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BLUEPRINT FOR WILDLAND FIRE SCIENCE IN CANADA (2019–2029)

S. Sankey, Technical Coordinator

Canadian Forest Service
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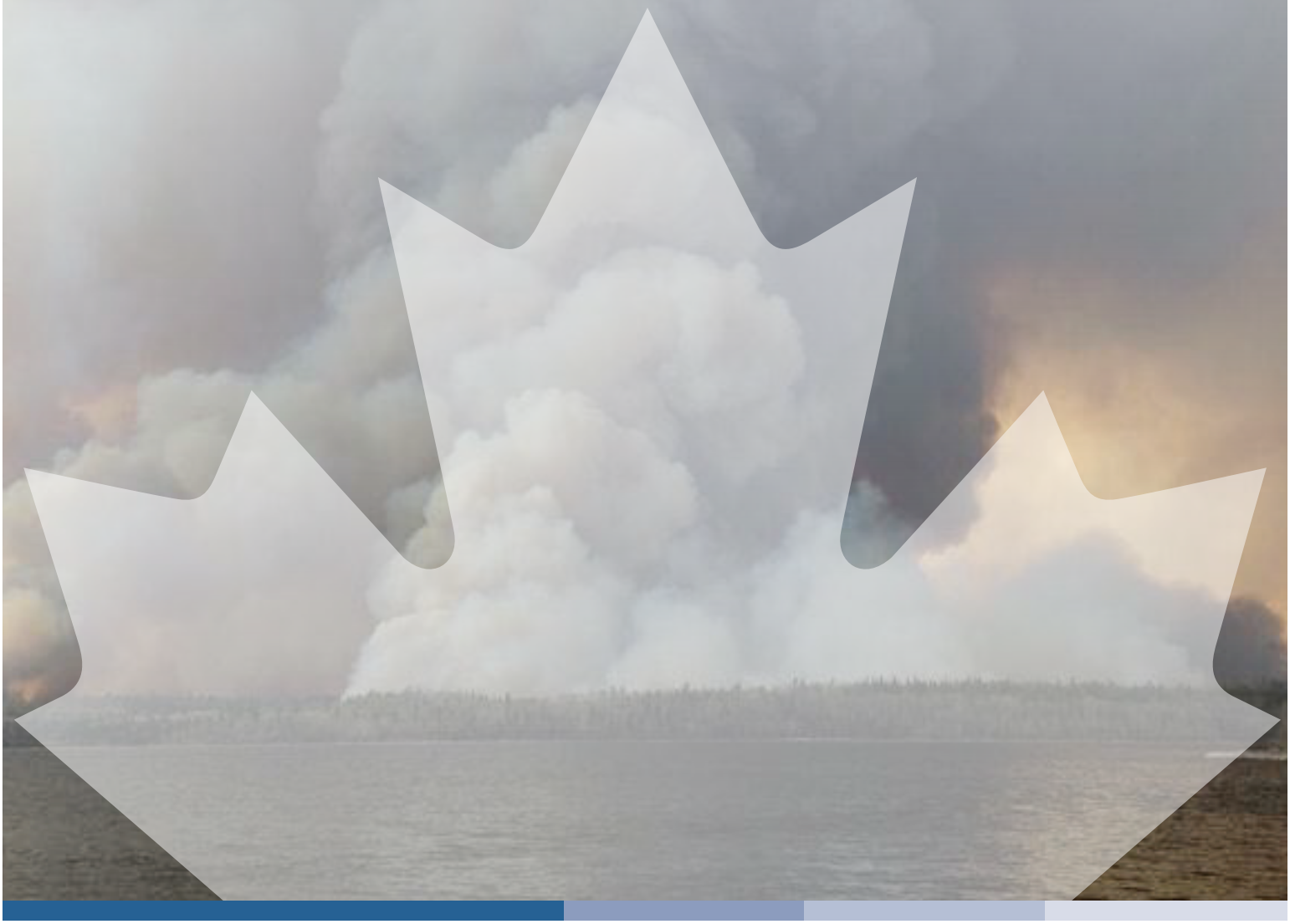

Canada

Building the *Blueprint*

A blueprint provides guidance or serves as a detailed plan or program of action. The *Blueprint for Wildland Fire Science in Canada (2019–2029)* is a strategic plan of action focused on building the capacity of wildland fire science nationally, to help Canada to prepare for a future of bigger, more intense, and more complicated wildland fire events.

The *Blueprint* has been developed by a pan-Canadian team of government, Indigenous, academic, and nongovernment partners. Input has been solicited from a broad range of constituents with interests in wildland fire science and its application.

The *Blueprint* reflects national interests and priorities. It was developed with the understanding that implementation of the related content and recommendations are a shared responsibility of the broad Canadian wildland fire community.

Blueprint Vision Statement

Canada is resilient to wildland fire.

Blueprint Mission Statement

To transform fire management and to strengthen Canadian resilience to wildland fire through research, development, and innovation.

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Cover image: photograph showing fire at Stanley Mission, Saskatchewan, 2014.

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ABSTRACT

The capacity of wildland fire science and technology in Canada is not keeping pace with the growing complexity of wildland fire. Fire seasons are becoming longer, fire events are becoming more severe, and experts predict that the area burned on an annual basis could double by the end of this century. However, wildfire research programs have declined, existing academic wildland fire science programs are limited, and a large cohort of experts has begun to retire. This research gap puts future public safety and security at risk. National wildland fire research capacity, which includes human resources, financial investments, and other supports for science, must be increased to inform the ways fire events are managed, communities are built, and preparations for emergencies are made. The *Blueprint for Wildland Fire Science in Canada (2019–2029)* presents a business case to increase investment in wildland fire science. Developed by a pan-Canadian team of experts, the *Blueprint* makes a number of recommendations to enhance the capacity of research over the coming decade.

RÉSUMÉ

La capacité canadienne en matière de science et de technologie sur les feux de forêt n'évolue pas au même rythme que la complexité croissante des enjeux qui y sont reliés. Les saisons des feux sont de plus en plus longues, les incendies sont de plus en plus intenses, et les experts prédisent que la superficie brûlée annuellement pourrait doubler d'ici la fin du siècle. Cependant, les programmes de recherche sur les feux de forêts ont été réduits, les programmes universitaires de science des feux de forêt sont présentement limités, et un grand nombre d'experts ont commencé à prendre leur retraite. Ces lacunes en matière de recherche met en péril la sécurité publique dans le future. Il faut augmenter la capacité nationale de recherche sur les feux de forêt, qui englobe les ressources humaines, les investissements financiers et d'autres mesures de soutien pour la science, afin d'orienter la façon de gérer les feux de forêt, de bâtir les collectivités et de se préparer aux urgences. Le *Plan directeur pour une science des feux de forêt au Canada (2019–2029)* présente une vision en vue d'accroître les investissements dans la science des feux de forêt. Préparé par une équipe pancanadienne d'experts, le *Plan directeur* fait plusieurs recommandations visant à renforcer la capacité de recherche au cours de la prochaine décennie.

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EXECUTIVE SUMMARY

Canada is at a critical crossroads in relation to wildland fire. The changing climate is creating longer fire seasons characterized by fires that are more severe, more complex, and more expensive to manage. At the same time, decades of fire suppression and forest management policies have changed landscapes, affecting the ways in which fires occur and behave. Additionally, more human activity is occurring in forested areas, which is placing more communities, infrastructure, and economic activities at risk from large wildland fire events.

Canada's capacity to address these current and emerging challenges is inadequate. The national capacity for research must increase to ensure that Canada is prepared for a more complex relationship with wildland fire. In turn, adaptive, evidence-based policies and practices will improve Canada's resilience to wildland fire. The *Blueprint for Wildland Fire Science in Canada (2019–2029)* presents a business case for investments to grow national wildland fire science and related innovation capacity.

Identifying Gaps and Priorities: Six Research Themes

The *Blueprint* presents six broad, yet strongly linked research themes. Individually, each theme provides a high-level overview of existing knowledge gaps and areas for research priority. Together, the themes illustrate the scope of the challenge ahead and the need for deliberate, collaborative efforts to inform existing science gaps and questions.

THEME 1	THEME 2	THEME 3	THEME 4	THEME 5	THEME 6
Understanding fire in a changing world	**Recognizing Indigenous knowledge**	**Building resilient communities and infrastructure**	**Managing ecosystems**	**Delivering innovative fire management solutions**	**Reducing the effects of wildland fire on Canadians**
Conducting fundamental physical fire science as a foundation for improved decision-making	Recognizing Indigenous knowledge and collaborating with Indigenous peoples for better wildland fire management	Protecting forest-based communities and infrastructure from wildland fire events	Understanding the effects of fire, both desirable and undesirable, on forest ecosystems	Transforming fire management through research and innovation	Addressing the long-term physical, mental, social, and economic well-being of people living with wildland fire

Recommendations

In response to the science gaps and research priorities identified within the six themes, the *Blueprint* recommends the following set of actions (organized within five overarching goals) to guide growth in the capacity for wildland fire science over the next decade.

Increase National Capacity for Research and Innovation in Wildland Fire Science

The capacity to conduct new and vital science must increase. A new generation of wildland fire researchers must be assembled and encouraged along with space for them to learn and do their work. Achieving these aims will require secure and stable funding, supported through coordination among governments, universities, and funding agencies. The following recommended actions are intended to increase national capacity for innovation in wildland fire science:

- **Reinvigorate postsecondary wildland fire science programs** using targeted new funding to expand academic programs and increase the number of graduates.
- **Enhance social science research as a core discipline in postsecondary wildland fire science programs** to enable better understanding of the human dimensions of wildland fire.
- **Grow core scientific capacity in the public sector** to accelerate development of new and improved decision-support tools and information.
- **Establish a national postsecondary network for wildland fire science** to connect researchers from biological, physical, social, economic, cultural, and engineering research disciplines with governments, research institutions, and research funding agencies.
- **Strengthen and support the work of existing partnerships, such as the Canadian Partnership for Wildland Fire Science**, until a national postsecondary network can be established.

Recognize Indigenous Knowledge as a Complementary Approach to the Delivery and Development of Wildland Fire Research

Indigenous knowledge and western knowledge are ways of knowing that can complement each other. In support of Canada's commitment to reconciliation and the creation of a new relationship with Indigenous peoples, Indigenous expertise must be recognized and respected as an equal and valid approach to understanding wildland fire and developing future fire management policies and practices. The following recommended actions are intended to encourage Indigenous knowledge and to ensure that it is included in the delivery and development of wildland fire research:

- **Under the guidance of Indigenous partners, establish an Indigenous Fire Knowledge Working Group** to provide leadership for collaborative fire science opportunities and activities involving both Indigenous and Western knowledge. The working group should develop a statement of commitment to acknowledge and recognize the important role of Indigenous knowledge in wildland fire management.
- **Explore opportunities for the inclusion of Indigenous fire knowledge as a component of postsecondary wildland fire research programs**, to be developed and taught by Indigenous knowledge holders.
- **Create experience equivalencies for professional wildland fire research positions**, with recognition of Indigenous experience and expertise as qualifications for professional research positions in fire management agencies and other organizations, and decreasing barriers for Indigenous knowledge holders and fire experts.

Enhance Knowledge Exchange Mechanisms to Improve the Ways in Which Wildland Fire Science and Technology are Shared, Understood, and Implemented

Stronger networking is needed to ensure that research activities and initiatives address and respond to information needs and that research results are available to those who need them most. The following recommended actions are intended to enhance knowledge exchange mechanisms and to improve the ways in which wildland fire science and technology are shared, understood, and implemented:

- **Create a virtual wildland fire knowledge exchange hub** to allow for ongoing information exchange, networking, and identification of science needs and priorities.
- **Develop regional venues for knowledge exchange and outreach**. Establish two wildland fire science knowledge exchange venues (one in eastern Canada and one in western Canada) to facilitate knowledge exchange among regionally based scientists, practitioners, governments, communities, industry, and the public.
- **Stabilize and maintain support for the biennial Wildland Fire Canada conference series**, including a dedicated home base and secure financial support.

Expand Partnerships and Welcome New Players

The complexity of challenges, risks, and considerations related to wildland fire calls for multipartner, multidisciplinary approaches and solutions. The following recommended actions are intended to expand partnerships and include new players:

- **Foster links between research disciplines and sectors outside traditional wildland fire science circles to fund research and drive innovation**. Canada's fire research community must deliberately and strategically build relationships with new partners to identify research needs, develop collaborative projects, secure stable project funds and resources, and apply new findings.
- **Build strategic international partnerships** with other countries that are also dealing with the challenges associated with wildland fire, to collaborate in achieving mutually beneficial outcomes.

