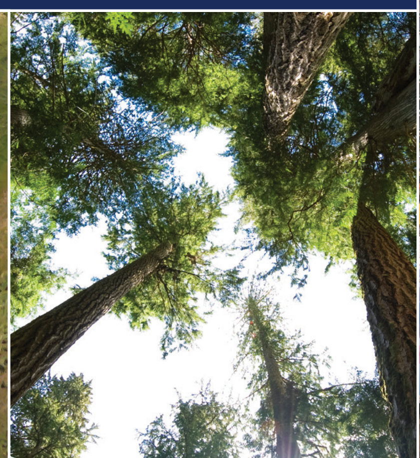
July 2019

# Preliminary Strategic Climate Risk Assessment for British Columbia



BRITISH COLUMBIA
Ministry of Environment and Climate Change Strategy

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# EXECUTIVE SUMMARY

British Columbia is already experiencing the effects of global climate change: average temperatures are increasing, sea levels are rising, and variable and extreme weather is becoming more frequent. Scientists expect these changes to accelerate and intensify in the years ahead, creating risks to society, natural resources, and ecosystems. Understanding and managing these risks will help protect B.C.'s residents, industries, and infrastructure while improving prosperity and reducing costs to future generations. This report considers climate risks in the 2050s (2040-2059) in B.C. to help the provincial government proactively prepare for the changing climate.

The B.C. Office of the Auditor General (OAG) has recommended that the provincial government undertake a province-wide climate risk assessment, building on existing assessments and case studies in sectors such as forestry, agriculture, mining, and transportation.

### Results at a Glance

- This project developed a climate change risk assessment framework for British Columbia and used it to evaluate and score the risks to the province from 15 specific events, in the 2050s.
- The risks of a **severe wildfire season** and of a **seasonal water shortage** are the two highest-ranked risks facing the province overall in the 2050s.
- B.C. also faces high risks **from heat waves, ocean acidification, glacier mass loss,** and **long-term water shortage**.
- Only one of the 15 risk events analyzed in this assessment, an increase in tick-borne Lyme disease was ranked as "low."
- The likelihood of most risk events increases over time based on projections of future climate change.

From January 2018 through March 2019, B.C.'s Climate Action Secretariat (CAS) worked with the consulting firm ICF, a 20-person Project Advisory Committee composed of representatives from eight B.C. ministries, and more than 70 experts to develop a risk assessment framework and apply it in an initial assessment of climate risks to B.C. at the provincial level.

## A Risk Assessment Framework for British Columbia

The project team began by developing a strategic climate risk assessment framework for British Columbia.

The framework, which the team developed based on a review of existing risk assessment frameworks and designed to be consistent with the *Risk Management Guideline for the B.C. Public Sector*, follows four high-level steps to evaluate climate risks, illustrated in the figure at right.


The framework provides a consistent, repeatable, and scalable approach that can be used or customized to analyze climate risks at multiple levels (from small communities to the entire province) and for multiple climate-related risks.

For example, the framework includes:

- A recommended process for defining risk events and scenarios, following a consequences-first approach. In other words, risk events and scenarios are defined by asking *What climate events would have provincially significant consequences?*
- Detailed scoring rubrics to allow consistent evaluation of the likelihood of each risk event scenario as well as potential consequences, accounting for unique considerations associated with climate risks.
- Consideration of multiple consequence categories to help nuance understanding of potential climate change impacts, differentiate between types of risk events, and inform appropriate responses.
- A scenario-based approach to evaluating risk events, to allow for evaluation of likelihood and consequences of that single scenario.

**Framework Provides Multiple Consequence Categories**

- Loss of life
- Morbidity, injury, disease, or hospitalization
- Psychological impacts
- Loss of social cohesion
- Loss of cultural resources
- Loss of natural resources
- Loss of economic productivity
- Loss of infrastructure services
- Cost to provincial government

## The Risk Assessment Process

Using the framework, the project team and advisory committee worked together to select 15 provincially significant risk events. They then defined a specific scenario for each risk event for further analysis. Each scenario represents one possible permutation of the risk event—such as a 25% decline in glacier area by 2050, or a 500-year flood on the Fraser River. The likelihood and consequence ratings for each risk event are specific to the chosen scenario. Climate change projections used in this risk assessment were based on Representative Concentration Pathway (RCP) 8.5, a high estimate of future growth in greenhouse gas concentrations (see Appendix A). The project team chose RCP8.5 because the aim of this assessment was to characterize, at a strategic level, the most problematic climate-related risks that could potentially occur in BC in coming decades. Other government agencies, public sector organizations, and local governments have also used RCP8.5 in climate assessments in BC. The key risk assessment findings are unlikely to depend on the RCP because the impacts associated with different RCP are similar for BC until later in the century.

Using a combination of desk research, expert consultations, and risk assessment workshops, the team estimated the *likelihood* of each scenario occurring (both in the present day, between 2000 and 2019 for most scenarios, and in the 2050s, between 2040 and 2059) to determine how climate change influences the likelihood of fixed-magnitude events.

Following the same process, the project team estimated the *consequences* for each risk event across nine dimensions, such as loss of life, psychological impacts, loss of natural resources, economic impacts, or cost to the B.C. government.

The team then multiplied the estimates of likelihood by the average consequence scores to arrive at an overall rating for each risk event. Based on the quality of the evidence base for each risk event, the project team assigned a confidence level to each rating.

## Results of the Risk Assessment

Severe wildfire season, seasonal water shortage, and heat wave are the three highest-ranked risks facing the province overall in 2050. They are closely related and could have further compounding consequences.

Three other risk events qualify as "high" risk, including ocean acidification, glacier mass loss, and long-term water shortage. Only one risk, an increase in vector-borne disease (in this case, tick-borne Lyme disease) was ranked as "low."

Other key findings include:

- Nearly all risk event scenarios (except moderate flooding and extreme precipitation and landslide) would have at least "major" province-wide consequences in at least one category.
- All but four risk event scenarios would have "catastrophic" consequences in one or more areas.
- The majority of risk event scenarios would have "catastrophic" economic consequences for British Columbia.
- The risk event scenarios with the greatest potential consequences across all categories, irrespective of likelihood, are those analyzed for severe wildfire season, severe riverine flooding, and severe coastal storm surge.

See the table and figure below for an overview of the likelihood, consequence, and risk scores for each risk event analyzed in this assessment. The figure further unpacks the risk assessment results and displays the detailed consequence ratings for each event, sorted from highest to lowest overall risk in 2050. Some risk events could have significant consequences across many or all of the consequence categories, while others could be dominated by consequences in one or two categories. For example, the impacts of knotweed would be primarily to natural resources. The severe riverine flooding and severe coastal storm surge risk events would have the highest overall consequences, but their relatively low likelihood reduces their overall risk relative to other events.

### Methodological Caveats

- Consequences are assessed at the provincial scale. Many of these risk events could be significant for individual communities or sectors of the province.
- The 15 risk event scenarios do not comprehensively cover how climate change could affect B.C. or represent the only provincially significant climate risks.
- The scenarios do not necessarily represent the most severe version of each risk event that could occur today or be possible by 2050; more severe and less severe versions of each scenario are also possible.
- Some risk events have a more robust evidence base than others. Confidence ratings are provided to indicate the relative strength of the evidence base for each scenario.
- This initial assessment could not adequately consider Indigenous perspectives or cultural values without appropriate engagement. A second phase of work is planned to consider Indigenous perspectives on the effects of climate change.

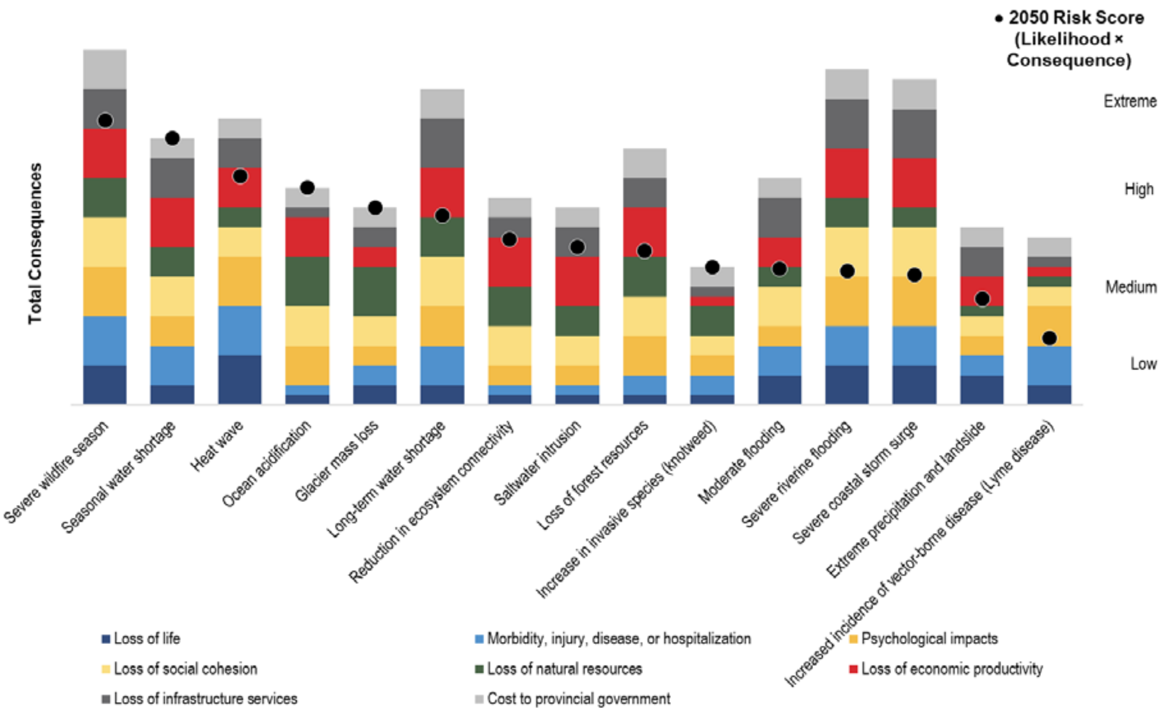
*Summary of Risk Assessment Rankings*

| RISK EVENT | PRESENT-DAY LIKELIHOOD | 2050 LIKELIHOOD | CONSEQUENCE | RISK SCORE AND RATING | |
|---|---|---|---|---|---|
| Severe wildfire season | 3 | 4 | 4.5 | **18.0** | **High** |
| Seasonal water shortage | 4 | 5 | 3.4 | **16.9** | **High** |
| Heat wave | 3 | 4 | 3.6 | **14.5** | **High** |
| Ocean acidification | 2 | 5 | 2.8 | **13.8** | **High** |
| Glacier mass loss | 1 | 5 | 2.5 | **12.5** | **High** |
| Long-term water shortage | 3 | 3 | 4.0 | **12.0** | **High** |
| Reduction in ecosystem connectivity | 3 | 4 | 2.6 | **10.5** | **Medium** |
| Saltwater intrusion | 1 | 4 | 2.5 | **10.0** | **Medium** |
| Loss of forest resources | 1 | 3 | 3.3 | **9.8** | **Medium** |
| Increase in invasive species (knotweed) | 4 | 5 | 1.8 | **8.8** | **Medium** |
| Moderate flooding | 2 | 3 | 2.9 | **8.6** | **Medium** |
| Severe riverine flooding | 1 | 2 | 4.3 | **8.5** | **Medium** |
| Severe coastal storm surge | 1 | 2 | 4.1 | **8.3** | **Medium** |
| Extreme precipitation and landslide | 2 | 3 | 2.3 | **6.8** | **Medium** |
| Increased incidence of vector-borne disease (Lyme disease) | 1 | 2 | 2.1 | **4.3** | **Low** |

Icon colour denotes overall confidence level in the risk rating based on the quality of the evidence base: **Low**, **Medium**, or **High**.

Low confidence = varying amounts and quality of evidence and little agreement between experts, or assessment made using only expert judgment. High confidence = Multiple sources of independent evidence based on reliable analysis and methods, with widespread agreement.

*Risk assessment results breakdown: consequences by risk event*




Note: Individual consequences are rated on a scale of 1 to 5 (Insignificant to Catastrophic). The size of the bar indicates individual consequence ratings. Though initiated, a robust assessment of the range of impacts to cultural resources in B.C. for each risk event scenario could not be completed within the scope of the existing project. As a result, an assessment of consequences to cultural resources is not presented in this report.

## Interactions between Risk Events

Instead of happening independently, climate risk events often occur simultaneously and are strongly interlinked. These compound risk events can have linked probabilities driven by the same underlying conditions and can in some cases trigger each other. Furthermore, the consequences of back-to-back events could be significantly greater than those of any single event alone, due both to more significant impacts of subsequent events and greater sensitivities or lower adaptive capacity of systems still recovering from previous events.

As climate change increases the probability and severity of a range of climate risk events in British Columbia, it also increases the potential for interacting and compound events. For purposes of illustration, this report assesses one combination of events likely to occur in British Columbia: a seasonal or long-term water shortage followed by wildfire, which in turn primes the landscape for severe landslides following heavy precipitation. Further assessment and scenario planning should evaluate the robustness of emergency services and disaster planning to respond to multiple disasters simultaneously. Additional assessment should also include consideration of other combinations of hazards, which have not been analyzed here in detail.

## Future Work and Next Steps

This report represents the first phase of a CAS initiative to better understand and prioritize climate risk in the province and to help government develop appropriate measures to address those risks. This report is intended to be used to inform decisions made by the Deputy Ministers' Council and Cabinet relating to government priorities that may be at risk due to climate change. It will also inform the development of a provincial climate change adaptation strategy, as committed to in the CleanBC Plan. Additional work is needed to build on this assessment, including:

- This initial assessment could not adequately consider Indigenous perspectives or cultural values without appropriate engagement. A second phase of work is planned to consider Indigenous perspectives on the effects of climate change. Indigenous perspectives shared during the engagement will be used to inform the provincial climate change adaptation strategy, in the spirit of reconciliation that the Province has committed to under the CleanBC Plan.
- Impacts to cultural resources, including Indigenous and non-Indigenous cultures, were included in the framework as one of the nine consequence categories, and were initially considered for analysis. However, it became clear that a robust assessment of the range of impacts to cultural resources in B.C. in each risk event scenario could not be completed within the scope of the existing project. As a result, an assessment of impacts to cultural resources is not presented in this report. This work is planned and will be informed by the engagement process described above.
- An important next step is to further evaluate the adequacy of existing risk mitigation efforts, considering the risk scores. The B.C. government already has several programs in place—including strategies to explicitly adapt to climate change as well as programs to address existing hazards—to address some of the climate risk events included in this assessment. Risk mitigations are factored into the B.C. Risk Register template, as they offset some amount of risk. This work has begun and will be expanded upon going forward.

CAS envisions updating this risk assessment periodically as part of government's public reporting requirements under the *B.C. Climate Change Accountability Act*.

# KEY TERMS

**Cascading risk events** – a combination of two or more risk events with linked probabilities that can trigger the occurrence of each other

**Compounding risk events** – a combination of two or more risk events with increased consequences beyond the sum of the individual risk events that compose them

**Consequence** – outcome of an event affecting objectives

**Cultural resource** – a human work, an object, or a place that is determined, on the basis of its heritage value, to be directly associated with an important aspect or aspects of human history and culture (Parks Canada, 2013)[1]

**Disruption to daily life** – the ability to carry out daily activities (e.g., traveling to work or school, operating a business, spending time with family)

**Health** – a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity (World Health Organization, 1948)

**Likelihood** – chance of something happening

**Loss of life** – number of deaths due to a specific event

**Mitigation** – this document uses the term "mitigation" to refer to risk mitigation (as opposed to greenhouse gas mitigation). See risk mitigation definition below.

**Morbidity** – having a disease or symptom of disease, or the amount of disease within a population (National Cancer Institute, No date)

**Natural resources** – biodiversity, ecosystems, ecosystem services, protected species, protected areas, and other resources provided by the natural environment

**Risk** – effect of uncertainty on objectives

**Risk cause** – climate-related hazards that are anticipated in B.C. and have the potential to negatively affect objectives

**Discrete risk cause** – a risk cause related to an individual extreme event (e.g., storm) or disaster that occurs over a relatively short period of time (e.g., days or weeks)

**Ongoing risk cause** – a risk cause related to a gradual change in climate that occurs over many years (e.g., sea level rise)

**Provincially significant** – resulting in "catastrophic" or "major" impacts to any one of the consequence categories as defined in the *Strategic Climate Risk Assessment Framework for British Columbia* (see **TABLE 2**)

[1] This is a widely used definition of "cultural resource" and one applied and interpreted broadly for this risk assessment. In evaluating potential impacts of climate change in this category, the project team considered impacts to Indigenous perspectives but recognizes that impacts to Indigenous People would also transcend this category.

**Risk event** – occurrence or change of a particular set of circumstances that could occur, due at least in part to climate change, and would have a significant impact on provincial objectives

**Risk mitigation** – actions taken to reduce the likelihood or consequences of a risk event

**Scenario** – this document primarily refers to two types of scenarios:

> **Emission scenario** – A plausible representation of the future development of emissions of greenhouse gases based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change, energy, and land use). Related to this is the term **climate scenario**, used in some of the literature, used to refer to a plausible and often simplified representation of the future climate that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change (Allwood et al., 2014).
>
> **Risk event scenario** – For a given risk event, a plausible set of specific circumstances such as location affected, time frame, and severity of hazard, to facilitate evaluation of likelihood and consequences

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# INTRODUCTION

Climate change poses important risks to British Columbia's residents, industries, infrastructure, natural resources, and ecosystems. To better understand these risks, the B.C. Climate Action Secretariat (CAS), Ministry of Environment and Climate Change Strategy, has developed a climate change risk assessment framework and a preliminary assessment of risks at the provincial level.

Risk assessments involve identifying risks and assessing their probabilities (*how likely is the risk to occur?*) and consequences (*what would be the impact if this risk occurred?*). Risks are scored and plotted on a matrix, so they can be ranked. Ranking risks helps decision makers set priorities and allocate resources. Events that score low in both probability and consequence are ranked as "low risk," and high-probability/high-consequence events are ranked as "high risk." Other events fall on a scale between these ratings.

The results of risk assessments can enable important conversations about risk tolerance, the relative importance of different assets, and the types of risk management responses needed.

### What is Risk?

Risk is the effect of uncertainty on objectives, typically characterized by the likelihood and consequences of different events. Once risks are known, they can be addressed in several ways: by avoiding or eliminating the cause of the risk, by mitigating it (lowering its impact), or by accepting the risk and developing a contingency plan to deal with it if it happens.

Uncertainty is a key component of risk: If we could predict the future with certainty there would be no risk, because we would know exactly what will happen and when. In the absence of certainty, decision makers must rely on the best available science to identify potential risks and estimate the likelihood that an event will occur. They typically use a combination of experience and expert judgment to estimate the potential consequences of an event.

## What is a risk assessment framework?

A risk assessment framework is a consistent methodology for conducting risk assessments. Risk assessment frameworks are designed to be transparent in their approach, so they can be used to guide fair and open decision making. They can also be designed to be replicable and scalable, allowing the same framework to be applied consistently to organizations as small as a neighbourhood or as large as an entire country. Frameworks also facilitate the process of updating risk assessments in a consistent way as new information becomes available.

## What is B.C.'s climate risk assessment framework?

CAS engaged the consulting firm ICF to develop a climate risk assessment framework that can be used to inform the prioritization of appropriate responses to risks by agencies across the provincial government. CAS's objective was to test the relatively new concept of using a risk assessment framework in the context of climate change, to build a framework for assessing risks in a consistent way, and to assess and prioritize a subset of provincially significant risks using the framework. The framework is flexible and scalable, and allows users to assess likelihoods and consequences in a consistent and defensible way.

B.C.'s strategic climate risk assessment framework establishes four high-level steps to identify climate risk priorities at the provincial level:

1. Understand the context (scope, objectives, and audience);
2. Identify risk events;
3. Analyze the likelihood and consequence of risks; and
4. Evaluate risks (assigning a risk rating and evaluating the adequacy of existing risk mitigation measures).

CAS developed the framework for use by the provincial government to assess climate-related risk events that are provincially significant in scope, and the language in this report reflects that. Other levels of government and organizations may choose to use this framework as a template when developing their own risk assessments and should identify risks that are significant at the scale they are considering. Similarly, they should tailor considerations such as objectives and consequence categories to suit their individual needs and contexts.

### What guiding principles did B.C. use in developing the framework?

CAS designed the framework to be transparent, compatible with existing standards, and replicable by other organizations. Transparency refers to the open documentation of assumptions, sources of information, and methodologies. To ensure compatibility with existing standards, CAS developed the framework to be consistent with the *Risk Management Guideline for the B.C. Public Sector* (Province of British Columbia Risk Management Branch and Government Security Office, 2012), which is based on the International Organization for Standardization (ISO) 31000 Risk Management standard that serves as the official standard in Canada. The framework is also compatible with B.C.'s Risk Register, which the province's Risk Management Branch uses to record and manage information for identified risks. Consistent with the risk register, the risk assessment focused on risk events that could have predominantly negative consequences for the province, as opposed to potential opportunities created by climate change.

The framework's straightforward four-step approach and its transparent nature will allow other organizations to use it in their own risk assessments, promoting a consistent approach.

### How did B.C. conduct its risk assessment?

Using the B.C. climate risk assessment framework, the project team and project advisory committee identified 15 illustrative provincially significant risk events (e.g., severe riverine flooding), and defined specific scenarios for each event (e.g., a 500-year flood on the Fraser River). The specific scenarios were designed to be provincially significant, meaning they would result in at least "major" consequences to at least one consequence category. The 15 selected risk events would have consequences across sectors and ministry responsibilities. Some events could have serious human health impacts, while others could have major consequences for infrastructure services and social cohesion. Some could have serious, complex consequences across multiple categories, while others could have extreme but isolated consequences. All risk events and their consequences could bring significant costs to government, in a variety of ways.

The project team used a combination of desk research, interviews with experts, and a workshop with experts internal and external to government to rate the likelihood and consequences of each of the 15 risk events. The team evaluated consequences using nine categories, representing health, psychological, social, environmental, infrastructural, and economic consequences (see Methodology section for details on these categories). The likelihood of each risk was evaluated for two timeframes, present day (2000-2019 for most scenarios) and mid-century (2040-2059), to investigate how the likelihood changes over time.

The team then plotted the likelihood and consequence ratings on a risk matrix to arrive at an overall risk rating for each event.

## What caveats apply to the risk assessment findings?

There are some important caveats to keep in mind when reviewing the findings in this report:

- This initial risk assessment evaluated 15 specific risk events considered as "provincially significant." This necessarily excluded many potential events that may be likely and could be significant for individual communities or sectors of the province but may not meet the definition of "provincially significant."
- The 15 risk event scenarios do not comprehensively cover how climate change could affect B.C. or represent the only provincially significant climate risks; instead they are examples of climate risks and help tell the story of the types of events that climate change could cause or exacerbate and the types of consequences those events could have. All of them are plausible scenarios that would have provincially significant consequences.
- Like all risk assessments, B.C.'s climate risk assessment ranked risks to the province based on their likelihood and consequences. It is important to understand, however, that lower-ranked risks should not be considered benign. All climate risks studied in this assessment have provincially significant consequences.
- For the purposes of this assessment, the project team chose to analyze how climate change would influence the likelihood of an event of a specific magnitude (e.g., a 500-year winter storm event in conjunction with a half metre of sea level rise). As such, the consequence rating is determined by the specific details of the scenario used in the assessment, assumed to occur in or by 2050. In reality, climate change influences both the likelihood and consequences of these different risk events. The scenarios do not necessarily represent the most severe version of each risk event that could occur today or be possible by 2050; more severe and less severe versions of each scenario are also possible. Therefore, each scenario represents just one version of a risk event, and one that would be provincially significant.
- To simplify and facilitate analysis, the risk assessment considers risk events in isolation. But many risks are interrelated. The consequences of back-to-back events could be significantly greater than any single event alone, both due to more significant impacts of subsequent events and greater sensitivities or lower adaptive capacity of systems still recovering from previous events. This report discusses an approach that could be used to evaluate the compounding effects of multiple risk events occurring in succession, a topic that the project team hopes to continue exploring in future work.
- Similarly, climate-related risks will occur in conjunction with other risks (such as economic risks, public health risks, or seismic hazards) that may be faced by B.C. during the same periods. Ranking and comparing climate risks with other types of risks was beyond the scope of this project but may be facilitated by including climate risks in B.C.'s Risk Register.

- The analysis of health consequences focused on health effects (including loss of life and morbidity) that can be reasonably attributed to a particular risk event scenario. Several risk events and their effects on morbidity could potentially lead to long-term decreases in life span. Where relevant, these effects are captured under the morbidity category (e.g., chronic and long-term health consequences that could ultimately lead to premature deaths) but not estimated under loss of life.
- Some risk events have a more robust evidence base than others. Where information was not available, we relied on expert judgment. The project team conducted interviews and held workshops to try to fill any gaps; the report utilizes confidence ratings and notes areas where information is currently lacking.
- This initial assessment could not adequately consider Indigenous perspectives or cultural values without appropriate engagement. References to impacts on Indigenous communities are included throughout the report based on existing published information. A second phase of work is planned to consider Indigenous perspectives on the effects of climate change (see next steps).
- The purpose of this risk assessment is to help the provincial government understand and prioritize which climate-related risks to manage and, thus, took a limited view in assessing risks. The risk assessment does not, for example, fully capture risks to local governments, ethnic minorities, or low-income/marginalized populations. Additionally, not all populations perceive risk in the same ways. CAS plans to address these gaps in future risk assessments.

## Who was involved in the risk assessment?

CAS managed the overall project, with guidance provided by a project advisory committee consisting of representatives from ministries across the B.C. government. With guidance from CAS and the project advisory committee, the ICF team drafted and finalized the risk assessment framework and conducted research to assess each of the 15 risks.

The risk assessment process involved stakeholders and experts both internal and external to government. Representatives internal to government participated in a first workshop to review and test the draft framework. At a second workshop, experts internal and external to government convened to review and vet draft risk assessment ratings. Throughout the course of conducting the risk assessment, the ICF team also conducted one-on-one interviews with experts specializing in different risk events or consequence types. In total, over 100 individuals contributed to this risk assessment. Please see the Acknowledgements for a full list.

## Next steps and future work

This report represents the first phase of a CAS initiative to better understand and prioritize climate risk in the province and to help government develop appropriate measures to address those risks. This report is intended to be used to inform decisions made by the Deputy Ministers' Council and Cabinet relating to government priorities that may be at risk due to climate change. It will also inform the development of a provincial climate change adaptation strategy, as committed to in the CleanBC Plan.

As mentioned, this initial assessment could not adequately consider Indigenous perspectives or cultural values without appropriate engagement. A second phase of work is planned to consider Indigenous perspectives on the effects of climate change. Indigenous engagement on climate risks and resilience will provide a more comprehensive understanding of climate risk in the province. Indigenous perspectives shared during the engagement will be used to inform the provincial climate change adaptation strategy, in the spirit of reconciliation that the Province has committed to under the CleanBC Plan. Simultaneously, the Climate Action Secretariat will engage with other Ministries and stakeholders including Public Sector Organizations to determine how the risk assessment framework could be used at different scales.

Impacts to cultural resources, including Indigenous and non-Indigenous cultures, were included in the Risk Assessment Framework as one of the nine consequence categories, and were initially considered for analysis. However, through the process it became clear that a robust assessment of the range of impacts to cultural resources in B.C. in each risk event scenario could not be completed within the scope of the existing project. As a result, an assessment of impacts to cultural resources is not presented in this report. This work is planned and will be informed by the engagement process described above.

Finally, to build on this assessment, address gaps, and capture a broader range of potential risks, the following additional work would be useful:

- Further evaluate the adequacy of existing risk mitigation efforts, considering the risk assessment results (this work has begun and will be expanded upon going forward).
- Expand the analysis of each risk event to include a range of future scenarios.
- Further explore the interactions and implications of cascading and compounding events.
- Conduct or encourage research to fill noted data gaps.
- Consider approaches that would be appropriate to use in specific contexts, for example understanding and building on Indigenous climate resilience.
- Examine risks to specific populations and ethnic communities, as well as gender-specific risks.

The *B.C. Climate Change Accountability Act* requires the Minister of Environment and Climate Change Strategy to prepare a public report every even-numbered calendar year, starting in 2020, describing the risks to B.C. from climate change, progress toward reducing those risks, actions taken to achieve that progress, and plans to continue risk-reduction efforts. This risk assessment represents a first step toward meeting that requirement, and can be updated in the future to account for new findings.

# METHODOLOGY

The project team developed and followed the *Strategic Climate Risk Assessment Framework for British Columbia,* which is consistent with the *Risk Management Guideline for the B.C. Public Sector* (Province of British Columbia Risk Management Branch and Government Security Office, 2012). The climate risk assessment framework includes four basic steps to determine priority climate risk events in the province, shown in **FIGURE 1**.

**FIGURE 1.** B.C. climate risk assessment framework overview.


## Select Risk Events

The project team and advisory committee worked together to identify and select 15 provincially significant risk events and define a specific scenario for each risk event for further analysis. Each scenario represents one possible permutation of the risk event. The 15 risk events and scenarios are:

- **Severe Riverine Flooding:** 500-year flood on the Fraser River
- **Moderate Flooding:** Moderate flood in a single community
- **Extreme Precipitation and Landslide:** Significant landslide in Hope triggered by extreme precipitation
- **Seasonal Water Shortage:** Months-long summer water shortage affecting two or more regions
- **Long-term Water Shortage:** Multi-year water shortage in at least one region
- **Glacier Mass Loss:** 25% decline in glacier area by 2050
- **Ocean Acidification:** 0.15 reduction in pH by 2050
- **Saltwater Intrusion:** At least seasonal saltwater intrusion into the Fraser River delta and surrounding communities by 2050
- **Severe Coastal Storm Surge:** 3.9 m storm surge during a king tide along the B.C. coast
- **Heat Wave:** Heat wave of at least three days that affects human health
- **Severe Wildfire Season:** At least one million hectares burned that affect human settlements and significant infrastructure
- **Loss of Forest Resources:** 25% decline in timber growing stock by 2050
- **Reduction in Ecosystem Connectivity:** Reduction in ecosystem connectivity in the Okanagan-Kettle region by 2050

- **Increase in Invasive Species:** Expansion of knotweed by 2050
- **Increased Incidence of Vector-borne Disease:** At least a doubling of Lyme disease cases

## Analyze Risk Events

### Likelihood

The risk event scenarios are fixed magnitude events. As a result, the project team evaluated the present day and 2050 likelihood of each scenario occurring to determine how climate change influences the likelihood of fixed magnitude events. Unless otherwise specified, the project team applied the following approach to evaluating likelihood, in line with the framework:

- Present-day refers to the 20-year time period centred around 2010 (i.e., 2000 to 2019). Depending on available data, some scenarios use an earlier "present day" time period.
- 2050 refers to the 20-year time period centred around 2050 (i.e., 2040 to 2059).
- Climate change projections are based on the Representative Concentration Pathway (RCP) 8.5 scenario.

For each scenario, the project team identified climate-related indicators and evaluated the best available projections of how those indicators may change from the present-day to 2050. Based on the available data, the project team applied the likelihood rating scale from the framework, shown in **TABLE 1**.

The rating scale distinguishes between "discrete" risk events (i.e., those caused by discrete hazards such as heat waves, floods, or wildfires) and "ongoing" risk events (i.e., those caused by gradual climate changes over time such as loss of glaciers).

**Why was RCP8.5 chosen for this analysis?**

- Representative Concentration Pathways describe different possible futures based on atmospheric concentrations of greenhouse gases. RCP8.5 is a high global emissions scenario.
- Projected temperature changes for BC are similar for each RCP for the 2050s and key findings would likely be unaffected by using a different RCP (Appendix A). The difference between the RCPs becomes substantive towards the end of the century.
- The aim of this assessment was to characterize, at a strategic level, the most problematic climate-related risks that could potentially occur in BC in coming decades, using best available evidence. Using RCP8.5 helps to identify such significant risks.
- Prudent assessment of risk involves explicit consideration of uncertainty.

**TABLE 1**. Likelihood Rating Scale for Discrete and Ongoing Climate-Related Risk Events

| LIKELIHOOD | RATING | CRITERIA FOR DISCRETE CLIMATE-RELATED RISK EVENTS | CRITERIA FOR ONGOING CLIMATE-RELATED RISK EVENTS |
|---|---|---|---|
| **Almost certain** | 5 | Event is expected to happen about once every two years or more frequently (i.e., annual chance ≥ 50%*). | Event is almost certain to cross critical threshold. |
| **Likely** | 4 | Event is expected to happen about once every 3 to 10 years (i.e., 10% ≤ annual chance < 50%). | Event is expected to cross critical threshold. It would be surprising if this did not happen. |
| **Possible** | 3 | Event is expected to happen about once every 11 to 50 years (i.e., 2% ≤ annual chance < 10%). | Event is just as likely to cross critical threshold as not. |
| **Unlikely** | 2 | Event is expected to happen about once every 51 to 100 years (i.e., 1% ≤ annual chance < 2%). | Event is not anticipated to cross critical threshold. |
| **Almost certain not to happen** | 1 | Event is expected to happen less than about once every 100 years (i.e., annual chance <1%). | Event is almost certain not to cross critical threshold. |

*Annual chance is the probability that an event will occur in a given year

## Consequences

For each risk event, the project team also evaluated the potential consequences of the scenario along nine dimensions:[2]

- Loss of life (e.g., number of fatalities associated with an event)
- Morbidity, injury, disease, or hospitalization (e.g., illness, disease, or other non-fatal health consequences associated with an event)
- Psychological impacts (e.g., potential impacts to mental health and well-being)
- Loss of social cohesion (e.g., potential impacts to quality of life, social services, community institutions, and trust in government)
- Loss of cultural resources (e.g., potential impacts to resources determined to be directly associated with an important aspect or aspects of human history and culture)
- Loss of natural resources (e.g., potential impacts to biodiversity, ecosystems, ecosystem services, protected species, protected areas, and other resources provided by the natural environment)
- Loss of economic productivity (e.g., potential disruptions to economic activity across any sector, including agriculture, energy production, forestry, mining, quarrying, oil and gas, construction, and manufacturing)
- Loss of infrastructure services (e.g., potential disruptions to energy, water, wastewater utility services or the movement of goods, services, and people)
- Cost to provincial government (e.g., potential expenses incurred or revenues lost to the provincial government as a result of the event)

[2] Through the risk assessment process, it became clear that a robust assessment of the range of impacts to cultural resources in B.C. for each risk event scenario could not be completed within the scope of the existing project. As a result, an assessment of consequences to cultural resources is not presented in this report.

These consequence categories are interrelated. For example, severe consequences to infrastructure services or loss of life could lead to more severe psychological impacts. In addition, though it is categorized in the framework under social consequences, psychological impacts are of course a critical component of overall health and the healthcare sector. Each rating is kept separate to help the province understand the different types of consequences at play and facilitate risk management. However, these interrelationships are explored, to the extent feasible, within the assessment for each risk event.

In addition, each of these consequences was assessed based on consequences at the provincial scale. For discrete events, consequences were assessed as if the scenario were to occur in 2050. This included, to the extent possible, consideration of how population, land use, and other changes could occur. For ongoing events, consequences consider cumulative effects of the scenario unfolding from the present-day to 2050.

Based on the available data for each consequence, the project team applied the consequence rating scale from the framework, shown in **TABLE 2**.

**TABLE 2.** Consequence Rating Scale for Climate-Related Risk Events

| | HEALTH | | SOCIAL FUNCTIONING | | CULTURAL RESOURCES | NATURAL RESOURCES | ECONOMIC VITALITY | | COST TO PROVINCIAL GOVERNMENT[x] |
|---|---|---|---|---|---|---|---|---|---|
| | **Loss of life** | **Morbidity, injury, disease, or hospitalization** | **Psychological impacts** | **Loss of social cohesion** | **Loss of cultural resources** | **Loss of natural resources** | **Loss of economic productivity** | **Loss of infrastructure services** | |
| **Catastrophic - 5** | 100+ people or >25% of a single community | 1,000+ people affected or >25% of a single community | Widespread and severe disturbance resulting in long-term psychological impacts (e.g., post-traumatic stress disorder (PTSD)) | Months-long disruption to daily life (e.g., inability to access employment, education)<br>Widespread, permanent loss of livelihoods or way of life<br>Severe, widespread erosion in public confidence in government<br>Erosion of community institutions and community cohesion | Resource can never recover; destruction is permanent and irreversible (e.g., destruction of an irreplaceable artifact or knowledge) | Resource can never recover; destruction is permanent and irreversible (e.g., extinction of a species within the province) | Potential direct and indirect economic losses of over $1 billion*<br>Long-term disruption or loss of an economic sector and associated job losses | Months-long disruption in infrastructure services<br>Major impediment to day-to-day life | Added cost is far beyond Contingency Reserve Fund (e.g., > $1.5 billion) |
| **Major- 4** | 10 to 100 people or > 15% of a single community | 100 to 1000 people affected or > 15% of a single community | Localized severe disturbance resulting in long-term psychological impacts (e.g., loss of home, identity, or sense of place) | Weeks-long disruption to daily life (e.g., inability to access employment, education)<br>Localized, permanent loss of livelihoods or way of life<br>Moderate erosion of public trust in government or community cohesion | Recovery of the resource will take decades | Recovery of the resource will take decades | Potential direct and indirect economic losses of over $100 million*<br>Months-long disruption to a major economic sector and associated job losses | Weeks-long disruption in infrastructure services<br>Major impediment to day-to-day life | Significant added cost; up to 2x Contingency Reserve Fund amount (e.g., $750 million to $1.5 billion) |
| **Moderate - 3** | 2 to 10 people or > 5% of a single community | 10 to 100 people affected or > 5% of a single community | Widespread moderate disturbance resulting in temporary psychological impacts (e.g., | Days-long disruption to daily life (e.g., inability to access employment, education)<br>Seasonal loss of livelihoods or way of life | Recovery of the resource will take years | Recovery of the resource will take years | Potential direct and indirect economic losses of over $10 million*<br>Weeks-long disruption to a major | Days-long disruption in infrastructure services<br>Major impediment to day-to-day life | Added costs can be covered within Contingency Reserve Fund but would detract from other priorities (e.g., >50% of |

| | HEALTH | | SOCIAL FUNCTIONING | | CULTURAL RESOURCES | NATURAL RESOURCES | ECONOMIC VITALITY | | COST TO PROVINCIAL GOVERNMENT[×] |
|---|---|---|---|---|---|---|---|---|---|
| | **Loss of life** | **Morbidity, injury, disease, or hospitalization** | **Psychological impacts** | **Loss of social cohesion** | **Loss of cultural resources** | **Loss of natural resources** | **Loss of economic productivity** | **Loss of infrastructure services** | |
| | | | feelings of fear and anxiety) | Minor erosion of public trust in government or community cohesion | | | economic sector and employment | | Contingency Reserve Fund or > $375 million) |
| **Minor- 2** | Low potential for multiple loss of life | <10 people affected | Localized moderate disturbance resulting in temporary psychological impacts (e.g., feelings of fear and anxiety) | Hours-day-long disruption to daily life (e.g., inability to access employment, education)<br>Low potential for erosion of public trust in government or community cohesion | Recovery of the resource will take months | Recovery of the resource will take months | Potential direct and indirect economic losses of over $1 million*<br>Days-long disruption to a major economic sector and employment | Hours-long disruption in infrastructure services | Added costs can be covered within Contingency Reserve Fund |
| **Insignificant - 1** | No possibility of loss of life other than through unforeseeable misadventure | No possibility for morbidity, injury, disease, or hospitalizations other than through unforeseeable misadventure | Minimal expected reactions of fear anxiety or disruption to daily life | Minimal disruption to daily life<br>Trust in government remains unchanged | Little impact or resource can recover within days | Little impact or resource can recover within days | Potential direct and indirect economic losses less than $1 million* | Temporary nuisance | No expected additional costs to government |

*Chained 2007 dollars. All dollar figures are in CAD unless otherwise specified.

[×]Based on a Contingency Reserve Fund of approximately $750 million (B.C. Ministry of Finance, 2018).

## Evidence Base

To determine the likelihood and consequence ratings, the project team gathered evidence through a combination of desk research, expert consultations, and a risk assessment workshop. Desk research consisted of conducting targeted internet searches for resources using key words such as the risk event type and a specific consequence category and reviewing many resources provided by CAS, the project advisory committee, and expert consultations. To address research gaps, the project team consulted many experts (as noted above in Acknowledgments) through email exchanges and interviews. The project team also held a workshop to vet initial likelihood and consequence ratings and address remaining knowledge gaps.

Where possible, the project team relied on peer-reviewed literature, followed by grey literature (e.g., government reports), input from experts on the different risk events, and expert judgment from workshop participants, in that order.

## Confidence

Based on the quality of the evidence base, the project team assigned a confidence level to each rating, following the definitions shown in **TABLE 3**.

**TABLE 3.** Confidence Rating Guidelines

| CONFIDENCE RATING | DESCRIPTION |
|---|---|
| Low | Varying amounts and quality of evidence and/or little agreement between experts; or assessment made only using expert judgment. |
| Medium | Several sources of high-quality independent evidence, with some degree of agreement. |
| High | Multiple sources of independent evidence based on reliable analysis and methods, with widespread agreement. |

## Evaluate Risk

To determine the final risk score, the project team multiplied the likelihood rating by the average consequence rating. Based on the total score, the risk event scenario is categorized as extreme, high, medium, or low risk (see **FIGURE 2**).

**FIGURE 2.** B.C. risk rating matrix.

**Risk Rating Matrix**

| | | | | | |
|---|---|---|---|---|---|
| 5 | LOW | MED | HIGH | EXT | EXT |
| 4 | LOW | MED | HIGH | HIGH | EXT |
| 3 | LOW | MED | MED | HIGH | HIGH |
| 2 | LOW | LOW | MED | MED | MED |
| 1 | LOW | LOW | LOW | LOW | LOW |
| **Likelihood** | 1 | 2 | 3 | 4 | 5 |

**Consequence**

| **Likelihood x Consequence** | |
|---|---|
| Score 0 - 5.9 | = Low |
| Score 6 - 11.9 | = Medium |
| Score 12 - 19.9 | = High |
| Score 20 - 25 | = Extreme |

## RISK ASSESSMENT FINDINGS: OVERALL

Climate change can take many forms, affecting nearly all aspects of life in British Columbia. This assessment analyzed 15 distinct climate risks to British Columbia between 2040 and 2059 to provide decision makers with information to support risk prioritization and risk management activities.

This B.C. climate risk assessment focuses on *provincially significant* climate risks and thus does not consider risks to specific regions or locations in the province unless they would result in catastrophic or major impacts at the provincial level.

**FIGURE 3** and **TABLE 4** summarize the overall results, showing risks based on the 2050 likelihood of each scenario. Severe wildfire season and seasonal water shortage are the two highest risks overall facing the province. As discussed in detail in the Interactions between Risk Events chapter, these two risk events happen to be closely related, and could have further compounding consequences. Four other risk events qualify as "high" risk, including heat wave, ocean acidification, glacier mass loss, and long-term water shortage.

**FIGURE 3.** Risk assessment results: 2050 likelihood and consequence of each scenario and overall confidence ratings in results.

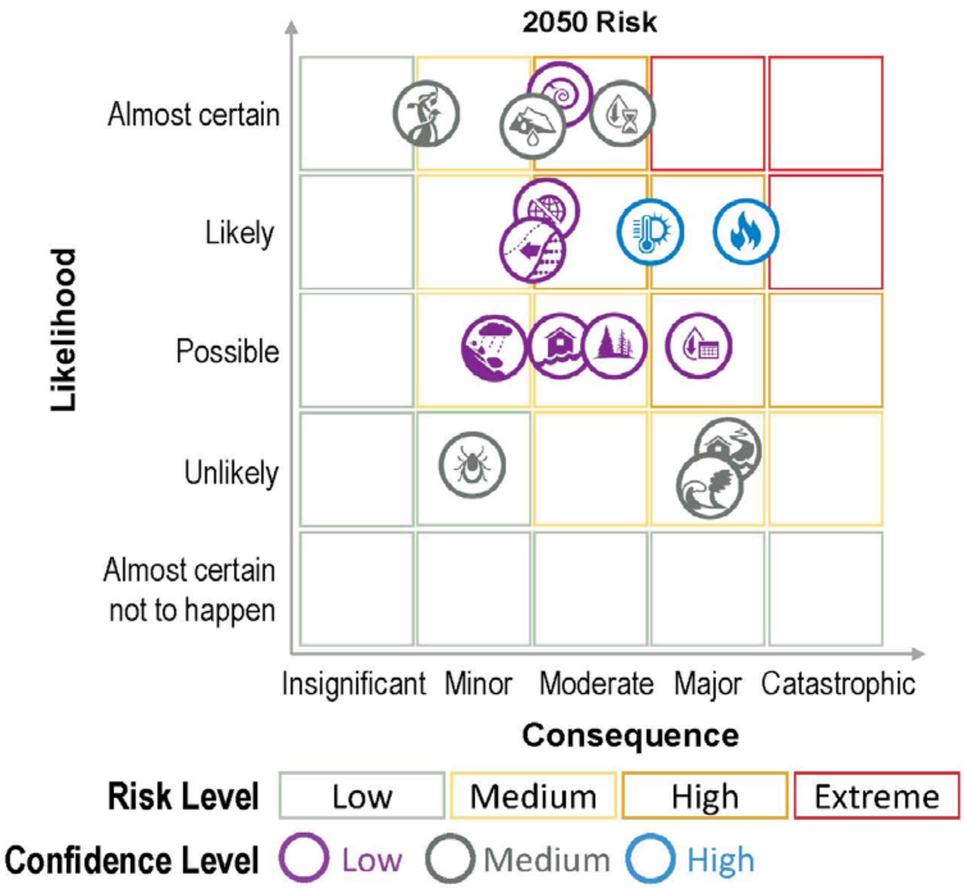


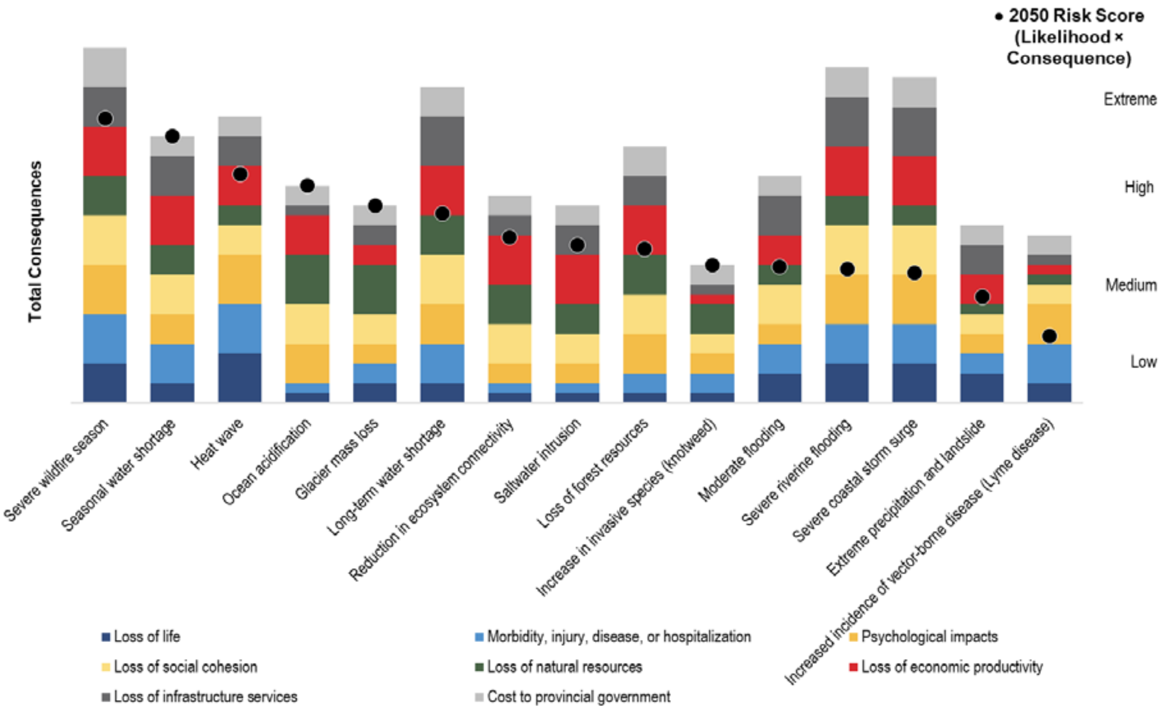
**TABLE 4.** Provincial Climate Risk Assessment Summary

| RISK EVENT | PRESENT-DAY LIKELIHOOD | 2050 LIKELIHOOD | CONSEQUENCE | RISK SCORE AND RATING | |
|---|---|---|---|---|---|
| Severe wildfire season | 3 | 4 | 4.5 | **18.0** | High |
| Seasonal water shortage | 4 | 5 | 3.4 | **16.9** | High |
| Heat wave | 3 | 4 | 3.6 | **14.5** | High |
| Ocean acidification | 2 | 5 | 2.8 | **13.8** | High |
| Glacier mass loss | 1 | 5 | 2.5 | **12.5** | High |
| Long-term water shortage | 3 | 3 | 4.0 | **12.0** | High |
| Reduction in ecosystem connectivity | 3 | 4 | 2.6 | **10.5** | Medium |
| Saltwater intrusion | 1 | 4 | 2.5 | **10.0** | Medium |
| Loss of forest resources | 1 | 3 | 3.3 | **9.8** | Medium |
| Increase in invasive species (knotweed) | 4 | 5 | 1.8 | **8.8** | Medium |
| Moderate flooding | 2 | 3 | 2.9 | **8.6** | Medium |
| Severe riverine flooding | 1 | 2 | 4.3 | **8.5** | Medium |
| Severe coastal storm surge | 1 | 2 | 4.1 | **8.3** | Medium |
| Extreme precipitation and landslide | 2 | 3 | 2.3 | **6.8** | Medium |
| Increased incidence of vector-borne disease (Lyme disease) | 1 | 2 | 2.1 | **4.3** | Low |

Icon colour denotes overall confidence level in the final risk rating: **Low**, **Medium**, or **High**

**FIGURE 4** further unpacks the risk assessment results and displays the detailed consequence ratings for each event, sorted from highest to lowest overall risk by 2050. Some risk events could have significant consequences across many or all consequence categories, while others could be dominated by consequences in one or two categories. For example, the impacts of knotweed would be primarily to natural resources. The severe riverine flooding and severe coastal storm surge risk events would have the highest overall consequences, but their relatively low likelihood reduces their overall risk relative to other events.

**FIGURE 4.** Detailed risk assessment results: consequences by risk event.




*Individual consequences are rated on a scale of 1 to 5 (Insignificant to Catastrophic). The size of the bar indicates individual consequence ratings.

Other high-level findings include:

- High-risk events include both discrete events (such as wildfires, water shortage, and heat waves), as well as slower-onset, gradual climate changes, such as ocean acidification and glacier mass loss.
- Nearly all risk events (except moderate flooding and extreme precipitation and landslide) would have at least "major" province-wide consequences in at least one category, and all but four would have "catastrophic" consequences in one or more areas.
- The majority of risk events would have "catastrophic" economic consequences.
- The risk events with the greatest potential consequences across all categories, irrespective of likelihood, are the scenarios analyzed for severe wildfire season, severe riverine flooding, and a severe coastal storm surge.

The following chapter and Appendix B detail the analysis of each risk event, including details of the scenario analyzed, its current and future likelihood, its consequences, and the strength of the evidence base.

Overall, the results indicate that the potential consequences of climate changes in B.C. between 2040 and 2059 are complex and wide-ranging. They may require similarly complex and wide-ranging solutions to mitigate these risks over time.

# RISK ASSESSMENT FINDINGS: BY RISK EVENT

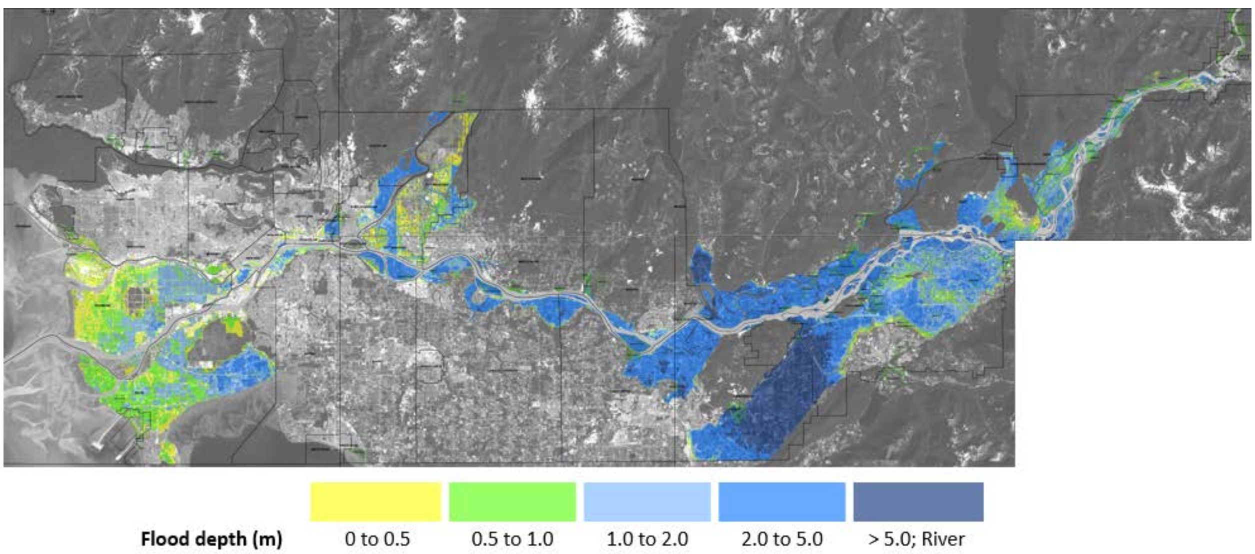
This chapter summarizes the key findings for each risk event. The full assessment of each risk event, including detailed documentation of the evidence base, is included in Appendix B.

