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WildFireSat

La mission GardeFeu

WildFireSat pathway for implementation and uptake in provincial and territorial fire management agencies

Natural Resources Canada
Canadian Forest Service
Great Lakes Forestry Centre
Information Report
GLC-X-36

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Cataloguing information for this publication is available from Library and Archives Canada.

WildFireSat pathway for implementation and uptake in provincial and territorial fire management agencies. (Information Report, GLC-X-36).

Issued also in French under the title: Marche à suivre pour la mise en œuvre et l'adoption de la mission GardeFeu par les agences provinciales et territoriales de gestion des incendies

McFayden, C.B., Hope, E., Johnston, J.M., Cantin, A.S., Crowley, M.A., DeBoer, S., de Jong, M.C., Johnston, L.M., Thompson, D.K., Young, D.J.

Electronic monograph in PDF format.

Includes bibliographical references.

PDF:
ISBN 978-0-660-68345-4 ISSN 2562-0738

Cat. no.: Fo123-2/36-2023E-PDF

Paper:
ISBN 978-0-660-68346-1 ISSN 0832-7122

Cat. no.: Fo123-2/36-2023E

FOREWORD

I was raised in a family of firefighters. That meant we lived on fire bases, learned to fish on the docks next to the twin otters, and had Smokey the Bear at every school event I can remember. All our friends were kids of the same sort. So, it's no surprise perhaps that myself, my siblings, and even cousins found ourselves in the crew system. Eventually my path led to research where I married another fire scientist. I feel like all of this is important here because I believe that spending a lifetime in fire management was foundational in defining the mission that would become WildFireSat. I am also keenly aware that my kids may very well find themselves neck deep in a swamp holding a pump above their heads while WildFireSat is in orbit, which is ever present in my decision making.

In 1986, Flannigan and Haar published a paper demonstrating that it was possible to observe wildfires from the AVHRR satellite instrument. This was a pivotal moment that along with other research caught the attention of the fire management community for the potential for satellites to help. When I was still quite young and not long after this, I remember my father (a provincial fire manager) talking about how someday satellites were going to change the way we do business. He was one of those early adopters of the Fire Weather Index (FWI) and Fire Behaviour Prediction (FBP) Systems, and he worked with the Canadian Forest Service on a lot of experimental burns around the same time. Looking back, I can understand where that forward thinking mindset came from. But within his career, the expectation for monitoring fires from space was never realised. In many ways it still hasn't.

Since 1986 we've made dramatic strides in the technology and science of space-based wildfire monitoring. We have multiple satellites capable of routinely detecting and characterizing wildfires worldwide. We have scientific evidence that these satellites can accurately estimate fire size, temperature, energy release, fuel consumption rates, smoke production rates, direction and speed of travel, and fire severity, map burned area with extreme precision, and even describe the fuels that surround them. In recent years more and more of these products are being used to inform fire management, monitor air quality, and carbon accounting. However, the use of satellites for wildfire monitoring has yet to reach the kinds of transformational change possible in daily fire management.

In the WildFireSat mission we are striving to deliver on the promises satellites made to our forebearers. I firmly believe that in the Mission Requirements and Science and Applications plan we have addressed the technical challenges that have formed barriers to operationalizing satellite data in the past. I am also very much aware that having a technically flawless system in no way translates to meaningful operational impact. At the end of the day what matters is trust, buy-in, and a sense of ownership on the part of the people who will decide whether this tool serves their purposes and can be relied on when it really matters. This is plain as day in what we have learned about the implementation of the FWI system. It's not the kind of buy in you get from bringing a finished product to market, or from speaking at conferences and workshops or anything like that. This comes from genuine, meaningful, and balanced exchanges between scientists and decision makers from start, to launch, and beyond.

The realized benefit of the WildFireSat mission is in the hands of our fire managers, but it is also the responsibility of the mission team to ensure that those same fire managers are front of mind in all that we do. What better way than keeping them at the table? Our approach for knowledge exchange is arguably the most critical component of the mission. It is a fountain of information for researchers and engineers trying to build better tools for operations, and a gateway for fire managers to access the knowledge of the scientists and broaden their own understanding of the often-peculiar world of satellite data.

It is our firm belief that through this pathway to implementation and uptake, Canada's fire managers will become the most equipped to use satellite data of any of their counterparts worldwide, while our scientists will possess the deepest understanding possible of their stakeholder priorities. That outcome will exist with or without WildFireSat itself reaching the launch pad, and as a result we have prioritised our knowledge exchange program to be every bit as central to the mission as the rest of the work that the Canadian Forest Service leads.

The success of this program is about much more than WildFireSat. The way my father fought fire wasn't all that different from the way I did. But the generational divide between myself and my kids will be dramatic due to climate change. The 2023 fire season was a sobering glimpse of what is on the horizon. Fire monitoring through Earth observation satellites may seem like a novelty today, but it will be an absolute necessity for those trying to adapt to the challenges of tomorrow. My kids are very likely going to be part of that effort, and I suspect many of you reading this may know young people who will be standing alongside them. This mission is for them, and the foundational work in this plan is an investment in the future that they will thank us for.

So, it is with great pride that we introduce the WildFireSat pathway for implementation and uptake in provincial and territorial fire management agencies – the most critical step in realizing the promises of the 1980s.

Dr. Joshua Johnston

Research Scientist and Principal Investigator
of WildFireSat

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EXECUTIVE SUMMARY

Background: WildFireSat is a satellite mission designed to provide vital information and intelligence in support of wildland fire management. An initiative of the federal government of Canada, it is expected to be operational around the 2029 Canadian wildland fire season. The success of this mission will depend on the suitability of WildFireSat products for use in operational wildland fire management and the adoption of those products by wildland fire management agencies. This requires a concerted effort to understand the end-users and work with them to tailor products to their needs while also sharing and building knowledge of remote sensing for operational fire management together.

Purpose: The purpose of this document is to describe a synthesis of the key concepts and strategies within the WildFireSat mission that will be used to support the implementation and uptake for provincial and territorial wildland fire management agencies.

Audience: The intended audience for this document is Canadian provincial and territorial wildland fire management agencies and their colleagues in emergency and wildland fire management.

INTRODUCTION

Wildland fires are needed but can be detrimental

Wildland fires are a natural process and fire-dependent and adapted ecosystems require fire for healthy functioning which is beneficial (Pausas and Keeley 2019; Wein and MacLean 1987). However, wildland fires can also be harmful and in some cases disastrous, such as the 2016 Horse River fire in Fort McMurray Alberta which resulted in billions in losses (MNP 2016) and the current 2023 wildland fires which resulted in at least 200,000 evacuees and hundreds of lost structures.

The global climate is changing. Canada is experiencing, and will continue to experience, longer fire seasons and worsening fire situations (Coogan et al. 2019, 2020; Flannigan et al. 2000, 2005 and 2009; Wotton et al. 2017; Wang et al. 2015, 2020, 2022; Wotton and Flannigan 1993). Managing wildland fire risk in a changing climate is inherently difficult and involves trade-offs between the beneficial and negative consequences from fire, all with a great deal of uncertainty.

Addressing wildland fire risk and resilience

It is recognized that addressing wildland fire risk requires a whole-of-society approach (Canadian Council of Forest Ministers 2021; Government of Canada 2023b). There are a range of approaches and activities that Indigenous Peoples, the public, industry, and government can adopt or continue that will help reduce the risk posed by wildland fire (e.g., Lake and Christianson 2020; Sankey 2018; Canadian Council of Forest Ministers 2016, 2021; Hoffman et al. 2022a; Johnston et al. 2020a; Hirsh et al. 2001). There is also a growing recognition of Indigenous Knowledge as a critical way of knowing and that its braiding with Western fire management through leadership by Indigenous Peoples, communities, and nations, can enhance Western science approaches leading to improved fire management, promoting

community safety and resilience (Canadian Council of Forest Ministers 2021; Mason et al. 2012; Neale et al. 2019; Eriksen and Hawkins 2014; Prince Albert Grand Council 2018).

Wildland fire information and intelligence

When a wildland fire occurs in Canada, decisions are made using the fire information that is available to fire managers. Information is not always complete, although decision-makers depend on the accuracy of this information (Taber et al. 2013). This is especially true in periods of escalated wildland fire activity. Reliable information about wildland fires, provided in the right way, and interpreted correctly, may make the difference between helpful fire intelligence vs. increasing uncertainty or hindering the decision-making (Zimmerman 2012; McLennan et al. 2006; Thompson and Calkin 2011; Lipshitz and Strauss 1997; Taber et al. 2013).

- **Fire information**: the specialized information used in conducting wildland fire management and operations. It includes information about the proximate physical setting (e.g., topography, fuels and fuel arrangement, wildland resources, assets), the current and forecasted fire environment (e.g., weather, fuel dryness), the current and forecasted fire behaviour and burned area, the current and potential fire effects, and impacts (Johnston et al. 2020b), and the current and potenttial effects of suppression.
- **Fire intelligence**: results from the processes of assembling, interpreting, analyzing and evaluating raw information.

Collecting fire information and intelligence

In many cases, Canadian wildland fire management agencies rely on ground or airborne reconnaissance to collect and communicate real-time field observations. This may be a person on a lookout tower, a helicopter with a firefighter crew on an initial attack, an Air Attack Officer working on airtanker operations, an infrared high-level aircraft performing night scans, or other operational activities. These methods have their strengths and limitations, for example aircraft are flexible in where and when they collect information, however,require airports to operate from and may also be constrained by flight duration, weather and smoke conditions. Likewise, towers can offer persistent surveillance, however, are not generally mobile and require a certain level of infrastructure support.

Collecting fire information and intelligence with Earth observation satellites

Satellite Earth observation (EO) data are another avenue for collecting fire information and intelligence. Unfortunately, there are significant gaps in the available satellite EO active fire data to fill these needs (e.g., Johnston et al. 2020b), and these issues are particularly acute in Canada. Most daytime overpasses from low Earth orbit EO satellites (e.g., the Terra and Aqua satellites that carry the MODIS instruments, SNPP/NOAA-20/NOAA-21 satellites that carry the VIIRS instrument) that are suitable for fire monitoring occur during the local solar time late-morning (~10:00-11:00) or early afternoon (~13:00-14:00). As Canadian fire activity typically peaks in the late afternoon / early evening (~16:00-18:00), current EO missions can provide very little information and intelligence to fire managers that is relevant to this critical ‘peak burn’ period. Furthermore, Geostationary EO satellites that can provide high temporal resolution imagery (e.g., every 10-15 minutes) in some locations, such as the GOES satellite mission, are of limited use for fire monitoring in Canada. Due to its northerly latitude, Canada is

positioned at the edge of the GOES field of view, where spatial resolution is very low (~8-32km^2, location dependent; Hall et al. 2019). This means that only very large fires can be detected in Canada using geostationary satellite systems, and this problem is compounded as latitude increases (de Jong and McFayden 2023; Johnston et al. 2020b; Johnston et al. 2018).

The world's first purpose-built operational satellite system for monitoring wildland fires

To address the challenges for suitable satellite-based fire information and intelligence over Canada, the 2022 Canadian Federal budget provided funding for WildFireSat, a new wildland fire monitoring satellite system (Government of Canada 2022 and 2023c). WildFireSat is a collaborative initiative of Natural Resources Canada (NRCan), the Canadian Space Agency (CSA), and Environment and Climate Change Canada (ECCC). It will be the world's first government agency, purpose-built[1], operational[2] satellite system dedicated to monitoring wildland fires (as described in Great Lakes Forestry Centre 2023).

> *"…WildFireSat is unique in that, through engagement with provincial and territorial fire management agencies, we will tailor a complete information system for the needs of fire management across the country."*
>
> *Great Lakes Forestry Centre 2023.*

Designed for fire monitoring, WildFireSat will provide daily coverage of the Canadian landmass, fire characterization, measurements of carbon emissions and smoke plume dynamics. As a result, Canada's wildland fire management agencies will receive information and intelligence on all active wildland fires in near real-time, at least twice daily.