Improve Governance and Coordination to Establish National Priorities and Define National Needs

The Canadian wildland fire science community recognizes the benefits of developing a nationally coordinated fire science agenda. The following recommended actions are intended to help establish national priorities and define national needs:

- **Develop a prioritized national research agenda and commit to regular measurement of outcomes and deliverables** to provide a framework for well-defined research activities and a shared understanding of the critical knowledge that is needed and the work already taking place, and to highlight opportunities for stronger multiplayer collaborations.
- **Establish a wildland fire research committee to coordinate national fire science activities**, which will serve as a mechanism to synchronize national research activities, to identify annual high-priority research needs, to liaise among various stakeholders, and to regularly assess and measure progress on the national research agenda.

The combined efforts of governments, Indigenous partners, postsecondary institutions, science-funding agencies, industry, and nonprofit sectors are needed to strengthen national research capacity, deliver targeted science outputs, and implement the recommendations presented in this *Blueprint for Wildland Fire Science in Canada*.

INTRODUCTION

Canada, like much of the world, is experiencing more frequent and more extreme wildland fire behavior. In recent years, large fires have blazed through communities, dampening economic activity, threatening critical infrastructure, and displacing hundreds of thousands of people. With each event, important questions arise: How and why are wildland fire events changing? What tools will assist in the response to increasingly complex fires? Can resilience be enhanced? Most importantly, how can lives and livelihoods be protected from the next large wildland fire event? In the coming years, Canada's ability to answer these questions and address these issues will be tested.

Preparing and managing for wildland fire events, now and in the future, requires evidence-based decisions, policies, and practices informed by strong science, technological innovations, and fire-related expertise. Canada is recognized around the world for the quality of its wildland fire research and for advancements in fire management decision-support tools. The existing capacity for research and innovation, however, has not kept pace with the rapidly changing complexity of wildland fire. In the face of growing wildland fire events, which put more lives, critical infrastructure, and economies at risk, new investment is now urgent.

In 2016, the Canadian Council of Forest Ministers reviewed the *Canadian Wildland Fire Strategy* (CWFS), a document that has guided wildland fire management in Canada over the past decade. While recognizing that significant progress has been made to implement the CWFS vision and to "protect Canadians, their communities, their resources, and the environment,"[1] this 10-year review also identified a critical new direction and new activities to ensure that the original goals of the CWFS would be finally and fully realized. Chief among these are calls to enhance collaboration among federal, provincial, and territorial agencies and to increase investments in innovation and collaborative research capacity.[2]

The *Blueprint for Wildland Fire Science in Canada (2019–2029)* is a direct response to these specific recommended actions. Developed by a pan-Canadian team of government, Indigenous, academic, and nongovernment partners, the *Blueprint* articulates the following priorities:

- identifies areas of national priority in relation to wildland fire science, to help inform research activities over the coming decade;
- aligns research themes and policy-related questions with the development of innovative fire management policy and practices in the future;
- recommends a series of initiatives that will attract new investments and collaborations; and
- enhances the integrated growth and application of wildland fire science across the country.

The *Blueprint* aims to encourage investments in Canada's capacity to conduct wildland fire science (in the form of human and financial resources, in-kind supports, and collaborative opportunities) over the next decade, both to transform how wildland fire is managed, and to ensure that Canada is resilient to future wildland fire events.

BACKGROUND

The Importance of Wildland Fire

A vast part of Canada's landmass, more than 347 million hectares, is forested (Fig. 1). For many of these forested areas, wildland fire is a critical agent of change and growth, necessary to maintain forest health and diversity. Among other things, fire helps facilitate forest regeneration, restore nutrients to the soil, and maintain healthy, diverse species habitat. Fire also plays an important cultural role. For millennia, Indigenous peoples have used wildland fire as a way to manage the landscape. Given these important uses, the occurrence of wildland fire is not something we can, or should, try to eliminate from the landscape; it is only when these events threaten people, critical infrastructure, vital ecosystems, and natural resources that they become a concern.

Wildland Fire in Canada, Now and in the Future

Climate Change and Wildfire

The effects of climate change become clearer with each passing year. The earth's atmosphere and oceans are warming. Levels of snow and ice have shrunk and concentrations of greenhouse gases have increased. Some parts of the world have experienced more frequent and severe droughts, while others have received heavier rainfall and floods. There is a warming trend. Each of the last three decades have been successively warmer at the Earth's surface than any preceding decade since 1850.[3] Seventeen of the world's warmest years have all occurred since 2001[4], and the last three years (2015–2017) have been the warmest years on record.

Although no single weather event can be attributed to climate change, scientists are able to identify how climate change affects the occurrence and intensity of these events. As general warming takes place, the frequency, strength, duration, size and timing of extreme events (including wildfires) has increased.

Recent and Projected Data

Since 1990, an average of 7500 wildland fires have burned about 2.4 million hectares of forest in Canada each year.[5] But various factors related to climate change (such as warmer temperatures, fluctuating and unpredictable precipitation levels, more lightning strikes, longer wildland fire seasons, and drier forest conditions in general) are increasing the intensity and size of wildland fire events.

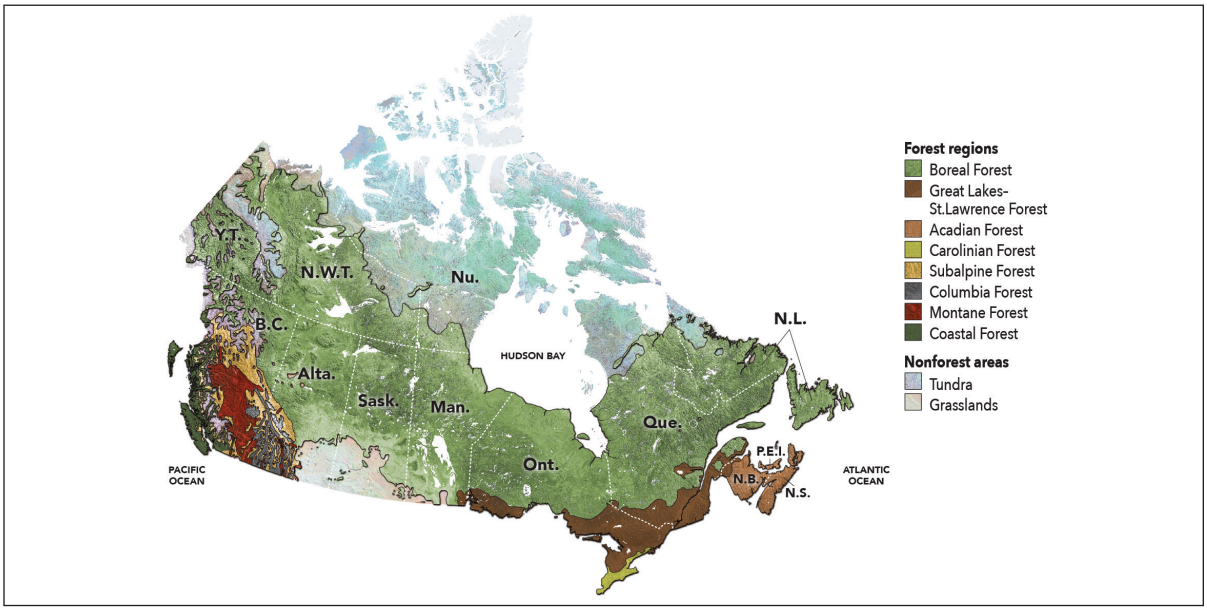

Figure 1. Canada's forested landmass.

Since the 1970s, the area burned annually by wildland fire has more than doubled. This increase is occurring despite efficiencies in fire management practices that have been implemented over the same period and despite the growth in total area under intensive fire management (Mike Flannigan, professor, University of Alberta, and director, Canadian Partnership for Wildland Fire Science, personal communication by phone, May 2018). Experts predict that by 2100, the area burned could at least double again.[6] Modeling of fire scenarios suggests that overall fire occurrence will increase by 25% by the year 2030 and by 75% by the end of the century.[7]

Fire Management Costs

Total costs for national wildland fire management activities range between $500 million and $1 billion per year and can be greater during years of high activity. Costs have risen by about $120 million per decade since the 1970s, with the sharpest increases occurring since the mid-1990s.[8] Given the anticipated growth in wildland fire activity, most Canadian provinces could see their annual expenditures as much as double by the end of the century, while total average annual costs for the country as a whole could exceed $1.4 billion over the same period.[9]

As the amount of area burned by wildland fire has been increasing, fire management agencies have been able to keep up only by spending more and more money on fire response. As budgetary resources tighten, this trend will simply be unsustainable. It is equally important to recognize that some fires will be too big or too intense to stop, regardless of how much is spent on control.

"For many provinces, annual costs that are currently considered extreme are projected to become commonplace by century's end."

– E.S. Hope, D.W. McKenney, J.H. Pedlar, B.J. Stocks, and S. Gauthier, Wildfire suppression costs for Canada under a changing climate.[10]

Effects on Canadians

Across Canada, there are 116.5 million hectares of wildland–urban interface (WUI), areas where homes, physical structures, and infrastructure (such as roads, bridges, railways, and utility services) either meet or are interspersed with the forest or other forms of burnable vegetation.[11] Nearly all (96%) of Canada's populated places include some level of WUI. The largest interface areas are located in Quebec, Alberta, Ontario, and British Columbia, the four provinces that account for 80% of fire management expenditures across Canada.[12] In the east, Nova Scotia, Prince Edward Island, and New Brunswick are areas of high-density WUI; although wildland fires occur less frequently in those regions, their likelihood of being interface fires is high.[13]

The size of Canada's WUI is growing as more human activity spreads into forested lands and other areas of vegetation, creating greater risks for people, communities, industrial activities, and physical infrastructure. These risks include challenges in terms of more evacuations, greater effects on physical and mental health, damage to infrastructure, and disruptions to business and industry.

- **More evacuations**: Evacuations cause social disruption, physical and mental health concerns, and economic disturbance for evacuees, their families, and their communities. On average, 13 500 people from 28 communities are evacuated every year due to wildland fire events (Fig. 2), and these numbers are on the rise.[14]

"[T]he number of evacuations as well as the number of evacuees has increased and these numbers are expected to continue to rise … as climate change leads to [increases in] the number, size and intensity of wildland fires."

– Canadian Council of Forest Ministers Wildland Fire Management Working Group, Canadian Wildland Fire Strategy: a 10-year review and renewed call to action.[15]

Despite making up less than 5% of Canada's total population, Indigenous people are overrepresented in such evacuation events. With more than half of Canadian reserves occurring within the WUI, one-third of all wildfire evacuees are Indigenous, and more than half of all smoke-related evacuations have involved Indigenous communities. (Amy Cardinal Christianson, research scientist, Canadian Forest Service, personal communication by phone and email, July 2017.)

