initiatives that target home vulnerability by accelerating development and implementation of programs[31] which empower and engage home and property owners to take wildfire risk reduction actions where they are most effective, within the home ignition zone.

Other, supporting recommendations are also included in the report regarding: important research follow-ups to the current investigation; a novel method for communicating wildfire risks and solutions using illustrated 'fire pathways'; improving the existing FireSmart hazard assessment system and ways of investigating future interface disasters; and changes to land use and building codes.

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[31] The fledgling FireSmart Canada Community Recognition Program, based on the proven and highly successful Firewise Communities USA program, is a leading example of one such program.

10. Literature cited

Beverly, J.L and P. Bothwell. (2011). Wildfire evacuations in Canada 1980 – 2007. Natural Hazards 59: 571-596.

Beverly, J.L, P. Bothwell, J.C.R. Connor and E.P.K. Herd. (2010). Assessing the exposure of the built environment to potential ignition sources generated from vegetative fuel. Intern'l J. of Wildland Fire. Vol. 19, Issue 3, pp 299-313.

Butler, B.W., J. Cohen, D.J. Latham, R.D. Schuette, P. Sopko, K.S. Shannon, D. Jimenez, and L.S. Bradshaw. (2004). Measurements of radiant emissive power and temperatures in crown fires. Can. Jour. of For. Res. 34: 1577-1587.

Calkin, D.E, J.D. Cohen, M.A. Finney, and M.P. Thompson. (2014). How risk management can prevent future wildfire disasters in the wildland-urban interface. Proc. Natl. Acad. of Science. U.S.A. 111, 746-51.

Canadian Council of Forest Ministers. (2016). Canadian Wildland Fire Strategy: A 10-year review and renewed call to action.

Caton, S.E., R.S. Hakes, M.J. Gollner, D.J. Gorham, and A. Zhou. (2016). Review of pathways for building fire spread in the wildland urban interface part I: Exposure conditions. Fire Technology. Published online. Springer Science + Business Media. New York.

Cohen, J.D. (2000). Examination of the home destruction in Los Alamos associated with the Cerro Grande fire. U.S.D.A., Forest Service, Rocky Mountain Research Station. Missoula Fire Lab, Missoula, MT.

Cohen, J.D. (2004). Relating flame radiation to home ignition using modeling and experimental crown fires. Can. J. For. Res. 34: 1616-1626.

Cohen, J.D. (1995). Structure ignition assessment model (SIAM). USDA For. Ser. Gen. Tech. Report PSW-GTR-158. P. 85-92, IN: The Biswell Symposium: Fire Issues and Solutions in the Urban Interface and Wildland Ecosystems.

Cohen, J.D. and R. Stratton. (2003). Home destruction within the Hayman fire perimeter. In: Graham, R.T., Technical Editor. 2003. Hayman fire case study. Gen. Tech. Rep. RMRS-GTR-114. Ogden, UT. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 396 p

de Groot, W.J., M.D. Flanigan & A.S. Cantin. (2013). Climate change impacts on future boreal fire regimes. Forest Ecology and Management. 294 (2013) 35 – 44.

Dittaro, Mike. (2008). Funding your community wildfire protection project. Protection Branch, BC Ministry of Forests and Range. In: Wildland/Urban Interface Fires, Fuel Management, and Ecosystems, conference proceedings. Columbia Mountains Institute. Cranbrook, British Columbia. Personal Comm.

Ellis, P. and A. Sullivan. (2004). The significance of urban fuels. Client report for Fire Management Unit, Department of Urban Services, Australia.

Flannigan, M.D., A.S. Cantin, W.J. de Groot, M. Wotton, A. Newbery & L.M. Gowman.. (2013). Global wildland fire season in the 21st century. Forest Ecology and Management. 294 (2013) 54-61.

Flannigan, M.D., K.A. Logan, B.D. Amiro, W.R. Skinner & B.J. Stocks. (2005) Future area burned in Canada. Climatic Change 2005(72):1-16.

Forestry Canada Fire Danger Group. (1992). Development and structure of the Canadian forest fire behavior prediction system. Information Report ST-X-3. 63p.

Fuglem, Peter. (1993). Personal communication. March 10, 2004.

M.J. Gollner, Hakes, R., Caton, S., and K. Kohler. (2015). Pathways for building fire spread at the wildland urban interface. Final Report. Fire Protection Research Institute. Quincy, MA.