## Severe Riverine Flooding

### Scenario

The specific scenario analyzed is today's "500-year flood" on the Fraser River, affecting the Lower Mainland (see **FIGURE 5**).[3] In this scenario, flood depths could exceed 5 m in some locations and last up to two weeks. The flood would most likely occur in the spring, caused by rapid snowmelt combined with heavy rainfall.

**FIGURE 5.** Severe flooding scenario: flood depths under present-day 500-year flood (Northwest Hydraulic Consultants, 2016).




[3] The "500-year" Fraser River flood is defined as the 1894 flood of record (Kerr Wood Leidal Associates Ltd, 2015; Northwest Hydraulic Consultants, 2016)

## Summary of Findings

Today's 500-year Fraser River flood event would result in extensive flooding in the B.C. Lower Mainland and affect more than 30% of the province's total population. In addition, this event threatens the integrity of existing flood management infrastructure (e.g., dikes). If this event occurred today, it would be the costliest natural disaster to date in Canadian history (Northwest Hydraulic Consultants, 2016).

Though by definition this is a low-likelihood, high-consequence event, climate change could make today's 500-year Fraser River flood up to five times more likely by 2050.

**FIGURE 6.** Risk assessment findings for severe flooding scenario.

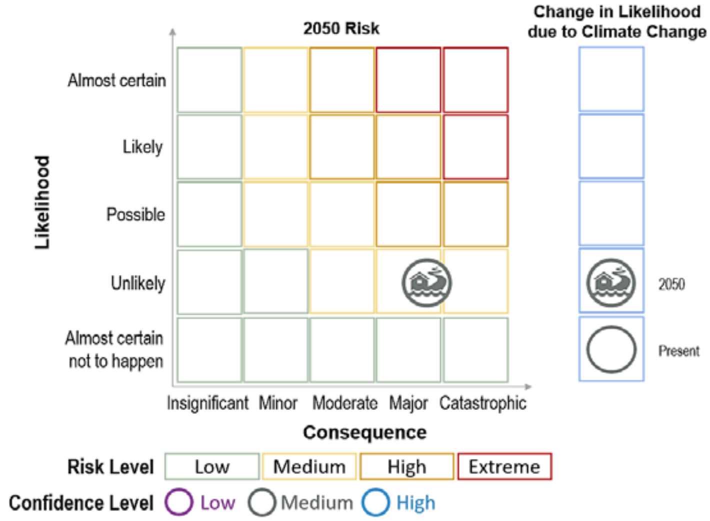



**FIGURE 6** and **TABLE 5** summarize the risk assessment results for this scenario. The highest consequences relate to losses to social functioning and economic vitality. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 5.** Risk Rating Evaluation for Severe Flooding Scenario

| SEVERE RIVERINE FLOODING: 500-YEAR FLOOD ON THE FRASER RIVER | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **1** | The "500-year flood" (for the Fraser River basin, a peak flow of 17,000 $m^3/s$) has a 0.2% chance of occurring in any year. | **2** | **Climate-related risk causes:** Severe spring flooding is driven by periods of hot weather, heavy rain during peak snowmelt, and snowpack volume.<br>**2050 projections:** The "500-year flood" is projected to have a 0.51% to 1% annual chance of occurring by 2050. | Medium |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **4** | Ten to 100 deaths could occur from fast-moving floodwaters and limited medical/emergency care. | High |
| | Morbidity, injury, disease, or hospitalization | **4** | More than 100 people are at risk of harm due to fast-moving floodwaters, debris, waterborne disease, limited access to critical services, or environmental contamination. | Medium |
| **Social functioning** | Psychological impacts | **5** | Severe psychological impacts are expected for individuals who experience damage to or loss of property or livelihood, evacuation, or loss of family members. | High |
| | Loss of social cohesion | **5** | Recovery and clean up could take months. There is also potential for widespread disruptions to a variety of institutions and services that would affect day-to-day life for at least weeks. | Medium |
| **Natural resources** | Loss of natural resources | **3** | Natural resources could experience damage due to inundation, debris, and water and soil contamination. Recovery could take years. | Low |
| **Economic vitality** | Loss of economic productivity | **5** | Losses are estimated at $22.9 billion, including the agriculture, transportation, energy industries, and damage to ecosystem services. | High |
| | Loss of infrastructure services | **5** | Disruptions to critical infrastructure services could last for months. | Medium |
| **Cost to provincial government** | | **3** | Costs to government might include flood response, post-event cleanup, health services, ecosystem recovery, Disaster Financial Assistance, and AgriRecovery, among others. | Medium |
| **OVERALL RISK** | **CURRENT** | **LOW (4.3)** | | **MEDIUM** |
| | **2050** | **MEDIUM (8.5)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **4.3** out of 25, which equates to **low risk**, and the 2050 risk rating is **8.5** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 1 x 4.3 = 4.3 (Low)

2050 Risk = 2 x 4.3 = 8.5 (Medium)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of this scenario is **1** and the 2050 likelihood of this scenario is **2**. By definition, a 500-year event currently has a 0.2% annual chance of occurring. To determine the likelihood of this flood event by 2050, the project team relied on climate change-influenced projections of Fraser River flood flow from the B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD).

By 2050, this flood scenario has a 0.51 to 1% annual chance of occurring. The project team used the conservative end of the range for the rating.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **4.3** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (4+4+5+5+3+5+5+3)/8

Overall Consequence = 4.3

#### HEALTH

*Loss of life: 4*

Due to the magnitude and location of this flood, 10 to 100 people could lose their lives from either direct or indirect causes. Direct loss of life could occur if people are caught in fast-moving floodwaters. In addition, limited medical or emergency care or loss of vital services such as power or clean water during and following the event could cause indirect loss of life. If warnings or evacuation orders are not issued in a timely manner, loss of life could exceed 100 people.

*Morbidity, injury, disease, or hospitalization: 4*

Flooding can cause health hazards beyond fatalities, such as injury, disease, or hospitalization from fast-moving flood waters or debris, limited access to critical infrastructure and services, or environmental contamination. For example, severe flooding can damage water supply systems, create conditions for water-borne diseases, or impair hospital or emergency response capacity. More than 100 people could experience ill health effects due to this scenario. If warnings or evacuation orders are not issued in a timely manner, this number could exceed 1,000 people.

### SOCIAL FUNCTIONING

*Psychological impacts: 5*

This flood scenario has the potential to affect nearly a third of the population of the province and cause severe psychological impacts such as PTSD and depression, particularly to those directly affected (e.g., through damage to or loss of property or livelihood, mandatory or voluntary evacuation, loss of family members or friends). In addition, if the transportation system or utility services are significantly affected there may be a shortage of food and services, further increasing stress and anxiety.

*Loss of social cohesion: 5*

Recovery and cleanup from a two-week-long flood event could take months, especially for hard-hit communities. For those directly affected by the flood damage (e.g., flooded home, flooded workplace or route to work), disruptions to daily life could last for months. The flood could also cause lingering after-effects to infrastructure services and disruptions to daily life. Given the potential for widespread disruptions to many critical institutions and services (e.g., wastewater treatment), even individuals who do not experience direct flood damage could experience at least a weeks-long disruption to daily life in terms of available services.

### NATURAL RESOURCES: 3

Although natural resources located in flood-prone areas are generally resilient to flood conditions, a 500-year severe flood will also extend to areas not accustomed to inundation. Ecosystems and natural resources could experience stress or damage due to inundation, debris, and water and soil contamination from nearby agricultural, industrial, or waste sites. This flood scenario is likely to affect a number of unique and fragile ecosystems such as riparian areas, intertidal marshes, and wetlands that could take years to recover.

### ECONOMIC VITALITY

*Loss of economic productivity: 5*

Total economic losses are estimated at $22.9 billion. Damages to multiple industries, including agriculture, transportation, and energy are each estimated at well over the "catastrophic" threshold of $1 billion. In addition, flooding could affect ecosystem services. When ecosystems are damaged by direct human use, natural disasters (such as flooding), or climate change, the services provided are often degraded or cease altogether. These services must then be replaced by costly man-made facilities or processes that provide the same services (e.g., the construction costs related to water runoff or flooding control if forest cover is removed or damaged).

*Loss of infrastructure services: 5*

Disruptions to critical infrastructure services (e.g., transportation, energy, communication, and wastewater treatment) could last for months depending on the extent of flood damage. Estimated infrastructure and institutional losses from this event are $4.7 billion. Impacts could include washed out transportation infrastructure, loss of electrical services, dike failure, and inundated wastewater treatment facilities, among others.

### COST TO PROVINCIAL GOVERNMENT: 3

This flood scenario would be the costliest natural disaster in Canadian history to date, indicating a significant cost to the provincial government. However, assuming that this event would trigger significant financial assistance from the Government of Canada through DFAA, the cost to the provincial government is expected to be on the order of $375 million to $750 million. The provincial government could bear costs such as flood response, post-event cleanup, health services, ecosystem recovery, Disaster Financial Assistance, and AgriRecovery and other business risk management programs, among others.

## Moderate Flooding

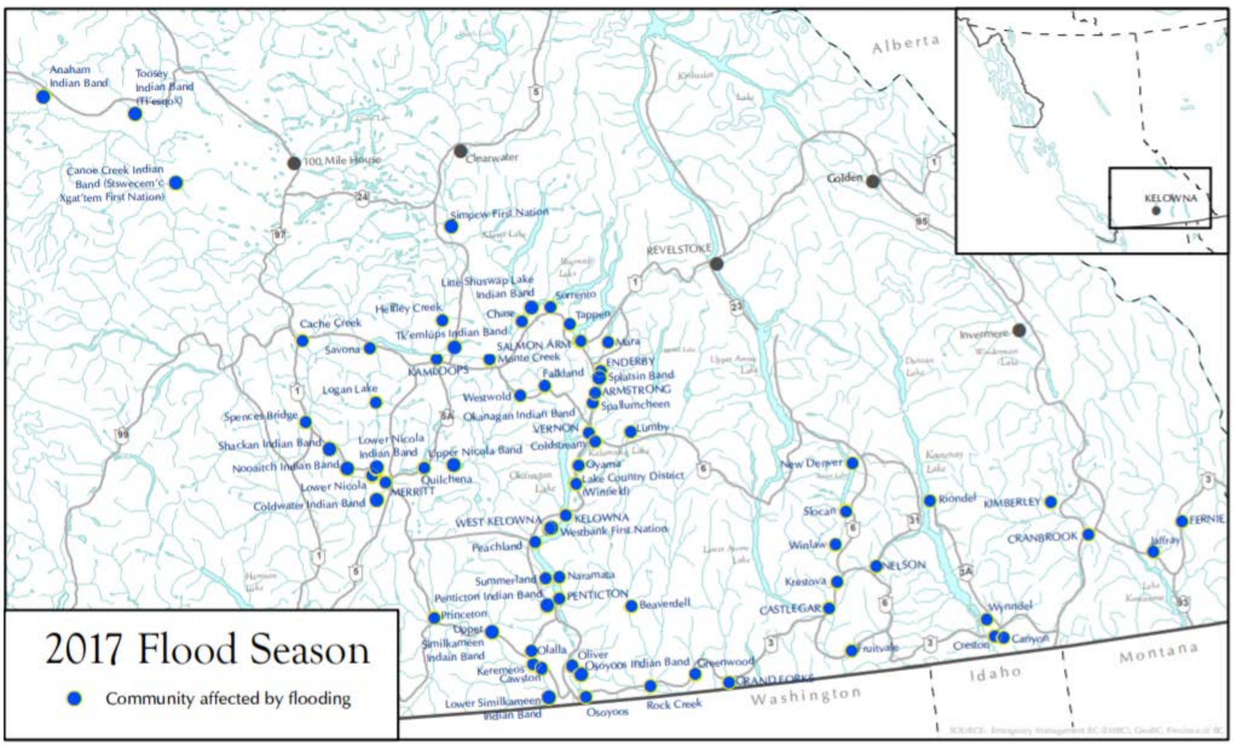
### Scenario

The specific risk event scenario analyzed is a moderate flood in a single B.C. community, which is designed to be representative of any location in British Columbia. A moderate flood, for the purpose of this assessment, is defined as one with a *greater than* 1% annual chance of recurrence (e.g., a 50-year event equals a 2% annual change of occurrence).

### Summary of Findings

B.C. experiences multiple flood events across the province each year. For example, **FIGURE 7** illustrates a subset of the communities affected by the 2017 flood season (Tzembelicos et al., 2018). A 2017 annual survey of local governments for the Climate Action Revenue Incentive Program found that urban and overland flooding from extreme weather events is the most common impact on and concern of local governments (Climate Action Revenue Incentive Program, 2018).

**FIGURE 7.** 2017 flood season in southeast B.C. (Tzembelicos, et al., 2018).



Although the location and severity of flooding varies from year to year, climate change is expected to increase the frequency of both major and moderate flood events. Therefore, in addition to potentially contributing to a major/severe flood (see Severe Riverine Flooding risk event), climate change is also expected to increase the frequency of lower-level floods in many parts of the province. This could include repeat flooding in certain locations, or more flood seasons with simultaneous flooding occurring in multiple communities, such as in 2017. Individually and cumulatively, more frequent moderate flood events can put a strain on both local and provincial government resources. This assessment uses recent moderate flooding in Cache Creek and Grand Forks as proxies to understand province-wide consequences of moderate flood events.

**FIGURE 8.** Risk assessment findings for moderate flooding scenario.

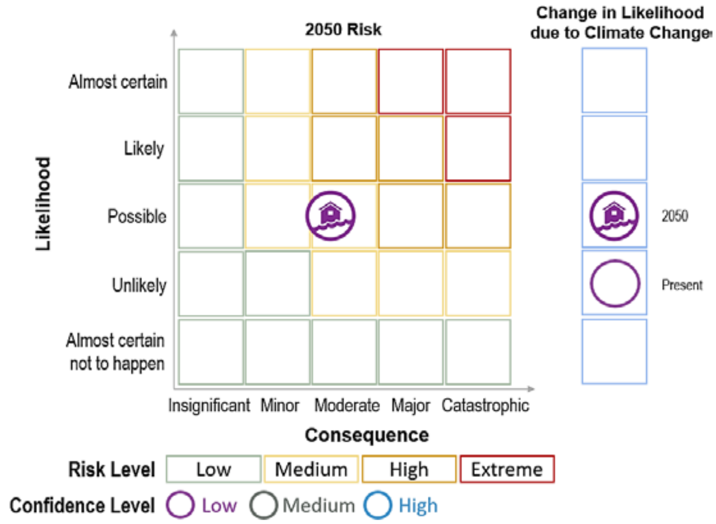



**FIGURE 8** and **TABLE 6** summarize the risk assessment results for this scenario. The highest consequences relate to loss of social cohesion and loss of infrastructure services. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 6.** Risk Rating Evaluation for Moderate Flooding Scenario

| MODERATE FLOODING: MODERATE FLOOD IN A SINGLE COMMUNITY | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **2** | A moderate flood event is defined as having a greater than 1% annual chance of occurrence. | **3** | **Climate-related risk cause:** Moderate flood frequency is driven by increased precipitation, more frequent heavy rain events, and increased temperatures causing greater snowmelt.<br>**2050 projections:** A moderate flood event is estimated to have a return period of 11 to 50 years due to a projected increase in 20-year annual maximum one day precipitation and changes in snowmelt | Low |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **3** | Two to 10 deaths could occur from fast-moving floodwaters and limited medical/emergency care. | Low |
| | Morbidity, injury, disease, or hospitalization | **3** | More than 5% of the community is at risk of harm due to fast-moving floodwaters, debris, limited access to critical infrastructure and services, or environmental contamination. | Low |
| **Social functioning** | Psychological impacts | **2** | Individuals affected by flood damage, temporary displacement, or disruptions to utilities are expected to experience moderate psychological impacts. | Medium |
| | Loss of social cohesion | **4** | For individuals who experience direct flood damage to homes or businesses, recovery and clean up could take weeks. Flooded roads could also disrupt daily life. | Low |
| **Natural resources** | Loss of natural resources | **2** | Natural resources could experience damage due to inundation, debris, and water and soil contamination. Recovery could take weeks to months. | Low |
| **Economic vitality** | Loss of economic productivity | **3** | Economic losses could range between $10 million and $99 million due to business/tourism losses, decreased agricultural productivity, and loss of ecosystem services, among other. | Low |
| | Loss of infrastructure services | **4** | Disruptions to transportation, water, electricity, and other infrastructure services could last for weeks. | Low |
| **Cost to provincial government** | | **2** | Costs to government might include flood response, post-event cleanup, health services, Disaster Financial Assistance, and AgriRecovery. | Medium |
| **OVERALL RISK** | **CURRENT** | **LOW (5.8)** | | **LOW** |
| | **2050** | **MEDIUM (8.6)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **5.8** out of 25, which equates to **low risk**, and the 2050 risk rating is **8.6** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 2 x 2.9 = 5.8 (Low)

2050 Risk = 3 x 2.9 = 8.6 (Medium)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of this scenario is **2** and the 2050 likelihood of this scenario is **3**. Moderate flooding is largely dependent on the frequency and magnitude of heavy precipitation events, which can quickly inundate surface water systems. To evaluate the scenario likelihood, the study team drew on recent projections for future maximum precipitation events across B.C., as well as expected changes in underlying climate-related causes, such as increased seasonal precipitation and air temperatures driving more vigorous snowmelt. The project team additionally considered future flood recurrence interval projections. Based on the standard return period of a moderate flood event as well as the proxy examples, these events are currently expected to happen about once every 51 to 100 years. As a result, the project team expects that in 2050, moderate flood events could happen about once every 11 to 50 years.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.9** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (3+3+2+4+2+3+4+2)/8

Overall Consequence = 2.9

**HEALTH**

*Loss of life: 3*

Depending on the depth and speed of floodwaters, two to 10 individuals could lose their lives from either direct or indirect causes. Direct loss of life could occur if people are caught in floodwaters. In addition, limited medical or emergency care or loss of vital services such as power or clean water during and following the event could cause indirect loss of life. If there is not sufficient advanced warning or evacuation prior to the flood, loss of life could be higher.

*Morbidity, injury, disease, or hospitalization: 3*

Moderate flood events have the potential to expose more than 5% of the community to injury, disease, or hospitalization from fast-moving floodwaters, debris, limited access to critical infrastructure and services, or environmental contamination. In addition, lower flood levels could give the false impression that waters are safe to wade or drive through, which may cause more injuries, disease, or hospitalizations.

### SOCIAL FUNCTIONING

*Psychological impacts: 2*

Moderate flooding has the potential to cause localized and temporary moderate psychological impacts, such as fear or anxiety, especially for those who were displaced or experienced flood damages. Disruptions to utility services could also cause increased stress and anxiety.

*Loss of social cohesion: 4*

A moderate flood event could cause weeks-long disruptions to daily life, especially for home owners, business owners, and farmers who experience direct flood damage. Even if community members do not experience direct flood damage to their homes or businesses, they may deal with flooded roads or helping with community clean up and recovery.

### NATURAL RESOURCES: 2

Natural resources located within a 50-year or 100-year floodplain are expected to be generally resilient to flood conditions given historic flooding events. The primary risks to natural resources from a moderate flood event are stress or damage due to inundation, debris, or contaminants from agricultural, industrial, or waste sites. Recovery of natural resources is estimated to take weeks to months depending on the location of the moderate flood and local conditions (e.g., ecosystem/species sensitivity or extent of environmental contamination).

### ECONOMIC VITALITY

*Loss of economic productivity: 3*

Loss of economic productivity will vary depending on the location of moderate flooding, but based on the proxy events and other cost information economic losses could feasibly range between $10 million and $99 million due to impacts to businesses, tourism, and agricultural productivity, among others. As a result, this scenario could cause a weeks-long disruption to at least one major economic sector. In addition, flooding could affect ecosystem services. When ecosystems are damaged by direct human use, natural disasters (such as flooding), or climate change, the services provided are often degraded or cease altogether. These services must then be replaced by costly man-made facilities or processes that provide the same services (e.g., the construction costs related to water runoff or flooding control if forest cover is removed or damaged).

*Loss of infrastructure services: 4*

Disruptions to transportation, water, and other infrastructure services could last for weeks depending on the severity of flood damage and number of people affected, causing major impediment to day-to-day life. Impacts could include washed out transportation infrastructure, damage to water supply systems, and power outages, among others.

### COST TO PROVINCIAL GOVERNMENT: 2

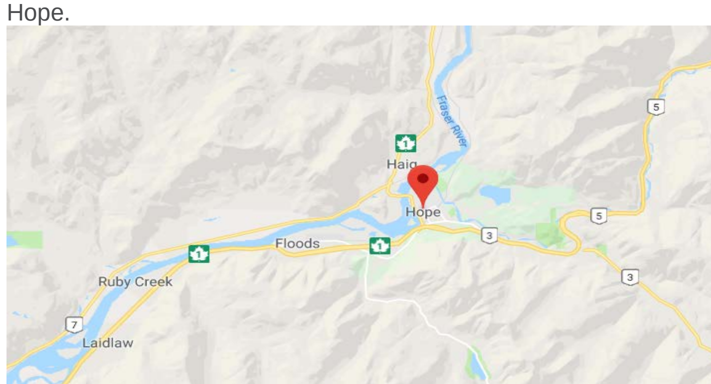
Based on the cost to the provincial government from the proxy events, costs to government from a single moderate flood event are expected to be on the order of $375 million or less. However, cost to the provincial government can vary from year to year depending on the location, number, and frequency of moderate flood events across the province. Costs to government might include flood response, post-event cleanup, health services, Disaster Financial Assistance, and AgriRecovery and other business risk management programs, among others.

## Extreme Precipitation and Landslide

### Scenario

The specific scenario analyzed is a significant landslide[4] in Hope, B.C. triggered by extreme precipitation. In this scenario, the landslide would affect one or more major transportation routes in Hope, B.C. (see **FIGURE 9**), causing provincially significant disruptions to transportation and the movement of goods and services across the province.

**FIGURE 9.** Map illustrating the intersections of Trans-Canada Highway (Highway 1), Highway 3, Highway 5, and Highway 7 in Hope.




### Summary of Findings

The majority of precipitation-driven landslides in B.C. are smaller debris flows or rock slides, which are likely to become more frequent due to climate change. This scenario, however, represents an extreme case in which Hope experiences a large and provincially significant precipitation-driven landslide that affects transportation across the province. Due to the mountainous terrain of B.C., disruptions to major transportation routes, especially in transportation hubs such as Hope, can cause significant delays and disruptions to the movement of goods and services. Furthermore, due to the volume of vehicles (7 million vehicles annually) and trains passing through Hope as well as a population of about 6,000 people, there is also a risk for injuries, deaths, property losses, and other damages (District of Hope, 2017).

**FIGURE 10.** Risk assessment findings for extreme precipitation and landslide scenario.

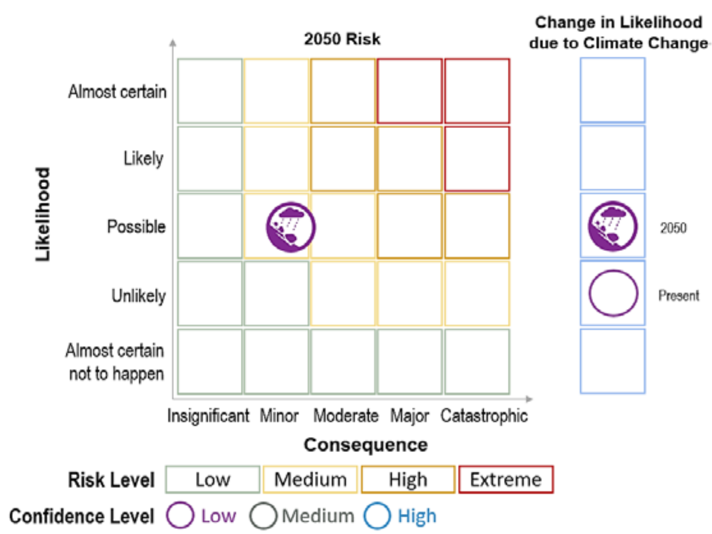



**FIGURE 10** and **TABLE 7** summarize the risk assessment results for this scenario. The highest consequences relate to loss of life, loss of economic productivity, and loss of infrastructure services. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

[4] A landslide is defined as the movement of rock, soil, and other debris down a slope as a result of gravitational pull (Green, Ricker, McPhee, Ettya, & Temenos, 2014). Landslide is a general term that encompasses many types of landslides (e.g., debris flow, mudslide, rock slide, rock avalanche). Landslides can be caused by a variety of factors including precipitation, snow melt, temperature change, permafrost melt, slope debuttressing from receding glaciers, earthquakes, volcanic activities, and human activities.

**TABLE 7**. Risk Rating Evaluation for Extreme Precipitation and Landslide Scenario

<table>
<tr><th colspan="5">EXTREME PRECIPITATION AND LANDSLIDE: SIGNIFICANT LANDSLIDE IN HOPE TRIGGERED BY EXTREME PRECIPITATION</th></tr>
<tr><th colspan="5">LIKELIHOOD</th></tr>
<tr><th>CURRENT RATING</th><th>JUSTIFICATION</th><th>2050 RATING</th><th>JUSTIFICATION</th><th>CONFIDENCE</th></tr>
<tr><td>2</td><td>Past significant events in 1965 and 2017 roughly indicate a major landslide about once every 52 years, which falls into the likelihood range of 51 to 100 years.</td><td>3</td><td>Climate-related risk cause: Heavy precipitation, warming temperatures, and rain-on-snow events can trigger landslides. In addition, landslide risk is largely dependent on underlying geology and physical factors, including hill slope steepness and bedrock deformation.<br>2050 projections: Multiple studies indicate an increase in the frequency of landslides due to increased heavy precipitation and temperature. Therefore, the likelihood could increase to a range of 11 to 50 years.</td><td>Low</td></tr>
<tr><th colspan="5">CONSEQUENCE</th></tr>
<tr><th>CATEGORY</th><th>CONSEQUENCE</th><th>RATING</th><th>JUSTIFICATION</th><th>CONFIDENCE</th></tr>
<tr><td rowspan="2">Health</td><td>Loss of life</td><td>3</td><td>Potential for up to 10 deaths due to falling debris if the landslide affects one of the three major highways.</td><td>Medium</td></tr>
<tr><td>Morbidity, injury, disease, or hospitalization</td><td>2</td><td>Fewer than 10 people are at risk of injury or harm due to falling debris or compromised drinking water supplies.</td><td>Medium</td></tr>
<tr><td rowspan="2">Social functioning</td><td>Psychological impacts</td><td>2</td><td>A landslide could cause localized, temporary psychological impacts for individuals directly affected by the landslide.</td><td>Low</td></tr>
<tr><td>Loss of social cohesion</td><td>2</td><td>A landslide could cause hours to days-long disruption to daily life primarily due to transportation impacts and localized property damage.</td><td>Low</td></tr>
<tr><td>Natural resources</td><td>Loss of natural resources</td><td>1</td><td>Impacts to natural resources within the path of the landslide could be significant, but overall impacts to natural resources in Hope will be minimal.</td><td>Low</td></tr>
<tr><td rowspan="2">Economic vitality</td><td>Loss of economic productivity</td><td>3</td><td>Damage or destruction of key infrastructure or economic resources could cause weeks-long disruptions to major economic sectors.</td><td>Low</td></tr>
<tr><td>Loss of infrastructure services</td><td>3</td><td>Infrastructure disruptions such as road closures or severed power lines could last for days and cause major impediments to day-to-day life at both a local and province-wide scale.</td><td>Medium</td></tr>
<tr><td colspan="2">Cost to provincial government</td><td>2</td><td>Costs to government might include response, clean up, health services, and Disaster Financial Assistance, among others.</td><td>Low</td></tr>
<tr><td rowspan="2">OVERALL RISK</td><td>CURRENT</td><td colspan="2">LOW (4.5)</td><td rowspan="2">LOW</td></tr>
<tr><td>2050</td><td colspan="2">MEDIUM (6.8)</td></tr>
</table>

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **4.5** out of 25, which equates to **low risk**, and the 2050 risk rating is **6.8** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 2 x 2.3 = 4.5 (Low)

2050 Risk = 3 x 2.3 = 6.8 (Medium)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present day likelihood of this scenario is **2** and the 2050 likelihood of this scenario is **3**. Past significant landslides in 1965 and 2017 indicate a current likelihood in the "unlikely" range of once every 51 to 100 years. However, there are strong indications that increases in heavy precipitation as well as warming temperatures will increase the frequency of landslides. Therefore, the project team judged that it is feasible for the 2050 likelihood of this scenario to be in the "possible" range of once every 11 to 50 years.

In addition to climate-related causes, landslide risk is largely dependent on underlying geology and physical factors, including hill slope steepness and bedrock deformation. Thus, areas most susceptible to severe landslide risk are likely more local than the regional-scale climate-related causes. To evaluate the scenario, the project team used indicators including the historical record of landslides in Hope, B.C., which may reflect landslides that occurred independent of climate forcing, and the latest provincial research on landslide drivers. The project team sought to evaluate the future likelihood of large landslides in the Hope, B.C. due to the combined influence of increasing climate stress and background geologic risk. As such, the project team considered primary climate-related risk causes including projections for air temperature, precipitation, and snowmelt through mid-century.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.3** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (3+2+2+2+1+3+3+2)/8

Overall Consequence = 2.3

**HEALTH**

*Loss of life: 3*

Historically, major landslides in B.C. have resulted in up to five deaths due to falling debris. A significant landslide in Hope could result in a similar number of deaths, in the range of two to ten, particularly if the landslide affects one of the three major highways.

*Morbidity, injury, disease, or hospitalization: 2*

Past major landslides in B.C. have resulted in fewer than 10 injuries each due to falling debris. A landslide could also comprise drinking water supplies, which could threaten public health. As a result, a landslide in Hope is expected to harm fewer than 10 people.

### SOCIAL FUNCTIONING

*Psychological impacts: 2*

A landslide can cause temporary psychological impacts for the individuals directly affected, such as those who are injured, lose a home, or lose a family member.

*Loss of social cohesion: 2*

Based on past events, a significant landslide in Hope could cause an hours- to days-long disruption to daily life for the affected area due to transportation infrastructure impacts. If a number of homes or businesses are damaged or destroyed, loss of social cohesion may be higher for the affected community.

### NATURAL RESOURCES: 1

Given the localized nature of a landslide, impacts to natural resources within the path of the landslide could be significant, but overall impacts to natural resources in Hope will be minimal. Landslide debris could erode into rivers and streams, decreasing water quality for aquatic habitats. In addition, changes in soil conditions could disrupt vegetation and forest resources in the affected area.

### ECONOMIC VITALITY

*Loss of economic productivity: 3*

Damage or destruction of key transportation infrastructure, utility infrastructure, or economic resources such as timber, could cause weeks-long disruptions to major economic sectors. For example, road/rail closures, delays, or reroutes could affect the movement of goods and services.

*Loss of infrastructure services: 3*

Based on past events, infrastructure disruptions such as road closures or severed power lines could last for days and cause major impediments to day-to-day life at both a local and province-wide scale. Transportation impacts are especially critical given that Hope, B.C. is a major intersection for several highways and rail lines.

### COST TO PROVINCIAL GOVERNMENT: 2

The primary cost to the provincial government is expected to be response and recovery (e.g., health services, cleanup, repairs), especially if major transportation routes are affected. In addition, the provincial government may provide Disaster Financial Assistance. These costs are expected to be on the order of $375 million or less.

## Seasonal Water Shortage

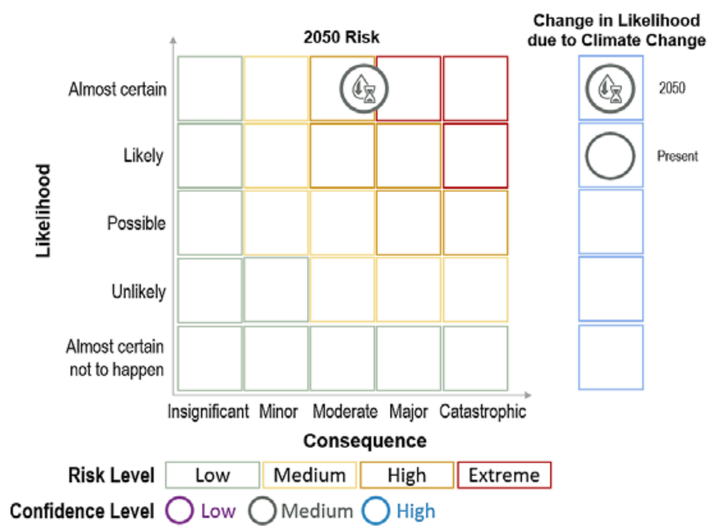
### Scenario

The specific risk event scenario analyzed is a summer water shortage affecting two or more regions of the province and lasting two or more months. The magnitude of this water shortage is equal to drought Level 4 as defined in the B.C. Drought Response Plan (the highest level where water supply is insufficient to meet socio-economic and ecosystem needs). The cause of the water shortage would vary depending on the hydrology of streams within the region. For example, in rainfall-dominated regions a water shortage could be caused by decreased summer precipitation, and in snowmelt-dominated regions a water shortage could be caused by earlier or more rapid snowmelt, or a reduced snowpack.

### Summary of Findings

Although reduced summer water supply is a natural feature of hydrology in many parts of B.C., the scenario analyzed has likely occurred infrequently in the past and can be considered relatively extreme. The summer of 2015 could be seen as a recent example when B.C. experienced drought Level 4 conditions affecting two regions of the province for slightly more than two months. Rising temperatures and changes in precipitation form, timing and intensity caused by climate change will increase the likelihood, and therefore the risk, of this scenario in the 2050s.

**FIGURE 11.** Risk assessment findings for seasonal water shortage scenario.




The impacts of an extreme summer water shortage can be wide-ranging and affect drinking water quality, ecosystem health, community water supply, and water-dependent industries. If such events occur more frequently in future, and particularly if they increase in magnitude, human health could be negatively affected by a rise in water-borne and vector-borne diseases. In addition, people with natural-resource-based livelihoods could face unemployment and lost livelihoods, which could result in psychological distress. Recovery from such extreme seasonal water shortages may take months and cost the economy and government millions of dollars.

**FIGURE 11** and **TABLE 8** summarize the risk assessment results for this scenario. The highest consequences relate to economic vitality, morbidity and disease, and loss of social cohesion. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 8.** Risk Rating Evaluation for Seasonal Water Shortage Scenario

| SEASONAL WATER SHORTAGE: SUMMER WATER SHORTAGE AFFECTING TWO OR MORE REGIONS AND LASTING TWO OR MORE MONTHS | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **4** | B.C. experiences significant seasonal and inter-annual hydrological variability. Seasonal water shortages as defined in this scenario likely occur approximately once every 3 to 10 years. | **5** | **Climate-related risk cause:** Higher temperatures and changes in seasonal precipitation (rain or snowfall).<br>**2050 projections:** Slight increases in annual precipitation are anticipated, but offset by increasing temperatures and decreases in summer precipitation. Rising temperatures could also result in reduced snowpack and earlier spring snowmelt. These changes could result in seasonal water shortages about once every two years or more frequently by 2050. | Medium |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **2** | There is low potential for multiple losses of life due to the impacts of seasonal water shortage. | Medium |
| | Morbidity, injury, disease, or hospitalization | **4** | Over 100 people could experience some negative health outcomes due to contaminated water sources, exposure to vector-borne disease, or fungal diseases. | Medium |
| **Social functioning** | Psychological impacts | **3** | Water usage restrictions, economic hardship, and seasonal loss of livelihood could result in temporary, widespread psychological impacts such as stress, anxiety, and depression. People with natural resource dependent-livelihoods could face more severe impacts. | Low |
| | Loss of social cohesion | **4** | Potential for weeks-long disruption to daily life, particularly for agriculturally-dependent communities. | Medium |
| **Natural resources** | Loss of natural resources | **3** | Degradation of wetland and forest habitats could affect many species. Higher river temperatures could cause stress for temperature-sensitive species, especially salmon. Natural resources could take years to recover. | Medium |
| **Economic vitality** | Loss of economic productivity | **5** | Losses could exceed $1 billion in agriculture, fisheries, forestry, tourism, and other water-dependent sectors. | High |
| | Loss of infrastructure services | **4** | Disruptions to electricity production and water treatment could last weeks. | Medium |
| **Cost to provincial government** | | **2** | Cost for emergency response, recovery, and lost revenue could be tens of millions of dollars. | Low |
| **OVERALL RISK** | **CURRENT** | **HIGH (13.5)** | | **MEDIUM** |
| | **2050** | **HIGH (16.9)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **13.5** out of 25, which equates to **high risk**, and the 2050 risk rating is **16.9** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 4 x 3.4 = 13.5 (High)

2050 Risk = 5 x 3.4 = 16.9 (High)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of this scenario is **4** (event expected about once every 3 to 10 years) and the 2050 likelihood of this scenario is **5** (event expected to happen about once every two years or more frequently). Summer water shortages equivalent to the scenario defined occur episodically in B.C. due to a range of underlying climate-related causes. Causes vary spatially; rain-dominated regions are particularly sensitive to deficits in summer rainfall and warmer air temperatures causing enhanced evapotranspiration, while watersheds fed by mountain snowmelt are particularly sensitive to the timing and rate of peak springtime melt and runoff.

The project team used GCM projections for precipitation, air temperature, and snowmelt as indicators to evaluate the likelihood of summer water shortages for the two system types (rain-dominated and snowfall-dominated). Some systems are hybrid or mixed and have characteristics of both types of systems. The project team additionally used projections of the April 1 snowpack level, typically used as an indicator of seasonal water supply, as an indicator for future water availability. The project team used the aggregate of these factors to find that this scenario will become more frequent in B.C. by mid-century, independent of the dominant underlying climate-related cause and assuming constant demand.

### *Consequence ratings*

The overall consequence rating is an average of the eight individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **3.4** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (2+4+3+4+3+5+4+2)/8

Overall Consequence = 3.4

#### HEALTH

*Loss of life: 2*

While water shortages have been associated with mortality in low-income countries, no deaths have been directly attributed to water shortage in Canada. Communities in B.C. have the capacity to prepare in advance and implement measures to protect affected communities from reductions in water supply. In addition, there is a small risk that complications due to respiratory, water-borne, or vector-borne illnesses. Thus, based on the available evidence, there is low potential for multiple losses of life due to the direct or indirect effects of this water shortage scenario. However, compounding impacts due to extreme heat or wildfire could contribute to low loss of life.

*Morbidity, injury, disease, or hospitalization: 4*

Water is vital for health and sanitation, so water shortages can negatively affect health if people turn to unsafe water sources. Contaminated water supplies have the potential to expose more than 100 people to health risks in B.C., although the impacts may be relatively minor if safe water supplies are provided to affected areas. Small water systems and private systems face greater risk than those connected to centralized water sources.

### SOCIAL FUNCTIONING

*Psychological impacts: 3*

Seasonal water shortages could result in temporary, widespread psychological impacts such as stress, anxiety, and depression due to water usage restrictions, economic hardship, and seasonal loss of livelihood. Psychological impacts will be especially prevalent for individuals that have natural-resource dependent livelihoods, such as farmers and fishermen.

*Loss of social cohesion: 4*

Seasonal water shortages could result in a weeks-long disruption to daily life as well as seasonal loss of livelihoods, especially for those in agriculturally dependent communities. If water supplies are compromised, some residents may need to adjust their behaviours or seek alternative water sources. Greater water scarcity could also increase competition between water users, which may increase conflict or social instability. Since water shortage may disproportionately affect vulnerable populations, it could have implications for maintaining social cohesion and equity.

### NATURAL RESOURCES: 3

Seasonal water shortages could cause environmental damages, particularly for aquatic species. Temperature-sensitive species such as salmon may experience heat stress and difficulties migrating due to low water levels. In addition, it is possible that a summer water shortage could result in damages to wetlands and forest ecosystems. For example, water shortages could make forests more susceptible to insect outbreaks and wildfire. The spatial area affected could be large and resources could take years to recover.

### ECONOMIC VITALITY

*Loss of economic productivity: 5*

Seasonal water shortages could have disproportionate financial impacts on agriculture, fisheries, forestry, tourism, and other water-dependent sectors. Agriculture generates over $14 billion in annual revenue, and forestry and logging account for around $9 billion in annual revenue. If B.C. experiences a summer water shortage that affects multiple regions of the province, losses in these sectors could exceed $1 billion in losses. In addition, this event could cause unemployment in natural-resource sectors.

*Loss of infrastructure services: 4*

Seasonal water shortages may result in weeks-long disruption of key infrastructure services, including electricity production and water treatment. Historically, water shortages in Canada and the Pacific Northwest have reduced hydroelectric production capacity, caused thermo-electric plants to shut down, and increased water and wastewater treatment requirements due to higher turbidity.

### COST TO PROVINCIAL GOVERNMENT: 2

The primary cost to the provincial government is expected to be emergency response and recovery funding to affected sectors, particularly for agriculture. Other costs could include health and utility services. Although the expected costs can't be fully quantified, the costs are expected to be on the order of $375 million or less.

## Long-term Water Shortage

### Scenario

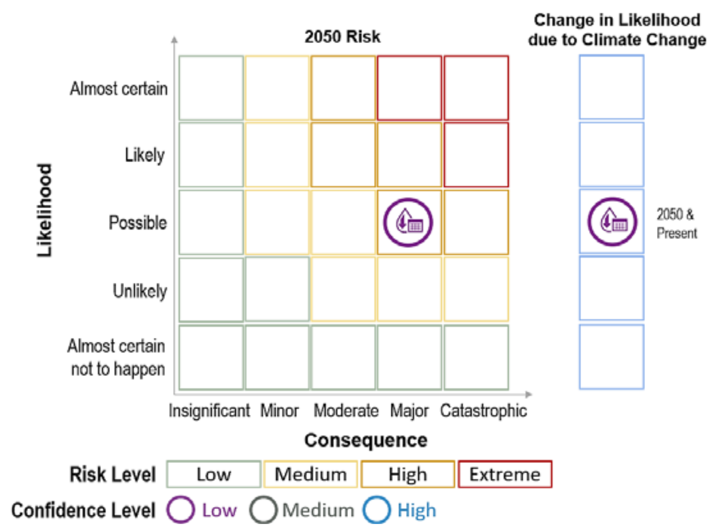
The specific risk event scenario analyzed is a long-term water shortage lasting for two or more years, affecting one or more regions of B.C., and characterized by insufficient supplies of both blue water and green water[5]. This event could be driven by a year-on-year decrease in precipitation and increase in temperature and could be exacerbated by increased evaporation and evapotranspiration.

### Summary of Findings

Historically, long-term water shortages have affected B.C. every few decades. Such an event affected B.C., Alberta, and Saskatchewan from 2001 to 2002; this event is considered one of Canada's worst natural disasters.

The risk related to this scenario is expected to increase by 2050. Although climate model results vary, higher temperatures are expected to increase evaporation and regional moisture deficit. When combined with below-average precipitation or low seasonal streamflow for several years, long-term water shortages could occur more frequently.

**FIGURE 12.** Risk assessment findings for multi-year water shortage scenario.




Regions in the interior of B.C. are particularly susceptible to long-term water shortages, which can result in losses across many sectors, including agriculture, forestry, industry, recreation, human health, and ecosystems. Reduced water supply can lead to losses in agricultural productivity, which is an important economic contributor in British Columbia. Additionally, long-term water shortages make land and forests more susceptible to other risks, such as wildfires and insect outbreaks. Recovery of some resources from long-term water shortages may take years or decades and cost the economy and government billions of dollars.

**FIGURE 12** and **TABLE 9** summarize the risk assessment results for this scenario. The highest consequences relate to loss of economic productivity, loss of infrastructure services, and loss of social cohesion. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

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[5] Blue water refers to liquid water in reservoirs, lakes, aquifers, rivers, etc. and green water refers to moisture in the soil and vegetation (Falkenmark & Rockström, 2006).

**TABLE 9.** Risk Rating Evaluation for Long Term Water Shortage Scenario

| **LONG-TERM WATER SHORTAGE: MULTI-YEAR WATER SHORTAGE RESULTING IN INSUFFICIENT WATER SUPPLY IN AT LEAST ONE REGION** | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **3** | Severe multi-year water shortages occur in the Canadian Prairies and interior B.C. approximately every 20 years. | **3** | **Climate-related risk cause:** Water shortages occur due to precipitation deficits, higher temperatures, and reduced snowpack.<br>**2050 projections:** Slight increases in annual precipitation and more frequent high intensity rainfall events are anticipated, yet rising temperatures could counteract these changes. Multiple seasons with high temperatures and below-average precipitation can result in water shortages. Large uncertainties are associated with predictions of multi-year dry spells. | Low |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **2** | There is low potential for multiple losses of life in B.C. | Medium |
| | Morbidity, injury, disease, or hospitalization | **4** | Hundreds of people could experience illness due to exposure to respiratory irritants and increased risk of water-borne, vector-borne, and fungal disease. | High |
| **Social functioning** | Psychological impacts | **4** | Loss of natural resource dependent livelihoods and economic hardship may contribute to localized, long-term psychological impacts. A larger population may experience moderate anxiety and distress. | Medium |
| | Loss of social cohesion | **5** | Months-long disruption to daily life and permanent loss of livelihoods, particularly for agriculturally dependent communities. Water restrictions could exacerbate general social instability. | Medium |
| **Natural resources** | Loss of natural resources | **4** | Soil erosion, wetland loss, habitat destruction, and forest degradation could disrupt wildlife and aquatic species, which could take decades to recover. | High |
| **Economic vitality** | Loss of economic productivity | **5** | Losses exceeding $1 billion could occur due to impacts on agriculture, fishing, forestry, transportation, recreation, tourism, and oil & gas. | High |
| | Loss of infrastructure services | **5** | Disruptions of hydroelectricity production, and water and wastewater treatment could last months. | Medium |
| **Cost to provincial government** | | **3** | Costs for emergency response and recovery, and lost revenue could exceed $375 million. | Low |
| **OVERALL RISK** | **CURRENT** | **HIGH (12.0)** | | **LOW** |
| | **2050** | **HIGH (12.0)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **12.0** out of 25, which equates to **high risk**, and the 2050 risk rating is **12.0** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 3 x 4.0 = 12.0 (High)

2050 Risk = 3 x 4.0 = 12.0 (High)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of this scenario is **3** (event expected about once every 11 to 50 years) and the 2050 likelihood of this scenario is **3**. Water shortages occur due to a range of underlying climate-related causes, including precipitation deficits, higher temperatures, and reduced snowpack. Long term shortages are most directly linked to prolonged episodes of below-average rainfall, which can result in total water availability below the long-term average over consecutive years. Often the impacts associated with reduced rainfall are exacerbated by seasonal climate stresses, such as heat waves and enhanced evapotranspiration. To evaluate the scenario, the project team used indicators including GCM projections and projected drought severity indices for mid-century. GCMs project significant warming and slight increases in precipitation in B.C., representing a future climate particularly sensitive to small changes in precipitation over consecutive years. Ultimately, multi-year water shortages have occurred in B.C. several times in the past century, and their frequency is likely to remain similar or increase slightly from historical incidence.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **4.0** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (2+4+4+5+4+5+5+3)/8

Overall Consequence = 4.0

**HEALTH**

*Loss of life: 2*

Based on the available evidence, there is low potential for multiple losses of life due to the direct impacts of long-term water shortages. While prolonged water shortages have been associated with mortality in low-income countries, communities in B.C. have the capacity to prepare in advance to protect communities from ill health effects. Long-term water shortages can have broader impacts to society by affecting surface and groundwater supplies, and food production. Although not accounted for here, compounding impacts due to extreme heat or wildfire may contribute to multiple deaths.

*Morbidity, injury, disease, or hospitalization: 4*

Water is vital for health and sanitation, so water shortages can negatively affect health if people turn to unsafe water sources. Contaminated groundwater and surface water, in addition to respiratory irritants, have the potential to expose hundreds of people to some level of illness during a multi-year water shortage. Ill effects could include bacterial infections from unsafe drinking water, water-borne and vector-borne diseases, or fungal diseases that become more prolific during the event. People living in rural areas or who are socioeconomically disadvantaged would likely experience disproportionate health impacts.

### SOCIAL FUNCTIONING

#### *Psychological impacts: 4*

A long-term water shortage could lead to severe, but localized, psychological impacts such as depression and loss of identity or way of life for individuals that have natural resource dependent livelihoods (e.g., farmers, fishermen, and cattle ranchers). The larger population may experience more moderate psychological impacts, such as anxiety and distress due to water restrictions or food security concerns. The extent of this impact depends on the location and severity of the water shortage, and on the resources provided to support people who are negatively affected.

#### *Loss of social cohesion: 5*

A long-term water shortage could result a months-long disruption to daily life and permanent loss of livelihoods in localized areas, especially those in agriculturally dependent communities. Access to water resources may become more restricted. In addition, restrictions for water users creates “winners” and “losers,” which could exacerbate social instability, although this impact is not expected to be widespread. Since water shortages may disproportionately affect vulnerable populations (e.g., socially disadvantaged persons, people dependent on natural resource-based livelihoods, and people without insurance), this could have severe implications for social cohesion.

### NATURAL RESOURCES: 4

A long-term water shortage in B.C. could cause extensive environmental damages, such as soil erosion, wetland loss, and habitat destruction. For example, water shortages could increase tree mortality and make forests more susceptible to insect outbreaks and wildfires. Additionally, temperature-sensitive species such as salmon could experience heat-stress and difficulties migrating due to low water levels. Depending on the severity of the water shortage, recovery of the resources could take decades.

### ECONOMIC VITALITY

#### *Loss of economic productivity: 5*

A long-term water shortage could reduce the productivity and economic contributions of major sectors, including agriculture, fishing, forestry, transportation, recreation, tourism, oil and gas, and other industries. Agriculture generates over $14 billion in annual revenue. Forestry and logging account for around $9 billion in annual revenue. If B.C. experiences a long-term water shortage that affects a large portion of the province, losses in these sectors could easily exceed $1 billion in losses. Long-term disruptions and unemployment could also occur in the agriculture sector.

#### *Loss of infrastructure services: 5*

Long-term water shortages may create prolonged disruptions of infrastructure services, including electricity production and water and wastewater treatment facilities. Historically, water shortages in Canada and the Pacific Northwest have reduced hydroelectricity production capacity, caused thermo-electric plants to shut down, and increased water treatment requirements due to higher turbidity.

### COST TO PROVINCIAL GOVERNMENT: 3

A long-term water shortage would result in costs to the provincial government for emergency response and recovery funding to affected sectors, such as agriculture and forestry. Recovery payments to farmers from past water shortages reached hundreds of millions of dollars, some portion of which is provided by the provincial government. Although the costs to the province are not established, the costs are expected to be on the order of $375 million to $750 million.

## Glacier Mass Loss

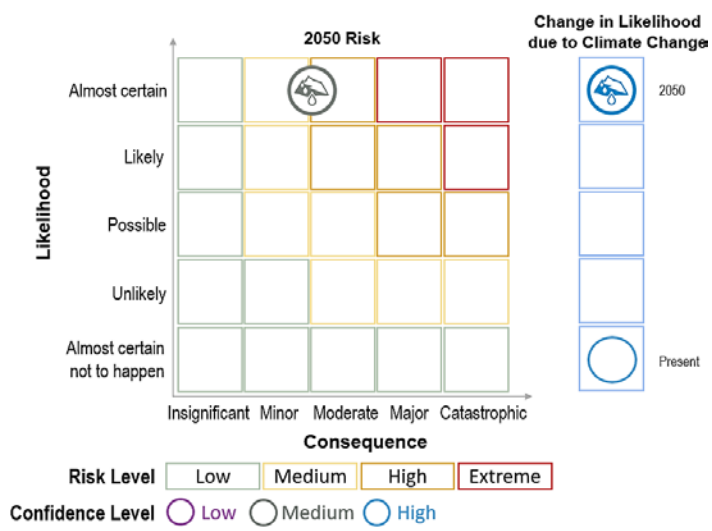
### Scenario

The specific risk event scenario analyzed is a 25% decline in glacier area within B.C. by 2050, relative to 2005. This event would be a province-wide, ongoing change driven by warming temperatures. Projected warming temperatures will cause glaciers to melt more quickly, losing a greater amount of area and volume. Similarly, higher temperatures are projected to increase the proportion of precipitation falling as rain rather than snow, which lowers the rate of glacier accumulation. Overall, this would result in the rate of glacier ablation outpacing accumulation. Other factors that contribute to glacier retreat are accumulation of snowpack, which also contributes significantly to runoff. In some cases, the distinction between how much glacier melt and snowmelt contribute to streamflow is unclear.