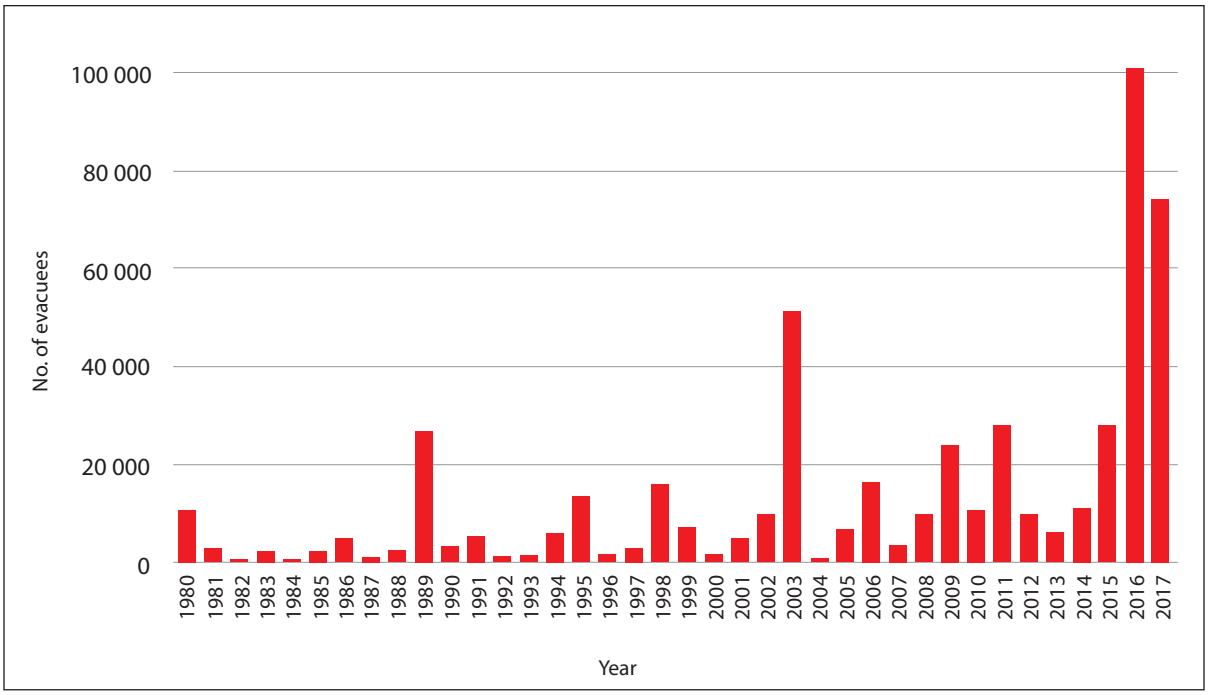

Figure 2. Number of wildfire evacuees in Canada (1980–2017). Source: Canadian Wildland Fire Evacuation Database.[16]

- **Greater effects on physical and mental health**: Wildland fire events have severe effects on human health and can strain regional health services. Even for people living hundreds of kilometers away, smoke from a fire event can irritate eyes and throats, trigger chronic respiratory and cardiac conditions, and, in some cases, lead to premature death. On average, Canada sees about two deaths each year related to wildland fire,[17] and smoke from fires has been associated with increases in emergency department and physician visits, as well as hospitalizations.[18] Extreme events can also cause immediate and ongoing psychological trauma for evacuees, first responders, and emergency service providers.

- **Damage to Infrastructure**: In addition to the immediate costs of fire response and suppression, wildland fires cause considerable damage to key infrastructure and services, including power and communication lines, utility services, and roads and railways. Fire events can jeopardize or contaminate the current and future supply of drinking water. Additionally, there are tremendous costs associated with rebuilding homes, businesses, and entire communities that have been damaged or destroyed by a major fire event. When these costs exceed what a province or territory "could reasonably be expected to bear on their own,"[19] the Government of Canada provides financial assistance to provinces and territories through Disaster Financial Assistance Agreements. Between 2005 and 2015, such payments for wildfire totalled more than $294 million.[20]

- **Disruptions to business and industry**: Economic losses from wildland fires are difficult to calculate and can include a broad spectrum of direct and indirect costs. A single fire event can force industrial shutdowns, cutting productivity and halting economic activity; shut down transportation routes and supply chains; decrease tax revenues; affect property values; and drive up insurance rates. In addition, local businesses may be forced to close and lay off employees, workers may have to relocate, and customers may take their business elsewhere, causing further losses to local businesses.

Preparing for a New Reality

Major Wildland Fire Events in Canada over the Past 10 Years

Fire events occur every year. The frequency and intensity of these events has increased, placing more people at risk and driving up firefighting costs. These escalating events are creating a new reality that must be taken into account in future planning processes and fire management activities. The year 2017 was one of the worst wildfire seasons in British Columbia's history. Over a period of 10 weeks, more than 1300 fires razed 1.2 million hectares of forest, prompting the province to issue its first state of emergency in 14 years. Sixty-five thousand people were evacuated, and air quality advisories were issued across western Canada as smoke spread into the Prairie provinces. On the ground, close to 5000 response personnel (provincial, national, and international) battled the fires. Various transportation routes, including rail lines, were forced to close. Provincial suppression costs eventually topped $568 million, with total costs (including emergency management and Canadian Red Cross response) reaching $780 million.[21]

In 2016, the Horse River wildfire burned through Fort McMurray and northeastern Alberta. It became the costliest natural disaster in Canadian history, eating up almost 600 000 hectares of forest, destroying 2400 buildings, and forcing 88 000 people from their homes. The city remained under evacuation orders for almost a month. Shutdowns of regional oil sands operations resulted in the loss of more than seven million job-hours.[22] Exports of refined energy products dropped 16%, while Canada's gross domestic product fell 0.4%.[23] Two years after the fire, total insured losses were assessed at about $3.8 billion.[24]

In 2015, Saskatchewan initiated the largest evacuation in its history, relocating almost 20 000 people from 54 northern communities under threat from wildland fire and smoke. For many area residents, these evacuations created a great deal of stress and cultural disruption as people were separated from their communities and their families. By the end of the event, more than 1.8 million hectares had burned.

The year 2014 was a record year for wildland fire in the Northwest Territories. Three hundred and eighty-seven fires (57% more than average) burned a total of 3.4 million hectares[25], almost twice the size of the average annual area burned for all of Canada.[26] The hospital in Yellowknife treated twice the usual number of patients for respiratory and allergy issues, and smoke was carried as far away as Portugal. Suppression costs topped $56.1 million, eight times the Territories' planned firefighting budget.

In 2013, there was a decrease in the number of wildland fire events, with only 5654 starts, down from the national 10-year annual average of 6750 starts. However, the area burned by those fires was almost double the average over the same timeframe: 3.6 million hectares, compared with the average of 1.9 million hectares. In northern Quebec, the driest conditions in 40 years triggered an outbreak of fires in the James Bay area. The main highway into the region was shut down, delaying deliveries of food and supplies, and more than 350 residents were evacuated from the small community of Eastmain. Particulates in the smoke triggered power failures across the province, including a complete shutdown of Montréal's Métro rapid transit system.[27]

In 2011, the Flat Top Complex wildland fire caused more than $700 million in losses in and around Slave Lake, Alberta. More than 10 000 people were evacuated, and hundreds of homes and businesses were destroyed. The province committed $289 million to disaster recovery.[28]

A series of early spring fires in 2010 burned close to 90 000 hectares in Quebec. One of the largest of these fires forced the evacuation of 1300 people from the community of Wemotaci. In Montréal, the quantity of smoke in the air was five times higher than the threshold for designating air quality as "poor."[29] More than 1200 firefighters were brought in to attack the fires, including 200 from other provinces, the territories, and the United States.

Fires near Halifax, Nova Scotia, forced the evacuation of residents in both 2009 and 2008.[30] Earlier in the decade, in 2003, a total of 27 000 British Columbians were evacuated, and 239 properties were destroyed in the Okanagan Mountain Park fire. Insured losses totalled $210 million, and tourism to the area dropped by an estimated 30% to 50%.[31]

The Global Reality

Canada is not alone in experiencing increasingly devastating effects from wildland fires. The year 2017 was the most expensive year for fighting wildfires in

the history of the United States, with fires burning across Montana, Washington, Idaho, Oregon, and California.[32] In California alone, nearly 9000 wildfires burned more than 485 000 hectares of land, killing at least 46 people and causing an estimated $18 billion in economic losses.[33]

The year 2017 also saw major fire events in Spain, Italy, France, Croatia, Greece, South Africa, Russia, and Greenland.[34] In Portugal, more than 100 people died, the largest loss of life due to wildfires in the country's history.[35] In Chile, at least 11 people died, thousands more were evacuated,[36] and 8% of the country's total forest area was destroyed.[37] The country's president called it the "greatest forest disaster" in Chilean history.[38]

"The wildfires of 2011 in Alberta and the 2003 fire season in British Columbia are considered by many wildfire experts to be a harbinger of an emerging new reality. … Wildfires will continue to make impressive and uncontrollable runs through Canadian wildlands. If the number and behavior of wildfires increase and development expands into wildland, 2003 and 2011 type events will logically become more frequent unless significant collaborative actions are taken by all parties (government, stakeholders, public) to prepare for and to mitigate the risks."

– P. Fuglem and B. Stocks, Wildfires in Canada: members of the Slave Lake wildfire review committee put their recommendations in context.[41]

The *Blueprint* has been developed over the course of the 2018 wildfire season, and final statistics for the year were not available at the time of publication; however, the season has been demonstrably challenging. Devastating fires have occurred in Greece, Sweden and California, and significant wildfire activity has taken place in Ontario and British Columbia. In Ontario, the number of fires is up almost three times the provincial 5-year average, and area burned is more than seven times greater over the same timeframe. British Columbia has declared 2018 the worst fire season in its history, with more than 1.25 million hectares burned, thousands evacuated or placed on alert, and costs of fire suppression topping $350 million. Each of these fires stands alone as a catastrophic event that caused massive personal, social, economic, and ecological disturbance. Taken together, they also reflect the changing nature of wildland fire, a new global normal[39] for which we must prepare.[40]

Canada at a Crossroads

As the nature of wildland fire changes, Canada's ability to address and understand it is at an important crossroads. Over the past 40 years, investments in critical fire science and technological innovation have not kept pace with current and emerging challenges. Understanding the new ways in which fire is behaving will help organizations and communities to prepare for future fire-related events. National research capacity, and the resources to conduct new and necessary science, must grow if we are to prepare for a more complex relationship with wildland fire.

"With the extreme conditions we're running into now, year after year, in terms of climate change, we have to change [our] thinking. We need to rethink … how you manage fires that have the potential to threaten communities or infrastructure."

– P. Beatty, Evidence to the House of Commons Standing Committee on Indigenous and Northern Affairs.[42]

WILDLAND FIRE SCIENCE IN CANADA

Science is critical to a nation's health, both as a foundation for progress and as a basis for evidence-based policy- and decision-making. In its widespread review of Canada's science and research competitiveness, the Advisory Panel on Federal Support for Fundamental Science reported that effective solutions for the challenges facing Canadian society require major contributions from science:

> Canada cannot address tomorrow's challenges based on yesterday's research…If Canada is to thrive in the 21st century, our capacity to formulate imaginative, innovative, and evidence-based public policy must be second to none. Policy-making, we understand, involves not just evidence, but values and circumstances. Assessing the relevant trade-offs will be the responsibility of our elected representatives. However, it is very much the responsibility of the research community to generate the relevant evidence, and the reciprocal responsibility of decision-makers to ensure that they have the tools and resources to do so.[43]

Historically, Canada has been a world leader in the delivery of wildland fire science and innovation. As the reality of living with wildland fire evolves, fire management policies and practices must continue to be informed by new and timely research that will transform how we adapt to increasing risks.

National Investments in Science

Canada's gross domestic expenditures on research and development have been decreasing over the past 15 years. Relative to other countries, Canada ranks below the average and median in terms of investments in total research spending.[44] Instead, Canada relies heavily on the higher education sector to conduct research. "[I]n 2015 almost 50 per cent of higher education expenditures in research and development in Canada was funded by universities and colleges themselves, while the federal government contributed only 23 per cent. [This] is having adverse effects on both research and higher education across Canada."[45]

In terms of capacity, the Expert Panel on the State of Science and Technology in Canada found that although Canada had the largest number of postsecondary graduates among nations within the Organisation for Economic Co-operation and Development, it was falling behind in terms of the number of researchers and the training of the next generation.[46] In recognition of this deficit, the Government of Canada's 2018 budget committed more than $6 billion to investments in science and innovation, including $1.2 billion for granting councils and research institutes and $140 million for academia.[47]

The picture for wildland fire science largely mirrors the one for research more generally: investments in federal research related to wildland fire have steadily declined since the 1970s.[48] Decreases in funding were initially offset by growth in research capacity at fire management agencies and universities; those offsets were insufficient to meet current or future needs.[49]

The lack of existing capacity is intensified by yet another important factor. Specifically, a generation of key researchers has begun to retire, resulting in a loss of expertise, experience, and leadership in national wildland fire research. Both the limited capacity and the impending loss of expertise must be acknowledged and addressed.

Definition of Wildland Fire Science

Wildland fire science is the objective, systematic and repeatable pursuit of knowledge, including practical applications and technologies, on topics pertaining to wildland fire; primary themes include physical and biophysical processes, ecology, prescribed fire, operational analytics, suppression systems, management systems, human dimensions, traditional knowledge, economics, and policy.[50,51]

This definition will need to be expanded in future to reflect emerging challenges and realities and to identify developing areas of need, create new opportunities for multisector collaborations, and enable the integration of a broader scope of interests and concerns relating to wildland fire.

