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BC FIRESMART™ COMMITTEE'S QUICK-DEPLOY WUI TEAM

Data Collection Framework

PROJECT NUMBER: 301013731

This framework focuses on developing an approach for gathering data intended to improve our understanding of how fire spreads and structures ignite within the Wildland Urban Interface (WUI).

The resultant research will intentionally be limited in scope as the framework outlines a research approach that is limited in scope to focus on FireSmart treatments within the SIZ. As such, the resultant research will not include studies into the effectiveness of landscape level fuel management activities, community scale hazard abatement, or the effectiveness of wildland or structural fire control actions.

The framework addresses critical components of a research deployment in the WUI. Included are prioritized research questions, supported by a decision tree to aid researchers in identifying specific research priorities that are congruent with the opportunities presented by individual WUI wildfire incidents. Tools, methodologies, equipment, and logistics required to gather the requisite data and answer the research questions are provided within the framework.

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1 INTRODUCTION/BACKGROUND

To address the impacts of wildfires in the Wildland Urban Interface (WUI) area, FireSmart principles have been heavily advocated for in recent years. Numerous international studies have shown that these guidelines, when applied by property owners within the Home Ignition Zone (HIZ)[1], are effective at reducing home loss, even in the most extreme wildfire conditions (BC FireSmart Committee, 2020). The basic premise of the guidelines is that proactive changes to the environment that have impact on one or more parts of the fire triangle can lead to less adverse outcomes from wildfires within the WUI. FireSmart has been identified as the most cost-efficient way to mitigate the loss of homes and create wildfire resilient homes (BC FireSmart Committee, 2020). Despite this, adoption of the FireSmart principles by BC homeowners remains low.

An incomplete body of empirical knowledge exists related to how a wildfire moves into a community, what materials ignite causing a structure to burn, and how fire further spreads within a community. To date, research has primarily relied on post-fire case studies to understand pathways to structural ignition. Despite this data, a knowledge gap still exists related to how to best increase the probability of a structure surviving.

BC FireSmart and the BC Wildfire Service (BCWS) have determined that data collected before, during, and after a wildfire impacts a community could be used to identify the effectiveness of fuel treatments and structural vulnerabilities. It is believed that obtaining this knowledge and its broad communication will contribute to greater public confidence and uptake in FireSmart practices. It is further expected that increasing knowledge of structural ignitions will improve existing risk reduction guidelines, thus enhancing the value to homeowners of adopting FireSmart principles. This could potentially lead to changes in building codes and community by-laws that increase a structure's and a community's resilience to wildfire.

The BC FireSmart Committee and the BCWS approached FPInnovations to develop a framework that can be used to support researchers in gathering empirical data during WUI events. The framework is intended to guide data collection methods, logistics, and the resources needed to facilitate the collection, storage, and eventual analysis of the data collected during a WUI fire.

Summer 2021 was the first fire season attempting data collection during a WUI event, and there was many learning experiences and thus changes to the methodologies and processes of data collection, but this is not a one-year undertaking. The relationship with the BC FireSmart Committee is expected to last many years, thus allowing for improvements or changes to what is learned in the first year.

The Institute of Catastrophic Loss Reduction (ICLR) produced a comprehensive report that identified 31 questions, that – if answered – would contribute to the knowledge base of how fire spreads, ignites structures, and progresses though a community (see APPENDIX II). These questions helped guide the development and focus of the methodologies for data collection.

[1] Home Ignition Zone (HIZ) is the area from and including the structure out 30 m.

The data collection has been broken down the into four categories: fuels, fire behaviour, structure vulnerabilities, and neighborhood characteristics. Appropriate methods intended to collect as much data as quickly as possible have been identified. The first half of this framework presents the methodologies for data collection to be used when a WUI wildfire incident occurs. The remainder of the framework will focus on logistics, dispatch, the Incident Command System (ICS), on-scene communications, team qualifications, fireline safety, and privacy issues.

This Framework has been revised based on experience and insights gained by the Research Group while deployed to the following Wildfires over the 2021 fire season:

- Sparks Lake Fire (K21001) July 3 – 8, 2021 (two different locations)
- Embleton Mountain Fire (Whitecroft) (K21644) July 13 – 14, 2021
- Tremont Creek Wildfire (K21849) July 14 –16, 2021
- Octopus Complex (K51800) July 21 – 24, 2021
- White Rock Lake Wildfire (K61884) August 11 – 13, 2021.
- Tremont Creek Wildfire – Cherry Creek

2 OBJECTIVES

The objective of this document is to develop a framework that can be used to guide a quick-deploy research team to safely, effectively, and efficiently gather data to further the understanding of the efficacy of FireSmart treatments and the exposure of structures during WUI events. The goals for data collection are to execute on:

1. Research that can be conducted before a wildfire enters the WUI.
2. Research that can be conducted concurrently while the WUI is being impacted by wildfire.
3. Research that can be conducted once the wildfire threat has decreased.

3 RESEARCH QUESTIONS

3.1 Prioritised Questions

The ICLR document puts forward a list of questions where the answers would contribute to understanding how fires spread into, ignite, and then spread within the FireSmart Home Ignition Zone (HIZ). Collecting data to answer these questions will contribute to identifying specific issues that may be addressed through education or changes to construction practices that could increase the probability of structures surviving an interface fire.

APPENDIX II APPENDIX IIAPPENDIX IIAPPENDIX IIlists the research questions. They were developed following literature reviews and through consultations with relevant experts (ICLR document Appendix II). The questions are broken down into four categories: vulnerability, exposure, fire progression pathways, and ember influx. These questions were arranged on importance and the feasibility of answering them using subject expertise and data collection methods.

3.2 Approach

The framework for quick-deploy data collection incorporates appropriate methods based on the amount of time available before a wildfire impinges on a community or structures. It presents a step-by-step methodology to document the hazards associated with vegetation (fuels), individual structures, and community arrangement. It includes data collection before, during, and after the fire has moved through the area in question. This qualitative approach is to collect as much data as possible before and after the fire, use the data to construct a case study of the event, and potentially identify key elements that will contribute to our knowledge of how fire enters and spreads within an interface area. Following year one of data collection, it was found that the higher probability of data collection will occur on single structures or acreages. The methodology presented in this Framework was initially developed for use in subdivisions, small communities, and towns. When using this Framework to determine data collection methods and time approximations use the methods for 'structure data collection' and when using the RPAS, the smallest study areas and flight altitudes.

3.3 Risks

Many variables can influence and complicate data collection during a wildfire incident. A list has been compiled of pre-identified risks that can affect data collection so researchers can take proactive actions to reduce the impact of these occurring. These have been broken into three categories: logistical, environmental, and equipment.

Logistical issues

- Time of initial call out
- Crew availability at the time of an incident
- Data collection time available before fire arrives
- Number of research crew on site
- Crew's ability to access to structures
- Incident Management Team (IMT) personnel not available to liaise with FPI staff and provide site orientation
- Delayed or lack of permission to enter site from IMT
- Firefighting activities in same area potentially rendering the data useless (structures protected or water damage on equipment)
- Jurisdictional issues

Physical Environment issues

- Size, layout, and geography of area: all affect time to set up and collect pre-fire data
- Weather: wind speeds, smoke
- Extreme fire behaviour

Equipment issues

- Battery issues with UAV
- UAV crash
- Camera issues with UAV
- Battery issues with in-fire cameras

- Firefighting water lands on sensors and dataloggers
- Equipment damaged by fire
- Possible theft of equipment when left on scene – addressed in 2021 Year-end Report

4 METHODOLOGIES

4.1 Overview

This framework will apply a wholistic, mass data collection approach to the development of a quick-deploy data collection program to be applied prior to an imminent WUI fire, during fire encroachment of a community, and in the aftermath of the fire passage.

Data collection at a WUI fire should document the following elements:

- Fire weather
- Fire behaviour
- Vegetative fuels
- Structural fuels

Some data collection processes are well established and need few improvements, e.g., fire weather monitoring is typically conducted by a wildfire management agency or an IMT. One innovation that can augment a typical data set is the strategic placement of lightweight weather sensors to record site-specific weather values at more frequent time intervals. This can provide valuable insights into post-fire analysis of how changes in wind speed or direction may have influenced the progression of a fire.

An optimum fire behaviour data collection process would capture video to demonstrate how primary ignition mechanisms (firebrand accumulations or radiant heat from an encroaching fire) initiate structure ignition. Attempts will be made to place cameras in the anticipated path of an encroaching fire front. However, there is no guarantee of collecting useable data from the cameras due to the erratic nature of fire spread rate, direction, and visibility. Therefore, it will be critical to focus time and resources on methods that will reliably provide viable data. These methods include remotely piloted aircraft system (RPAS) imagery, ground-based imagery, and visual assessments.

Robust fuel and structure assessments will be the primary focus of the quick-deploy data collection program to evaluate how different fuel factors contribute to structure ignition and loss. Both vegetative and structural fuels within a structure ignition zone will be documented through multiple processes.

Emphasis in this data collection program will be on collecting as much pre-fire data as possible and comparing this with post-fire data. A comparative analysis of pre-fire and post-fire data will be a key element of a data analysis framework.

Availability of researchers and equipment resources at the time of a WUI wildfire occurrence represents a practical constraint on ability to gather meaningful data. As a minimum, to effectively deploy and capture data, three persons are required: an RPAS pilot; a researcher to collect still, video, and 360° photographs; and one person to begin setting up the in-fire cameras. It is anticipated that other researchers would arrive to assist in post-fire documentation.