To ensure WildFireSat is used and useful for wildland fire management agencies, the mission will include capacity building initiatives aimed for increased integration and support in real world decision-making. Given the complexity of the fire management agencies, and their priorities to deliver safe and effective programs, it is expected that agency wide implementation cannot happen immediately. Prelaunch preparedness is an important focus for the WildFireSat mission to ensure the agencies are ready at the start of satellite operations.

[1] Public satellites that carry instruments that currently provide fire products were not designed solely for fire monitoring purposes– at best, fire monitoring was considered during the design stages, but was only one of many competing applications, and design compromises were made to accommodate other measurements.

[2] In the context of satellite missions "operational" means that there is a certain level of service for the operational end-users (e.g., guarantee in the continuity of service, timeliness).

"…the rate and extent of WildFireSat data product integration into operational fire management is very important. The WildFireSat program aims to maximize the satellite's utility for operational fire management from the onset through deliberate product design, testing, and proactive fire management community knowledge exchange…"

McFayden et al. 2023a."

Read more about the WildFireSat mission:

- WildFireSat: The world's first purpose-built operational satellite system for monitoring wildfires (Great Lakes Forestry Centre, 2023) – https://cfs.nrcan.gc.ca/publications?id=40873

PURPOSE OF THIS DOCUMENT

The purpose of this document is to describe a synthesis of the key concepts and strategies within the WildFireSat mission that will be used to support the implementation and uptake for provincial and territorial wildland fire management agencies.

DOCUMENT PATHWAY

This document will build on key aspects to scope and design the approach for achieving the objective of the WildFireSat mission relative to implementation and uptake. Figure 1 illustrates this pathway which corresponds to the sections of this document.

- **High level objective:** A high degree of implementation and uptake of WildFireSat data and products in the operational wildland fire management by the provincial and territorial fire management agencies for real-world impact.
- **High level strategy:** The objective will be achieved through the application of knowledge exchange principles and processes through all stages of WildFireSat development.

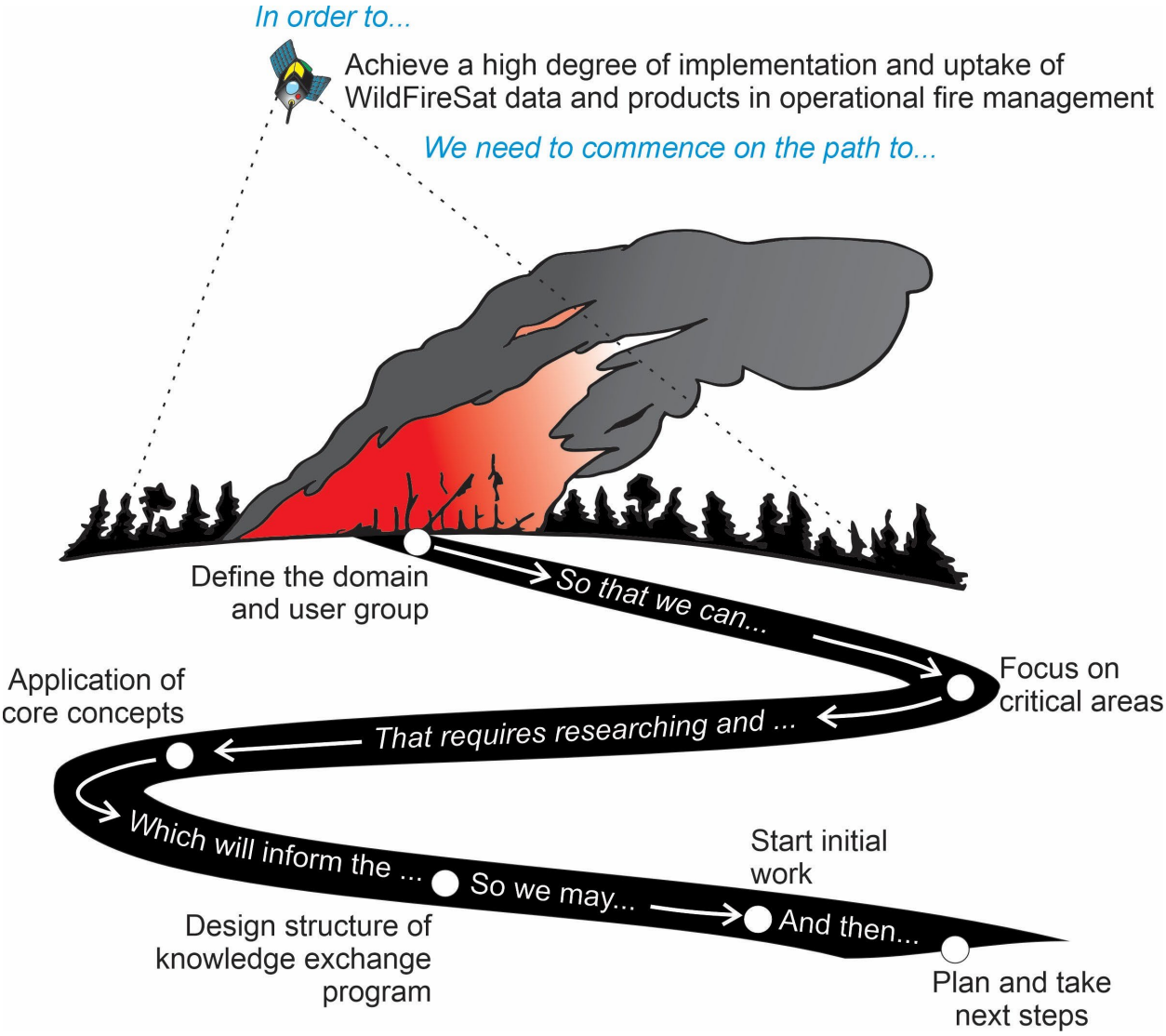

Figure 1. The document roadmap and relationships between sections.

1. DOMAIN AND USER GROUPS

This document is focused on the Canadian provincial and territorial wildland fire management agencies that will use the Level 2+ satellite data products in operational fire management (see Figure 2 for the WildFireSat concept of operations data levels and flow). Level 2+ data are those that are quality controlled and for direct use by an end-user.While some WildFireSat data gathered over Canada will be openly available in accordance with the Government of Canada's commitment to open government, other value-added data products may only be available through appropriate sharing agreements. Level 2+ data corresponds to the output products of WildFireSat development Tiers which are:

- Tier 1 - Exclusively WildFireSat Data: active fire measurement and characterization, fire environment characterization.
- Tier 2 - Virtual Constellation (WildFireSat combined with other satellite systems): data synthesis and event categorization, fire progression monitoring and analysis, fire behaviour characterization.
- Tier 3 - Modelling Products (Tier 1 and 2 products are used to drive external wildland fire modelling tools): incorporate auxiliary geo-spatial data and modelling techniques to provide greater context for decision-making based on tools such as fire growth modelling (e.g., including wildland-urban interface, fuel data).

WildFireSat data products may include (but are not limited to):

- Maps of wildland fire size, shape, location, with actively burning areas identified.
- The direction of travel and speed of various sections of the fires.
- How hot the fire is burning, and the potential effectiveness of various firefighting methods relative to the behaviour (e.g., ground crews, bulldozers, or air attack).
- The estimated arrival time of the fire to nearby communities, industrial installations, infrastructure and known cultural values.
- Enhanced products from fire emissions models that quantify smoke production from fires and will contribute to the improvement of atmospheric modelling systems that predict how high smoke is travelling and transformed in the atmosphere, and where and when it will impact air quality near the ground.

To further describe the Canadian fire management operational end-users, we first provide a somewhat detailed context to the domain.

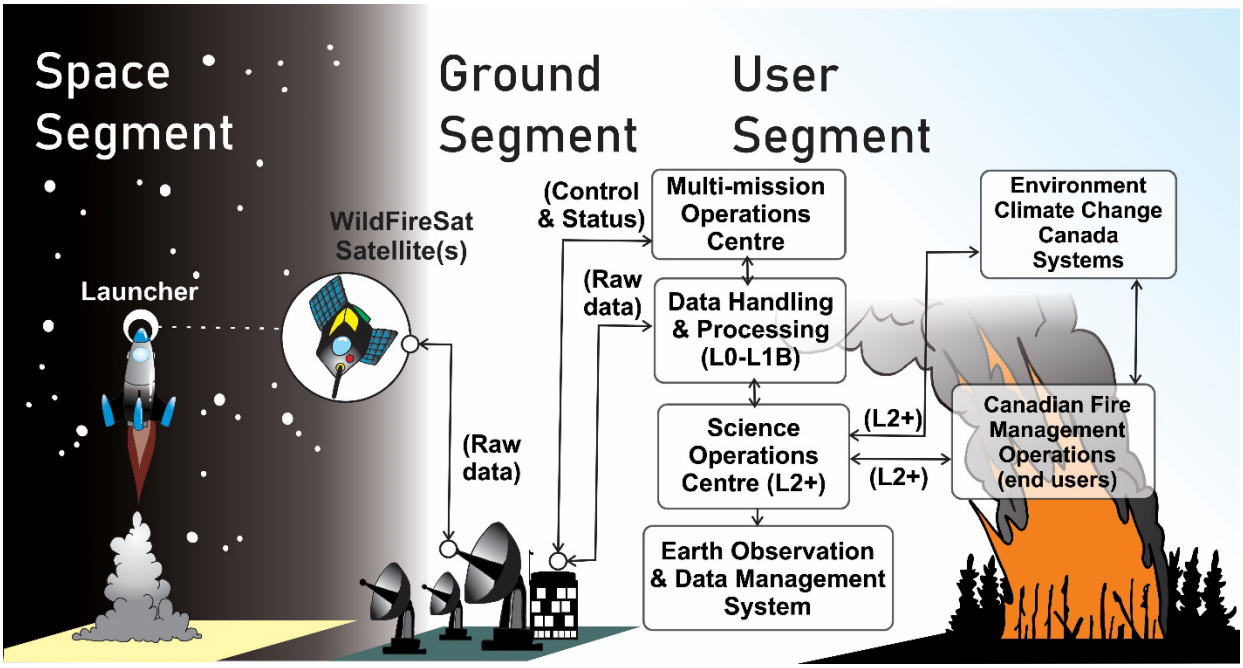

Figure 2. Illustration of the concept of operations for WildFireSat, version 2023.08.21. Adapted from the WildFireSat Canadian Operational Mission – Concept of Operations for authoritative version.

1.1 Wildland fire management domain

Indigenous fire stewardship

Indigenous Peoples have lived with fire in the boreal forest and fire-prone regions in Canada and have used fire since time immemorial for numerous purposes including community safety and resilience and as a tool for resource management (Christianson et al. 2022; Hoffman et al. 2021; Hoffman and Christianson et al. 2022). Indigenous fire stewardship (sometimes synonymous with fire management) is Indigenous-led fire response that includes the use or suppression of fire for desired outcomes, the intergenerational teachings of fire-related knowledge, beliefs, and practices regarding fire regimes and their effects, and the role of cultural burning in fire-prone ecosystems and habitats (Lake and Christianson 2020). Globally, Indigenous fire stewardship spans thousands of years, many cultures and is part of a holistic approach to taking care of the land across the world. Due to colonization, Indigenous fire stewardship practices were criminalized and the long-standing relationship with fire has been buried under colonial and Western fire management strategies, agency-led fire suppression policies, and regulatory authorities (Christianson et al. 2022; Hoffman and Christanson et al. 2022; Hoffman et al. 2021; Zahara 2020). Despite this, fire continues to have important ecological, cultural, spiritual, and ceremonial significance for many Indigenous cultures, and many Indigenous People continue to be carriers of fire knowledge (Sankey 2018; Hoffman and Christianson et al. 2022).