Science and innovation related to wildland fire takes place in many organizations across the country, including federal, provincial, and territorial governments; nongovernment organizations; universities and colleges; and the private sector.

The Canadian Forest Service, part of Natural Resources Canada, houses the largest contingent of wildland fire researchers within a single organization in Canada. Work takes place across a wide range of research areas, including fire behavior and ecology, risk prediction and assessment, fire management, effects of climate change, human dimensions of wildland fire, and development of decision-support tools.

Provinces and territories also facilitate and conduct research, as do some smaller, nongovernment organizations, including FPInnovations, the Canadian Interagency Forest Fire Centre, and the Canadian Partnership for Wildland Fire Science. The research performed by these organizations focuses on wildfire operations and response support, as well as land and resource management.

Most of the wildland fire research across the country is being done by academics working in postsecondary institutions. Generally, these activities have been difficult to characterize and quantify, largely because wildland fire research can take place within many different disciplines and faculties, such as forestry, environmental or ecological sciences, engineering, operations research, biological sciences, and social sciences. (Fig. 3; Fire researchers by institution based on bibliometric data, personal communication, Cynthia Franklin, Innovation Advisor and Andrée McCracken, Policy Analyst, Natural Resources Canada, email, March 13, 2018).

A recent survey, conducted in support of this *Blueprint*, asked researchers nationwide to classify their wildland fire research activities and areas of work. Assessment of the 57 responses[52] indicated that current research efforts in Canada take place primarily in the following areas:

- fire regimes: historical and contemporary fire regimes, frequency, seasonality, intensity, size, severity, spatial configuration;

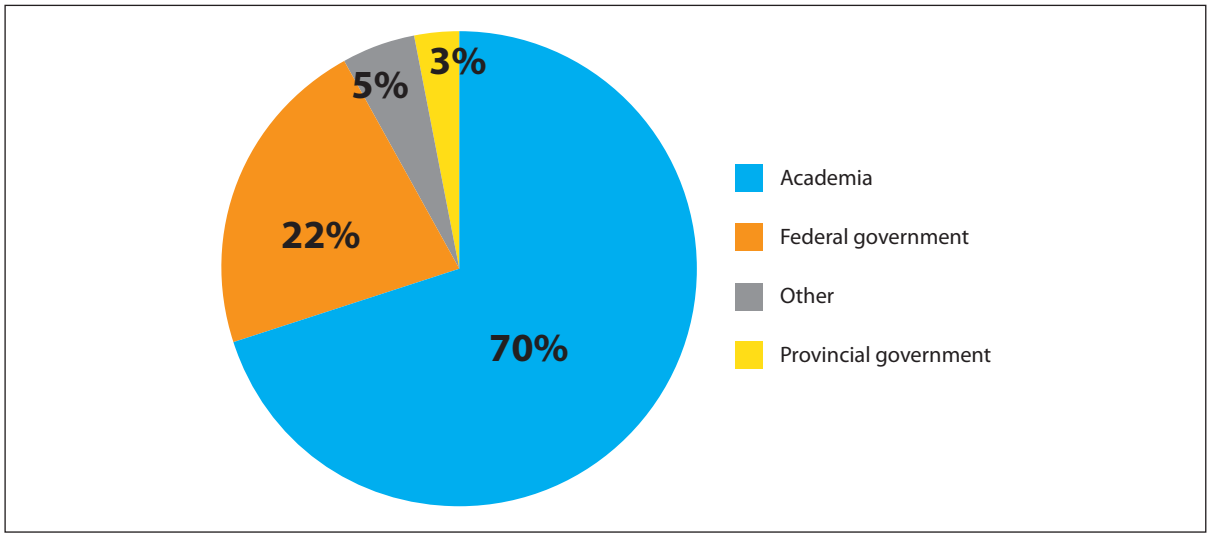

Figure 3. Fire researchers by institution type. Source: Cynthia Franklin, Innovation Advisor, Natural Resources Canada, personal communication, email, March 13, 2018.

- ecological processes: landscape variability/change, vegetation response, disturbance interactions (insects, disease), air and water quality, soils, habitat, carbon and nutrient cycles, botany, plant physiology; and
- planning: concepts, systems, planning aids, budgets, allocation of resources, operational plans, community protection plans, forest management plans, other related plans (land management, integrated resources, land use, protected areas, ecology).

Responses indicated that more university-based research takes place in the areas of fire regimes, fire effects, fire impacts, and ecological processes. Federal government research activities appear more evenly spread out across the continuum of research areas. Notably, responses to the survey indicate gaps in a number of new or critical research areas:

- physical and chemical processes: combustion, heat transfer;
- socioeconomic processes: economic activity, industrial activity, property, timber supply, nontimber values, fire management budgets/costs;
- policy: appropriate responses, managed wildfire, modified response, allowable burned area locations and targets; and
- prevention: communication, education, regulation.

Overall, Canada's contingent of wildland fire scientists is relatively modest. Approximately 60–70 individuals are engaged in full-time wildland fire research, with a combined annual expenditure of about $5 million (Integrating Fire Science to Support Resource Sharing Strategic Plan 2017–2022, Personal communication, Dave Bokovay, Operations Manager, Canadian Interagency Forest Fire Centre, telephone conversation, 8 August, 2018). Coordination of and collaboration on research efforts occurs largely on an ad hoc basis. However, existing networks and well-established connections could serve as a stepping stone to the development of a broader, better-integrated research community with cohesive research priorities and activities.

SCIENCE THEMES TO IDENTIFY KNOWLEDGE GAPS AND RESEARCH PRIORITIES

A critical question facing Canadian governments and fire management agencies is "How will we protect lives and livelihoods from wildland fire disasters?" The question is not simple, nor are the answers.

This section presents and discusses six distinct but interlinked themes. Each theme represents an important area of wildland fire research activity. Taken together, they demonstrate the scope of the challenge ahead and the need for focused efforts to inform existing science gaps and questions.

Importantly, this *Blueprint* recognizes Indigenous knowledge as an essential theme within this work. Indigenous knowledge is created by Indigenous peoples, and is based on local, long-term observation, analysis, and experience. As such, it must be valued as both a stand-alone and a complementary path to knowledge, with equally challenging needs and priorities.

Ultimately, work within and across these six themes will rely on collaboration among governments, Indigenous partners, academia, research organizations, and funding agencies. It will require development of new partnerships and stronger relationships between researchers and end users. It will also require dedicated financial resources to allow the necessary science and innovation to take place.

Theme 1: Understanding Fire in a Changing World

Conducting fundamental physical fire science as a foundation for improved decision-making

Understanding the physical nature of wildland fire is a critical component in how we prepare for and respond to it. Our ability to predict and model fire activity (for example, estimating when and where a fire is likely to occur, how severe it could be, or how flames and smoke might spread) is determined by knowledge generated by fundamental science. Critical questions exist. For example, Canada lacks a comprehensive framework for wildfire risk assessment. Methods and models are needed to estimate wildfire risk at all scales, combining hazard with the likely exposure, vulnerability, and value of assets in or near wildlands to inform preparedness and mitigation planning. In particular, despite high-profile fire events over the past few years, the

mechanisms of fire spread and damage within the WUI remain poorly understood. Advanced models are needed to characterize the processes of fire spread to and within the interface. Such modeling will provide the critical information foundation on which to build a comprehensive risk assessment framework, one that is specifically adapted for communities, industry, and infrastructure in the forest.

Furthermore, changes on the landscape are altering the context of wildfire in Canada. Factors such as climate change, pest infestations, and past fire-suppression practices and policies, which have increased the amount of burnable vegetation currently available, are combining to create challenging conditions for successful fire management. Fire behavior and the related potential for fire activity under these shifting conditions needs to be better understood; similarly, the ways in which changes in the fire regime could in turn transform existing forest ecosystems also need to be better understood.

An additional consideration is the link between green house gas emissions produced from combustion of forest biomass during a fire and national (and global) efforts to reduce greenhouse gases. These emissions contribute to climate change. The 2015 Paris Climate Agreement, to which Canada is a signatory, seeks to balance human-caused carbon emissions with the removal of green house gases (i.e., CO_2) through carbon sinks to limit increases in global average temperatures. Wildfire emissions can be large, and they need to be considered in assessing Canada's total produced greenhouse gases and in meeting commitments to reduce carbon emissions. Managing forest fuels (vegetation) and fire can contribute to reducing emissions, but more research is required in this area.

Smoke from wildfire creates several health and safety concerns, including health effects on residents and firefighting personnel, and visual obstruction for aircraft pilots and remote sensing tools. Evacuation decisions are often based solely on the presence of smoke, which creates a need for information about current and expected conditions in communities. Smoke from wildfires can affect the air quality of communities tens or even hundreds of kilometres from the source. As a result, enhanced smoke modeling will be an important tool for public health agencies and emergency management planners.

Finally, as the nature and behavior of fire changes, the complexity of fire management decision-making has increased. During the wildland fire season, decision-makers assess fire activity on a daily, sometimes hourly, basis, whereas incident managers and fire crews assess changing fire behavior in real time. Fire managers also project wildfire activity over the short to medium term (up to 14 days) to anticipate and plan for firefighting personnel and equipment needs. Science to support adaptive operational and response activities is needed. Additionally, the Canadian Forest Fire Danger Rating System, which provides the foundation for characterizing the current and projected fire environment, needs modernization to meet current and future demands. Although the spatial and temporal resolution of environmental data and the complexity of fire management decision-making have increased, the basic components of this rating system have not been changed for several decades.

New fundamental knowledge related to these key challenges will aid in the development of new models and tools to enhance fire intelligence and prediction, and to improve protection in the WUI. As a result, Canada will be better able to prepare for and respond to current fire activity and to mitigate the effects of a changing fire regime.

Priority Research Topics

- **Wildfire risk**: Develop knowledge and methods to determine the wildfire risk to Canadians and assets at daily, weekly, annual, and multi-decadal scales.
- **Fire danger**: Examine the interactions that changing climate and landscapes have on fire occurrence, fire behavior, and fire intensity, and determine how future fires may differ from those in the past.
- **Smoke and emissions**: Perform enhanced modeling of smoke production and spread, and conduct more research on the interactions of smoke emissions with the atmosphere and climate.
- **Measurement improvements and novel data sources**: Achieve advances in the collection of accurate, timely, and accessible data, including those from earth observation technologies, which form the foundation for all models and decision-support tools.

Theme 2: Recognizing Indigenous Knowledge

Recognizing Indigenous knowledge and collaborating with Indigenous peoples for better wildland fire management

Indigenous peoples have lived with and used wildfire over thousands of years. For many Indigenous cultures, intentional burning is used for a variety of outcomes, including modifying the landscape, managing the vegetation, reducing risks to communities, improving aesthetics, maintaining trails, reducing forest pests, and extending the growing season (by warming soil in spring to melt frost and encourage earlier growth of essential plant food sources).[53,54,55,56,57,58,59] Fire also has important spiritual and ceremonial significance for many Indigenous cultures, and today many Indigenous people continue to be keepers of fire knowledge or to work in a variety of fire management professions, including seasonal firefighting.

> **"First Nations have been using prescribed burning since time immemorial. First Nations Knowledge of the land, regeneration of our food sources, and knowing when to apply our knowledge are gaps that outside agencies have not tapped into."**
>
> ***– Personal communication, Chelsea Enslow, Bonaparte Indian Band, email, February 21, 2018***

Indigenous peoples' ancient relationship with fire has resulted in a "body of knowledge and beliefs transmitted through oral tradition and first-hand observation."[60] However, through more than 150 years of colonization, Indigenous knowledge has been systematically devalued, ignored, and outlawed. Likewise, Indigenous people have been, and continue to be, overlooked as participants in western science practices, despite the contributions they could make.

Indigenous knowledge and western science are independent but complementary tools of discovery. Each uses observation, data collection, and logic to make sense of the world. The differences between them lie in approach, scope, and application: whereas western science seeks to understand the world by studying individual parts, Indigenous knowledge looks at the world in a more holistic, connected way.[61] Despite these differences, "Indigenous knowledge and [western] science can work together to address a jointly defined problem, each bringing their own expertise to the table."[62]

Recognition of Indigenous knowledge and collaboration with Indigenous peoples can enhance wildland fire science in Canada. On its own, Indigenous knowledge is an advanced knowledge

system worthy of respect as an equal and valid approach to understanding fire. It also provides opportunities for mutual learning and information sharing in ways that will inform wildland fire management across the country. To accomplish these goals, mechanisms to support the development of Indigenous fire knowledge must be built, and collaborative opportunities for Indigenous knowledge and Western science to work together must be facilitated.