### Summary of Findings

B.C. has around 17,000 glaciers that cover approximately 25,000 km² or about 3% of the province. Glacier area declined by approximately 11% between 1985 and 2005. Due to projected increases in temperature, glacier area is projected to further decrease by 30 to 50% by 2050, relative to 2005.

**FIGURE 13.** Risk assessment findings for glacier mass loss scenario.




Glaciers represent a vital freshwater resource for the province, contributing to rivers that support communities, industry, hydroelectricity generation, irrigation, and ecosystems. By the 2050s, the contribution of glaciers to streams and rivers will decline and associated streamflow is projected to decrease. This change has already occurred in some basins, whereas others will experience a short-term increase in flow followed by a decline. Timing and amount of flow could affect natural ecosystems and communities. Particularly during summer months, water supply could be reduced for agriculture, power generation, and industry. This risk assessment focuses on the impact of glacier retreat by mid-century; evidence of the long-term reduction in water supply is included for reference to understand the trends of glacier decline.

**FIGURE 13** and **TABLE 10** summarize the risk assessment results for this scenario. The highest consequences relate to natural resources and cultural resources. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 10.** Risk Rating Evaluation for Glacier Mass Loss Scenario

| GLACIER MASS LOSS: 25% DECLINE IN GLACIER AREA BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| 1 | From 1985 and 2005, glacier area declined by approximately 11%, ranging from -24% to -8% across the province. | 5 | **Climate-related risk cause:** Projected temperature increases would likely increase glacier retreat in spring and summer and increase the proportion of precipitation falling as rain rather than snow.<br>**2050 projections:** By 2050, glacier area in western Canada is projected to shrink by 30 to 50% relative to 2005 and glacier volume is projected to shrink by 35 to 40%. Models show general agreement. | High |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | 2 | There is low likelihood of multiple losses of life due to glacier mass loss in B.C. | Low |
| | Morbidity, injury, disease, or hospitalization | 2 | Reductions in freshwater supply and quality due to lower flows and higher sedimentation could pose minor health risks to communities. | Medium |
| **Social functioning** | Psychological impacts | 2 | People and communities with identities or livelihoods tied to glaciers may experience moderate psychological impacts. | Low |
| | Loss of social cohesion | 3 | Changes in seasonal water supply may reduce access to freshwater supplies for agriculture and other industries, resulting in seasonal loss of livelihood or way of life for a small population. | Low |
| **Natural resources** | Loss of natural resources | 5 | Streamflow and stream temperature could be permanently affected in some regions, particularly during dry summer months, which could have severe impacts on aquatic species, particularly salmon. | High |
| **Economic vitality** | Loss of economic productivity | 2 | Losses in agriculture, outdoor recreation, and sports fishing that could surpass $1 million. | Medium |
| | Loss of infrastructure services | 2 | Reductions in seasonal water supply could disrupt transportation, hydropower dams, agricultural assets, and other infrastructure services. Prolonged disruptions to services are not anticipated. | Medium |
| **Cost to provincial government** | | 2 | Potential costs include lost revenue, reduced hydroelectric capacity, and reduced water rental fees. | Low |
| **OVERALL RISK** | **CURRENT** | **LOW (2.5)** | | **MEDIUM** |
| | **2050** | **HIGH (12.5)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **2.5** out of 25, which equates to **low risk**, and the 2050 risk rating is **12.5** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 1 x 2.5 = 2.5 (Low)

2050 Risk = 5 x 2.5 = 12.5 (High)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of this scenario is **1** and the 2050 likelihood of this scenario is **5**. Glaciers in B.C. have experienced an increasing rate of retreat over the last century. Projected temperature increases by 2050 would negatively affect glaciers in two ways. First, glacier retreat would very likely increase during spring and summer. Second, higher winter temperatures would increase the amount of precipitation falling as rain, rather than snow, which would result in glacier ablation significantly outpacing accumulation. Multiple reputable sources of evidence indicate that glacier loss will likely be greater than 25% by mid-century and as much as 70 to 95% by the end of the century. The project team considered projected change in glacier area and volume for glaciers in Western Canada as primary indicators to evaluate the likelihood of the scenario. Additional climate drivers of glacier mass loss, such as temperature and precipitation projections, are also considered. Interpretation of the likelihood rating should consider geographic variability; glacier area will decline most rapidly for glaciers at lower elevations and in southern B.C. compared to more northern and mountainous regions.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.5** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (2+2+2+3+5+2+2+2)/8

Overall Consequence = 2.5

#### HEALTH

*Loss of life: 2*

The largest threat to life due to glacier retreat is from glacier outburst floods, which can cause catastrophic damage. Globally, glacier flooding and disasters related to the destabilizing effects of glacier retreat have caused deaths and severe injuries. However, due to the location of glaciers in B.C. and the characteristics of its glacier lakes, it is unlikely that glacier mass loss will contribute to multiple losses of life. According to experts, glacier lakes in B.C. can be monitored and stabilized through engineering mechanisms to manage flood risk. In addition, there are also few population centres located in close proximity to glaciers that would be affected by these types of events.

*Morbidity, injury, disease, or hospitalization: 2*

Although the extent of these impacts has not been quantified for B.C., changes in water quality or quantity due to glacier retreat could affect human health. For example, high sediment and nutrient contributions due to glacier retreat could reduce water quality and increase the strain on water treatment facilities. Overall, the resulting negative health outcomes are expected to be minor.

## SOCIAL FUNCTIONING

*Psychological impacts: 2*
Glaciers are a key part of the landscape in some areas of the province. As glaciers melt, people and communities with identities or livelihoods tied to glaciers may experience moderate psychological impacts. People may experience fear, anxiety, and grief over observed losses in glacier mass as well as the prospect of continued glacial retreat. In addition, as glaciers continue to retreat past 2050, this could cause loss of identity/sense of place for individuals whose culture or livelihoods are heavily embedded in the land.

*Loss of social cohesion: 3*
Changes in seasonal water supply from glaciers may reduce access to freshwater supplies for agriculture and other industries. In addition, fish habitat and migration patterns in glaciated river systems may change. Therefore, due to glacier retreat, people may experience seasonal loss of livelihoods or ways of life. Due to the relatively low contribution of glacier melt to most major river systems, this is likely to affect a small portion of the population by 2050.

## NATURAL RESOURCES: 5

The consequences of glacier melt will depend greatly on geographic area but could result in permanent changes for certain areas of the province (e.g., Vancouver Island). Especially during the dry summer months or during exceptionally dry years, glaciers help maintain streamflow and temperatures conducive for fish habitat in some river systems. After peak flow has passed, which has already happened in some river systems and could happen by mid-century in others, streamflow is expected to decline in glacier-fed systems, which could have severe impacts on ecosystem and aquatic health. Since glacier retreat could be permanent and irreversible, resources that depend on glaciers may never recover to current levels.

## ECONOMIC VITALITY

*Loss of economic productivity: 2*
Glacier loss could reduce economic productivity by reducing water availability for the agriculture sector, changing landscapes upon which recreation and tourism depend, affecting extractive industry operations, and endangering fish species that support a major industry. Losses associated with these wide-ranging impacts could exceed $1 million (though the full extent of these impacts has not been quantified). These impacts will be compounded by other changes that further diminish water supply.

*Loss of infrastructure services: 2*
As glaciers retreat in B.C., short-term higher river flow and rates of retreat may contribute to increased likelihood or magnitude of a variety of flood events, including glacier outburst floods and avalanches. However, experts expect that major floods are not expected to occur in the province. Changes in seasonal water supply could lead to disruptions to transportation, hydropower dams, agricultural assets, and other infrastructure services, although the overall decrease in glacier runoff could be counteracted by increases in precipitation. These impacts are not expected to result in prolonged disruptions to services.

### COST TO PROVINCIAL GOVERNMENT: 2

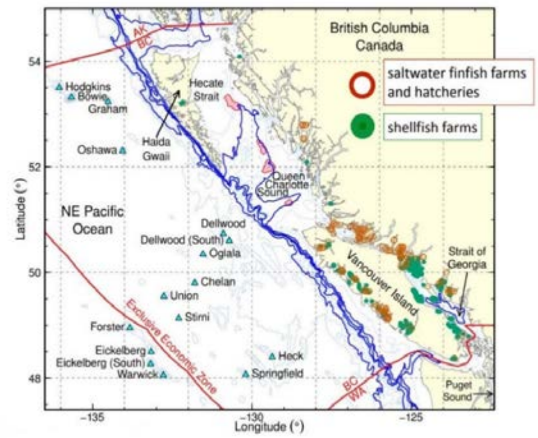
Glacier retreat could negatively affect the fisheries sector, which would cost the provincial government in terms of revenue from taxes, licences, and permits. It could also result in reduced hydroelectric capacity, requiring the province to turn to more expensive fuel alternatives. Some portion of water rental fees could also decline. Although the scale of economic impacts due to glacier retreat are not fully quantified, the cost to the provincial government is expected to be on the order of $375 million or less.

## Ocean Acidification

### Scenario

The specific scenario analyzed is ocean acidification, characterized by a 0.15 pH reduction along the B.C. coast by 2050 from present-day (1990 to 2010) levels. Acidification is caused by increased atmospheric carbon dioxide emissions. Ocean currents and upwelling also facilitate more acidic waters along the Pacific coast.

**FIGURE 14.** Map of shellfish farms along the B.C. coast (Haigh, Ianson, Holt, Neate, & Edwards, 2015).




### Summary of Findings

B.C.'s aquaculture industry represents more than half of total aquaculture production in Canada (Stocks, 2016). See **FIGURE 14** for a map of B.C. shellfish farms (shown in green).

However, ocean pH levels are at their lowest in 20 million years, threatening B.C.'s shellfish industry and other marine life (Canadian Climate Forum, 2017; Fisheries and Oceans Canada, 2012). For example, ocean acidification prevents or decreases the calcification of shells and skeletons, disrupting shellfish growth and development (Okey, Alidina, Lo, & Jessen, 2014; Haigh, Ianson, Holt, Neate, & Edwards, 2015; Washington State Blue Ribbon Panel on Ocean Acidification, 2012). A 0.15 reduction in pH would cause decreased calcification and population decline for a majority of marine shellfish, including oysters, clams, scallops, mussels, pteropods and snails (Parker et al., 2013).

**FIGURE 15.** Risk assessment findings for ocean acidification scenario.

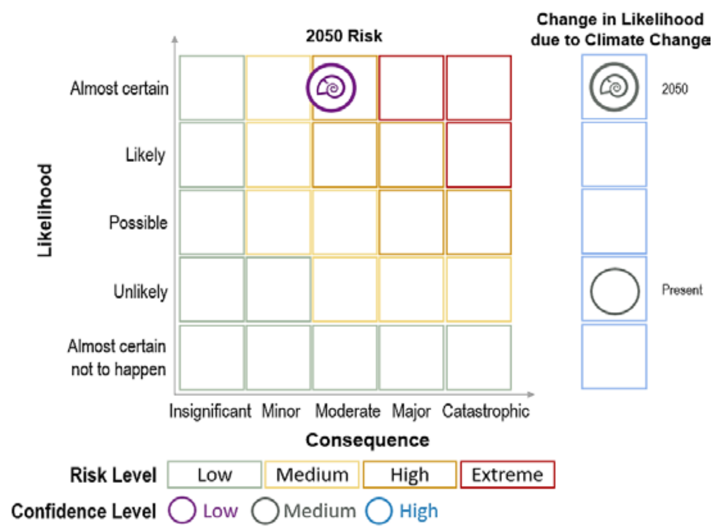



**FIGURE 15** and **TABLE 11** summarize the risk assessment results for this scenario. The highest consequence relates to natural resources and cultural resources. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 11.** Risk Rating Evaluation for Ocean Acidification Scenario

| OCEAN ACIDIFICATION: 0.15 REDUCTION IN PH BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| 2 | Current global surface ocean pH of 8.1 falls below the critical threshold of 7.95 but, given the variability of B.C.'s naturally low pH, there is some potential to temporarily cross the threshold. | 5 | **Climate-related risk cause:** Increased carbon dioxide emissions causes ocean acidification. **2050 projections:** A decrease in pH of 0.15 units, which meets or surpasses the critical threshold of some bivalve and gastropod species. | Medium |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | 1 | There is no evidence that ocean acidification causes loss of life. | Low |
| | Morbidity, injury, disease, or hospitalization | 1 | There is no evidence that ocean acidification causes morbidity, injury, disease, or hospitalization. | Low |
| **Social functioning** | Psychological impacts | 4 | For individuals directly connected to the ocean, ocean acidification could cause severe, long-term impacts (e.g., depression, loss of identity). | Low |
| | Loss of social cohesion | 4 | Ocean acidification could cause permanent loss of livelihoods or way of life for coastal communities and could affect food supplies, employment opportunities, and community culture and identity. | Low |
| **Natural resources** | Loss of natural resources | 5 | Shellfish and other marine life could experience decreased calcification and altered behavioural and chemical responses. These species will be weakened permanently and likely unable to recover. | Medium |
| **Economic vitality** | Loss of economic productivity | 4 | Economic impacts may include higher mortality of shellfish, decreased growth and productivity, and job losses. | Medium |
| | Loss of infrastructure services | 1 | There is no evidence that ocean acidification causes loss of infrastructure services. | Medium |
| **Cost to provincial government** | | 2 | Costs to government might include lost revenue and taxes as well as resources or programs to help the shellfish industry cope with acidification. | Low |
| **OVERALL RISK** | **CURRENT** | **LOW (5.5)** | | **LOW** |
| | **2050** | **HIGH (13.8)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **5.5** out of 25, which equates to **low risk**, and the 2050 risk rating is **13.8** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 2 x 2.8 = 5.5 (Low)

2050 Risk = 5 x 2.8 = 13.8 (High)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of a 0.15 reduction in pH levels along the B.C. coast is **2** and the 2050 likelihood of this reduction is **5**. The critical threshold (pH decrease of 0.15) is relative to present-day (1990 to 2010) global average pH levels of 8.1 (i.e., to pH levels of 7.95). In addition, the B.C. coast typically exhibits lower pH levels relative to the global mean, suggesting local ocean acidification may exceed the global average.

Given the natural variability and fluctuation of ocean pH along the B.C. coast, the project team assessed the current likelihood of crossing the 0.15 threshold as unlikely, but there is some potential to briefly cross the threshold during a period of particularly acidic conditions.

The project team used global surface ocean pH projections from IPCC AR5 (2014) as the primary indicator to evaluate this scenario. Additional indicators include a consideration of background B.C. ocean pH levels relative to the global average. The project team complemented IPCC projections with results from other studies investigating ocean pH reduction magnitudes in coastal subregions and for specific marine species. Ultimately, a preponderance of evidence and projections indicate that ocean pH will likely pass the critical threshold by 2050.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.8** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (1+1+4+4+5+4+1+2)/8

Overall Consequence = 2.8

**HEALTH**

*Loss of life: 1*

There is no evidence that suggests ocean acidification causes direct loss of life. There is speculation, however, that ocean acidification may contribute to shellfish toxins, which could threaten health.

*Morbidity, injury, disease, or hospitalization: 1*

There is no evidence that ocean acidification causes morbidity, injury, disease, or hospitalization. There is speculation, however, that ocean acidification may contribute to shellfish toxins, which could potentially threaten health.

## SOCIAL FUNCTIONING

*Psychological impacts: 4*

Given that the ocean is a large part of B.C.'s identity, culture, and economy, ocean acidification could cause localized, severe, and long-term psychological impacts (e.g., depression, loss of identity), particularly for individuals whose lives are directly connected to the ocean. For the broader B.C. population, psychological impacts may be moderate or insignificant.

*Loss of social cohesion: 4*

Ocean acidification could cause localized, permanent loss of livelihoods or way of life for coastal communities and those reliant on the shellfish industry for food or employment. Ocean acidification could decrease food supplies, decrease employment opportunities, cause economic losses, and affect community culture and identity.

## NATURAL RESOURCES: 5

Shellfish and other marine life are particularly vulnerable to ocean acidification and are already showing signs of distress. By 2050, shellfish and other marine life could experience significant impacts, such as decreased classification for scallop, oyster, clam, limpet, periwinkle, and whelk. In addition, acidification can alter critical behaviours and chemical reactions in the bodies of fish that may affect their ability to survive. While these species may not be lost entirely, they will be weakened permanently and likely unable to recover if ocean acidification persists.

## ECONOMIC VITALITY

*Loss of economic productivity: 4*

The fish and shellfish industry is a critical component of B.C.'s economy. Based on the value of the industry and potential severity and extent of acidification impacts, the project team concluded that direct and indirect economic losses could total more than $100 million (the threshold for a score of 4). Impacts may include higher mortality of shellfish, decreased growth and productivity, and job losses. However, through certain management practices, farmers may be able to reduce shellfish exposure to more acidic ocean water, which could help lessen, but not prevent economic losses.

*Loss of infrastructure services: 1*

Ocean acidification is not expected to cause loss of infrastructure services. There is speculation that ocean acidification could affect the lifespan of critical infrastructure due to corrosion, but there is little evidence and the effect is likely to be small compared with that of other impacts to nearshore infrastructure. By the time gradual changes associated with ocean acidification manifest, the asset is likely to already be at the end of its useful life (Cooley, 2019; Workshop feedback, 2019).

## COST TO PROVINCIAL GOVERNMENT: 2

Costs of ocean acidification are expected to primarily affect the shellfish industry by 2050. Disruptions to the food web could also have cost implications for commercial fishing. However, costs to government could include lost revenue and taxes as well as resources or programs to help the shellfish industry cope with acidification. These costs are expected to be on the order of $375 million or less.

## Saltwater Intrusion

### Scenario

The specific scenario analyzed is at least seasonal saltwater intrusion into the Fraser River delta and surrounding communities, including Richmond, Delta, and Surrey, B.C., caused by 0.5 m of sea level rise by 2050 from present day (2000) levels. Saltwater intrusion is most likely to affect irrigation water availability from August to October.[6] The position of the salt wedge in the Fraser River is driven by sea level rise, tides, river flow, and water use.

### Summary of Findings

Over the course of the 21st century, sea level rise is expected to eventually lead to coastal inundation of low-lying areas. By 2050, the freshwater/saltwater interface is expected to extend farther up the Fraser River, which may also cause saltwater intrusion of groundwater and freshwater aquifers[7] in low-lying areas of the Fraser River delta region (Government of British Columbia, 2016). The research collected for this risk event deals primarily with encroachment of the freshwater/saltwater interface due to sea level rise. Saltwater intrusion is expected to have the most significant impacts on agriculture and freshwater supplies. Agriculture is a significant component of the delta's economy, accounting for $170 million in total gross farm receipts[8] for 2010 (BC Agriculture & Food Climate Action Initiative, 2013).

**FIGURE 16.** Risk assessment findings for saltwater intrusion scenario.

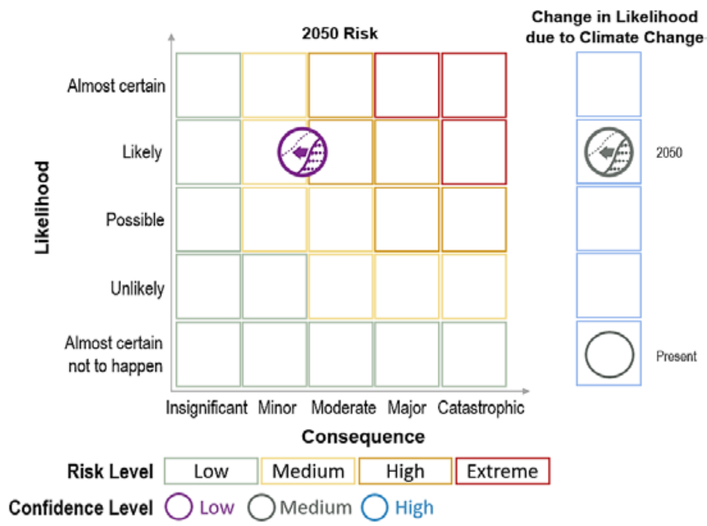



**FIGURE 16** and **TABLE 12** summarize the risk assessment results for this scenario. The highest consequence relates to loss of economic productivity. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

[6] August to October is the critical period for irrigation when Fraser flow has declined from Freshet conditions.

[7] Aquifer salinization can occur from above due to inundation or storm surge, laterally due to encroachment of the freshwater/saltwater interface, or from below due to pumping (Klassen & Allen, 2016; Werner, et al., 2013).

[8] Gross farm receipt refers to the gross farm receipts of the agricultural operation in the year prior to Census or the last complete accounting (fiscal) year. This includes receipts from all agricultural products sold, program payments and custom work receipts. It does not include sales of forestry products (firewood, pulpwood, logs, fence posts, pilings, etc.), of capital items (quota, land, machinery, etc.), or receipts from the sale of any goods purchased only for retail sales. It is gross receipts before deducting expenses (Statistics Canada, 2018).

**TABLE 12.** Risk Rating Evaluation for Saltwater Intrusion Scenario

| SALTWATER INTRUSION: AT LEAST SEASONAL SALTWATER INTRUSION INTO THE FRASER RIVER DELTA AND SURROUNDING COMMUNITIES BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| 1 | This scenario does not occur today. | 4 | **Climate-related risk cause:** Sea level rise will drive the salt wedge farther upstream in the Fraser River.<br>**2050 projections:** Sea level rise is projected to increase between 0.5 to 0.6 m by 2050. | Medium |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | 1 | There is no evidence that seasonal saltwater intrusion causes loss of life. | High |
| | Morbidity, injury, disease, or hospitalization | 1 | There is no evidence of other health risks as long as freshwater is accessible from alternative sources. | Low |
| **Social functioning** | Psychological impacts | 2 | Impacts to agriculture operations and irrigation could cause moderate and temporary psychological impacts, such as stress or anxiety, for farmers. | Low |
| | Loss of social cohesion | 3 | Agricultural communities may experience seasonal losses of livelihoods and potentially a loss of trust in the government or water utility. | Low |
| **Natural resources** | Loss of natural resources | 3 | Short-term impacts include a decline in plant health and soil fertility. Longer-term impacts include a gradual, but permanent change in ecosystem composition and health near the saltwater/freshwater interface. | Low |
| **Economic vitality** | Loss of economic productivity | 5 | Economic impacts include decreases in agricultural productivity, increased soil salinity, a potential change in the type of crops grown in the region, and a reduction in ecosystem services. | Medium |
| | Loss of infrastructure services | 3 | There may be a permanent loss of existing freshwater wells and aquifers. The high mineral content of saltwater could corrode pipelines and pumps used to extract freshwater. | Low |
| **Cost to provincial government** | | 2 | Costs might include management of sensitive ecosystems and protected areas or even supplying emergency water supplies to affected communities. | Low |
| **OVERALL RISK** | **CURRENT** | **LOW (2.5)** | | **LOW** |
| | **2050** | **MEDIUM (10.0)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **2.5** out of 25, which equates to **low risk**, and the 2050 risk rating is **10.0** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 1 x 2.5 = 2.5 (Low)

2050 Risk = 4 x 2.5 = 10.0 (Medium)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of seasonal saltwater intrusions in the Fraser River delta is **1** and the 2050 likelihood of this scenario is **4**. The key indicator is a critical threshold of 0.5 m of sea level rise.

The frequency of saltwater intrusion is dependent on a range of underlying processes acting on a range of timescales. Sea level rise and lower river flows increase the likelihood and frequency of coastal saltwater intrusions, while heavy precipitation can abate intrusions by increasing runoff into the ocean. To evaluate the scenario likelihood, the project team focused on several indicators, including local sea level rise and precipitation projections and observations saltwater wedge extents in the Fraser River.

Sea level rise is expected to meet or exceed 0.5 m by 2050 at multiple sites within the Fraser River delta. In addition, water availability for irrigation is expected to significantly decrease under just 0.3 m of sea level rise.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.5** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (1+1+2+3+3+5+3+2)/8

Overall Consequence = 2.5

#### HEALTH

*Loss of life: 1*
Seasonal saltwater intrusion would not cause loss of life, assuming freshwater is accessible from other sources during the duration of the intrusion event.

*Morbidity, injury, disease, or hospitalization: 1*
As long as freshwater is available from other sources, saltwater intrusion is not expected to cause cases of morbidity, injury, disease, or hospitalization other than through unforeseeable misadventure.

#### SOCIAL FUNCTIONING

*Psychological impacts: 2*
Farmers may experience moderate and temporary psychological impacts due to seasonal saltwater intrusion. Impacts to irrigation and operations in particular could cause stress or anxiety.

*Loss of social cohesion: 3*

Agricultural communities within the Fraser River delta will be affected by seasonal loss of livelihood due to saltwater intrusion. In addition, impacts to freshwater supplies could result in some erosion of public trust in the government or the water utility.

### NATURAL RESOURCES: 3

Short-term impacts of saltwater intrusion include a decline in plant health and soil fertility, especially for sensitive and salt-intolerant species or ecosystems. Recovery for these species and ecosystems could take years. Longer-term changes in water and soil salinity could lead to a gradual, but permanent change in ecosystem composition and health near the saltwater/freshwater interface as species redistribute based on salt tolerance. Despite these changes, it is unlikely that natural resources would be lost permanently.

### ECONOMIC VITALITY

*Loss of economic productivity: 5*

Significant losses in water availability for irrigation as well as increased soil salinity could lead to long-term decreases in agricultural productivity. Higher salinity may also cause a shift in the types of crops grown in the region. In addition, saltwater intrusion may affect ecosystem services. When coastal or riverine ecosystems are damaged by direct human use, natural disasters, or climate change, the services provided are often degraded or cease altogether. These services must then be replaced by costly man-made facilities or processes that provide the same services (e.g., the construction of a water treatment plant or shipments of topsoil if forests and vegetation are lost).

*Loss of infrastructure services: 3*

As sea level rise and saltwater intrusion become increasingly chronic, there may be a permanent loss of existing freshwater wells and aquifers. In addition, the high mineral content of saltwater could corrode pipelines and pumps used to extract freshwater. Existing wells may need to be relocated higher up the river to collect adequate freshwater for irrigation.

### COST TO PROVINCIAL GOVERNMENT: 2

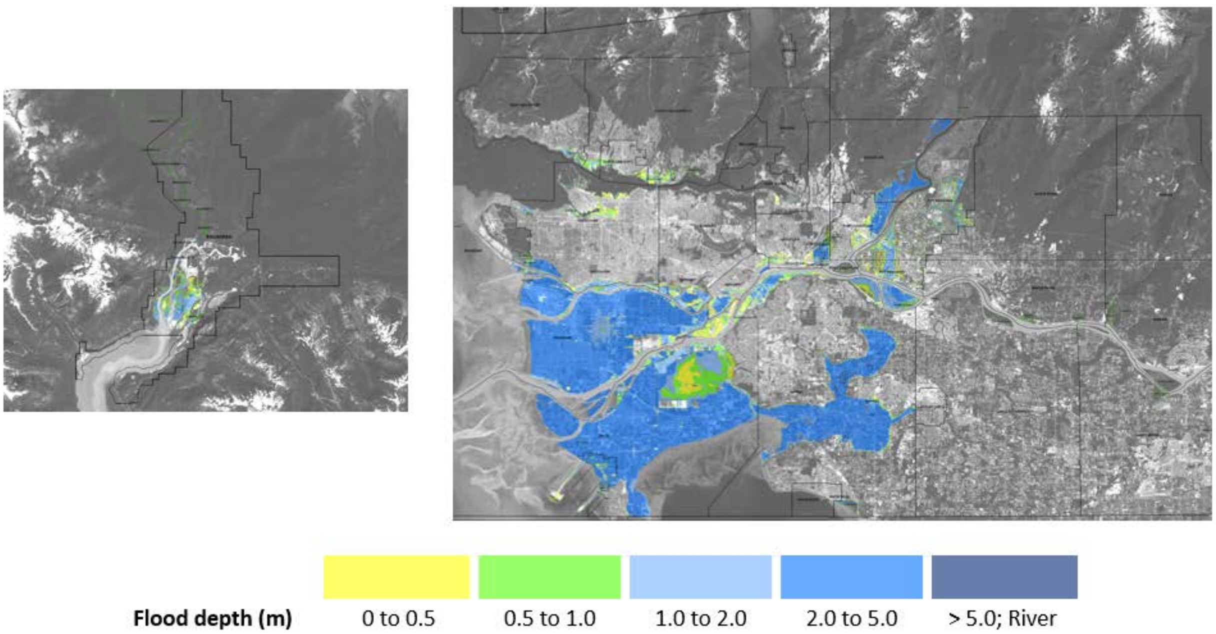
The costs of saltwater intrusion are expected to fall primarily on individual water users or water suppliers. Costs to the provincial government could include management of sensitive ecosystems and protected areas or in extreme cases supplying emergency water supplies to affected communities. Although the costs to the provincial government are not well understood, costs are expected to be on the order of $375 million or less.

## Severe Coastal Storm Surge

### Scenario

The specific scenario analyzed is a storm surge of at least 3.9 m (caused by today's "500-year" winter storm with 3.4 m of surge plus 0.5 m of sea level rise), arriving during a king tide[9] along the B.C. coast. In this scenario, flood depths[10] could reach up to 5 m in some locations (see **FIGURE 17**) and last for two days.

**FIGURE 17.** Severe storm surge scenario: flood depths under present-day 500-year coastal storm and 1 m sea level rise (equivalent to 0.5 m sea level rise coinciding with king tide).



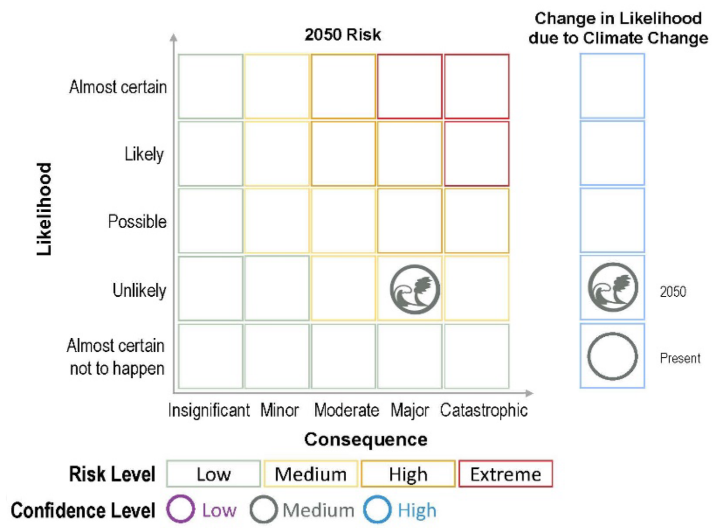

[9] King tide is defined as an infrequent, but predictable high tide event without exacerbation from an accompanying storm. King tides occur on average two to three times a year typically during the winter months.
[10] Based on coastal flood mapping from Squamish to White Rock completed for the Lower Mainland Flood Management Strategy for a 500-year coastal event and 1 m sea level rise (Northwest Hydraulic Consultants, 2016). The Lower Mainland Flood Management Strategy of a 500-year coastal event and 1 m of sea level rise is the best available data source. Because sea level rise projections for 2050 are 0.5 m, the project team decided to modify the 500-year and 1 m sea level rise scenario for the purposes of this risk assessment, where the 1 m represents a combination of 2050 sea level rise (0.5 m) and the king tide. As a result, inundation is likely to be less than projected, however this mapping does not take into account wave run up, wind setup or land subsidence.

## Summary of Findings

B.C. has more than 27,200 km of coastline and already experiences some coastal flooding when storms arrive during king tide events (Government of Canada, 2016; Northwest Hydraulic Consultants, 2016).

A present-day 500-year winter storm arriving at king tide, combined with 0.5 m of sea level rise, would result in significant flooding along the B.C. coast. In addition, this event threatens the integrity of existing flood management infrastructure (e.g., dikes). A 2016 flood vulnerability assessment for the lower mainland revealed that a major coastal flood event would become the costliest natural disaster to date in Canadian history (Northwest Hydraulic Consultants, 2016).

**FIGURE 18.** Risk assessment findings for severe storm surge.




Approximately four out of five B.C. residents live in coastal areas, increasing the risk of significant impacts to critical infrastructure and daily life (Government of Canada, 2016).

**FIGURE 18** and **TABLE 13** summarize the risk assessment results for this scenario. The highest consequences relate to social functioning, cultural resources, and economic vitality. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 13.** Risk Rating Evaluation for Severe Storm Surge Scenario

| SEVERE COASTAL STORM SURGE: 3.9 M STORM SURGE DURING A KING TIDE ALONG THE B.C. COAST | | | | | |
|---|---|---|---|---|---|
| **LIKELIHOOD** | | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | | **CONFIDENCE** |
| **1** | The 500-year coastal storm surge event has a 0.2% chance of occurring in any year. | **2** | **Climate-related risk cause:** Sea level rise due to increasing temperatures and glacial melt as well as king tides and El Niño cycles.<br>**2050 projections:** Although there is uncertainty regarding how climate change may affect coastal storms over time, sea level is projected to rise by up to 0.5 m by 2050 in B.C., which will increase the depth and frequency of significant coastal flood events. | | Medium |
| **CONSEQUENCE** | | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | | **CONFIDENCE** |
| **Health** | Loss of life | **4** | Ten to 100 deaths could occur from fast-moving floodwaters or limited medical/emergency care. | | Medium |
| | Morbidity, injury, disease, or hospitalization | **4** | More than 100 people are at risk of harm due to fast-moving floodwaters, debris, disease, limited access to critical infrastructure and services, or environmental contamination. | | Low |
| **Social functioning** | Psychological impacts | **5** | Severe psychological impacts are expected for individuals who experience damage to or loss of property or livelihood, evacuation, or loss of family member. Moderate impacts could be widespread. | | Medium |
| | Loss of social cohesion | **5** | Direct recovery and clean up from flood damage could take months. Damages could also cause localized impacts to livelihoods. | | Medium |
| **Natural resources** | Loss of natural resources | **2** | Natural resources could experience erosion, temporary saltwater intrusion, or contamination due to flooding; recovery could take months. | | Low |
| **Economic vitality** | Loss of economic productivity | **5** | Total economic losses are estimated at $24.7 billion, including agriculture, transportation, and energy. | | Medium |
| | Loss of infrastructure services | **5** | Infrastructure and institutional losses are estimated at $1.8 billion. Disruptions to critical infrastructure services could last for months. | | Medium |
| **Cost to provincial government** | | **3** | Costs to government might include flood response, post-event cleanup, health services, ecosystem recovery, Disaster Financial Assistance, and AgriRecovery, among others. | | Medium |
| **OVERALL RISK** | **CURRENT** | **LOW (4.1)** | | | **MEDIUM** |
| | **2050** | **MEDIUM (8.3)** | | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **4.1** out of 25, which equates to **low risk**, and the 2050 risk rating is **8.3** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 1 x 4.1 = 4.1 (Low)

2050 Risk = 2 x 4.1 = 8.3 (Medium)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of this scenario is **1** and the 2050 likelihood of this scenario is **2**. A present-day 500-year coastal flood with a 3.4 m storm surge, by definition, has a 0.2% annual chance of occurring. By 2050, sea level rise, king tides, and El Niño cycles are assumed to influence the likelihood of this scenario, and the project team evaluates these as indicators for the scenario. Unlike riverine flood events, there is larger uncertainty regarding whether coastal storm events will increase in frequency or intensity over time. However, climate change will increase the likelihood of significant local sea level rise by 2050 and, in turn, the depth and frequency of large flooding events when contemporaneous with large storms and/or king tides. Therefore, the project team judges that the 2050 scenario has a higher likelihood than the present-day scenario.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **4.1** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (4+4+5+5+2+5+5+3)/8

Overall Consequence = 4.1

**HEALTH**

*Loss of life: 4*

Due to the magnitude and location of the event, 10 to 100 people could lose their lives from either direct or indirect causes. Direct loss of life could occur if people are caught in fast-moving floodwaters. In addition, limited medical or emergency care or loss of vital services such as power or clean water during and following the event could cause indirect loss of life. If warnings or evacuation orders are not issued in a timely manner, loss of life could even exceed 100 people.

*Morbidity, injury, disease, or hospitalization: 4*

Coastal storm surge and flooding can cause health hazards beyond fatalities, such as injury, disease, or hospitalization from fast-moving floodwaters or debris, limited access to critical infrastructure and services, or environmental contamination. For example, storm surge can damage water supply systems, create conditions for water-borne diseases, or impair hospital or emergency response capacity. More than 100 people could experience ill health effects due to this scenario. If warnings or evacuation orders are not issued in a timely manner, this number could exceed 1,000 people.

### SOCIAL FUNCTIONING

*Psychological impacts: 5*

Severe coastal storm surge could cause widespread and severe psychological impacts such as PTSD or depression for coastal populations as well as some interior populations that are directly affected by the event (e.g., people experiencing damage to or loss or property, mandatory or voluntary evacuation, loss of family members or friends). More moderate psychological impacts such as stress and anxiety are also possible for those who do not experience the storm directly, but are affected by limited transportation or utility services.

*Loss of social cohesion: 5*

For those directly affected by storm surge (e.g., flooded home, flooded workplace or route to work), disruptions to daily life could last for months. Damages could also cause localized impacts to livelihoods (e.g., aquaculture and agriculture). There are also likely to be lingering after-effects to infrastructure services and institutions that could last for months after a coastal storm surge event. Given the potential for widespread disruptions to many critical institutions and services (e.g., wastewater treatment), even individuals who do not experience direct damage could experience at least a weeks-long disruption to daily life in terms of available services.

### NATURAL RESOURCES: 2

Given that coastal environments are generally resilient to coastal storm events, natural resources could recover within months of the event. Ecosystems in the affected area could experience erosion, temporary saltwater intrusion, or contamination due to flooding of agricultural, industrial, transportation, and hazardous waste sites.

### ECONOMIC VITALITY

*Loss of economic productivity: 5*

Total economic losses could be an estimated $24.7 billion. Damages to multiple industries, including agriculture, transportation, and energy are estimated above the catastrophic threshold of $1 billion each. In addition, coastal storm surge may affect ecosystem services. When coastal ecosystems are damaged by direct human use, natural disasters, or climate change, the services provided are often degraded or cease altogether. These services must then be replaced by costly artificial facilities or processes that provide the same services (e.g., the construction of a water treatment plant or shipments of topsoil if forests and vegetation are lost).

*Loss of infrastructure services: 5*

Disruptions to critical infrastructure services (e.g., transportation, communications, energy, and wastewater treatment) could last for months depending on the extent and depth of flood damage. Estimated losses to infrastructure and institutional from this event are $1.8 billion. Impacts could include inundation of key transportation infrastructure, loss of electrical services, and dike failure, among others.

### COST TO PROVINCIAL GOVERNMENT: 3

A 500-year coastal storm surge event is estimated to be the costliest natural disaster in Canadian history to date, indicating a significant cost to the provincial government. However, assuming that this event would trigger significant financial assistance from the Government of Canada through DFAA, the cost to the provincial government is expected to be on the order of $375 million to $750 million. The provincial government could bear costs including flood response, post-event cleanup, health services, ecosystem recovery, Disaster Financial Assistance, and AgriRecovery and other business risk management programs, among others.

## Heat Wave

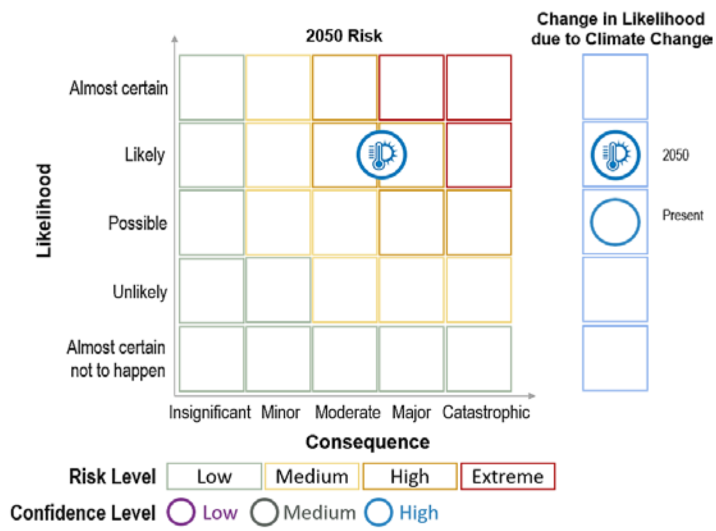
### Scenario

The specific risk event scenario analyzed is a heat wave of at least three days in several regions across the province, resulting in significant consequences to human health. Other factors such as humidity/wet bulb temperature, Heat Index measurements, nighttime temperatures, and regional variations in relative extreme temperatures will play a role in the magnitude of a heat wave event.

### Summary of Findings

Heat waves are extended periods of time with relatively high temperatures for a given location. A provincially significant heat wave would be one that would have severe negative outcomes for human health. For example, in 2009, B.C. experienced a heat wave that brought temperatures above 31°C in coastal areas and above 36°C inland. This event contributed to approximately 200 additional deaths and a total cost estimated at around $120 million (Henderson & Kosatsky, 2012; Stewart et al., 2017).

**FIGURE 19.** Risk assessment findings for heat wave scenario.




Heat waves are defined in many different ways, often as a relative extreme temperature compared to average temperatures. In this assessment, the likelihood of 3+ days above 32°C was chosen. As heat waves become more frequent and severe, the effects could be more significant, leading to a range of negative impacts. The largest risk is to human health. People tend to become adapted to gradually rising temperatures, but extreme heat events can manifest in dire health consequences. In addition, a heat wave could result in stress to infrastructure and transportation systems, economic productivity, and ecosystems.

**FIGURE 19** and **TABLE 14** summarize the risk assessment results for this scenario. The highest consequences relate to loss of life; morbidity, injury, disease, or hospitalization; and psychological impacts. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 14.** Risk Rating Evaluation for Heat Wave Scenario

| HEAT WAVE: HEAT WAVE OF AT LEAST THREE DAYS THAT AFFECTS HUMAN HEALTH | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **3** | Event is expected to happen about once every 11 to 50 years. | **4** | **Climate-related risk cause:** Increase in average and extreme temperatures.<br>**2050 projections:** Extreme heat days (particularly days above 32°C) are projected to become more common. An extreme heat wave could be expected to happen about once every 3 to 10 years. | High |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **5** | Over 100 excess mortalities could occur in B.C. | High |
| | Morbidity, injury, disease, or hospitalization | **5** | Over 1,000 people could experience negative health impacts, ranging from dehydration to heat stroke and respiratory illnesses. Urban populations are particularly vulnerable because of the heat island effect. | High |
| **Social functioning** | Psychological impacts | **5** | Extreme heat events can trigger and exacerbate mental, behavioural, and cognitive disorders, causing widespread and severe psychological impacts. Widespread moderate impacts may also occur. | High |
| | Loss of social cohesion | **3** | A heat wave could exacerbate marginalization of vulnerable populations and increase the possibility of violent crime. Disruptions to daily life could last the duration of the heat wave. | High |
| **Natural resources** | Loss of natural resources | **2** | Heat stress could result in minor damages to wildlife, forests, and fish. Recovery could occur in months. | Medium |
| **Economic vitality** | Loss of economic productivity | **4** | Economic losses in agriculture (crops and livestock), damage to fish populations, reduced labour productivity, and increased costs of electricity could exceed $100 million. | High |
| | Loss of infrastructure services | **3** | Disruptions to energy systems and transportation infrastructure could last multiple days, impeding day-to-day activities. | Medium |
| **Cost to provincial government** | | **2** | Potential costs include emergency management and response, short-term reductions in tax revenue, and losses in productivity for city workers. | Low |
| **OVERALL RISK** | **CURRENT** | **MEDIUM (10.9)** | | **HIGH** |
| | **2050** | **HIGH (14.5)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **10.9** out of 25, which equates to **medium risk**, and the 2050 risk rating is **14.5** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 3 x 3.6 = 10.9 (Medium)

2050 Risk = 4 x 3.6 = 14.5 (High)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of three consecutive days with 32°C heat is **3** and the 2050 likelihood of this scenario is **4**. Although there is no standard definition of a heat wave affecting human health, as described above, the project team selected a primary climate change indicator to evaluate the change in likelihood of this scenario: days above 32°C. This threshold was chosen as particularly significant for health risks in British Columbia (Phillips D., 2013; Hansen et al., 2008; HealthLink BC, 2018).

In order to evaluate this scenario, the project team calculated the number and change in days per year above this threshold for mid-century (2040 to 2059) relative to the baseline time period (1980 to 1999) using bias-corrected, downscaled output from the CanESM2 Global Climate Model (GCM) and assuming RCP8.5 for the entire province. Cooler regions of British Columbia could experience heat wave conditions at temperatures lower than 32°C. For example, while the historical 95$^{th}$ percentile maximum temperature in the Central Plateau region is approximately 32°C, historical maximum temperatures in coastal B.C. and Rocky Mountains can be as low as 27°C (Henderson et al., 2013). As a result, the likelihood and consequence ratings should be viewed through this lens of regional variability. However, it is clear that B.C. will experience broad increases in maximum temperatures through mid-century, independent of location. In this scenario, projected increases in the magnitude of heat across the province are assumed to indicate the increasing likelihood of heat waves by mid-century. The project team used additional historical datasets and projections, often with varying baseline time periods, to support this evaluation.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **3.6** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (5+5+5+3+2+4+3+2)/8

Overall Consequence = 3.6

**HEALTH**

*Loss of life: 5*

In Canada, extreme heat events are the leading weather-related cause of death. During past extreme heat events in B.C., over 100 excess mortalities occurred. Since the frequency and severity of heat waves in B.C. will likely be higher than historical events, more than 100 mortalities could occur again in British Columbia.

*Morbidity, injury, disease, or hospitalization: 5*

Heat waves can contribute to a range of medical conditions beyond fatalities when people are unable to maintain acceptable body temperatures. Impacts range from heavy sweating and dehydration to heat stroke and chronic cardiac disease. Particularly acute negative health outcomes could occur for vulnerable populations, including the elderly, infants, socioeconomically disadvantaged, pregnant women, people experiencing homelessness, and those with preexisting conditions. Given that heat waves could occur over large areas (including in urban areas), it is likely that over 1,000 people could be affected by some type of heat-related illness, although the severity of impact will vary.

### SOCIAL FUNCTIONING

*Psychological impacts: 5*

Extreme heat waves can trigger or exacerbate mental, behavioural, and cognitive disorders ranging from negative feelings of exhaustion or stress to suicide. Psychological impacts would likely be more severe for those with underlying mental health issues or for those experiencing other life stressors (e.g., low socioeconomic status, minority ethnic status, age). Thus, a heat wave is expected to cause widespread and severe psychological impacts. Many people could also experience indirect effects due to loss of livelihood, electricity service disruptions, or distress due to concern for family members experiencing negative health outcomes due to extreme heat.

*Loss of social cohesion: 3*

A three or more days-long heat wave could cause many disruptions to daily life (e.g., limited outdoor exposure, school cancellations, traveling to a cooling centre, checking in on neighbours). On the more extreme end, heat waves can exacerbate marginalization for racial and ethnic minorities, those who are socially isolated, homeless persons, etc. In addition, many studies indicate that the rate of violent crime increases during heat events. These incidents have the potential to erode public trust and disrupt community cohesion for the duration of the event.

### NATURAL RESOURCES: 2

A heat wave could stress wildlife and ecosystems that are not accustomed to extreme temperatures. In general, long periods of above average temperature could result in damages to ecological systems, such as heat-stress to aquatic ecosystems and susceptibility of forests to wildfire and insect outbreaks. However, a three-day event would likely result in minor damages and resources could recover quickly. Extreme temperatures occurring simultaneously with water shortages or contributing to wildfire could result in much greater compounding damages.

### ECONOMIC VITALITY

*Loss of economic productivity: 4*

During a heat wave, major losses occur due to reduced agricultural productivity, heat stress to livestock, damage to fish populations, reduced labour productivity, and increased cost of electricity. For example, the 2009 heat wave contributed to costs exceeding $120 million. By the 2050s, the potential direct and indirect economic losses of a heat wave in B.C. could contribute to economic losses of well over $100 million.

*Loss of infrastructure services: 3*

Due to a severe heat wave, infrastructure services such as electricity and transportation could be disrupted for multiple days, impeding day-to-day activities. For example, extreme heat reduces the capacity of power plants to produce energy, reduces transmission efficiency, and increases demand for electricity, all of which can increase the likelihood of power outages. Loss of infrastructure services during a heat wave could have significant implications for human health and the economy that could last several days.

### COST TO PROVINCIAL GOVERNMENT: 2

The Government of British Columbia would incur additional costs for emergency management and response, healthcare, and short-term reductions in tax revenue due to a heat wave. The productivity of city maintenance and operations could decrease, and the government may need to shift schedules or provide more frequent breaks to workers. There could also be costs related to public education to reduce the public health risk associated with extreme heat. Although the cost has not been quantified in B.C., added costs are expected to be on the order of $375 million or less.

## Severe Wildfire Season

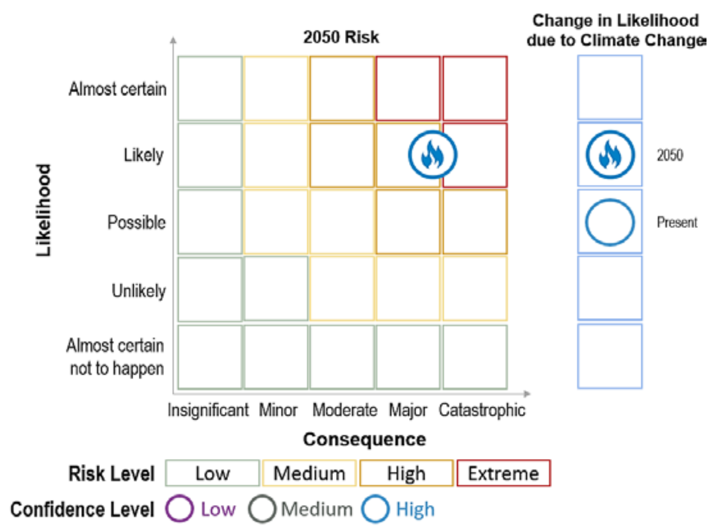
### Scenario

The specific risk event scenario analyzed is a severe wildfire season that burns at least one million hectares and affects human settlements and significant infrastructure (e.g., occurs in the Wildland Urban Interface or Industry/Critical Infrastructure Interface). In B.C., humans and lightning cause the majority of wildfire starts. However, climate factors such as higher temperatures and drought contribute to conducive conditions for large and prolonged fire seasons. Other key contributors to severe wildfire include the amount of fuel, fuel load, fuel distribution, and fuel moisture.

### Summary of Findings

The 2017 and the 2018 wildfire seasons set new records for area burned in B.C., becoming the first fires to burn over one million hectares since 1950. These events produced significant consequences across the province. With projected increases in temperature and decreases in summer precipitation, in addition to an abundance of dry fuel, conditions in some areas could be more conducive for severe wildfires in the future. Annual area burned is projected to increase by up to 4% by 2050, exceeding 9 million hectares across Canada. As this trend continues through the end of the century, B.C. could experience extreme wildfires more frequently.

**FIGURE 20.** Risk assessment findings for severe wildfire season scenario.




The consequences of wildfires for the provincial government are greater when they occur in the Wildland Urban Interface (WUI) because human settlements are more likely to be affected. Severe wildfires could contribute to negative health outcomes for residents across the province, due to direct exposure to smoke, particulate matter, and other hazardous substances (e.g., polycyclic aromatic hydrocarbons, volatile organic compounds). The results can be particularly dangerous for pregnant women, infants, and those with pre-existing health conditions. Displacement due to wildfires, along with loss of possessions and livelihoods, could contribute to extreme psychological distress and long-term impacts to health as well as economic losses to individual citizens.

Additionally, severe wildfires may disrupt operations and damage infrastructure across multiple industries, including tourism, timber, mining, and agriculture, resulting in economic losses. Wildfires may disrupt infrastructure systems such as transportation, electricity supply, telecommunications, water treatment, and sewage systems.