The methodologies presented below are based on the following equipment constraints:

- 20 in-fire cameras
- Four RPAS units (preferably two flying at once)
- Three 360°-degree cameras

Communications with the IMT will be critical. Specifically, engagement with the Fire Behaviour Analyst (FBAN), also called the Wildland Fire Behaviour Specialist, is required to identify the anticipated point of entry where fire may move into a community and thus focus data collection activities. It is probable that data collection and structure protection activities will focus on the same areas; if this is the case, structural protection measures take priority. Pre- and post-fire data may be collected in these areas, but the placement of equipment to collect data during the fire may not be possible. In this situation, communication with the Structural Protection Specialist (SPS) will be important to determine where equipment placement can be made. During the Sparks Lake deployment the Research Team worked closely with the SPU crew and thus were there during sprinkler setup and could place our cameras outside the wetting range.

The following data collection processes will be used to describe the vegetative fuel environment and structural fuel components:

- RPAS imaging
- Ground-based imaging
    - 360°-degree imaging
    - Imaging to document specific fuel elements of concern
    - 360°-degree video with spoken commentary for structure assessments and fuel characteristics
    - Video from in-fire cameras
- Visual assessment of the structure ignition zone

In addition to the processes applied for documentation of structural and vegetative fuels, these data collection procedures will be implemented to document fire behaviour, fire chronology and progression, and fire weather.

4.2 Researcher Assignments Upon Arrival

Upon arrival at the scene of an incident, the following assignments and number of researchers will be used, until circumstances change the configurations:

- Liaison specialist – one researcher
- RPAS operations – two researchers
- Ground-based imagery collection in HIZ and NCZ – two researchers
- Equipment placement – one researcher

The liaison specialist will work with Scene Management to identify the most probable study area and then maintain constant communication. There will be three potential RPAS pilots, and two can begin flying missions. Two researchers will start ground-based data collection. The researcher tasked with equipment placement will work closely with the liaison specialist to identify best locations. The SPS liaison dedicated to the team can assist researchers in ground-based data collection or by helping to place in-fire cameras.

This generalised list is based on all researchers being on site. The number of researchers per task will vary, depending on how many researchers are on site. It is based on data collection in neighborhoods and subdivisions. Group configurations will change if single structures or acreages are the research areas. Two or three researchers can be used in these instances.

Ignition Assessment System (IAS)

The IAS is a module of six components, outlining a wide range of data that may be gathered during a WUI fire in order to address many outstanding questions and knowledge gaps related to the ignition hazards and ignition vulnerability of homes typically associated with catastrophic losses. It consists of forms that allow researchers to quantify the exposure from wildfire at the community, neighborhood, and structural levels.

The methodologies presented below incorporate the ability to collect the data required to quantify the exposures. The methods will allow the researchers to quickly collect data (video, photographs) that can be used after the incident to complete the IAS forms.

4.3 RPAS Imaging

RPAS imaging has been identified as the most efficient way to gather large volumes of data in the form of images/video for a broad area of interest. RPAS can be flown at different altitudes to capture the information required to achieve different objectives, e.g., a Remotely Piloted Aircraft (RPA) can be flown low to collect individual images of specific structures to identify the fuels in the immediate ignition zones adjacent or touching the structure. Low-altitude flights can document specific structural features, including gutters, vents, windows, etc., where ignitions are suspected to occur. To capture wildland fuels information, the RPA can be flown at a higher altitude to capture forest stand characteristics on a larger scale and potentially identify pathways a fire may follow. Higher-altitude images can also provide an overview of the entire neighbourhood. Programmed flights can be utilized to ensure that identical photos are taken following a fire event for comparison purposes. Areas as large as 100 hectares can be captured in an hour and a half, depending on user requirements. Larger areas captured in a shorter period compromise image resolution since the flights need to be conducted from a higher altitude. RPAS data collection will be broken down into three categories focusing on imaging of each of the following: neighbourhood, wildland fuels, and structures. Ideally, two researchers will pilot two RPAS units to maximize data collection.

4.3.1 Neighbourhood Data Collection

RPAS Oblique Photos Mission:

An oblique photos mission will fly a waypoint mission to collect repeatable, oblique photos before and after the fire. A repeatable, programmed mission will ensure that photos are taken at the same coordinates, altitude, and orientation. The following guidelines have been developed for this data collection process:

- 60 m flight altitude and -20° gimbal angle provide good field of view and image resolution suitable for neighbourhood coverage.
  - Other angles and altitudes can be programmed into the flights if needed.
- Make sure to focus and then set to manual focus before starting mission, so that it does not search for focus during the flight.
- In the DJI pilot app, if the mission fails to take any photos, modify the mission to include a hover at each waypoint for 10 to 20 seconds and manually press the shutter button; all other mission settings seemed to work during the tests.

Troubleshooting skipped photos:

1. Calibrate IMU
2. Calibrate compass
3. Reset camera and gimbal settings; do not forget to restore any necessary settings
4. Change SD card and do a full format on the computer (do not do a quick format, as this does not isolate damaged parcels)
5. Format the SD card again inside the RPAS, so it sets up the proper file folder system.

Oblique photo checklist based on time available:

1. >24 hours available – early arrival
   a. Oblique photos of first 4 streets of the area suspected to be breached by wildfire. The area should be expanded as time allows, if the >24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible.
2. <24 hours available – late arrival
   a. Oblique photos of first 2 streets of the area suspected to be breached by wildfire. The area should be expanded as time allows, if the <24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible.

RPAS Mapping Missions:

Mapping missions will follow a hierarchical list that expands the area to be mapped with available time before fire impingement. A high-resolution stitched orthomosaic map can be used for identifying fuels and hazards near structures. Furthermore, the periphery of the photos can be used to identify fuel structure and potentially material types on the sides of houses. At higher altitudes, image resolution may not be adequate in identifying specific structural elements or vegetative fuel features.

The stitched orthomosaic images can be used in conjunction with GIS software (QGIS, ArcMap, ArcGIS Pro, etc.) to measure distances and in some cases create 3D models of structures and forests. Wildland fuels may be evaluated using other software to determine stand height, tree density, and potentially other stand characteristics.

None of the RPAS currently owned can fly directly over individuals while in flight. They can fly within a 5m horizontal distance, thus from a 60 m altitude it should be easy to spot and avoid any personnel not involved in the operations due to increased field of view of the flight area. This would not be an issue if flying over evacuated areas.

Mapping mission checklist based on time available:

1. >24 hours available – early arrival
    a. Map the first 4 streets of the area suspected to be breached by wildfire. The area should be expanded as time allows, if the >24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible.
2. <24 hours available – late arrival
    a. Map the first 2 streets of the area suspected to be breached by wildfire. The area should be expanded as time allows, if the <24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible.

RPAS Mapping Time Estimates:

Time estimates were calculated for the DJI Phantom 4 Pro V2, using distance interval mode in the DJI Pilot app. Another capable app to use is the Drone Deploy mapping app; it is free to use with a free account but stitching of the images requires a subscription. In Table 1 the highlighted altitudes provide a good compromise between image resolution and the time to complete the mission and are recommended in most situations. The pilot should choose the altitude based on available time and desired resolution. The time includes 80% frontal overlap and 70% side overlap, adds 25% to the time for enhanced 3D image capture, and adds 10% to the time for battery changes. Altitudes lower than 60 m can be chosen but pilots must remain cautious of changes in elevation and tall objects. The 60 m altitude should be utilized, when possible, as it provides excellent resolution and better 3D stitching reconstructions.

Table 1. Times for mapping areas of varied sizes, shaded area is the recommended altitude

Area (ha)	Altitude (MAGL)	GSD (cm/pixel)	Time to complete (h/min)
100	**120**	**3.29**	**1:13**
	100	**2.74**	**1:27**
	80	**2.19**	**1:47**
	60	**1.64**	**2:19**
50	**120**	**3.29**	**0:38**
	100	**2.74**	**0:43**
	80	**2.19**	**0:53**
	60	**1.64**	**1:09**
25	**120**	**3.29**	**0:22**
	100	**2.74**	**0:24**
	80	**2.19**	**0:29**

Area (ha)	Altitude (MAGL)	GSD (cm/pixel)	Time to complete (h/min)
	60	1.64	0:38
10	120	3.29	0:9
	100	2.74	0:12
	80	2.19	0:13
	60	1.64	0:17

Most dispatches in 2021 focused on individual structures or acreages. The time required to fly these and would be similar to or less than flying 10 ha at 60 MAGL as highlighted in the Table above.

Beyond Visual Line of Sight (BVLOS) Missions:

Section 901.54 of the RPAS regulations requires that line of sight flight must be maintained with the unaided eye (pilot or observer). However, this means that a larger RPAS can be flown further from the pilot since it will be easier to see. Some RPAS may be lighter in colour and can blend into the sky more easily than others of the same size. It may be best to increase contrast of the airframe by painting or vinyl wrapping the airframe to a black, red, or orange colour for high contrast. Then the pilot can fly the RPAS to a greater horizontal distance and still fly within the line-of-sight regulations.

Transport Canada has established draft operational regulations that allow for Beyond Visual Line of Sight (BVLOS) flights through a Special Flight Operations Certificate (SFOC). The regulations and application procedure can be found below:

tc.canada.ca/en/aviation/drone-safety/fly-your-drone-beyond-visual-line-sight#toc3

Transport Canada states that their service standard for processing SFOCs is 21 calendar days. Therefore, approval for BVLOS flights should not be incorporated into potential flight plans. Research groups should attempt to obtain permission and pre-approval for BVLOS flights under certain conditions, but this should not be relied upon.