Indigenous Peoples have a unique relationship with the Crown and Canada due to modern and historical Treaties—many of which were agreed to before the creation of Provinces and Territories. Due to separation of powers in federal and provincial legislation, largely enacted without consultation and consent of Indigenous people, operational fire management is primarily a role of the Provinces and Territories who act on behalf of the Crown (Tough 2003;

Laidlaw and Passelac-Ross 2010). As they are self-determining, Indigenous nations must be meaningfully included and have space created for a leadership role in wildland fire management, respecting and recognizing this unique relationship. These jurisdictional relationships and interactions are complex. Barriers and challenges remain with the current fire policies and regulatory authorities (Beverly and Bothwell 2011; Christianson 2014; Hoffman and Christianson et al. 2022; McGee et al. 2019).

The authors acknowledge the importance and value of Indigenous science and ways of knowing with respect to land management. This approach emphasises knowledge co-development and co-creation with Indigenous Peoples on tools or products that may influence them, their community safety and resilience, and how their territories are viewed and managed. Although this document is directed towards provincial and territorial fire management agencies, the WildFireSat team is aware that meaningful inclusion of Indigenous People, their knowledge, and needs in WildFireSat knowledge exchange is necessary and will involve Indigenous organizations or end-users following appropriate protocols as part of this initiative, see Section 5.4.

Read more on Indigenous fire stewardship and Indigenous Peoples' relationship with fire:

- The right to burn: barriers and opportunities for Indigenous-led fire stewardship in Canada (Hoffman and Christianson et al. 2022) https://cfs.nrcan.gc.ca/publications?id=40761
- Centering Indigenous voices: The role of fire in the boreal forest of North America (Christianson et al. 2022) – https://cfs.nrcan.gc.ca/publications?id=40751

Provincial, territorial, and federal government wildland fire management

When a wildland fire occurs in Canada, many of the provincial and territorial fire management agencies are the first responders and typically prioritize fire suppression, with the goal being extinguishment in higher risk situations (Tymstra et al. 2020). However, there are instances where wildland fires are allowed to burn without full suppression to achieve other objectives (e.g., for ecological benefit). Some jurisdictions use boundaries or zones that indicate areas prioritizing suppression and areas where fires may not be fully suppressed (see Tymstra et al. 2020). Another approach is where decisions are made to contain or allow area burned according to each fire's circumstances without zone directed response (see Boychuck and McFayden 2017).

An important role of the federal government in wildland fire is to support the provinces and territories with science and technology as well as manage fires on some federal lands (amongst other roles). Federal departments and agencies involved in supporting fire management on federal lands include but are not limited to Parks Canada, and the National Defence Fire Service. The interactions of different levels of government for wildland management fire is complex. Although similar in many ways, each fire management agency has its own mandate, strategies, and priorities (for more information on fire management in Canada see Tymstra 2020).

No single fire management agency can maintain the firefighting resource levels necessary to fully manage the extreme peaks in fire load experienced in Canada. Canada is characterized by periods of a few manageable fires each day, to periods with hundreds of new fires in weather conditions conducive to extreme fire behaviour, resulting in many fast-moving and intense fires. Adding to the challenge, these fires may be spread across an incredibly large area. Furthermore, as stated earlier, fire plays an important role in healthy and sustainable ecosystems and therefore not all fires should be extinguished in Canada.

To manage situations of fire escalatiion across the country, Canada relies on a coordinated sharing of its firefighting resources (e.g., equipment, firefighters) between the provincial, territorial, and federal agencies. Resource sharing is brokered through the Canadian Interagency Forest Fire Centre (CIFFC), a not-for-profit corporation operated by the federal, provincial, and territorial wildland fire management agencies. CIFFC coordinates mutual aid and facilitates national and international resource exchange (Canadian Interagency Forest Fire Centre 2023).

Read more on the Canadian Wildland Fire Management Strategy:

- Canadian Wildland Fire Strategy. A 10-year review and renewed call to action (Canadian Council of Forest Ministers, 2016) – https://cfs.nrcan.gc.ca/publications?id=37108
- Action Plan 2021-2026. A roadmap for implementing the Canadian Wildland fire management strategy, a whole of government approach (Canadian Council of Forest Ministers, 2021) – https://www.ccfm.org/releases/wildland-fire-management-working-group-action-plan-2021-2026/

Aspects of wildland fire in Canada

Annually, between 1980-2021 there was an average of ~7,500 fires seen across the country (Canadian Forest Service 2021a). There is huge variation in what areas of the country are impacted by fire any given year. The amount of area burned can vary significantly from year to year and on average (1980-2021) ~2.5 million hectares burn every year. At the time of this writing, Canada is having its worst fire season on record (Government of Canada 2023a). In the last 40 years, the record annual area burned in Canada was over 7 million hectares in 1989 (Canadian Forest Service 2021a), but the 2023 fire season has shattered this record with over 18 million hectares burned (Canadian Interagency Forest Fire Centre 2023a).

The following maps illustrate relevant aspects of fire management in Canada to show the scale and scope of the challenge. Figure 3 shows the area burned by wildland fire from 1980 to 2021.

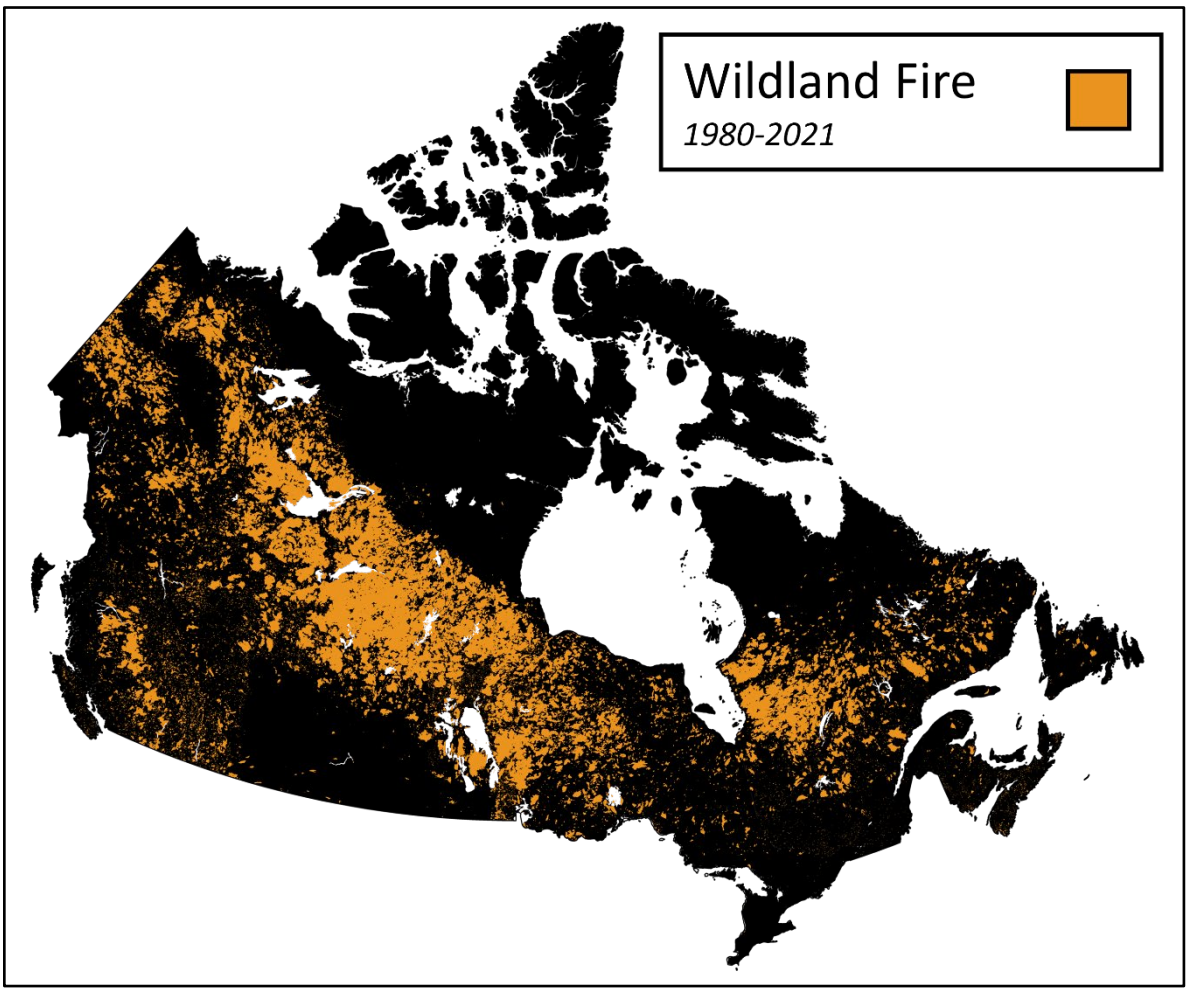

Figure 3. The area burned in Canada between 1980 and 2021; data from the National Fire Database (Canadian Forest Service 2021a) and the National Burned Area Composite (Canadian Forest Service 2021b).

Much of Canada is very remote and there are widespread areas where people, their homes and infrastructure are located near wildland fuels which are potentially susceptible to fire (Figure 4). This is referred to as the wildland-human interface, consisting of urban, industry and infrastructure interfaces (Johnston and Flannigan 2018). When there is fire within these interface areas there are critical concerns for impacts to human life and property.

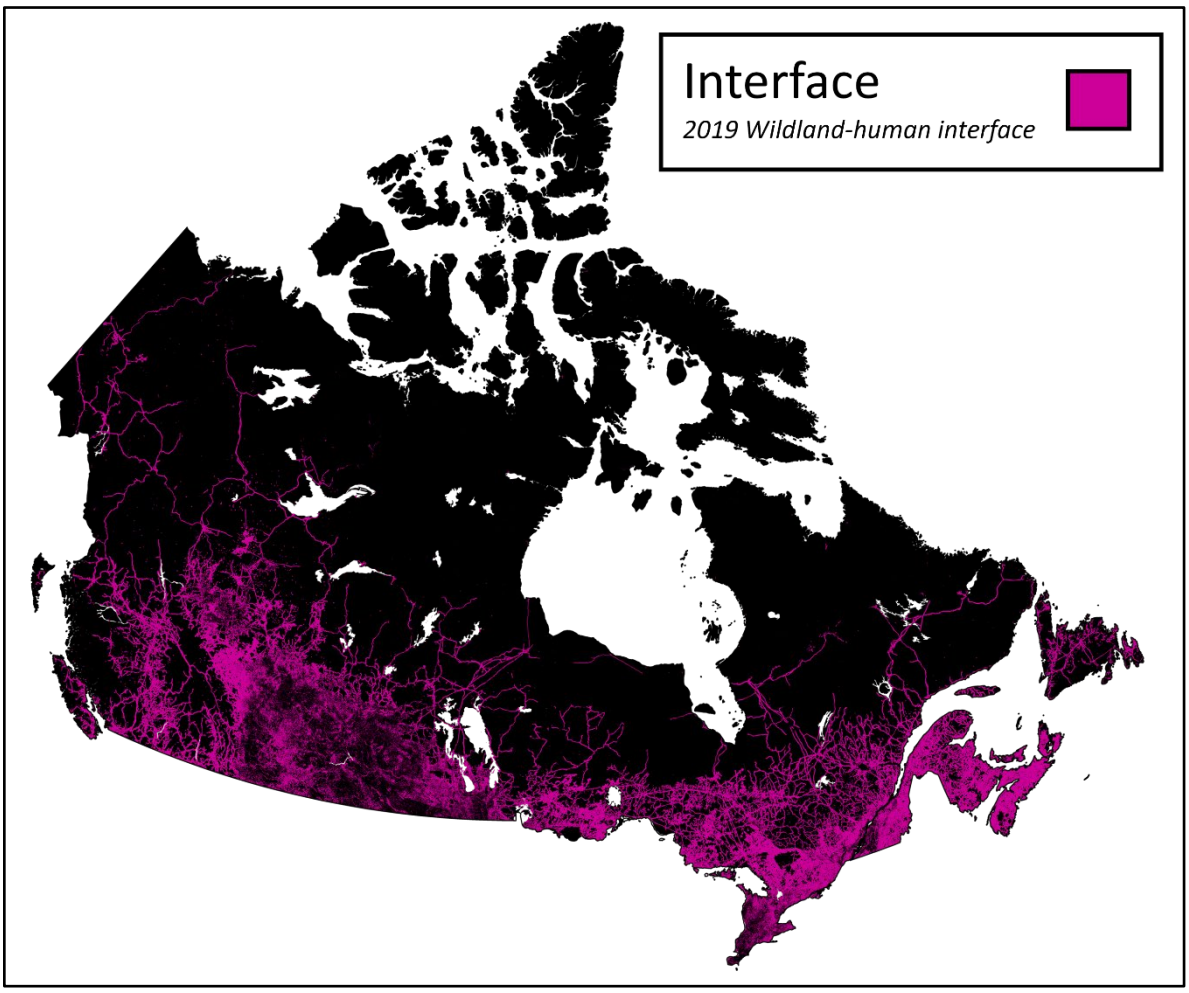

Figure 4. The wildland-human interface from 2019; data updated from Johnston and Flannigan 2018.