**FIGURE 20** and **TABLE 15** summarize the risk assessment results for this scenario. The highest consequences relate to morbidity, injury, disease, and hospitalization; psychological impacts; loss of social cohesion; and loss of economic productivity. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 15.** Risk Rating Evaluation for Severe Wildfire Season Scenario

| **SEVERE WILDFIRE SEASON: AT LEAST ONE MILLION HECTARES BURNED THAT AFFECT HUMAN SETTLEMENTS** | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **3** | This scenario currently has a 50-year recurrence interval. | **4** | **Climate-related risk cause:** Higher temperatures and low precipitation.<br>**2050 projections:** Projected changes in precipitation and temperature may create conditions more conducive for wildfires, increasing the likelihood to a 10 to 50% chance of annual occurrence. | High |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **4** | Ten to 100 possible mortalities due to direct and indirect effects of wildfire and associated smoke, and limited emergency and medical care. | Medium |
| | Morbidity, injury, disease, or hospitalization | **5** | Over 1,000 people could experience health effects due to smoke inhalation, air pollution, and limited access to critical infrastructure and services. | High |
| **Social functioning** | Psychological impacts | **5** | Uncertainty regarding evacuations and the spread of the fire can cause fear and anxiety, while people that lose their homes, loved ones, or ways of life could experience long-term psychological impacts. | High |
| | Loss of social cohesion | **5** | Tens of thousands of people could experience disruptions to daily life that last for months to years. Populations dependent on agriculture or forestry could lose their livelihoods. | High |
| **Natural resources** | Loss of natural resources | **4** | Forests and forest ecosystems could be damaged, displacing wildlife and transforming landscapes. Ash and debris may degrade water quality and cause damage to aquatic habitats. | High |
| **Economic vitality** | Loss of economic productivity | **5** | Economic losses could surpass $1 billion and result in long-term disruptions. Valuable ecosystem services could be lost. | High |
| | Loss of infrastructure services | **4** | Wildfire could disrupt transportation, electricity supply, telecommunications, and water treatment and sewage systems for weeks or months. | Medium |
| **Cost to provincial government** | | **4** | Potential costs include costs for fire suppression and emergency management and response for affected communities. | Medium |
| **OVERALL RISK** | **CURRENT** | **HIGH (13.5)** | | **HIGH** |
| | **2050** | **HIGH (18.0)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **13.5** out of 25, which equates to **high risk**, and the 2050 risk rating is **18.0** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 3 x 4.5 = 13.5 (High)

2050 Risk = 4 x 4.5 = 18.0 (High)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day (i.e., 2000 to 2020) likelihood of this scenario is **3** and the 2050 likelihood of this scenario is **4**. The likelihood rating is based on indicators including projections of annual area burned, wildfire frequency, and wildfire increases attributed to human-induced climate change over the historical record. To put these indicators in context, the assessment of likelihood considers projected changes in underlying climate-related causes, such as air temperatures, precipitation, and snowmelt. The assumption is that absolute magnitude changes associated with the range of indicators is indicative of likelihood increases through mid-century. Ultimately, climate change could amplify the risk of severe wildfires, and, coupled with the expected growth of the wildland-urban interface (the area where human settlements and wildland vegetation intermingle), drive increased likelihood of a catastrophic one million hectares wildfire toward mid-century. The 2017 and 2018 wildfire seasons both surpassed one million hectares burned in total, which far exceeds the 70-year average and suggests that unprecedented fire seasons may become more common.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **4.5** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (4+5+5+5+4+5+4+4)/8

Overall Consequence = 4.5

#### HEALTH

*Loss of life: 4*

Wildfires could result in loss of life if individuals are caught in affected areas, or indirect loss of life in the aftermath due to limited medical or emergency care or exposure to harmful smoke inhalation. Historically, the literature documents few direct deaths in B.C. due to wildfire. However, the inhalation of fine particulate matter in smoke can have severe repercussions for human health. By mid-century, loss of life due to intense wildfires could increase, particularly if fires occur closer to the wildland-urban interface. Although there is uncertainty about how this consequence could change in the future, mortality could fall in the range of 10 to 100 people during the wildfire season. More deaths may occur if emergency response does not have sufficient time or support to ensure everyone is evacuated or if evacuation routes are cut off.

*Morbidity, injury, disease, or hospitalization: 5*

Wildfire can create many health effects beyond fatalities, including risk of disease or hospitalization due to smoke inhalation, air pollution, and limited access to critical infrastructure and services after the event. Given the widespread effects to air quality, over 1,000 people could experience ill health effects due to a one-million-hectare fire, particularly if it is near population centres. Some portion of these effects could be more severe, such as burns or major smoke inhalation. In addition, a larger number of people could be affected by health effects due to air pollution and exposure to fine particulate matter. Some people could experience acute respiratory and cardiovascular symptoms, while others could experience short-lived irritation due to smoke exposure. Vulnerable populations, particularly infants, the elderly, pregnant women, and those with pre-existing conditions are at greater risk of morbidity and disease related to wildfire.

### SOCIAL FUNCTIONING

*Psychological impacts: 5*

Depending on the location of the wildfire, disturbances could be widespread and result in loss of people's homes, belongings, and well-being. Uncertainty regarding evacuations and the spread of the fire can cause fear and anxiety, while people that lose their homes, loved ones, or ways of life could experience long-term psychological impacts such as post-traumatic stress disorder (PTSD).

*Loss of social cohesion: 5*

Wildfires could lead to months- to years-long disruptions to daily life. Displacement could cause disruptions to employment and education. In addition, those dependent on timber or agriculture may experience long-term loss of livelihoods, and Indigenous communities may experience significant disruptions to traditional ways of life.

### NATURAL RESOURCES: 4

While fire plays in important role in the health and re-establishment of some ecosystems, a severe fire season could cause extensive damage to forests and forest ecosystems. Wildfires could destroy wildlife habitat, displacing animals and causing health problems due to burns and smoke inhalation. Some resources, such as annual plants, will recover quickly, while others, such as old growth forest, could take decades to recover from major disruptions. In some cases, new species and ecosystems may move in after the event, resulting in ecological transformations. Additionally, the soil erosion, ash, and debris washed into waterways can degrade water quality, causing damage to habitat for fish and aquatic life.

### ECONOMIC VITALITY

*Loss of economic productivity: 5*

Wildfires may bring about closures for many businesses, including those in agriculture, tourism, timber, and mining. Additionally, wildfires cause physical damage to land, buildings, and other infrastructure necessary to support productivity. Although the full extent of these impacts has not been quantified, available evidence suggests potential direct and indirect economic losses could easily surpass $1 billion and result in long-term disruptions to certain economic sectors such as the timber industry.

*Loss of infrastructure services: 4*

Depending on the size and location of the wildfire, the extent of losses in infrastructure services could vary. Impacts may include damage to electricity infrastructure, telecommunications, roads and bridges, water treatment and sewage systems, private property, and require building modifications to overcome declining air quality. These damages to infrastructure could disrupt services to people in affected areas for weeks or months at a time.

### COST TO PROVINCIAL GOVERNMENT: 4

The provincial government is responsible for fire suppression costs, which could exceed $500 million in a large fire season like 2017. Based on the literature, the costs could increase by at least 50%, which would increase fire suppression costs to around $850 million to $1 billion. There could be other costs unaccounted for that would bring the costs of preparedness and recovery up to a higher level. Some portion of these costs would likely be covered by the Government of Canada, if this event would trigger the DFAA. Total costs to the province are expected to be on the order of $750 million to $1.5 billion.

## Loss of Forest Resources

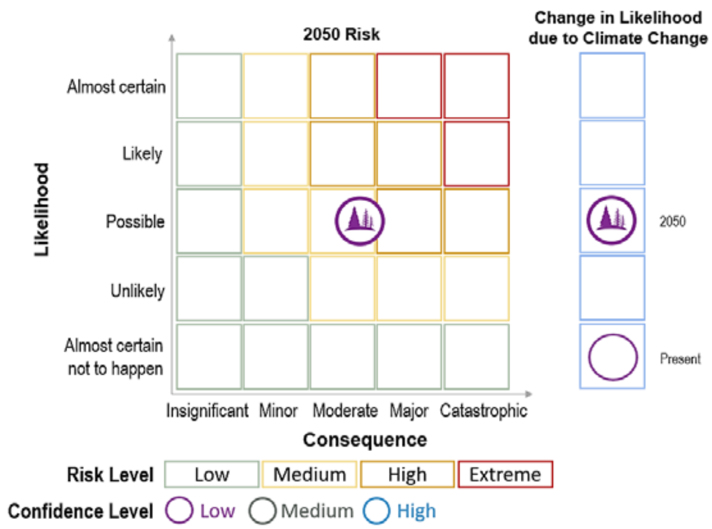
### Scenario

This scenario represents loss in forest resources, measured as a 25% decline in timber growing stock, in B.C. from 2010 to 2050. Forest loss could be exacerbated due increased temperatures and seasonal changes in precipitation, in addition to major disruptions (wildfire and pest outbreaks).

### Summary of Findings

Since the 1990s, B.C. has lost millions of hectares of forest to the mountain pine beetle (MPB) epidemic. Droughts in 2001 and 2002 also took a toll on forest resources, making them more susceptible to disease and wildfire. With warmer temperatures and more frequent or severe droughts, B.C.'s forests could experience greater losses due to pests and wildfire in the coming decades.

**FIGURE 21.** Risk assessment findings for forest resource loss scenario.




Loss of B.C.'s forest resources could have detrimental effects to cultural resources, natural resources, and economic productivity. Many of B.C.'s species depend on forests for habitat and ecosystem regulation, which could decline if forests are compromised or die. Additionally, forestry and forestry-supported industries contribute significantly to the economy. Loss of resources could result in rising unemployment and loss of livelihood for forestry-dependent communities.

**FIGURE 21** and **TABLE 16** summarize the risk assessment results for this scenario. The highest consequences relate to loss of economic productivity. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 16.** Risk Rating Evaluation for Forest Resource Loss Scenario

| LOSS OF FOREST RESOURCES: 25% DECLINE IN TIMBER GROWING STOCK BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **1** | This scenario has not occurred. | **3** | **Climate-related risk cause:** Warmer temperatures and changes in precipitation patterns.<br>**2050 projections:** Between 2010 and 2080, timber growing stock on the total land base could decline by as much as 14% due to decreased growth, increased decay, and a greater risk of wildfire. Decline is projected on the timber harvesting land base, while forests may expend in other areas. | Low |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **1** | Loss of life is unlikely to occur. | Low |
| | Morbidity, injury, disease, or hospitalization | **2** | A small number of people could experience mild health impacts, resulting from increased pollen and allergens, reduced water quality, and disruptions to ecosystem services. | Low |
| **Social functioning** | Psychological impacts | **4** | Mild effects could be widespread due to a loss of aesthetic value and natural areas for recreation. People with forest-dependent livelihoods could experience severe psychological impacts. | Low |
| | Loss of social cohesion | **4** | Communities reliant on forestry industries could experience localized, permanent losses of livelihood. | Medium |
| **Natural resources** | Loss of natural resources | **4** | Forest loss will contribute to reduced habitat and biodiversity, increased erosion and sedimentation, and a decline in ecosystem services. | High |
| **Economic vitality** | Loss of economic productivity | **5** | Expected losses in the forestry and logging industry, downstream forest-dependent industries, and nature-based tourism could exceed $1 billion. | Medium |
| | Loss of infrastructure services | **3** | Rural communities may experience major impediments to daily life or incur major costs associated with loss of maintained roads. | Low |
| **Cost to provincial government** | | **3** | Potential costs include losses in tax revenue, stumpage fees, and tourism revenue. | Low |
| **OVERALL RISK** | **CURRENT** | **LOW (3.3)** | | **LOW** |
| | **2050** | **MEDIUM (9.8)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **3.3** out of 25, which equates to **low risk**, and the 2050 risk rating is **9.8** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 1 x 3.3 = 3.3 (Low)

2050 Risk = 3 x 3.3 = 9.8 (Medium)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

Based on these findings and the likelihood rating criteria, the present-day likelihood of this scenario is rated as **1** (i.e., almost certain not to cross critical threshold) and the 2050 likelihood of this scenario is rated as **3** (i.e., just as likely to cross critical threshold or not). The project team used the decline in timber stock due to climate change as the primary indicator to evaluate this scenario and, additionally, considers a range of underlying climate-related causes, including increasing air temperatures, drought and wildfire risk, and beetle infestation. Between 2010 and 2080, timber growing stock across all of B.C. could decline by as much as 14%, resulting in major consequences for natural resources, cultural resources, and the economy (Metsaranta, Dymond, Kurz, & Spittlehouse, 2011). Forest resources have already seen large reductions in British Columbia; the Mountain Pine Beetle epidemic alone is estimated to have destroyed millions of hectares of pine forest since the 1990s.

At the same time, timber stock decline will vary across the province due to regional differences in projected climate. Faster tree growth rates have been measured in B.C. forests where moisture is plentiful, potentially offsetting losses locally. However, because climate is expected to warm significantly, and warmer and drier conditions may exacerbate the risk of pest outbreaks, resulting in an accelerated decline of B.C.'s forests by mid-century.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **3.3** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (1+2+4+4+4+5+3+3)/8

Overall Consequence = 3.3

#### HEALTH

*Loss of life: 1*

Loss of forest resources is not expected to cause loss of life. However, there are some secondary and compounding risks for mortality, due to events such as wildfire and landslides, which could be exacerbated due to forest resource loss.

*Morbidity, injury, disease, or hospitalization: 2*

While the loss of ecosystem services from damaged forest resources could affect a large proportion of the B.C. population, effects could be relatively minor. The drivers of morbidity, injury, and disease would include the quantity or type of pollen and allergens in the air causing respiratory illnesses or poor water quality increasing risk of water-borne illness. However, there are some secondary and compounding risks to health due to events such as wildfire and landslides, which could be exacerbated due to forest resource loss.

### SOCIAL FUNCTIONING

*Psychological impacts: 4*

For people and communities that depend on forest resources for their livelihoods, psychological impacts could be severe. Changes in the forest industry, unemployment, and loss of identity or purpose could have cascading effects on psychological wellbeing. Forest resources also provide psychological values due to positive feelings associated with the aesthetic of forests and spending time in nature. Thus, the broader population could experience more moderate psychological impacts such as anxiety or grief due to changes in the beauty of nature areas that people enjoy.

*Loss of social cohesion: 4*

Loss of forest resources could affect some populations disproportionately, particularly communities reliant on forestry industries. Thus, a major loss of forest resources could cause a localized, permanent loss of livelihoods for these communities.

### NATURAL RESOURCES: 4

Forest ecosystems, as an important natural resource, may be lost due to a variety of climate impacts. On some sites, forests could take decades or centuries to recover after a disruption, while trees may fail to re-establish on others. In addition, biodiversity and wildlife supported by these forest environments would likely experience decline and some species dependent on certain tree species could go extinct or need to migrate to new ecozones. Forest loss would impede ecosystem services, including carbon sequestration. However, this does not account for potential positive outcomes resulting from shifts to different ecosystems (e.g., grasses replacing forested areas), which would lower the overall impact on natural resources by providing new intact habitats and maintaining some ecosystem services.

### ECONOMIC VITALITY

*Loss of economic productivity: 5*

Loss of forest resources could have a detrimental impact on the economy of B.C., including direct losses to the forestry industry and indirect losses to nature-based tourism. In the short-term after a disturbance, there is an increase in productivity due to salvage logging, which will collapse in the long term. There would also be downstream effects on industries supported by forestry, including pulp and paper processing. Based on estimates from the literature, B.C. could experience losses in the timber industry of $5 to 32 billion from 2010 to 2080. Assuming around half of these losses occur by 2050, this would range from $2.5 to 16 billion. Rural communities reliant on forest industries could collapse due to forest resource loss.

*Loss of infrastructure services: 3*

Rural communities may experience major impediments to daily life or incur major costs to continue using roads that were previously maintained by the forest service or forest industry.

### COST TO PROVINCIAL GOVERNMENT: 3

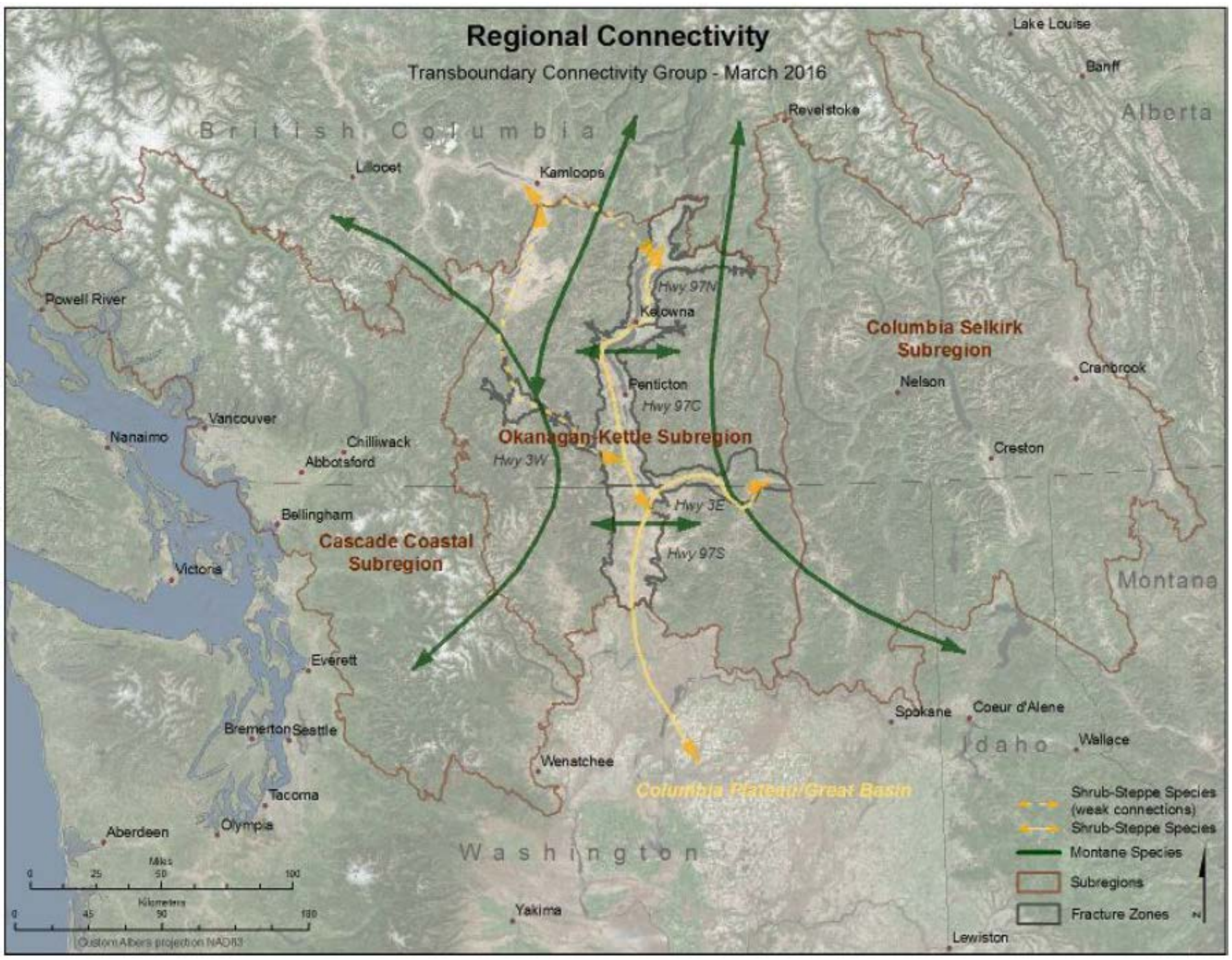
Cost to the provincial government from a decline in forest resources would include lost revenue from stumpage fees and tax revenue from businesses and individuals dependent on forest resources. Damages to the timber industry from the MPB resulted in a loss of $250 million; loss of forest resources could have an impact of similar scale. Additional costs could include losses in tourism and forest recreation and costs to decommission roads previously maintained by the forest industry. As a result, the costs to government are expected to be on the order of $375 million to $750 million.

## Reduction in Ecosystem Connectivity

### Scenario

The specific scenario analyzed is reduction in ecosystem connectivity[11] in the Okanagan-Kettle region (see **FIGURE 22**), caused by changes in temperature and precipitation that result in wildfires, floods, pests, ecosystem shifts, and other stressors. Although this assessment focuses on climate drivers, human development is another factor that can affect ecosystem connectivity. For the purposes of this assessment, a reduction in ecosystem connectivity is defined by a negative change from present conditions.

**FIGURE 22.** Movement patterns for shrub-steppe and montane species in the Okanagan-Kettle Region (Transboundary Connectivity Group, 2016).




[11] Ecosystem connectivity is defined to include both connectivity between ecosystems within the region and connectivity with ecosystems in surrounding regions.

## Summary of Findings

Ecosystem connectivity is vital for facilitating movements of wildlife populations, maintaining species diversity, and maintaining high-quality habitats. Disconnected habitat fragments can lead to habitat isolation and population decline.

Climate change and human development threaten ecosystem connectivity in the Okanagan-Kettle region by disconnecting and changing species' habitat and causing ecosystem shifts. For areas with decreasing habitat suitability for a species, these changes can cause further isolation of habitats and decline of habitat quality. For areas with increasing habitat suitability for a species, however, climate change could help expand the ecosystem and increase connectivity. All of these shifts could have larger implications for ecosystem services and biodiversity.

**FIGURE 23.** Risk assessment findings for ecosystem connectivity scenario.

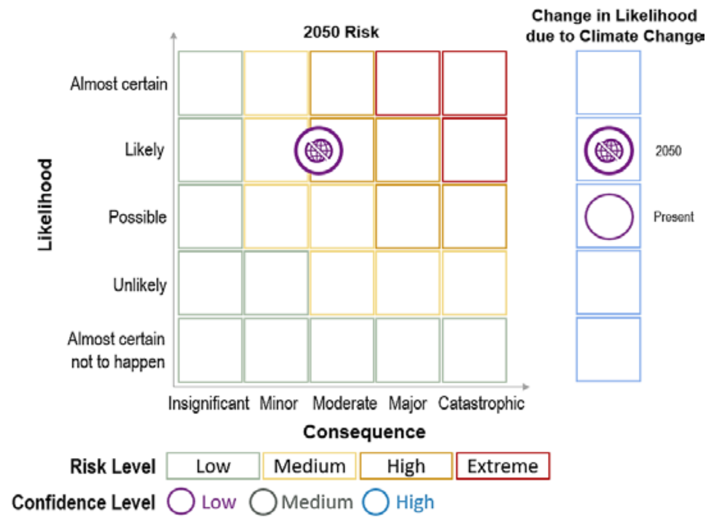



**FIGURE 23** and **TABLE 17** summarize the risk assessment results for this scenario. The highest consequences relate to loss of economic productivity. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 17.** Risk Rating Evaluation for Ecosystem Connectivity Scenario

| REDUCTION IN ECOSYSTEM CONNECTIVITY: REDUCTION IN ECOSYSTEM CONNECTIVITY IN THE OKANAGAN-KETTLE REGION BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **3** | At present, persistent bioclimate envelopes support ecosystem connectivity. | **4** | **Climate-related risk cause:** Changes in temperature and precipitation.<br>**2050 projections:** Climate projections for bioclimate envelopes indicate that ideal climate conditions for high-elevation and high-latitude ecosystems will contract and become more fragmented while climate conditions for low-elevation and low-latitude ecosystems will expand. | Low |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **1** | There is no evidence of loss of life. | High |
| | Morbidity, injury, disease, or hospitalization | **1** | There is no evidence for morbidity, injuries, diseases, or hospitalizations. | High |
| **Social functioning** | Psychological impacts | **2** | Reduction in ecosystem connectivity could cause moderate psychological impacts, and lead to loss of identity or sense of place for some individuals or communities. | Low |
| | Loss of social cohesion | **4** | The scenario could lead to localized and permanent loss of livelihood for some communities. | Low |
| **Natural resources** | Loss of natural resources | **4** | All ecosystems within the Okanagan-Kettle region will experience some degree of climatic shift and change in ecosystem connectivity, which could have implications for ecosystem services and biodiversity. | Medium |
| **Economic vitality** | Loss of economic productivity | **5** | Reduction in ecosystem connectivity could cause long-term disruption and potential job losses for the agriculture, forestry, and tourism industries. | Low |
| | Loss of infrastructure services | **2** | A loss of ecosystem services benefits could require infrastructure as an alternative (e.g., water filtration or flood control). | Low |
| **Cost to provincial government** | | **2** | Costs to government might include replacing lost ecosystem services, damage compensation for increased wildlife pressure on agricultural land, and recovery efforts for declining species or ecosystems. | Low |
| **OVERALL RISK** | **CURRENT** | **MEDIUM (7.9)** | | **LOW** |
| | **2050** | **MEDIUM (10.5)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **7.9** out of 25, which equates to **medium risk**, and the 2050 risk rating is **10.5** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 3 x 2.6 = 7.9 (Medium)

2050 Risk = 4 x 2.6 = 10.5 (Medium)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of this scenario is **3** and the 2050 likelihood of this scenario is **4**. At present, persistent bioclimate envelopes (i.e., ecological and climate distributions) support ecosystem connectivity throughout B.C. (Utzig, 2012).

To assess the likelihood of change, the project team evaluated several bioclimate envelope projections as an indicator of future ecosystem dispersion and reduced connectivity in the Okanagan-Kettle region. The project team focused on the bioclimate envelopes supporting Ponderosa Pine Forest, Engelmann Spruce-Subalpine Fir Forest, and Cedar Hemlock Forest because these species are particularly susceptible to climate change and represent an integral part of the regional landscape.

However, projected shifts in bioclimate envelopes represent a shift in optimal climate conditions rather than a shift in species location. While existing vegetation will experience increasing stress due to bioclimate envelope shifts, permanent forest change will take decades to complete. As a result, the magnitude of connectivity reduction will likely be low through mid-century, even if some reductions are likely to occur.

The project team additionally considered projected changes to wildfire risk and pests as secondary indicators of ecosystem dispersion and connectivity. These events can act as local tipping points by quickly clearing existing vegetation and facilitating accelerated ecosystem shifts within the affected area.

Ultimately, climate projections for bioclimate envelopes indicate that ideal climate conditions for high elevation and latitude ecosystems (e.g., alpine) will contract and become more fragmented while climate conditions for low elevation and latitude ecosystems will expand. Although the timescales on which ecosystem connectivity may change are not well constrained, the project team assumes that some reduction is likely to occur by 2050. The project team notes more significant changes are likely through the second half of the 21st century. The magnitude of change and whether or not there is a net reduction in ecosystem connectivity is additionally dependent on human development, management practices, and the magnitude of impacts to each ecosystem and the species of interest.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (1+1+2+4+4+5+2+2)/8

Overall Consequence = 2.6

project team rated the overall consequence of this scenario as **2.6** out of 5.

### HEALTH

*Loss of life: 1*
Reduction in ecosystem connectivity is not expected to cause loss of life.

*Morbidity, injury, disease, or hospitalization: 1*
Reduction in ecosystem connectivity is not expected to cause morbidity, injury, disease, or hospitalization.

### SOCIAL FUNCTIONING

*Psychological impacts: 2*
Reduction in ecosystem connectivity has the potential to cause moderate psychological impacts within the Okanagan-Kettle region, such as feelings of fear, anxiety, and grief over observed changes in ecosystem connectivity as well as the prospect of continued change. In addition, a reduction in ecosystem connectivity could lead to loss of identity/sense of place for individuals whose culture or livelihoods are heavily embedded in the land.

*Loss of social cohesion: 4*
Reduction in ecosystem connectivity has the potential to cause localized and permanent loss of livelihood or way of life, particularly for individuals whose culture or livelihoods are heavily embedded in the land. For example, reduction in ecosystem connectivity could change access to certain species or habitats, which could have implications for traditions or employment opportunities.

### NATURAL RESOURCES: 4

A reduction in ecosystem connectivity could lead to the decline of some ecosystem types and species, particularly those at higher elevations. However, climate suitability for other ecosystems could expand under climate change, which could increase the abundance and connectivity of some species. Overall, as climate changes, the distribution of species across the region will change, which may negatively affect connectivity, ecosystem services, and biodiversity, especially if species are relocating at different paces or in different directions. Recovery of ecosystem connectivity could take decades, but for high elevation ecosystems, climate change could eventually result in permanent losses.

### ECONOMIC VITALITY

*Loss of economic productivity: 5*
Reduction in ecosystem connectivity could cause long-term disruptions and potential job losses for the agriculture, forestry, and tourism industries. In addition, there may be significant losses in ecosystem services. When the size or shape of these ecosystems are distorted, whether by direct human use, natural disasters, or climate change, the services provided are often degraded or cease altogether. These services must then be replaced by costly man-made facilities or processes that provide the same services (e.g., the construction of a water treatment plant or shipments of topsoil if forests and vegetation are lost).

*Loss of infrastructure services: 2*
Reduction in ecosystem connectivity may cause a loss of ecosystem services benefits that require infrastructure as an alternative (e.g., water filtration or flood control). The scale of impact will vary depending on local conditions.

### COST TO PROVINCIAL GOVERNMENT: 2

Reduction in ecosystem connectivity could cause a loss of key ecosystem services, which the government may be responsible for replacing (e.g., filter air and water, capture runoff, fertilize plants). Given the gradual nature of ecosystem shifts, a significant reduction in ecosystem services is not expected by 2050. Other costs could include damage compensation from increased wildlife pressure on agricultural land and recovery efforts for declining species or ecosystems. As a result, costs to government are expected to be on the order of $375 million or less.

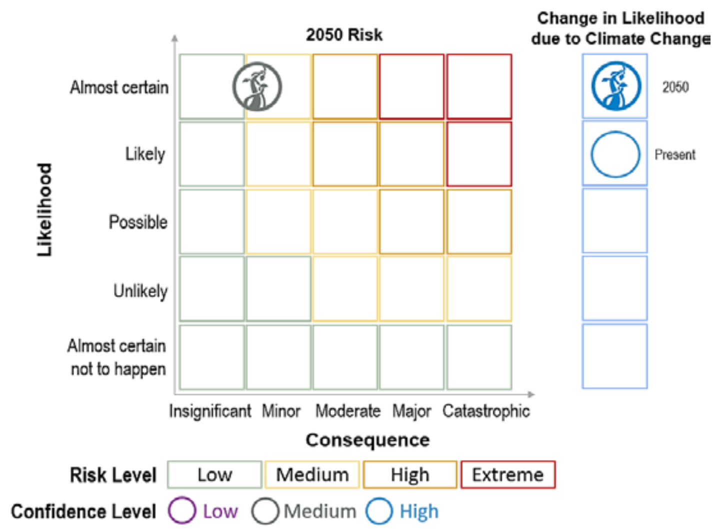
## Increase in Invasive Species

### Scenario

The specific scenario analyzed is the expansion of invasive knotweed (i.e., Japanese Knotweed, Giant Knotweed, Bohemian Knotweed,[12] and Himalayan Knotweed) across B.C. caused by increasing temperatures. Knotweed is tolerant of a range of soil types and climate conditions and is currently found in southern B.C., including Vancouver Island, Central Coast, Sunshine Coast, North Coast, Lower Mainland, Nechako, Cariboo, Thompson-Okanagan, and the Kootenays.

### Summary of Findings

**FIGURE 24.** Risk assessment findings for invasive species scenario.




Knotweed is identified by the International Union for Conservation of Nature as one of the world's 100 worst invasive species (Invasive Species Council of B.C., 2017). Knotweed is native to Asia and was first introduced to B.C. as an ornamental plant (Invasive Species Council of B.C., 2017). Knotweed is now one of the primary invasive species B.C. is working to control, in part due to its ability to grow through concrete and asphalt, which can cause significant damage to infrastructure (Invasive Species Council of B.C., 2017).

All four species of knotweed found in B.C. are invasive, but Bohemian Knotweed is the most aggressive in terms of its dispersal ability and the difficulty involved in killing and removing it (Schaefer, 2015). Knotweed currently occupies only a small fraction of its total potential range, but as temperatures increase knotweed is expected to expand its range by 2050, which may have negative consequences for infrastructure integrity and the health and abundance of native species. However, the potential consequences of knotweed expansion can be managed as long as its spread is controlled.

**FIGURE 24** and **TABLE 18** summarize the risk assessment results for this scenario. The highest consequences relate to loss of natural resources. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

[12] Bohemian Knotweed is a hybrid of Japanese Knotweed and Giant Knotweed and the fastest spreading of the four species due to its ability to spread via both fragment regeneration and wind-dispersed seeds.

**TABLE 18.** Risk Rating Evaluation for Invasive Species Scenario

| INCREASE IN INVASIVE SPECIES: EXPANSION OF KNOTWEED BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **4** | Knotweed occupies a small percentage of its current potential range and is already likely to spread at present. | **5** | **Climate-related risk cause:** Increased temperatures.<br>**2050 projections:** Increasing temperatures, precipitation, and growing degree days are almost certain to facilitate spread of knotweed and further expand potential range without control measures. | High |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **1** | There is no evidence that knotweed causes loss of life. | High |
| | Morbidity, injury, disease, or hospitalization | **2** | Fewer than 10 people could experience injury or hospitalization as a result of poor knotweed management. | Medium |
| **Social functioning** | Psychological impacts | **2** | The invasion of knotweed into homes or businesses could cause localized and moderate feelings of fear and anxiety given the potential extent of damage and difficulty and expense of treatment. | Low |
| | Loss of social cohesion | **2** | Knotweed control could minimally affect daily life. In addition, if knotweed is poorly managed, there could be minor erosion of public trust in government. | Low |
| **Natural resources** | Loss of natural resources | **3** | Knotweed can quickly outcompete existing vegetation and may be detrimental to certain species or ecosystems. Prolonged herbicide treatment could damage the surrounding ecosystem. | Medium |
| **Economic vitality** | Loss of economic productivity | **1** | Loss of economic productivity is assumed to be low. If knotweed is untreated, it could damage business infrastructure or disrupt agriculture and the movement of goods. | Low |
| | Loss of infrastructure services | **1** | Knotweed management could be a nuisance to transportation asset owners, but would not cause disruptions to infrastructure services or daily life unless severely untreated. | Low |
| **Cost to provincial government** | | **2** | Costs to government would include knotweed treatment and disposal costs on Crown lands. | Low |
| **OVERALL RISK** | **CURRENT** | **MEDIUM (7.0)** | | **MEDIUM** |
| | **2050** | **MEDIUM (8.8)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **7.0** out of 25, which equates to **medium risk**, and the 2050 risk rating is **8.8** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

### Risk Calculation

Risk = Likelihood x Average Consequence

Present Risk = 4 x 1.8 = 7.0 (Medium)

2050 Risk = 5 x 1.8 = 8.8 (Medium)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of this scenario is **4** and the 2050 likelihood of this scenario is **5**. Knotweed currently occupies only 25% to 36% of its potential range. As a result, the spread of knotweed is likely, even under the current climate. To evaluate the likelihood of further knotweed expansion, the project team considered climate thresholds determining current and future knotweed range, including a threshold based on annual degree days above 0°C. The project team also evaluated changes in underlying climate-related causes for knotweed expansion, including increasing air temperatures and precipitation. The geographic extent considered in this scenario is confined to regions where climate is conducive to knotweed habitat. This includes the majority of southern B.C. (approximately south of 54°N latitude), including coastal B.C., large swaths of the Central Plateau, and low-lying valley locations in the Rocky Mountains and Coastal Range. Looking forward, increasing annual temperature, precipitation, and growing degree days will almost certainly facilitate the spread of knotweed across the province by mid-century.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **1.8** out of 5.

### Consequence Calculation

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (1+2+2+2+3+1+1+2)/8

Overall Consequence = 1.8

#### HEALTH

*Loss of life: 1*

Knotweed expansion is not expected to cause loss of life.

*Morbidity, injury, disease, or hospitalization: 2*

Although knotweed is not expected to cause direct harm, less than 10 people could experience injury or hospitalization as a result of poor knotweed management. For example, if herbicide application regulations are not followed properly or if transportation corridors, septic systems, and other infrastructure are not maintained to clear excess vegetation, there is a minor possibility for harm (e.g., traffic accidents due to obstructed sightlines).

## SOCIAL FUNCTIONING

### *Psychological impacts: 2*

The invasion of knotweed into homes or businesses could cause localized and moderate feelings of fear and anxiety for those with knotweed on or near their property given the potential extent of damage and difficulty and expense of treatment.

### *Loss of social cohesion: 2*

Although knotweed is a nuisance to treat, it is generally the responsibility of the individual property owner and therefore would only minimally affect social cohesion. The government is, however, responsible for treating knotweed on Crown land so there is a minor possibility for erosion of public trust in government if knotweed is poorly managed. There is some evidence that knotweed could affect daily life, but only under extreme circumstances and for a limited number of people.

## NATURAL RESOURCES: 3

Knotweed can quickly overtake and outcompete existing vegetation and therefore can be detrimental to certain species and ecosystems. In addition, knotweed is difficult to control and may require multiple applications of herbicide, which could damage surrounding ecosystems. As a result, removal of knotweed and recovery of native species could take years.

## ECONOMIC VITALITY

### *Loss of economic productivity: 1*

If knotweed is left untreated, it has the potential to damage business infrastructure or disrupt agriculture and the movement of goods. However, loss of economic productivity from knotweed alone is assumed to be low. The consideration of multiple noxious weeds or multiple invasive species would likely warrant a higher rating.

### *Loss of infrastructure services: 1*

Knotweed would not disrupt infrastructure services unless it is uncontrolled or untreated and causes significant damage. However, asset managers are likely to maintain infrastructure and treat knotweed before it becomes a significant problem. As a result, knotweed can be considered a nuisance to transportation asset owners and would not cause disruption to daily life.

## COST TO PROVINCIAL GOVERNMENT: 2

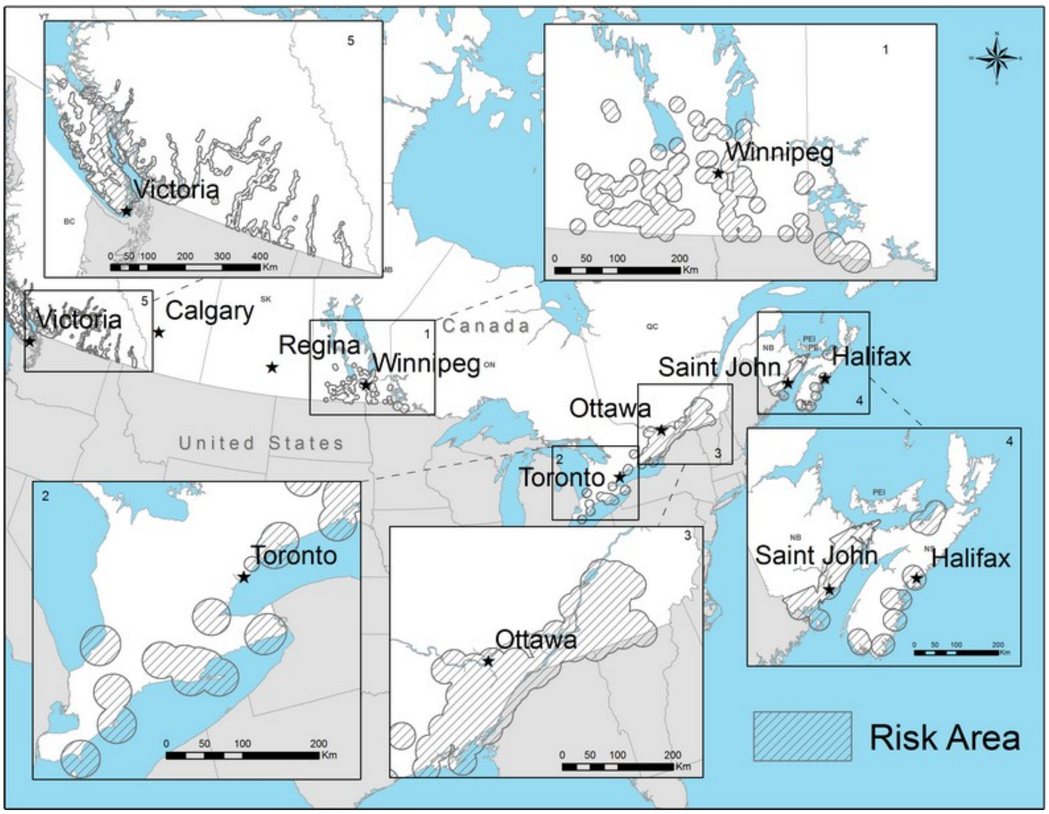
An expanded range for knotweed due to climate change indicates that control costs could increase over time. While most of these costs will be borne by municipalities and private landowners, the province is responsible for knotweed management on Crown lands. Based on costs of knotweed control for Metro Vancouver, the extrapolated cost to the provincial government at the provincial scale is more reasonably around $1,000,000 and therefore costs are expected to be on the order of $375 million or less.

## Increased Incidence of Vector-borne Disease

### Scenario

The specific risk event scenario analyzed is at least a doubling of Lyme disease cases within B.C. over three years, occurring before 2050. Changes in temperature and precipitation[13] could allow *Ixodes pacificus* ticks to spread across the province of British Columbia, primarily starting in the areas currently supporting tick populations (the lower mainland and southern Vancouver Island) and moving eastward and northward. **FIGURE 25** shows the areas of the country where Lyme disease is already a risk. In B.C., this is primarily in the southwestern corner of the province.

**FIGURE 25.** Lyme disease risk areas in Canada (Government of Canada, 2018).

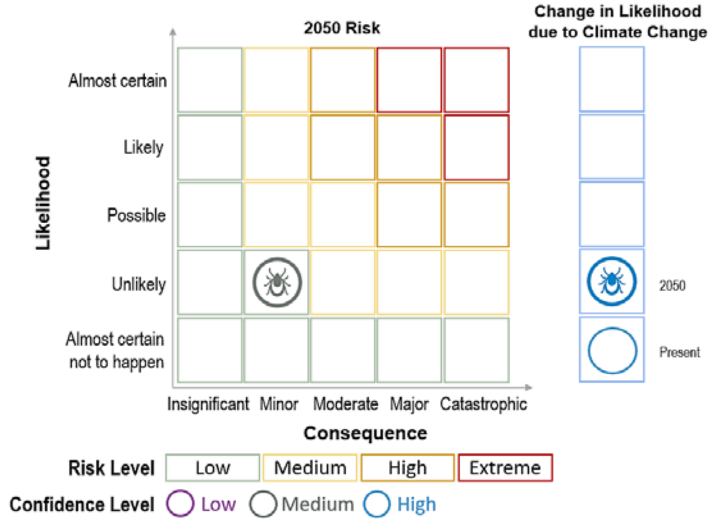



[13] Little research is available on the climate drivers for *Ixodes pacificus*, and how ticks may be affected by climate change, as confirmed by expert interviews.

## Summary of Findings

The risk of Lyme disease in B.C. has remained relatively low while it has spread rapidly in the eastern part of the country. At least a doubling in the number of cases of Lyme disease within a three-year period would reflect a rapid increase in infection similar to what has occurred in eastern Canada. However, the likelihood of a doubling in Lyme disease is low according to available evidence and expert opinion.

**FIGURE 26.** Risk assessment findings for vector-borne disease scenario.




Lyme disease can lead to severe and chronic health symptoms. In addition, those affected could experience disenfranchisement and depression due to misdiagnosis or persistent morbidity. Individuals affected by Lyme may not be able to participate in school, work, or other elements of society, contributing to economic losses and loss of well-being. The costs to government to treat Lyme patients and increase prevention activities could also increase.

**FIGURE 26** and **TABLE 19** summarize the risk assessment results for this scenario. The highest consequences relate to morbidity, disease, and hospitalization; and psychological impacts. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 19.** Risk Rating Evaluation for Lyme Disease Scenario

| INCREASED INCIDENCE OF VECTOR-BORNE DISEASE: AT LEAST A DOUBLING OF LYME DISEASE CASES | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| 1 | The risk in B.C. is low (<0.5 cases per 100,000 population, <1% tick infection rate). The rate of infection has been stable for decades. | 2 | **Climate-related risk cause:** Temperature and precipitation influence tick behavior and range.<br>**2050 projections:** Warmer conditions could increase host-seeking activity, change the life cycle, or expand suitable habitat for *Ixodes pacificus* ticks. However, significant change in infection is not expected given the characteristics of this tick vector and the fact that many of the populated areas of B.C. are already exposed to *Ixodes pacificus*. | High |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | 2 | There is low potential for multiple losses of life due to Lyme disease, except in extreme circumstances. | Medium |
| | Morbidity, injury, disease, or hospitalization | 4 | 22 to 120 people per year could experience symptoms of Lyme disease, ranging from mild fever, headaches, and rash to severe and chronic neurological, musculoskeletal, and cardiac issues. | Medium |
| **Social functioning** | Psychological impacts | 4 | People with untreated Lyme disease may present symptoms similar to psychiatric disorders. Misdiagnosis and chronic issues could cause distress for patients. | Low |
| | Loss of social cohesion | 2 | A doubling of Lyme could cause some erosion to public trust. | Low |
| **Natural resources** | Loss of natural resources | 1 | No evidence of impacts to natural resources. | Low |
| **Economic vitality** | Loss of economic productivity | 1 | Affected individuals could have reduced economic productivity. Outdoor recreation and tourism revenue could be lost. Overall costs expected to be less than $1 million. | Medium |
| | Loss of infrastructure services | 1 | No evidence of impacts to infrastructure services. | High |
| **Cost to provincial government** | | 2 | Potential costs include additional costs to the health system (approximately $88,000-$480,000), losses in revenue, and costs for public outreach. | Medium |
| **OVERALL RISK** | **CURRENT** | **LOW (2.1)** | | **MEDIUM** |
| | **2050** | **LOW (4.3)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **2.1** out of 25, which equates to **low risk**, and the 2050 risk rating is **4.3** out of 25, which equates to **low risk**. See the Risk Calculation text box at right.

### Risk Calculation

Risk = Likelihood x Average Consequence

Present Risk = 1 x 2.1 = 2.1 (Low)

2050 Risk = 2 x 2.1 = 4.3 (Low)

## Evidence Base

See Appendix B for the full evidence base for this this assessment.

### *Likelihood rating*

The present-day likelihood of this scenario is **1** and the 2050 likelihood of this scenario is **2**. The scenario is ongoing with a threshold defined as a doubling of Lyme disease cases in three years. Given that the ticks that carry Lyme disease are more prolific under warming conditions, higher temperatures due to climate change could increase host-seeking activity or change the habitat range, contributing to a rise in the number of Lyme disease cases. However, despite warming over the past several decades, the rate of infection in B.C. has remained low and stable. Given that many of the populated areas of B.C. are already exposed to *Ixodes pacificus*, it appears unlikely that Lyme disease cases in B.C. will double within a 3-year period by 2050. However, the projected impact of future warming on tick populations and distribution is not fully understood. To evaluate the likelihood of this scenario, the project team considered both the historical incidence rate of Lyme disease and changes to climate-related controls on its host population and range, including air temperatures and precipitation.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.1** out of 5.

### Consequence Calculation

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (2+4+4+2+1+1+1+2)/8

Overall Consequence = 2.1

**HEALTH**

*Loss of life: 2*

There is no evidence of deaths attributed to Lyme disease in Canada. Proper diagnosis can be challenging, which means deaths may have been incorrectly attributed. However, most people who would be infected with Lyme disease in B.C. could experience negative health outcomes unlikely to result in death. There is a low potential for multiple losses of life in B.C. due to Lyme disease.

*Morbidity, injury, disease, or hospitalization: 4*

A doubling of Lyme disease could result in approximately 22 to 120 people who experience negative health impacts. Some portion of those people will suffer few or mild symptoms that can be treated, such as fever, headaches, and a skin rash. However, if left untreated, Lyme disease can lead to severe neurological, musculoskeletal, and cardiac issues that can result in chronic symptoms. Consequences are significant but, due to the suspected low level of reporting and difficulties diagnosing the disease, analyzing the full extent of infection is difficult. The risk of morbidity, disease, or hospitalization will be the most significant consequence due to Lyme disease.

## SOCIAL FUNCTIONING

### *Psychological impacts: 4*

In some cases, people infected with Lyme disease may experience various symptoms akin to psychiatric disorders, including depression, anxiety, schizophrenia, and bipolar disorder. Additionally, chronic Lyme can manifest in symptoms that mimic other diseases. The resulting misdiagnosis or chronic issues without proper care can exacerbate distress and anxiety of patients. While the psychological impacts of Lyme disease are severe, the affected population is likely small.

### *Loss of social cohesion: 2*

If the rate of Lyme disease were to double within a short period of time, there could be greater pressure on the government as well as outrage from advocacy groups. This could result in erosion of public trust in the government. However, a doubling of Lyme disease cases in B.C. is a small portion of the population and may not result in the level of outrage observed in other regions of Canada.

## NATURAL RESOURCES: 1

Lyme disease is not expected to have a substantive impact on natural resources in British Columbia.

## ECONOMIC VITALITY

### *Loss of economic productivity: 1*

Due to illness, more than 100 people could become unable to continue pursuing their education, career, and personal objectives, resulting in losses in productivity and societal costs. However, given the individualized nature of the impacts, the overall economic losses across the province due to a doubling of Lyme disease would be relatively small. There may also be losses in revenue for outdoor recreation and tourism if people limit time outside.

### *Loss of infrastructure services: 1*

Lyme disease is not expected to result in losses to infrastructure services in British Columbia.

## COST TO PROVINCIAL GOVERNMENT: 2

The primary cost to the provincial government is healthcare services, which are shared between the federal and provincial government. For 22 to 120 cases of Lyme disease, health care costs are estimated at $88,000 to $480,000. There could also be additional costs to the health system, losses in productivity, and efforts required to educate the public about Lyme disease prevention and treatment. These costs are expected to be on the order of $375 million or less.

# INTERACTIONS BETWEEN RISK EVENTS

While the preceding chapters of this risk assessment assess the likelihood and consequences of each hazard event individually, managers and stakeholders recognize that climate change can compound hazard events. This chapter presents an integrated assessment that considers potential interactions between events. The analysis finds that British Columbia may be at risk from a range of compound risk events exacerbated by climate change.

Instead of happening independently, climate-related hazards often occur simultaneously and are strongly interlinked. These compound risk events can have linked probabilities driven by the same underlying conditions, and can in some cases trigger each other. Furthermore, the impacts of these compound events can build upon each other, in some cases increasing the consequences of compound hazard events beyond the sum of the individual hazards that compose them.

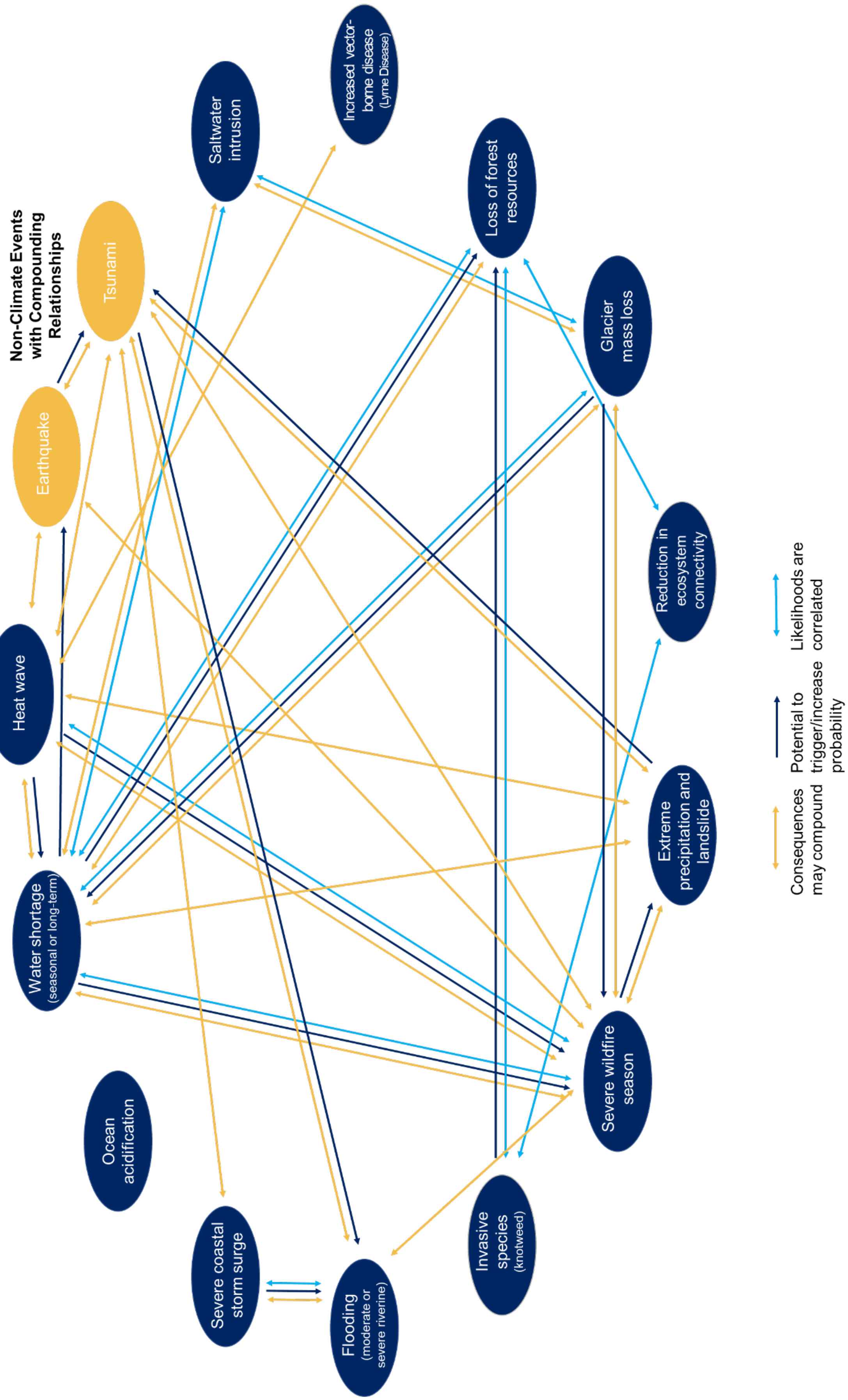
For purposes of illustration, this chapter assesses one combination of events that may be most likely to occur in British Columbia: a seasonal or long-term water shortage followed by wildfire, which in turn primes the landscape for severe landslides following heavy precipitation. This compound event is plausible, particularly under the effects of climate change, and it could have severe impacts on the province, particularly if hazards overlap in a way that magnifies their consequences. To better understand and prepare for these risks, this chapter identifies specific mechanisms of compounding impact, and select geographies where this compounding event is most likely to occur.