Flight within restricted wildfire airspace requires a Special Flight Operations Certificate (SFOC) which involves proper training and documentation. The SFOC allows for beyond visual line of sight flight and high flights between 400-2000 ft AGL only with a NOTAM for wildfire designated airspace or within 3 NM of an active fire with a visible smoke column. An agreement with the authority having jurisdiction (AHJ) is necessary for approval in addition to proper documentation of emergency, maintenance, recording, training, and communication procedures.

Site assessments must account for errors, worst-case scenarios, and include all items of concern within the area the RPAS can fly to from the take off location. Furthermore, the assessments need to consider what would happen if the pilot were to lose connection to the RPAS or the RPAS were to lose GNSS connection for automated flight missions.

The SFOC allows for flight in atypical airspace that is usually found around an active wildfire. Risk to the public is generally low for RPAS missions in these areas due to control in both the air and on the ground by the responding agencies. Furthermore, these areas are usually evacuated or have limited access. Flights under the SFOC still need to comply with RPAS regulations that are not specifically given an exemption from the SFOC. The approval process for an SFOC needs to be completed annually and can be updated upon renewal. The SFOC allows for pre-approval of flights under the specified stipulations to streamline operations and increase response times for flying during incidents.

4.3.2 Wildland Fuels

An RPAS will provide a quick assessment of the vegetative fuels leading from the wildland area into the interface area. A higher altitude neighbourhood view will provide this data. These flights can start at lower altitudes for specific fuel characteristics and progress to higher altitudes to provide a view of potential pathways from the wildland into the community. These images can be compared to those collected from the ground to provide an accurate description of the fuel environment. Similar to the neighbourhood oblique photos, 60 m/-20° missions can be paired with additional nadir photos to get a good representation of the fuel environment. These areas can also be incorporated into mapping missions to determine some stand level characteristics through post-processing of the images. The images can be stitched together and create 3D models and point clouds for analysis.

4.3.3 Fuel Treatment Areas and Control

If there are fuel treatment areas in the projected WUI impingement zone, attempt to capture imagery for both the fuel treatment area and a control area (untreated natural stand adjacent to treated area). For small treatment areas, a single image may be sufficient. Otherwise, plan a flight path that will capture multiple images that can be stitched together. FPInnovations is currently undertaking work on a project investigating the efficacy of fuel treatments impacted by wildfire for the BCWS Prevention section. If possible, we would combine the data collection for both projects contemporaneously.

- See Table 1 above.

Fuels photo checklist based on time available:

1. >24 hours available – early arrival
   a. Map 10 ha of fuels along the area suspected to be breached by wildfire. Complete an oblique photo mission with 6 locations for angle and nadir photos. The area should be expanded as time allows, if the >24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible.
2. <24 hours available – late arrival
   a. Complete an oblique photo mission with 6 locations for angle and nadir photos. The area should be expanded as time allows, if the <24- hour minimum data collection requirements for other sections are fulfilled. Add 10 ha mapping mission if time allows. Increase collection zone extent by 50% at that time and expand other sections as possible.

4.3.4 Structures

An RPAS will be used to assist in data collection of the individual structures for FireSmart structure assessments – see APPENDIX III for a list of assessments that can be addressed with RPAS imagery of the structure. Testing has shown that 20 to 30 m is the ideal above-ground altitude to capture imagery for a backyard photo of a medium-sized house. This altitude provides adequate field of view to view most of the property while maintaining high resolution for assessment of materials and debris found on the property. Pictures should be collected from the front, back, and both sides. This process should take 1 to 2 min per property. For larger properties, altitude can be increased to up to 40 m, or additional photos can be captured to collect all the required fuel components. It is not recommended to go above 40 m, as the resolution decreases substantially, and the change in perspective flattens out any prominent features in the photos. Figure 1 shows examples of Field of View (FOV) in images captured from different altitudes taken with the DJI Phantom 4 Pro V2.

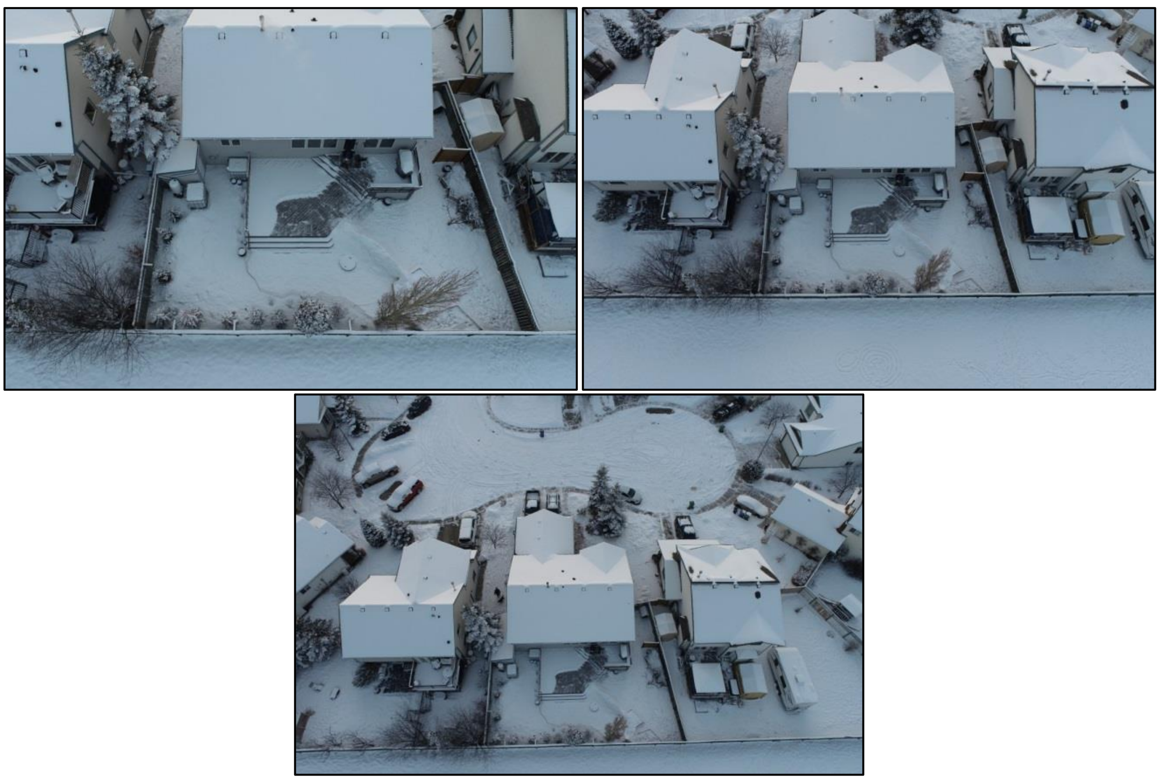


Figure 1. Clockwise from upper left – Structure reference photos taken from altitudes of 20 m, 30 m, and 40 m

APPENDIX III is a table showing the data that can be collected using different techniques. It identifies what can be collected by the RPAS and what would be left for the ground-based cameras to collect, thus increasing the efficiency of the data collection process.

Summary – Key Points

- Primary method for data collection. Most area covered in shortest time.
- Can be used for community, neighborhood, and structural data collection. Optimal altitudes for each listed and time per area estimates.

- Same methods used if arrival is early or late – just quantity of data changes.
- Reduces the amount of ground-based data collected when used.
- Ideally, two RPAS will be flying collecting data at the same time.

4.4 Ground-based Imaging

In most WUI incidents, time is of the essence and photo documentation processes will need to be pre-planned with different options available to respond to different scenarios. These options include aerial imagery and ground-based imagery with specific techniques available for each.

Documenting fuels in the structure ignition zone is critical to understanding how ignitions occur and which fuel elements (vegetative or other) create a pathway to structure ignition and which fuels inhibit fire spread. A simple, yet structured photo documentation of fuels will lend to efficient data collection, management, and analysis.

Ground-based imaging can supplement aerial imaging with more detailed photos. Ground-based imaging can replace aerial imaging when smoke conditions or air operations preclude flying an RPA. Ground-based imagery will include:

- 360°-degree imagery
- Detailed photo capture of specific structural and vegetative fuel elements using a pre-determined shot list.
- Video will also be a valuable tool to capture imagery at a property level in a short timeframe. A clear advantage of this technique is that details, such as site description and shot location, can be spoken into the video camera rather than recorded manually.
    - A disadvantage of video is that analysis and the snipping appropriate images will be more time-consuming than capturing still images.

Each of these photo documentation techniques has advantages and disadvantages with different scales of coverage and degrees of detail. Time will be the most critical limitation for capturing imagery, and drone imagery will be the first tool to be applied to cover the largest area in a short timeframe. It is expected that the high-resolution imagery of the drone camera will capture most larger vegetative elements. A greater level of detail and resolution may be required to capture smaller fuels, such as ornamentals, in the Non-Combustible Zone (NCZ). Aerial imagery may not adequately capture these elements since visibility may be obscured by smoke or vegetation may not be clearly visible in the flight path.

While ground-based imaging will be more time-consuming than aerial imaging, there will be greater flexibility in recording details that might be undetected by aerial imaging. Specifically, it will be critical to document fuels in the NCZ and other fuels that are suspected as a potential pathway to structure ignition. Greater detail can be captured in a ground-based survey.