"The vastness and complexity of today's challenges require the mobilisation of the best available knowledge for decision-making. Indigenous knowledge holders and scientists contribute different understandings. By virtue of their differences in temporal and spatial scale, qualitative vs. quantitative nature, or holistic vs. specialised character, they are largely complementary. Where Indigenous knowledge and science can work together to address a jointly defined problem, each bringing their own expertise to the table, their co-produced knowledge may lead to novel solutions. For this to happen, building dialogues that ensure mutual respect is crucial."

***– UNESCO, Local knowledge, global goals.*[63]**

There are additional considerations. First, as older fire knowledge keepers pass away, their expertise is being lost. Second, Canada has committed to reconciliation, through the Truth and Reconciliation Commission Calls to Action (specifically numbers 43 and 44)[64] and as a signatory to the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP). Specifically, Article 31(1) of the UNDRIP reads as follows:[65]

> Indigenous peoples have the right to maintain, control, protect and develop their cultural heritage, traditional knowledge and traditional cultural expressions, as well as the manifestations of their sciences, technologies and cultures. … They also have the right to maintain, control, protect and develop their intellectual property over such cultural heritage, traditional knowledge, and traditional cultural expressions.

Recognition of Indigenous knowledge and collaboration with Indigenous knowledge keepers presents a complex challenge for Canada's scientific communities, especially where ownership, control, access, and possession of the knowledge is concerned. However, there is a collective opportunity to show leadership, to honour reconciliation, to identify shared critical science priorities, and ultimately to develop new collaborative approaches to how we will live with wildland fires. Research activities related to creating Indigenous knowledge must be generated by communal decision-making within Indigenous communities. As such, the following three activities are presented in this *Blueprint* as areas that should be addressed before appropriate and specific research activities can occur.

Priority Research Topics

- **Valuing Indigenous expertise**: Recognize and respect Indigenous understanding of wildland fire as an equal and complementary path to knowledge.
- **Building collaborative mechanisms for western science and Indigenous knowledge**: With guidance from fire knowledge keepers and Indigenous elders, develop mechanisms for collaborative wildland fire research that include both Indigenous knowledge and Western science activities.
- **Enhancing Indigenous fire knowledge**: Identify and establish opportunities for Indigenous knowledge holders to conduct wildfire research, in both the Indigenous and the western science contexts.

Theme 3: Building Resilient Communities and Infrastructure

Protecting forest-based communities and infrastructure from wildland fire events

Building resilient communities and infrastructure entails anticipating wildfire — not just considering the possibility of its occurrence, but counting on it — to influence how, where, what, and why structures are built. It also entails reducing risks, limiting losses, and building robust structures and recovery systems, which in turn will create safer communities and more secure physical infrastructure.[66] Currently, hundreds of Canadian communities and their infrastructure systems lie within WUI areas, where they are vulnerable to the direct and indirect effects of wildland fire. More research is required to help protect communities and infrastructure, and to develop building practices, planning directives, and other techniques that will reduce the risks and costs associated with wildland fire.

National and provincial fire codes are designed to minimize the risks of structural fires in Canada. In addition, a variety of nonmandatory risk reduction measures are compiled into risk-assessment and risk-reduction guidebooks for use by property owners. For example, Canada's FireSmart program provides guidance and best practices that homeowners, communities, industry, and other forest-based stakeholders can voluntarily implement to reduce risks from wildland fire. More evidence collected from communities affected by wildland fire is needed to determine how the voluntary application of fire risk-reduction principles (such as FireSmart) can be made more effective in protecting infrastructure.

Additional research is required to document the benefits of voluntary risk-reduction practices in the WUI in a Canadian context (i.e., developing Canadian-based data for applications specific to Canada), and to encourage implementation of those practices. Research is also required to evaluate current construction, civil engineering, community design, and public safety standards to determine whether any changes to codes, policies, or regulations are warranted. This would support new and existing efforts, such as work underway by the National Research Council, to integrate climate resiliency into building and infrastructure design and codes. Research could also lead to the development of new building materials and might serve to inform emerging issues related to property insurance in the WUI, a subject of substantially increasing interest to the insurance industry in wildfire-prone areas. New science will also benefit emergency management planning, by helping in the establishment of evacuation routes and other emergency measures.

Priority Research Topics

- **Protection of structures**: Conduct research for a better understanding of how fire spreads from the WUI into urban settings; to develop safer building materials; and to quantify the return on investment of protection and mitigation measures.
- **Management of the WUI**: Develop science-based models, policies, and practices to better guide land-use planning, community development, and risk mitigation activities.
- **Development of codes, standards, and regulations**: Improve building codes, development standards, and regulations for built structures (community, industrial, infrastructure) to inform how and where structures are built or retrofitted.
- **Voluntary adoption of best practices**: Undertake studies to understand the social influences that result in adaptive actions and to enhance resilience.

Theme 4: Managing Ecosystems

Understanding the effects of fire, both desirable and undesirable, on forest ecosystems

Wildland fires play an important ecological role as disturbance events for a wide range of ecosystems, including forests, grasslands, and shrublands. When they occur, fires can have both desirable and undesirable effects on ecosystems and the values attached to them. The challenge comes in finding an appropriate balance so as to maintain the essential role of fire for ecosystem health, while simultaneously protecting human safety and health and preserving vital ecosystem goods and services.

Great value is placed on forest-based goods and services. Forests and grasslands carry cultural and spiritual importance to many people, and society values the recreational opportunities, beauty, and peace they can provide. Economically, forestry-based activities inject over $23 billion into Canada's gross domestic product and create jobs for more than 211 000 people. From an ecological perspective, forests purify water and air, prevent soil erosion, modulate climate, and provide species habitat. Although today there is a greater understanding of ecosystem functions than in the past, gaps remain in terms of what is known about the complex interactions among wildland fire, landscapes, and people. Climate change is adding to the unknowns.

Research is needed to investigate three main aspects related to ecosystem management. First, more must be learned about the immediate, short-term, and long-term effects of fire on ecosystems and related ecological processes. These processes and effects encompass overall ecosystem health and resilience, vegetation, wildlife, hydrology, carbon stocks, and soils. A second gap that requires more analysis focuses specifically on fire regimes (characterized by fire frequency, size, shape, severity, cause, and timing) and how they interact with other forest disturbances, such as climate change, insect outbreaks, and disease. It is critical to learn more about the ubiquity and necessity of fire on the landscape and to identify and document how much the fire environment has changed, creating baseline knowledge that will allow for comparisons between current and future conditions. Finally, the ways in which fire can be strategically used to maximize its ecological benefits and minimize societal risks must be more fully examined. This research would include the application of prescribed burning or allowing more fires to burn under specified conditions to reduce risk and ensure long-term ecological integrity.

Priority Research Topics

- **Fire effects on ecological processes**: Describe, evaluate, and predict the immediate and long-term effects of wildland fire on ecosystems (and their components) and on ecological health and resilience, especially in the context of a changing climate. Understand the effects of fire on ecological goods and services, such as carbon storage, timber and biomass supply, biodiversity, water, and traditional and recreational uses of the forest.
- **Past, present, and future fire regimes**: Improve the descriptions of fire regimes (in terms of frequency, size, shape, severity, cause, and timing) and how fire regimes interact with other disturbances (such as climate change, insect outbreaks, diseases).
- **Strategic use of fire**: Develop strategic, evidence-based programs and policies for the use of prescribed fire and modified response in sustainable forest and land management practices, in a way that maximizes ecological benefits while minimizing societal risks.
- **Integration of approaches to managing fire and other natural resources**: Use forest harvesting and silvicultural techniques to minimize wildfire risk. Understand transboundary issues in fire management.

Theme 5: Delivering Innovative Fire Management Solutions

Transforming fire management through research and innovation

Science and technology are the building blocks for innovative fire management and decision-making. Fire managers need novel solutions (including evidence-based tools, policies, practices, and procedures) to better respond to the rapidly changing nature of wildland fire. Fire management practices need to be more responsive and agile. Bridging the gap from foundational science (Theme 1) to operational fire management is crucial in addressing progressively more dangerous and changing fire regimes.

Innovative science and technologies (such as remote sensing and earth observation tools) will allow for earlier and more accurate detection of fires and hot spots. New models and decision-support frameworks will build more accurate risk assessments (so that managers will know what might burn and when) and will assist with fire response and emergency management planning. Enhanced fire monitoring and smoke forecasting will help to protect the health and safety of communities. New science and technologies will also improve the effectiveness of firefighting equipment and provide guidance to improve the health and safety of firefighters and other first responders.

Effective knowledge exchange is also critical for protecting people and communities. Permanent mechanisms are needed to facilitate the sharing of information, making sure that science gets into the hands of fire managers and practitioners (the end users) while also communicating the priorities and needs of end users back to researchers. Ultimately, facilitating this two-way flow of information will provide a higher return on investments in research and innovation.

Effective planning that optimizes scarce resources and enables the most efficient deployment of firefighting assets is equally important. Fire managers must work within, and take cues from policy and economic frameworks while relying on additional tools, such as weather forecasts, trend forecasts, and identification of long-term challenges, which provide additional guidance for planning activities. Finally, organizations must also have the capacity to manage the increases in the quantity and complexity of data that are anticipated with advancements in risk assessment and forecasting systems. Innovative fire management solutions will allow for better decision-making and improved policy and economic frameworks to protect people, property, and forests.

Priority Research Topics

- **Improvements to operational response**: Perform foundational and applied science activities to create and improve innovative fire management solutions and to assist in decision-making, so that fire response will be faster, safer, more effective, and more efficient.
- **Improvements to planning**: Perform appropriate science activities to improve preparation, mitigation, response, and recovery activities, including national risk assessments, innovative and effective technology development for decision support, development of better data management tools, and longer-term weather forecasting.
- **Knowledge exchange**: Develop effective mechanisms and frameworks to ensure that knowledge transfer (of both needs and results) takes place among scientists, decision-makers, fire managers and agencies, and the public, so that everyone has the information they need to protect people and properties from fire events.
- **Occupational health and safety**: Conduct research to enhance the physical and mental health and safety of firefighters, first responders, and others engaged in wildland fire response and mitigation.

Theme 6: Reducing the Effects of Wildland Fire on Canadians

Addressing the long-term physical, mental, social, and economic well-being of people living with wildland fire

The images have become familiar. Residents fleeing communities, surrounded by smoke and burning embers. Firefighters battling flames on the frontlines. Volunteers and first responders providing assistance and relief to people forced out of their homes. Communities uprooted and spread apart. Scenes of burned buildings and cars, covered with ash, that confront people as they come home to rebuild.

These images offer glimpses into the confusion, anger, sadness, and fear that a wildfire event can cause, but they do not provide a full picture of the enormous imprint that this type of event can leave. In fact, surprisingly little is known about the socio-economic costs of a natural disaster such as wildfire over both the short and the long term.

There is a need for more socioeconomic research to better understand the true costs (both direct and indirect) of wildland fires. In particular, a full financial accounting of landscapes and values at risk and the return on investment for spending on prevention and mitigation is lacking. Without an understanding of wildfire economics, a business case for fire management cannot be made, and the most cost-effective management approaches cannot be developed.

Another major issue is the lack of social science research to help understand public perceptions of wildfire risk and mitigation efforts, including how to influence human behavior to reduce new fire starts and how to approach and engage the public about the positive and negative aspects of wildfire. More social science is also required to assess the effects wildland fire can have on Indigenous communities and people, the preparedness of Indigenous communities across Canada, the characteristics of successful postfire recovery, and criminality associated with deliberate ignition of wildfires.

Public engagement is a critical element in creating wildfire resilience because prevention activities at the level of homeowners and communities yield the greatest returns. More research is needed to inform public education and awareness on various topics, including prevention, prescribed burning, homeowner mitigation actions, land-use planning, and the ecological benefits of fire. Much work is also needed to improve the ways in which people and communities experience wildfire events, including dissemination of information to those affected, knowledge of evacuation routes, and reduction of the trauma associated with evacuation experiences. Work is also needed to help affected people understand fire management and the types of action required to

battle wildfires and to rebuild with greater resilience. This has become known in international emergency management circles as Build Back Better.[67]

The psychological and health effects of wildland fire events need to better understood, including the mental health effects and costs caused by fire-related loses and evacuations. In addition, the effects on first responders of wildfire and of longer fire seasons need further study, including the implications of post-traumatic stress disorder. Research on these physical and mental health effects will inform the types of support that should be offered to communities and responders in the aftermath of a fire. The effects of exposure to wildfire smoke over the immediate and longer term also need to be better understood, and new partnerships among health professions will need to be forged.