## Potential for Compound Risk Events in B.C.

B.C. could experience multiple compound and interconnected climate-related events through mid-century, as shown in the impact web in **FIGURE 27**. For example, sea level rise causes greater coastal erosion and, in turn, increases vulnerability to storm surge and coastal flooding. Soot and fine particulates released from wildfires, as well as dust picked up from charred landscapes, can settle on mountain glaciers and ice caps producing more snow and ice melt. This can disrupt normal runoff patterns and increase the risk of downstream flooding in mountain-fed watersheds. Heat waves and water shortages often occur simultaneously and can lead to a range of subsequent events, including severe wildfires and reduced air quality. In turn, the landscapes burned by wildfires are more prone to flooding and landslides. Climate change will very likely exacerbate these hazards and their connections through mid-century. While theoretically the occurrence of any two events at one time could have some degree of compounding consequences, the impact web links only those whose compounding consequences are readily apparent.

In addition, not all compounding events are climate driven. As a tectonically active region, B.C. can experience earthquakes. Earthquakes can trigger tsunamis or landslides that impart additive consequences on communities by flooding the coast or inland river systems.

**FIGURE 27.** Compounding impact web illustrating interconnected nature of climate hazards and their likelihood and consequences. Climate hazards considered here are based on risk event scenarios as defined in this report.



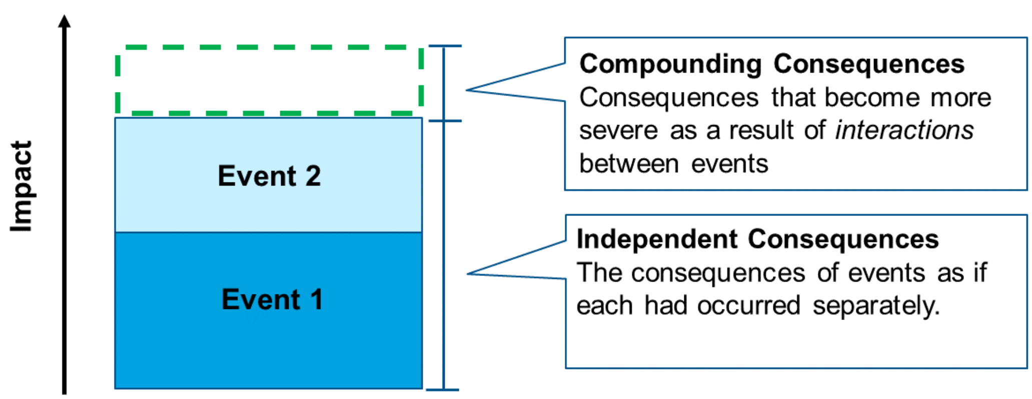
## Overview of Compound Risk Events

Compound events are the combination of climate stresses and hazards to form significant impacts (Zscheischler et al., 2018). Oftentimes, compound events form a cascade whereby individual hazards increase the likelihood of one another. For example, changing precipitation patterns can cause severe water shortages that, in turn, increase the likelihood of wildfires. Traditional assessments potentially underestimate risk by considering only one hazard at a time. Consideration of the interconnected nature between hazards and their consequences may provide a more complete evaluation. This approach could prove critical in answering the mounting challenges associated with increasingly complex hazards in a changing climate.

In addition to interconnections between the likelihoods of hazard occurrence, compound risk events can also involve interactions between the consequences of multiple hazards, worsening the impacts. Individuals or communities facing simultaneous or closely sequenced hazards may experience heightened vulnerability and compromised resilience relative to the experience of facing a single hazard at a time.

The consequences of compound events can be particularly damaging to individuals and communities exposed to multiple hazards within a limited period of time. These consequences can be broken into two categories, as illustrated in **FIGURE 28**. The independent consequences of compound hazards are the impacts of the events as if each had occurred separately. In addition, however, compound hazard events may have *compounding* impacts: impacts that are more severe because multiple events occurred simultaneously or in sequence (Gill and Malamud, 2014).

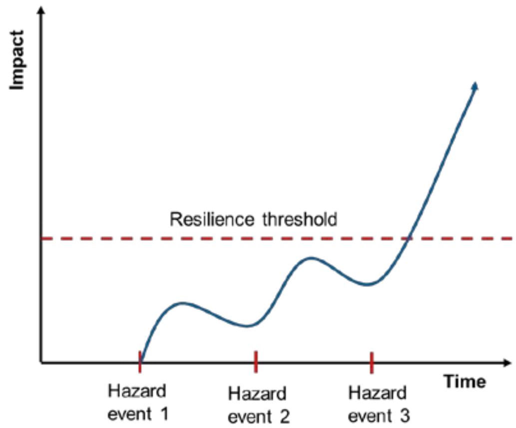
**FIGURE 28.** Independent and compound consequences of contemporaneous hazards.




A well-documented example of compounding consequences is the 1991 eruption of Mount Pinatubo in the Philippines, which occurred at the same time as the landfall of Typhoon Yunya. The combination of heavy rainfall and volcanic ash produced severe debris flows and caused structures to buckle under the weight of wet ash, multiplying the impacts of two events beyond the simple sum of their independent consequences (Gill and Malamud, 2014).

One of the mechanisms by which the impacts of multiple hazards may compound is if the sum of independent consequences exceeds certain thresholds of impact, beyond which physical assets or communities are unable to cope. **FIGURE 29** illustrates this concept for a hypothetical series of three subsequent hazards.

**FIGURE 29.** Illustration of the impacts of multiple hazards in exceeding a resilience threshold.




An example of this concept in action is the 2011 earthquake-tsunami event that struck Onagawa, Japan. Post-event research indicates that the earthquake weakened the foundations of buildings such that they were subsequently toppled by wave inundation. While the earthquake or wave action alone may not have levelled the buildings, the buildings' foundations were unable to withstand the compound impacts of both hazards (Latcharote et al., 2017). While there are many other potential mechanisms by which coincident hazards may have compounding impacts, the relative rarity of compound events and difficulty of identifying and quantifying those impacts have limited the amount of research in this area.

Similarly, subsequent hazards can increase the vulnerability of communities over time (**FIGURE 30**). This can take place on a physical level (as in the example above); on an economic level through the impacts of multiple economically destabilizing events; or on a psychosocial level through the impacts of repeated trauma and the breakdown of community cohesion following multiple major disruptions.

**FIGURE 30.** Progressive increase in vulnerability following multiple disasters (source: ICF adaptation of Gill and Malamud, 2016).

## Example Compound Event: Water Shortage, Wildfire, and Landslide Cascade

The compound event considered here is a seasonal or long-term water shortage, followed by severe wildfire and a precipitation-induced landslide in a critical provincial area. The project team selected this scenario to frame and illustrate the overarching concepts and impacts associated with other compound events. The scenario was identified as the most provincially significant of all possible permutations and particularly pertinent given its history of occurrence along the western coast of North America.

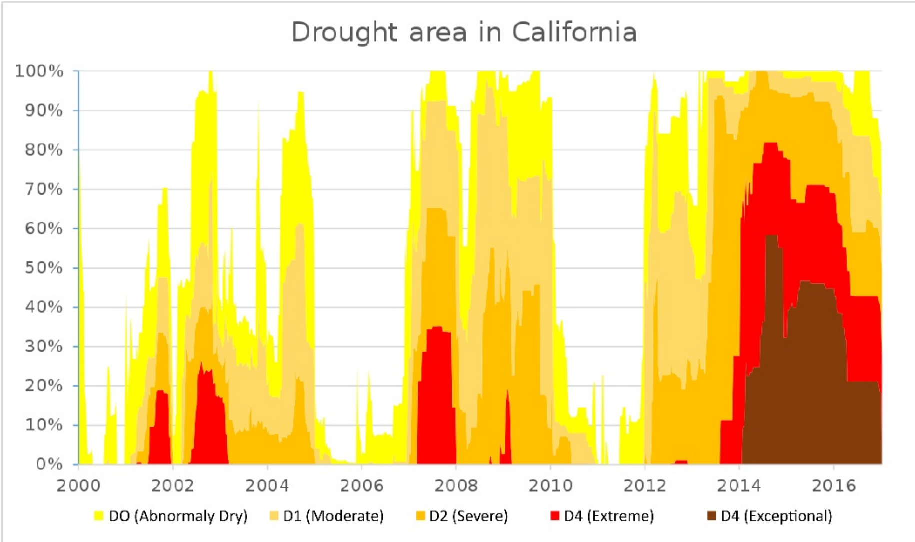
Recent natural disasters in California provide a rich evidence base through which to understand the potential scope and consequences of the compound event scenario in British Columbia. California experienced a historic water shortage between 2012 and 2017 (**FIGURE 31**), with much of the state experiencing higher temperatures and reduced precipitation, snowpack and streamflow (Lund et al., 2018). The severe drought led to a range of consequences. Snowpack in the Sierra Nevada Mountains was reduced by more than 60% over this time period. Because snowpack melts slowly over the spring and summer, feeding regional reservoirs and ultimately representing 65% of the state's water resources, California was met with extreme water shortages for agriculture, livestock, and industry.

### Cascading Events and Landscape Preconditioning

Hazards caused by a shared underlying climate condition can trigger each other through the concept of landscape preconditioning. In this way, compounding hazards are linked in a cascade, which makes subsequent hazards and their consequences more likely. For example, in this scenario:

- Water shortages precondition the landscape for wildfire by desiccating wildfire fuel
- Wildfires precondition the landscape for landslides by burning vegetation, creating hydrophobic soils and increasing runoff during rainfall events
- Landscape preconditioning lowers hazard thresholds:
  - Wildfires spread more rapidly after landscape desiccation due to water shortages
  - Less precipitation is required to initiate landslides following wildfire
- Increased likelihood persists after initial hazards subside due to landscape imprinting:
  - Landslide risk remains high after wildfire is extinguished and until significant vegetation and soil reclamation has occurred

**FIGURE 31.** Time series showing relative California drought area and severity (U.S. Drought Monitor).




Underlying climate drivers causing the severe water shortage also increased the likelihood of wildfires. Several subregions of California were ravaged by wildfires in 2016 and 2017, including foothills above the communities of Montecito and Santa Barbara. In December 2017, the Thomas wildfire destroyed 1,063 structures, cleared the land of vegetation, and caused $2.2 billion in damages (Ding, 2018). The next month, an atmospheric river system, or a band of enhanced water vapour transport from the Pacific Ocean, brought heavy precipitation to the same area. In Southern California, 25% of the average annual precipitation fell in an 11-day period in January 2017 due to this rain event (NOAA, 2018). Outside Montecito, the landscape had become hydrophobic, clear of vegetation and destabilized by the Thomas Wildfire and was saturated by rainfall, causing a series of destructive landslides that inundated the community. The landslides ultimately claimed 21 lives and injured more than 160 people.

This evidence base demonstrates both the potential compounding and cascading nature of climate hazards. California absorbed consequences from each hazard; although the individual hazards each had their own geographic extent and duration, the impacts were integrated and felt statewide. At the same time, the succession of climate hazards created a cascade, whereby each event increased the likelihood of the subsequent event, and were ultimately initiated by the same underlying climate stressors including increasing air temperatures and precipitation deficits.

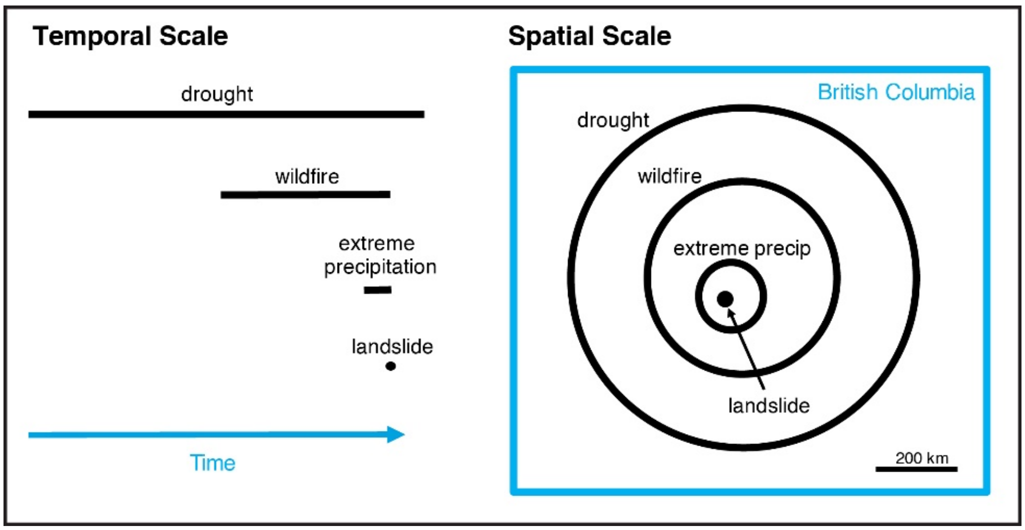
The 2012 to 2017 California drought was atypically dry and warm, with a frequency of occurrence between roughly 20 to 1,200 years (Lund et al., 2018). While natural variability will always control the occurrence of climate hazards to some degree, research has shown that climate change makes extreme seasonal and long-term water shortages and wildfires more likely (e.g., Williams et al., 2015).

Of course, there are fundamental differences between the climate of B.C. and that of California. In general, B.C. has more frequent and smaller-magnitude precipitation events that inundate the Coastal Mountain Range, whereas California's Mediterranean climate is more susceptible to episodic dry spells and atmospheric river-type precipitation events.

Despite these differences, the two regions share underlying conditions necessary for water shortages, wildfires, and heavy precipitation. B.C. recently experienced historic water shortages and wildfire seasons, which suggests that the province is susceptible to the compound event of interest, particularly given that climate change will likely amplify these stresses. For example, a large landslide born from a wildfire zone following heavy rainfall in 2004 covered houses and blocked Highway 3A in the Kuskonook Creek catchment. In addition, the city of Kelowna experienced compounding impacts associated with nearly simultaneous flood, drought and wildfire in 2017.

Compound events result from multiple processes acting on a range of spatial and temporal scales. When evaluating provincial risk, it is important to consider the integrated impacts from hazards acting across these scales (**FIGURE 32**). For example, risk assessments should consider both the longer duration and larger impacts associated with drought and comparatively shorter duration and localized impacts associated with landslides.

**FIGURE 32.** Compound events result from multiple processes acting on a range of spatial and temporal scales.




## Likelihood

### *Overall Likelihood in B.C.*

Risk analysts traditionally evaluate the likelihood of single events, such as return intervals for droughts, wildfires, or landslides. However, to fully appreciate risks associated with the compound scenario, it is important to consider the many connections between hazards and ways in which seemingly disparate climate-related events are often coupled. Such instances are considered cascades.

As with all cascading events, the compound scenario considered here is, in principle, a low-likelihood and high-risk event. However, likelihood evaluations must recognize that hazards within the cascade are coupled rather than independent, and thus each hazard increases the likelihood of subsequent hazards. This differs from the traditional view of event probability, where the likelihood of a combination of events is proportional to the product of each individual event probability. Cascading hazards are coupled through the concept of landscape preconditioning, whereby the landscape is altered to facilitate subsequent hazards. For example, landscape desiccation during water shortages facilitates ignitions and increases the amount of fuel available for large wildfires. Wildfires, in turn, clear vegetation and rework soil to become hydrophobic, which increases the amount of runoff during rainstorms that can trigger landslides. In some cases, the landscape remains preconditioned well after the initial hazard subsides.

Elevated landslide risk could persist for years after wildfires cease and until significant vegetation and soil reclamation has occurred.

The compound event of interest could occur as different permutations of the cascade. While extreme permutations (e.g., multi-year water shortage followed by a 1-million-hectare wildfire and destructive landslide) have the largest impacts, they are less likely than smaller-scale permutations (e.g., year-long water shortage followed by a 200-hectare wildfire and landslide in a rural community) that occur more frequently across the province. While small-scale events have reduced impacts locally, their cumulative impact across the province could be large over time.

The likelihood of a long-term water shortage, followed by severe wildfire, and precipitation-induced landslide in a critical provincial area will increase through mid-century. The project team found that climate-related causes such as increasing air temperatures and changing precipitation patterns will make water shortages and wildfires more severe and frequent in British Columbia. In addition, GCMs reveal that warming will support higher water vapour concentrations and transport into storms, producing more frequent and intense heavy precipitation events (e.g., Fischer and Knutti, 2015), and increasing the likelihood of rainfall-driven landslides in the province. By mid-century, climate change will expand the fingerprints of water shortages, wildfires, and heavy precipitation across the province to affected larger and more varied regions of B.C. than have been affected historically.

Hotter and more arid conditions will support more frequent water shortages and wildfires through mid-century. GCM projections show that B.C. will experience more heat waves (>32°C) and a 1.8°C increase in annual mean temperatures by 2050 relative to the historical baseline (1971 to 1990), assuming RCP8.5) (Pacific Climate Impacts Consortium, 2012). While it remains difficult to predict changes to precipitation patterns, GCM model ensembles reveal a 1% decrease in summertime precipitation (Pacific Climate Impacts Consortium, 2012), as well a dramatic reduction in springtime (April 1) snowpack volume (Metro Vancouver, 2016). These trends are expected to be most pronounced in regions already prone to water shortages, including throughout Southern B.C., the Interior Plateau and low-lying valleys in the Columbia Mountains. Climate Moisture Index (CMI) deficits are expected to increase by roughly 200% in these areas by 2080 relative to the historical baseline (1981 to 2000), signaling more favourable background conditions for both water shortages and wildfires (Natural Resources Canada, 2017). As a result of these climate trends, the expected number of large wildfires (> 200 ha) in B.C. is expected to double though 2080 assuming RCP8.5 (Natural Resources Canada, 2017).

Annual precipitation is expected to increase by roughly 6% in B.C. and heavy precipitation events are expected to become more frequent and severe (Pacific Climate Impacts Consortium, 2012). At the same time, moderate precipitation (i.e., < 95% percentile) could be sufficient to initiate landslides if the landscape has been preconditioned by wildfire. This suggests that the precipitation threshold for rainfall-driven landslides could be lowered within the compound event, if water shortages and wildfires become more common in a warming climate.

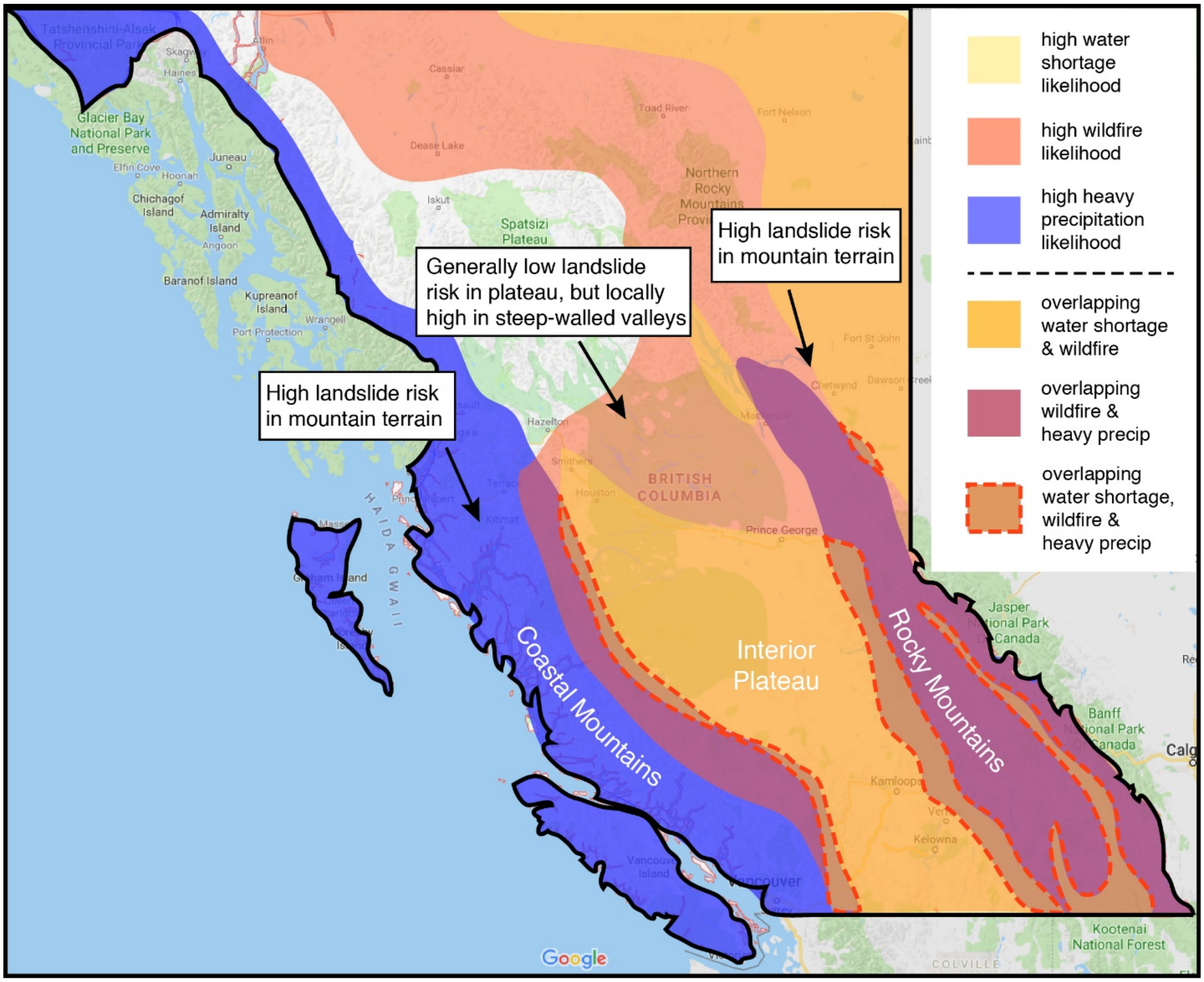
### *Geographic Screening of Likelihood*

In addition to evaluating the future likelihood of the compound event, the project team conducted a geographic screening to determine what regions of the province are most at risk (**FIGURE 33**). In general, the Interior Plateau experiences a relatively warm and dry continental climate, which is historically susceptible to water shortages and large wildfires (**FIGURE 33**). At the same time, because the plateau is situated on the leeside of the Coastal Mountain Range, the region is less susceptible to extreme rain events. The predominantly low-slope terrain also has a low risk for landslides, except for in the locally steep-walled river valleys that dissect the plateau.

By comparison, the Coastal and Rocky Mountain ranges that encircle the Interior Plateau experience high annual precipitation and more frequent heavy rainfall events (**FIGURE 33**). The risk of water shortages is comparatively low, except in warmer low-lying valley systems. Wildfire risk is high in forested portions of the Rocky Mountains and moderate in the wet, maritime climate associated with much of the Coastal Range. Landslide risk is high within the steep-sloped and geologically complex mountain terrain.

Areas most susceptible to the compound event are those where elevated water shortage, wildfire, heavy precipitation and landslide risks are collocated **FIGURE 33**). Based on these criteria, the compound event is most likely in the foothills that bound the Interior Plateau and also within the steep low-lying valley locations throughout the Interior Plateau and adjacent mountain ranges. While these areas are expected to experience higher risks, that does not discount the compound event from occurring in other regions of the province. As with all climate variables, the occurrence of any given climate hazard contains natural uncertainty, which should be considered when applying exposure projections to risk assessments.

**FIGURE 33.** Geographic screening of the compound event likelihood. Shaded areas represent elevated risk due to individual climate-related hazards. Annotations show relative landslide risks corresponding to different geographic regions: mountainous areas are susceptible to landslides, while the Interior Plateau generally has smaller landslide risks, except for in locally steep valley systems. The compound event is most likely where individual hazards overlap.




## Potential Consequences

### *Overall Consequences*

Beyond interacting likelihoods, this compound event could have many compounding and interacting consequences. While each of the events (water shortage, wildfire, and a precipitation-induced landslide) is considered separately in other chapters of this report, this section explores additional considerations around the additive and compounding consequences that could ensue if these events occur in a closely spaced cascade. In these potential compounding scenarios, consequence ratings of the combined events may be greater than the sum of the individual events had they occurred separately.

**TABLE 20** outlines potential compounding consequence scenarios that could ensue from this example event.

**TABLE 20.** Compounding Consequence Scenarios from Water Shortage, Wildfire, and Landslide

| COMPOUNDING SCENARIO | POTENTIAL IMPACTS |
|---|---|
| Wildfire event occurs following drought | • Extent of wildfire damage is greater due to drier fuel load. |
| Multiple major landslides affect critical road transport corridors, disrupting wildfire relief and recovery efforts | • Emergency response personnel could be delayed in reaching affected communities.<br>• Transport disruptions caused by landslides could delay repairs to electric transmission lines affected by wildfires, further extending power outages.<br>• These impacts could result in increased loss of life, psychological impacts, and loss of social cohesion. |
| Medical facilities damaged by wildfires could be forced to close for prolonged periods, compounding impacts of subsequent landslide event | • Lack of access to immediate medical care could result in increased loss of life from the landslide event.<br>• Consequences could be especially severe if a debris flow blocks highway access to other nearby treatment facilities. |
| Multiple hazard events occurring simultaneously or in close succession may overtax provincial emergency response capabilities | • Reduced availability of provincial emergency response personnel, funding, and equipment could increase severity of loss of life and injury, increase economic damage, and reduce trust in government. |
| Cumulative impacts of a multi-year water shortage followed by a wildfire could cause economic impacts across multiple industries (e.g., agriculture and forestry) | • The severity and cross-sector nature of these impacts could result in a cascade of job losses, migration, and long-term damage to economic vitality and social cohesion. |
| Wildfire and landslides introduce ash and human contaminants into waterways, exacerbating water shortage | • Wildfires have negative short and long-term impacts on water supply and quality via the introduction of ash into waterways and reservoirs and increased long-term erosion and sedimentation (USGS, 2018).<br>• Landslides can also introduce sediment, organic matter (including additional wildfire ash), and human contaminants into waterways (Geertsema, 2009).<br>• The significance of a loss of water quality is magnified during a time of water shortage, potentially affecting agriculture and public health. |
| Landslide creates debris dam and obstructs river, exacerbating flooding from heavy precipitation | • Large areas of land outside of typical floodplains could experience severe flooding.<br>• In 2014, a landslide in Oso, Washington, dammed the North Fork Stillaguamish River and formed a lake 2.5 miles long, flooding homes (USGS, 2017). |
| Drought and wildfire predispose topsoil to severe erosion in subsequent precipitation event | • Drought and wildfire can reduce plant and litter layer cover, leading to increased vulnerability to erosion (Colorado State University Extension, 2012; Agriculture and Agri-Food Canada, 2016).<br>• This loss of topsoil may have damaging effects on agriculture, forestry, and ecosystems. |

## *Geographic Screening of Consequences*

British Columbia's Interior Plateau faces the greatest risk from compounding consequences. This region faces high risk from water shortage and wildfire, and several of the major highways that provide access to the region run through landslide-prone territory. While landslide risk in most of the plateau is relatively low due to its flat terrain, Highways 5, 1, and 16 include significant sections that run through landslide-prone mountains on the eastern and western sides of the plateau as well as through local landslide-prone valleys. In 2017, the city of Kamloops declared a state of emergency due to landslides near Highway 5 (Slattery, 2017) and additional landslides in 2018 caused a partial closure of another portion of the same road (Kergin, 2018). In addition, major railway corridors for the Canadian National

Railway, B.C. Rail and the Canadian Pacific Railway run through landslide-prone valleys that coincide with areas of high water-shortage and wildfire likelihoods.

In addition to transportation infrastructure, significant portions of B.C. Hydro's transmission infrastructure runs through areas susceptible to wildfire and landslides. B.C. Hydro has explicitly acknowledged this risk in at least some areas, such as West Kelowna, where it is currently scoping options for redundant transmission capacity (B.C. Hydro, 2018b). As the linked likelihood of wildfires and landslides increases, however, this risk warrants further scrutiny, especially in northern parts of the province where available transmission maps suggest that redundancy is more limited (B.C. Hydro, 2018a).

## Summary and Research Gaps

As climate change increases the probability and severity of a range of hazard events in British Columbia, it also increases the potential for interacting and compound hazards. While the probability of these interacting hazard events is lower than that of any individual hazard occurring on its own, many relevant hazards have correlated likelihoods or can even trigger one another in a cascade scenario. Furthermore, the potentially grave impacts that can occur as consequences compound upon each other make consideration of interacting hazards a critical element of worst-case-scenario risk assessment.

This analysis focused on the risk of a water shortage, wildfire, and landslide scenario—perhaps the most plausible for British Columbia—and showed that potential impacts may be severe. This is particularly true in regions of the province already prone to all three hazards, and where hazard events may disrupt critical infrastructure and services.

Further assessment and scenario planning should evaluate the robustness of emergency services and disaster planning to respond to multiple disasters simultaneously. Additional assessment should also include consideration of other combinations of hazards, which have not been analyzed here in detail.

# CONCLUSION

The results of risk assessments can enable important conversations about risk tolerance, the relative value of different assets, and the types of risk management responses needed. The assessment provides a starting point for considering, prioritizing, and coordinating risk management activities across the province. It demonstrates the wide range of risks that climate change poses to the province, as well as their complexity across regions, sectors, and domains of ministerial responsibility. As such, these risks will require a coordinated effort to manage.

In addition, the assessment has highlighted important knowledge gaps and process improvements that would further enhance understanding of climate risks. To build on this assessment, address gaps, and capture a broader range of potential risks—beyond the next steps identified earlier—the following additional work would be useful:

- Further evaluate the adequacy of existing risk mitigation efforts, considering the risk assessment results (this work has begun and will be expanded upon going forward).
- Expand the analysis of each risk event to include a range of future scenarios.
- Further explore the interactions and implications of cascading and compounding events.
- Conduct or encourage research to fill noted data gaps.
- Consider approaches that would be appropriate to use in specific contexts, for example understanding and building on Indigenous climate resilience.
- Examine risks to specific populations and ethnic communities, as well as gender-specific risks.

The *B.C. Climate Change Accountability Act* requires the Minister of the Environment and Climate Change Strategy to prepare a public report every even-numbered calendar year, starting in 2020, describing the risks to B.C. from climate change, progress toward reducing those risks, actions taken to achieve that progress, and plans to continue risk-reduction efforts. This risk assessment represents a first step towards meeting that requirement, and can be updated in the future to account for new findings.

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## APPENDIX A: WHY WAS RCP8.5 CHOSEN FOR THIS ANALYSIS?

The aim of this assessment was to characterize, at a strategic level, the most problematic climate-related risks that could potentially occur in BC in coming decades, using best available evidence. Using RCP8.5, a high estimate of future growth in greenhouse gas concentrations, helps to identify such significant risks. The project team based the assessment of the likelihood of the fifteen climate risk events occurring in the 2050s on climate change studies that modeled impacts under RCP8.5.

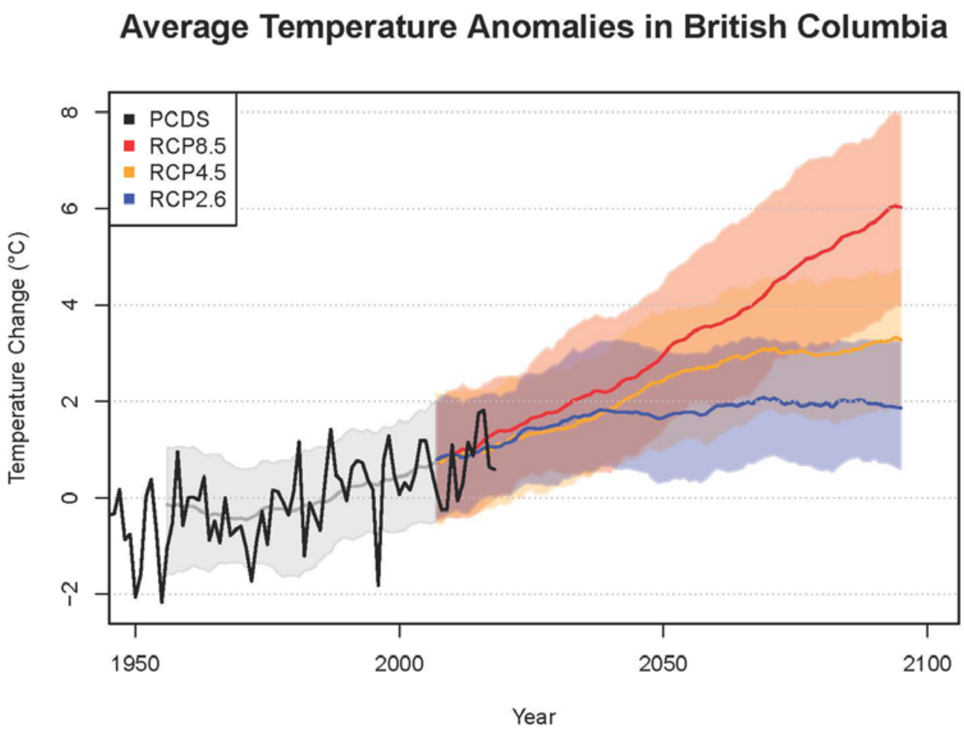
RCP8.5 is characterized by increasing greenhouse gas concentrations in the atmosphere over time. This scenario would result in the greatest temperature change by 2100 of the four scenarios used in the IPCC's 5th Assessment Report (van Vuuren, Edmonds, Kainuma, et al., 2011). The RCP8.5 scenario describes a global future by 2100 that assumes high population growth (12 billion), low economic growth and development (global GDP 250 trillion US2005$ in 2100), high energy demand (nearly 3-fold increase), largely met by fossil fuels (including a nearly 10-fold increase in coal use), and modest improvements in energy intensity (0.5% per year over the course of the century) (Riahi, Rao, Krey et al., 2011). The increase in concentrations of greenhouse gases in the atmosphere are projected to be greatest in the latter half of the 21st century. Atmospheric concentrations of greenhouse gases as measured in 2018 are consistent with projected levels for RCP8.5 (NOAA, 2019; Meinshausen et al. 2011).

Prudent assessment of risk involves explicit consideration of uncertainties. Assuming a high greenhouse gas concentration scenario in risk assessment helps to account for these uncertainties as it encompasses greenhouse concentrations of the other RCPs. All RCPs are based on assumptions that include near-term trends and long-term projections of multiple socio-economic variables. Assumptions about individual variables, and their interaction within each of the RCPs, are subject to uncertainty. The scientific community refines the emissions scenarios as new information becomes available and updated scenarios are used in climate modelling research to inform future climate impact projections.

Projected temperature changes for BC are similar for each RCP by the 2050s (Figure 34). At 2050, the difference between the trend lines for RCP2.6 and RCP8.5 is less than the range of natural variability observed in historical annual temperatures. Assuming the future climate will have a similar range of natural variability in average temperature, there will be little discernable difference in climate impacts in 2050 between the RCPs. As a result, using a different RCP is unlikely to affect the key risk assessment findings.

Recent regional climate impact studies, risk assessments, and adaptation plans conducted by provincial and regional governments and public sector organizations in BC use RCP8.5.

**FIGURE 34.** Average temperature anomalies in British Columbia by deviation from 0. Black line (Pacific Climate Data Set, PCDS) shows past temperatures. Coloured lines are average temperature projections under three scenarios: RCP8.5 (red); RCP4.5 (yellow); and RCP2.6 (blue). Shading around each scenario indicates uncertainty in the projections. (Pacific Climate Impacts Consortium, 2019).

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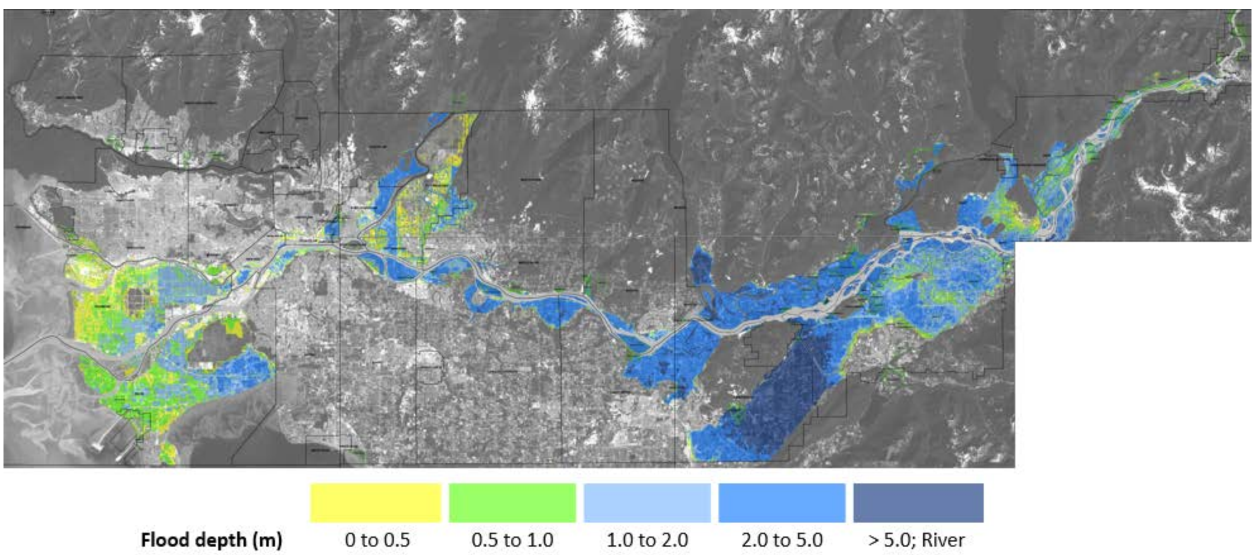
# APPENDIX B: DETAILED RISK ASSESSMENT FINDINGS

## Severe Riverine Flooding

### Scenario

The specific scenario analyzed is today's "500-year flood" on the Fraser River, affecting the Lower Mainland (see **FIGURE 35**).[14] In this scenario, flood depths could exceed 5 m in some locations and last up to two weeks. The flood would most likely occur in the spring, caused by rapid snowmelt combined with heavy rainfall.

**FIGURE 35.** Severe flooding scenario: flood depths under present-day 500-year flood (Northwest Hydraulic Consultants, 2016).




[14] The "500-year" Fraser River flood is defined as the 1894 flood of record (Kerr Wood Leidal Associates Ltd., 2015b; Northwest Hydraulic Consultants, 2016)

## Summary of Findings

Today's 500-year Fraser River flood event would result in extensive flooding in the B.C. Lower Mainland and affect more than 30% of the province's total population. In addition, this event threatens the integrity of existing flood management infrastructure (e.g., dikes). If this event occurred today, it would be the costliest natural disaster to date in Canadian history (Northwest Hydraulic Consultants, 2016).

Though by definition this is a low-likelihood, high-consequence event, climate change could make today's 500-year Fraser River flood up to five times more likely by 2050.

**FIGURE 36.** Risk assessment findings for severe flooding scenario.

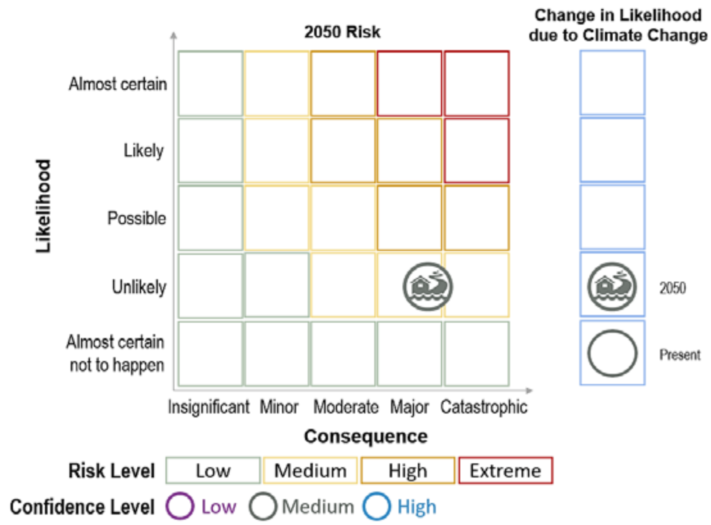



**FIGURE 36** and **TABLE 21** summarize the risk assessment results for this scenario. The highest consequences relate to losses to social functioning and economic vitality. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 21.** Risk Rating Evaluation for Severe Flooding Scenario

| **SEVERE RIVERINE FLOODING: 500-YEAR FLOOD ON THE FRASER RIVER** | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| 1 | The “500-year flood” (for the Fraser River basin, a peak flow of 17,000 $m^3/s$) has a 0.2% chance of occurring in any year. | 2 | **Climate-related risk causes:** Severe spring flooding is driven by periods of hot weather, heavy rain during peak snowmelt, and snowpack volume.<br>**2050 projections:** The “500-year flood” is projected to have a 0.51% to 1% annual chance of occurring by 2050. | Medium |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | 4 | Ten to 100 deaths could occur from fast-moving floodwaters and limited medical/emergency care. | High |
| | Morbidity, injury, disease, or hospitalization | 4 | More than 100 people are at risk of harm due to fast-moving floodwaters, debris, waterborne disease, limited access to critical services, or environmental contamination. | Medium |
| **Social functioning** | Psychological impacts | 5 | Severe psychological impacts are expected for individuals who experience damage to or loss of property or livelihood, evacuation, or loss of family members. | High |
| | Loss of social cohesion | 5 | Recovery and clean up could take months. There is also potential for widespread disruptions to a variety of institutions and services that would affect day-to-day life for at least weeks. | Medium |
| **Natural resources** | Loss of natural resources | 3 | Natural resources could experience damage due to inundation, debris, and water and soil contamination. Recovery could take years. | Low |
| **Economic vitality** | Loss of economic productivity | 5 | Losses are estimated at $22.9 billion, including the agriculture, transportation, energy industries, and damage to ecosystem services. | High |
| | Loss of infrastructure services | 5 | Disruptions to critical infrastructure services could last for months. | Medium |
| **Cost to provincial government** | | 3 | Costs to government might include flood response, post-event cleanup, health services, ecosystem recovery, Disaster Financial Assistance, and AgriRecovery, among others. | Medium |
| **OVERALL RISK** | **CURRENT** | **LOW (4.3)** | | **MEDIUM** |
| | **2050** | **MEDIUM (8.5)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **4.3** out of 25, which equates to **low risk**, and the 2050 risk rating is **8.5** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 1 x 4.3 = 4.3 (Low)

2050 Risk = 2 x 4.3 = 8.5 (Medium)

## Evidence Base

### *Risk Event Scenario*

This scenario represents one illustrative permutation of a severe riverine flood in the province. The consequence ratings are specific to this scenario, but many of the types of consequences described may be transferable to other related scenarios, such as a severe flood in a different river basin.

The specifics of this scenario were based on the *Lower Mainland Flood Management Strategy: Analysis of Flood Scenarios* identified suitable flood scenarios for a regional assessment of flood vulnerability for present day and 2100 (Kerr Wood Leidal Associates Ltd, 2015; Northwest Hydraulic Consultants, 2016). The Fraser River flood scenarios represent freshet flooding from snowmelt and rainfall. The present-day scenario is a 1-in-500 Fraser River flood event and current sea level. This is equivalent to the 1894 flood of record (peak flow of 17,000 $m^3/s$ at Hope). The report does not specify the flood duration, but assumes a two-week flood duration in its loss estimates. Therefore, the project team applied the same assumption here.

### *Likelihood rating*

The present-day likelihood of this scenario is **1** and the 2050 likelihood of this scenario is **2**. By definition, a 500-year event currently has a 0.2% annual chance of occurring. To determine the likelihood of this flood event by 2050, the project team relied on climate change-influenced projections of Fraser River flood flow from the B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD).

By 2050, this flood scenario has a 0.51 to 1% annual chance of occurring. The project team used the conservative end of the range for the rating.

**Likelihood Rating Drivers**

Type of risk event: Discrete

Climate change indicator: Change in likelihood of today's 500-year flood on Fraser River

"Present day" period: 2016

Source of 2050 projections: Modeling study of climate change influence on the 500-year Fraser River flood scenario from 2016 to 2100. Project team interpolation of 2100 projections to 2050.

Emission scenario: SRES A1B and B1

Supporting evidence includes:

- A 1-in-500-year flood event, by definition, has a 0.2% annual chance of occurring.
- Severe spring flooding in the Fraser River is driven by periods of hot weather, heavy rain during peak snowmelt, and snowpack volume. Historically, weather factors such as periods of hot temperatures and heavy rain during peak snowmelt account for 60 to 80% of the flood risk and snowpack volume accumulated over the winter accounts for the remaining 20 to 40% of the flood risk (River Forecast Centre, 2012). Studies reveal that daily high temperatures exceeding 25°C between mid-May and mid-June (compared to the normal high temperature of 18°C) occurring over eight or more consecutive days can produce rapid snowmelt and flooding conditions. Similarly, 30 to 50 mm of rainfall over 48

hours in the Fraser River watershed can produce high flows, while 70 mm or more of rain over 48 hours during peak snowmelt can produce extremely high flows (River Forecast Centre, 2012).

- Modeling from FLNRORD finds that major flood events in the Lower Mainland are increasing in frequency and magnitude. Hydrologic models project that today's 200- to 500-year flood events may occur once every 50 years in 2100 (i.e., today's 500-year event will have a 2% annual chance of occurrence in 2100) (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2014; Pacific Climate Impacts Consortium, 2015; Office of the Auditor General of British Columbia, 2018).[15]
- In order to evaluate the chance of occurrence of a 500-year flood by 2050, the project team interpolated between annual chance evaluations associated with the present day (2016)[16] and 2100. The project team interpolated using both a linear trend to capture a constant rate of change and an exponential trend to capture delayed change, with the assumption that these two scenarios best represent the range of potential pathways for increasing floods over the next century. Following this scheme, the project team estimates the annual chance of today's 500-year flood will fall between 0.51% and 1% for the Frasier River basin by 2050.

**Confidence: Medium**

There are several sources of high-quality independent evidence, and some degree of agreement.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **4.3** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (4+4+5+5+3+5+5+3)/8

Overall Consequence = 4.3

### HEALTH

*Loss of life: 4*

Due to the magnitude and location of this flood, 10 to 100 people could lose their lives from either direct or indirect causes. Direct loss of life could occur if people are caught in fast-moving floodwaters. In addition, limited medical or emergency care or loss of vital services such as power or clean water during and following the event could cause indirect loss of life. If warnings or evacuation orders are not issued in a timely manner, loss of life could exceed 100 people.

[15] The hydrologic model predicting future Fraser River flood frequencies uses two Global Climate Models (GCMs), including HadGEM A1B and HadCM3 B1, which together capture a realistic range of future climate change. Both GCMs were prepared for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment (AR4), which used the most advanced emission scenarios available at the time. These GCM experiments use Special Report on Emission Scenarios (SRES) to describe future global emissions, rather than the most current Representative Concentration Pathways (RCPs) that were part of IPCC AR5. However, there is broad agreement between the two projection scenarios. For example, radiative forcing trajectories under SRES A1B and B1 approximate RCP8.5 and 4.5, respectively, through mid-century. As a result, the project team is confident that the order-of-magnitude projections described within are the best available resource to evaluate the scenario.

[16] The Lower Mainland Flood Management Strategy defines the present day 500-year flood scenario as the 1894 flood of record, rather than a present day time period. Therefore, the project team chose 2016, the year the report was published, to represent present day in the interpolation calculations (Northwest Hydraulic Consultants, 2016).

Supporting evidence includes:

- Approximately 2.6 million people reside in the Lower Mainland and account for 54% of B.C.'s total population (4.8 million people) (Stats Canada, 2018). The population density of Lower Mainland B.C. is 169 people per square kilometre (Public Safety Canada, No date). Within the Lower Mainland, 500,000 people (19%) live or work within the Lower Fraser floodplain and 1.5 million people (58%) are dependent on infrastructure in the Lower Fraser floodplain (Public Safety Canada, No date; Office of the Auditor General of British Columbia, 2018). As a result, more than 30% of the total population (at least 1.5 million people) would be affected by a 500-year flood.
- During the last flood event of this magnitude (in 1894), 10 people died (Northwest Hydraulic Consultants, 2016). Specific causes of death (e.g., drowning vs. injury) are unknown.
- On average flood waters become unsafe at flow depths of 0.8 to 0.9 metres (Shu, Han, Kong, & Dong, 2016). However, low-height, high-velocity floodwaters may be more hazardous to people than high-height, low-velocity floodwaters (Gomez, Kure, Udo, & Mano, 2016).
- At least 10 deaths could occur from a 500-year flood in the Lower Fraser given the number of people exposed, increased population density compared to the 1894 flood event, and a variety of death rate estimates:
  - In North America, 40 people per year, on average, die from floods, based on data from 2006 to 2015 (Guha-Sapir, Hoyois, Wallemacq, & Below, 2017).
  - Flash floods and floods associated with tropical storms are associated with larger fatality numbers than river floods (Ashley & Ashley, 2008).
  - In Washington and Oregon, the river flood mortality rate is 12 and 22 per 100,000 people, covering 1959 to 2005 (Ashley & Ashley, 2008).
  - In the U.S., the deadliest river flood event was a January 1969 flood in California that killed 41 people (Ashley & Ashley, 2008).
  - Public Safety Canada has previously assessed that flooding "could result in more than 50 fatalities" (Public Safety Canada, No date).
- Other factors that could influence loss of life are whether medical or emergency care is accessible during the event and whether utility services such as power and clean water are available (Workshop feedback 2019). See the loss of infrastructure services section for more details on in infrastructure impacts.

**Confidence: High**

A flood event of this magnitude has not occurred in the Fraser River basin since 1894 and development along the Fraser River has changed dramatically over time. A far greater number of people are exposed than in 1894, though more advanced warning of flooding is also available compared to then. Loss of life is ultimately dependent on a number of unknown variables including how quickly flood waters rise, how much warning people are given to evacuate, and how many people evacuate. In addition, there are varying amounts and quality of evidence regarding the flood mortality rate for Canada and British Columbia. A more detailed analysis would be necessary to compute precise mortality risk based on extent and depth of modeled flooding, population demographics (including age and gender), timing of warning, evacuation behaviour, and other factors. However, based on a multitude of sources and evidence from previous events, mortality from this event is likely to be at least 10 people.

### *Morbidity, injury, disease, or hospitalization: 4*

Flooding can cause health hazards beyond fatalities, such as injury, disease, or hospitalization from fast-moving flood waters or debris, limited access to critical infrastructure and services, or environmental contamination. For example, severe flooding can damage water supply systems, create conditions for water-borne diseases, or impair hospital or emergency response capacity. More than 100 people could experience ill health effects due to this scenario. If warnings or evacuation orders are not issued in a timely manner, this number could exceed 1,000 people.

Supporting evidence includes:

- Approximately 2.6 million people reside in the Lower Mainland of B.C., including 500,000 people (19%) who live or work within the Lower Fraser floodplain and 1.5 million people who are dependent on infrastructure in the Lower Fraser floodplain (Public Safety Canada, No date; Office of the Auditor General of British Columbia, 2018). The population density of Lower Mainland B.C. is 169 people per square kilometre (Public Safety Canada, No date).
- There are many populations vulnerable to flooding in Lower Mainland B.C., including growing elderly populations, low-income populations, and immigrant populations. Indigenous communities located along the Fraser River could also be vulnerable to flooding (Public Safety Canada, No date).
- Severe flooding can cause many threats to public health and safety. For example:
  - Severe flooding can damage water supply systems or overwhelm treatment capacity, which may result in a Boil Water Notice threatening public health (Government of British Columbia, No date).
  - Environmental contamination from a flood event would be most significant in areas near agricultural land, transportation and industrial sites, and hazardous waste storage facilities (Northwest Hydraulic Consultants, 2016). Agricultural contaminants may include manure, deceased livestock, or chemical inputs such as pesticides.
  - A study of flood and health risks in Bolivia found that long-duration flood events with shallow flooded areas create increased health risks for water-borne and vector-borne diseases (Gomez, Kure, Udo, & Mano, 2016).
  - Low-height, high-velocity floodwaters may be more hazardous to people than high-height, low-velocity floodwaters (Gomez, Kure, Udo, & Mano, 2016).
  - Limited access to critical infrastructure and services may limit immediate access to medical treatment and inflate health impacts. Under the present day 500-year flood scenario, six ambulance stations and four hospitals are vulnerable to flooding (Northwest Hydraulic Consultants, 2016).
  - Other negative health outcomes include diseases spread through food contamination or insects, carbon monoxide poisoning, and mental health effects (see the psychological impacts section) (Government of Canada, 2018).
- Public Safety Canada has previously assessed that injury impacts from severe riverine flooding will be high and widespread and will require federal support or intervention (Public Safety Canada, No date).

**Confidence: Medium**

A flood event of this magnitude has not occurred in the Fraser River basin since 1894 and development along the Fraser River has changed dramatically over time, suggesting a greater potential for morbidity, injury, disease, or hospitalizations. Several sources of evidence confirm the range of negative health outcomes that could affect the large number of people within the affected area. The number of people affected is ultimately dependent on a number of unknown variables including how quickly flood waters rise, how much warning people are given to evacuate, and how many people evacuate.

## SOCIAL FUNCTIONING

### *Psychological impacts: 5*

This flood scenario has the potential to affect nearly a third of the population of the province and cause severe psychological impacts such as PTSD and depression, particularly to those directly affected (e.g., through damage to or loss of property or livelihood, mandatory or voluntary evacuation, loss of family members or friends). In addition, if the transportation system or utility services are significantly affected there may be a shortage of food and services, further increasing stress and anxiety.

