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Wildfire Risks to Resource Roads in British Columbia

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Abstract:

Wildfire risks in British Columbia are currently elevated and continue to increase. The subject of this report is to review the state of knowledge about how wildfires will impact resource roads now and in the future. Available wildfire hazard information along with resource road vulnerabilities are summarized and links to wildfire risks are established. The report also discusses how our understanding of risk might be improved with better information about wildfire impacts to resource road infrastructure, standardizing valuation of resource road function to support budget priorities, and standardizing variables for use in projections of future wildfire hazards and how projections may be combined with current wildfire hazard ratings. Improved understanding about wildfire risks to resource roads is necessary to initiating effective adaptation actions and strategies that create resilience.

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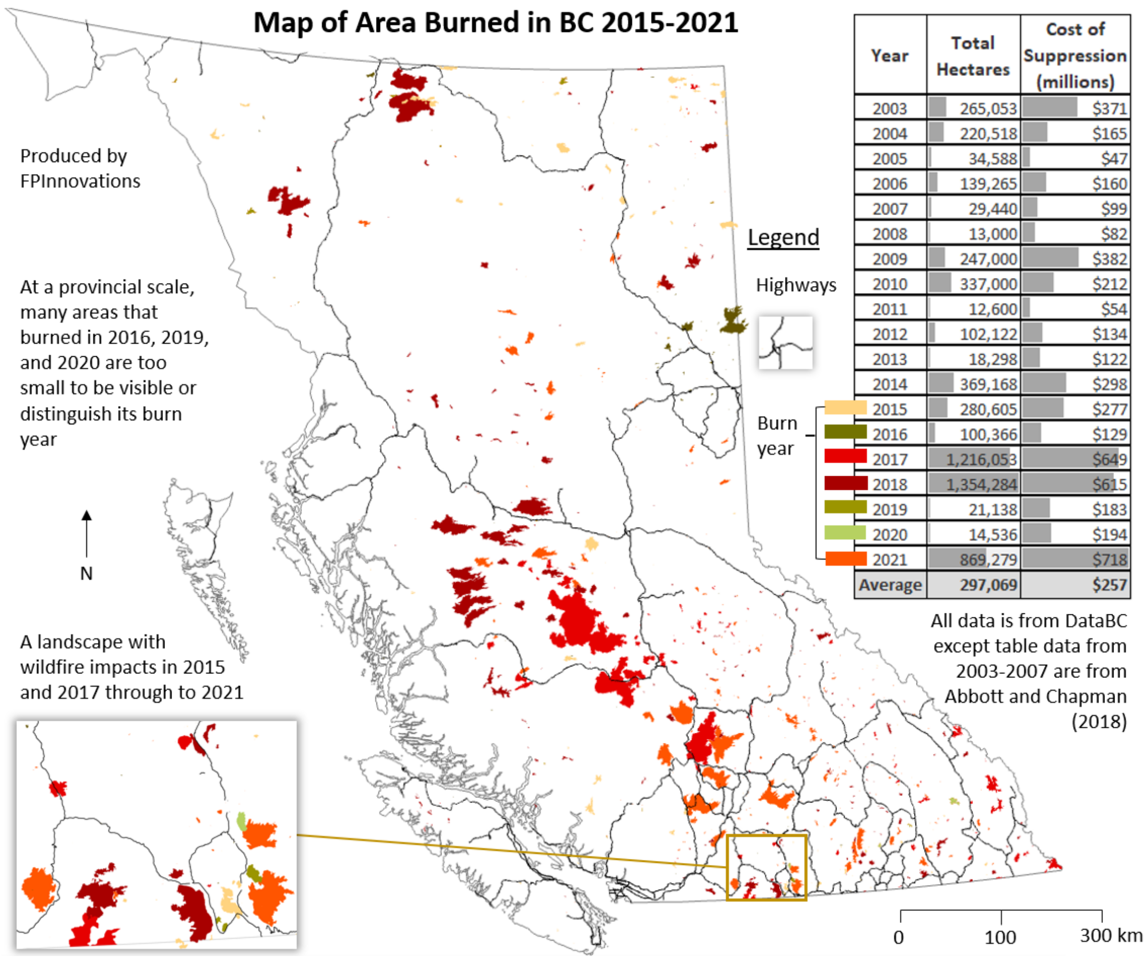
1 INTRODUCTION

The potential impacts of wildfires in British Columbia (BC) are elevated for the foreseeable decades. Central reasons for this include the many years of wildfire suppression strategies that built up fuel loads across the province, continued urban development that expands the wildland-urban boundary, and impacts from climate change (BC Government, 2010). The 2003 Kelowna-area firestorm highlighted the increased wildfire hazard from fuel buildup and wildland boundary expansion (Filmon, 2004) and prompted greater attention to wildfire by the BC government. The impacts related to climate change became clearer only later as climate models advanced. By 2009, BC had an extensive research plan for climate change impacts to wildfire (BC Government, 2009) and after BC's next large wildfire event in 2017, a review (Abbott & Chapman, 2018) suggested climate change as a contributing factor. This, in turn, prompted many new wildfire initiatives (BC Government, 2021a), including this report on how wildfires will impact resource roads now and in the future. While the focus is on BC, the content applies across Canada.