"Canada's capacity in wildland fire response has been built on past investments in science, decision analysis and practical technology application. … [T]he investment in science and the university trained people who carry out such work has consistently diminished. The problems of the future will not be resolved by relying on the science of the past nor will they be resolved without focused programs in government and universities."

– Canadian Council of Forest Ministers Wildland Fire Management Working Group, Canadian Wildland Fire Strategy: a 10-year review and renewed call to action.[68]

Ultimately, living within the new reality described above will require that new actors and partners be engaged and that fire-related activities be moved into novel realms; examples may include new regulatory and planning frameworks, the engagement of insurance providers, and the expansion of fire-related research networks and funding to involve Indigenous communities. Community organizations and partners must collaborate to find solutions, such as creating more fire-resilient landscapes and multiple evacuation routes.

Priority Research Topics

- **Economic analysis and evaluation**: Create a full cost analysis of the direct and indirect effects of fire events and values at risk, and gather evidence of the return on investment of mitigation activities.
- **An understanding of the human dimensions**: Enhance social science research relating to public perceptions, attitudes, and responses to wildland fire.
- **Public health**: Conduct research to understand the full consequences of wildland fire on physical and mental health and to improve emergency response and recovery supports during and after a fire event.
- **Community health and well-being**: Improve the ways in which communities experience wildland fire events, including preparation, mitigation, evacuation, and postfire rebuilding.

THE WAY FORWARD: IMPLEMENTING THE *BLUEPRINT*

The *Blueprint for Wildland Fire Science in Canada (2019–2029)* has been shaped by expert input from across the country and reflects insight and guidance from individuals and organizations who conduct wildland fire science, who apply that science to decision-making and planning, or who have interests in understanding fire effects. On the basis of this guidance and the priority research topics identified in the previous section, the *Blueprint* makes the following recommended actions, organized according to five overarching goals. Actions taken in response to these recommendations will shape wildland fire science outcomes over the coming decade and will help in realizing the CWFS vision for "innovative and integrated approaches to wildland fire management in Canada in the 21st century." [69]

Increase National Capacity for Research and Innovation in Wildland Fire Science

The capacity to conduct new and vital science must increase. Government-led research programs have seen gradual reductions in funding and staff, and a large cohort of research scientists has begun to retire. In universities, the number of wildland fire science programs, courses, and instructors currently on offer is limited. Emerging challenges in wildfire science urgently demands selection and grooming of a new generation of fire scientists. They must be entrusted and equipped to discover, develop, and apply multi-disciplinary approaches to increasingly complex problems. Achieving these aims will require secure and stable funding, supported through coordination among governments, universities, and funding agencies.

Recommended actions

- **Reinvigorate postsecondary wildland fire science programs**. Invest targeted new funding to facilitate the expansion of existing academic programs or the creation of new programs and to increase the number of graduates. University representatives have expressed preferences to use existing mechanisms and processes such as those related to the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Social Sciences and Humanities Research Council of Canada (SSHRC).
- **Enhance social science research as a core discipline in postsecondary wildland fire science programs**. Currently, insufficient numbers of social scientists (e.g., sociologists, psychologists, economists, anthropologists) are looking at the human dimensions of wildland fire. More research is required to investigate the physical, mental, social, and economic effects of wildland fire on human populations.
- **Grow core scientific capacity in the public sector**. Increase base funding to encourage and enhance scientific capabilities, technology transfer, and research in the public sector. Investments in public sector science will accelerate the development of new and improved science-based decision-support tools and information.
- **Establish a national postsecondary network for wildland fire science**. This network will be a postsecondary collaborative with dedicated funding and appointed academic chairs. The network will connect researchers from biological, physical, social, economic, cultural, and engineering research disciplines with governments, research institutions, and research funders across the country. It will provide cooperative research opportunities, linking research partners on projects that address national wildland fire science needs and priorities.
- **Strengthen and support the work of existing partnerships, such as the Canadian Partnership for Wildland Fire Science**, until a national postsecondary network can be established. Originally established in 2009 as the Western Partnership for Wildland Fire Science, the Partnership links member organizations

to address priority research needs related to wildland fire science. It serves as a strong model for an expanded national network and provides an established format to build upon.

Recognize Indigenous Knowledge as a Complementary Approach to the Delivery and Development of Wildland Fire Research

Indigenous knowledge and western knowledge are ways of knowing that can complement each other. In support of Canada's commitment to reconciliation and the creation of a new relationship with Indigenous peoples, Indigenous expertise must be recognized and respected as an equal and valid approach to understanding wildland fire and developing future fire management policies and practices.

Recommended actions

- **Under the guidance of Indigenous partners, establish an Indigenous Fire Knowledge Working Group**. The working group will facilitate the retention, development, and sharing of Indigenous fire knowledge. The working group will provide strategic leadership and oversight for collaborative fire science opportunities and activities involving both Indigenous and Western knowledge and respecting Indigenous ownership, control, access, and possession considerations. It is further recommended that this working group develop a statement of commitment to acknowledge and recognize the important role of Indigenous knowledge in wildland fire management and to commit members to the development of partnerships that will ensure that Indigenous knowledge becomes an integral component of national and provincial wildfire management activities.
- **Explore opportunities for the inclusion of Indigenous fire knowledge as a component of postsecondary wildland fire research programs**. Such curriculums must be developed and taught by Indigenous knowledge holders. Students will graduate with an awareness of Indigenous cultural and practical applications of wildland fire and will start their careers already having experience in integrating Indigenous knowledge and western fire science.
- **Create experience equivalencies for professional wildland fire research positions**. Indigenous people in Canada face inequitable access to education and employment opportunities. Many organizations emphasize academic and professional work experience as key qualifiers for employment. This practice excludes many Indigenous people from hiring processes and from representation in the workplace. Indigenous education (formal and informal) and work and life experiences should be considered as experience equivalencies. These equivalencies will recognize Indigenous experiences and expertise as qualifications for professional research positions in fire management agencies and other organizations, creating more opportunities and decreasing barriers for Indigenous knowledge holders and fire experts.

Enhance Knowledge Exchange Mechanisms to Improve the Ways in Which Wildland Fire Science and Technology are Shared, Understood, and Implemented

It is essential to improve the ways in which knowledge is shared and needs are communicated. Stronger networking is needed to ensure that research activities and initiatives address and respond to information needs and that research results are available to those who need them most.

Recommended actions

- **Create a virtual wildland fire knowledge exchange hub**. The hub will serve as an interface among researchers, fire management practitioners, and others with an interest in the application of wildland fire science. It will increase the uptake of research outcomes in wildland fire management and will provide a forum to share best practices and lessons learned. It will also provide a virtual platform for ongoing information exchange, networking, and identification of science needs and priorities.
- **Develop regional venues for knowledge exchange and outreach**. Establish two wildland fire science knowledge exchange venues (one in

eastern Canada and one in western Canada) to facilitate knowledge exchange among regionally based scientists, practitioners, governments, communities, industry, and the public. These venues will focus on developing and disseminating local solutions to regionally based fire management challenges and on developing trust-based relationships between and among key partners.

- **Stabilize and maintain ongoing support for the biennial Wildland Fire Canada conference series**. Wildland Fire Canada is a biennial conference that serves as a venue for both networking and exchange of best practices for fire managers across Canada. It requires a dedicated home base and secure financial support if it is to continue. It should become a national flagship event supporting a robust system of knowledge exchange in Canada.

Expand Partnerships and Welcome New Players

The complexity of challenges, risks, and considerations related to wildland fire calls for multipartner, multidisciplinary approaches and solutions. Effort must be directed toward building collaborations with academic disciplines and professional organizations traditionally outside the wildland fire science community. These collaborations should include but are not limited to the following individuals and groups:

- health care agencies;
- insurance providers;
- engineers;
- municipal land-use planners;
- Indigenous communities;
- the forest industry;
- oil and gas producers;
- emergency response agencies;
- National Research Council of Canada;
- NSERC;
- SSHRC;
- building code developers;
- traditional land users;
- broader university departments and specialties (e.g., anthropology, economics, meteorology, architecture, psychology, political science, sociology); and
- various federal, provincial, and territorial departments and agencies.

Recommended actions

- **Foster links between research disciplines and sectors outside traditional wildland fire science circles to fund research and drive innovation**. Canada's fire research community must deliberately and strategically build relationships with new partners to identify research needs, develop collaborative projects, secure stable project funds and resources, and apply new findings.
- **Build strategic international partnerships**. Canada is not alone in dealing with the challenges associated with wildland fire. There are mutually beneficial outcomes to be gained through enhancing international collaborations on these shared challenges, including access to new or unique facilities, technologies, skills, and specializations; sharing of costs and broader leveraging of funds; increased capacity; and collective development of solutions to global problems.

Improve Governance and Coordination to Establish National Priorities and Define National Needs

The Canadian wildland fire science community recognizes the benefits of developing a nationally coordinated fire science agenda. Indeed, recommendations for a formalized governance mechanism and identification of national research priorities have been in place for decades.

Recommended actions

- **Develop a prioritized national research agenda and commit to regular measurement of outcomes and deliverables**. Development of a national research agenda will identify and address existing gaps in knowledge. This

research agenda will provide a framework for well-defined research activities and a shared understanding of the critical knowledge that is needed and the work that is already taking place, as well as highlighting opportunities for stronger multiplayer collaborations. Progress on the research agenda should be measured biennially. Additionally, it is recommended that this *Blueprint* be reviewed in five years, to assess progress on recommendations and to measure improvements in science capacity.

- **Establish a wildland fire research committee to coordinate national fire science activities**. The committee will establish and maintain a mechanism to synchronize national research activities and to identify annual high-priority research needs. It will liaise with academia, governments, and industry to develop science projects that respond to emerging fire management needs. It will regularly assess and measure progress on the national research agenda. The committee could coordinate or provide oversight for the following recommended actions in this *Blueprint*:
  - Establish a national postsecondary network for wildland fire science.
  - Establish an Indigenous Fire Knowledge Working Group.
  - Create a virtual wildland fire knowledge exchange hub.
  - Develop regional venues for knowledge exchange and outreach.
  - Stabilize and maintain support for the biennial Wildland Fire Canada conference series.
  - Foster links between other research disciplines and sectors outside traditional wildland fire science circles.
  - Build strategic international partnerships.
  - Develop a prioritized national research agenda.

  Proven models exist for the coordination of national wildland fire science activities, including the Joint Fire Science Program in the United States and the Bushfire and Natural Hazards Cooperative Research Centre in Australia, and a review of these types of organizations will be useful.

CONCLUSION

Science is the foundation for what is known about wildland fire, from its effects on ecosystems and people to the ways in which we build, manage, and prepare for threatening fire events. This *Blueprint* has identified six science themes and has recommended a related set of actions to guide the growth in capacity for wildland fire science over the next decade. Priority research topics have also been identified to assist with future funding decisions and to guide the development of new partnerships and collaborative research opportunities.

The next steps are the responsibility of the broader fire science community. The combined efforts of governments, Indigenous partners, postsecondary institutions, science-funding agencies, industry, and nonprofit sectors are needed to strengthen national research capacity, to deliver targeted science outputs, and to implement the recommendations set forth in this *Blueprint for Wildland Fire Science in Canada (2019–2029)*.

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APPENDIX I

Glossary

Note: Unless otherwise indicated, the source of all definitions is the Canadian Wildland Fire Management Glossary.[1]

Adaptation: Initiatives and measures to reduce the vulnerability of natural and human systems to actual or expected effects of climate change.[2]

Agency: A division of government with a specific function and offering a particular kind of assistance. Agencies are defined either as jurisdictional (having statutory responsibility for incident management) or as assisting or cooperating (providing resources or other assistance). Government organizations are most often in charge of an incident, although in certain circumstances private-sector organizations may also be involved. Additionally, nongovernment organizations may provide support.