Supporting evidence includes:

- The severity of flooding is the most significant factor in determining mental health effects of flood events (Foudi, Oses-Eraso, & Galarraga, 2017). Other important factors include post-disaster life stressors and level of social support (Goldmann & Galea, 2014).
  - Flood survivors have experienced distress, anxiety, pain, depression, and social dysfunctions, including, in severe cases, post-traumatic stress disorder (Foudi, Oses-Eraso, & Galarraga, 2017; Goldmann & Galea, 2014).
  - Suffering material, physical, or intangible damage negatively affects mental health. Material damage (e.g., structural damage or damage to household contents), however, has the smallest effect (Foudi, Oses-Eraso, & Galarraga, 2017).
  - Key risk factors that may increase vulnerability to disasters include age, low socioeconomic status, minority ethnic status, previous mental health issues, and low social support (Goldmann & Galea, 2014). The relative importance of these factors for flooding-related disasters in particular is unknown.
- Interviews conducted after a 2014 flood event in Burlington, Ontario, as part of a study on the mental health effects of flooding revealed both short-term and long-term mental health impacts (Intact Centre on Climate Adaptation, 2018):
  - Within a month of the event, 47% of flooded household[17] respondents were worried or stressed about flooding, compared to 11% of households that have never flooded.
  - Three years after the event, 48% of flooded household respondents were worried about flooding during rain events, compared to 3% of households that have never flooded.
  - For 56% of flooded households interviewed, at least one household member had to take time off from work. The average length of time per flooded household was seven days off work.
- The average cost of a flooded basement is $43,000, which can add financial stress to those affected by flooding (Intact Insurance, 2018).
- If this flood scenario occurred in the present day, an estimated 266,000 people would have to seek shelter due to building impacts (Northwest Hydraulic Consultants, 2016). Further population growth by 2050 could increase this number.

[17] Flooded households experienced basement flooding only.

- Disruptions to the transportation system may limit food supply in as little as four days. Disruptions to ferry and barge terminals may also significantly affect the delivery of goods to Vancouver Island and other coastal communities (Northwest Hydraulic Consultants, 2016).
- Disruptions to utility services may further delay recovery and the ability of evacuated individuals to return home, increasing stress and anxiety. See the loss of infrastructure services section for more details.
- Psychological impacts related to agriculture are likely to be significant due to loss of agricultural livelihoods and assets, difficulty relocating livestock and possible associated losses (e.g., dairy animals), limited ability to transport critical agricultural inputs (e.g., feed) and outputs (e.g., crops), and increased stress or anxiety from farm management challenges and complexities (MacNair, 2019). In addition, farmers affected by a spring freshet flood will not be able to quickly or easily recover due to impacts to both annual and perennial crops. High value perennials such as berries can take years to recover (BC Agriculture & Food Climate Action Initiative, 2012). See the loss of economic productivity section for projected losses of agricultural crops from this scenario.
- During a 1948 Fraser River flood (a 1-in-200 year flood), 16,000 people were evacuated, 2,300 homes were damaged or destroyed, and 1,500 residents were left homeless. In addition, floodwaters inundated transcontinental rail lines and the Trans-Canada Highway (Northwest Hydraulic Consultants, 2016).

**Confidence: High**

There are several high quality sources detailing potential mental health effects from flooding, including post-disaster stressors such as disruptions to transportation or agriculture. There is widespread agreement across multiple sources that flooding of this magnitude, which would have ripple effects lasting for more than six months and affect more than 30% of the population, would cause severe psychological impacts. However, more specific research on psychological impacts of flooding in B.C. is needed to better understand the scope and extent of impacts.

### *Loss of social cohesion: 5*

Recovery and cleanup from a two-week-long flood event could take months, especially for hard-hit communities. For those directly affected by the flood damage (e.g., flooded home, flooded workplace or route to work), disruptions to daily life could last for months. The flood could also cause lingering after-effects to infrastructure services and disruptions to daily life. Given the potential for widespread disruptions to many critical institutions and services (e.g., wastewater treatment), even individuals who do not experience direct flood damage could experience at least a weeks-long disruption to daily life in terms of available services.

Supporting evidence includes:

- Many communities are located within the flooded area under this scenario (shown in **FIGURE 35**), indicating that many communities could experience direct flood damage to homes and critical institutions. This includes 54 of 90 First Nations' reserves and treaty lands, which are expected to experience some level of inundation from a 500-year flood (Northwest Hydraulic Consultants, 2016).
- Even individuals who do not experience direct flood damage may assist with community cleanup efforts that last for days or weeks following the event.

- There is significant potential for interruption to day-to-day life due to the following (see the loss of infrastructure services section for additional impacts):
  - There is potential for inundation of all wastewater treatment facilities in metro Vancouver and the Fraser Valley Regional District. These facilities serve the entire urban population base including some areas that may be directly affected by flooding (Northwest Hydraulic Consultants, 2016).
  - Six police stations, 19 fire halls, six ambulance stations, four hospitals, and 116 schools could be flooded under this scenario (Northwest Hydraulic Consultants, 2016). Other local and provincial government infrastructure could also be vulnerable to flooding.
  - Communication facilities are vulnerable to system overload or damage from a flooding event including call centres, cell towers, cables, and internet and telephone land lines (Northwest Hydraulic Consultants, 2016).
  - Flooding could cause disruption to individual and commercial fishing, which could be especially disruptive for Indigenous and rural communities. A decrease in fishing for Indigenous communities affected by a dam breach in 2014 resulted in a shift in diet, physical activity, and cultural practices as well as a decrease in community income and employment opportunities (Shandro et al., 2016).
- For agricultural communities, severe flooding may significantly damage annual and perennial crops causing seasonal or potentially long-term impacts to livelihood. Impacts to local or regional food security are also possible due to decreased agricultural productivity (BC Agriculture & Food Climate Action Initiative, 2012; BC Agriculture & Food Climate Action Initiative, 2014).
- The risk to government reputation from any loss of life due to flooding is significant (Public Safety Canada, No date).

**Confidence: Medium**

There are several high quality sources that support significant impacts to social cohesion. Whether or not disruptions to the broader population that do not experience direct flood damage to their homes, workplace, or community last longer than the two-week duration of the flood is dependent on the extent of damage to infrastructure services. Impacts to drinking water systems and elements of local government infrastructure are largely unknown, as are the extent of damage and timeline for recovery for all infrastructure services. This rating assumes a significant portion of the population will experience disruptions that last beyond the duration of the flood event.

### NATURAL RESOURCES: 3

Although natural resources located in flood-prone areas are generally resilient to flood conditions, a 500-year severe flood will also extend to areas not accustomed to inundation. Ecosystems and natural resources could experience stress or damage due to inundation, debris, and water and soil contamination from nearby agricultural, industrial, or waste sites. This flood scenario is likely to affect a number of unique and fragile ecosystems such as riparian areas, intertidal marshes, and wetlands that could take years to recover.

Supporting evidence includes:

- The Lower Fraser River and its estuary support unique and fragile ecosystems such as riparian areas, intertidal marshes, and wetlands. The floodplain and channels of the lower Fraser River between Hope and Mission are host to some of the most biologically significant riparian and aquatic ecosystems in Canada. In addition, they are known to support 30 or more fish species including the largest spawning population of salmon in B.C. and are part of a major salmon migration route. These ecosystems could be adversely affected by a large flood in the region (Public Safety Canada, No date).

- The Public Safety Canada flood risk assessment for B.C. rated environmental impacts at the highest risk level, primarily due to contamination concerns (Public Safety Canada, No date).[18] Due to the presence of heavy industry along the Fraser River, this flood scenario is likely to cause significant environmental and ecosystem impacts, including contamination of surface and groundwater. Locations near agricultural land, transportation, industrial sites, and hazardous waste storage facilities have an elevated risk of contamination during a flood event. Possible contaminants include chemicals, fertilizers, petroleum products, raw sewage, and hazardous waste (Public Safety Canada, No date).
- This flood scenario would result in 656,000 tons of debris (Northwest Hydraulic Consultants, 2016). Debris may disrupt or contaminate sensitive habitats or ecosystems.
- Impacts to natural resources could also negatively affect ecosystem services. See the economic productivity section for more information.

**Confidence: Low**

There are varying amounts and quality of evidence regarding severe flooding impacts to natural resources. Knowledge gaps include how the flood scenario would affect endangered species, migratory birds, and sensitive ecosystems. In addition, recovery time will vary depending on the affected species and ecosystems as well as local conditions. As a result, this rating relies heavily on expert judgment.

## ECONOMIC VITALITY

### *Loss of economic productivity: 5*

Total economic losses are estimated at $22.9 billion. Damages to multiple industries, including agriculture, transportation, and energy are each estimated at well over the "catastrophic" threshold of $1 billion. In addition, flooding could affect ecosystem services. When ecosystems are damaged by direct human use, natural disasters (such as flooding), or climate change, the services provided are often degraded or cease altogether. These services must then be replaced by costly man-made facilities or processes that provide the same services (e.g., the construction costs related to water runoff or flooding control if forest cover is removed or damaged).

Supporting evidence includes:

- Total economic losses for this flood scenario are estimated at $22.9 billion, which includes direct building losses, transportation losses, agricultural losses, and infrastructure/institutional losses (Northwest Hydraulic Consultants, 2016; Fraser Basin Council, 2016).

[18] A "5" rating for environmental impacts is defined by a variety of possible criteria, including greater than 75% of flora or fauna affected or one or more ecosystems significantly impaired; air quality has significantly deteriorated; water quality significantly lower than normal or water level greater than three meters above highest natural level; soil quality or quantity significantly lower (i.e., significant soil loss, evidence of lethal soil contamination) than normal; greater than 15% of local area affected.

- Modelling using Hazus indicated $9 billion in building losses, including 3,600 buildings damaged and 690 buildings destroyed. The majority of losses are attributed to residential and commercial buildings (Northwest Hydraulic Consultants, 2016).[19]
- Transportation losses are estimated at $7.7 billion (Northwest Hydraulic Consultants, 2016).[20]
- Agricultural losses for this scenario could reach $1.6 billion.[21]
  - Damage to agricultural buildings is estimated at $223 million and damage to agricultural equipment is estimated at $50.7 million (Northwest Hydraulic Consultants, 2016).[22]
  - Fraser River flooding could also result in the loss of 70% of forage, 50% of annuals, 50 to 80% of perennials, 60% of poly greenhouse crops, 70% of greenhouses, and 10% of the dairy[23] sector (Northwest Hydraulic Consultants, 2016).[24]
- Infrastructure/institutional losses are estimated at $4.7 billion (Northwest Hydraulic Consultants, 2016). See the loss of infrastructure services section for more details.

- Over one third of farmland in the Lower Mainland is located within the Fraser River floodplain and therefore vulnerable to flooding.[25] Additional agricultural impacts include (BC Agriculture & Food Climate Action Initiative, 2014):
  - Disruptions to supply chains (e.g., farm inputs and transportation)
  - Permanent or seasonal losses of productivity
  - Livestock relocation and stress
  - Soil and water contamination from farms due to chemicals, nutrients, or pathogens
  - Water-logged soils
- Two energy utilities in False Creek and Richmond are vulnerable to inundation (Northwest Hydraulic Consultants, 2016).
- Loss of life also has an economic impact. The range of loss of life from 10 to 100 can be valued at $52 to $520 million, based on the number of lives projected to be lost (Treasury Board of Canada Secretariat, 2007).[26,27]
- The Public Safety Canada flood risk assessment for B.C. rated the local economic impact category as "greater than 15% of local economy impacted" (Public Safety Canada, No date).
- Properly functioning ecosystems provide an array of free benefits to humans in the form of ecosystem services. These services fall into the broad categories of supporting, provisioning,

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[19] This estimate is based on Hazus modeling and is based on default recovery times ranging from 1 to 33 months. Hazus (Hazus-MH 2.1) was developed by the U.S. Federal Emergency Management Agency and adapted for Canadian conditions by Natural Resources Canada. Building-related loss projections encompass the cost of repair or replacement of residential, commercial, industrial, and public/institutional buildings damaged or destroyed by flood, and include losses relating to inventory, relocation, and wages.
[20] Loss projections for transportation revenues from delays and cancellations in cargo shipping. Losses from interruptions to rail traffic were estimated based on freight trans-shipped through Port Metro Vancouver. Interruptions to highway traffic and to Vancouver International Airport were discussed but not quantified. Transportation losses assume four weeks of disruptions.
[21] Agricultural losses were estimated based on Land Use Inventory information and Stats Canada's 2011 Census of Agriculture data. Farmer losses from Hazus data were based on flood inundation exceeding a two week critical period. Loss projections for agriculture include agricultural buildings and equipment damaged or destroyed, lost farm gate sales, and replanting costs.
[22] Estimated losses based on two-week flood durations.
[23] Livestock estimates were based on the assumption that most livestock would be moved to higher ground prior to an impending flood. Any losses due to insufficient time to complete evacuations are not accounted for.
[24] The agricultural loss estimates are based on the assumption that flooding occurs between May and June and lasts for two weeks.
[25] Percentage determined using inundation mapping.
[26] Value in 1996 CAD.
[27] The Treasury Board of Canada Secretariat expects departments to use a Value of a Statistical Life of $5.2 million adjusted for inflation since 1996.

regulating, and cultural services, and may or may not be directly tied to market activity. Examples of these ecosystem services include: nutrient recycling and soil formation (supporting), timber and crops (provisioning), carbon sequestration and water purification (regulating), and spiritual significance and recreation (cultural).

- In B.C.'s Lower Mainland alone, forests provide an estimated $1.2 billion annually in flood protection services (Wilson, 2010).[28] Extrapolating to the entire province, flood protection services provided by forests are estimated at an annual value of $52 billion.[29]
- Flooding that results in the damage of additional ecosystems, would result in additional ecosystem service damages. In the Lower Mainland, it is estimated that ecosystems provide $5.4 billion worth of benefits per year (Wilson, 2010). Extrapolating to the entire province, ecosystem services provide an estimated annual value of $232 billion.
- The subset of industry and ecosystem services that could be affected by a severe flood is unknown, but expected to be relatively large compared to the moderate flood scenario given the vast area of the floodplain and the number of communities affected.

**Confidence: High**

Although is it difficult to estimate the total cost to economic productivity, there are several sources of high-quality independent evidence that indicate costs will be significantly above the $1 billion threshold. Indirect costs are largely not accounted for in the literature, suggesting that the estimates presented are conservative estimates for costs to economic productivity.

*Loss of infrastructure services: 5*

Disruptions to critical infrastructure services (e.g., transportation, energy, communication, and wastewater treatment) could last for months depending on the extent of flood damage. Estimated infrastructure and institutional losses from this event are $4.7 billion. Impacts could include washed out transportation infrastructure, loss of electrical services, dike failure, and inundated wastewater treatment facilities, among others.

Supporting evidence includes:

- Infrastructure/institutional losses for this scenario are estimated at $4.7 billion (Northwest Hydraulic Consultants, 2016).[30,31]
- A 2015 review of the status of dikes along the Fraser River found that 96% of dikes in the Fraser Valley do not meet current standards and rated most dikes as "fair to poor" or "poor to unacceptable" (Northwest Hydraulic Consultants, 2015). As a result, it is likely that 36 dikes would fail under this flood scenario (Northwest Hydraulic Consultants, 2016).

[28] Values in present-day, 2018 CAD.
[29] This extrapolation was conducted by scaling the flood protection values for B.C.'s Lower Mainland (Wilson, 2010) to the entire area of British Columbia.
[30] Infrastructure and institutional buildings are defined as substations, airports, marine facilities, rail lines, critical highway routes and arterial roads, rapid transit lines, wastewater treatment plants, police and emergency services, hospitals, municipal halls and work yards, and other structures.
[31] Infrastructure/institutional losses are order-of-magnitude estimates based on rough assumptions and replacement costs by FEMA. They do not incorporate durations.

- All wastewater treatment facilities in Metro Vancouver and the Fraser Valley Regional District could flood under this scenario. These facilities serve the entire urban population base including some areas that may be directly affected by flooding (Northwest Hydraulic Consultants, 2016).
- A major flood can also disrupt water supply systems by causing flood damage to infrastructure or overwhelming the capacity of the system and thereby not being able to adequately treat the water (Vancouver Coastal Health, 2019).
- Twenty-three hydro substations are expected to flood under this scenario. This could result in loss of electrical service for an undetermined amount of time (Northwest Hydraulic Consultants, 2016).
- Although some transmission towers are expected to be exposed to flooding and scouring, the sensitivity of the transmission grid is deemed low due to transmission lines being elevated above floodwaters (Northwest Hydraulic Consultants, 2016).
- For the oil and gas industry, flooding can disrupt operations (e.g., oil extraction) and damage infrastructure (e.g., pipelines) (Lapp, 2019).
- Communication facilities are vulnerable to system overload or damage from a flooding event including call centres, cell towers, cables, and internet and telephone land lines (Northwest Hydraulic Consultants, 2016).
- Six airports, including Vancouver International Airport, are deemed vulnerable to flooding[32] (Northwest Hydraulic Consultants, 2016).
- Port facilities are vulnerable to flooding, although the degree of vulnerability is dependent on the specifics of each facility (e.g., the location of electric motors) (Northwest Hydraulic Consultants, 2016). The Port of Metro Vancouver is Canada's largest, busiest, and most diverse port and is therefore critical to the province and Canada's economy (Public Safety Canada, No date).
- All three Class 1 railways (CN Rail, CP Rail, BNSF) as well as the Southern Railway of B.C. shortline are vulnerable to flood-related disruptions. There could be losses of freight and cargo shipments and loss or reduction of freight services in the Lower Mainland affecting supply chains and causing cascading effects. Passenger rail services are also vulnerable. Rail bridges may also be vulnerable to scour damage (Northwest Hydraulic Consultants, 2016).
- A number of provincial highways and municipal arterial roads north and south of the Fraser River are subject to inundation (Northwest Hydraulic Consultants, 2016).
- Although most of the rapid transit lines are elevated, the Expo Line and Millennium Sky Train lines may still be vulnerable to flooding due to the location of power sources and electrical equipment. Flood damages could cause loss of service (Northwest Hydraulic Consultants, 2016).
- The Public Safety Canada risk assessment for B.C. rated the impacts to transportation infrastructure, energy, and utility infrastructure as the highest risk level due to the number of vulnerable critical infrastructure (Public Safety Canada, No date).

**Confidence: Medium**

Multiple risk assessments have evaluated the consequences of a 500-year flood on the Fraser, including assessing potential impacts to a variety of infrastructure. The extent of damage and timeline for recovery,

[32] The Lower Mainland Flood Management Strategy does not specify what riverine or coastal flood scenarios each airport is vulnerable to. Vancouver International Airport, however, is noted to be vulnerable to this scenario.

however, are unknown and dependent on the specifics of the flood event (e.g., duration and extent of inundation for each infrastructure asset).

### COST TO PROVINCIAL GOVERNMENT: 3

This flood scenario would be the most costly natural disaster in Canadian history to date, indicating a significant cost to the provincial government. However, assuming that this event would trigger significant financial assistance from the Government of Canada through DFAA, the cost to the provincial government is expected to be on the order of $375 million to $750 million. The provincial government could bear costs such as flood response, post-event cleanup, health services, ecosystem recovery, Disaster Financial Assistance, and AgriRecovery and other business risk management programs, among others.

Supporting evidence includes:

- The level of expected damage from this scenario would be costlier than any disaster to date in Canadian history (Northwest Hydraulic Consultants, 2016; Public Safety Canada, No date). The scenario considered here is expected to result in $22.9 billion in total economic losses[33] (Fraser Basin Council, 2016).
- During the 1948 Fraser River flood event, recovery costs were $150 million (in 2010 dollars) (Northwest Hydraulic Consultants, 2016). The Fraser Basin Council estimates damages from the 1948 flood at $210 million (in 2010 dollars) (Fraser Basin Council, No date). At a per diem cost of roughly US$316, the present day cost of a single-day evacuation for the 1948 Fraser River flood (16,000 people evacuated) is US$5,056,000 (U.S. Department of State, 2019).
- Costs to the provincial government would include flood response, post-event cleanup, and AgriRecovery and other business risk management programs (e.g., Production Insurance, AgriInvest, AgriStability).
  - Assuming that over 260,000 people would have to evacuate their homes for a flood of this magnitude, at a per diem cost of roughly US$316, the cost of a single-day evacuation is US$82,160,000 (U.S. Department of State, 2019).
  - The project team was unable to precisely estimate the agriculture-related business risk management program costs for this scenario. However, if all or a majority of the existing flood mitigation infrastructure failed, this event would likely trigger a federal-provincial recovery initiative under the AgriRecovery policy framework (Agriculture and Agri-Food Canada, 2018a). For AgriStability, losses at the individual farm level would have to exceed a 30% margin decline for the whole farm (Agriculture and Agri-Food Canada, 2018b).
- The provincial government would likely be responsible for some portion of health care costs, although the project team could not determine the exact cost share between the federal and provincial government for the following estimates:

[33] This figure includes residential, commercial, industrial, public/institutional buildings, interrupted cargo shipments, infrastructure, and agriculture losses. Building-related loss projections encompass the cost of repair or replacement of residential, commercial, industrial, and public/institutional buildings damaged or destroyed by flood, and include losses relating to inventory, relocation, and wages. Loss projections for interrupted cargo shipments are based on revenues from delays and cancellations in cargo shipping. Loss projections for agriculture include agricultural buildings and equipment damaged or destroyed, lost farm gate sales, and replanting costs.

- According to the Canadian Institute for Health Information (2017), the cost of a standard hospital stay in B.C. is on average $6,135.[34] Although not all cases of morbidity, injury, or disease are likely to result in hospitalization, the estimated range of 100 to 1,000 hospitalizations as a result of severe flooding can be valued at $613,500 to $6,135,000. Some portion of this cost would be covered by the provincial government.
- An estimated 30% to 60% of affected populations will need some form of mental health-related assistance following a disaster (NIST, 2017). Rates for severe, moderate, and mild mental illness can range from 6% to 26% up to 30 months following a disaster (FEMA, 2012,). Treatment costs for these mental illness cases are estimated at (FEMA, 2012):
  - 12 months post disaster: US$822 per person
  - 18 months post disaster: US$639 per person
  - 24 months post disaster: US$567 per person
  - 30 months post disaster: US$414 per person

- Other costs to government might include:
  - Cleanup and recovery from contaminants (Workshop feedback, 2019).
  - Habitat restoration for sensitive species and ecosystems (Workshop feedback, 2019).
  - Infrastructure repairs (Workshop feedback, 2019).
- If the Government of B.C. declares a natural disaster eligible for Disaster Financial Assistance,[35] local government bodies, homeowners, residential tenants, small business owners, charities, and farmers can apply for monetary assistance from the provincial government for uninsurable losses (Wadhwani, 2018; Huffpost Canada, 2015; Government of British Columbia, 2018).
  - For individuals, the province will cover up to 80% of uninsurable disaster-related damages greater than $1,000, to a maximum claim of $300,000 (Government of British Columbia, 2018).
  - For local governments, the province will cover up to 80% of recovery measures greater than $1,000 to replace essential materials, including rebuilding or replacing essential public infrastructure (Government of British Columbia, 2018).
  - The province will also cover 100% of the cost to local governments to run emergency operations centres (Wadhwani, 2018).
- For a large-scale disaster such as a 500-year flood, the Government Canada would likely provide financial assistance through the DFAA, which would significantly lower the burden on the provincial government (Public Safety Canada, 2019). For example:
  - For a disaster totaling $1.5 billion, the Government of Canada would provide $1.3 billion in financial assistance to the Government of British Columbia. The province would be responsible for $179 million.
  - For a disaster totaling $500 million, the Government of Canada would provide $421 million in financial assistance to the Government of British Columbia. The province would be responsible for $79 million.
  - For a disaster totaling $50 million, the Government of Canada would provide $19 million in financial assistance to the Government of British Columbia. The province would be responsible for $31 million.

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[34] The value is in 2017 CAD. This measure divides a hospital's total inpatient expenses by the number of hospitalizations it sees in a year. The number is adjusted for some differences in the types of patients a hospital sees to make it more comparable with other hospitals.
[35] Eligibility is determined between the provincial and local government.

**Confidence: Medium**

Estimating the total cost to the provincial government presents many challenges. In particular, there is a knowledge gap regarding the cost of AgriRecovery, insurance programs, and other business risk management programs. In addition, this rating assumes significant financial assistance from the Government of Canada. If the province was responsible for the total cost of the disaster it could exceed the "catastrophic" threshold.

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## Moderate Flooding

### Scenario

The specific risk event scenario analyzed is a moderate flood in a single B.C. community, which is designed to be representative of any location in British Columbia. A moderate flood, for the purpose of this assessment, is defined as one with a *greater than* 1% annual chance of recurrence (e.g., a 50-year event equals a 2% annual change of occurrence).

### Summary of Findings

B.C. experiences multiple flood events across the province each year. For example, **FIGURE 37** illustrates a subset of the communities affected by the 2017 flood season (Tzembelicos et al., 2018). A 2017 annual survey of local governments for the Climate Action Revenue Incentive Program found that urban and overland flooding from extreme weather events is the most common impact on and concern of local governments (Climate Action Revenue Incentive Program, 2018).

**FIGURE 37.** 2017 flood season in southeast B.C. (Tzembelicos et al., 2018).

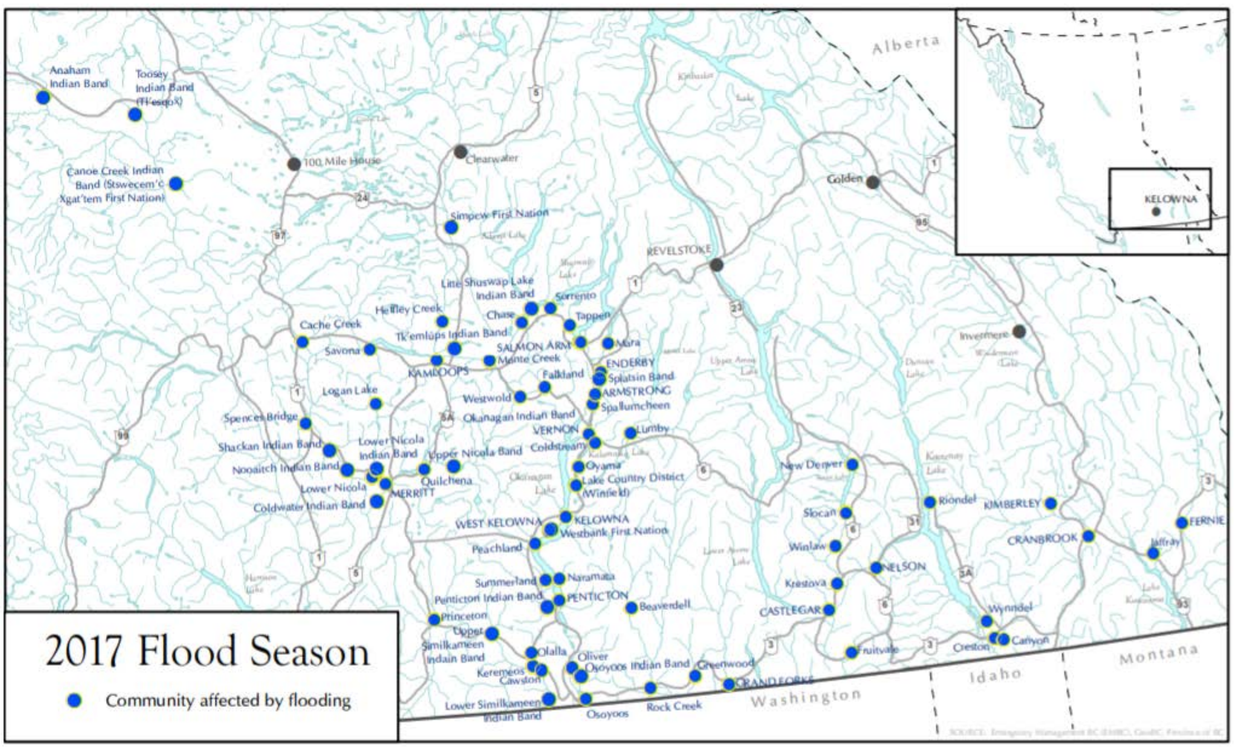
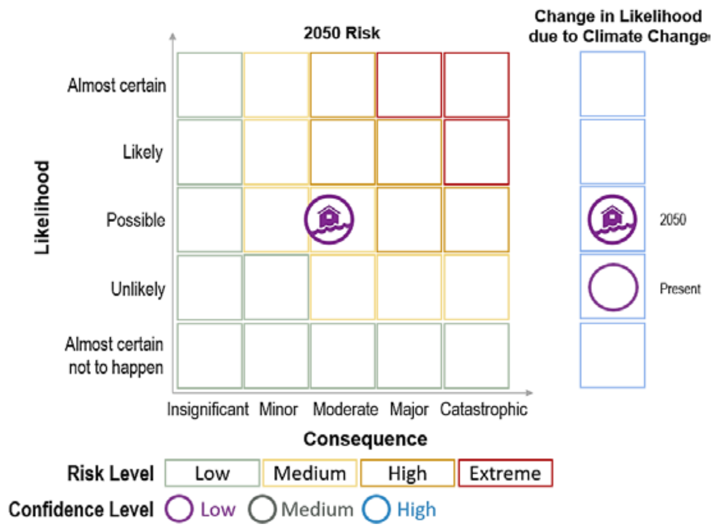


**FIGURE 38.** Risk assessment findings for moderate flooding scenario.




Although the location and severity of flooding varies from year to year, climate change is expected to increase the frequency of both major and moderate flood events. Therefore, in addition to potentially contributing to a major/severe flood (see Severe Riverine Flooding risk event), climate change is also expected to increase the frequency of lower-level floods in many parts of the province. This could include repeat flooding in certain locations, or more flood seasons with simultaneous flooding occurring in multiple communities, such as in 2017. Individually and cumulatively, more frequent moderate flood events can put a strain on both local and provincial government resources. This assessment uses recent moderate flooding in Cache Creek and Grand Forks as proxies to understand province-wide consequences of moderate flood events.

**FIGURE 38** and **TABLE 22** summarize the risk assessment results for this scenario. The highest consequences relate to loss of social cohesion and loss of infrastructure services. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 22.** Risk Rating Evaluation for Moderate Flooding Scenario

| MODERATE FLOODING: MODERATE FLOOD IN A SINGLE COMMUNITY | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **2** | A moderate flood event is defined as having a greater than 1% annual chance of occurrence. | **3** | **Climate-related risk cause:** Moderate flood frequency is driven by increased precipitation, more frequent heavy rain events, and increased temperatures causing greater snowmelt.<br>**2050 projections:** A moderate flood event is estimated to have a return period of 11 to 50 years due to a projected increase in 20-year annual maximum one day precipitation and changes in snowmelt | Low |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **3** | Two to 10 deaths could occur from fast-moving floodwaters and limited medical/emergency care. | Low |
| | Morbidity, injury, disease, or hospitalization | **3** | More than 5% of the community is at risk of harm due to fast-moving floodwaters, debris, limited access to critical infrastructure and services, or environmental contamination. | Low |
| **Social functioning** | Psychological impacts | **2** | Individuals affected by flood damage, temporary displacement, or disruptions to utilities are expected to experience moderate psychological impacts. | Medium |
| | Loss of social cohesion | **4** | For individuals who experience direct flood damage to homes or businesses, recovery and clean up could take weeks, and flooded roads could disrupt daily life. | Low |
| **Natural resources** | Loss of natural resources | **2** | Natural resources could experience damage due to inundation, debris, and water and soil contamination. Recovery could take weeks to months. | Low |
| **Economic vitality** | Loss of economic productivity | **3** | Economic losses could range between $10 million and $99 million due to business/tourism losses, decreased agricultural productivity, and loss of ecosystem services, among other. | Low |
| | Loss of infrastructure services | **4** | Disruptions to transportation, water, electricity, and other infrastructure services could last for weeks. | Low |
| **Cost to provincial government** | | **2** | Costs to government might include flood response, post-event cleanup, health services, Disaster Financial Assistance, and AgriRecovery. | Medium |
| **OVERALL RISK** | **CURRENT** | **LOW (5.8)** | | **LOW** |
| | **2050** | **MEDIUM (8.6)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **5.8** out of 25, which equates to **low risk**, and the 2050 risk rating is **8.6** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence
Present Risk = 2 x 2.9 = 5.8 (Low)
2050 Risk = 3 x 2.9 = 8.6 (Medium)

## Evidence Base

### *Risk Event Scenario*

This scenario represents one example of a single moderate flood in British Columbia. While these consequence ratings are for just one moderate flood, these events could occur in multiple locations at once, as in 2017. The cumulative effects of multiple moderate flood events could result in higher consequence ratings.

Examples of "moderate floods" from the recent past that inform this scenario and assessment of consequences include:

- Cache Creek experienced three moderate flood events in a span of four years (Roden, 2018; Azpiri, 2018; Brend, 2018):
  - In early spring 2018, the Village of Cache Creek experienced 90-year flood levels when the Bonaparte River and its tributaries overflowed due to rapid snowmelt prompting a state of local emergency. In addition, this flood event occurred in early spring when typically flooding does not occur until late spring. The 2017 Elephant Hill wildfire is thought to be a contributing factor to the early flooding as there was less vegetation and a more impervious surface layer, which facilitated more runoff (Azpiri, 2018).
  - In May 2017, Cache Creek experienced rapid snowmelt and significant flooding resulting in one death (Roden, 2018).
  - On May 23, 2015, Cache Creek experienced 26 millimetres of rain in less than an hour causing significant flash flooding and damage to homes and infrastructure (Roden, 2018; Huffpost Canada, 2015).
- Grand Forks experienced a 70-year flood in May 2018. The event was triggered by two days of intense rainfall and temperatures above 20°C, which caused increased snowmelt when snowpack was already 150% above normal levels (Wadhwani, 2018; CTV News, 2018).
- Dawson Creek experienced a 100-year flood in June 2016 due to 98.6 mm of rain over a two day period, causing significant damage to homes and infrastructure (Canadian Disaster Database, 2019).

## *Likelihood rating*

The present-day likelihood of this scenario is **2** and the 2050 likelihood of this scenario is **3**. Moderate flooding is largely dependent on the frequency and magnitude of heavy precipitation events, which can quickly inundate surface water systems. To evaluate the scenario likelihood, the study team drew on recent projections for future maximum precipitation events across B.C., as well as expected changes in underlying climate-related causes, such as increased seasonal precipitation and air temperatures driving more vigorous snowmelt. The project team additionally considered future flood recurrence interval projections. Based on the standard return period of a moderate flood event as well as the proxy examples, these events are currently expected to happen about once every 51 to 100 years. As a result, the project team expects that in 2050, moderate flood events could happen about once every 11 to 50 years.

**Likelihood Rating Drivers**

Type of risk event: Discrete

Climate change indicators:

- Change in 20-year annual maximum precipitation (1971-2000 to 2070-2100)
- Change in likelihood of historical 100-year flood events

"Present day" period: Varies by indicator

Source of 2050 projections: Varies by indicator

Emission scenario: Varies by indicator

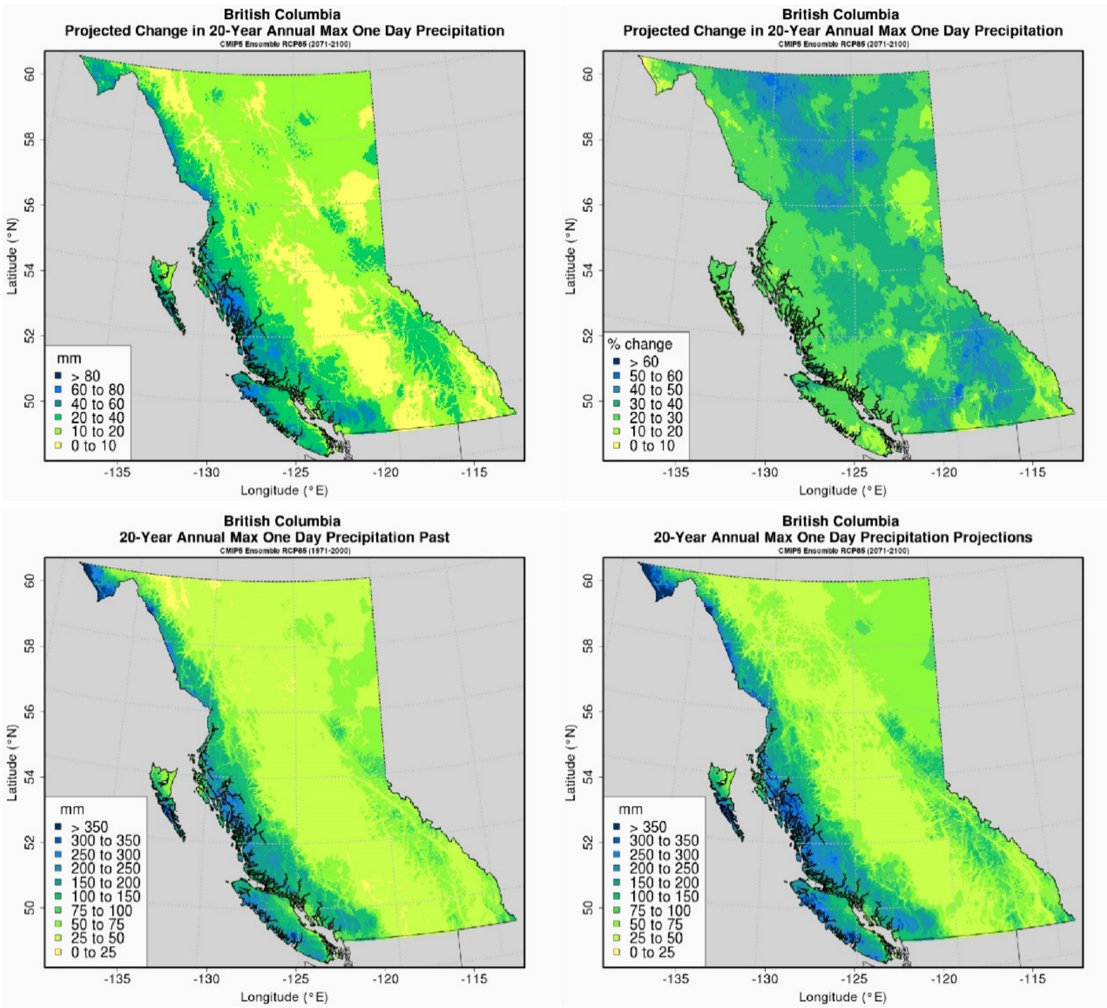
Supporting evidence includes:

- Ensemble median GCM projections indicate that a range of climate-related causes will drive more frequent moderate flooding by mid-century in British Columbia. These include increasing temperatures causing earlier and more rapid snowmelt; increasing annual and winter precipitation causing more rainfall during the traditional flood season; and increased frequency and severity of heavy rainfall events. The project team draws on the following B.C. climate projections expected for mid-century relative to the historical baseline (1961 to 1990) (Pacific Climate Impacts Consortium, 2012):

- Increase in annual mean temperature of 1.8°C ($10^{th}$ to $90^{th}$ percentile: 1.3°C to 2.7°C)
- Increase in annual precipitation of 6% ($10^{th}$ to $90^{th}$ percentile: 2% to +12%)
- Decrease in summer precipitation of 1% ($10^{th}$ to $90^{th}$ percentile: -8% to +6%)
- Increase in winter precipitation of 8% ($10^{th}$ to $90^{th}$ percentile: -2% to +15%)

- The Pacific Climate Impacts Consortium used ensemble averages from a set of 12 statistically downscaled GCMs to map the change in annual maximum daily precipitation (**FIGURE 39**) between the baseline time period (1971 to 2000) and end-of-century (2071 to 2100) assuming emissions follow RCP8.5 (Sobie, 2017). These extreme daily precipitation events strongly control the occurrence of destructive moderate flooding. The analysis shows a marked increase in extreme short-term precipitation throughout the $21^{st}$ century. Coastal B.C. may see an additional 60 to 80 mm of rain per event, while the largest percentage increases are expected to occur in north central B.C. and the Southeastern Rocky Mountains. The analysis is for end-of-century but suggests that the results are indicative of the direction of mid-century change. While the magnitude of change may be lower (by ~50%), the spatial pattern of change is likely similar to what will be experienced by mid-century.

**FIGURE 39.** Projected change in 20-year annual maximum one day precipitation for British Columbia between 1971 to 2000 and 2071 to 2100. (Top left) absolute precipitation change (mm); (top right) percentage precipitation change; (bottom left) baseline maximum one day precipitation; (bottom right) projected maximum one day precipitation. Figures provided by the Pacific Climate Impacts Consortium.




- Projections of future flood hazards reveal that return periods for historical 100-year flood event will reduce to 50 years or less by 2100 for low-lying and flood prone areas across British Columbia (Gaur, Gaur, & Simonovic, 2018). As a result, flood risk will become increasingly amplified in areas currently most prone to flooding.[36] The underlying drivers of this shift in flood frequency are warmer temperatures causing earlier and more rapid snowmelt and increased precipitation. Both of these factors contribute to expected increases in peak flows.
- To illustrate the projections elucidated here, the project team considers recent historical evidence of moderate flooding in the province. Several communities have experienced moderate flooding in the last few years primarily due to snowmelt and heavy rain, including:

[36] Projections also indicate that for high elevation areas experiencing increased temperatures and decreased snowfall in winter, a historic 100-year flood event will have a future (2100) return period of 165 to 200 years (Gaur, Gaur, & Simonovic, 2018).

- Recent flood events in Cache Creek were most commonly a result of rapid snowmelt, but decreased vegetation from wildfire damage and flash flooding were also contributing factors (Azpiri, 2018; Roden, 2018; Huffpost Canada, 2015).
- The May 2018 Grand Forks flood event was caused by heavy rain, warm temperatures, and snowmelt. The amount of snowmelt was further exacerbated by above average snowpack (Wadhwani, 2018; CTV News, 2018).

**Confidence: Low**

There are varying amounts and quality of evidence, particularly regarding the future return period of flood events. More detailed studies are necessary to determine increasing moderate flood risk in individual river systems. In addition, the increased likelihood of moderate flooding may vary across the province. River systems historically prone to frequent, disruptive floods are likely most at risk of climate-amplified flooding.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.9** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (3+3+2+4+2+3+4+2)/8

Overall Consequence = 2.9

### HEALTH

*Loss of life: 3*

Depending on the depth and speed of floodwaters, two to 10 individuals could lose their lives from either direct or indirect causes. Direct loss of life could occur if people are caught in floodwaters. In addition, limited medical or emergency care or loss of vital services such as power or clean water during and following the event could cause indirect loss of life. If there is not sufficient advanced warning or evacuation prior to the flood, loss of life could be higher.

Supporting evidence includes:

- Rapid snowmelt and flooding in Cache Creek in 2017 resulted in one direct death (Roden, 2018; Brend, 2018). The other proxy flood events did not cause loss of life.
- In North America, 40 people per year die, on average, from floods based on data from 2006 to 2015 (Guha-Sapir, Hoyois, Wallemacq, & Below, 2017).
- In Washington and Oregon, the river flood mortality rate is 12 and 22 per 100,000 people, during the period from 1959 to 2005 (Ashley & Ashley, 2008).
- On average flood waters become unsafe at flow depths of 0.8 to 0.9 metres (Shu, Han, Kong, & Dong, 2016). However, low-height, high-velocity floodwaters may be more hazardous to people than high-height, low-velocity floodwaters (Gomez, Kure, Udo, & Mano, 2016).
- Other factors that could influence loss of life are whether medical or emergency care is accessible during the event and whether utility services such as power and clean water are available.

**Confidence: Low**

Loss of life is ultimately dependent on a number of unknown variables including how quickly flood waters rise, how populated the flooded area is, whether people are given warning to evacuate, and how many people evacuate. Given that moderate flood events are local in nature, there is likely to be variability between communities. In addition, there are varying amounts and quality of evidence regarding the flood mortality rate for Canada and British Columbia. A more detailed analysis would be necessary to compute precise mortality risk based on extent and depth of modeled flooding, population demographics (including age and gender), timing of warning, evacuation behaviour, and other factors. As a result, this rating relies on expert judgment.

*Morbidity, injury, disease, or hospitalization: 3*

Moderate flood events have the potential to expose more than 5% of the community to injury, disease, or hospitalization from fast-moving floodwaters, debris, limited access to critical infrastructure and services, or environmental contamination. In addition, lower flood levels could give the false impression that waters are safe to wade or drive through, which may cause more injuries, disease, or hospitalizations.

Supporting evidence includes:

- The Government of Canada lists the following negative health outcomes due to flooding: drowning, injuries, diseases spread through water contamination and sewage backup, diseases spread through food contamination, diseases spread by insects, carbon monoxide poisoning, and mental health effects (Government of Canada, 2018).
- Damage and impacts to water supply systems (e.g., overwhelmed treatment capacity), may result in a Boil Water Notice threatening public health (B.C. Ministry of Health, 2018).
- On average flood waters become unsafe at flow depths of 0.8 to 0.9 metres (Shu, Han, Kong, & Dong, 2016). However, low-height, high-velocity floodwaters may be more hazardous to people than high-height, low-velocity floodwaters (Gomez, Kure, Udo, & Mano, 2016).
- Environmental contamination from a flood event could be significant in areas near agricultural land, transportation and industrial sites, and hazardous waste storage facilities (Northwest Hydraulic Consultants, 2016). Agricultural contaminants may include manure, deceased livestock, or chemical inputs such as pesticides.

**Confidence: Low**

The number of people affected is ultimately dependent on a number of unknown variables including how quickly flood waters rise, how populated the area is, whether people are given warning to evacuate, and how many people evacuate. Given that moderate flood events are local in nature, there is likely to be variability between communities. As a result, this rating relies on expert judgment.

## SOCIAL FUNCTIONING

*Psychological impacts: 2*

Moderate flooding has the potential to cause localized and temporary moderate psychological impacts, such as fear or anxiety, especially for those who were displaced or experienced flood damages. Disruptions to utility services could also cause increased stress and anxiety.

Supporting evidence incudes:

- The severity of flooding is the most significant factor in determining mental health effects of flood events (Foudi, Oses-Eraso, & Galarraga, 2017). Other important factors include post-disaster life stressors and level of social support (Goldmann & Galea, 2014).
  - Flood survivors have experienced distress, anxiety, pain, depression, and social dysfunctions, including, in severe cases, post-traumatic stress disorder (Foudi, Oses-Eraso, & Galarraga, 2017; Goldmann & Galea, 2014).
    - Many psychosocial impacts were observed in Grand Forks following the 2018 flood event, including an increase in opioid usage and substance abuse (Lavoie, 2018).
  - Suffering material, physical, or intangible damage negatively effects mental health. Material damage (e.g., structural damage or damage to household contents), however, has the smallest effect (Foudi, Oses-Eraso, & Galarraga, 2017).
  - Key risk factors that may increase vulnerability to disasters include age, low socioeconomic status, minority ethnic status, previous mental health issues, and low social support (Goldmann & Galea, 2014). The relative importance of these factors for flooding-related disasters in particular is unknown.
- Interviews conducted after a 2014 flood event in Burlington, Ontario as part of a study on the mental health effects of flooding revealed both short-term and long-term impacts (Intact Centre on Climate Adaptation, 2018):
  - Within a month of the event, 47% of flooded household[37] respondents were worried or stressed about flooding, compared to 11% of households that have never flooded.
  - Three years after the event, 48% of flooded household respondents were worried about flooding during rain events, compared to 3% of households that have never flooded.
  - For 56% of flooded households interviewed, at least one household member had to take time off from work. The average length of time per flooded household was seven days.
- The average cost of a flooded basement is $43,000, which can cause financial stress (Intact Insurance, 2018).
- Evacuations and displacements can also cause psychological impacts. Examples include:
  - Flash flooding in Cache Creek in 2015 resulted in evacuation orders for 23 homes and evacuation alerts for 40 homes. In total, 100 people took shelter at a local community centre. As for damages, seven homes were severely damaged from floodwaters, mud, and debris (Huffpost Canada, 2015).
  - The Grand Forks May 2018 flooding resulted in 32 evacuation orders for 1,993 homes and 36 evacuation alerts for 930 homes. In the Grand Forks area, 2,800 people were displaced and 30 people were rescued by boat after rivers reached their highest levels since 1948 (Wadhwani, 2018; CTV News, 2018).
  - Dawson Creek flooding in 2016 resulted in 60 evacuations and damage to 400 homes (Canadian Disaster Database, 2019).
- Disruptions to utility services may further delay recovery and the ability of evacuated individuals to return home, increasing stress and anxiety. See the loss of infrastructure services section for more details.

[37] Flooded households experienced basement flooding only.

- Depending on the severity and location of the flooding event, agricultural impacts such as seasonal or longer-term loss of agricultural income and assets could cause psychological impacts. Annual crops may be lost and longer term losses and recovery are possible for perennial crops. With sufficient warning, livestock relocation may occur but is likely to be challenging and costly (MacNair, 2019).
  - For example, one family experienced psychological stress after their meat chickens ultimately died of shock after being rescued from flood waters during the 2018 Grand Forks event (Lavoie, 2018).

**Confidence: Medium**

There are several high-quality sources detailing potential mental health effects from flooding, including post-disaster stressors such as disruptions to utility services or agriculture. Given the scale of the event, psychological impacts are assumed to be limited to those who experience more severe damage and are expected to largely subside over time as the community recovers. More specific research on psychological impacts of flooding in B.C. is needed to better understand the scope and extent of impacts from a moderate-scale flood event.

*Loss of social cohesion: 4*

A moderate flood event could cause weeks-long disruptions to daily life, especially for home owners, business owners, and farmers who experience direct flood damage. Even if community members do not experience direct flood damage to their homes or businesses, they may deal with flooded roads or helping with community clean up and recovery.

Supporting evidence includes:

- Moderate flooding can cause flood damages to homes and businesses:
  - A 2015 flood in Cache Creek severely damaged seven homes (Huffpost Canada, 2015).
  - The 2018 Grand Forks flood caused damage to multiple homes, businesses, and farms. Six months after the flood, 28 downtown businesses remain closed and many residents are still without permanent homes (Lavoie, 2018).
  - The 2016 Dawson Creek flood caused damage to 400 homes (Canadian Disaster Database, 2019).
  - A review of the 2017 flood season found that 15 Indigenous communities across B.C. experienced flood damage to homes and infrastructure (Tzembelicos et al., 2018).
  - Specific impacts to farmers and agricultural practices are dependent on the timing and location of the flood event. Spring floods are especially disruptive and damaging for annual and perennial crops. Recovery for certain high-value crops (e.g., berries) can take years (BC Agriculture & Food Climate Action Initiative, 2012).
- Moderate flooding can cause flood damages to local institutions:
  - The 2015 Cache Creek flood also caused flood damage to the Village of Cache Creek fire hall. Volunteers spent an hour clearing debris to free emergency vehicles. In addition, some firefighting equipment was damaged or washed away (The Canadian Press, 2015).
  - The 2016 Dawson Creek flood divided the city in half, separating the city's hospital from the fire hall. This created additional challenges for emergency responders (Canadian Disaster Database, 2019).
- Moderate flooding can also cause disruptions to daily life:

- Following the Cache Creek flooding in 2015, residents and volunteers spent days clearing mud and debris deposited around the community (The Canadian Press, 2015).
- Cache Creek Elementary School was evacuated due to rapidly rising floodwaters in spring 2018 (Roden, 2018).
- All streets in downtown Grand Forks were flooded in spring 2018 (Wong & Nassar, 2018).
- The Dawson Creek event caused power outages throughout the Peace River region affecting over 6,000 individuals. In addition, a section of Highway 97 that connects Peace River to the rest of the province was closed and a bridge was washed out in Dawson Creek, causing disruptions to transportation (Canadian Disaster Database, 2019).
- For agricultural communities, moderate flooding may significantly damage annual and perennial crops causing seasonal or potentially long-term impacts to livelihood. Impacts to local or regional food security are also possible due to decreased agricultural productivity (B.C. Agriculture & Food Climate Action Initiative, 2014; BC Agriculture & Food Climate Action Initiative, 2012; Pacific Institute for Climate Solutions, 2011).
- Disruption to individual and commercial fishing, especially for Indigenous and rural communities could also affect daily life. For example, a decrease in fishing for Indigenous communities affected by a dam breach in 2014 resulted in a shift in diet, physical activity, and cultural practices as well as a decrease in community income and employment opportunities (Shandro et al., 2016).
- Disruptions to drinking water quality and other utility services could disrupt daily life and threaten public health until services are restored. In addition, water contamination affect the use of certain Indigenous sites by Indigenous communities (B.C. Parks, 2019). See the loss of infrastructure services section for more details on impacts to infrastructure services.

**Confidence: Low**

There are varying amounts and quality of evidence related to loss of social cohesion. The rating depends largely on anecdotal evidence and expert judgement.

### NATURAL RESOURCES: 2

Natural resources located within a 50-year or 100-year floodplain are expected to be generally resilient to flood conditions given historic flooding events. The primary risks to natural resources from a moderate flood event are stress or damage due to inundation, debris, or contaminants from agricultural, industrial, or waste sites. Recovery of natural resources is estimated to take weeks to months depending on the location of the moderate flood and local conditions (e.g., ecosystem/species sensitivity or extent of environmental contamination).