Figure 1 shows wildfire activity in BC since 2015, and a table summarizing total area burned and the associated suppression costs since 2003. Other costs, notably insurance claims and flooding damage in following years, are not included. There is high year-to-year variability in burned area and suppression costs; however, the three years with greatest area burned by wildfires occurred in the last five years. Larger fires tend to occur in the BC Interior where there is a concentration of industrial activities and communities compared to other regions, as well as weather patterns that can promote lightning ignitions and rapid spread.

Resource roads play a vital role in many aspects of reducing wildfire risk, including wildfire suppression efforts, maintaining access for rural and Indigenous communities, evacuations, fireproofing communities as part of linear firebreaks, fuel reduction within road rights-of-way, and providing access for post-wildfire remediation activities. In BC, active resource roads on Crown land that have higher industrial traffic volumes, connect to communities, or have high recreational value are called Forest Service Roads (FSRs) – the subject of this report. An improved understanding of how FSRs are managed and operated in terms of wildfires can enhance resilience of FSRs and their surroundings in the face of increasing wildfire threat. This discussion of wildfire-FSR interactions uses the following definitions: hazard is the potential probability of a wildfire occurring; vulnerability is the degree of potential damage to FSR infrastructure and uses; and risk is the hazard multiplied by the FSR vulnerability. FPInnovations has conducted a series of resource road studies looking at the risks from climate change to function and serviceability since 2018 (Bradley and Forrester, 2018; Partington et al; 2018; Partington and Bradley, 2019; Partington and Bradley, 2020); however, this research focused on flooding rather than wildfire risks.

The objectives of this report are to review available wildfire risk information applicable to FSRs and to identify the associated potential impacts to FSR function and serviceability. The review considers FSR uses during, in the years following wildfires, and in the distant future while accounting for climate change. An additional objective is to identify research needs to address gaps in knowledge and understanding.



Year	Total Hectares	Cost of Suppression (millions)
2003	265,053	$371
2004	220,518	$165
2005	34,588	$47
2006	139,265	$160
2007	29,440	$99
2008	13,000	$82
2009	247,000	$382
2010	337,000	$212
2011	12,600	$54
2012	102,122	$134
2013	18,298	$122
2014	369,168	$298
2015	280,605	$277
2016	100,366	$129
2017	1,216,053	$649
2018	1,354,284	$615
2019	21,138	$183
2020	14,536	$194
2021	869,279	$718
Average	297,069	$257

Figure 1. Map of burn areas resulting from BC wildfires 2015 – 2021, along with a table of area of burned per year and associated suppression costs for 2003 – 2021.

2 CONSIDERING FOREST SERVICE ROADS

BC has approximately 700 000 km of resource roads. More than 180 000 km of these are permit roads used by the forest industry as haul roads and managed through licencing agreements, and another 240 000 km are cutblock roads (Forest Practices Board, 2015). Approximately 65 000 km of the resource roads are FSRs and, of these, 12 000 km are capital roads (Pickup, 2020), which provide access to small communities, rural areas, and/or recreation sites of high value. The Engineering Branch of the Ministry of Forests manages and monitors FSRs while local area districts are responsible for local operations. Maintenance of FSRs can involve Ministry of Forests district offices, BC Timber Sales, or forest industry licensees. If considering wildfire risks, capital roads that serve communities are likely to be a highest priority; however, other nearby roads also may need to be considered as priorities if, for example, post-wildfire landslide or rockfall hazards from these roads would jeopardize downstream or downhill capital road infrastructure. Furthermore, all types of resource roads are relevant to potential suppression efforts, remediation, and landscape level mitigation. Figure 2 shows FSR roads and permit roads in relation to all other roads in BC.