Evacuations are often used to protect people, and unfortunately, they have become a more frequent necessity in recent years. Figure 5 shows evacuations due to fire, which ultimately have impacted well over a half million people from 1980 to 2021, with many remote communities being disproportionately impacted (Christianson et al. in review; Beverley and Bothwell 2011; Erni et al. 2021; McGee et al. 2019; McGee 2021). The recent 2023 fire season will add a record-breaking number of evacuees to this count.

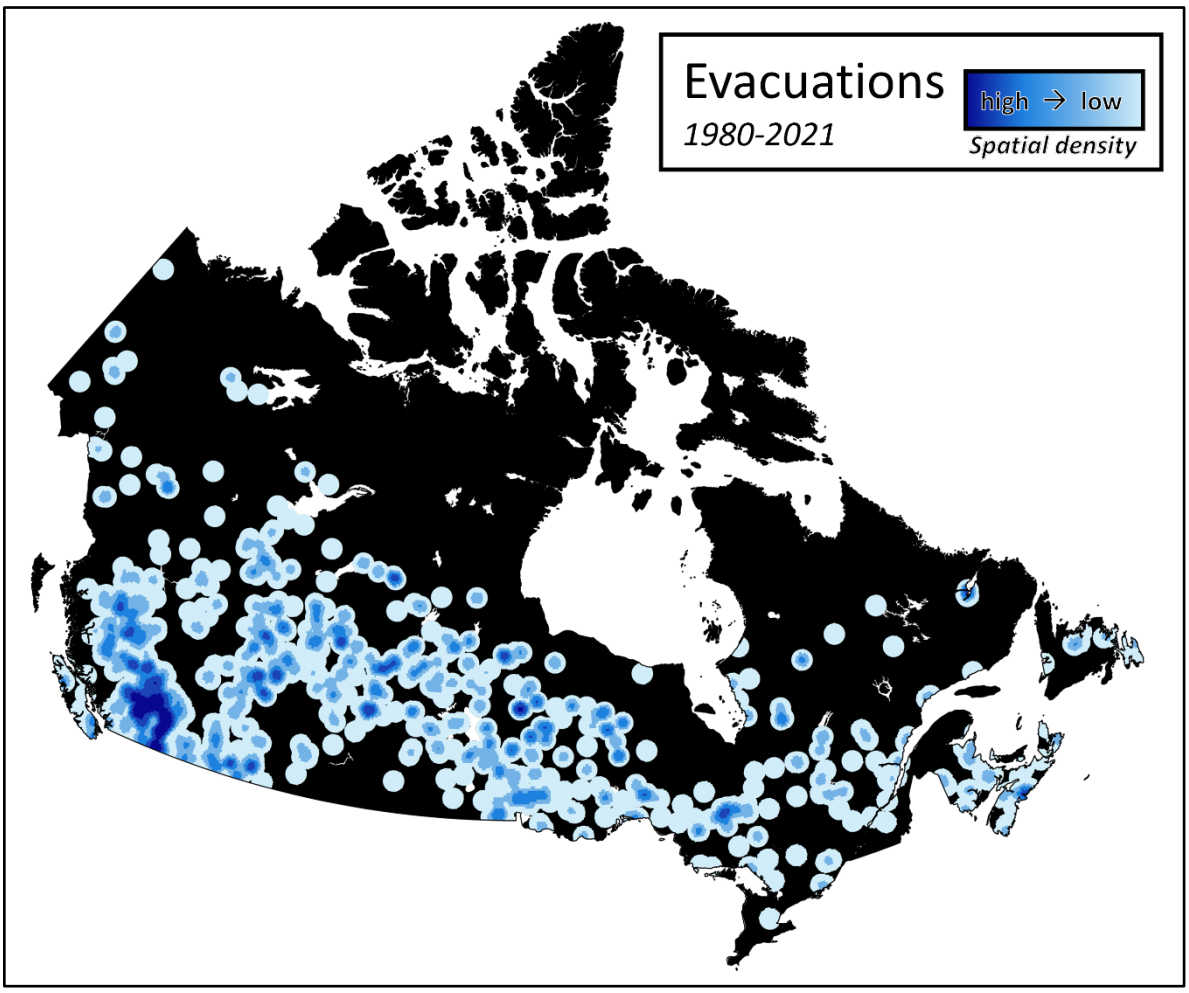

Figure 5. Location of evacuations due to wildland fire between 1980 and 2021, with darker blue indicating more evacuations in that area (data from Canadian Forest Service 2021c).

Management paradigms

Emergency management as described in "An Emergency Management Framework for Canada" (Emergency Management Policy and Outreach Directorate 2017) and wildland fire management as described in the "Canadian Wildland Fire Strategy A 10-year Review and Renewed Call to Action" (Canadian Council of Forest Ministers 2016) are examples management paradigms with similar but important differences. Emergency and wildland fire management are generally organized under aspects of prevention, mitigation, preparedness, response, and recovery. However, an important contrast is that not all wildland fires are emergencies. As a result, fire managers cannot solely focus on emergency or disaster response, but must also consider forest planning, habitat, and other important aspects and benefits of fire on the landscape (e.g., MNRF 2014).

The management of fire operates on a continuum, from the desired application of beneficial fire (e.g., prescribed burning), allowing fire on the landscape for ecological purposes (e.g., monitoring a fire), returning "good fire" to the land through cultural burning (e.g., Muskrats to Moose Project Team 2023) through to the suppression of typical wildland fires (e.g., small, and low impact) and firefighting on catastrophic disaster fires. The tactics and strategies to used in these various scenarios are broad. For clarity we describe wildland fire management as follows:

- **Wildland fire management:** the activities concerned with the protection of people, property, and wildland areas from wildland fire, and the use of fire to achieve protection and land use objectives. Aspects include the processes and strategies for wildland fire prevention, mitigation, and response (adapted from MNRF 2014, Government of Canada 2023d).

The spatial and temporal scopes of wildland fires, their effects, impacts, and the associated decision-making are very wide. Individual fires range in size from very small to hundreds of thousands of hectares and last from less than a day to several weeks or months (or even years). The impacts from the decisions made on a specific fire, on a given day, can cascade over decades and larger areas to affect the fire regime, ecosystem health, and future risk. Fire management strategies and decisions must consider how to approach the scope (e.g., Simard 1991; Tedim 2015; Boychuk et al. 2020; Taylor 2020). Correspondingly, it is important to consider the scope when developing or applying any model or tool for a particular aspect of wildland fire management.

The scope for the tactical and strategic decisions and the corresponding fire management functionalities necessary for a purpose-built wildland fire satellite mission are described in Johnston et al. (2020b). This scope is described as operational fire management and includes the decisions made in the daily tactical and shorter-term strategic planning and processes of fire operations:

- **Operational wildland fire management**: planning for and carrying out the operational activities of wildland fire management, such as wildland fire preparedness, discovery, suppression, monitoring, and mitigation.

We recognize the value of WildFireSat pre- and post-fire information and intelligence to both the research community and for other applications that operate at different time/space scales such as, forest management (Crowley et al. 2023).

1.2 End-user(s)

The primary end-users in this document are described as operational fire managers: operational in that they plan for and carry out the activities of operational wildland fire management, and fire managers[3] meaning they work in a wildland fire management domain or otherwise manage the fire.

This definition of end-users prioritizes the people who may create, interpret, or otherwise interact with WildFireSat products in operational wildland fire management.

[3] Fire manager is synonymous with practitioner and is not meant to infer a manager in the human resources sense.

Read more about the development of the WildFireSat user requirements tailored to wildland fire management and operational fire managers:

- Development of the User Requirements for the Canadian WildFireSat Satellite Mission (Johnston et al. 2020b) – https://cfs.nrcan.gc.ca/publications?id=40964

Provincial, territorial, and federal operational wildland fire management user agencies are:

- Alberta, Wildfire Management Branch
- British Columbia, Wildfire Service
- Government of Canada, National Defence Fire Service
- Manitoba, Wildfire Service
- New Brunswick, Forest Fire Management Branch
- Newfoundland and Labrador, Forest Fire Management
- Northwest Territories, Department of Environment and Climate Change
- Nova Scotia, Fleet and Forest Protection
- Ontario, Aviation, Forest Fire and Emergency Services
- Parks Canada, National Fire Management Division
- Prince Edward Island, Department of Environment, Energy and Climate Action
- Québec, Société de protection des forêts contre le feu (Ministère des Forêts, de la Faune et des Parcs)
- Saskatchewan, Public Safety Agency
- Yukon Territory, Wildland Fire Management Branch

Note: The Nunavut Territory does not have a specific wildland fire management agency.

Some examples of fire managers (i.e., end-users) are:

- Incident commanders
- Plans section chiefs
- Operations section chiefs
- Duty officers (regional command)
- GIS specialists/technicians
- Fire intelligence specialists/technicians
- Fire detection specialists/technicians
- Fire behaviour analysts
- Long-term analysts
- Predictive services specialists/technicians
- Air attack officers
- Other positions and roles on incident command teams and in agency operations

Read more about provincial and territorial fire management agencies on the Canadian Forest Fire Interagency Center website:

- https://ciffc.ca/fire-information/member-agencies

We acknowledge that there are other end-user groups not directly addressed in this document that may be informed from WildFireSat data and products (e.g., Indigenous Peoples, municipalities, industry, researchers, and the public).

2. STRATEGIC FOCUS

The conceptual interactions between any fire management agency workload, mandate and organizational structure as described in previous sections is simplified in Figure 6. This is meant to be illustrative; the nature of fire management program design is much more complex. The attributes that drive the strategies and activities that an agency employs to manage fire and the subsequent demands for fire intelligence and associated decision-making are shown as a cycle, relative to the use of remote sensing. Figure 6 also illustrates two priorities which guide this strategy: understanding wildland fire decisions and capacity.