Supporting evidence includes:

- Flood-prone ecosystems (e.g., wetlands) and the species that reside in those ecosystems are generally resilient to flooding and would be able to bounce back quickly following a flood event (U.S. Federal Emergency Management Agency, 2014).
- Depending on the location of the flood, environmental contaminants could be a concern. Locations near agricultural land, transportation, industrial sites, and hazardous waste storage facilities have an elevated risk of contamination during a flood event. Possible contaminants include chemicals, fertilizers, petroleum products, raw sewage, and hazardous waste (Public Safety Canada, No date).

Recovery from contaminants could take months or even years depending on the scale of contamination and sensitivity of the contaminated area.

- Impacts to natural resources could also negatively affect ecosystem services. See the economic productivity section for more information.

**Confidence: Low**

The proxy events did not indicate any specific impacts to natural resources, and existing literature focuses on more severe flood events. Other knowledge gaps include how moderate flooding would affect endangered species or sensitive ecosystems. In addition, recovery time will vary depending on the affected species and ecosystems as well as local conditions. As a result, this rating relies heavily on expert judgment.

## ECONOMIC VITALITY

### *Loss of economic productivity: 3*

Loss of economic productivity will vary depending on the location of moderate flooding, but based on the proxy events and other cost information economic losses could feasibly range between $10 million and $99 million due to impacts to businesses, tourism, and agricultural productivity, among others. As a result, this scenario could cause a weeks-long disruption to at least one major economic sector. In addition, flooding could affect ecosystem services. When ecosystems are damaged by direct human use, natural disasters (such as flooding), or climate change, the services provided are often degraded or cease altogether. These services must then be replaced by costly man-made facilities or processes that provide the same services (e.g., the construction costs related to water runoff or flooding control if forest cover is removed or damaged).

Supporting evidence includes:

- The Grand Forks flood in May 2018 cost $26 million in business losses, $30 million in lost tourism, and more than $10 million in household damages. As of November 2018, 28 businesses in downtown Grand Forks remain closed and the city is planning to buy between 80 and 120 properties in flood plain areas, if funding can be secured, at a cost of $60 million to $90 million (Lavoie, 2018).
- The Village of Cache Creek estimated the cost of damages from the 2015 flood to be at least $400,000 and that the cost to local property owners could be millions more (The Canadian Press, 2015).
- Moderate recurring flooding across the province could result in decreased agricultural productivity due to temporarily flooded agricultural lands and water logged soils; loss of crops, livestock, or assets; livestock relocation and stress; soil and water contamination from chemicals, nutrients, or pathogens; damage to farm infrastructure (e.g., drainage systems or machinery); or supply chain disruptions (BC Agriculture & Food Climate Action Initiative, 2012; Pacific Institute for Climate Solutions, 2011). The timing of flood events is also important. For example, flooding early in the agricultural cycle may affect seeding and planting, which will cause ripple effects throughout the growing season in terms of yield and productivity (BC Agriculture & Food Climate Action Initiative, 2012).
- Other sectors that could be affected by moderate flooding include parks and tourism, energy, and transportation (Workshop feedback, 2019).

- Loss of life also has an economic impact. The range of loss of life from 2 to 100 can be valued at $10.4 to $520 million, based on the number of lives projected to be lost (Treasury Board of Canada Secretariat, 2007).[38,39]
- Properly functioning ecosystems provide an array of free benefits to humans in the form of ecosystem services. These services fall into the broad categories of supporting, provisioning, regulating, and cultural services, and may or may not be directly tied to market activity. Examples of these ecosystem services include nutrient recycling and soil formation (supporting), timber and crops (provisioning), carbon sequestration and water purification (regulating), and spiritual significance and recreation (cultural).

- In B.C.'s Lower Mainland alone, forests provide an estimated $1.2 billion annually in flood protection (Wilson, 2010).[40] Extrapolating to the entire province, flood protection services provided by forests are estimated at an annual value of $52 billion.[41]
- Flooding that causes damage to additional ecosystems would result in additional ecosystem service damages. In B.C.'s Lower Mainland, ecosystems provide an estimated $5.4 billion worth of benefits per year (Wilson, 2010). Extrapolating to the entire province of B.C., ecosystem services provide an estimated annual value of $232 billion. The subset of industry and ecosystem services that could be affected by a moderate flood is unknown, but expected to be relatively small considering a single moderate flood event affects a small area and only a few communities.

**Confidence: Low**

There are varying amounts and quality of evidence on loss of economic productivity due in part to the localized nature of moderate flood events. Economic losses will vary depending on the location, timing, and extent of flooding. In addition, there is limited information on how industries other than agriculture would be affected by a moderate flood event.

*Loss of infrastructure services: 4*

Disruptions to transportation, water, and other infrastructure services could last for weeks depending on the severity of flood damage and number of people affected, causing major impediment to day-to-day life. Impacts could include washed out transportation infrastructure, damage to water supply systems, and power outages, among others.

Supporting evidence includes:

- Moderate flooding can cause damage to transportation infrastructure (e.g., bridges or culverts). For example:

- The 2018 Grand Forks flood temporarily inundated or washed out many roads, including a segment of Highway 3 (Macmahon, 2018).
- Flood waters from the 2018 Cache Creek event flooded the junction of Highway 97 and Highway 1 (Macmahon, 2018; Roden, 2018).

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[38] Value in 1996 CAD.
[39] The Treasury Board of Canada Secretariat expects departments to use a Value of a Statistical Life of $5.2 million adjusted for inflation since 1996.
[40] Values in present-day, 2018 CAD.
[41] This extrapolation was conducted by scaling the flood protection values for B.C.'s Lower Mainland (Wilson, 2010) to the entire area of British Columbia.

  - Flood waters from the 2016 Dawson Creek event closed a critical section of Highway 97 that connects the Peace River region to the rest of the province, washed out a bridge in the City of Dawson Creek, and submerged two other bridges in Dawson Creek. This resulted in significant transportation disruptions (Canadian Disaster Database, 2019).
- Moderate flooding can also damage water supply systems or overwhelm treatment capacity (B.C. Ministry of Health, 2018).
  - For example, flooding in Dawson Creek in 2016 caused water pumps to shut down for 42 days due to the high turbidity of the river. Otherwise, the turbidity likely would have damaged the pumping system infrastructure (City of Dawson Creek, 2016).
- Moderate flooding also has the potential to damage energy, communication, and flood protection infrastructure (e.g., dikes) (Northwest Hydraulic Consultants, 2016). For example, the Dawson Creek flood caused power outages throughout the Peace River region affecting over 6,000 individuals (Canadian Disaster Database, 2019).

**Confidence: Low**

There are varying amounts and quality of evidence on loss of infrastructure services due in part to the localized nature of moderate flood events. Impacts to infrastructure services will vary depending on the location and extent of flooding. In addition, there is limited information on how these infrastructure services could be specifically affected by a moderate flood event.

### COST TO PROVINCIAL GOVERNMENT: 2

Based on the cost to the provincial government from the proxy events, cost to government from a single moderate flood event is expected to be on the order of $375 million or less. However, cost to the provincial government can vary from year to year depending on the location, number, and frequency of moderate flood events across the province. Costs to government might include flood response, post-event cleanup, health services, Disaster Financial Assistance, and AgriRecovery and other business risk management programs, among others.

Supporting evidence includes:

- The total cost of flood response in 2017 is estimated at more than $73 million. However, emergency response is typically the responsibility of local governments (Tzembelicos et al., 2018).
- Costs to the provincial government could include flood response, post-event cleanup, and AgriRecovery and other business risk management programs (e.g., Production Insurance, AgriInvest, AgriStability). For example, a moderate flood in Metro Vancouver in 2010/2011 caused significant losses for vegetable producers. Crop insurance and AgriRecovery payments for compensation of losses and assistance to return to production totaled $6.3 million (BC Agriculture & Food Climate Action Initiative, 2012).
  - The project team was unable to precisely estimate the agriculture-related business risk management program costs for this scenario. However, if all or a majority of the existing flood mitigation infrastructure failed, this event would likely trigger a federal-provincial recovery initiative under the AgriRecovery policy framework (Agriculture and Agri-Food Canada, 2018). For AgriStability, losses at the individual farm level would have to exceed a 30% margin decline for the whole farm (Agriculture and Agri-Food Canada, 2018).

- The provincial government would likely be responsible for some portion of health care costs, although the project team could not determine the exact cost share between the federal and provincial government for the following estimates:
  - According to the Canadian Institute for Health Information (2017), the cost of a standard hospital stay in B.C. is on average $6,135.[42] Although not all cases of morbidity, injury, or disease are likely to result in hospitalization, the estimated range of 10 to 100 hospitalization as a result of moderate flooding can be valued at $61,350 to $613,500. Some portion of this cost would be covered by the provincial government.
  - An estimated 30% to 60% of affected populations will need some form of mental health-related assistance following a disaster (NIST, 2017). Rates for severe, moderate, and mild mental illness can range between 6% to 26% up to 30 months following a disaster (FEMA, 2012). Treatment costs for these mental illness cases are estimated at (FEMA, 2012):
    - 12 months post disaster: $822 per person
    - 18 months post disaster: $639 per person
    - 24 months post disaster: $567 per person
    - 30 months post disaster: $414 per person
- Other potential costs to government include:
  - Restoration of natural systems and resources (e.g., clearing debris, contaminants) (Workshop feedback, 2019).
  - Infrastructure repairs or replacement (Workshop feedback, 2019).
- If the Government of B.C. declares a natural disaster eligible for Disaster Financial Assistance, [43] local government bodies, homeowners, residential tenants, small business owners, charities, and farmers can apply for monetary assistance from the Government of B.C. for uninsurable losses (Wadhwani, 2018; Huffpost Canada, 2015; Government of British Columbia, 2018).
  - For individuals, the province will cover up to 80% of uninsurable disaster-related damages greater than $1,000, to a maximum claim of $300,000 (Government of British Columbia, 2018).
  - For local governments, the province will cover up to 80% of recovery measures greater than $1,000 to replace essential materials, including rebuilding or replacing essential public infrastructure (Government of British Columbia, 2018).
  - The province will also cover 100% of the cost to local governments to run emergency operations centres (Wadhwani, 2018).
- If the event is declared a large-scale natural disaster that triggers DFAA, some portion of the cost could be covered by the federal government (Public Safety Canada, 2019). For example:
  - For a disaster totaling $500 million, the Government of Canada would provide $421 million in financial assistance to the Government of British Columbia. The province would be responsible for $79 million.
  - For a disaster totaling $50 million, the Government of Canada would provide $19 million in financial assistance to the Government of British Columbia. The province would be responsible for $31 million.

[42] The value is in 2017 CAD. This measure divides a hospital's total inpatient expenses by the number of hospitalizations it sees in a year. The number is adjusted for some differences in the types of patients a hospital sees to make it more comparable with other hospitals.
[43] Eligibility is determined between the provincial and local government.

- In recent years, the federal government contributed $65 million in financial assistance for a 2016 flood at Dawson Creek and $3.8 million for a 2012 flood near Sicamous (Canadian Disaster Database, 2019).

- Estimated costs to the Village of Cache Creek following the 2015 flash flooding were $400,000, not including costs to private property owners in the village (Huffpost Canada, 2015). In addition, the Cache Creek event resulted in the evacuation of 100 people. At a per diem cost of roughly US$330, the cost of a single-day evacuation is US$33,000 (U.S. Department of State, 2019).
- Response costs for the Grand Forks event totaled $25 million (Lavoie, 2018). In addition, the Grand Forks event resulted in the evacuation of 2,800 people. At a per diem cost of roughly US$330, the cost of a single-day evacuation is US$932,000 (U.S. Department of State, 2019). The City of Grand Forks received many forms of aid from the province:

- In preparation for the Grand Forks flood, the province provided 10 sand bagging machines, sand bags, and 10 kilometres of temporary flood barrier dams (Wadhwani, 2018).
- If the city of Grand Forks can receive financial support from the federal or provincial government, it plans to purchase 80 to 120 properties in the floodplain for more than $60 million. The city also hopes to build new dikes, elevate homes, and reinforce the riverbank (Lavoie, 2018).
- The provincial household emergency assistance program helped Grand Forks residents make repairs to their homes. However, six months after the flood a dozen families still needed emergency winter housing and were put up in hotels (Lavoie, 2018).
- The provincial government also provided $2.9 million in business recovery for Grand Forks. Small businesses received up to $18,500 each in flood relief (Saylors, 2018a).
- The province awarded the City of Grand Forks and Community Futures Boundaries more than $655,000 in Rural Dividends grants to assist with community and business development post-flood (Saylors, 2018b).

**Confidence: Medium**

There are several sources of high-quality evidence regarding cost to the provincial government from a moderate flooding event. In particular, there is a knowledge gap regarding the cost of business risk management programs and emergency assistance programs. The cost to the provincial government from moderate flooding will depend on the location and extent of damage from the flood as well as how many communities are affected by moderate flooding and how frequently moderate flood events occur. In addition, it is unknown whether a long-term water shortage would qualify for DFAA, in which case the federal government could provide significant financial assistance.

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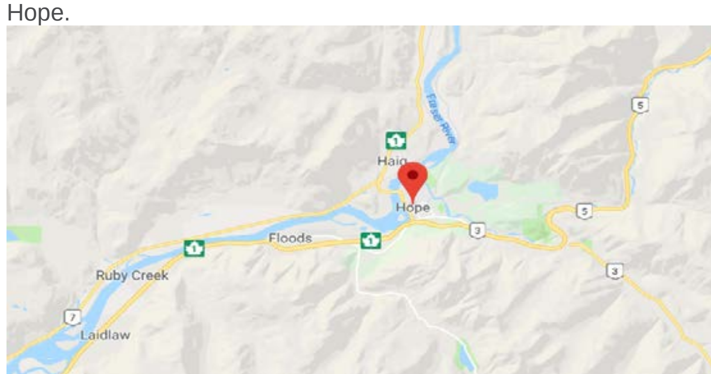
# Extreme Precipitation and Landslide

## Scenario

The specific scenario analyzed is a significant landslide[44] in Hope, B.C. triggered by extreme precipitation. In this scenario, the landslide would affect one or more major transportation routes in Hope, B.C. (see **FIGURE 40**), causing provincially significant disruptions to transportation and the movement of goods and services across the province.

**FIGURE 40.** Map illustrating the intersections of Trans-Canada Highway (Highway 1), Highway 3, Highway 5, and Highway 7 in Hope.




## Summary of Findings

The majority of precipitation-driven landslides in B.C. are smaller debris flows or rock slides, which are likely to become more frequent due to climate change. This scenario, however, represents an extreme case in which Hope experiences a large and provincially significant precipitation-driven landslide that affects transportation across the province. Due to the mountainous terrain of B.C., disruptions to major transportation routes, especially in transportation hubs such as Hope, can cause significant delays and disruptions to the movement of goods and services. Furthermore, due to the volume of vehicles (7 million vehicles annually) and trains passing through Hope as well as a population of about 6,000 people, there is also a risk for injuries, deaths, property losses, and other damages (District of Hope, 2017).

**FIGURE 41.** Risk assessment findings for extreme precipitation and landslide scenario.

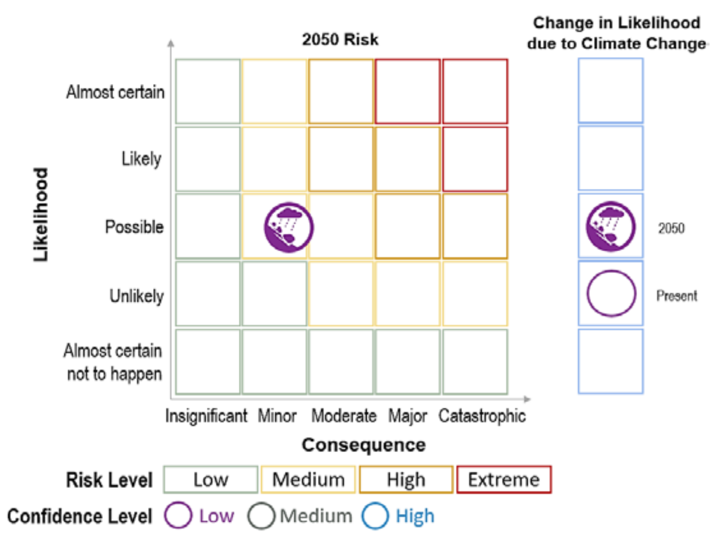



**FIGURE 41** and **TABLE 23** summarize the risk assessment results for this scenario. The highest consequences relate to loss of life, loss of economic productivity, and loss of infrastructure services. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

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[44] A landslide is defined as the movement of rock, soil, and other debris down a slope as a result of gravitational pull (Green, Ricker, McPhee, Ettya, & Temenos, 2014). Landslide is a general term that encompasses many types of landslides (e.g., debris flow, mudslide, rock slide, rock avalanche). Landslides can be caused by a variety of factors including precipitation, snow melt, temperature change, permafrost melt, slope debuttressing from receding glaciers, earthquakes, volcanic activities, and human activities.

**TABLE 23**. Risk Rating Evaluation for Extreme Precipitation and Landslide Scenario

| EXTREME PRECIPITATION AND LANDSLIDE: SIGNIFICANT LANDSLIDE IN HOPE TRIGGERED BY EXTREME PRECIPITATION | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **2** | Past significant events in 1965 and 2017 roughly indicate a major landslide about once every 52 years, which falls into the likelihood range of 51 to 100 years. | **3** | **Climate-related risk cause:** Heavy precipitation, warming temperatures, and rain-on-snow events can trigger landslides. In addition, landslide risk is largely dependent on underlying geology and physical factors, including hill slope steepness and bedrock deformation.<br>**2050 projections:** Multiple studies indicate an increase in the frequency of landslides due to increased heavy precipitation and temperature. Therefore, the likelihood could increase to a range of 11 to 50 years. | Low |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **3** | Potential for up to 10 deaths due to falling debris if the landslide affects one of the three major highways. | Medium |
| | Morbidity, injury, disease, or hospitalization | **2** | Fewer than 10 people are at risk of injury or harm due to falling debris or compromised drinking water supplies. | Medium |
| **Social functioning** | Psychological impacts | **2** | A landslide could cause localized, temporary psychological impacts for individuals directly affected by the landslide. | Low |
| | Loss of social cohesion | **2** | A landslide could cause hours to days-long disruption to daily life primarily due to transportation impacts and localized property damage. | Low |
| **Natural resources** | Loss of natural resources | **1** | Impacts to natural resources within the path of the landslide could be significant, but overall impacts to natural resources in Hope will be minimal. | Low |
| **Economic vitality** | Loss of economic productivity | **3** | Damage or destruction of key infrastructure or economic resources could cause weeks-long disruptions to major economic sectors. | Low |
| | Loss of infrastructure services | **3** | Infrastructure disruptions such as road closures or severed power lines could last for days and cause major impediments to day-to-day life at both a local and province-wide scale. | Medium |
| **Cost to provincial government** | | **2** | Costs to government might include response, clean up, health services, and Disaster Financial Assistance, among others. | Low |
| **OVERALL RISK** | **CURRENT** | **LOW (4.5)** | | **LOW** |
| | **2050** | **MEDIUM (6.8)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **4.5** out of 25, which equates to **low risk**, and the 2050 risk rating is **6.8** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 2 x 2.3 = 4.5 (Low)

2050 Risk = 3 x 2.3 = 6.8 (Medium)

## Evidence Base

### *Risk Event Scenario*

This scenario represents one permutation of extreme precipitation triggering a landslide in the province. The consequence ratings are specific to this scenario, but many of the types of consequences, if not the magnitudes, may be transferable to other related scenarios.

The specifics of this scenario were based on:

- Many research studies and documentation indicate that extreme precipitation is key to triggering debris flows[45] and "abundant and widespread shallow landsliding" in Canada. Alternatively, large-volume, deep-seated landslides are controlled by longer-term hydrological factors, but are also expected to be affected by climate change (Cloutier, Locat, Geertsema, Jakob, & Schnorbus, 2015; Geertsema, Schwab, Blais-Stevens, & Sakals, 2009). More recent significant landslide events triggered by extreme precipitation include:

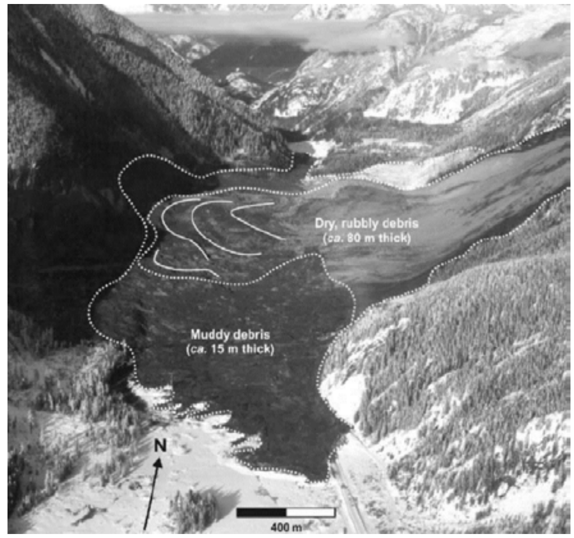
- November 2017: A series of five landslides after heavy rain and unusually warm temperatures closed or caused delays to the Trans-Canada Highway (Highway 1) between Chilliwack and Hope for about 1.5 days (CBC News, 2017).

**FIGURE 42.** Location and extent of the Hope slide of 1965 along Highway 3 (Green, Ricker, McPhee, Ettya, & Temenos, 2014).


[45] Debris flows are the most common type of landslide in B.C. and are defined as "a saturated slurry of earth, rock, and vegetation, which most often flows in a confined channel" (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).

- Spring 2012: A series of damaging landslides across southern B.C. were triggered by high precipitation and high snowpack from the previous winter as well as high precipitation and high snowpack from the year prior, creating wet conditions (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013). The most damaging landslides occurred in Sicamous, Johnsons Landing, and Fairmont Creek.

**FIGURE 43.** Photo of debris from Hope landslide in 1965 (Orwin, Clague, & Gerath, 2004).




- Although "The Hope Slide" on January 9, 1965 was not driven by precipitation, it is one of the largest landslides in Canadian history and is referenced in this risk event to help consider potential consequences of an extreme landslide event in Hope. The landslide affected a 3 km stretch of the Hope-Princeton Highway (Highway 3), spreading 47 million cubic metres of debris 85 metres thick and causing four deaths (B.C. Ministry of Energy, Mines and Petroleum Resources, No date). **FIGURE 42** illustrates the location and extent of the Hope Slide and **FIGURE 43** shows the resulting debris deposits.
- Hope includes several major provincial transportation routes, disruption of which could be provincially significant: Trans-Canada Highway (Highway 1), Highway 3, Highway 5, Highway 7, Canadian National Railway (CNR), and the Canadian Pacific Railway (CPR).

## *Likelihood rating*

The present day likelihood of this scenario is **2** and the 2050 likelihood of this scenario is **3**. Past significant landslides in 1965 and 2017 indicate a current likelihood in the "unlikely" range of once every 51 to 100 years. However, there are strong indications that increases in heavy precipitation as well as warming temperatures will increase the frequency of landslides. Therefore, the project team judged that it is feasible for the 2050 likelihood of this scenario to be in the "possible" range of once every 11 to 50 years.

In addition to climate-related causes, landslide risk is largely dependent on underlying geology and physical factors, including hill slope steepness and bedrock deformation. Thus, areas most susceptible to severe landslide risk are likely more local than the regional-scale climate-related causes. To evaluate the scenario, the project team used indicators including the historical record of landslides in Hope, B.C., which may reflect landslides that occurred independent of climate forcing, and the latest provincial research on landslide drivers. The project team sought to evaluate the future likelihood of large landslides in the Hope, B.C. due to the combined influence of increasing

### Likelihood Rating Drivers

Type of risk event: Discrete

Climate change indicators:

- Increase in heavy rain events
- Increase in rain-on-snow events
- Increase in air temperature

"Present day" period: 1961-1990

Source of 2050 projections: Varies by indicator

Emission scenario: Varies by indicator

climate stress and background geologic risk. As such, the project team considered primary climate-related risk causes including projections for air temperature, precipitation, and snowmelt through mid-century.

Supporting evidence includes:

- Thousands of small landslides occur annually across Canada, with the most damaging typically located in B.C., Alberta, Quebec, and Ontario. Landslides exceeding one million cubic metres initiate at least once every 10 years in Canada (Natural Resources Canada, 2008). Geomorphic hazard studies reveal that large landslides can occur more frequently in parts of British Columbia. Geertsema (2006) found that approximately 2.3 landslides exceeding 5,000 cubic metres initiate in Northern B.C. annually.
- A study of all documented debris flows in nearby Chilliwack, B.C. from 1980 to 2007 found that 18 debris flows were driven by either intense rainfall or rain-on-snow events, indicating a relatively high annual frequency of precipitation-driven debris flows in one community (Sutton, 2011). Most of these debris flows, however, were insignificant in terms of damage.
- Recent landslide events in the Hope area are indicative of active slope instabilities that will likely facilitate further landslide events on decadal timescales. To calculate the current likelihood of a significant landslide, the project team calculated a rough back-of-the-envelope proxy for landslide frequency in Hope, B.C. using two past significant landslides in 1965 and 2017, which indicate a major landslide about once every 52 years.[46] This is a rough estimate based on the frequency of past significant landslide events, as opposed to significant precipitation-driven landslide events.
- The likelihood of a precipitation-driven landslide in B.C. increases from April to June for interior B.C. when heavy rains and snowmelt saturate the soil. For coastal B.C., the wet season for landslides persists between fall and winter as a result of coastal storms and atmospheric rivers. In addition, heavy rains can cause snowpack to become unstable (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013; The Weather Network, 2017).
- An IPCC special report found that there is “high confidence that changes in heavy precipitation will affect landslides in some regions” (IPCC, 2012). These and other climate change impacts likely to contribute to an increase in the risk of landslides and debris flows in B.C. include:

- More intense and frequent heavy rain events increase the likelihood of landslides, particularly in the winter and early spring, by increasing the soil water content. However, projections reveal a decline in summer precipitation, which may decrease the probability of precipitation-driven landslides during summer months (University of Washington College of the Environment, 2016).
- Warmer winter temperatures and increased winter precipitation increase the likelihood of more frequent rain-on-snow events, which are a known cause of landslides (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
- Increasing air temperatures increases the likelihood of landslides by “facilitating soil breakdown, allowing more water to penetrate soils, reducing snow accumulation, and increasing the risk of

[46] This calculation is a rough approximation of likelihood based on available and accessible historical data. There may be other landslide events that occurred during this timeframe that would increase the frequency of major landslides. A geologic or sedimentological study is needed to calculate a more accurate long-term return frequency of landslides in and around Hope.

wildfire and other threats to forest health" (University of Washington College of the Environment, 2016; B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).

- Warming temperatures may also contribute to increased landslide activity due to changes in freeze-thaw cycles, which can cause slope instability and rock slides[47] (Geertsema & Pojar, 2007; B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).

- Climate projections for the Fraser Valley from 1961 to 1990 baseline to 2050 include (Pacific Climate Impacts Consortium, 2012):

- Increase in annual mean temperature of 1.8°C (10th to 90th percentile: 1.1°C to 2.6°C)
- Increase in annual precipitation of 7% (10th to 90th percentile: -2% to +11%)
- Decrease in summer precipitation of 13% (10th to 90th percentile: -25% to +5%)
- Increase in winter precipitation of 6% (10th to 90th percentile: -4% to +15%)
- Decrease in spring snowfall of 55% (10th to 90th percentile: -74% to -15%)
- Decrease in winter snowfall of 24% (10th to 90th percentile: -40% to -11%)

- Location-specific landslide projections include:

- A thesis on *Risk Analysis of Landslides Affecting Major Transportation Corridors in Southwestern B.C.* found that rock fall events are expected to occur 1.4 to 4.6 times more frequently during winter months than summer months along Highway 1, CNR, and CPR between Vancouver and Hope, due in part to the influences of rain, snow, and freeze-thaw. Furthermore, the thesis points to heavy rain as an important factor for debris flows, stating that debris flows are three to four times more likely to occur during or after storm events compared to clear conditions (Hazzard, 1998).
- The Puget Sound region, which is geologically similar to Lower Mainland B.C., is expected to experience an increase in the frequency of landslides due projected increases in rainfall frequency and intensity and a projected decrease in snowpack (University of Washington College of the Environment, 2016).
- Coastal B.C. is expected to experience an increase in the frequency of debris flows due to increased rainfall intensity, particularly in late fall and winter (Cloutier, Locat, Geertsema, Jakob, & Schnorbus, 2015). A study of climate change and landslides in coastal southwest B.C. supports this prediction finding a 10% increase in 4-week antecedent moisture conditions and a 6% expected increase in short-term (24-hr) precipitation by the end of the century (Jakob & Lambert, 2009).
- A thesis on *The Occurrence and Behaviour of Rainfall-Triggered Landslides in Coastal B.C.* found that the critical rainfall intensity threshold for triggering landslides on Vancouver Island is 80 to 100mm in a 24-hour period. The thesis also found that rain-on-snow events are a significant trigger as well (Guthrie, 2009).

**Confidence: Low**

Although several sources of high-quality independent research indicate an increase in the frequency of precipitation-driven landslide events, there is less certainty regarding the likelihood of large precipitation-driven events. Another unknown is whether precipitation-driven landslides would increase in magnitude by 2050, thereby also influencing the frequency of large-scale events. More information is needed on the predictability of large precipitation-driven landslide events to more confidently assess the likelihood.

[47] Rock slides are defined as "landslides consisting mainly of unconsolidated earth materials," which can be especially large (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.3** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (3+2+2+2+1+3+3+2)/8

Overall Consequence = 2.3

### HEALTH

*Loss of life: 3*

Historically, major landslides in B.C. have resulted in up to five deaths due to falling debris. A significant landslide in Hope could result in a similar number of deaths, in the range of two to ten, particularly if the landslide affects one of the three major highways.

Supporting evidence includes:

- On average, landslides result in the death of about one person per year in B.C. (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
- Significant events in B.C. and Washington, however, have resulted in multiple fatalities including:
  - 2014 landslide in Oso, Washington, which has a similar geology to Lower Mainland B.C.: 43 deaths (Giovannetti, 2014)
  - 2012 landslide at Johnsons Landing on Kootenay Lake: four deaths (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013)
  - 2007 landslide at Legate Creek: two deaths (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013)
  - 2005 landslide in the District of North Vancouver: one death (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013)
  - 1990 debris avalanche[48] during a heavy rain-on-snow event at Belgo Creek: three deaths (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013)
  - 1975 debris avalanche in the Meager Creek Valley: four deaths (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013)
- In addition, a number of landslide-related deaths occur on roadways:
  - Four people died on Highway 3 from the 1965 Hope Slide after a smaller earlier avalanche blocked their path on the roadway (Green, Ricker, McPhee, Ettya, & Temenos, 2014).
  - Five people died on the Trans-Canada Highway after a debris flow in 1968 (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
  - 26 people died between 1958 and 1996 due to landslides along major transportation routes: Highway 99, Highway 1, the British Columbia Railway, the Canadian National Railway (CNR), and the Canadian Pacific Railway. Of these deaths, one occurred on Highway 1 and eight occurred on the CNR, both of which pass through Hope (Hazzard, 1998).

[48] Debris avalanches are defined as “landslides consisting mainly of unconsolidated earth materials (‘soil’) which occur on open slopes, usually in an unsaturated state” (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).

- 12 people died between 1958 and 1983 due to 14 debris flow events along Highway 99 between West Vancouver and Squamish (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).

**Confidence: Medium**

There are several sources of evidence from past landslide events in and around Hope that support the possibility of two to 10 deaths. Loss of life, however, is ultimately dependent on when and where the landslide occurs (e.g., the number of cars on the highway at the time of the landslide or the population density of the affected area).

*Morbidity, injury, disease, or hospitalization: 2*

Past major landslides in B.C. have resulted in fewer than 10 injuries each due to falling debris. A landslide could also comprise drinking water supplies, which could threaten public health. As a result, a landslide in Hope is expected to harm fewer than 10 people.

Supporting evidence includes:

- From 1958 to 1996, 11 people were injured due to landslides along major transportation routes: Highway 99, Highway 1, the British Columbia Railway, the Canadian National Railway (CNR), and the Canadian Pacific Railway. Of these injuries, five occurred on Highway 1 and one occurred on the CNR (Hazzard, 1998).
- More recently in 2017, three people were rescued from their vehicles with no injuries after five landslides closed a segment of the Trans-Canada Highway between Chilliwack and Hope (CBC News, 2017).
- Additionally, two people were injured, one fatally, when the 2005 District of North Vancouver landslide destroyed a home (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
- The debris and aftermath of a landslide also have the potential to compromise drinking water supplies, which could threaten public health (B.C. Ministry of Health, 2018).

**Confidence: Medium**

Several sources of evidence from past landslide events support the possibility for fewer than 10 injuries or hospitalizations. The number of injuries and hospitalizations, however, will vary based on the population density where the landslide occurs as well as the number of vehicles on the road at the time of impact.

## SOCIAL FUNCTIONING

*Psychological impacts: 2*

A landslide can cause temporary psychological impacts for the individuals directly affected, such as those who are injured, lose a home, or lose a family member.

Supporting evidence includes:

- Based on an existing literature review of health impacts associated with landslides (worldwide), the prevalence of PTSD may be higher after landslides than after other types of disasters (Kennedy, Petley, Williams, & Murray, 2015).

- The key determining factors for post-disaster mental health issues are the degree and severity of exposure as well as post-disaster life stressors and level of social support (Goldmann & Galea, 2014).
  - Common psychopathologies that manifest after disasters (e.g., hurricanes, terrorist attacks) include post-traumatic stress disorder, major depressive disorder, substance abuse disorder, general anxiety disorder, and prolonged grief disorder (Goldmann & Galea, 2014). The prevalence of these various mental health impacts from landslide-related disasters are unknown.
  - Key risk factors that may increase vulnerability to disasters include age, low socioeconomic status, minority ethnic status, previous mental health issues, and low social support (Goldmann & Galea, 2014). The relative importance of these factors for landslide-related disasters in particular is unknown.

**Confidence: Low**

There is limited information available on the psychological impacts of landslides. In addition, the number of people who could experience psychological impacts is dependent on when and where the landslide occurs, but is assumed to be small.

*Loss of social cohesion: 2*

Based on past events, a significant landslide in Hope could cause an hours- to days-long disruption to daily life for the affected area due to transportation infrastructure impacts. If a number of homes or businesses are damaged or destroyed, loss of social cohesion may be higher for the affected community.

Supporting evidence includes:

- Landslides can damage or temporarily close major transportation routes (see the loss of infrastructure services section for more information), which can affect people's daily lives. Clearing the road of debris may take hours to days depending on the extent of damage.
- Landslides also frequently damage or destroy homes and other buildings or property. Examples include:
  - A series of landslides around Johnsons Landing in 2012 destroyed or damaged five homes (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
  - A landslide at Fairmont Hot Springs in 2012 damaged a number of condos and single-family homes (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
  - The Testalinden Dam Failure in 2010, triggered a large debris flow which damaged or destroyed several homes and also covered 24 hectares of agricultural land downstream (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
  - A 2005 landslide in the District of North Vancouver destroyed one home (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
  - A 2004 debris flow trigged by heavy rain on land that burned in a wildfire the previous year destroyed two homes (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
  - A 1990 debris avalanche during a heavy rain-on-snow event at Belgo Creek destroyed one home (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
  - From 1958 to 1996, landslides along Highway 99 and Highway 1 damaged or destroyed three homes (Hazzard, 1998).

**Confidence: Low**

The extent of damage and impact on daily life will depend on the location of the landslide. Based on past events, the impacts to social cohesion are expected to be relatively small and primarily affect travel routes. If a significant portion of the community experiences property loss, however, the impacts may be more severe.

### NATURAL RESOURCES: 1

Given the localized nature of a landslide, impacts to natural resources within the path of the landslide could be significant, but overall impacts to natural resources in Hope will be minimal. Landslide debris could erode into rivers and streams, decreasing water quality for aquatic habitats. In addition, changes in soil conditions could disrupt vegetation and forest resources in the affected area.

Supporting evidence includes:

- Landslide debris flows can erode rivers and streams, decrease water quality, alter groundwater and river flow, increase sediment levels, alter stream morphology and aquatic habitats, and in extreme cases, dam rivers or streams (Geertsema, Highland, & Vaugeouis, 2009; Rahr, 2019).
  - Dams can be short-term or long-term depending on the material and the existing sediment levels and conditions of the river or stream (Geertsema, Highland, & Vaugeouis, 2009). A recent survey of landslide dams in the Peace River region found that dams persisted for up to two decades and were gradually diminished due to stream incision and sediment infilling (Miller et al., 2018).
  - Dams can also lead to flooding, which depending where the flood occurs, could further damage surrounding or downstream natural resources. Trees and other vegetation exposed to prolonged or permanent inundation will not recover. (Geertsema, Highland, & Vaugeouis, 2009).
  - Debris flows can also disrupt or eliminate fish habitats due to decreased water quality and damming of rivers and streams. Changes in stream morphology due to dams and excess sediment can affect spawning beds, egg incubation areas, and rearing habitats for fish. (Geertsema, Highland, & Vaugeouis, 2009). In addition, disruptions to certain fish species (e.g., salmon) may cause additional negative effects on the larger ecosystem (e.g., disruptions to the food chain) (Rahr, 2019).
- In addition, landslides generally decrease forest productivity due to soil-striping (Geertsema, Highland, & Vaugeouis, 2009). A study of landslide-induced forest damage on Queen Charlotte Islands off of the B.C. coast found that the return period for forest cover is longer for landslide areas than for logged areas. In addition, forest productivity was 70% lower in landslide areas than logged areas (Geertsema, Highland, & Vaugeouis, 2009).
- Although there are many negative effects of landslides on natural resources, changes in site and soil conditions can lead to changes in vegetation, which can increase habitat diversity across the landscape (Geertsema & Pojar, 2007). A series of landslides across the landscape over time creates a patchwork of diverse habitats in different stages of succession and recovery, which provide opportunities for different types of vegetation and wildlife.

**Confidence: Low**

There are varying amounts and quality of evidence on impacts to natural resources. The significance of natural resource losses ultimately depends on the scale and value of the land involved in the landslide and the subsequent consequences. For example, although ecosystem recovery of the affected area can take decades, similar ecosystem habitat likely surrounds the affected area, minimizing the impact. In addition, there may be value in landslides increasing habitat diversity.

## ECONOMIC VITALITY

### *Loss of economic productivity: 3*

Damage or destruction of key transportation infrastructure, utility infrastructure, or economic resources such as timber, could cause weeks-long disruptions to major economic sectors. For example, road/rail closures, delays, or reroutes could affect the movement of goods and services.

Supporting evidence includes:

- Economic losses can occur from damaged roads, rail lines, and other transportation infrastructure; traffic delays and reroutes; and road and rail closures (Hazzard, 1998). Interruptions to the transportation system can have ripple effects on the movement of goods and services as well as emergency supplies. For example, landslides from 1958 to 1996, (Hazzard, 1998):
  - Blocked or closed highways 78 times, nine of which were on Highway 1
  - Delayed trains 106 times on the British Columbia Railway (B.C.R) and Canadian National Railway (CNR)
  - Damaged trains or speeders 16 times and derailed trains six times
  - Damaged Highway 99 three times, the B.C.R track 70 times, and the CNR track two times
- Landslides could damage or destroy private, business, or municipal property (Workshop feedback, 2019).
- A 2006 coastal storm event on Vancouver Island triggered hundreds of landslides over the course of the winter causing over US$1 million in damages, primarily due to impacts to timber and utility companies (Guthrie, 2009).
- The impacts of landslides on fish habitats could also have implications for salmon and recreational fishing (Workshop feedback, 2019).
- Loss of life also has an economic impact. The range of loss of life from one to 10 can be valued from $5.2 to $52 million, based on the number of lives projected to be lost (Treasury Board of Canada Secretariat, 2007).[49,50]

**Confidence: Low**

There are varying amounts and quality of evidence regarding the economic costs of landslides on various economic sectors. More information is needed on the specific costs to each major economic sector.

### *Loss of infrastructure services: 3*

Based on past events, infrastructure disruptions such as road closures or severed power lines could last for days and cause major impediments to day-to-day life at both a local and province-wide scale. Transportation impacts are especially critical given that Hope, B.C. is a major intersection for several highways and rail lines.

[49] Value in 1996 CAD.
[50] The Treasury Board of Canada Secretariat expects departments to use a VSL of $5.2 million adjusted for inflation since 1996.

Supporting evidence includes:

- A study of the impacts of landslides on infrastructure in west-central B.C. found that shallow, rapid debris slides and avalanches in west-central B.C. typically close roads or rail lines on an annual basis. On some occasions, they have severed pipelines, power lines, and hydro-transmission lines. Infrastructure damage most commonly occurs from being struck by rocks or debris, but can also occur if the infrastructure is located on the unstable ground released during a landslide. (Geertsema, Schwab, Blais-Stevens, & Sakals, 2009).
- Landslides can cause significant damage or disruption to transportation services. For example:
  - 2017: A series of five landslides after heavy rain caused delays and closures along parts of Highway 1. The debris covered the entire width of the highway and was about 5 m deep in some areas. The closure lasted for about one and a half days and the detour route via Highways 7 and 9 experienced heavy traffic. After one day, one lane was opened for alternating traffic. The landslides also caused delays to the Canadian National Railway, which runs along the highway (The Canadian Press, 2017; CBC News, 2017; News 1130 Staff, 2017).
  - 2017: Heavy rains caused landslides on the Copper River Forest Service Road in the Kitimat area, causing damages estimated at $5 million (Link, 2017).
  - 2007: A landslide at Legate Creek closed Highway 16 for several days (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
  - 2004: A debris flow triggered by heavy rain on land burned by a wildfire the previous year blocked Highway 3A for several days (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
  - 1991: A rock slide near Loggers Creek closed the Sea-to-Sky highway for 12 days (B.C. Ministry of Energy, Mines and Petroleum Resources, No date).
  - 1990: Debris flow and mudslides closed sections of three highways and reduced the TransCanada Highway to one lane near Revelstoke, British Columbia. The estimated total cost of the landslides was over $18 million (Canadian Disaster Database, 2018).
  - 1968: A debris flow blocked portions of the Trans-Canada Highway (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
  - 1965: The Hope Slide blocked portions of Highway 3 (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
  - From 1958 to 1996, landslides damaged or destroyed bridges seven times on Highway 99 and B.C.R (Hazzard, 1998).
  - From 1958 to 1996, landslides damaged or destroyed vehicles 43 times on Highway 99 and Highway 1 (Hazzard, 1998).
- Landslides can also cause disruptions to utility services. For example:
  - Landslides can cause changes to the water quality of rivers and streams, which can affect drinking water quality due to excess sediment and organic material in the water supply. For example, in 2006, the Greater Vancouver Regional District initiated a water boil advisory after a series of landslides in the watersheds that supply drinking water reservoirs (Geertsema, Highland, & Vaugeouis, 2009). Other pollutants and materials can also enter the drinking water supply as a result of landslides.
  - A 2018 landslide in Old Fort cut utility services (e.g., power, water) from a rural community for nearly one month (Alaska Highway News, 2018; Hennig, 2018).

- A series of landslides after heavy rain in November 2017 caused downed power lines (CBC News, 2017).
- Since 1978, three of six landslides in west-central B.C. severed natural gas pipelines (Geertsema, Schwab, Blais-Stevens, & Sakals, 2009).
  - Cost estimates for damage due to a severed pipeline causing a spill may be as high as $30 to $50 million (Hungr, 2004).
- From 1958 to 1996, landslides caused downed powerlines one time on Highway 1 (Hazzard, 1998).

- Landslides can also disrupt other infrastructure services. For example:
  - A landslide at Fairmont Hot Springs in 2012 damaged infrastructure at Fairmont Hot Springs Resort, including water pipes, a road, and a golf course. In addition, the landslide damaged flood/debris flow control infrastructure (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2013).
- Disruptions can also be recurring. For example, the Vancouver to Squamish highway has been affected by 14 major debris torrents since 1906 (B.C. Ministry of Energy, Mines and Petroleum Resources, No date).

**Confidence: Medium**

There are several sources of high quality independent evidence that support a days-long disruption to infrastructure. The severity of infrastructure damage and disruption, however, is dependent on where exactly the landslide occurs.

### COST TO PROVINCIAL GOVERNMENT: 2

The primary cost to the provincial government is expected to be response and recovery (e.g., health services, cleanup, repairs), especially if major transportation routes are affected. In addition, the provincial government may provide Disaster Financial Assistance. These costs are expected to be on the order of $375 million or less.

Supporting evidence includes:

- A 1991 rock slide near Loggers Creek, which closed the Sea-to-Sky highway for 12 days, cost $7 million in repairs and preventive structures (B.C. Ministry of Energy, Mines and Petroleum Resources, No date).
- The provincial government would likely be responsible for some portion of health care costs, although the project team could not determine the exact cost share between the federal and provincial government for the following estimates:
  - According to the Canadian Institute for Health Information, the cost of a standard hospital stay in B.C. is on average $6,135.[51] Although not all cases of morbidity, injury, or disease are likely to result in hospitalization, the estimated range of one to 10 hospitalizations as a result of an extreme precipitation landslide can be valued at $6,135 to $61,350. Some portion of this cost would be covered by the provincial government.

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[51] The value is in 2017 CAD. This measure divides a hospital's total inpatient expenses by the number of hospitalizations it sees in a year. The number is adjusted for some differences in the types of patients a hospital sees to make it more comparable with other hospitals.

- An estimated 30% to 60% of affected populations will need some form of mental health-related assistance following a disaster (NIST, 2017). Rates for severe, moderate, and mild mental illness can range between 6% to 26% up to 30 months following a disaster (FEMA, 2012,). Treatment costs for these mental illness cases are estimated at (FEMA, 2012):
  - 12 months post disaster: US$822 per person
  - 18 months post disaster: US$639 per person
  - 24 months post disaster: US$567 per person
  - 30 months post disaster: US$414 per person
- Other potential costs to government include clearing debris and repairing damage to utilities and other infrastructure (Workshop feedback, 2019).
- If the Government of B.C. declares a landslide eligible for Disaster Financial Assistance,[52] local government bodies, homeowners, residential tenants, small business owners, charities, and farmers can apply for monetary assistance from the provincial government for uninsurable losses. A landslide may be eligible if is the direct result of extreme precipitation as opposed to pre-existing slope instability (Wadhwani, 2018; Huffpost Canada, 2015; Government of B.C., 2018).
  - For individuals, the province will cover up to 80% of uninsurable disaster-related damages greater than $1,000, to a maximum claim of $300,000 (Government of British Columbia, 2018).
  - For local governments, the province will cover up to 80% of recovery measures greater than $1,000 to replace essential materials, including rebuilding or replacing essential public infrastructure (Government of British Columbia, 2018).
  - The province will also cover 100% of the cost to local governments to run emergency operations centres (Wadhwani, 2018).
- If the event is declared a large-scale natural disaster that triggers DFAA, some portion of the cost could be covered by the federal government (Public Safety Canada, 2019).

**Confidence: Low**

There is limited information available on the cost to the provincial government from an extreme precipitation-driven landslide in Hope. As a result, this rating relies heavily on expert judgment. In addition, it is unknown whether a landslide would qualify for DFAA, in which case the federal government could provide significant financial assistance.

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[52] Eligibility is determined between the provincial and local government.

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## Seasonal Water Shortage

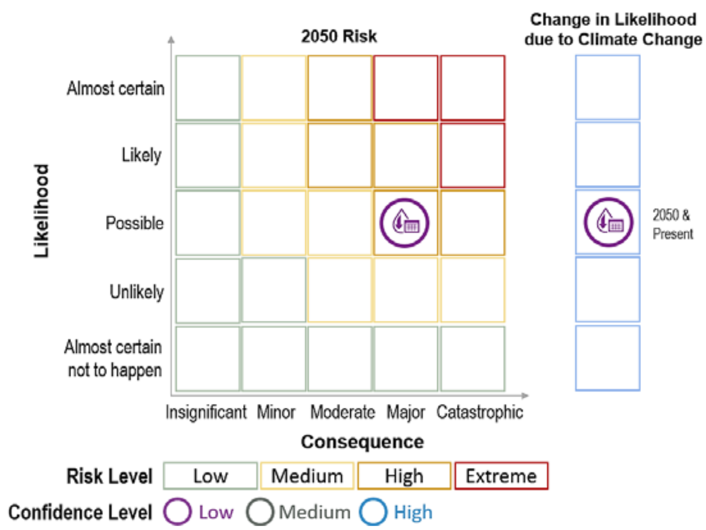
### Scenario

The specific risk event scenario analyzed is a summer water shortage affecting two or more regions of the province and lasting two or more months. The magnitude of this water shortage is equal to drought Level 4 as defined in the B.C. Drought Response Plan (the highest level where water supply is insufficient to meet socio-economic and ecosystem needs). The cause of the water shortage would vary depending on the hydrology of streams within the region. For example, in rainfall-dominated regions a water shortage could be caused by decreased summer precipitation, and in snowmelt-dominated regions a water shortage could be caused by earlier or more rapid snowmelt, or a reduced snowpack.

### Summary of Findings

In the past decade, B.C. has experienced several severe seasonal water shortages such as those in 2015 and 2017. The risk of water shortage in B.C. is projected to increase under climate change due to rising temperatures and changes in precipitation that could affect both rain- and snowmelt-dominated systems. The impacts can be wide-ranging and affect drinking water quality, ecosystem health, and water-dependent industries.

**FIGURE 44.** Risk assessment findings for seasonal water shortage scenario.




If these events become more common, human health could be negatively affected by a rise in water-borne and vector-borne diseases. In addition, people with natural-resource-based livelihoods could face unemployment and lost livelihoods, which could result in psychological distress. Recovery from seasonal water shortages may take months and cost the economy and government millions of dollars.

**FIGURE 44** and **TABLE 24** summarize the risk assessment results for this scenario. The highest consequences relate to economic vitality, morbidity and disease, and loss of social cohesion. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 24.** Risk Rating Evaluation for Seasonal Water Shortage Scenario

| SEASONAL WATER SHORTAGE: MONTHS-LONG SUMMER WATER SHORTAGE AFFECTING TWO OR MORE REGIONS | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **4** | B.C. experiences significant seasonal and inter-annual hydrological variability. Seasonal water shortages occur approximately once every 3 to 10 years. | **5** | **Climate-related risk cause:** Higher temperatures and changes in seasonal precipitation (rain or snowfall).<br>**2050 projections:** Slight increases in annual precipitation are anticipated, but offset by increasing temperatures and decreases in summer precipitation. Rising temperatures could also result in reduced snowpack and earlier spring snowmelt. These changes could result in seasonal water shortages about once every two years or more frequently by 2050. | Medium |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **2** | There is low potential for multiple losses of life due to the impacts of seasonal water shortage. | Medium |
| | Morbidity, injury, disease, or hospitalization | **4** | Over 100 people could experience some negative health outcomes due to contaminated water sources, exposure to vector-borne disease, or fungal diseases. | Medium |
| **Social functioning** | Psychological impacts | **3** | Water usage restrictions, economic hardship, and seasonal loss of livelihood could result in temporary, widespread psychological impacts. Those with natural resource dependent livelihoods could face more severe impacts. | Low |
| | Loss of social cohesion | **4** | Potential for weeks-long disruption to daily life, particularly for agriculturally-dependent communities. | Medium |
| **Natural resources** | Loss of natural resources | **3** | Degradation of wetland and forest habitats could affect many species. Higher river temperatures could cause stress for temperature-sensitive species, especially salmon. Natural resources could take years to recover. | Medium |
| **Economic vitality** | Loss of economic productivity | **5** | Losses could exceed $1 billion in agriculture, fisheries, forestry, tourism, and other water-dependent sectors. | High |
| | Loss of infrastructure services | **4** | Disruptions to electricity production and water treatment could last weeks. | Medium |
| **Cost to provincial government** | | **2** | Cost for emergency response, recovery, and lost revenue could be tens of millions of dollars. | Low |
| **OVERALL RISK** | **CURRENT** | **HIGH (13.5)** | | **MEDIUM** |
| | **2050** | **HIGH (16.9)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **13.5** out of 25, which equates to **high risk**, and the 2050 risk rating is **16.9** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 4 x 3.4 = 13.5 (High)

2050 Risk = 5 x 3.4 = 16.9 (High)

## Evidence Base

### *Risk Event Scenario*

The specific risk event scenario analyzed is a months-long (at least two months) summer water shortage affecting two or more regions of the province. The cause of the water shortage (in which available supply is not enough to meet demand) would vary depending on the hydrology of the region. This scenario represents just one example of a seasonal water shortage in British Columbia. The likelihood and consequence ratings presented here are specific to this scenario, but many are likely transferable to other related scenarios.

The specifics of this scenario were based on:

- Water shortage refers to a deficit in water supply to meet demand. Within the evidence base, many sources refer to the consequences of "drought," which is widely used in the literature. However, the term "drought" can have many meanings (see text box). The literature is not in agreement in how to define drought or water shortage, and the two terms are not equivalent. The consequences presented here are based on an interpretation of the available literature in the context of the chosen summer water shortage scenario.
- The location of a water shortage is a significant factor in terms of its consequences. If shortages occur in watersheds that supply urban areas or major agricultural zones, the consequences could affect a large number of people and critical systems, although these systems could also have greater adaptive capacity. Smaller communities, on the other hand, may be less prepared. In addition, consequences will vary depending on the significance of the watershed for fish or other sensitive species and habitats.
- This assessment considers a summer water shortage as a consequential event that could be a result of a variety of factors affecting supply.