A comparative analysis of pre-fire and post-fire imagery will be essential to determining an ignition mechanism (firebrands or encroaching fire front) and identifying fuels that were initially ignited and contributed to sustained burning and fire spread.

If the RPAS cannot be flown due to weather, smoke, or potential airspace conflicts, ground-based imaging will serve as an alternative. 360° cameras will be mounted onto an extendable pole that can elevate the camera up to 7 to 8 m above the ground. This will allow for similar site and structural characteristics to be collected, while still maintaining efficiency and reducing the number of metrics that need to be assessed in the field. The 360° cameras should still provide a vantage point that allows for identification of materials and rough estimates of distances. The Assessment Checklist (APPENDIX III) identifies what data collection methods are used, based on the ability of the RPAS to fly or not.

Structure photo checklist based on time available and method:

1. >24 hours available – early arrival
    1. Take pictures of structures on the first 4 streets while alternating structures collected to cover more area. The area should be expanded as time allows, if the >24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible. After 6 streets have been sampled in an alternating fashion, go back to the first street, and start filling in houses.
2. <24 hours available – late arrival
    1. Take pictures of structures on the first 2 streets while alternating structures collected to cover more area. The area should be expanded as time allows, if the <24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible. After 4 streets have been sampled in an alternating fashion, go back to the first street, and start filling in skipped structures.

Quick reference sheets are located in the Appendix for data collection using RPAS and ground-based data collection for fuels and structures. These outline briefly what and how to collect the data. APPENDIX IV is the quick-reference sheet for RPAS operations. APPENDIX V outlines fuels data collection, and APPENDIX VI concerns structure assessments.

A systematic approach to collecting ground-based photo data will be essential to cover high priority areas quickly and efficiently. A structured data collection process will lead to a more efficient data management system and effective comparative analysis of pre-fire and post-fire images. This applies for both still and video data collection. A cue card has been developed to assist with 360 video data collection of each structure (APPENDIX VI). It is organized to guide the researcher through all aspects that need to be narrated or addressed visually in the video starting from 30m away and up to the structure itself on each side.

Some fundamentals

- More detailed photo documentation may be conducted on properties in an area that has a high probability of wildfire encroachment or firebrand showers.
- Site identification: In the initial image for a series of photos for a house or property, include the house number or use a dry erase board to note the house or property number.
- For still images, use the horizontal photo orientation.
- When taking pre-fire images, envision potential pathways for ignition and record these elements. Are there obvious vegetative elements that will contribute to fire spread in Zones 1 and 2?

- Establish a structured approach to photo/video documentation.
  - Start the photo sequence looking at the primary structure from the street or the laneway of a larger property.
  - Work clockwise around the primary structure taking photos/video from each side looking toward the structure. This set of images should capture trees, shrubs, and grasses in the structure ignition zone.
  - Move in toward the structure to take photos of the non-combustible zone; take a photo from an oblique view from about 2 to 3 metres from the side of the structure.
- A photo/video documentation protocol should be a repeatable so that post-fire images accurately represent the same area as the pre-fire images.
  - Optimally, post-fire 360°-degree images and other photos should be taken from the same location as pre-fire photos. This will allow for more effective comparative presentation of pre-fire and post-fire images.
- For photo pairs, use a camera (smart phone) with the same focal length.
  - Attempt to return to the same location as the pre-fire photo. The location data will be available in the photo metadata or can be overlaid on an image. A hand-held GPS will be required to return to that location for a post-fire photo. This should get the photographer ±4 m from the original location.
  - If greater accuracy or alignment with the original location is required, view the original photo to line up the shot more accurately.

During ground-based data collection, it will be important to document specific hazardous fuel elements that will contribute to or inhibit fire spread. Examples of these fuel elements include:

1. Crown spacing and evidence of crown-to-crown fire spread
2. Ladder fuels and evidence of vertical fire spread in trees
3. Proximity of crown fuels to structures
4. Point of ignition to identify ignition mechanisms (firebrands or encroaching flame front)
5. Pathways to ignition: Fuel elements (vegetative or other) that support sustained burning and fire spread
6. Elements that inhibit fire spread
7. Vegetation composition in the NCZ. Include adjacent structural material.
8. Non-vegetative fuels, such as landscaping materials, wooden fences, vehicles

Summary

- Supplements RPAS data collection
- Combines fuels and structure exposure data
- 5 to 10 minutes per structure. Work 30 m out, then into structure.
- Quantity based on how much time. Data collection methods the same.
- Two researchers collect data

4.5 Fire Behaviour Evaluation

Fire behaviour data will be collected by instruments placed in and around the structures, video cameras aimed at structures, and street view video data. Observations made by others will also be collected. By describing the observed fire behaviour, we will attempt to put together a fire chronology and map the pathways the fire travelled into the community and how it spread through the community.

FPInnovations equipment to collect data during the fire includes:

- In-fire cameras
- Video: handheld and 360° cameras
- Tripods for cameras

Ideal camera locations include:

- Between structures
- Oblique street view of multiple structures (on street, not utility pole)
- View of structure and Zone 1a + more
- View of interface between vegetative and structural fuels
- View of vegetative fuels

Locations will be identified while on site for the specific placement of the cameras, as there are many variables. The goal is to collect data to be used to assist in the building of the fire chronology and the mapping of pathways by providing fire behaviour information.

4.5.1 Fire Chronology

Data collected by video cameras can be used to contribute to building a fire chronology. The data will be time-stamped, allowing the location of the fire to be known at exact times. Cameras placed in distinct locations and data from different sensors can then be used to draw fire progression maps, allowing to build a fire spread chronology. This data can be combined with overhead observations (Air Attack Officers, helicopters, tankers, etc.). These aerial platforms take time- stamped photos that can be used to add to the chronology.

4.5.2 Mapping of Pathways

Data collected during a fire's arrival into a community and within the community will be used, along with post-fire data, to determine the pathways of fire spread through the community. Fuels, both vegetation and associated with structures, will have been collected and will be used to identify possible pathways and then used to confirm using post-fire images.

Summary

- In-fire camera boxes placed, based on FBAN predictions of fire spread
- One researcher to install cameras
- General locations for cameras to start
- Many sources for chronology data can be collected post-fire

4.6 Structure Assessment

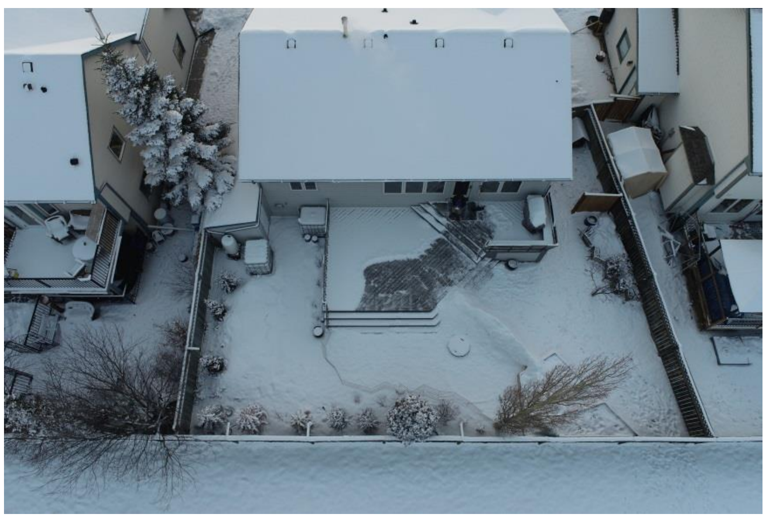
The approach to developing a methodology for data collection will be to follow the NFPA 921 guideline to be consistent with industry standards. Using the Scientific Method as defined within NFPA 921, the team will look to collect data starting with establishing pre-fire conditions as defined in NFPA 921 4.4.3.3 "*The use of previously collected data from a properly documented scene can be used successfully in an analysis of an incident to reach valid conclusions through the appropriate use of the Scientific Method.*"

Pre-fire

The Research Team will determine the potential for a WUI event (defining the problem) and arrive at a location before deploying equipment for data gathering (data collection). The focus will be on the structure and the 1.5 m NCZ by using a variety of cameras, drones, and ember measurement devices (if possible). The team will also utilize a modified FireSmart Home Ignition Zone Scorecard (or IAS scorecard) to document a structure's level of exposure. Photo-documentation – georeferenced images

The research crew will be limited by the number of in-fire cameras, so placement is important. These locations will be identified as the most probable structures to be impacted by fire moving into a community through close communication with the FBAN or Fire Behaviour Specialist, based on their fire spread modeling.

UAV Imagery – taken at 20 m AGL



Structure – location identified

4.6.1 FireSmart Hazard Checklist

This Checklist is designed for fast data collection. It provides a general overview of the elements to focus on, while 360°-degree photos and handheld video data is collected. The IAS is incorporated into these simple headers. It can be expanded on following an event, using the photos for specific characteristics and descriptions. It can be developed for use on a phone or tablet.