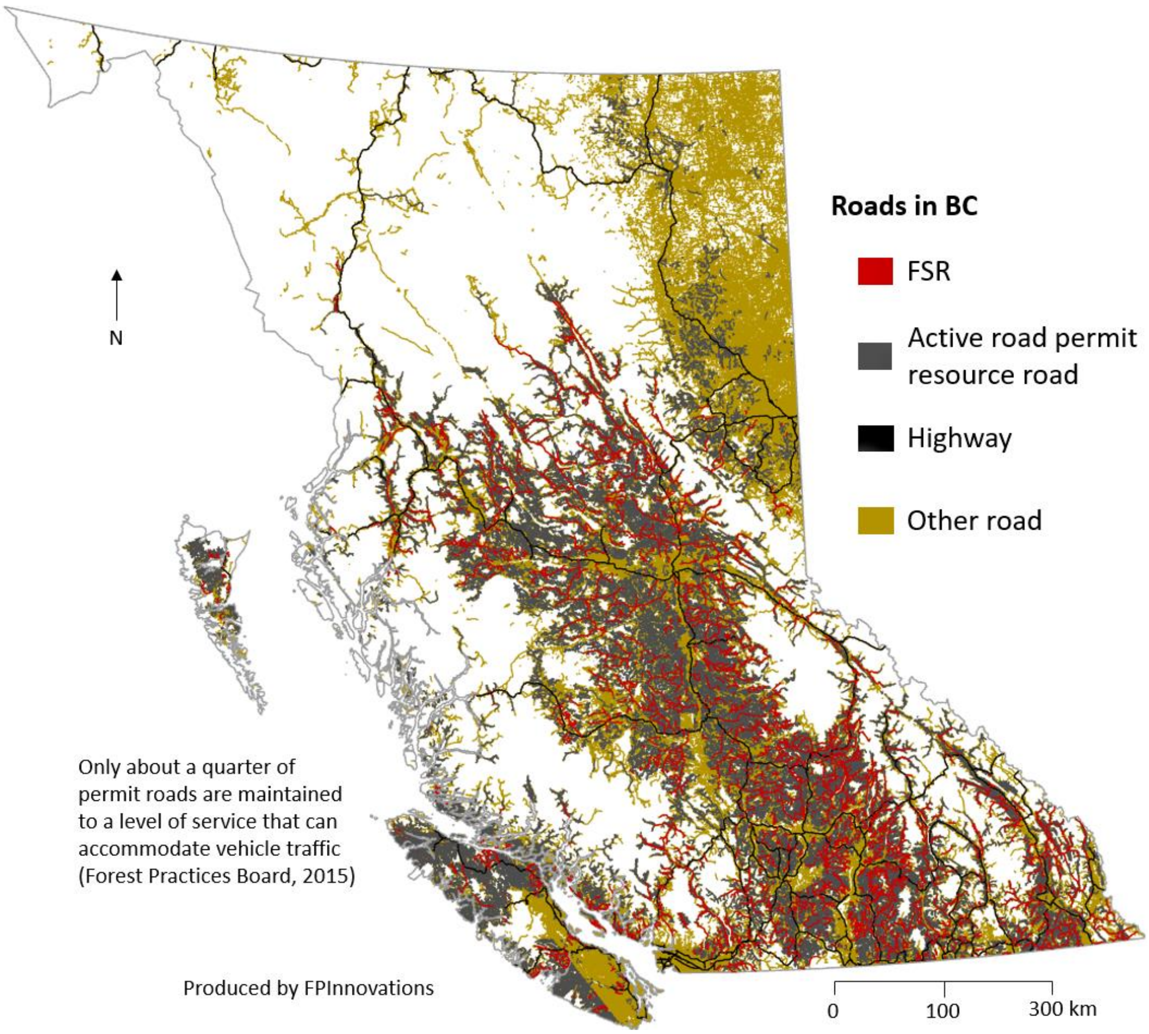


Figure 2. All roads in BC classified to highlight the footprint of FSRs and active permit roads in relation to all other roads. All source data is from Data BC.

3 RELEVANT WILDFIRE INFORMATION

The fundamental factors that influence wildfire behaviour are local weather, fuel, and topography (BC Government, 2010). Information applicable to describing current wildfire hazards for FSRs is available from the British Columbia Wildfire Service (BCWS), and recent burn information classified by burn severity is available from the Ministry of Forests, Forest Analysis and Inventory Branch. On the other hand, an approach to considering future climate impacts is not well defined and so a variety of information sources need to be considered and interpreted. The following sections review information sources for use in estimating wildfire hazards applicable to FSRs during wildfires, in the period immediately following a wildfire, and the distant future.

3.1 Current Wildfire Risk and Hazard Information

As part of its mandate, BCWS produces and maintains a set of wildfire threat maps for Crown land that are generally known as the Provincial Strategic Threat Analysis (PSTA). Note that the term wildfire threat corresponds to the concept of hazard as defined in this report. Communities that receive funding for community wildfire resilience planning use PSTA maps as a starting point to identify and prioritize activities that include field validations of the PSTA maps (BC Government, 2020). While several PSTA maps are available, the Threat Rating Map and its derivates are referenced in guidance about wildfire resilience planning for communities (BC Government, 2021a).

The Threat Rating Map summarizes relative threats between areas using a 50 by 50-meter resolution grid. It combines threat maps for head fire intensity, fire density, and spotting impact, and weights these by 60%, 30%, and 10%, respectively (BC Government, 2015). Head fire intensity estimates the energy output at the head of the fire and references the fire weather index; fire density uses historical wildfire data to represent the potential wildfire ignition and spread; and spotting impact considers atmospheric conditions that can affect how a fire can spread by embers traveling.

There are two other relevant maps related to the Threat Rating Map in the PSTA dataset and both use a Wildland-Urban Interface (WUI) to define an area of interest. The first, called the WUI Threat Rating Map, uses up to 2 km buffers around structures and critical infrastructure to clip the Threat Rating Map. The second, called the WUI Risk Class Map, also clips the Threat Rating Map but with slightly different buffer definitions, and then multiplies it by a density map of structures within the buffer area. The product, after some normalizing and classification, is called a Risk Class Map. This multiplication yields a risk score as the Threat Rating Map is treated as likelihood of hazard information about relative wildfire risk, and the structure density map is a proxy for relative consequences resulting from vulnerabilities; according to the industry ISO 31000:2018 definition of risk (ISO, 2018) likelihood multiplied by consequence defines risk.

For FSRs, the WUI-based maps show important concepts but use buffers that result in a negligible amount of FSRs included. Creating an FSR-specific Threat Rating Map is possible by defining buffers along road surfaces and/or around crossings to use as a clip area. Producing a risk map analogous to the Risk Class Map for communities could further define a proxy layer that informs relative consequences along with community-specific information. This could involve data like the Ministry of Forests' corporate bridge registry, which could provide locations of crossings and associated vulnerability to fire, or information identified over the course or workshops. Figure 3 shows an example of the BC Threat Rating Map clipped by a typical right-of-way of the FSR network that has "FSR" in its road name. While the map is of limited operational value, it provides a strategic view of relative threat of wildfires between regions. Areas with relatively lower threat ratings include those areas that were recently burned or those with less flammable fuels.