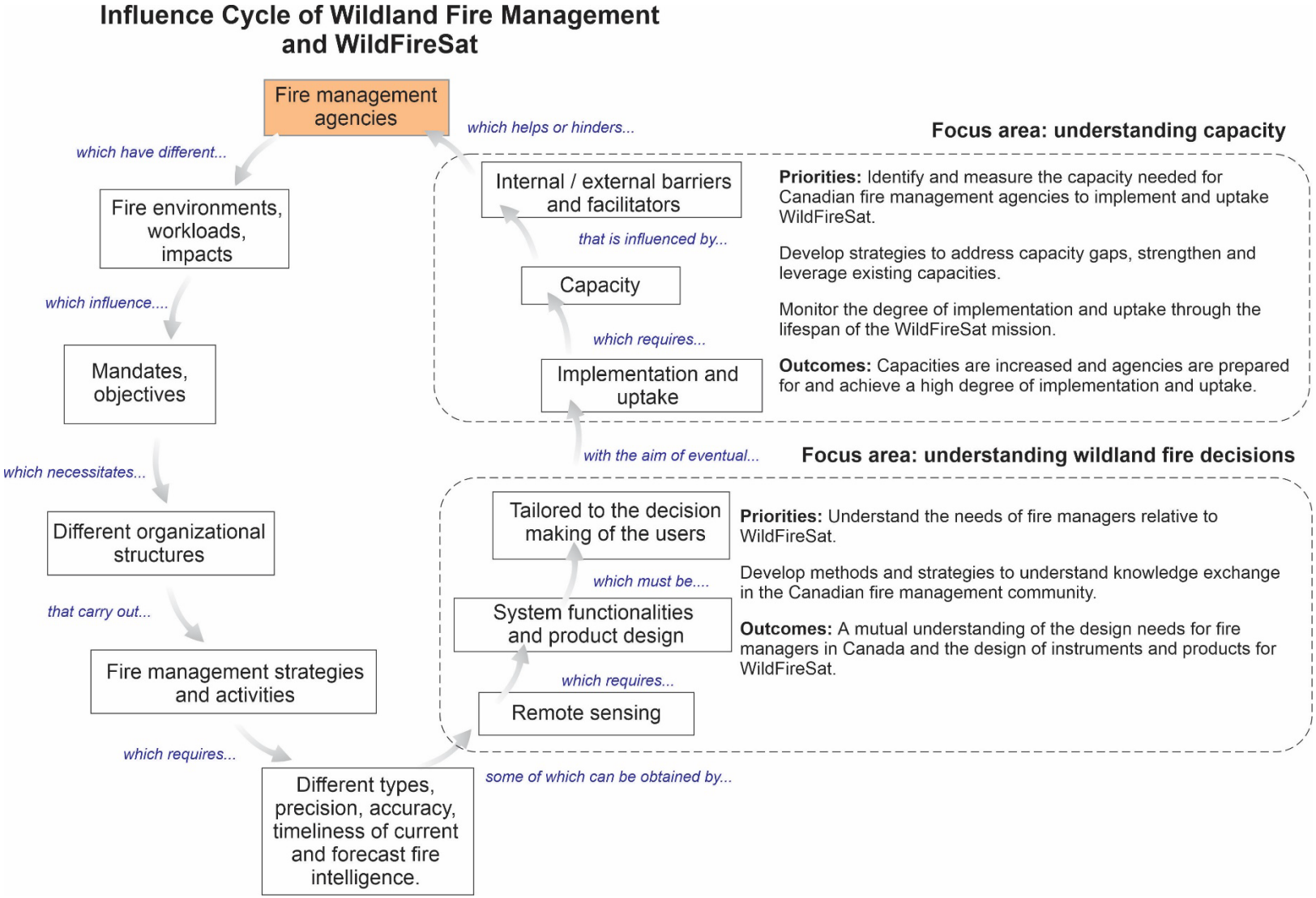

Figure 6. Concept map of the interactions between fire management agency design and influencing factors and use of remote sensing products. The orange square is the starting point.

2.1 Focus area: understanding wildland fire decisions

Fire managers seek the tools that they can trust and that meet the real-world needs (Thompson et al. 2022). Whether decisions need a quick response using expertise and the information on hand, or if there is time for a more analytical approach, there are some shared factors in decision-making. It is important to understand these factors, and the different perspectives of the decision-makers and those affected by the decisions and the outcomes. Doing so will illuminate the real-world nature of the decisions. To ensure WildFireSat products will be relevant to the decision-makers, WildFireSat product designers must also understand fire manager objectives in decision-making and how those objectives might vary under different situations. This understanding can inform the data products being developed to ensure they are suitable for the uses. This understanding can be accomplished through knowledge exchange principles and activities.

2.2 Focus area: understanding capacity

Wildland fire management is a high-stakes domain. The willingness of an agency to adopt new tools, techniques or modify its current processes requires several aspects of capacity. Ultimately, the degree of implementation, uptake, and the sustainability of the application of WildFireSat in fire operations is dependent on those capacities. McFayden et al. (2022) listed important capacities, including: financial capacity; capacity through organizational commitment; coordination and training capacity; social capacity; and human resource capacity (e.g., personnel, expertise, experience). Any innovation that requires significant investment, training, and time prior to adoption may not be fully used by fire management agencies, especially if that innovation or requires divertiing otherwise committed resources. Understanding how barriers for capacity affects fire managers using WildFireSat is an important task, which can also be accomplished through knowledge exchange principles and activities.

3. CORE STRATEGY CONCEPTS

The following section describes the core concepts that underpin our strategic approach to ensure the successful implementation and uptake of WildFireSat within operational fire management in Canada. These concepts allow us to address questions arising from the two focus areas (Sections 2.1 and 2.2).

3.1 Knowledge exchange

In the wildland fire management context, the optimal path between an idea and implementation of a solution for fire management should be aided by the knowledge exchange (KE) process.

- **Knowledge exchange (KE)**: the process where knowledge is co-created, shared, and transformed for the benefit of research and fire managers where both are thought of as knowledge holders and producers (adapted from Graham et al. 2006; Reed et al. 2014; McFayden et al. 2023b and the references therein).

"…Ultimately, people and relationships are a crucial vehicle for overcoming barriers to successfully integrating science into practice..."

McFayden et al. 2023b.

Our goal is to engage in collaborative KE throughout the WildFireSat initiative – our KE work is not just a communication push at the end of the development process that states "here is our product". McFayden et al. (2023b) synthesized KE for fire management as an overarching system where reciprocal understanding takes place which leads to more suitable outcomes. In that model, KE involves sub-processes of knowledge exchange and technical transfer between diverse groups and domains of expertise, where the interface between these processes is aided by knowledge brokers.

- **Knowledge brokers:** are the impetus behind implementation and uptake. Knowledge brokers are a bridge between groups and are trusted opinion leaders. They help facilitate the research to operations processes (adapted from McFayden et al. 2023b, and references therein).

The processes of sharing and developing knowledge through the interacting phases of understanding the problems, exploring options, understanding the systems, and adapting knowledge for focused applications (McFayden et al. 2023b, and references therein) will provide a deeper understanding for both the WildFireSat team and fire managers when done iteratively and sustained through the lifespan of the mission.

Read more about the conceptual framework for KE in wildland fire research and practice developed in part to support of the WildFireSat mission:

- A Conceptual Framework for Knowledge Exchange in a Wildland Fire Research and Practice Context (McFayden et al. 2023b) – https://cfs.nrcan.gc.ca/publications?id=40954

3.1.1 High level barriers and facilitators to knowledge exchange

KE is not a simple process and there are facilitators or barriers that help or hinder it. McFayden et al. (2023b) organized some common barriers and facilitators to KE from the literature into central themes for the fire management context. Two of which we identified as broadly important in WildFireSat implementation and uptake (i.e., capacity and readiness) which we will expand on in subsequent sections (3.2 and 3.3). The others were communication, collaboration, trust, clear and aligned objectives, timing, motivation and ownership and authority.

Tosupport the success of WildFireSat use in operational fire management tailored strategies are needed to mitigate or enhance these barriers and facilitators to KE and successful adoption of WildFireSat data products.

3.1.2 Learning from past successes in knowledge exchange

To better understand the barriers and facilitators to support WildFireSat implementation we looked to a Canadian focused case study of one of the most successful examples of fire

science implementation and uptake in Canadian fire management, the Canadian Forest Fire Danger Rating System (CFFDRS) (see McFayden et al. 2022). The aim of that study was to identify and explore key factors contributing to this success through a retrospective case study.

Successful implementation and uptake of CFFDRS was associated with facilitators such as relationships between fire managers and researchers, and their shared experiences of trust in the knowledge brokers. Engaging early in the development and planning for training needs with the end-users was also flagged as important.

> *"…there needs to be that trust with the organization that developed [the product] and in the person who's in the program who has to deliver it and explain it..."*
>
> *McFayden et al. 2022.*

By adapting the perspectives and lessons learned from KE from the past, the WildFireSat mission's approach to support implementation and uptake may be more successful. While we recognize that lessons from the past are important, we likewise are aware that fire management organizations, cultures and technologies have evolved since CFFDRS was first introduced (McFayden et al. 2022). Therefore, we will not solely rely on these historical lessons but also elicit a current perspective through active fire management agency engagement.

Read more about a case-study and insights of successful wildland fire management KE and the barriers and facilitations for integration of the Canadian Forest Fire Danger Rating System:

- A case-study of wildland fire management knowledge exchange: the barriers and facilitators in the development and integration of the Canadian Forest Fire Danger Rating System in Ontario, Canada (McFayden et al. 2022) – https://cfs.nrcan.gc.ca/publications?id=40771

3.1.3 WildFireSat KE principles and best practices

The following are some of the principles or best practices for moving through this KE process for WildFireSat and fire management agencies and include: (adapted from McFayden et al. 2023b and McFayden 2022):

- Knowledge that is held by researchers and fire managers is best shared or co-produced through bi-directional sharing and collaboration.
- Mutual exchange between the WildFireSat development team and fire managers will be focused through shared experiences. Engagement must include activities where the WildFireSat development teams engage with fire managers during their day-to-day operations.
- People and relationships are a crucial vehicle for overcoming barriers to successfully implementing WildFireSat into practice. The WildFireSat mission recognizes this and will prioritize activities that facilitate fostering relationships with fire managers.
- Effective KE depends on networks of diverse people and teams where individuals can contribute in several ways that suit their expertise and interests. The WildFireSat mission

will encourage and support inclusivity and diversity in KE engagement across the fire management and research domains.

- Knowledge brokers within fire management agencies are necessary to facilitate the KE process. The WildFireSat mission will support and work directly with knowledge brokers in fire management agencies.
- The WildFireSat development team and fire managers must work together to address operational challenges and maintain mutual incentives to engage in beneficial collaboration and develop trust.

3.2 Capacity

As one of the nine primary barriers and facilitators to KE, the capacity of fire management agencies and fire managers to eventually make use of the WildFireSat products must be considered in early stages of development.

> *"... Fire management agencies have finite funds to cover many operational activities, and research and development may be seen as a risky investment without clear demonstration of cost and benefit..."*
>
> *McFayden et al. 2022. (Supplementary Material A2)*

Capacity can be defined in many ways, and it is simply the capacity to do "something" by "someone" (e.g., Honadle 1981; Mizrahi 2004; Lusthaus et al. 1999; Prajogo et al. 2006; Brinkerhoff and Morgan 2010; Hossain et al. 2016). For clarity, we define the term as follows:

- **Capacity:** the actual or potential abilities and capabilities that enable a wildland fire management agency to adapt for and implement WildFireSat products into operational fire management.

An organizations level of capacity is difficult to measure. However, we believe there are certain factors that can provide insight for the development of strategies to address capacity gaps[4]. The first step is to assess the baseline capacity for each fire management agency for relative to capacity to use WildFireSat data products.

[4] The exploration of capacity is also done in support of the Committee for Earth Observation Satellites, Disasters Working Group (see https://ceos.org/ourwork/workinggroups/disasters/wildfire-pilot/).

3.3 Readiness

Readiness was also identified as one of the nine important barriers and facilitators in McFayden et al. (2023b) and is essentially an early assessment of some attributes of capacity (a baseline). To inform this baseline assessment a model specific to the WildFireSat mission was developed (McFayden et al. 2023a).

- **Readiness**: an organization's state of preparedness for effective adoption, assimilation, and exploitation of WildFireSat (adapted from Lokuge et al. 2019).

> *"…Incremental changes and especially transformational changes take time, effort, and knowledge. There is a time-limited opportunity before launch during which agencies can prepare in advance, and therefore be ready to fully benefit much more rapidly from WildFireSat products..."*
>
> *McFayden et al. 2023a.*

McFayden et al. (2023a) evaluated readiness via a set of attributes, including: (1) the degree and scope of understanding and use of satellite active fire products, (2) organizational factors affecting use, including the capabilities represented by people, processes, and structure, and (3) the type and agility of information technology use. Figure 7 illustrates the general conceptual model for the WildFireSat readiness assessment.

A national assessment and agency specific assessments of readiness for WildFireSat were completed for twelve of Canada's fire management agencies. As described in McFayden et al. (2023a) the national assessment suggests that some agencies had characteristics indicating that they would be able to incorporate WildFireSat data products into their operations more readily than others. Fire management agencies appear to be more ready in terms of information management and information technology, while relatively less prepared when it comes to organization and understanding (described in Figure 7). Individual readiness reports were co-authored with the fire management agencies for their internal consumption and application.