Graham, R. (Project Leader). (2011). Fourmile Canyon fire preliminary findings. USDA, Forest Service. Rocky Mountain Research Station. Revised October 12, 2011.

Hakes, R.S., S.E. Caton, M.J. Gollner, and D.J. Gorham. (2016). A review of pathways for building fire spread in the wildland urban interface part II: Response of components and systems and mitigation strategies in the United States. Fire Technology. Published online. Springer Science + Business Media. New York.

Institute for Business & Home Safety (IBHS). (2007). Mega Fires: The case for mitigation, the Witch Creek wildfire. Tampa, FL. 46p.

Johnston, Lynn M. (2016). Mapping Canadian Wildland Fire Interface Areas. MSc thesis. Department of Renewable Resources. University of Alberta. 161 pgs.

Marenghides, A. and W. Mell. (2009). A case study of a community affected by the Witch and Guejito fires. NIST Technical Note 1635. U.S.Dept. of Commerce. Nat'l. Inst. of Standards and Technology.

Moore, R., Cohen, J.D. and R. Stratton. (2008). Home destruction examination – Grass Valley fire. Report R5-TP-026b. U.S. Department of Agriculture, Forest Service.

Moritz, M.A. and S.G. Knowles. (2016). Coexisting with fire: Promoting the right kind of fire – and smarter development- is safer and more cost-effective than fighting a losing battle. American Scientist, Vol 104. July.

National Fire Protection Assoc. (2013). 1144 Standard for Reducing Structure Ignition Hazards from Wildland Fire. Quincy, MA.

National Wildland/Urban Interface Fire Program. (2003). Firewise communities workshop: Participant workbook. Second edition. Batterymarch Park, Quincy, MA.

National Wildland/Urban Interface Fire Program. (2006). Firewise: Community solutions to a national problem. Firewise Communities. 61p.

Partners in Protection. (2003). FireSmart: protecting your community from wildfire. Second edition. Capital Color Press Ltd. Edmonton, Alberta.

Quarles, S.L., Y. Valachovic, G.M. Nakamura, G.A. Nader, and M.J. De Lasaux. (2010). Home survival in wildfire-prone areas: Building materials and design considerations. University of California, Agriculture and Natural Resources. Publication 8393.

Rissel, S. and K. Ridenour. (2013). Ember production during the Bastrop Complex fire. Forest Management Today. Vo. 72, No. 4. Texas.

Safford. H.D., D.A. Schmidt, and Chris H. Carlson. 2009. Effects of fuel treatments on fire severity in an area of wildland-urban interface, Angora fire, Lake Tahoe Basin, California. Forest Ecology and Management.15p.

Scott, J.H. and E.D. Reinhardt. (2001). Assessing crown fire potential by linking models of surface and crown fire behavior. Res. Paper RMRS-RP-29. Fort Collins, CO. U.S.D.A., For. Serv. Rocky Mtn. Res. Stn.

Walkinshaw, S., D. Schroeder, and G. Hvenegaard. (2012). Evaluating the effectiveness of FireSmart priority zones for structure protection. Proj. Note, Jan. 2012. FP Innovations, Wildfire Ops. Hinton, AB.

Wang, X., D. Thompson, G. Marshall, C. Tymstra, R. Carr & M. Flannigan. (2015). Climatic Change (2015) 130:573-86.

Wildland/Urban Interface Working Team. (2006). Assessing wildfire hazards in the home ignition zone. Student Workbook. Natl. WUI Fire Program. Firewise Communities; NFPA. HIZ-SWB-2006.

Wilson, A.G. and I.S. Ferguson. (1986). Predicting the probability of house survival during bush fires. J. of Environmental Management. 23, 259-270.

Appendix 1: Field Data Collection Forms

Date:
Form#:

FireSmart: Rapid residential hazard assessment form

District: Street name: House #:

Factor		Characteristics and point ratings					Case:
Structure							
1	Roofing material	Metal, tile, asphalt, ULC rated shakes; non-combustible		Unrated wood shakes			
		0		30			
2	Roof cleanliness	Non-combustible material	Scattered material <1cm		Clogged >1cm deep		
		0	2		3		
3	Building exterior	Non-combust.	Log, heavy timber		Wood, vinyl, shakes		
		0	1		6		
4	Eaves, vents and openings	Closed; screened	Closed; not screened		Open; unscreened; debris		
		0	1		6		
5	Balcony, deck or porch	N/A; fire resistant/ closed	Combustible/closed in		Combustible; not closed		
		0	2		6		
6	Window and door glazing	Tempered	Double pane		Single pane		
			Sm/med	Large	Sm/med	Large	
		0	1	2	2	4	
7	Location of combustibles	None or >10m from structure		<10m from structures			
		0		6			
8	Setback from edge of slope	Adequate		Inadequate			
		0		6			
8a	Ember accumulators	None to few	Moderate		Abundant		
		0	5		10		
Priority Zone 1 (0 – 10m) and Priority Zone 2 (10 – 30m)							
9	Forest Overstory	Deciduous	Mixedwood		Coniferous		
					Separated	Continuous	
	PZ-1	0	30		30	30	
	PZ-2	0	10		10	30	
10	Surface Vegetation	Lawn; non-combust.	Wild grass or shrubs		Dead/down woody		
					Scattered	Abundant	
	PZ-1	0	30		30	30	
	PZ-2	0	5		5	30	
11	Ladder fuel	Absent	Scattered		Abundant		
	PZ-1	0	10		20		
	PZ-2	0	5		10		
Sum							
Priority Zone 3 (30+m)							
12	Forest Overstory	Deciduous	Mixedwood		Coniferous		
					Separated	Continuous	
		0	15		15	30	
13	Surface Vegetation	Lawn; non-combust.	Wild grass or shrubs		Dead/down woody		
					Scattered	Abundant	
		0	5		5	15	
14	Ladder fuel	Absent	Scattered		Abundant		
		0	5		10		
15	Slope	0-10%	10 – 25%		Dead/down woody		
			Even	Gullied	Even	Gullied	
		0	4	5	8	10	
16	Slope position	Valley bot.m/lower	Mid-slope		Upper slope		
		0	3		5		
Hazard Levels: LOW = 0-42 MOD = 43-58 HIGH = 59-70 EXTREME = 70+							

FireSmart: Rapid residential hazard assessment form (p. 2)

Photograph #'s:	
Address:	

Adjacent forest/wildland fuel	
FBP Fuel Type	Fuel Height
Distance: Home to Fuel Patch	Fuel Patch Size (ha.)
Azimuth to Fuel Patch	Dominant species
Wind Dir'n. at Time of Fire	Fire type closest to home
Forest Density	Length of perimeter burned
% perimeter with crown fire	% perimeter with Hi I Surf fire + Intermittent Crown fire:
NOTES:	

Home information			
Home Type	Home Age	Siding Type	Roof Material
Vent Types	Gable:	Soffit:	Roof:

Distance to Nearest Homes	Rt:	Lt:	Rear:	Front:
Outbuildings:	Number:	Dist: m	Burned:	FireSmart: Y / N

Attachments:	Balc:	Porch:	Deck:	Fence:	Other:

# of Adjacent Homes: max. 8	# Adj. Homes Burned:	# Homes in Burn Patch:
Combustible Fence Attached:	Burned to Home:	Charred/burned home:

DAMAGE REPORT: (full or part loss, which parts, severity, extent):

Fire Suppression Actions:

Fire behavior and impact of fire on vegetation and other combustibles

	Bare Ground	Mulch or Litter	Grass/ Forbs	Cw	B2	B1	A2	A1
PZ-1								
Ember Abundance (#/m^2)				–	–	–	–	–
Ember Damage Noted?	–				–	–	–	–
% Scorched	–							
% Burned	–							
% Coni /Dec Burn (100)	–	–						
Fire Spread to Home	–							
PZ-2								
Ember Abundance				–	–	–	–	–
Ember Damage	–				–	–	–	–
Veg Scorch %	–							
Veg Burn %	–							
% Conifer / % Decid.	–	–						
Veg Fire Spread to PZ1	–							
Miscellaneous combustibles								
Ember Abundance								
Ember Damage								
Scorch %								
Burn %								

Notes: (heat source for scorch, burn)

FireSmart: Rapid residential hazard assessment form (p. 3)

Form#:

District, street address:

Home Burned or Unburned? **Total Loss or Partial Loss?** **Not Paired – Only exposed with damage?**
Paired with other home? **Isolated Survivor?** **Country Residential or Dense Urban?**