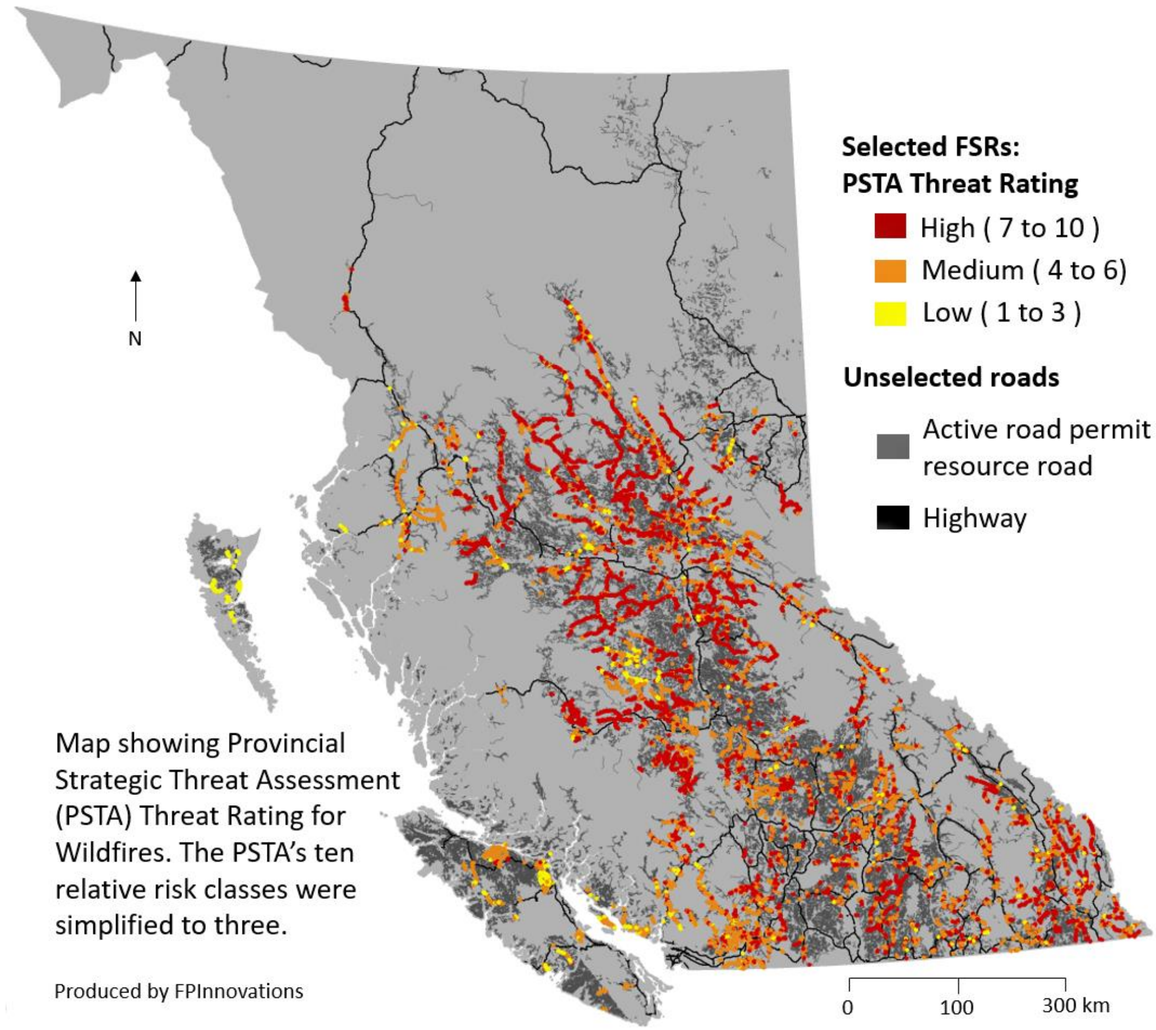


Figure 3. Possible method to assess wildfire threat to FSRs – PSTA Threat Rating Map clipped by subgroup of FSRs using a 12.5-meter buffer to isolate the FSR right-of-ways. Since capital roads are not defined in any dataset from DataBC, to emphasize where capitalized FSRs may be, FSRs were selected from forest tenure dataset that also were named "FSR" the Digital Atlas to eliminate some less important roads.

3.2 Utilizing Recent Post-Wildfire Risk and Hazard Information

In the several years following a wildfire, FSRs in or downhill of a burned area can have elevated risks of landslides, rockfall, and flooding. The Forest Analysis and Inventory Branch maintains a burned areas dataset that includes burn severity information and can be useful to inform relative risk calculations. While professional surveys can provide much more detailed data, the severity-of-burn dataset provides strategic province-wide information.

The burn severity dataset represents relative hazard information. Other non-wildfire datasets, such as a digital elevation models, watershed details, and crossing design information, may be combined with it to define relative changes to vulnerability or risk. Side slope gradient is needed for assessing changes to rockfall and landslide risks, watershed areas are needed to delineate changes to hydrology, and a stream crossing design flood is needed to estimate relative vulnerability or risk increases.