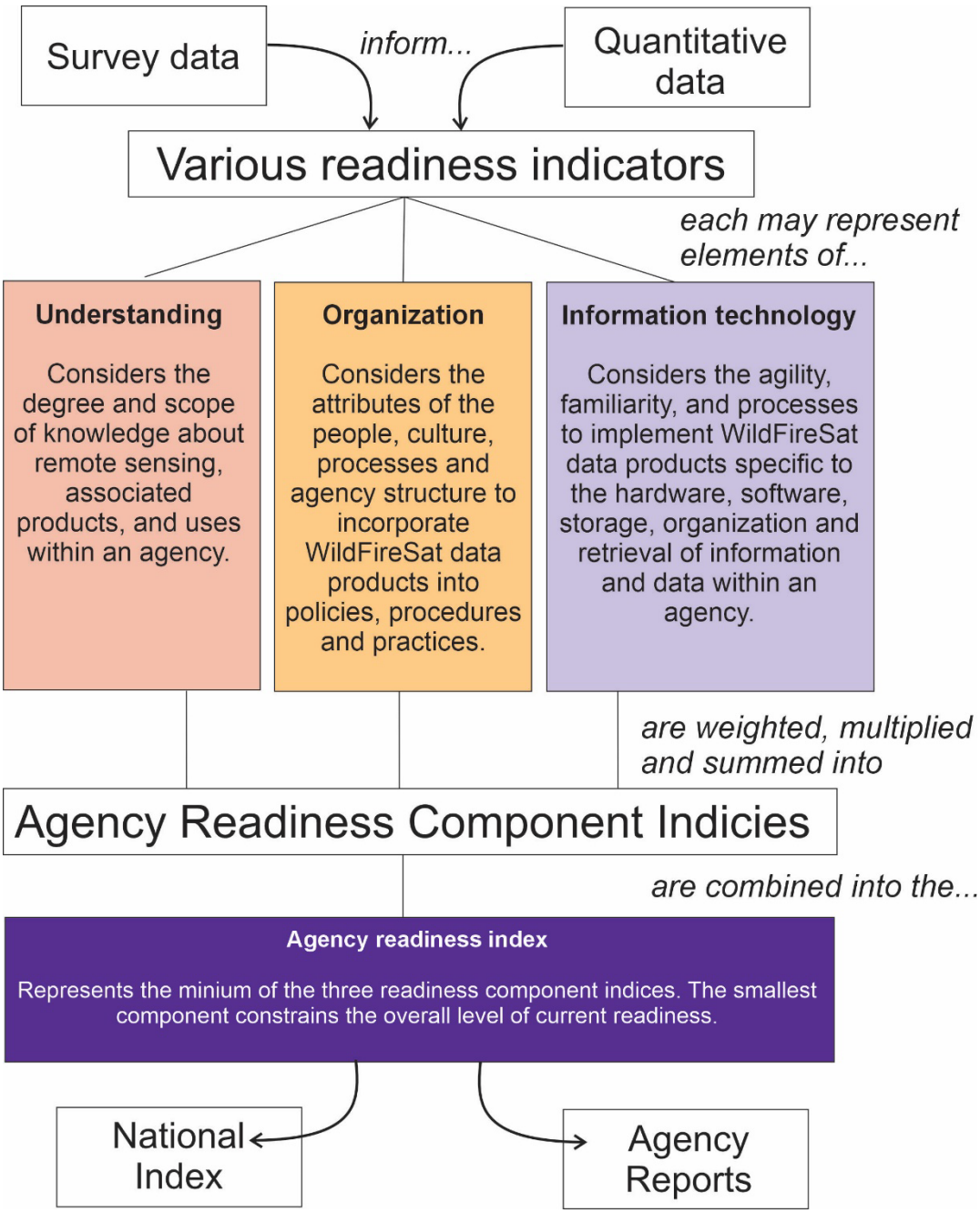

Figure 7. Model for WildFireSat readiness assessment, adapted from McFayden et al. 2023a.

Read more about the Canadian Fire Management agency readiness for WildFireSat:

- Canadian Fire Management Agency Readiness for WildFireSat: Assessment and Strategies for Enhanced Preparedness (McFayden et al. 2023a) – https://cfs.nrcan.gc.ca/publications?id=40934

Critical dates:

- WildFireSat Canadian provincial and territorial fire management agency readiness assessment completed 5 years prior to launch.
- Readiness revisited 1 year prelaunch.

3.4 Implementation and uptake

In general, implementation is focused on the organizational processes used to put WildFireSat data products into practice and is an outcome of the KE process (McFayden et al. 2023b). There are process-based methodologies that fire management agencies can use to implement WildFireSat data products, such as a policy review cycle, procedure task team, or project plan. This requires some level of commitment from an organization to resource and maintain the implementation. Implementation can have different meanings, but here we define it as:

- **Implementation:** a systematic approach taken by a fire management agency to assess the suitability of WildFireSat data products, adopt and integrate them into common practice, and sustained adoption through time (adapted from Powell et al. 2012; Olswang and Prelock 2015; Rapport et al. 2018).

Implementation may include decisions required by an agency, such as determining 1) the need for WildFireSat products, 2) the suitability of the products for decision-making and use cases, 3) the appropriate level of use of WildFireSat products by fire managers (i.e., passively or as a matter of standard procedure), 4) the type of training required and 5) the level of documentation required (e.g., recording decisions, policy).

Where implementation is focused on organizational integration, uptake is focused on the people within the organization their perspectives, attitudes, sense of trust and ownership.

- **Uptake*:*** to adopt WildFireSat products in the culture of an organization and the people within it.

It is important to note that in this model of capacity, a fire management agency can implement WildFireSat, but fail to achieve uptake (i.e., there are processes to use it, but no one does). Likewise, an agency employee can trust WildFireSat products (i.e., seek out products freely available and use them as a personal choice) but if the agency does not implement the data products, then institutional sustainability of the use is likely more fragile and dependant on individuals. Our objective is to promote both implementation and uptake of WildFireSat by fire management agencies. Figure 8 illustrates a conceptual relationship between implementation and uptake. The numbers represent a notional scale of impact (the real-world changes) as a result of the levels of implementation and uptake. The numbers are non-linear representing our feelings on the weighting towards uptake. There is some ideal degree of implementation and uptake that are most suitable for WildFireSat products. Determining this is not simple and trade-offs are required considering the cost to achieve implementation and uptake and the

resulting impact. It is possible that not every fire management agency needs the same level of implementation and uptake to achieve their desired impact.

What constitutes full organizational implementation is also an important consideration and is likely relative to the needs and structure of the agency. For example, an agency that has a policy that empowers agile modelling for staff that are encouraged to use public WildFireSat data; if this suits the organizational needs it could be considered “full implementation”. Other agencies may want to tailor an internal information system to automate WildFireSat data products, develop mandatory training, and put in place requirements and standards for use. This may also be considered “full implementation”. These are both potential examples of full implementation that are quite different in terms of policies, procedures, resources and so on.

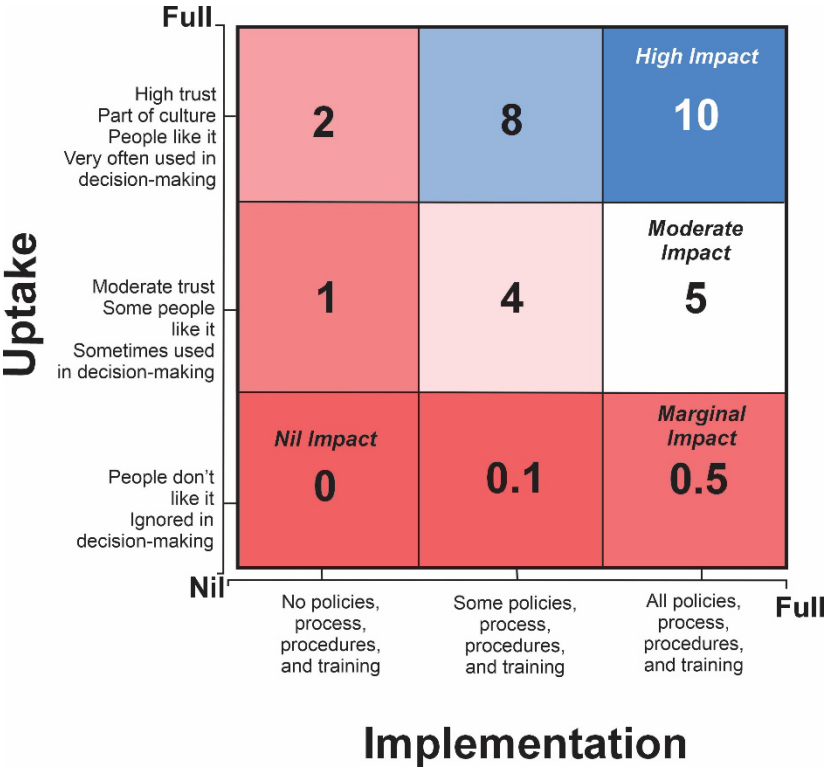

Figure 8. Interactions of implementation and uptake and impact.

In summary, the level of uptake is about the people in the organization, level of implementation is about the policy and processes of the organization. The impact is about the degree of real-world change that is brought about. The appropriate levels of implementation and uptake depends on a fire management agency’s unique need. It is our task to work through these questions alongside the fire management agencies and support, not prescribe, the appropriate levels of implementation and uptake they decide to pursue.

4. KNOWLEDGE EXCHANGE PROGRAM ELEMENTS

The following section outlines the key components of the KE program developed for the WildFireSat mission. These are not exhaustive and will evolve through the life of the WildFireSat mission.

4.1 Develop a collaborative Fire Management Knowledge Exchange (FMKE) team

A critical component to WildFireSat success will be to engage with the wildland fire management decision-makers in meaningful ways to ensure mutual understanding. Tothis end we assembled a Fire Management Knowledge Exchange (FMKE) team comprised of knowledge brokers within each federal, provincial, and territorial fire management agency and other government operational groups (e.g., CIFFC and the Canadian Association of Fire Chiefs). The objective of the FMKE is to bring together those with fire management expertise to collaborate with each other and with the WildFireSat team. The FMKE is not intended to prescribe work for the provinces and territories, nor act in an oversight role. The FMKE is focused on relationship building and knowledge co-producion.

FMKE members are experts in the workings of their respective fire management agencies. The CIFFC member agency participants were solicited through the CIFFC Management Committee. Although supported by their respective agency, it is important to flag that participation on the FMKE was voluntary by the agency and participants. This voluntary nature of participation in the FMKE was done to attract genuine interest and collaboration (i.e., those interested and passionate will more likely volunteer to participate).

The FMKE is a critical component of our overall approach to KE with the provincial and territorial fire management agencies. The FMKE allows us to form relationships with agency knowledge brokers while also having an avenue to share expertise respective expertise. FMKE activities include recurring meetings along with specific task-oriented sessions. FMKE members will play a key role in the development of a community of practice and training materials.

There are many ways to engage provincial and territorial agencies that range in formality and purpose. We prioritize opportunities that support the relationship and trust building. There are strengths and weakness associated different types of meetings i.e., in person, virtual or hybrid (see Standaert et al. 2022). To ensure we are both efficient (time, money, impact) and effective (objectives, outcomes) while also considering the constraints, WildFireSat engagement will prioritize both in-person and virtual meetings under the following circumstances:

- In-person meetings:
    - The objectives are complex, require multiple and interacting topics, group or joint sessions that run concurrently, to set long-term goals or make progress on a certain project. Where there is opportunity to leverage attendance with other meetings.
- Virtual meetings:
    - The objectives are simple, information sharing, one-way communications, single topics, to review progress and provide updates on work.