General ember behavior			
Ember evidence obliterated by fire intensity?			
Did embers land and quench immediately?			
Did embers cause other combustibles to smolder?		Material:	
Did embers cause other combustibles to flame?		Material:	
Did burning combustible spread fire to contact home?		Combustible or non-combustible part of home?	
Did that part of home self-extinguish?		Part of home:	
Depth of Ember Accum. at junctions: cm	Ash only: cm	Ember only: cm	Ash + Emb: cm

Signs of Accumulation and Scorch on Surviving Home	
Roof	
Deck	
Balcony	
Porch	
Wall base	
Outbuildings	

Site diagram: (homes, streets, forest, wind, fire direction)

Fire pathway notes: (heat or ignition from fire, embers, homes) (vegetation or combustibles to home)

Appendix 2: Results for Less Common Home Survival/Loss Situations

Part I: Hazard distribution by hazard category for high exposure, isolated ignition, and isolated survivor situations.

Overall hazard was also broken down into its three component categories for properties located in the three other home survival/loss situations described in section 3.2. Results are summarized below.

Table A-1: Summary of hazard points awarded in special cases of home survival/ loss by hazard category

	Major Hazard Categories		
	Structural	**Vegetation/ Fuel**	**Ignition sites**
Homes resistant to high exposure			
Average Point Values for Surviving Homes	10	37	4
Range of Point Values for Surviving Homes	6 – 14	0 – 50	0 – 14
% of Total Hazard attributed to each hazard category	22%	71%	7%
N = 5			
Homes that ignited and burned in isolation			
Average Point Values for Homes Destroyed	20	38	8
Range of Point Values for Homes Destroyed	9 – 44[32]	0 – 98	0 – 16
% of Total Hazard attributed to each hazard category	31%	57%	12%
N = 5			
Isolated surviving homes			
Average Point Values for Surviving Homes	6	30	4
Range of Values for Surviving Homes	2 – 15	27 - 36	0 – 12
% of Total Hazard attributed to each hazard category	14%	75%	11%
N = 3			

Without exception, all hazard category totals for surviving homes were assessed with lower point values and averages than for homes that ignited and were destroyed.

Similar to paired urban and country residential homes, the average values for total hazard in all categories are lower for surviving homes than for burned homes. This is true even in Situations II and IV where homes survived the harshest of conditions and heat exposure without igniting. This appears to be particularly strong validation for the efficacy of recommended FireSmart guidelines in reducing the risk of wildfire losses. This result should provide motivation to residents who are wary of the benefits of risk mitigations, and help residents weigh mitigation benefits more realistically against other considerations.

[32] This high rating skewed, the result of a lone wood shingle roof (i.e. 30 pts.); the only combustible roof observed within the study.

Part II: Hazard distribution by hazard category for high exposure, isolated ignition, and isolated survivor situations.

Overall vegetation/fuel hazard ratings were also broken down according to Priority Zones for properties located in the three special situations, and results are summarized below.

Table A-2: Distribution of vegetation/fuel hazard by Priority Zone in special cases.

	Vegetation/Fuel Priority Zones		
	Priority Zone 1	Priority Zone 2	Priority Zone 3
Homes resistant to high exposure			
Average Point Values for Surviving Homes	2	1	22
Range of Veg'n/fuel Point Values for Surviving Homes	1 - 10	0 – 3	0 - 43
% of Total Hazard by Priority Zone	6%	26%	68%
N = 5			
Homes that ignited and burned in isolation			
Average Point Values for Homes Destroyed	20	9	12
Range of Veg'n/fuel Point Values for Homes Destroyed	0 - 50	0 - 25	0 – 30
% of Total Hazard by Priority Zone	53%	16%	31%
N = 5			
Isolated surviving homes			
Average Point Values for Surviving Homes	1	2	29
Range of Veg'n/fuel Point Values for Surviving Homes	0 – 3	2	25 – 31
% of Total Hazard in each Hazard Category	3%	6%	91%
N = 3			

The pattern noted in Section 4.4.2 was again very evident, and perhaps even stronger, in situations where unique or particularly harsh conditions had been experienced. Homes which ignited and burned in isolation correlated to home ignition zones with relatively abundant non-conforming vegetation within 30m of the home, and most importantly to substantial amounts of flammable vegetation within 10m of structures. Not surprisingly, each of the so-called 'miracle homes' that survived in neighbourhoods where virtually all other homes had been destroyed exhibited stringent compliance with FireSmart vegetation/fuel management guidelines.

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