The Provincial burn severity datasets start from 2015 and have three burn classes. The classification method uses satellite data to define these classes. Figure 4 shows the burn areas in BC since 2015 and emphasizes burn severity information for an area of interest. Combining this information with stream data and crossing design information could help inform a relative risk score for post-wildfire flooding.

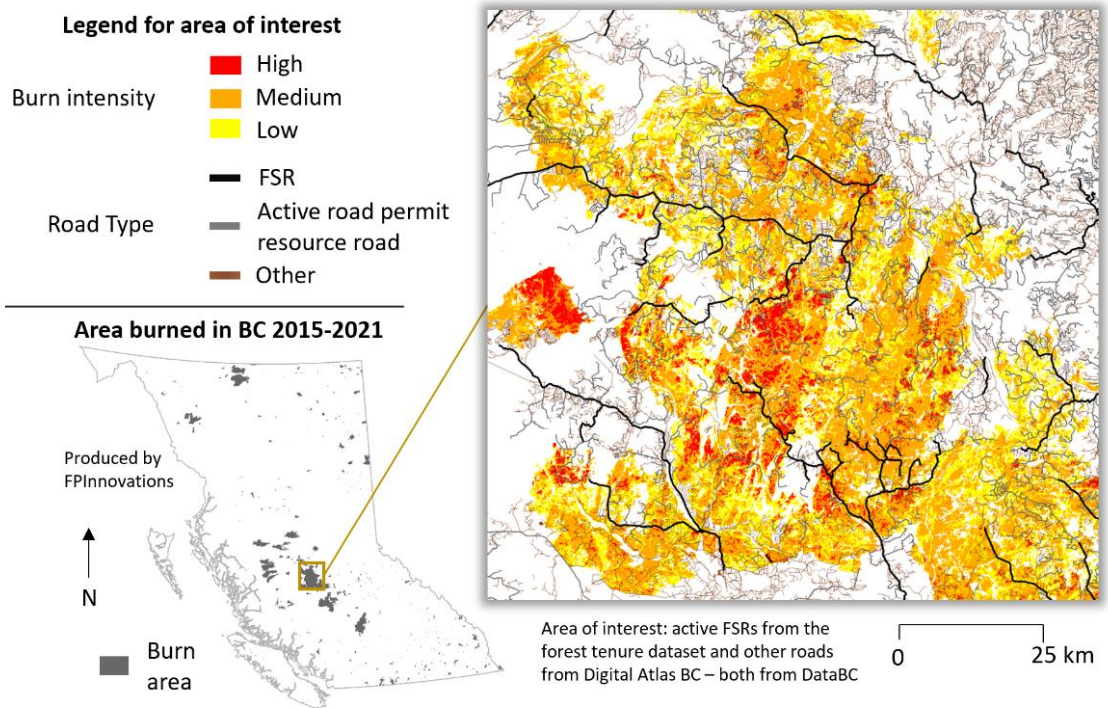


Figure 4. Burn areas in BC since 2015 with a detail exemplifying how burn severity information looks. The area of interest has a high resource road density inside the burn area.

3.3 Projections for Wildfire Risk and Hazard Information

While there is consensus within the BC government about climate change increasing wildfire risks, there is no standard way to define this increase or how it might differ between regions. If referencing publicly available climate change datasets for BC as a starting point, then projections about wildfire conditions, or any climate event, must link to average and extreme values for temperature and precipitation grids spanning 1950 to 2100 available from Global Climate Models (GCMs). For BC and Canada, these are available downscaled to a daily, 56 km^2 resolution (Murdock et al, 2013).

A common wildfire conditions forecast metric, such as the fire weather index (FWI), is not suitable as a projection variable because it includes references to higher-order variables like wind. Projections about wind are not based on wind measurements but, rather, would need to be derived from downscaled GCM temperature and precipitation grids, and this would increase uncertainty in the process. To minimize uncertainty, instead, approaches reference more basic climate indicators at the cost of them having more general relationships to wildfires. Defining a proxy variable in this way is an available method within the industry standards (ISO, 2018) when data is lacking about the risk of interest.

Many potential proxy variables for wildfire hazard have been identified. At a general level, climate change that increases temperatures and decreases precipitation raises the risks of wildfire (BC Government, 2021b). Examples of more specific suggestions for changes to climate indicators that can be derived from GCMs include increases to average yearly temperature, increases to maximum yearly temperature, decreases to summertime precipitation, increases in number of days in a year with days over 30 degrees, and increases in intensity and duration of hot and dry summer conditions (BC Government, 2019b). Figure 5 illustrates projected changes in BC for to the yearly hottest day by the 2050s, which may have some relationship to wildfire hazard (along with many other temperature and non-temperature-based climate indicators). The source data for Figure 5 is the Pacific Climate Impacts Consortium (PCIC) daily resolution projection dataset that spans 1950-2100 and refers to average projections for the time period between 2040 and 2069.