Table 2. General structural data collection observation list

Roof material
Gutter type and roof cleanliness
Vents and openings
Eaves
Building exterior or siding
Building exterior condition
Ground to siding clearance
Balcony, deck, porch
Position on slope
Window glass
1.5 m from furthest extent of home (includes decks, overhangs)
Wood piles and other combustible materials (e.g., vehicles)
Outbuildings not meeting Firesmart guidelines

4.6.2 Focus Areas – Exposure

In-fire cameras, heat flux sensors and potentially an ember-meter should focus on potential paths of fire spread to the structure through the SIZ. These include but are not limited to:

- Exterior cladding (make these numbers and associate with the photo below)
- Roofing material
- Eaves
- Windows
- Ventilation openings
- Soffits

Focus will also be on combustible materials observed in the HIZ, such as vehicles, ATV's, RV's, and yard equipment as they are fuel packages that may increase the exposure hazard to the structure.

Figure 2 identifies areas of concern for high probability ember areas and potential ignition areas.

Figure 2. Areas of concern for fire ignitions and spread around a structure

A handheld video camera will be used at each house with dialogue for each structure to identify and video document the areas of concern listed above and identify the best location to place the in-fire cameras. This will take 5-10 minutes per structure.

It is inherently difficult to collect video data during the ignition process in and around structures due to many issues. Because of this research will also focus on visual indicators following the fire spread if not captured by video. This includes ember collection areas, char marks on vegetation and structures and fire spread direction indicators.

4.6.3 Ember Accumulation Areas and Measurement

The ability to collect data on ember accumulation is exceedingly difficult, but three methods will be attempted to determine where embers accumulate and potentially collect numbers to estimate the density of embers that land in and around structures.

- Camera boxes: A method has been developed to count the 'pings' impacting in-fire camera boxes. Embers landing on or striking the boxes create an audible ping that is picked up by the video cameras within the boxes. This audio can be analyzed, and the number of pings counted. The area of the box allows us to estimate the density of embers.
- In-fire video allows researchers to identify areas where embers are landing and accumulating. The video collected is also able to show ignitions that may result from an ember accumulation.
- The possible use of a prototype ember-ometer recently developed by the CFS. It is an acoustic machine that will collect data on the number of embers that land on it. It will be placed in locations believed to be accumulation areas based on the layout of the structure. It may be trialed if available.

4.6.4 Structure Density / Neighborhood Configuration

Data will be collected by UAV. If unable to fly will be documented by ground crew. Distances between houses can be calculated and the number of houses per area can be determined. Data can also be collected by Google Map or recent aerial photography.

Summary

- General checklist incorporates the IAS
- Methodology follows NFPA 921 data collection standards
- Includes from 30 m out into structure
- 5-10 minutes per structure for data collection
- Density data can be gathered from RPAS

APPENDIX VII is a quick reference card that walks researchers through the key points of the Ignition Assessment System. It assists researchers when they are performing the narrated video around each structure.

4.6.5 Post-Fire Data Collection

Little emphasis was given to this aspect of the research in the classroom or field training but identifying fire cause and spread in the NCZ following a fire event will require adherence to the NFPA 921 guidelines.

As well as collecting post-fire data from the same spots the use of a professional fire investigator to review the burn evidence would be beneficial. If this is possible it would follow this process:

Considering Fire Science and Fire Dynamics as defined in NFPA 921, following the WUI event the team can then collect the equipment and attempt an observational analysis of the structures affected by the WUI event.

- Documenting the structural fire scene following the NPFA 921 guidelines and analyze all the data.
- The team will then formulate hypotheses for each structure fire developing an ignition source analysis to determine all competent ignition sources and ignition sequences (paths in which fire spread to structure).
- Once these hypotheses have been tested the probable structural ignition scenario for each structure will be developed.
- The team can then look at all the resulting conclusions and determine if there are any commonalities in how the structures did or did not survive the WUI event.

The data collected will be preserved in a purpose-built database to build on from fire season to fire season.

The Quick-Deploy Research Team will collect all relevant data associated with a WUI fire impacting a structure or structures within the scope of the study. The data will include all photos, videos, and related data observed pre fire and during fire. In the Post-fire environment, the team will observe and collect or document data using a quick reference guide. Ideally both structures that survived the incident and those that did not will be used for data collection. Partially burned structures will also be used.

“Fire Effects”	*The observable or measurable changes in or on a material as a result of fire.*
“Observations”	*Fire effects will be observed and organized in four basic categories: Discoloration, Deformation, Deposition, and Mass Loss.* Observations shall consider material affected, magnitude of effect, gradient of effect, shape, size, location/geometry, direction, orientation, measurable effects, and time. 1. RPAS: Photograph and video the subject area for comparison to pre-fire conditions. Observations made of demarcation areas for extent of fire damage and areas of most-to-least. 2. Ground Teams: Observe, measure, document, photograph, and video fire effects in and around target structures using the attached guide.
“Discoloration”	*Materials that are increased in temperature, change phase, and are chemically changed by exposure to heat often result in a change of color to the affected surface.*
“Deformation”	*The visible or measurable change in shape represented as bending, buckling, or distortion of an item known as deformation. Many materials change shape temporarily or permanently during fires. Nearly all materials expand when heated. That expansion can affect the integrity of the structure, which results in observations of bending, buckling or distortion.*
“Deposition”	*Soot, which is predominantly carbon, is produced from combustion of carbon-based fuels. Smoke and soot can deposit or settle out of heated gases from the fire as they encounter cooler surfaces. Deposition of soot and smoke changes the color and texture of the surface. The observation of the lack of soot or smoke deposition is also important for the fire*

	investigators for reconstruction or location purposes.
“Mass Loss”	*As liquid and solid materials are heated and undergo physical and chemical changes, the original material is being converted to a gas. This loss of mass from the original material results in an observable change to the material.*

Structure Location	Discoloration	Deformation	Deposition	Mass Loss
Roof				
Eaves				
Exterior Cladding				
Windows				
Gas/Electrical Service				
Decks/Balconies				
1.5M Zone				
ATV’s, RV’s Vehicles				
Outbuildings/yard feature structures				

There will be occasions when researchers are not able to place their equipment in areas that get impacted by wildfire but are then able to visit these areas post fire. In these situations, the researchers are able to do analysis on the structures and if a structure survives, some general data can be collected to understand why. Basic information such as fuel reduction, green spaces and structure location can be collected. The surviving houses can be compared to those that did not survive. This value-added information collected in these situations can be used by FireSmart BC for education purposes. Evaluation protocols for this type of data collection can be developed and included in this Framework as it is a living document at this time.

4.7 Using Decision Trees to Establish Workflows

Quick reference sheets are in APPENDIX IV and APPENDIX VI outline the workflow for data collection based on arrival time (early or late) for the RPAS imaging, ground-based imaging and structural imaging. These decision trees lay out the steps for data collection and if further information is required the report can be consulted. RPAS imaging includes data collection on fuels, structures and neighborhoods. Ground-based imaging includes data collection on interface vegetation, the SIZ and structures. These decision trees can be applied to single structure or acreage situations.

4.8 Equipment List

4.8.1 Equipment List presented in Appendix I

It contains the equipment required for pre- and post-fire data collection as well as the equipment required for in-fire data collection. The list is specific to data collection needs.

4.8.2 Identified Equipment Needs

The following items were identified and purchased for the project during the fire season:

- 360°- degree cameras: purchased
- Chainsaw to facilitate access and egress to fire affected areas - acquired
- Pylons: purchased
- Computer power to process 360° images: still required

It has been identified that a camera mount that rotates with an in-fire camera box would be ideal for street views and corner areas on structures. The development of this will be investigated.

A list of further items identified as being valuable for project execution can be found in the Year-end Report. This list is composed of mostly electronics and data storage items.

5 DATA SHARING WORKPLAN

5.1 Requirements

BC FireSmart Committee has approached FPInnovations to develop a framework that outlines the requirement for a quick-deploy research team capable of documenting wildland urban interface (WUI) fires as individual case studies. Two types of data will be collected: visual materials and research data. These two types of data are large and complex. Multiple researchers need to access the same data at the same time for different questions. The BC FireSmart Committee will also need to access the visual materials for their own information and communications' needs.

A data sharing strategy, infrastructure, and sound protocols are required to ensure data sharing is efficient, effective, and secure.

FPInnovations has experience to coordinate data sharing and management between multiple agencies. Two examples where this has been occurred is for NWT Fort Providence Research Site and Alberta Pelican Mountain Research Site.

The Research Team will:

1. Develop a data collaboration platform
2. Develop a structure and protocol to organize data
3. Administer the data collaboration platform

5.2 Protocols

- Develop a data depository structure
    - Consolidate reference materials to have a draft of potential data.
    - Define data requirement with researchers
    - Define data catalog and metadata

- Develop a collaboration platform that allows to store large quantity of data
    - An SFTP server within Canada
    - 1TB storage incremental per year

A data-sharing platform and the associated protocol will be developed to share the collected data. An SFTP site has been created to be a data collaboration platform. A data structure template was developed to accommodate, but not limit to, the framework of data requirement. Authentication and authorization policy were applied to all users of the SFTP site to comply with data security requirements

5.3 Post-Fire Data Analysis

Following a WUI incident, the collected data will be analyzed to determine fire behaviour as it approached the community, structural ignition's locations and fire spread, and subsequent fire spread through the community and be presented in a case study format.

6 TEAM COMPOSITION

6.1 Personnel

6.1.1 Researcher Qualifications for Framework Development

1. **Mike Benson**: Fire Operations background, Aerial fire fighting, ICS, Communications, Fire Management. Broad Firefighting background. Kamloops, BC. **Role: ICS Liaison**

2. **Greg Baxter**: Fire Behaviour Specialist training, Fuels Management, Firefighter Safety, Firefighting background. Penticton, BC. **Role: Ground-based data collection**.