Canadian Council of Forest Ministers (CCFM): The CCFM is composed of 14 federal, provincial, and territorial ministers (elected officials). Established in 1985, the CCFM provides a forum for the representatives' respective governments to exchange information, work cooperatively, provide leadership, and generate actions related to forestry-related matters of interest to all Canadians, above and beyond the work done by individual governments.[3]

Canadian Interagency Forest Fire Centre (CIFFC): Founded in 1982, the CIFFC has a mandate to (1) provide operational wildland fire management services to member agencies that will, by agreement, gather, analyze, and disseminate fire management information to ensure cost-effective sharing of resources; and (2) to actively promote, develop, refine, standardize, and provide services to member agencies that will improve wildland fire management in Canada.

Canadian Partnership for Wildland Fire Science: Organization initiated in June 2009, through a memorandum of understanding signed by the three founding partners: Alberta Agriculture and Forestry (AAF), the University of Alberta School of Forest Science and Management (UofA), and the Canadian Forest Service (CFS), represented by the Northern Forestry Centre (NoFC). Originally known as the Western Partnership for Wildland Fire Science, it was formed to address priority research needs through the creation of a fire science hub linking the AAF and NoFC with researchers at the UofA and other Canadian and international research institutions.[4]

Canadian Wildland Fire Strategy (CWFS): At the 2004 meeting of the CCFM, members of the Council identified the need for a new strategic approach to wildland fire management in Canada, based on a risk management framework (mitigation, preparedness, response, and recovery). In October 2005, the Ministers signed the CWFS Declaration, expressing unanimous commitment to a new common vision, shared principles, and a proposed path of action to enhance wildland fire management. The CWFS was reviewed and renewed in 2016.[5]

Decision-support system: A generic term for the various systems used by fire management agencies in Canada that employ computer software designed tools to facilitate the storage, compilation, analysis, and display of fire intelligence data and other related information on the fire environment, fire-suppression resources, fire occurrences, and values at risk, in support of planning and daily operational decision-making with respect to wildfires and prescribed fires.

Extreme wildland fire behavior: A level of fire behavior that often precludes any fire suppression. It usually involves one or more of the following characteristics: high rate of spread and head fire intensity, crowning, prolific spotting, presence of large fire whirls, and a well-established convection column. Fires exhibiting such phenomena often behave in an erratic and dangerous manner.

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

Fire danger: A general term used to express an assessment of both fixed and variable factors of the fire environment that determine the ease of ignition, rate of spread, difficulty of control, and fire effects.

Fire ecology: The study of the relations among fire, the physical environment, and living organisms.

Fire effects/impacts: Any ecosystem effects that are attributable to a fire, whether immediate or long-term. May be detrimental, beneficial, or benign. (Adapted from CIFFC)

Fire environment: The surrounding conditions, influences, and modifying forces of topography, fuel, and fire weather that determine fire behavior.

Fire frequency: The average number of fires that occur per unit time at a given geographic location.

Fire management: The activities concerned with protection of people, property, and forest areas from wildfire and the use of prescribed burning for the attainment of forest management and other land-use objectives, all conducted in a manner that considers environmental, social, and economic criteria. Fire management represents both a land management philosophy and a land management activity. It involves the strategic integration of factors such as knowledge of fire regimes, probable fire effects, values at risk, required level of forest protection, cost of fire-related activities, and prescribed fire technology into multiple-use planning, decision-making, and day-to-day activities to accomplish stated resource management objectives. Successful fire management depends on effective prevention, detection, and presuppression of fires; availability of adequate fire-suppression capability; and consideration of fire ecology relations.

Fire management planning: The systematic, technological, and administrative management process of determining the organization, facilities, resources, and procedures required to protect people, property, and forest areas from fire and to use fire to accomplish forest management and other land-use objectives.

Fire regime: The kind of fire activity or pattern of fires that generally characterizes a given area. Some important elements of the characteristic pattern include fire cycle or fire interval, fire season, and the number, type, and intensity of fires.

Fire suppression: All activities concerned with controlling and extinguishing a fire once it has been detected.

Interface fire/Wildland–urban interface fire: A wildfire that affects development located adjacent to or within forested areas.[6]

Mitigation: Efforts to reduce loss of life and property by lessening the potential effects of a disaster.[7]

Modified response: A wildfire that is managed using a combination of suppression techniques, including direct and indirect attack as well as monitoring to steer, contain or otherwise manage fire activity within a predetermined perimeter such that costs and/or damage are minimized and/or benefits from the fire are maximized.[8]

Preparedness: Activities that lead to a safe, efficient, and cost-effective fire management program in support of land and resource management objectives through appropriate planning and coordination.[9]

Prescribed fire: Any fire used for prescribed burning. Such a fire is usually ignited according to an agency's policy and management objectives.

Prevention: Actions taken to avoid the occurrence of negative consequences associated with a given threat. Prevention activities may be included as part of mitigation efforts.

Risk: Broadly, the effect of uncertainty on objectives. Risk is often expressed in terms of a combination of the consequences of an event and the associated likelihood of its occurrence.

Risk assessment: The process of estimating the probabilities of hazardous events taking place within a specified time period in a specified context.[10]

Wildfire: An unplanned or unwanted natural or human-caused fire; contrasts with a prescribed fire.

Wildfire risk: Wildfire risk is the combination of the likelihood of a wildfire occurring combined with the potential effects of that fire.

Wildland fire: Any nonstructure fire, other than a prescribed fire, that occurs in the wildland.[11]

Wildland–urban interface (WUI): The area where homes and other types of human development meet or are intermixed with wildland fire fuels.

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APPENDIX 2

Identifying National Wildland Fire Science and Innovation Activities

A companion document to the *Blueprint for Wildland Fire Science in Canada (2019–2029)*

Developing a National Wildland Fire Science Research Strategy

The *Blueprint for Wildland Fire Science in Canada (2019–2029)* categorizes existing science and innovation needs within a framework of six broad themes:

- Theme 1: Understanding fire in a changing world
- Theme 2: Recognizing Indigenous knowledge
- Theme 3: Building resilient communities and infrastructures
- Theme 4: Managing ecosystems
- Theme 5: Delivering innovative fire management solutions
- Theme 6: Reducing the effects of wildland fire on Canadians

Any listing of specific science projects within these themes is outside the stated scope of the *Blueprint*. However, one of the recommendations calls for the development of a coordinated national research agenda to create a "framework for well-defined research activities and a shared understanding of the critical knowledge that is needed and the work that is already taking place, as well as highlighting opportunities for stronger multiplayer collaborations." The identification of detailed activities and projects will likely be a major component of this process.

Identifying science activities: a first step toward a national research agenda

In addition to the expert input and guidance provided by members of the *Blueprint* Steering and Implementation committees, more than 100 individuals and organizations from across the country provided feedback on science needs and interests in relation to wildland fire. This feedback is compiled in the following pages, in a tabular format aligned with the six *Blueprint* themes, as a starting point for discussion and an initial step in developing the national research agenda.

Considerable collective effort and expertise has gone into the development of these tables, but readers are cautioned to remember that the information remains in draft form and will require continued refinement and discussion by the fire research community.

Theme 1: Understanding fire in a changing world

Conducting fundamental physical fire science as a foundation for improved decision-making

Knowledge gap/need	Relevant priorities/activities
The Canadian Forest Fire Danger Rating System (CFFDRS) must be enhanced as the foundation of a modernized wildfire risk assessment system.	Develop national models of wildfire occurrence, severe fire occurrence, and fire load for a 14-day outlook period, based on statistical models relating numbers and duration of fires to explanatory variables (e.g., lightning strike density, human development, fuel moisture, atmospheric stability), and develop models of daily burn probability: • Enhanced understanding of factors influencing both days with large numbers of fires and occurrence of large fires. • National analysis of factors influencing human-caused fires. • Methodologies to produce daily burn probability and event likelihoods. Understand and forecast large fire growth: • Conduct virtual burns to study fires under extreme conditions so as to improve the models used to predict extreme fire events. • Improve "now-casting" by incorporating as much current information about fuels, fire, and weather into current operational fire-growth models; incorporate advanced weather prediction models (e.g., WRF, GEM) to provide hourly predictions of potential fire growth of all large fires in Canada. Combine operational fire-growth predictions with smoke emissions models to capture more precisely the conditions leading to large smoke events; extend forecasts to 3–5 days.
Reengineer systems to seamlessly assimilate and integrate new spatial "big data" sources from remote sensing and numeric weather modeling to accurately predict fire danger at high-resolution community scale (about 1 km).	Create new nationally consistent fire environment data sets to support the development of new decision systems and risk analyses, including snow melt, vegetation greenness, historic fire weather, and high-resolution fuels data sets around communities. Improve modeling and forecasting of fire weather and fuel moisture at hourly to weekly scales: • Evaluate grid-based remote sensing, land surface analyses, and forecast products for assimilation into the Canadian Wildland Fire Information System: i. NDVI vegetation greenness; ii. soil moisture active and passive products (snow depth, snow water equivalent, soil); iii. Canadian Precipitation Analysis; iv. new national scale 2-km resolution weather forecast products vs. medium (10–14 days) range NAEFS and European forecasts. Develop scientific improvements to the moisture models that drive the Fire Weather Index (FWI) system (e.g., stand-specific moisture models, addition of solar radiation, improvements to hourly models including latitude effects, and development of subhourly models). Evaluate landscape interpolation methodologies. Evaluate medium-term seasonal and long-term weather and FWI forecasting, and improve methodologies.

Theme 1: Understanding fire in a changing world, continued

Knowledge gap/need	Relevant priorities/activities
New models are needed to assess fire behavior potential in forests where the fuel structure and load have been modified through management, insect mortality, or changing climatic conditions (with associated changes in composition, structure, density, and other characteristics) to inform mitigation measures, particularly fuel management.	Create next-generation fire behavior prediction tools to represent variation due to age dynamics, stand density effects, and mortality, including managed and novel fuel types: • methods to characterize fuel structure and biomass and novel fuel types (LiDAR, enhanced forest inventory) to support next-generation fire behavior modeling; • structurally based fire behavior models incorporating surface fire spread, transition to crowning, and crown fire submodels; • field experiments to validate models. Assess firebrand spotting distances, and investigate methods to represent ember spotting
Mechanisms of fire spread and damage within the wildland–urban interface (WUI) and urban areas are poorly understood. As such, advanced models are needed to predict fire spread adjacent to and within the WUI and to inform mitigation measures, including fuel reduction, building code changes and development of appropriate response tactics.	Evaluate and test physical models suitable for assessing fire behavior potential at high resolution (i.e., at a scale of meters) in the WUI interface (e.g., FIRETEC, Wildfire Dynamics Simulator to support fuel management planning [clearing, thinning, pruning]).
A national framework for fire risk assessment across the landscape and, importantly, near communities is a key gap for planning and prioritizing wildfire mitigation programs.	Develop a risk assessment framework for wildland fire.
Methods are needed to portray wildfire risk by combining burn probability with likely exposure, vulnerability, and value of assets in or near wildlands in a manner that can inform planning and policy development for a variety of stakeholders.	Improve tools to map wildfire risk and generate event sets. Reengineer current simulation models for parallel processing on supercomputers, to move models from research to operational tools. Develop and maintain data sets to support national wildland fire risk assessment. • improved national fuel layer. • enhanced wildland urban interface map, database and update process. Develop new risk assessment methods and identify fundamental knowledge gaps. • methods to link fire events, WUI exposure and potential damage in a pilot area and methods to map firesheds. • assessment of the likelihood of evacuations, and the likelihood of structure ignition.

Theme 1: Understanding fire in a changing world, concluded

Knowledge gap/need	Relevant priorities/activities
There is limited publicly available information on wildland fire hazards that can be used for community land-use planning	Created national fire hazard maps and event sets. • maps of current fire risk and seasonal partitioning of outputs • statistical models of future burn probability. • higher resolution maps of burn probability for high-priority areas.
A comprehensive analysis of climate change impacts on fire activity is needed to inform future predictions.	In key ecoregions, perform a comprehensive assessment of historical fire, climate, vegetation, and atmosphere relations at all scales, including enhanced data sets from historical fire maps (NBR) and synthesis of climate, vegetation, and fire interactions from past climates, including past warm periods.
There is a pressing need to understand the short-, medium-, and long-term effects that climate change will have on wildland fire regimes, and, in turn, on forests, communities, infrastructure and industry.	Develop explicit coupling for wildfire suppression processes with models of future wildfire activity (e.g., changing forest fuels, fire occurrence, and fire behavior) to allow complex, nationally relevant questions about changing wildfire management effectiveness and enhanced resource needs to be evaluated.