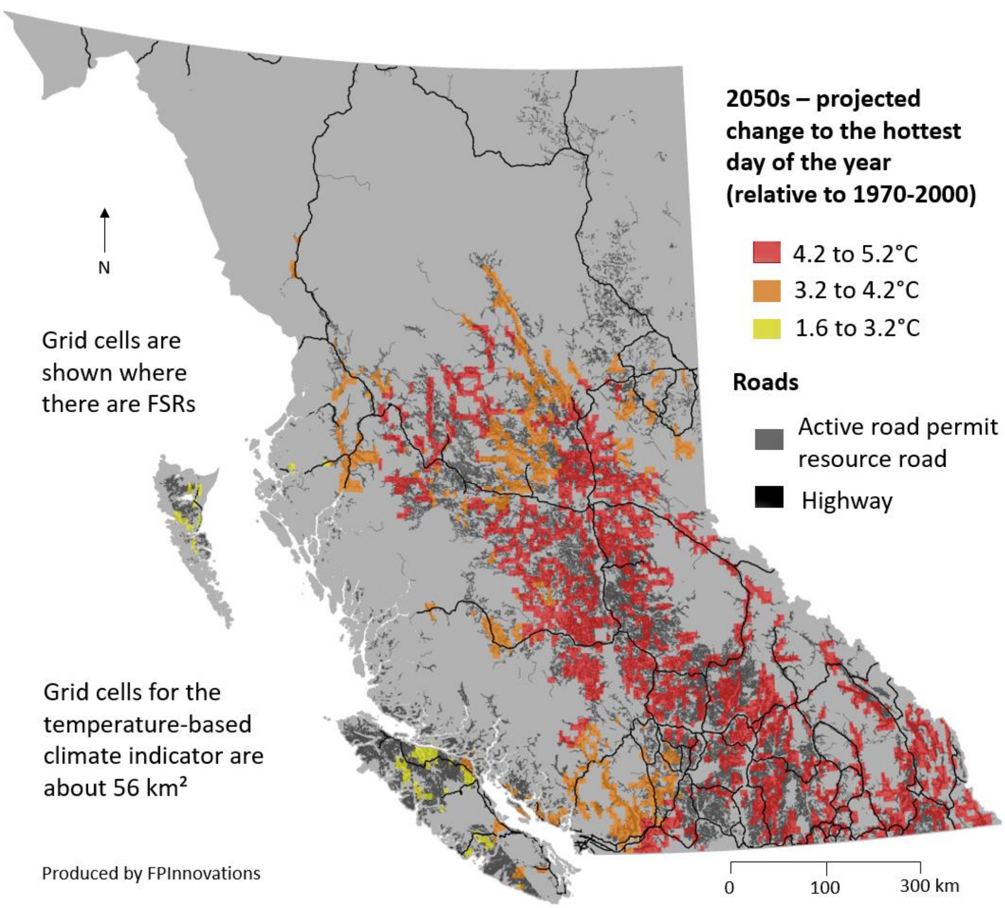


Figure 5. Forecast change in expected yearly hottest day in BC by 2050 using a scenario that assumes no significant reduction of greenhouse gas emissions (Representative Concentration Pathway 8.5). Postprocessed using data from PCIC. Cells are shown for FRSs selected in figure 3.

Currently, PSTA models do not account for climate change. Adding a climate change risk layer could use online tools that reference some general climate indicators. Tools that include climate indices that may have links to wildfire include ClimatData.ca, PCIC Climate Explorer, ClimateBC.ca, and the Climate Vulnerability Forest Management (CVFM) tool. Other than the CVFM tool, the tools do not mention links between some of the climate indicators and wildfires. Furthermore, none of the climate indicators available from these tools show changes in return period-based hazard information. Professional judgment, possibly complemented by quantitative analysis, would need to transform this information into changes in probabilities. Combining hazard information with a consequence layer that defines FSR vulnerability could then quantify relative wildfire risk after some normalization and classification of the result. Projecting changes in wildfire risk is an area of active research by the BC government, PCIC, and other organizations (BC Government, 2022a).

4 VULNERABILITY OF FSRS

The following sections consider potential impacts to FSRs from immediate wildfire events and post-wildfire effects in both the short and long terms. Several targeted interviews with key stakeholder organizations and with others recommended by those stakeholders helped inform the impacts that are identified. The first two sections reference resource road infrastructure elements (e.g., bridges, culverts, retaining walls, signs, and right-of-way areas that may include utility structures like hydro lines) in terms of function and serviceability. Function refers to the road's ability to act as a safe, resilient, and competent running surface that provides access for road users, while serviceability refers to its engineered design life and maintenance requirements. The third section identifies climate change impacts to FSRs.

4.1 FSR Vulnerability During Wildfires

Wildfires can cause dramatic loss of FSR (resource road) functionality especially in terms of loss of access and increased risk to road users. Wildfires burning next to roads can prevent their use for wildfire suppression activities, cut off access to communities and other resources, and prevent their use by emergency vehicles or even for evacuations from threatened communities. Even before reaching the roadway and directly threatening road users, the smoke from wildfires may reduce travellers' safety through loss of visibility, increased stress and distraction of drivers, degraded air quality, and even livestock hazards on the road because of fence damage.

Wildfires also can damage or destroy a wide variety of industrial infrastructure and resource road infrastructure found within FSR right-of-ways. Vulnerable industrial infrastructure includes items such as utility towers, poles, and transmission lines, and associated installations; above-ground pipeline facilities and suspended pipeline river crossings; and industrial vehicles and equipment within the right-of-way. Vulnerable resource road infrastructure includes livestock fencing; road signage and light standards; wooden, steel, concrete, and asphalt components on bridges; plastic culverts; engineered road structures (e.g., retaining walls); and vegetative ground cover. Table 1 provides a comprehensive listing of vulnerable resource road infrastructure and the expected types of wildfire impacts.