3. **Steve Hvenegaard**: Fire Behaviour Specialist, Fuels Management, ICS, Firefighting background, Drone pilot. Nelson, BC. **Role: Aerial Data collection.**

4. **Rex Hsieh**: IT Specialist, Equipment operation and development, Data Management. Wildfire and PB experience. Edmonton, BC. **Role: Equipment and Ground-based data collection.**

5. **Razim Refai**: Mechanical Engineer. Aviation, Structure Materials Science, Equipment operation and development, Data Management. Kamloops, BC. **Role: Ground-based data collection and reserve Aerial Data collection.**

6. **Brandon MacKinnon**: GIS, UAV pilot and data collection, Fuels Specialist (AAF Fuels Inventory Crew Leader), Equipment operation, Data Management, First Responder Level First Aid. Cochrane, AB. **Role: Aerial data collection, equipment.**

7. **(Contractor):** Structure Specialist, Materials, Codes, Building Engineering, Fire Inspector and Investigation. FireSmart – WUI Technical Committee for NRC (National Research Council) Standards. Penticton, BC. **Role: Structural data collection (pre- and specifically post-fire).**

The group comes self-contained with equipment for documenting fire behaviour: in-fire video, still cameras, 360° cameras, portable weather station, drones, radios, PPE, and fuel measurement equipment. We also have access to develop and build any specialized equipment that may be required as well as have access to burn labs if testing for verification is required.

All personnel have either wildfire, experimental fire, or prescribed fire experience.

6.1.2 Training

Classroom and field training are available for those collecting data specifically designed to provide background and theory for the IAS data. Classroom theory includes the following presented in four sections:

1. Understanding Wildland-Urban Fire Destruction
2. Home Destruction Related to Extreme Wildfires – How The Disasters Occur
3. A Physical Basis for the Home Ignition Zone (HIZ)
4. Identifying HIZ Characteristics Related to Home Ignition Potential

A field day of IAS practice is included as part of this training.

A one-day training course is proposed for next spring to provide the researchers with a very basic knowledge of post-fire investigations. This will assist the researchers in understanding some basic aspects of fire ignition and spread of structures. This training is not to replace fire investigators but is intended to increase the researchers knowledge in an area where they have little experience.

Fire Entrapment Avoidance training should also be taken. This can be provided by the BCWS.

6.1.3 Crew Travel and Accommodations

A vehicle with equipment can be centrally located, depending on the location of the data collectors. Research crews will arrive at a scene self-sufficient in terms of equipment needs and can either stay at hotels (preferred) or in fire camps. During Covid-19, hotels are the preferred option. The WUI data collection team should react quickly and be on site in southern BC within 12 hours.

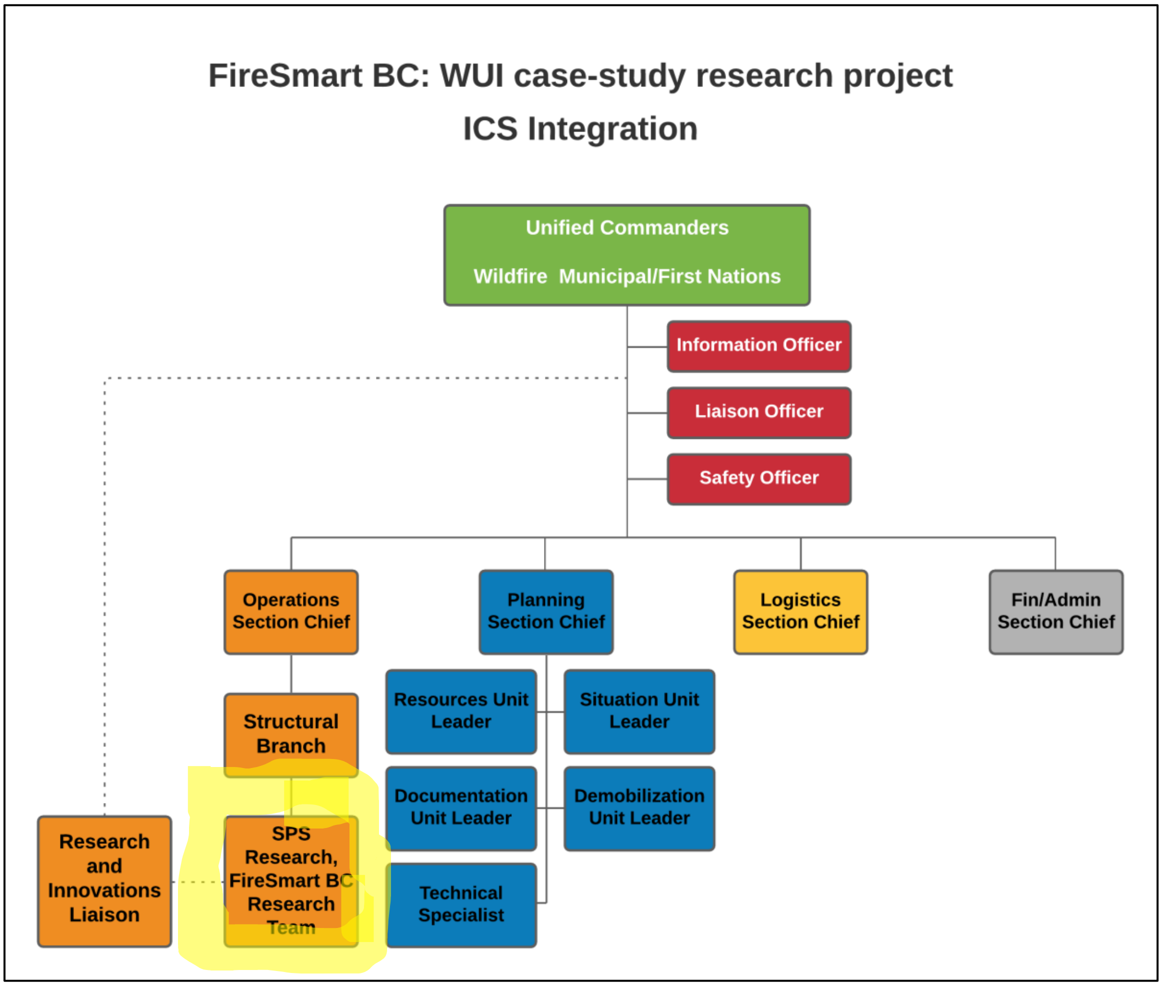
Depending on circumstances, one group may arrive early while another crew follows up. The early crew will begin integration into the Incident Command System and begin data collection. The minimum number of people required to collect data is three (with at least one capable of piloting an UAV).

6.2 Duty Roster

A Duty Roster will be set up to identify the personnel and resources that are available to respond to a WU event during the fire season in BC (July 1 to September 15 in 2021).

7 ICS

7.1 ICS Integration



WUI research undertaken within this framework will fall under the Operations Section Chief and the Structural Branch in the Incident Command System. The WUI Research Team will liaise with Research and Innovations personnel as well as the Structural Protection Specialist who will be dedicated to work with the Data Collection Team.

7.2 Request, Notification, and Arrival Protocol

The WUI Research Team will be notified for dispatch at the same time the Structural Protection Units are requested by the BCWS. Up until this time, the Research Team will be monitoring fire danger conditions and ignitions to prepare for a possible deployment. Upon arrival, the Research Team will contact the Research and Innovations Liaison of the BCWS. This protocol will be re-evaluated on an annual basis for its applicability.

BCWS/FPInnovations Deployment Request Flow Sheet

The following details the decision making and flow chart of resource requesting for FPInnovations.

Acronyms:

BCWS - British Columbia Wildfire Service

PWCC - Provincial Wildfire Control Centre

RRT - Resource Request Tracker (BCWS)

IMT – Incident Management Team

IC – Incident Commander

SPS – Structure Protection Specialist

SPCO – Structure Protection Coordinator

Requesting of FP Innovations resources:

- On site field resource (Structure Protection Specialist) creates a resource request and sends to Incident Commander (may not always be an IMT IC) on site for approval of Research Team resources.
- Once IC approves, Incident/Zone Logistics creates resource request in RRT and sends to PWCC Logistics.
    - Add two request Items, one for "Crew – Other (Crew)" and one for "Single Resource – Command – Liaison Officer".
    - In the "Crew – Other (Crew)" RRT, the Assigned Resource Note should say "SPP Research Team".
- PWCC Logistics forwards request to PWCO via. email for approval.
- Once approved, PWCC Logistics
    - forwards RRT request via email to Kelsey Winter with Deployment Request to complete;
    - contacts Michael McCulley to activate Liaison role and provide deployment manifest.
- Once completed, Kelsey Winter emails back the filled-out Deployment Request and advises PWCC Logistics.
- PWCC Logistics completes the RRT Request and Mark Filled. PWCC Logistics sends a copy of the completed Deployment Request to the SPCO email.

Releasing of BCWS resources:

- SPS Research and Liaison are notified by Research Team when they have completed their work.
- SPS Research advises Incident Commander, SPCO, and FPInnovations that resources are going to be released (provide date and time).
- SPCO advises PWCC Logistics that resources have been released.

FPInnovations is not to go to PWCC or Fire Centres directly when requesting or releasing resources.

7.3 Communications

7.3.1 With ICS

The Research Team will have a dedicated person whose responsibility will be communications with the ICS 'Research and Innovations Liaison' if one is available.