In-person meeting priority examples:

- Annual workshops (e.g., FMKE team, topic specific focus groups)
- Joint stakeholder workshops
- Tier collaborative sessions
- Remote sensing and wildland fire science and operations conferences (e.g., Wildland Fire Canada Conference; Canadian Remote Sensing Symposium)

Virtual meeting priority examples:

- Tri-weekly FMKE update meetings
- Low complex project update meetings with task teams
- Briefings and technical updates (e.g., CIFFC national conversations)

Critical Dates:

- Annually at least one face to face with the FMKE 5 years pre-launch with a duration of 3 years post launch.

4.1.1 FMKE team and WildFireSat Tier development team collaboration

The collaboration of the FMKE team and the WildFireSat Tier development teams will occur iteratively both coordinated and organically throughout the development process. The WildFireSat Tier leads are included in the FMKE. Specific to the Tier development, the primary role of the FMKE is to provide subject matter expertise on aspects of operational fire management. A primary focus will be on how Tier products are presented to end-users in terms of file formats, access, visualizations, and interpretations which will be informed at the sandbox testing stage (Section 5.2). The intent is that the FMKE and the Tier development teams are “open door” accessible and there is a focus on building and sharing knowledge of their respective domains which will feed into uptake and implementation support.

Topics for tailoring the representation of WildFireSat products will include:

- Determine, quantify, and communicate uncertainty/confidence in general.
- Identify and communicate false positives (e.g., gas flares, industrial areas).
- Aspects of fire characteristics for operations (e.g., rate of spread vs. progression).
- Data sources for integrating into WildFireSat synthesis pipeline.

Critical dates:

- WildFireSat Fire Management Knowledge Exchange (FMKE) team formed 5 years prior to launch.
- FMKE sustained 3 years post launch and revisited for duration.

4.2 Determine strategies for increased likelihood of implementation and uptake

We propose that the following strategies and activities (Table 1) may increase fire management agency readiness, capacity and ultimately lead to the appropriate degree of implementation and uptake of WildFireSat products. We recognize that these strategies and activities can support multiple components of readiness as well as implementation and uptake. These strategies are first presented in supplementary S.4 of McFayden et al. (2023a).

Table 1. Strategies and activities to improve WildFireSat implementation and uptake from as presented in McFayden et al. 2023a, Supplementary Information S4. WildFireSat Strategies and Activities to Increase Readiness.

Strategy	Activities
Increasing education and training in remote sensing and for interpretation of fire intelligence for decision-making	• Develop a range of educational materials on the types, kinds, and uses of remote sensing for operational fire management. • Develop accessible training courses in the fundamentals of decision-making and model interpretation to better understand and use the fire intelligence possible with WildFireSat. • Ensure training/education is considered as a requirement for products and delivery mechanisms developed by WildFireSat.
Increasing expertise within agencies and within the broader fire management community	• Develop a community of practice for remote sensing and fire intelligence between fire management agencies and with subject-matter-experts within accessible national agency groups. • Create an environment (e.g., sandbox environment) for agencies to collaboratively try and experiment with remote sensing and fire intelligence prior to WildFireSat availability. • Create a forum for compiling lessons learned best practices and communications. • Support exchange of fire management staff between agencies of different levels of remote sensing readiness to learn from their experiences and approaches in use of current systems.
Fostering active communications between development team and fire management community in the design and development of WildFireSat products	• Maintain a WildFireSat Fire Management Knowledge Exchange (FMKE) team, with Provincial and Territorial representation and the product development teams for WildFireSat. • Involve fire management staff in the development of WildFireSat products early and iteratively. • Regular meetings between WildFireSat team and with various fire management cadres, groups, and subject matter experts. • Participate in collaborative communications, conferences, and other venues. • Prioritize in-person engagement, learning and knowledge exchange opportunities.

Strategy	Activities
Alignment and compatibility of information management and technology with the fire management agencies requirements	• Provide open access to WildFireSat products and data where appropriate. • Allocate time, and staff to promote use of free and open-source software. • Support and encourage coordination of joint/common fire management data standards across agencies where possible and appropriate (e.g., the Canadian Wildland Fire Information Framework initiative). • Develop WildFireSat products for compatibility with agency data standards when not aligned with open standards. • Distribute test data products so that agencies can explore incorporation into their systems in advance of the real data being made available.
Increasing capacity for implementation	• Increase or allocate the time, resources, and staff to develop implementation plans and procedures within agencies (e.g., formal assignments, internships). • Explore opportunities for agency partnerships in implementation readiness projects such as through the Canadian Interagency Forest Fire Centre, agency compacts. • Partner with fire management agencies of similar needs on joint implementation strategies. • Investigate use of new or existing national frameworks for dissemination of fire management data and products (e.g., Canadian Wildland Fire Information Framework).

Read more on the strategies and activities elicited from engagement with the fire management agencies:

- Supplementary Information– Canadian Fire Management Agency Readiness for WildFireSat: Assessment and Strategies for Enhanced Preparedness (McFayden et al. 2023a, Supplemental S4. WildFireSat Strategies and Activities to Increase Readiness) –https://www.mdpi.com/article/10.3390/fire6020073/s1

Critical dates:

- Strategies and activities identified 5 years prior to launch.
- Revisited and refined 2 years prior to launch.
- Post launch sustainability strategies developed 2 years post launch.

4.3 Develop capacity specific for WildFireSat implementation and uptake

The implementation of WildFireSat by a fire management agency will require a deliberate decision. The current paradigm of many fire management agencies requires some formalization in process. There may be less tolerance for untested, untried, ad hoc tools used in an official context. Olswang and Prelock (2015) noted that there are several inherent capacity barriers to implementation. Namely, the relevance of an innovation (e.g., WildFireSat), attributes of the organization, the practitioner's (fire managers') motivation to change their current practices and the realized benefits to sustain the work. Simply, the benefit of the change must be worth the effort.

This motivation to change, relative to the other pressing priorities and capacity constraints is a critical consideration in wildland fire management. The implementation and uptake of innovation has been and remains an ongoing challenge in provincial and territorial fire management agencies and elsewhere (Thompson et al. 2022). There is a rapid increase in wildland fire research and associated applied products, and this rate of growth is expected to accelerate into the future (Sankey 2018; Santos et al. 2021; Neger and Rosa-Pas 2022.). At the same time, more challenging and longer wildland fire seasons, expanding work demands (e.g., McBay 2012; Gordon 2014), among other factors, are likely to negatively impact an agency's capacity to adopt new innovations. This emphasises the importance of capacity building.

4.3.1 Capacity building initiatives

The WildFireSat mission will include initiatives to encourage the preparedness and development of capacities necessary to support agency specific needs. These initiatives will focus on developing capacity in the following areas, for example:

- Organizational resource and planning capabilities.
- Training and education capabilities.
- Human resource, expertise, and experience.

This may be achieved by projects tailored to meet local needs under the strategies described in Table 1. To support this work, we have developed a method to identify fire management agencies with similar attributes in certain areas relative to remote sensing in operational wildland fire management. This can be used to identify and encourage agency collaboration on joint strategies and leverage strengths.

Read more on the methods used to group provincial and territorial fire management agencies by similarities and dissimilarities particular to remote sensing use in operational fire management:

- Supplementary Information – Canadian Fire Management Agency Readiness for WildFireSat: Assessment and Strategies for Enhanced Preparedness (McFayden et al. 2023a, Supplemental S3. Clustering Method and Results) – https://www.mdpi.com/article/10.3390/fire6020073/s1

Critical dates:

- Capacity building initiatives commence 3 years prior to launch.
- 5-year duration.

5. EARLY PROGRESS

The following are initiatives commenced at the writing of this document. They were developed following the strategies identified in Table 1. This is not an exhaustive list, and these programs will be refined, completed, expanded and new ones commenced over the life of WildFireSat.

5.1 Development of a community of practice for Canadian Interagency Forest Fire Centre member agencies

The WildFireSat mission will support development of a Community of Practice (CoP) pilot project that will tie together provincial and territorial fire management staff representing different expertise and knowledge so they can extend the concepts of the application of remote sensing research and practice for operational wildland fire management in Canada.

In Canadian fire management agencies, there is likely no single group that holds the requisite knowledge for all potential applications of remote sensing for operaonal fire management within fire management agencies. This leads to a disconnected knowledge base within and across agencies. A CoP designed specifically for Canadian fire management agency staff will be facilitated by the Canadian Interagency Forest Fire Centre (CIFFC) to bridge this gap.

The following will inform the development of a CoP for remote sensing in operational fire management.

- **CoP Domain**: The domain is the topic of focus for the community, i.e., remote sensing.
- **CoP Practice:** The practice is the design, selection, use, coordination and interpretation of data and products from remote sensing for operational fire management.

Critical Dates:

- Establish a CoP pilot for remote sensing in operational fire management 4 years prior to launch.
- 5-year duration and revisited for duration.

5.2 Sandbox development

The WildFireSat sandbox will be a virtual environment created as part of the WildFireSat Science Operations Centre (SOC) and hosted on the Canadian Wildland Fire Information Framework (CWFIF) to develop, test, and demonstrate the products for both the WildFireSat team and the fire management agencies. The sandbox allows for experimentation, without affecting live scenarios. Once created, the sandbox will be available throughout the lifetime of the mission to provide constant interaction with existing and new iterations of products. Within the sandbox there may be the potential to offer various delivery implementations within a fire management agency, various product and symbology iterations, and feedback is of critical importance. The sandbox will be independent of the production system and software, so any work within the sandbox will not affect that of the production pipeline. The development of the sandbox will be iterative (agile) and releases on the sandbox are expected. The sandbox environment will allow:

- Gradual release of products pre-launch
- Updates to existing algorithms
- Updates to product display
- Simulated data, precursor mission data, operational mission data
- Feedback

Developers

- Access to test integration into their own systems
- Provide feedback to the Product Operations team on items such as:
    - Integration/delivery methods
    - Speed of delivery
    - Feedback on the sandbox itself

Users

- View examples of products on internal interactive maps
- Provide feedback to the science team on items such as:
    - Product display
    - Delivery method
    - Description
    - Results vs. expectations
    - Intended audience of each product

Critical Dates:

- Sandbox is planned to be available for fire management 2 years prior to launch.

5.3 Training and education development

Through development of a curriculum, we will increase fire management agency staff awareness and understanding of remote sensing science, the current capabilities of remote sensing technologies, and factors affecting their use in fire management operations. The focus of the curriculum will be specific to fire management in Canada.

The direction of the curriculum will be supported through collaboration with the subject-matter-experts at the Canadian Forest Service and the FMKE team to ensure the applicability of the curriculum. The training and educational content will evolve along with the mission, starng with satellite basic knowledge to tailored WildFireSat technical training. Delivery of training and education materials will be assessed based on target audience needs and prioritize inclusivity and accessibility.

The following is the scope of the prelaunch training and education development:

- Prelaunch training and education scope: the basics of types, kinds and uses of remote sensing in fire management developed with and for an operational fire management audience.

Critical Dates:

- CIFFC project approved 4 years prior to launch.
- Curriculum completed 3 years prior to launch.
- Self-learning online modules completed 2 years prior to launch.

5.4 Engagement with Indigenous Peoples

The WildFireSat mission will provide ethically sound and meaningful recognition, inclusion of and support for Indigenous Peoples, their knowledge, and fire stewardship activities relative to WildFireSat. Capacity constraints are a critical consideration in wildland fire management, particularly for Indigenous Peoples, communities, and Nations (Hoffman and Christianson et al. 2022). The WildFireSat initiative will:

- Directly involve Indigenous Peoples and nations, elders and knowledge carriers, groups/ organizations in the fire and emergency management space, and related entities (for example Yukon First Nations Wildfire; National Indigenous Fire Safety Council; Prince Albert Grand Council; First Nations Emergency Services Society of British Columbia; Saskatchewan First Nations Emergency Management; Northern Inter-Tribal Health Authority).
- Make opportunities for Indigenous-specific initiatives for Indigenous land, fire, emergency, and social services managers and groups, to participate in culturally informed resources related to the capacity building activities in Section 4.3.1.
- Support and participate in the broader Canadian Forest Service Indigenous activities (e.g., Government of Canada 2023e).
- Provide provincial and territorial fire management agencies with WildFireSat content to support their own fire outreach activities with Indigenous groups.