Table 1. List of Infrastructure elements that highlights those that can be damaged during a wildfire event.

Infrastructure class	Infrastructure element	Vulnerability to wildfire
Signs and lighting		
	Road sign	Burned paint, burned wooden post
	Light standards & poles	Burned or melted
Culverts		
	Plastic elements	Melted exposed ends
	Wood elements	Moderate to severe burning
Bridges		
	Wooden superstructure elements (deck, guard rails, delineator signs, cross ties, girders)	Burned timbers
	Steel superstructure elements	Superheated steel may become brittle
	Concrete superstructure elements	Superheated concrete may crack
	Wooden substructure elements	Burned piles and timbers
	Steel substructure elements	Superheated steel may become brittle
	Concrete substructure elements	Cracking
Engineered structures		
	Plastics	Melted exposed material
	Steel	Superheated steel may become brittle
	Concrete	Cracking
Ground cover in right-of-way		
	Vegetation, erosion control materials	Burned vegetation and materials
Livestock fencing		
	Wooden fence posts	Burned fence posts

4.2 FSR Vulnerability After Wildfires

Wildfires may continue to have impacts on FSRs even after the flames are out. A comprehensive program of post-wildfire inspections is usually necessary to assess the resulting severity of damage to equipment and infrastructure within the FSR right-of-way and options to restore functionality (repair, replace, etc.). Intense wildfires may generate flame temperatures exceeding 1200° C which are capable of damaging wooden, concrete, and steel elements of resource road bridges. Fire impacts to bridges may be easily observable and quantifiable, or they may be difficult to detect and evaluate. The Ministry of Forests has developed guidance for post-wildfire inspections of FSR bridges (BC Government, 2018).

In addition to structural or functional damage to equipment and infrastructure within the right-of-way, road users also may encounter hazards caused by damaged trees, utility towers, or utility poles leaning over or blocking the roadway. Similarly, electrical lines previously supported by these towers or poles may now be sagging towards or even fallen onto the roadway where electrical shock may be an additional hazard.

Hope et al. (2015) state that "following a wildfire, the chances of soil erosion, landslides, and floods increase, and resultant damage downslope and downstream of the area burned may be catastrophic". Loss of vegetative cover reduces soil fertility and forest productivity. Loss of vegetative cover also exposes the native mineral soils and allows rain and wind to rapidly erode and transport them to nearby streams and rivers where potentially widespread and long-lasting degradation of water quality and aquatic habitat can occur. Loss of vegetation results in runoff from rainstorms and snowmelt being concentrated on slopes and road ditches, and consequently, rapidly reaching streams where it increases downstream storm flows (Hope et al., 2015). If used as a fireguard, FSRs may be purposefully burned to remove vegetation or heavy equipment used to expose mineral soils in the right-of-way.

As noted, wildfires can increase the incidence of landslides and rock falls. Where mass wasting, landslides, and rock falls occur in or above the FSR right-of-way, the road surface and inside ditch may be partially or fully blocked and a hazard to road users created. These effects can create an ongoing hazard and the need for additional ongoing road inspections and maintenance.

Intense wildfires can create changes in soil porosity and hydrophobicity and, thereby, reduce infiltration and increase overland flow. By removing vegetation and creating hydrophobic soils, wildfires increase overland flow rates and volumes, and redirect drainage. Experience in southern BC has been that high-intensity late summer or fall rainfall onto wildfire-exposed bare soils can increase storm flows by one or two orders of magnitude (Hope et al., 2015). Greater overland flows also can result in locally raised water table that weaken roads and create challenges for road access. Loss of crown cover promotes faster snowmelt in the spring from rain-on-snow events, further promoting storm flows and the potential for flooding.

After a wildfire, soil from mass wasting and large woody debris from the burned forest may become mobilized and deposited into stream channels where it can block or redirect drainage. Crossing structures on FSRs may become blocked by accumulations of mobilized bedload and large woody debris; and, where this occurs upstream of other crossings (e.g., rail crossings, public highway crossings, utility structures, independent power projects), the hazard can be far greater. The current state of knowledge about stream crossing design is incomplete and does not accurately estimate the crossing structure's opening area that would be required to pass both the design storm flow plus expected concentrations of large woody debris, sediment, and bedload contained in the storm flows.

An important consequence to FSRs from increasingly frequent wildfires is the increase in costs for inspecting and restoring impacted infrastructure, and assessments of changes to local soils, hydrology, and geomorphology in burned over terrain around the FSRs. Other substantial costs can accrue from road and right-of-way clean up activities and maintenance needed to restore safe access and to slow continued degradation. Finally, where infrastructure damage, erosion, mass wasting, or other processes have caused loss of access on an FSR this can impact future roadway uses, projects, and developments.

4.3 FSR Vulnerability to Wildfire Considering Climate Change

In the longer term, climate change may increase wildfire frequency and severity and thereby exacerbate all risks in terms of function and serviceability of FSRs. Two second order effects to consider are changes in extreme precipitation events that may begin to impact post-wildfire areas more, and changes to the economic viability of forest operations as a whole, due to cumulative wildfire impacts over many decades.