7.3.2 Inter-Crew Communications

The Research Crew will all be equipped with personal radios programmable for the frequencies required for safe work and communications. FPInnovations arrives with their own radios and utilise a generic team call sign system to expedite radio communications. Call signs are provided to the ICS and SPU's and will have an FPInnovations A, B, C, etc., format for ease of use.

7.4 Access and Privacy Issues

The research group will actively protect privacy. All access of data will be tracked and controlled. A Privacy Impact Assessment has been conducted.

Data will be stored on a data server. The server is in a locked server room. The server room access is monitored. Data access is through a SFTP (Secured File Transfer Protocol) service. Data will be encrypted while transferring through internet. Authentication and authorization policy will apply to individual users. No shared or anonymous account will be allowed. Any personal information will be cleaned off the data sets when to be used on reports and any final deliveries.

Data collected while on site will be stored in a locked box until it has been uploaded to the server.

BC Privacy practices will be followed regarding any issues surrounding private property and the images collected.

7.5 Deployment Flow Guidelines

Appendix VII outlines the entire deployment flow from the initial notification to post-fire data analysis. It is broken into five sections: Preparedness, Mobilization, Execution, Demobilization, and Post-Event Data Processing. It is a step-by-step system highlighting all the different aspects of data collection.

8 SAFETY

8.1 On-Scene Logistics

8.1.1 Arrival On Site

The research team will report through the Research and Innovations Liaison to the IC, Safety Officer, and Plans section immediately upon arrival at an incident to open communications and will follow the instructions provided. It is anticipated that a researcher presence at operations meetings would support integration within the incident organization structure.

8.1.2 Fireline Safety

The research team will adhere to any concerns raised by the on-site Safety Officer, and a minimum of one researcher will attend safety briefings. Researchers will all be equipped with radios monitoring a pre-determined channel while on the fire and will work in pairs.

8.1.3 Escape Routes, Travel

Discussions and on-site consultations with the Fire Safety Officer will identify escape routes, safety areas, and evacuation routes and procedures. Travel in and out of site will take place on approved routes. This information will be updated on a regular basis and more frequently as fire approaches.

8.1.4 Personal Protective Equipment (PPE)

All researchers and contractors will be wearing approved PPE. No breathing apparatus will be used.

8.1.5 Evacuations

The research team will follow evacuation orders and have continual communications with wildfire response staff to keep informed on the current and forecasted conditions.

APPENDIX I: FPINNOVATIONS EQUIPMENT LIST

Sampling Section	Item	Quantity
RPAS Imagery	RPAS	1
	Erayak 800W power inverter w/ 12 V deep cycle battery	1
	Air Frequency Radio	1
Ground Based Imaging	In-fire camera package	10
	360 camera	3
	24' Docapole	3
	360 camera rooftop truck mount	2
Fire Behaviour Evaluation	Portable weather station	1
Structure Assessment	30m measuring tape	2
Data management	Field laptop	1
	Portable hard drive	2
	Power bar	4
General Items	Backpack hand pumps	1
	First aid kits	1
	Shovel	
	Fire extinguisher	
Individual data collector	Field laptop	1
	Compass	1
	GoPro camera	1
	Kestrel	1
	Flagging tape	1
	Handheld radio	1
	Smart phone	1
	PPE	
	Flash lights	1

APPENDIX II: ICLR RESEARCH QUESTIONS

1. Vulnerability

Q1: What structural elements and which aspects of them are most susceptible to ignition from embers?

Q2: When elements of a structure (e.g., walls, deck, roof) are exposed to extreme radiant heat causing ignition, where does the fire spread and/or enter the structure to sustain ignition?

Q3: What principal combustibles found in the SIZ and specific characteristics of those objects provide sites for sustained ignition from embers or heat flux from wildland fires?

Q4: What vulnerable elements of vehicles/RVs/ATVs and machinery lead to ignition?

Q5: How likely is fire from ignited combustibles to spread to and ignite the structure?

Q6: Why have some homes burned and others not?

2. Exposure

Q1: What are the physical characteristics (e.g., type of material, size, number/density, accumulation patterns) of live embers arriving on structures and other combustibles in the SIZ?

Q2: For each structure (burned and unburned) and its specific elements, what was the level of exposure to direct flame contact and/or radiant heat of the wildland fire? Is there a correlation between level of exposure and whether it burned?

Q3: What is the critical number or mass flux of embers sufficient to result in building ignition?

Q4: Is there a "heat shielding" effect from vegetation or other features with the SIZ? What are the qualities of effective heat shielding objects resulting in reduced exposure?

Q5: Is exposure to wildfire igniting vehicles, RVs, ATVs, and other machinery? Or is this ignition caused by exposure from adjacent burning structures?

Q6: What are the relevant conditions (distance, duration, amount, etc.) when structures ignite from flame or radiant heat of wildland fire?

Q7: Are there differences in the exposure levels to embers between burned and unburned homes and ignited versus non-ignited fuels (structural, landscaping, and vegetative materials)?

Q8: Is tempered glass required when heat exposure to adjacent burning homes is not a factor?

3. Fire progression pathways

Q1: Are existing FireSmart fuel reduction standards for crown fire hazard (i.e., 1 to 3 crown width spacing) effective at breaking the fire spread pathway between tree canopies in the SIZ?

Q2: Are existing FireSmart fuel reduction standards for crown fire hazard (i.e., 1 to 3 crown width spacing) effective at breaking the fire spread pathway between coniferous shrubs in the SIZ?

Q3: For creeping surface fire, where specifically did fire first enter the property? What objects or fuels comprised the pathway across the SIZ leading to ignition of the structure?

Q4: How effective is the 1.5 m "non-combustible" zone at preventing ignition of the primary structure? Is it adequate or excessive?

Q5: What roles do materials (e.g., landscaping timbers, mulch, dry sod) play in the spread of smouldering fire and eventual ignition of other, more flammable fuels in the SIZ?

Q6: Do motor and recreational vehicles and gas-powered machinery aid fire spread in the SIZ?

4. Ember influx

Q1: To what degree do fire environment conditions and fire behaviour characteristics influence the types, amounts, sizes, transportation distance, distribution pattern and efficacy of embers?

Q2: For what period of time and at what distance is the built environment impacted by incoming embers from the advancing wildfire? Is this constant for all forest fuel types?

Q3: Is there a correlation between the rate of structural ignitions in the WUI and known characteristics of extreme wildland fire behaviour (e.g., column, instability, high rate of spread, fire whirls)?

5. Fire spread between structures

Q1: What are primary means (e.g., flame, radiant heat, embers) of fire spread between structures?

Q2: How is structure-to-structure fire spread influenced by density of homes, type, age, slope, wind, building design and materials, intervening fuels, etc. under free-burning conditions?

Q3: Are current building codes adequate under conditions with little or no structure protection?

Q4: What is the character of embers from burning structures? How do they sustain fire spread?

6. Others: Uncategorized

Q1: Within the entire built environment, does the pattern of fire spread/destruction correlate with structure density, ignition potential of homes, continuity of other fuels and fire weather?

Q2: Will factors affecting fire spread in vegetation or ignition potential of structures observed in WUI case studies be helpful in calibrating or testing other physical models relating to wildfire?

Q3: Can third-party information (e.g., images, video, dispatch records, 9-1-1 calls) be compiled to develop a fire chronology of the event?

Q4: Tree removal guidelines in the SIZ are not site-specific, raising resident concerns of being overly stringent?

APPENDIX III: ASSESSMENT CHECKLIST BY DATA COLLECTION TYPE

	House assessment	RPAS	360 camera on pole	Only possible on ground not from photos	All 3	360 + Ground
1	Roof Material	Yes	Yes	Yes	RPAS	360/Ground
2	Gutter type and roof cleanliness	Yes to roof/gutter cleanliness, maybe to gutter type	Yes	Yes to roof type, maybe to gutter type, maybe to roof and gutter cleanliness	RPAS/Ground	360/Ground
3	Vents and openings	Maybe	Maybe	Maybe	RPAS	360
4	Eaves	No	Yes	Yes	Ground	360
5	Building exterior or siding	No	Yes	Yes	360	360
6	Building exterior condition	No	Yes	Yes	RPAS	360
7	Ground to siding clearance	Maybe	Yes	Yes	RPAS	360
8	Balcony, deck, porch	Maybe	Yes	Maybe	RPAS/360/Ground	360/Ground
9	Position on slope	Yes	Maybe	Yes	360	360
10	Window glass	Maybe, estimate glass size and potentially multi vs single pane	Yes, potentially glass type	Yes, potentially glass type	RPAS/360/Ground	360/Ground

	House assessment	RPAS	360 camera on pole	Only possible on ground not from photos	All 3	360 + Ground
11	0-1.5 m from furthest extent of home (includes decks, overhangs)	Maybe	Yes	Yes	RPAS/360	360
12	1.5-10 m Woodpiles and other combustible materials (eg. Vehicles)	Maybe	Yes	Yes	RPAS/360	360
13	1.5-10 m Outbuildings not meeting firesmart guidelines	Maybe	Yes	Yes	RPAS/360	360
14	1.5-10 m Forest vegetation (trees)	Yes	Yes	Yes	RPAS	360
15	1.5-10 m Surface vegetation and combustible materials	Maybe	Yes	Yes	RPAS/360	360
16	10-30 m Forest vegetation (trees)	Yes	Yes	Yes	RPAS	360
17	10-30 m Flammable shrub spacing (coniferous – eg. Cedar or juniper)	Maybe	Yes	Yes	RPAS/360	360
18	10-30 m Surface vegetation	Maybe	Yes	Yes	RPAS/360	360
19	10-30 m Low-lying tree branches	Maybe	Yes	Yes	RPAS/360	360/Ground