5.5 Engagement with aligned Canadian fire and emergency management

There are other partners and stakeholders in fire and emergency management in Canada. For example, municipal fire departments which may respond to wildland fires within their jurisdictions and emergency response. Other federal and provincial departments have aligned responsibilities in fire management. The WildFireSat mission will explore opportunities to engage with these communities, for example:

- Canadian Association of Fire Chiefs
- Public Safety Canada
- Canadian Interagency Forest Fire Centre
- Government of Canada, Department of National Defence

5.6 International wildland fire management engagement

Wildland fire management is a global challenge and Canada relies on international support and partnerships. International fire management jurisdictions have their own context but also have similarities (e.g., Tedim et al. 2015; Montiel-Molina 2013). Although WildFireSat focuses on the unique needs of Canadians, it will also be positioned to learn and participate in initiatives of mutual interest, for example:

- The Canadian Forest Service (CFS) is leading the Committee of Earth Observation Satellites Working Group Disasters Wildfire Pilot. The objectives of this project are complementary to the WFS mission and will provide a fundamental basis for defining global priorities for active-fire monitoring and characterization. Partners include the Canadian Space Agency, the National Aeronautics and Space Administration (NASA) of

the United States of America (USA), and the United Nations Food and Agriculture Organization.

- Formal partnerships with USA government agencies. Members of the National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) sit on the WildFireSat User and Science Team and are working closely with the WildFireSat team to maximize synergies between WildFireSat and the NOAA/NASA Joint Polar Satellite System. The WildFireSat team are also working with the United States Forest Service (USFS) on active fire remote sensing and other fire management challenges via a joint CFS-USFS memorandum of understanding. Partnerships with USA government agencies. Members of National Environmental Satellite, Data, and Information Service.
- Collaboration with international organizations and committees to improve the integration of end-users and KE throughout all phases of satellite missions (e.g., NASA Fire Information for Resource Management System; NASA Applied Sciences Wildland Fires and FireSense programs; UN-Group on Earth Observation – Global Observation of Forest Cover and Land Dynamics; European Commission's Global WildFire Information System; NASA-USFS Tactical Fire Remote Sensing Advisory Committee; United States Geological Survey National Land Imaging Program; North American with the European Union Arctic PASSION Project.

5.7 Public communications plan

It is important to engage and communicate with the public and other stakeholders. There will be a separate public communications plan which Natural Resources Canada will maintain for WildFireSat and mission partners focused on key milestones in development. The WildFireSat mission team will provide review and support for the province and territory communications plans around WildFireSat as requested and able.

The federal public communications plans will be jointly coordinated with:

- Natural Resources Canada
- Canadian Space Agency
- Environment and Climate Change Canada

Critical Dates:

- Correspond to Mission milestones (e.g., procurement milestones) via social media
- Respond to media inquiry as needed.

5.8 Documentation planning

WildFireSat will document the mission plans, strategies, technical reports, and scientific articles. A determination will be made on the audience and suitable format for documentation (e.g., peer review scientific journals, technical reports). Publicly available documents will be hosted on a webpage maintained by the Canadian Space Agency and jointly organized with the Canadian Forest Service. The WildFireSat mission will pursue open access licensing as the primary option for all WildFireSat related publications.

5.9 Identifying potential new science products for practical application

The WildFireSat mission Science and Applications Plan, to be released in its first edition in late 2023, is an iterative document that evolves with time with scientific development and operational user input. This Plan provides explicit detail on each mission data product and its place in the mission data flow. Input from the User and Science Team around the revision and refinement of existing products, as well as the inclusion of new products within the mission scope, will be manifested in the WildFireSat science plan and algorithms that it describes.

Through engagement with fire management agencies, it may become apparent that there are high value opportunities for applied products in support of the interpretation and utilization of WildFireSat products that are outside Science and Applications Plan. These will be considered for WildFireSat support or communicated as ideas and concepts for others to consider, such as through the CIFFC Research and Integration Innovation Committee.

5.10 Strategies for underserved fire monitoring actors

Outside of fire management needs, we recognize that our knowledge of potential end-users is limited to those who are already connected to the existing networks of the WildFireSat knowledge exchange and science teams. However, we acknowledge that fire monitoring extends far beyond this community to include land managers, scientists, researchers, and organizations with broad focuses in pre-, active, and post-fire stages of Earth observation usage (e.g., Crowley et al. 2023). To better understand who else is in the Canadian and global fire monitoring community, we will be collaborating with researchers from the Canadian Forest Service, NASA Applied Sciences Wildland Fires program, and the USGS National Land Imaging Program, to identify barriers to uptake and collaboration for underserved fire monitoring actors. This multi-year research project will use bibliometric analyses, survey data, social network analyses, and archetype analyses to determine identity-based characteristics of these underserved actors. Additionally, a future complementary project led by our collaborators at the USGS National Land Imaging program and NASA Wildland Fires will seek to expand the geographic region of this work beyond Canada leading up to the launch of WildFireSat. The project was launched in May 2023 with targeted completion within three years. The outcomes will include recommendations for targeted resource development (e.g., training, software/computing resources, tools, and information systems) for underserved end-users and researchers.

6. TIMELINES

The following is a timeline of the critical dates listed in this document. This is not an inclusive list of all implementation timelines.

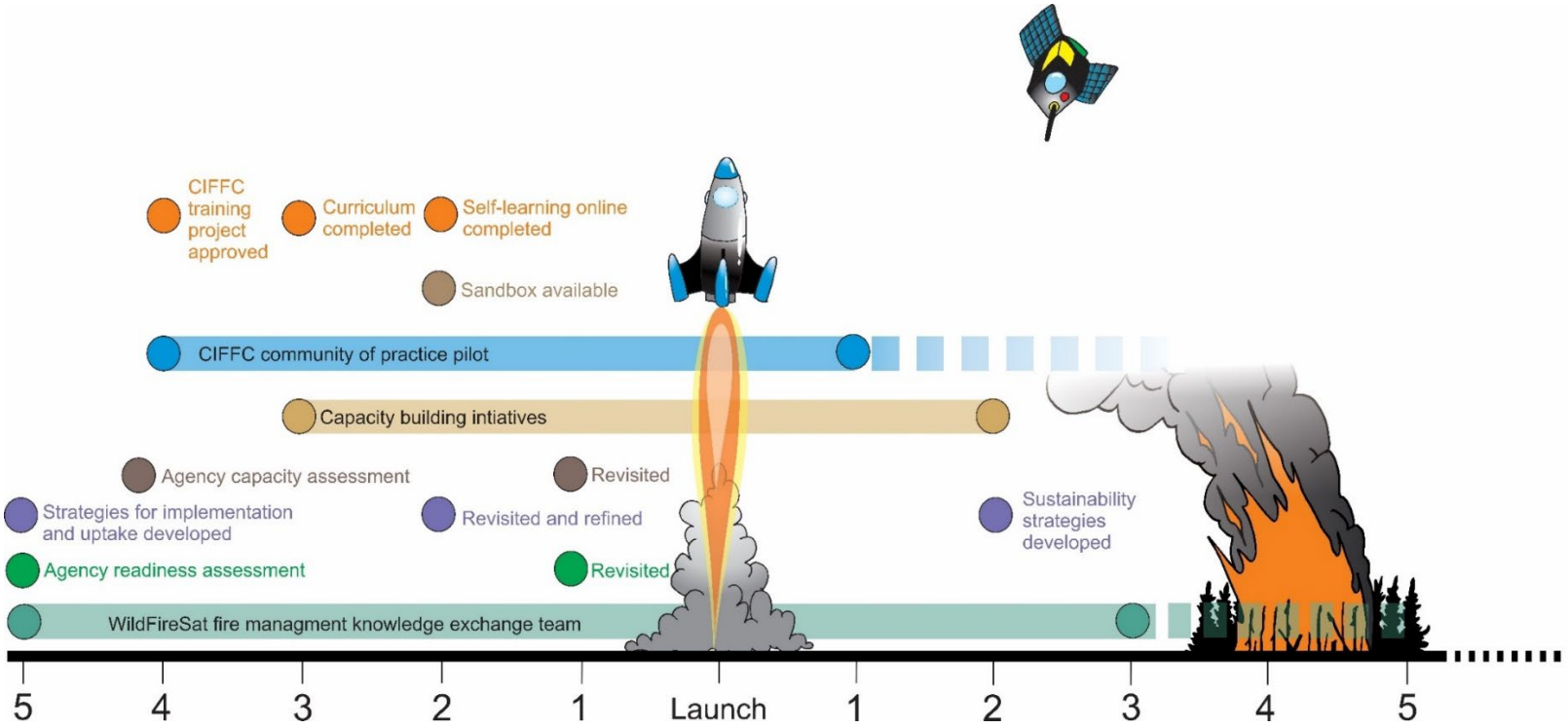

Figure 9. Timeline of critical dates along the path to implementation and uptake of WildFireSat. WildFireSat graphics first appear in the Mission Requirements Document.

7. THE PATH AHEAD

This document lays out the current pathway for uptake and implementation of WildFireSat products. We expect that the path will evolve as we work together with the wildland fire management agencies. It is important for fire managers to develop a sense of ownership and trust in WildFireSat. This requires that knowledge exchange is continuous through the life of the mission. This document lays out the initial path to follow with some key landmarks, however the future direction is open to navigate together.

> *"…WildFireSat is the only public satellite monitoring system ever created to respond directly to the needs of, and in conjunction with, front line fire managers in Canada..."*
>
> *Great Lakes Forestry Centre, 2023.*

8 ACKNOWLEDGMENTS

We thank the past and present members of the Fire Management Knowledge Exchange team for their participation and advice. We also thank from the Canadian Forest Service Meghan Sloane, Shannon Mizzi and Leah MacPherson for editorial assistance, Stan Phippen for publication preparation; and Denis Dufour from the Canadian Space Agency for helpful feedback.

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APPENDIX 1: GLOSSARY OF TERMS

The following terms are defined within this document. These are not the sole definitions of these terms and context dependent to this document.

Capacity: the actual or potential abilities and capabilities that enable a wildland fire management agency to adapt for and implement WildFireSat products into operational fire management.

Fire information: the specialized information used in conducting wildland fire management and operations. It includes information about the proximate physical setting (e.g., topography, fuels and fuel arrangement, wildland resources, assets), the current and forecasted fire environment (e.g., weather, fuel dryness), the current and forecasted fire behaviour and burned area, the current and potential fire effects, and impacts (Johnston et al. 2020b), and the current and potential effects of suppression.

Fire intelligence: results from the processes of assembling, interpreting, analyzing and evaluating raw information.

Implementation: a systematic approach taken by a fire management agency to assess the suitability of WildFireSat data products, adopt and integrate them into common practice, and sustained adoption through time (adapted from Powell et al. 2012; Olswang and Prelock 2015; Rapport et al. 2018).

Knowledge brokers: are the impetus behind implementation and uptake. Knowledge brokers are a bridge between groups and are trusted opinion leaders. They help facilitate the research to operations processes (adapted from McFayden et al. 2023b, and references therein).

Knowledge exchange (KE): the process where knowledge is co-created, shared, and transformed for the benefit of research and fire managers where both are thought of as knowledge holders and producers (adapted from Graham et al. 2006; Reed et al. 2014; McFayden et al. 2023b and the references therein).

Operational wildland fire management: planning for and carrying out the operational activitties of wildland fire management, such as wildland fire preparedness, discovery, suppression, monitoring, and mitigation.

Uptake*:* to adopt WildFireSat products in the culture of an organization and the people within it.

Readiness: an organization's state of preparedness for effective adoption, assimilation, and exploitation of WildFireSat (adapted from Lokuge et al. 2019).

Wildland fire management: the activities concerned with the protection of people, property, and wildland areas from wildland fire, and the use of fire to achieve protection and land use objectives. Aspects include the processes and strategies for wildland fire prevention, mitigation, and response (adapted from MNRF 2014, Government of Canada 2023d).

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