Landscape changes, including those from wildfires, can affect design floods and should be considered by designers (EGBC & ABCFP, 2021; EGBC 2018). Climate change impacts to these design floods also should be considered since floods are generally projected to increase due to more frequent and intense storms, more rain-on-snow events, regional increases in precipitation, and more concentrated timing of annual precipitation events. Kurowski et al. (2022) provide more information about applicable tools for designers to plan for these changes. Most crossings on FSRs are in smaller watersheds and referencing GCM-derived precipitation-based climate indicators at these crossings therefore is not ideal since typical times of concentration for a small watershed in BC that are well under an hour while GCMs have a 24-hour resolution. There are two streamlined approaches to estimating changes to local scale flooding due to climate change, both of which adjust IDF curves: IDF_CC and the temperature scaling method that is outlined at ClimateData.ca (Kurowski, in press).

The cumulative impacts of wildfires over decades or more may have significant impacts to the BC forest industry. The economics of forest harvesting not only provides jobs and tax revenues but also provides a way to fund resource road maintenance and decommissioning. Given that wildfires may increase in frequency and severity, available volumes and harvest seasons are likely to be reduced, and costs of harvesting, transport and processing will rise as a consequence of dealing with burned wood. Furthermore, budgets allocated for repairing wildfire damage will not be available for infrastructure improvements and other forest investments. Government may be faced with additional costs for FSR maintenance and decommissioning as forest operations shrink in scale (BC Government, 2021b). Additional costs could include losses in tourism and forest recreation. The BC government (2021b) also notes the potential for reduced access quality to rural communities and Indigenous communities if industry is no longer maintaining the routes.

5 IMPROVING OUR UNDERSTANDING

Improving our understanding of wildfire risks to FSRs depends both on better hazard and improved vulnerability information. While wildfire hazard maps are and will continue to have inherent uncertainty, information regarding vulnerability of FSRs could be much more certain; however, budget constraints, among other issues, currently prevents achieving this certainty. For example, the status and design of many smaller water crossings are often not in any database (Pickup, 2020). This suggests that more comprehensive and complete FSR inventory information and associated wildfire vulnerabilities would be the easiest way to improve current understanding about wildfire risk to FSRs. Addressing this need will likely require verifying existing datasets, establishing new asset database components, and creating a system to maintain an improved inventory and manage liability. Improvements to wildfire hazard information will be ongoing but are dependent on continuous updates and technical improvements in fire behavior models and ways to summarize results.

A standard approach to defining wildfire risks for FSRs would be useful for comparing risks and spending priorities between multiple FSR assessments but is not established. A standard could either be defined for groups to implement, or a province-wide hazard-based analysis could be provided so that groups could use a common template dataset. Preparing a province-wide risk information layer is unfeasible given the lack of vulnerability information (e.g., culvert material) necessary to define risk. Defining vulnerability can also depend on information that is not in any infrastructure database but depends on recognized values (e.g., community access or fireguard).

The inclusion of climate change effects into defining wildfire hazard is still a new subject and several aspects of it remain unclear. First, the lack of standard climate indicators to reference introduces variance into projection results. Second, it is unclear how to then combine the results with PSTA maps, even if a standard analysis approach were defined. Multiple solutions exist to combine the current and projected hazard maps; climate change impacts will influence the PSTA relative hazard map and will do so with varying emphasis depending on assigned weightings for climate change impacts. Given the inherent uncertainty in climate models incorporating a sensitivity analysis is recommended (EGBC, 2020). The result of a sensitivity analysis of climate change impacts on wildfire risk defines a range of possible values for an area, which can be interpreted differently depending on risk tolerance at the FSR.

6 CONCLUSIONS

The objectives of this study were to review available wildfire risk information applicable to FSRs and to identify the associated potential impacts to FSR function and serviceability. This review was to consider FSR uses during and after wildfires and in the distant future considering climate change. An additional objective was to identify research needs to address gaps in knowledge and understanding.

This report identified PSTA layers useful for characterizing wildfire hazards to FSRs, historical burn intensity data that can inform post-wildfire hazards, and tools that can be referenced and interpreted to account for climate change influences on wildfire hazards. Additionally, associated FSR vulnerabilities corresponding to these hazards were identified.

A discussion highlighted knowledge gaps in available wildfire information and related processes. To understand risk better, the easiest improvement would be to examine FSR vulnerabilities through improved inventory information and improved understanding of how FSRs can be vulnerable. To compare different risk assessments and inform prioritizing spending on activities at regional or provincial scales, a standard approach to defining FSR vulnerabilities and recognized values is needed. Including climate change in risk assessments will require standards for defining climate indicator(s) as proxies to wildfire hazards and for combining them with PSTA map information.

While this report focused on hard-earned BC wildfire expertise, the experiences of wildfires and impacts to resource roads are shared with the rest of Canada. Furthermore, the underlying wildfire analysis approaches and climate change tools are applicable to all of Canada.

There exists an opportunity to better define wildfire hazards for FSRs and combine this with FSR vulnerabilities to report on risks. A comprehensive list of risks could help to develop wildfire risk assessments specific to resource roads and is also a good entry point for discussions about possibilities for adaptation.

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