	House assessment	RPAS	360 camera on pole	Only possible on ground not from photos	All 3	360 + Ground
	(coniferous)					
20	Distances	Yes	Yes	Yes	RPAS/360	360/Gro und

APPENDIX IV: RPAS QUICK-REFERENCE SHEET

RPAS		
Type	**Early Arrival (>24 hours)**	**Late Arrival (<24 hours)**
Structure Assessment (1)	Take pictures of structures on the first 4 streets while alternating structures collected to cover more area. The area should be expanded as time allows if the >24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible. After 6 streets have been sampled in an alternating fashion go back to the first street and start filling in houses.	Take pictures of structures on the first 2 streets while alternating structures collected to cover more area. The area should be expanded as time allows if the <24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible. After 4 streets have been sampled in an alternating fashion go back to the first street and start filling in skipped structures.
Mapping mission of neighbourhood (2)	Map the first four streets of the area suspected to be breached by wildfire. The area should be expanded as time allows if the >24 hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible.	Map the first two streets of the area suspected to be breached by wildfire. The area should be expanded as time allows if the <24 hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible.
Fuels (3)	Map 10 ha of fuels along the area suspected to be breached by wildfire. Complete an oblique photo mission with 6 locations for angle and nadir photos. The area should be expanded as time allows if the >24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible.	Complete an oblique photo mission with 6 locations for angle and nadir photos. The area should be expanded as time allows if the <24-hour minimum data collection requirements for other sections are fulfilled. Add 10 ha mapping mission if time allows. Increase collection zone extent by 50% at that time and expand other sections as possible.

Neighbourhood oblique photo missions **(4)**	Oblique photos of first four streets of the area suspected to be breached by wildfire. The area should be expanded as time allows if the >24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible.	Oblique photos of first two streets of the area suspected to be breached by wildfire. The area should be expanded as time allows if the <24-hour minimum data collection requirements for other sections are fulfilled. Increase collection zone extent by 50% at that time and expand other sections as possible.

APPENDIX V: STRUCTURE ASSESSMENT QUICK-REFERENCE SHEET

Structures		
Type	**Early Arrival (>24 hours)**	**Late Arrival (<24 hours)**
Structure Assessment	Select starting structure: Individual photos of each structure on first 4 streets of the area suspected to be breached by wildfire. The area should be expanded as time allows Focus images on items in checklist: roof material and condition, windows, siding materials, vents, eaves, and electrical and gas service locations. Use video with narration for each structure.	Select starting structure: Individual photos of each structure on first 2 streets of the area suspected to be breached by wildfire. The area should be expanded as time allows. Focus images on items in checklist: roof material and condition, windows, siding materials, vents, eaves, and electrical and gas service locations. Use video with narration for each structure.
Structure Ignition Zone (SIZ)	Photo and video documentation of the SIZ for each structure. If possible complete on all four sides of the structure starting at the front and working clockwise. Verbally identify any fuels, materials and engineered characteristics of concern. The area should be expanded as time allows. Focus observations on vegetation, balconies, decks, overhanging trees, outbuildings, woodpiles. Identify areas where embers may accumulate. Complete structures on first 4 streets in area of concern.	Photo and video documentation of the SIZ for each structure. If possible complete on all four sides of the structure starting at the front and working clockwise. Verbally identify any fuels, materials and engineered characteristics of concern. The area should be expanded as time allows. Focus observations on vegetation, balconies, decks, overhanging trees, outbuildings, woodpiles. Identify areas where embers may accumulate. Complete for structures on first two streets and expand as time allows.
Vehicles, trailers, etc.	Identify and document any vehicles (cars, trucks, trailers, recreation vehicles, etc.) in the vicinity of the structure that could act as either a fire spread mechanism or an ember receiver. Complete structures on first 4 streets in area of concern.	Identify and document any vehicles (cars, trucks, trailers, recreation vehicles, etc.) in the vicinity of the structure that could act as either a fire spread mechanism or an ember receiver. Complete structures on first 2 streets in area of concern.
In-fire data collection	Based on expected fire progression and where the Structure Protection Units are established, identify individual structures for the placements of in-fire equipment which include in-fire cameras and heat flux sensors. Locate cameras: between structures, street view, structure, and zone 1A, interface area, fuels. Placement of sensors will depend on site. Will depend on number of in-fire cameras available.	Based on expected fire progression and where the Structure Protection Units are established, identify individual structures for the placements of in-fire equipment which include in-fire cameras and heat flux sensors. Locate cameras: between structures, street view, structure, and zone 1A, interface area, fuels. Will depend on number of in-fire cameras available. Number of cameras put in should not vary.

APPENDIX VI: IAS NARRATION CUE CARD

IAS NARRATION CUE CARD

*Voice distances as they are hard to determine accurately from video

*Yellow = No time and must still narrate!

*One continuous video per structure/property

Surrounding Area

<u>Home introduction</u>

- Date and time (24 hr)
- Address (GPS coordinates if no address)

<u>HIZ Zone 2 (10 – 30 m)</u>

- Canopy separation (m)
- Trees % conifer
    - Distances of conifer clusters
- Canopy base height
- Shrub surface cover %
    - % conifer
    - Distances of conifer clusters
- Flammable surface debris
    - Continuous or non-continuous
- Flammable surface material
    - Grass cover percentage and height
    - % cured
    - Etc…
- Identify structures
    - Distances
    - Area (L x W)

HIZ Zone 1 (1.5 – 10 m)

- Canopy separation
- Trees % conifer
    - Distances of conifer clusters
- Canopy base height
- Shrub surface cover %
    - % conifer
    - Distances of conifer clusters
- Flammable surface debris
    - Continuous or non-continuous
- Flammable surface material
    - Grass cover percentage and height
    - % cured
    - Etc…
- Identify structures
    - Distances
    - Area (L x W)
- Fuel tanks
    - Distance
    - Surface under it
    - Hose type

HIZ – Non-Combustible Zone (0 – 1.5 m)

- Surface cover present and percentage
    - Mulch
        - Size
    - Grass
        - Height, % cover, % cured
    - Litter
- Conifers and distance
- Anything else flammable

Structure (completed per side Alpha, Bravo, Charlie, Delta and working clockwise from front)

Foundation

- Distance to siding
- Sub-sheathing material
- Lathing (plaster)/skirting
    - material

Attachments

- Presence
    - Decks, fences, etc…
- Materials
- Contact with wall
- Any flammable objects

Walls

- Overhangs/pushout features
- Siding material
- Vents and mesh sizes
- Window ledges and ember accumulation points
    - Condition (cracking)
- # of panes in window and size
    - Glass type
- Inflammable/flammable inside corners
    - Length
    - Flammable debris
    - Cube corners
- Outer facing flammable wood boards
    - Length
    - Flammable debris

Gutters and Eaves

- Presence/absence
- Gutter material
- Flashing material
- Fascia material
- Flammable debris
- Eaves closed or open
    - Material
    - Mesh size
        - Mesh material
    - Horizontal surfaces adjacent to eaves (presence/absence)

Roof

- Roofing material and condition
- Debris
- Gaps in material
- Vents
    - Screening size and type
- Vertical siding touching roof surface
    - Material
    - Flashing material
    - Distance from roof where flammable material starts
    - Debris or areas where embers can accumulate

APPENDIX VII: RESEARCH TEAM DEPLOYMENT FLOW GUIDELINES

BC FireSmart Committee Quick Deploy WUI Team Data Collection Framework

Deployment Flow Guidelines

Preparedness

1. Each team member will ensure that they are familiar with the framework.
2. Individual roles and responsibilities will be understood and practiced.
3. Research equipment will be kept in good working order and ready for deployment.
4. Situational awareness of wildfires and trends will be maintained.
5. Constant awareness of researcher availability will be maintained.

Mobilization

1. Michael Benson and Greg Baxter will receive dispatch notification.
2. They will initiate a team meeting to plan and prioritize deployment response.
3. Team members will travel to the incident.
4. Team members will check in with the Plans Section at the Incident Command Post.
5. Michael or Greg will contact R&I and SPS liaisons.
6. Michael or Greg will obtain briefings on safety, communications, contact information, AHJ information, operation plans, and fire behaviour predictions and then disseminate to the other team members.

Execution

1. Identify areas at risk of fire impingement and establish a sampling area buffer zone.
2. Deploy RPAS for aerial assessments once approved to do so.
3. Initiate ground-based structure assessment using 360 video and narration card.
4. Identify priority locations for in-fire camera placement.
5. Deploy and start in-fire cameras with considerations to battery-life limitations:
    a. ~5 hours @ 1080p30
    b. ~13 hours @ interval photos every 1 second (processed later in FFMPEG)
    c. Working on extending this with increased battery life and storage space
7. Initiate street level structure assessment using vehicle mounted 360 cameras to expand coverage area efficiently.
8. Repeat execution steps for post-fire data collection.

Demobilization

1. Debrief research deployment onsite with research team and liaisons.
2. Research team to sign out with plans section.
3. Return to home locations.
4. Ensure all equipment is returned and prepared for future deployment.

Post-Event Data Processing

1. Confirm data quality before archiving.
2. Organize and archive data.

3. Convert all data types from proprietary formats to standard formats for potential future distribution.
4. Analyze data.

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