Note: WRF = Weather Research Forecasting;
GEM = Global Environmental Multi-scale;
NDVI = Normalized Difference Vegetation Index;
NAEFS = North American Ensemble Forecast System;
LiDAR = Light Detection and Ranging (remote sensing technique);
NBR = Normalized Burn Ratio.

Theme 2: Recognizing Indigenous knowledge

Recognizing Indigenous knowledge and collaborating with Indigenous peoples for better wildland fire management

Knowledge gap/need	Relevant priorities/activities
Development of an Indigenous FireSmart program.	Perform research on preferences for and acceptance of FireSmart activities in Indigenous communities.
Support for coexistence of Indigenous knowledge and western science: • Need to integrate existing western science practices and structures with Indigenous practices. • Need to involve Indigenous communities in research planning and implementation.	Conduct research on best practices from other countries (e.g., Northern Territory of Australia; Kurok Tribe in California). Create a platform for scientists and Indigenous knowledge keepers to jointly develop science priorities and create opportunities for collaborating and sharing information. Collaborate with Indigenous knowledge keepers and communities to perform research on Indigenous fire management (historical and current): • develop an understanding of how Indigenous peoples have used and applied fire in the past, how they are currently using and applying fire, and how that knowledge can be applied to fire management practices in Canada; • conduct Indigenous knowledge workshops and field trips, including burning. Perform research on co-management of traditional lands for fire.
Lack of recognition of research that involves, collaborates with, and supports Indigenous peoples and Indigenous knowledge	Graduate more Indigenous researchers. Create a platform that will facilitate collaboration among western researchers, Indigenous communities, and Indigenous knowledge keepers. Ensure that any and all research taking place on traditional lands includes a requirement for Indigenous involvement.

Theme 3: Building resilient communities and infrastructure

Protecting forest-based communities and infrastructure from wildland fire events

Knowledge gap/need	Relevant priorities/activities
Knowledge of what's at risk	Perform risk assessments for communities, critical infrastructure, etc.
Need to identify social influences that result in action and change.	Conduct multidisciplinary research into: • values and views of residents, businesses, and individual communities; • motivators and instruments that can contribute to risk reduction.
Need to understand how fire behaves in an urban setting.	Gather data-driven field observations and laboratory-derived conclusions to determine science-based building requirements and needs.
Need for cost–benefit analyses of the multitude of potential costs and effects of wildland fire (e.g., socioeconomic analysis; analysis on effectiveness of mitigation).	Quantify the cost and benefits of various approaches. Capture the health costs associated with wildfire events. Determine the social cost resulting from disruption of lives and stress. Analyze the effectiveness of mitigation activities.
Need for more Canadian data to support and inform fire management activities.	Present research analyses in terms that can be used by residents and community leaders.
Need to invest efforts in the "Development" category of FireSmart, which has been grossly overlooked (i.e., lack of application).	Extend the development guide and related research results through proactive outreach to communities and development organizations. Identify barriers and opportunities for integration into practice.
Need to explore the link between resilient communities and ecological impacts/integrity.	Determine how resilient communities can benefit water quality, air quality, species diversity, recreation values, and wildlife by identifying: • wildfire effects on community resilience; • wildfire risk reduction effects on community resilience; • ecological health effects on wildfire risk.
Need to identify climate change impacts at the community level, for the purpose of community planning.	Work with communities to develop research programs that will better inform the potential changes and desired future state of community lands based on long-term climate change.
Need to understand the role of Indigenous knowledge in resilient communities.	Document Indigenous knowledge, and explore ways to apply these concepts.

Theme 4: Managing ecosystems

Understanding the effects of fire, both desirable and undesirable, on forest ecosystems

Knowledge gap/need	Relevant priorities/activities
Description, evaluation, and prediction of first-order (immediate) and second-order (long-term) fire effects.	How do fire-induced vegetation changes affect reburn events in the future? How do fires affect vegetation composition and succession at various spatial scales, ranging from population dynamics to ecosystem structure? How do fire intensity and severity affect carbon storage and dynamics? How does wildfire affect the habitat of wildlife (big or small, aquatic or terrestrial)? How can we better leverage remote sensing to characterize and monitor the first- and second-order effects of fires? Develop a range of methods (including but not limited to, remote sensing) to assess and monitor burn severity at a national scale. How does climate change affect any of these elements?
Fire regimes and interactions with other disturbances.	We need to describe the past, evaluate the present, and predict future fire regimes, including better characterization and identification of regimes with low or mixed severity. Extend geographic coverage of baseline/historical fire regime knowledge. What is the current condition of the fire regime compared with its historical condition (Fire Regime Condition Class)? Is the departure meaningful? How do fire regimes interact with other natural disturbances (e.g., flooding, insects, disease)? Where do fire refugia exist on the landscape? How does climate change affect any of these elements?
Fire effects on ecosystem health and resilience.	How do we define and characterize "fire-resilient ecosystems"? What should the metrics be? How does fire affect conservation of not just the charismatic megafauna, but also other wildlife, plants, and biodiversity in general? How can we link fire, climate change, and resilient ecosystems, trees, and vegetation structures? What are the wildfire risks associated with investments in conservation (such as habitat restoration and critical habitat preservation)? How do invasive species contribute and respond to fire? How does climate change affect any of these elements?

Theme 4: Managing ecosystems, concluded

Knowledge gap/need	Relevant priorities/activities
Fire effects on ecosystem services.	How does fire affect human values of ecosystems? How do fires affect recreation and scenic values, nontimber forest products, hunting, drinking water, clean air, and other ecosystem services? How does fuels management designed to protect WUI values affect ecosystem services (trade-off analysis)? How do we quantify effects of fires on ecosystem services, given that some are very local (a patch of blueberries) and others are global (emissions of carbon dioxide)? How does climate change affect any of these elements?
Integration of sustainable management of fire and natural resources.	How can we better integrate fire and forest management? What can we learn from traditional ecological knowledge? How do fuel treatments affect ecological dynamics? When and where is salvage logging appropriate? How do fires affect timber supply? Do managed landscapes (forestry) reduce fire risk? What are the best silvicultural approaches to reducing fire risk? Can prescribed fire be used to aid silvicultural and other natural resource objectives? What policies act as barriers to implementing silvicultural and fuel treatments and prescribed burning intended to reduce wildfire risk? What role do protected areas play with regard to fire management (both within the protected area and through interaction of the protected area with its surrounding landscape)?
Assessments, information, and decision support.	Conduct wildfire risk assessments. Develop an integrated fire effects framework for dissemination of information. Develop public education tools to improve fire ecology knowledge. Develop models to enable "gaming" to examine the effects of fuels treatments (mechanical and prescribed fire) on fire behavior. Develop databases to enable the sharing and distribution of information related to fire ecology, regimes, and effects.
Strategic use of fire.	How can we use modified responses to fire and prescribed fire to burn safely for ecological objectives? How can we use modified responses to fire and prescribed fire for risk reduction objectives? Improve FBP system to incorporate fire regimes of mixed and low fire severity regimes. What do fire regime studies reveal about thresholds for fire? Are some areas burning too much or not enough? Develop something analogous to the Fire Regime Condition Class system?

Theme 5: Delivering innovative fire management solutions

Transforming fire management through research and innovation

Knowledge gap/need	Relevant priorities/activities
Operations (short-term weather, suppression, firefighter safety, etc.): • Improvements to operational wildland fire response capability.	Add fire-suppression effect into fire growth simulations. Perform research into fire spotting processes (ember production and transport). Perform research into improvements to weather observations and processes at the operational scale (such as stability indices or an increase in number and availability of upper air stations to support fire operations). Further integrate fire danger rating and mapping. Develop national wildfire safety systems (mostly fireline-level) that allow for quick and relevant lessons on fire entrapments, injuries, near-hits, etc. The systems should also allow quick reports on incidents, including wins (dangerous situations that were avoided). Perform research and development related to innovative fire-suppression systems, including chemicals, equipment, and tools (both ground and air).
Planning (prediction of fire occurrence, medium-and long-term weather forecasting, risk assessment and management, etc.): • Improved planning processes and metrics.	Develop and implement fire occurrence prediction models, at regional and national scales. Develop and implement resource demand models, at regional and national scales. Improve medium-term fire forecasting (10–14 days) and apply to resource demand modeling. Develop metrics to measure efficiency and effectiveness of initial attack. Integrate fire management objectives with forest management. Improve forecasting of smoke trajectories and the effects of smoke on air quality.
Management (fuel mapping and characterization, fuel management, FireSmart, links to forest management, policy, economics, etc.): • Improved wildland fire management practices.	Develop methodologies for wildland fuel classification. Integrate developments in fire behavior science and advances in fuel characterization and mapping. Perform research into the effectiveness, efficiency, and cost-effectiveness of fuel treatments and the FireSmart program. Integrate forest management objectives and practices with fire regimes and fire management. Analyze and integrate natural hazards policy and natural resource management for all hazards and resources. Provide economic justification for spending on preparedness. Use prescribed fire for both silvicultural and fuel management purposes. Create fire regime thresholds or condition classes for fire management. Strategically use prescribed fire and fire regimes to allow for increased fire on the landscape when appropriate.

Theme 5: Delivering innovative fire management solutions, concluded

Knowledge gap/need	Relevant priorities/activities
Data, situational awareness, and methods (data/information management, fire detection, use of drones, fire mapping, decision-support systems [also in decision-making], etc.): • Data management, technology, and development of tools.	Develop means to provide near-real-time fire activity information to provincial and regional fire managers. Deliver better, more timely fire information (such as fire boundaries, weather, and behavior, as well as crew location and productivity) to incident management teams responsible for specific fires. Provide better access to national wildland fire data. Improve the integration and coordination of national fire data through a collaborative national initiative with open and interoperable data services. Improve the integration of tools for response, emergency preparedness, and use at all levels (fireline to emergency management). Explore new technology for data collection and intelligence gathering, such as remote sensing. Develop simple tools to make daily tasks more efficient, such as mobile-friendly incident action plans. Develop a mechanism to provide for integration and support of widely used models. Create a national, online, searchable burn severity database.
Knowledge transfer (communication, extension, case studies, knowledge transfer from researchers to practitioners, Indigenous knowledge, etc.) • Methods of communicating, transferring knowledge, learning from others, and integrating Indigenous knowledge into wildland fire science.	Create a way to capture fire management knowledge from experienced staff and communicate ("translate") it effectively for future staff members (for example, a database of case studies of past fire experiences or a "lessons learned" center for wildland fire). Identify ways to integrate Indigenous knowledge into wildland fire management. Integrate knowledge from other disciplines or countries into wildland fire management.
Decision-making (decision science, risk management frameworks, decision-support systems [also data and tools], etc.): • Need to ensure the right decisions are made.	Develop decision-support systems. Develop risk management frameworks. Improve situational awareness at multiple levels (fireline, provincial, national). Perform research into decision science, such as mathematical modeling, statistics, and expert systems to assist with all levels of fire management decision-making and system design. Implement risk assessment at national and local scales.

Theme 6: Reducing the effects of wildland fire on Canadians

Addressing the long-term physical, mental, social, and economic well-being of people living with wildland fire

Knowledge gap/need	Relevant priorities/activities
Understanding of the short- and long-term mental health effects of fire events	Perform research in collaboration with mental health researchers and communities who have experienced wildfire.
Understanding of the short- and long-term physical and mental health effects of fire on first responders	Conduct research in collaboration with first responders, agencies, and health researchers on the following topics: • firefighting safety; • nutrition; • sleep; • physical fitness; • injury prevention; • cognitive function, stress, and psychosocial fitness.
Understanding of the full scope of how fire events affect communities	Develop a better understanding of the sociological, economic, and psychological effects of fires on communities, through case studies with communities that have been affected by wildfire, with development of recommendations for other communities to follow: • Many Indigenous communities are at high risk of being affected by wildfire, and research should be prioritized in this area. Perform research on the effects of evacuations, and examine why we evacuate communities (are there other options?).
Building of partnerships to enhance community resilience	Create collaborations and partnerships with organizations involved in related research.
Risk communication, including public education	Conduct research to understand how people perceive risk and the most effective ways to educate the public about wildfire: • Develop more effective prevention messaging. • Develop effective communication strategies related to FireSmart. Conduct research concerning the effectiveness of prevention messaging by agencies. Conduct research concerning appropriate real-time communication and the provision of information during fire events.
Monitoring of smoke and its effects on human health	Develop more accurate smoke models that are publicly accessible and easy to understand. Perform research in collaboration with health partners on the effects of wildfire smoke on members of the public and firefighters.