**Types of Drought**

There is no universally accepted definition of drought; criteria may include precipitation, stream flow, lake and reservoir levels, groundwater supply, soil moisture, crop yields, and economic hardship. Different types of drought include:

1. **Meteorological drought**

   Deficiency in precipitation over a given period of time or for a certain length of time, resulting in dryness.

2. **Hydrological drought**

   When rainfall deficit decreases available water supply, including stream flow, reservoir and lake levels and groundwater levels decline.

3. **Agricultural drought**

   When rainfall deficits have impacts on agriculture through low water supply, soil water deficits, reduced groundwater, or reduced reservoir levels needed for irrigation.

4. **Socioeconomic drought**

   Impact of drought conditions (any of above) on supply and demand of commodities that are damaged due to the water deficit, such as fruits, vegetables, grains, and meat.

Source: (National Weather Service, 2019; NOAA, 2019; Hill, 2015)

In B.C., summer water shortages may be caused by different drivers depending on the hydrology of the region, including reduced snowpack, low spring/summer precipitation, or declining glacier runoff (although this is considered in the Glacier Mass Loss risk event). For example (Eaton & Moore, 2007):

- Rain-dominated regions (e.g., the coastal lowland areas and lower elevations of the windward side of the Coast Mountains such as Carnation Creek) would experience summer water shortages due to reductions in summer precipitation.
- Snowfall-dominated regions (e.g., the interior plateau and mountain regions, and higher-elevation zones of the Coast Mountains such as the Coquihalla River) would experience water shortages due to higher temperatures reducing the proportion of precipitation falling as snow and increasing the rate of snowmelt.
- Hybrid/mixed regions (e.g., coastal and near-coastal areas such as the Capilano River) rely on both rainfall and snowmelt.
- Glacier-dominated regions are similar to snowfall-dominated regimes, but glaciers augment snowmelt until late summer.

- In the past several years, B.C. experienced summer water shortages of unusual magnitude that caused major consequences to the province. These examples refer to drought, as it has been defined by the B.C. Drought Information Portal as "a deficiency of precipitation over an extended period of time, resulting in a water shortage" (Government of British Columbia, 2018c). For example:

- In 2015, B.C. experienced a drought considered severe based on the historical record, reaching "Level 4" in several regions (see **FIGURE 45** for an explanation of the rating scale). For all of July and August, Vancouver Island experienced Level 4 drought, and eight other basins experienced a combination of Level 3 and Level 4 drought for around two months (Government of British Columbia, 2018c).
  - The drought season started with below-average snowpack, which melted in early spring due to a heat wave. Drought conditions increased with little precipitation during the summer. These factors contributed to severe drought in the southern part of the province, which peaked in late August (Government of British Columbia, 2018c).
  - Due to the drought, B.C. issued extreme-low streamflow advisories, which resulted in water restrictions. Some rivers had their lowest flows in the 80- to 100-year record (Szeto, Zhang, White, & Brimelow, 2016). Additionally, the drought contributed to one of the most extreme wildfire seasons B.C. had experienced, although that record has since been surpassed (Szeto, Zhang, White, & Brimelow, 2016).

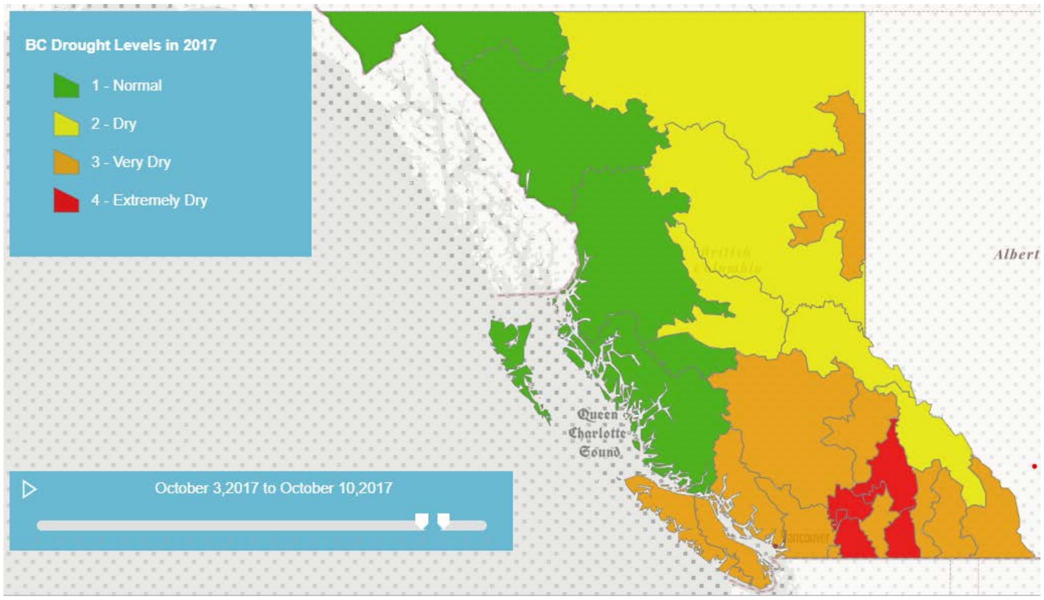
**FIGURE 45.** B.C. drought classification system (Government of British Columbia, 2018b).

Drought Classification

| Level | Conditions | Significance | Objective |
|---|---|---|---|
| 1 (Green) | Normal Conditions | There is sufficient water to meet human and ecosystem needs | Preparedness |
| 2 (Yellow) | Dry Conditions | First indications of a potential water supply problem | Voluntary conservation |
| 3 (Orange) | Very Dry Conditions | Potentially serious ecosystem or socio-economic impacts are possible | Voluntary conservation and restrictions |
| 4 (Red) | Extremely Dry Conditions | Water supply insufficient to meet socio-economic and ecosystem needs | Voluntary conservation, restrictions and regulatory action as necessary |

- In 2017, B.C. experienced Level 4 drought conditions in South Thompson, Nicola, Similkameen, and Kettle basins from late August through mid-October (see **FIGURE 46**). The drought season started late due to spring flooding but minimal rainfall during the summer made it one of the driest summers in recent history (the driest in 70 years, with less than half normal rainfall during the growing season) (Government of British Columbia, 2018c).
    - Due to the water shortage (combined with high heat), the agricultural sector suffered from reduced crop productivity, along with limited livestock feed and water availability for irrigation (Agriculture and Agri-Food Canada, 2017).
    - B.C. also experienced the worst wildfire season it had seen, surpassing 2015 (Cherneski, 2018).

**FIGURE 46.** B.C. drought levels from October 3 to October 10, 2017, where it reached the maximum extent of high-level drought (Government of British Columbia, 2018c).




## *Likelihood rating*

The present-day likelihood of this scenario is **4** (event expected about once every 3 to 10 years) and the 2050 likelihood of this scenario is **5** (event expected to happen about once every two years or more frequently). Summer water shortages occur episodically in B.C. due to a range of underlying climate-related causes. Causes vary spatially; rain-dominated regions are particularly sensitive to deficits in summer rainfall and warmer air temperatures causing enhanced evapotranspiration, while watersheds fed by mountain snowmelt are particularly sensitive to the timing of peak springtime melt and runoff.

### Likelihood Rating Drivers

Type of risk event: Discrete

Climate change indicators:

- Annual average temperature
- Summer precipitation
- Spring snowfall
- April 1 snowpack
- Portion of winter precipitation falling as snow
- Spring average temperature

"Present day" period: Varies by indicator

Source of 2050 projections: Varies by indicator

Emission scenario: Varies by indicator

The project team used GCM projections for precipitation, air temperature, and snowmelt as indicators to evaluate the likelihood of summer water shortages for the two system types (rain-dominated and snowfall-dominated). Some systems are hybrid or mixed and have characteristics of both types of systems. The project team additionally used projections of the traditional April 1 snowpack level as an indicator for future water availability. The project team used the aggregate of these factors to find that this scenario will become more frequent in B.C. by mid-century, independent of the dominant underlying climate-related cause and assuming constant demand.

The likelihood rating was determined based on:

High-level findings

- As demonstrated by the conditions in 2015 and 2017, severe drought often results from the combined effects of low snowpack, warmer-than-average spring temperatures, and dry and hot summers (Szeto, Zhang, White, & Brimelow, 2016). Temperature, precipitation, and snowfall in B.C. are all projected to change in ways that could increase the likelihood of severe seasonal water shortages, although the affects will depend greatly on the hydrological regime considered.
- Over the second half of the 20th century, there has been a regional trend toward more severe water shortages in southern and western Canada (Warren & Lemmen, 2014). In the future, seasonal water shortages are expected to become more frequent and severe in British Columbia (Moore, 2015b), which could have the greatest impact on Vancouver Island, the Gulf Islands, the Lower Mainland, and the Southern Interior, according to climate models (Auditor General of B.C., 2018).
- By the 2050s, annual average temperatures are projected to increase by 1.8°C (1.3°C to 2.7°C)[53], which could increase evaporation. Summer precipitation is projected to decrease by 1% (-8% to +6%) and spring snowfall is projected to decrease by 58% (-71% to -14%) (Pacific Climate Impacts Consortium, 2012). These factors contribute to an increasing risk of summer water shortage.
- There is a high level of agreement in projections that fall, winter, and spring precipitation will increase in the interior of British Columbia. Along the south coast of B.C., projections suggest increases in winter, spring, and fall precipitation. Meanwhile summer precipitation is expected to decrease. This would affect streamflow in major river systems. For example, the Peace River and Upper Columbia River show reductions in the influence of snow, including a shift to higher discharge in winter, an earlier freshnet, and reduced summer discharge. However, discharge will still generally retain the characteristics of a nival regime. In the Campbell River system, discharge is expected to transition almost entirely to a pluvial system (Schnorbus, Werner, & Bennett, 2012).
- The Pacific Decadal Oscillation (PDO) and El Niño Southern Oscillation (ENSO) influences the climate and hydrology, including precipitation, snowfall, glacier mass balance, etc. El Niño and positive PDO are both associated with warmer temperatures and less precipitation in British Columbia (Natural Resources Canada, 2015; Asong, Wheater, Bonsal, Razavi, & Kurkute, 2018). Although there is uncertainty in the projections, climate change could increase the strength of El Niño events, which may result in warmer and drier conditions for the province (Whitfield, Moore, Fleming, & Zawadzki, 2010).

Water shortages in rain-dominated regions:

- Projections indicate that fall, winter, and spring precipitation could increase in the interior, while summer precipitation will decline in southern British Columbia. Summers will be drier and low flow events will be more frequent and increase in magnitude, which would likely drive more summer water shortages (Government of British Columbia, 2016).
- In the Vancouver region, summer is already the driest season and summer precipitation is projected to decline by 19% (-41 to 1%) by the 2050s (Metro Vancouver, 2016).
- In coastal lowland areas and lower elevations of the windward side of the Coast Mountains such as Carnation Creek, rainfall is the primary contributor to streamflow. These systems could experience water shortages due to reductions in precipitation (Eaton & Moore, 2007).

[53] The range represents the 10th to 90th percentile of projections as a change from the 1961-1990 baseline.

Water shortages in snowpack-dominated regions:

- There are two components to snowpack decline—a lower proportion of precipitation falling as snow (accumulation) and earlier snow melt—both of which are expected to continue through mid-century. These changes would cause a decrease in summer discharge in snow-dominated hydrologic regimes (Schnorbus & Cannon, 2014).
  - By mid-century, higher temperatures would reduce the proportion of precipitation falling as snow and B.C.'s snowpack is expected to decline significantly. Distinct from natural variation, climate change-driven snowpack decline is around 4% (Jost & Weber, Potential Impacts of Climate Change on B.C. Hydro's Water Resources, 2012). This could impact many important watersheds. For example:
    - The central and north coast of B.C. and high elevations along the south coast show the most notable projected declines in snowfall (Pike et al., 2010).
    - In the Vancouver watershed, April 1 snowpack depth is projected to decrease by almost 60% by the 2050s relative to the 1971 to 2000 historical baseline (Metro Vancouver, 2016). This suggests that seasonal water shortages will become increasingly frequent as spring snowpack declines.
    - In the interior plateau and mountain regions, and higher-elevation zones of the Coast Mountains, watersheds are supplied primarily by snowpack. In these zones, winter precipitation falls as snow and remains in storage until spring melt. These systems would experience water shortages due to higher temperatures reducing the proportion of precipitation falling as snow and increasing the rate of snowmelt (Eaton & Moore, 2007).
    - In the Fraser Basin, the proportion of precipitation falling as snow is projected to decrease by almost 50% in the 2050s compared to the historical baseline (1980 to 2009) (ul Islam, Déry, & Werner, 2017). Models project that SWE could decline by 28% by the 2050s across the Fraser River Basin. Although precipitation will offset some changes in snowfall, the timing of discharge will change significantly (Pike et al., 2010).
    - In the Stuart and Nautley sub-basins, snowmelt contribution to runoff is projected to decrease by 20% (ul Islam, Déry, & Werner, 2017).
    - The portion of winter precipitation falling as snow in the Lower Columbia-Kootenay is expected to decline by 15% by the end of the century (from 85% from 1961 to 1990 to 50% by 2100). In the majority of other regions, the proportion is expected to decline by close to 50% (Columbia Basin Trust, 2017).
  - With higher spring temperatures, snowmelt is projected to occur earlier, which would reduce late summer streamflow in some basins. For example:
    - By the 2050s, the timing of snowmelt could change. Spring snowmelt is projected to occur around 25 days earlier, which would increase early spring runoff for the Fraser River and result in earlier low-flow conditions during the summer (ul Islam, Déry, & Werner, 2017). In addition, earlier melt will result in reduced late-summer streamflow and a longer dry season (Columbia Basin Trust, 2017).
    - By 2045, reduced snowpack and early snow melt, coupled with higher evapotranspiration in early summer, is expected to lead to earlier spring peak flows and reduced runoff volumes from April-September between 75 to 90% in the Columbia River Basin (Hamlet & Lettenmaier, 2007).
    - In the Okanagan Plateau region, snow melt could occur 16 days earlier under a 2°C warming and 37 days earlier under 4°C of warming (Pike et al., 2010).
- The risk of water shortage is expected to be greater in warmer and drier hydrologic regions such as the Lower Columbia-Kootenay, the Upper Kootenay and the Columbia-Kootenay Headwaters. The

cooler and wetter hydrologic regions such as Canoe Reach and the Northwest Columbia could expect to experience these changes to a lesser extent and/or in a delayed timeframe (Columbia Basin Trust, 2017).

- Some watersheds may be augmented by glacier melt. Projections show that glacier-augmented systems will experience low flow more frequently and for longer periods. See Glacier Mass Loss risk event.

**Confidence: Medium**

Seasonal water shortages have occurred multiple times in recent years, and it is likely that they will become more frequent by mid-century as climate conditions promoting water deficits become more prevalent. While the spatial extent for this scenario is province-wide, seasonal water shortages are inherently transient and may affect multiple regions over short time periods within a single year. Other regions are sensitive to water sourced from glaciers, which is considered in the Glacier Mass Loss risk event. In addition, water shortages depend on demand exceeding supply. While the models demonstrate that water supply could decrease, demand has been assumed to remain constant, although it will likely change in the future.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **3.4** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (2+4+3+4+3+5+4+2)/8

Overall Consequence = 3.4

### HEALTH

*Loss of life: 2*

While water shortages have been associated with mortality in low-income countries, no deaths have been directly attributed to water shortage in Canada. Communities in B.C. have the capacity to prepare in advance and implement measures to protect affected communities from reductions in water supply. In addition, there is a small risk that complications due to respiratory, water-borne, or vector-borne illnesses. Thus, based on the available evidence, there is low potential for multiple losses of life due to the direct or indirect effects of this water shortage scenario. However, compounding impacts due to extreme heat or wildfire could contribute to low loss of life.

Supporting evidence includes:

- While no deaths have been directly attributed to water shortage in Canada, the effects of economic damage may have contributed to excess morbidity and mortality (Health Canada, 2008). Deaths have been documented in low-income countries due to water shortages (Yusa et al., 2015) but are unlikely in British Columbia.
- In the western U.S., some studies indicated that mortality risk increased during periods where extreme or exceptional drought conditions were worsening (i.e., becoming more severe on the U.S.

Drought Monitor scale from one day to the next) for elderly adults between 2000 and 2013 (Berman, Ebisu, Peng, Dominici, & Bell, 2017).

- Water shortages can increase the risk of respiratory illnesses, and water-borne and vector-borne disease (Ostry, Ogborn, Takaro, Bassil, & Allen, Climate Change and Health in British Columbia, 2008; Yusa et al., 2015). Although no evidence was found, complications from these illnesses could result in deaths.
- Water shortages occur gradually, which gives the province time to respond and mitigate the risk of loss of life. If people lose access to water, drinking water would need to be provided. Therefore, the greatest risk would be faced by people living in rural areas who are far from water distribution or those who ignore warnings and drink from contaminated sources (Workshop feedback, 2019).
- Compounding factors that may accompany water shortages, such as more severe wildfire or extreme temperatures, could contribute to higher mortality (see Severe Wildfire Season and Heat Wave risk events).

**Confidence: Medium**

There is little literature documenting mortality due to water shortages, which could mean it is not well understood or that it is not a major risk during water shortages. Given that deaths could mostly be avoided, possible mortality arises from people being pushed to drink from contaminated water sources or complications from indirect effects on health. Expert reviewers agree that there is a low likelihood for loss of life in British Columbia.

### *Morbidity, injury, disease, or hospitalization: 4*

Water is vital for health and sanitation, so water shortages can negatively affect health if people turn to unsafe water sources. Contaminated water supplies have the potential to expose more than 100 people to health risks in B.C., although the impacts may be relatively minor if safe water supplies are provided to affected areas. Small water systems and private systems face greater risk than those connected to centralized water sources.

Supporting evidence includes:

- Approximately 78% of B.C.'s population depends on surface water supplies for drinking water. Since the 1980s, B.C.'s major urban centres have experienced several extreme water resource limitations. In the Capital Region District and Greater Vancouver Regional District, in addition to smaller, rapidly developing communities, drinking water supplies may become stressed (Walker & Sydneysmith, 2008).
- Reduced water levels and streamflow can result in stagnation and increased concentration of nutrients and contaminants (Government of British Columbia, 2016; Yusa et al., 2015). Dry conditions increase surface-water evaporation, which lowers water levels and increases the concentration of dissolved matter (Health Canada, 2008). Decreases in water quality could negatively affect human health.
- Treatment plants are designed to meet a threshold for reduction in contaminants and the risk of disease could increase if low-flow conditions increase the concentration of contaminants. When authorities determine that water sources may be unsafe, some individuals may continue to drink it and suffer health consequences, while others may turn to unhealthy alternative beverages. Water

shortages could necessitate water distribution. If users are on private or remote water systems, reaching water supplies could be difficult (Workshop feedback, 2019).

- Water shortage may increase the risk of water-borne disease (Ostry, Ogborn, Takaro, Bassil, & Allen, Climate Change and Health in British Columbia, 2008). For example:
  - Increased concentrations of pathogens during low water levels are thought to increase the risk of infection to recreational water users exposed to water-borne pathogens. For example, leptospirosis cases have been associated with water shortages and swimming in lakes in the U.S. (Yusa et al., 2015).
  - Water shortage conditions are associated with greater risk from water-borne diseases such as hepatitis A (Yusa et al., 2015). And dry conditions can also increase the concentration of Giardia and Cryptosporidium in groundwater sources and water storage locations, particularly in areas close to livestock farms (Yusa et al., 2015).
  - Several serious diseases are associated with seasonal water shortage conditions followed by a wet spring, including Campylobacteria and anthrax. Generally, there are only zero to two cases in Canada each year, although incidence may become more prevalent (Yusa et al., 2015).
- Water shortage can affect respiratory health and increase illnesses related to exposure to toxins, rates of injury and infectious diseases (food- and vector-borne diseases) (Yusa et al., 2015). For example:
  - Water shortages can enable some types of vector-borne diseases (Berry, Clarke, Fleury, & Parker, 2014). West Nile Virus and Eastern Equine Encephalitis may be linked to water shortage, although other factors may be more consequential in spreading these diseases. Those who spend time outdoors participating in recreation or due to their occupation are at a greater risk of contracting diseases (Yusa et al., 2015).
  - Dry conditions may encourage the growth of various fungi that can negatively affect health. For example, warm and dry conditions and low soil moisture promote colonies of Cryptococcus gattii in Canada. More than 100 cases of this disease were detected on Vancouver Island in 1999. Between 1999 and 2007, there were 218 reported cases in British Columbia, which has the largest infected population in Canada and the world (Yusa et al., 2015).
- Water shortage could affect vulnerable populations disproportionately, including pregnant and nursing women, dialysis patients, and immuno-compromised individuals (Yusa et al., 2015).
- Compounding factors that may accompany seasonal water shortages, such as more severe wildfire or extreme temperatures, could contribute to higher mortality. See Severe Wildfire Season and Heat Wave risk events.

**Confidence: Medium**

There are several sources of high-quality evidence on the negative impacts of water shortages on water quantity and quality that can result in negative health outcomes. However, little information is available about the health outcomes in B.C. due to past water shortages. In addition, it is difficult to determine whether these impacts would occur during a seasonal water shortage, or whether a more prolonged shortage would be needed. Expert reviewers estimate that more than 100 people could be affected, although the exact numbers are not known.

## SOCIAL FUNCTIONING

### *Psychological impacts: 3*

This water shortage scenario could result in temporary, widespread psychological impacts such as stress, anxiety, and depression due to water usage restrictions, economic hardship, and seasonal loss of livelihood. Psychological impacts will be especially prevalent for individuals that have natural-resource dependent livelihoods, such as farmers and fishermen.

Supporting evidence incudes:

- The key determining factors for post-disaster mental health issues are the degree and severity of exposure as well as post-disaster life stressors and level of social support (Goldmann & Galea, 2014).
  - Key risk factors that may increase vulnerability to disasters include age, low socioeconomic status, minority ethnic status, previous mental health issues, and low social support (Goldmann & Galea, 2014). The relative importance of these factors for a seasonal water shortage event in particular is unknown.
- Water shortage affects mental wellbeing, particularly for those with natural-resource dependent livelihoods, such as farmers, fishermen, etc.
  - During a water shortage, farmers could face irrigation restrictions. Damage to crops or reduced access to fishing could reduce income for dependent populations and increase stress. For example, farmers who lose their livelihoods and experience financial burdens may experience stress, anxiety, emotional and psychological distress, or grief (Yusa et al., 2015).
  - In most areas, summer water restrictions reduce or prohibit outdoor water use for activities such as watering lawns, filling pools, or power washing. As the severity of the water shortage increases, the restrictions become stricter (City of Vancouver, 2019).
  - The anticipation or potential for seasonal water shortages can increases anxiety for farmers as well as household water users that may be affected by water use restrictions. The year-to-year uncertainty of water availability and potential for more frequent water shortages can be especially stressful (Workshop feedback, 2019).
- Crop failures and economic hardship could also lead to hunger, malnutrition, and associated stress disorders (Health Canada, 2008).

**Confidence: Low**

There is limited evidence on psychological impacts due to seasonal water shortage. Additional data on psychological impacts from previous seasonal water shortages is needed to better understand the scale and magnitude of impact. As a result, this rating relies heavily on expert judgment and assumes that water restrictions will affect a large number of people (e.g., household water users).

### *Loss of social cohesion: 4*

This water shortage scenario could result in a weeks-long disruption to daily life as well as seasonal loss of livelihoods, especially for those in agriculturally dependent communities. If water supplies are compromised, some residents may need to adjust their behaviours or seek alternative water sources. Greater water scarcity could also increase competition between water users, which may increase conflict or social instability. Since water shortage may disproportionately affect vulnerable populations, it could have implications for maintaining social cohesion and equity.

Supporting evidence includes:

- By definition, a seasonal water shortage would cause a months-long disruption to daily life, especially for those in agriculturally dependent communities (Workshop feedback, 2019). Crop irrigation could be restricted or suspended, which would reduce crop productivity or even result in losses to irrigated crops (Crawford & Beveridge, 2013; Crawford & MacNair, 2012). In the worst case, agricultural producers could face major economic losses and workers could lose employment (Yusa et al., 2015), which could hurt the vitality of rural communities.
- The predicted decreases in water quality could increase the costs to obtain quality drinking water through either enhanced water treatment infrastructure or purchased drinking water. This could limit water supplies, particularly for small, remote communities. For example, many Indigenous communities are in remote areas and have limited economic means to maintain, refurbish, and replace infrastructure (CIER, 2008).
- Decreased water quantity would affect transportation on water bodies and leave less water available for agriculture (farming and ranching), hydroelectric power production, and fisheries for B.C.'s Indigenous communities (CIER, 2008; Joe, Bakker, & Harris, 2017).
- Water shortages could create "winners" and "losers" based on water allocations and restrictions. Social cohesion can be compromised due to competition for resources (Caldwell & Boyd, 2009).
- Water shortage may have disproportionate impacts on vulnerable populations, including socially disadvantaged, agriculturally dependent communities, people without insurance, and people without financial resources (Yusa et al., 2015).
- In 2015, after restrictions when into effect, residents turned to "drought shaming" by calling the authorities to report neighbour's water wastage (Hager, 2015). Struggles over water use could result in disputes or distrust.

**Confidence: Medium**

There are several sources of evidence documenting the types of social challenges that could emerge due to water shortages. In B.C., similar results could occur. Expert reviewers anticipate that water shortage could result in months-long disruptions for people due to changes such as water use restrictions, and, ultimately, exacerbate social instability.

### NATURAL RESOURCES: 3

This water shortage scenario could cause environmental damages, particularly for aquatic species. Temperature-sensitive species such as salmon may experience heat-stress and difficulties migrating due to low water levels. In addition, it is possible that a summer water shortage could result in damages to wetlands and forest ecosystems. For example, water shortages could make forests more susceptible to insect outbreaks and wildfire. The spatial area affected could be large and resources could take years to recover.

Supporting evidence includes:

- Seasonal water shortages affect surface water by lowering lake and reservoir levels and reducing streamflow (Yusa et al., 2015). These impacts can cause environmental damages, such as reduced water quality, wetland loss, soil erosion and degradation, and aquatic habitat destruction (Bonsal & Regier, 2007). For example:

- B.C. has around 5.28 million hectares of wetlands that provide critical habitat for fish, birds, and other wildlife (Government of British Columbia, 2018e). Seasonal water shortage could damage wetlands by lowering water levels in riparian environments. Amphibian species could suffer due to reduced wetland area (Workshop feedback, 2019).
- Lower flow conditions can increase river temperatures, resulting in negative impacts for fish and aquatic organisms including salmon and trout (Deitch, Van Docto, Obedzinski, Nossaman, & Bartsh, 2018; Ministry of Environment and Climate Change Strategy, 2018; National Park Service, 2018). The majority of Canadian sockeye salmon live in the Fraser River. Temperatures above 15°C can cause stress, depleting energy reserves and making salmon more susceptible to disease. Warmer river temperatures tend to reduce fitness, survival, and reproductive success of salmon (White, Wolf, Anslow, Werner, & Creative, 2016).
- Salmon spawn in streams in B.C. and migrate back and forth to the ocean. Lower flow conditions and changes in flow variability may make migration difficult (PSF, 2011).
- Reductions in spring and summer flows in snowmelt-dominated watersheds exposes salmon eggs to greater risk of scour as a result of salmon spawning towards the center of rivers; increased water temperatures could shift migration and spawn time (Crozier, 2016).
- Damage to salmon populations can have large ecological repercussions, as they are vital to the food chain. Around 137 species rely on salmon, including bald eagles and bears (PSF, 2011; White, Wolf, Anslow, Werner, & Creative, 2016).

• The effects of water shortage on forests and forest ecosystems will vary depending on the location of forests and the species of trees exposed (Mote et al., 2003). For example:

- Direct impacts of low water availability include reduced growth, increased tree mortality, and failure to regenerate (NRCan, 2017).
  ▪ In the U.S. Pacific Northwest and Canada's boreal forests, forested ecosystems have already experienced mortality due to water shortages (Warren & Lemmen, 2014). Dieback of aspen-dominated woodland has been a persistent and possibly increasing phenomenon in western Canada, resulting in a 5 to 7% loss in biomass (Chang et al., 2014).
  ▪ In 1998, and again in 2003, the southern interior of B.C. experienced drought that contributed to over 10,000 hectares of tree mortality. Some mortality resulted directly from water stress though much of the mortality was due to secondary insect attacks on stressed trees (Woods, Heppner, Kope, Burleigh, & Maclauchlan, 2010).
- When forests are stressed by water shortages, they may be more susceptible to wildfires, insect infestations, and disease. For example:
  ▪ In B.C., there has been extensive tree mortality due to insects, particularly the mountain pine beetle, which have transformed the forests of the interior. In 1999, drought affected over 10,000 hectares of forest in the Kamloops region. Extensive mortality occurred due to insects attracted to water-stressed trees (Walker & Sydneysmith, 2008).
  ▪ Water stress may reduce tree vigour and make forests more susceptible to insect attack (Allen et al., 2010). Insects include bark beetles, spruce budworms, and Douglas-fir beetles (Mote et al., 2003; van der Kamp, 2016). Beetle populations could increase to epidemic levels in B.C. due to warm, dry conditions (Woods, Heppner, Kope, Burleigh, & Maclauchlan, 2010). Other pests include: Douglas-fir beetles, Ips engraver beetles, lodgepole pine beetles, twig beetles, and elm bark beetle (Joy & Maclauchlan, 2000).

- Water stress can also predispose trees to root disease (Woods, Heppner, Kope, Burleigh, & Maclauchlan, 2010).

**Confidence: Medium**

There are multiple sources of independent evidence reporting widespread damages to natural resources, particularly forests and salmon populations, due to water shortages in British Columbia. However, it is not fully known the severity of impacts that would result from a seasonal water shortage. The consequences will depend on the magnitude and duration of the event, and the sensitivity of each species to water shortages. Expert reviewers agree that recovery of some resources could take years.

## ECONOMIC VITALITY

*Loss of economic productivity: 5*

This water shortage scenario could have disproportionate financial impacts on agriculture, fisheries, forestry, tourism, and other water-dependent sectors. Agriculture generates over $14 billion in annual revenue, and forestry and logging account for around $9 billion in annual revenue. If B.C. experiences a summer water shortage that affects multiple regions of the province, losses in these sectors could exceed $1 billion in losses. In addition, this event could cause unemployment in natural-resource sectors.

Supporting evidence includes:

Water shortages can reduce the productivity and economic contributions of many sectors, including agriculture, forestry, transportation, recreation and tourism, and energy (Moore, 2015b). For example:

- As of 2017, agriculture, forestry, fishing, and hunting accounts for 1.69% of B.C.'s GDP (Statista, 2018). Between 2014 and 2016, agriculture, seafood, and food and beverage processing produced revenues between $12 and $14 billion (AgriService BC, 2018).
- Losses to the agriculture, fisheries, and livestock sector could include:
- In 2015, Washington State Department of Agriculture concluded that the seasonal drought generated economic losses for the agriculture sector between US$633 and US$773 million (McLain, Hancock, & Drennan, 2017). Another source reported that Washington State experienced estimated losses of US$336 million from reductions in fish and agricultural production (U.S. Department of Agriculture, U.S. Forest Service, 2018).
- Increased unemployment in natural-resource-based sectors, including temporary displacement from agriculture (Yusa et al., 2015).
- Reduced agricultural and livestock production, with resulting economic losses (Health Canada, 2008; Crawford & MacNair, 2012). Negative consequences could include:
  - Loss of crop productivity. Water shortage can reduce crop growth and quality, resulting in smaller harvests, particularly for dryland production. More frequent water shortages may decrease crop yields and increase costs (Crawford & Beveridge, 2013).
    - Farmers may forgo a second crop if the water supply is limited. For example, in the summer of 2017, farmers harvested the first cut of dryland forage crops but the second cut did not occur in the Southern Interior due to water shortage (Agriculture and Agri-Food Canada, 2017).

    - Seasonal water shortage can have long-lasting effects on perennial plants (e.g., orchards, blueberry bushes) that require consistent irrigation. If water supply is affected, death of trees could have prolonged and severe financial implications (Workshop feedback, 2019).
  - Reduced water availability for livestock (Government of British Columbia, 2018a).
  - Lower pasture and forage growth. Water shortages may reduce forage production for livestock (Government of British Columbia, 2015) and also reduce the productivity of grassland ranges. If farmers lose forage crops and buy feed, this will increase production costs and reduce profits (Workshop feedback, 2019).
    - In 2007, the cattle sector received $7.5 million in drought assistance to provide feed for cattle, and, in 2010, a series of drought years resulted in payouts of $11.4 million in crop insurance (Crawford & MacNair, 2012).
  - Increased irrigation and management costs. Water shortages could dry soils, increasing the need for irrigation, while water supplies may be reduced (U.S. EPA, 2017).
    - In the Okanagan River watershed, agriculture accounts for 75% of consumptive use and crops depend entirely on irrigation. Of the 18,416 hectares of irrigated agricultural land, 75% are irrigated with surface water and 21% draws on groundwater (BC Agriculture & Food Climate Action Initiative, 2016). In irrigation-dependent regions such as Okanagan, summer water shortages can cause major disruptions, reducing the quality and health of perennial crops (including high-value fruit trees and wine grapes) (Walker & Sydneysmith, 2008). A seasonal water shortage could reduce surface water supplies or result in limitations on withdrawals that would reduce irrigation supply.
    - Crop water demand is expected to increase while inflow in the Okanagan Lake is expected to decrease by 80 to 93% by 2050 (Neilsen et al., 2006).
    - Irrigation may be restricted later in the summer due to water shortage, after cropping decisions have already been made (Moore, 2015b).
  - Altered soil properties and aeolian erosion. Water shortages can reduce soil fertility. For example, nitrogen and boron are vulnerable to low water availability. Crops that require nitrogen, such as corn and grasses, may accumulate high levels of nitrates when experiencing water stress, which can be toxic to livestock (Moore, 2015a). However, these consequences are relatively minor compared to direct impacts to crops and livestock.
  - Supply chain impacts (input/forage, loss of supply). For example:
    - Restrictions to water withdrawals from rivers in 2015 forced ranchers to buy hay and feed for their livestock. Hay prices increased by at least $100 due to reduced supply in western Canada. At the same time, the price of cattle dropped by around 35%, reducing the well-being of ranchers in the region (Holmes, 2016).
    - As a proxy, western Saskatchewan and eastern Alberta received 40% of normal rainfall in 2015. The resulting drought reduced suitable pastureland, which increased the price of feeding cattle. This change increased the price of beef to the highest level since 1995 (ground beef prices increased by 33% and sirloin steak increased by $44 from 2013 and 2015) (Alberta Water, 2018).
- In a representative year, commercial salmon fishing in B.C. can bring in $30 million in value and $100 million in post processing value (PSF, 2011). Reduced river flows and higher water temperatures could lead to losses in the fisheries industry, as discussed in the previous section.
- In 2016, B.C.'s forest industry generated $32.96 billion in output and contributed $12.94 billion to the province's GDP. Forestry and logging accounted for around 28% of the industry's

contribution (PwC, 2017). Other industries like pulp and paper mills also depend on healthy forest resources. The forest industry could experience losses due to large die-off of forests. Forest insect and disease pests have cost Canada hundreds of millions of dollars in revenue losses, prevention, and control investments, and environmental mitigation efforts. The Canadian Council of Forest Ministers reported that the annual cost to manage one invasive pest species could be $34 million (Natural Resources Canada, 2017). As discussed in the section above, water stressed trees are more susceptible to damages due to pests and wildfire. However, the full affect has not been quantified and would depend on the magnitude of the seasonal water shortage.

- Water shortage could result in economic losses to the water-based tourism and recreation industry, including:

- Reduced quantity and quality of recreational water supplies (Yusa et al., 2015) could have negative economic impacts on communities that rely on water-based recreation and tourism. Tourism peaks during summer months when water shortages could be most severe (Ministry of Environment and Climate Change Strategy, 2018).
- Summer tourism may decline due to water restrictions, which would reduce revenue in certain locations. For example, fishing bans due to low flow conditions could reduce travel and revenues from recreational fishing, which contributes over $300 million to B.C.'s GDP (Stroomer & Wilson, 2012). There are approximately 300,000 licence holders in the province (Government of British Columbia, 2018d) and recreational anglers spend over $550 million annually on fresh and saltwater sport fishing (PSF, 2011).
- Communities near waterfronts or vacation areas may experiences economic losses (Alberta Water, 2018).
- Water sports retailers and renters may lose business during water shortages (Alberta Water, 2018).

- Economic losses to other companies and industries that rely on stable water supplies could include:

- Water restrictions that reduce business for landscapers and other water-dependent companies. In 2015, landscapers and pressure-washing companies had to lay off employees as their businesses declined during the drought (Stevenson, 2015).
- Mining operations may have to reduce production due to water shortages. For example, Mount Milligan copper-gold mine applied for additional water allocations but would need to reduce operations if water is not available (Centerra, 2018).
- The oil and gas sector could experience losses due to suspended water allocations during summer seasonal water shortage, which B.C. experienced in 2010 and 2012 (B.C. Oil & Gas Commission, 2012). In summer 2010, the B.C. Oil and Gas Commission suspended surface water withdrawals in four river basins for several months (Campbell & Horne, 2011). Some operators build off-stream reservoirs to store water during freshet events and use during drier periods. However, if the industry is not able to get water, operations could halt (Workshop feedback, 2019).

**Confidence: High**

There are multiple sources of high-quality information on the severe impacts of water shortages on the agriculture sector and several sources documenting losses to other water-reliant sectors. It is likely that these estimates do not represent the full range of economic consequences but are representative of the types of costs to the economy. Due to the scale of these industries, losses could exceed $1 billion.

*Loss of infrastructure services: 4*

This water shortage scenario may result in weeks-long disruption of key infrastructure services, including electricity production and water treatment. Historically, water shortages in Canada and the Pacific Northwest have reduced hydroelectric production capacity, caused thermo-electric plants to shut down, and increased water and wastewater treatment requirements due to higher turbidity.

Supporting evidence includes:

- Seasonal water shortage can reduce streamflow and have a detrimental effect on hydropower generation, which supplies around 90% of B.C.'s electricity. For example, the Columbia River Basin's hydropower production is vulnerable to lower water supply and changing river flow patterns (Walker & Sydneysmith, 2008). Lower streamflow (run-of-river production) or lower reservoir levels result in reduced power output from hydroelectric dams, which could necessitate changes in dam operations or purchasing electricity from alternative sources. Reduced hydroelectricity could increase the costs to utilities and customers (U.S. Department of Energy & U.S. Department of Homeland Security, 2011). Previous seasonal shortages have resulted in a variety of impacts, including:
  - In 2015, B.C. Hydro stopped or limited electricity production at facilities in the Lower Mainland and Vancouver Island because of low water levels. When water shortages coincide with high temperatures, this can be more problematic because peak electricity demand increases as people use fans, air conditioners, and increased refrigeration (B.C. Hydro, 2015).
  - In 2010, severe drought in northeast B.C. reduced water supply in reservoirs, which forced B.C. Hydro to increase electricity imports at the cost of $220 million (U.S. Department of Energy & U.S. Department of Homeland Security, 2011).
  - In 2005, Washington State estimated that the drought conditions increased the cost of supplying electricity by between US$200 and US$300 million, which would be equivalent to a 4 to 7% increase in costs to consumers (U.S. Department of Energy & U.S. Department of Homeland Security, 2011).
- Thermo-electric plants require water for cooling. Water shortage, and associated higher water temperatures, can reduce energy production and efficiency. This can increase the probability of blackouts, which would negatively affect many industries (U.S. Department of Energy, 2012).
- During low flow conditions, water and wastewater treatment plants may become stressed. If water pressure drops, increased turbidity may increase the risk of water contamination and the need for greater water treatment. Bacteria and contaminants in greater concentrations will also increase the strain on treatment facilities, which are designed to manage a certain load. If well water levels decline, additional treatment would be required to treat alternative water sources to ensure that health is not at risk (Yusa et al., 2015).
- If B.C. Hydro must reduce operations, water treatment plants may not be the priority for being reconnected, which could have escalating consequences for health systems that depend on the plan (Workshop feedback, 2019).
- The northeast does not have infrastructure to handle seasonal drought and supply may shut down. In this case, water would need to be brought in (Workshop feedback, 2019).

**Confidence: Medium**

There are multiple sources of evidence of the high risks of water shortage to electricity production. However, it is not clear how long these systems would take to recover from a disruption, since little research is available on the extent of water shortage impacts to the province from previous events and the losses incurred.

### COST TO PROVINCIAL GOVERNMENT: 2

The primary cost to the provincial government is expected to be emergency response and recovery funding to affected sectors, particularly for agriculture. Other costs could include health and utility services. Although the expected costs can't be fully quantified, the costs to government are expected to be on the order of $375 million or less.

Supporting evidence includes:

- Costs to government from water shortages include emergency response and recovery funding and lost revenue from affected industries. Example expenses to government could include:
  - Supplying water to communities without access to safe drinking water. In the lead up, there could be costs associated with developing drinking water protection plans to prepare small water systems for water shortages. In addition, the government would likely provide support for drought response planning (Workshop feedback, 2019).
  - Public outreach to inform people about the water shortage and appropriate responses (Workshop feedback, 2019).
  - Additional hours required from Environmental Health Officers to connect water systems, conduct surveys, and conduct outreach to communities and water systems facing challenges (Workshop feedback, 2019).
  - Losses in tax revenue and reduced applications for new water licenses (Workshop feedback, 2019).
- The project team was unable to precisely estimate the agriculture-related business risk management program costs for this scenario. However, assistance for the agriculture sector could include Production Insurance and funding through AgriStability. For AgriStability to respond, the losses at the individual farm level would have to exceed a 30% margin decline for the whole farm (Agriculture and Agri-Food Canada, 2018b). Since Production Insurance and AgriStability would provide direct coverage of the types and levels of loss that could occur due to water shortage, it is unlikely that this event would trigger support through AgriRecovery (Agriculture and Agri-Food Canada, 2018a). The agriculture sector has faced major losses due to past events that required government intervention. For example:
  - Non-irrigated crops face a greater risk due to water shortages. In response to losses in non-irrigated forage and grain crops in the Peace region, Production Insurance paid $9.2 million in 2008 and $9.6 million in 2010 (B.C. Ministry of Agriculture, 2019).
- The provincial government would likely be responsible for some portion of health care costs, although the project team could not determine the exact cost share between the federal and provincial government for the following estimates:
  - Although the negative health outcomes of water shortage will vary, some people may require hospitalization. According to the Canadian Institute for Health Information, the cost of a standard

hospital stay in B.C. is on average $6,135.54. Although not all cases of morbidity, injury, or disease are likely to result in hospitalization, the estimated range of over 100 hospitalizations as a result of seasonal water shortage can be valued at over $613,500. Some portion of this cost would be covered by the provincial government.

- If a seasonal water shortage qualifies as a disaster, an estimated 30% to 60% of affected populations could need some form of mental health-related assistance (NIST, 2017). Rates for severe, moderate, and mild mental illness can range between 6% to 26% up to 30 months following a disaster (FEMA, 2012). Treatment costs for these mental illness cases are estimated at (FEMA, 2012):
  - 12 months post disaster: US$822 per person
  - 18 months post disaster: US$639 per person
  - 24 months post disaster: US$567 per person
  - 30 months post disaster: US$414 per person

- If the event is declared a large-scale natural disaster that triggers DFAA, some portion of the cost could be covered by the federal government (Public Safety Canada, 2019). However, it is unknown whether a seasonal water shortage could qualify for DFAA.

**Confidence: Low**

There is limited reporting of the costs to the provincial government due to lost revenue and emergency response during past water shortage events. The rating is based primarily on expert judgment. Additional data are needed to account for the full cost to the provincial government expected due to seasonal water shortage. In addition, although the costs of a singular seasonal water shortage are expected to be on the order of $375 million or less, the cumulative costs through 2050 could be more significant if these events occur more frequently. Furthermore, it is unknown whether a seasonal water shortage would qualify for DFAA, in which case the federal government could provide significant financial assistance.

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[54] The value is in 2017 CAD. This measure divides a hospital's total inpatient expenses by the number of hospitalizations it sees in a year. The number is adjusted for some differences in the types of patients a hospital sees to make it more comparable with other hospitals.

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# Long-term Water Shortage

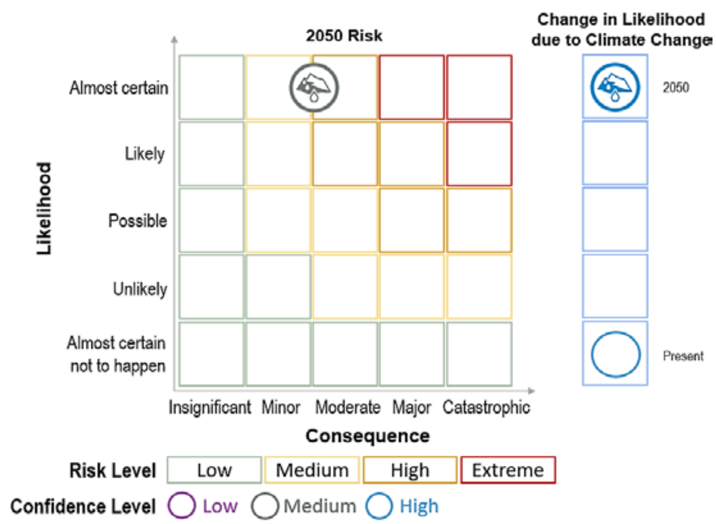
## Scenario

The specific risk event scenario analyzed is the occurrence of multi-year water shortage, driven by a year-on-year decrease in precipitation and increase in temperature, that results in insufficient supplies of both blue water and green water[55] in at least one region of the province. This event could be exacerbated by increased evaporation and evapotranspiration.

## Summary of Findings

Historically, severe multi-year water shortages have affected B.C. every few decades. For example, the drought that occurred from 2001 to 2002, which affected B.C., Alberta, and Saskatchewan, is considered one of Canada's worst natural disasters. Although models vary, higher temperatures are expected to increase evaporation and regional moisture deficit. When combined with below-average precipitation or low seasonal streamflow for several seasons, multi-year water shortages could occur.

**FIGURE 47.** Risk assessment findings for multi-year water shortage scenario.




The interior of B.C. is particularly susceptible to water shortages, which can result in losses across many sectors, including agriculture, forestry, industry, recreation, human health, and ecosystems. Reduced water supply can lead to losses in agricultural productivity, which is an important economic contributor in British Columbia. Additionally, multi-year water shortages make land and forests more susceptible to other risks, such as wildfires and insect outbreaks. Recovery of some resources from severe water shortage may take years or decades and cost the economy and government billions of dollars.

**FIGURE 47** and **TABLE 25** summarize the risk assessment results for this scenario. The highest consequences relate to loss of economic productivity, loss of infrastructure services, and loss of social cohesion. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

[55] Blue water refers to liquid water in reservoirs, lakes, aquifers, rivers, etc. and green water refers to moisture in the soil and vegetation (Falkenmark & Rockström, 2006).

**TABLE 25.** Risk Rating Evaluation for Long Term Water Shortage Scenario

| LONG-TERM WATER SHORTAGE: MULTI-YEAR WATER SHORTAGE IN AT LEAST ONE REGION | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **3** | Severe multi-year water shortages occur in the Canadian Prairies and interior B.C. approximately every 20 years. | **3** | **Climate-related risk cause:** Water shortages occur due to precipitation deficits, higher temperatures, and reduced snowpack.<br>**2050 projections:** Slight increases in annual precipitation and more frequent high intensity rainfall events are anticipated, yet rising temperatures could counteract these changes. Multiple seasons with high temperatures and below-average precipitation can result in water shortages. Large uncertainties are associated with predictions of multi-year dry spells. | Low |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **2** | There is low potential for multiple losses of life in B.C. | Medium |
| | Morbidity, injury, disease, or hospitalization | **4** | Hundreds of people could experience illness due to exposure to respiratory irritants and increased risk of water-borne, vector-borne, and fungal disease. | High |
| **Social functioning** | Psychological impacts | **4** | Loss of natural resource dependent livelihoods and economic hardship may contribute to localized, long-term psychological impacts. A larger population may experience moderate anxiety and distress. | Medium |
| | Loss of social cohesion | **5** | Months-long disruption to daily life and permanent loss of livelihoods, particularly for agriculturally dependent communities. Water restrictions could exacerbate general social instability. | Medium |
| **Natural resources** | Loss of natural resources | **4** | Soil erosion, wetland loss, habitat destruction, and forest degradation could disrupt wildlife and aquatic species, which could take decades to recover. | High |
| **Economic vitality** | Loss of economic productivity | **5** | Losses exceeding $1 billion could occur due to impacts on agriculture, fishing, forestry, transportation, recreation, tourism, and oil & gas. | High |
| | Loss of infrastructure services | **5** | Disruptions of hydroelectricity production, and water and wastewater treatment could last months. | Medium |
| **Cost to provincial government** | | **3** | Costs for emergency response and recovery and lost revenue could exceed $375 million. | Low |
| **OVERALL RISK** | **CURRENT** | **HIGH (12.0)** | | **LOW** |
| | **2050** | **HIGH (12.0)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **12.0** out of 25, which equates to **high risk**, and the 2050 risk rating is **12.0** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 3 x 4.0 = 12.0 (High)

2050 Risk = 3 x 4.0 = 12.0 (High)

## Evidence Base

### *Risk Event Scenario*

This scenario represents one illustrative permutation of a long-term water shortage. The consequence ratings are specific to this scenario, but many may be transferable to other related scenarios.

The specifics of this scenario were based on:

- There are various ways to define a water shortage, which occurs when water supply is insufficient to meet demand. In this scenario, drought, defined as a shortage of precipitation over an extended period of time, which results in insufficient supply (NRCan, 2017), is used as a proxy for water shortage. A shortage could occur due to a multitude of factors, but the consequences will be similar.
- The risk of drought is highly regional. Along the Pacific Coast, there could even be increases in precipitation. However, precipitation is expected to decline in the interior.
- Historically, most areas of Canada have experienced periodic droughts,[56] although the duration, severity, and extent have varied. The Canadian Prairies and the interior valleys of B.C. tend to be most susceptible to drought because of their proximity to the Rocky Mountains, which contribute to highly variable precipitation (Yusa et al., 2015; Bonsal et al., 2011). These areas experienced devastating multi-year droughts during the 1890s, 1930s, 1960s, 1980s, and 1999 to 2005 (Hanesiak et al., 2011; Asong, Wheater, Bonsal, Razavi, & Kurkute, 2018; Yusa et al., 2015).
- The drought from 2001 to 2002, which affected the interior region of B.C., is considered one of Canada's worst natural disasters and the most severe drought in the region since the 1930s (Wheaton, Kulshreshtha, Wittrock, & Koshida, 2008).
  - Precipitation was below normal for eight consecutive seasons from September 2000 through August 2002 for the Canadian Prairies (Bonsal & Regier, 2007; Mishra & Singh, 2010), which have conditions similar to portions of B.C.'s interior on a larger scale. Exceptionally dry and warm conditions contributed to persistent water shortage.
  - According to the Standardized Precipitation Index (SPI), 2001 and 2002 were the worst one-year droughts since 1961, and, together, the worst two-year drought since 1929 to 1930. Based on Palmer Drought Severity Index (PDSI), 2002 was one of the worst one-year droughts on record (Bonsal & Regier, 2007).
- The consequences of multi-year water shortages are more severe than those of seasonal water shortages and require more time to recover from. The consequences of a long-term water shortage would likely be similar but more severe than a seasonal water shortage.
  - Previous events demonstrate that multi-year water shortages can be catastrophic for British Columbia. In the Canadian Prairies, the 2001 to 2002 drought resulted in $5.8 billion losses for

[56] Droughts are defined as a shortage of precipitation over an extended period of time, which results in insufficient supply (NRCan, 2017).

Canada's GDP, agricultural losses and poor yields, reduced hydroelectric generation, soil degradation, and an increase in wildfire following the drought (Cherneski, 2018). In B.C., river flow and reservoir levels were lower than average, reducing irrigation supply in the Kelowna Irrigation District; livestock sales declined in 2002; hydroelectric power generation decreased and B.C. purchased power from neighbouring jurisdictions; and some recreational areas were affected by low lake levels (Wheaton, Kulshreshtha, Wittrock, & Koshida, 2008).

### *Likelihood rating*

The present-day likelihood of this scenario is **3** (event expected about once every 11 to 50 years) and the 2050 likelihood of this scenario is **3**. Water shortages occur due to a range of underlying climate-related causes, including precipitation deficits, higher temperatures, and reduced snowpack. Chronic shortages are most directly linked to prolonged episodes of below-average rainfall, which can result in total water availability below the long-term average over consecutive years. Often the impacts associated with reduced rainfall are exacerbated by seasonal climate stresses, such as heat waves and enhanced evapotranspiration. To evaluate the scenario, the project team used indicators including GCM projections and projected drought severity indices for mid-century. GCMs project significant warming and slight increases in precipitation in B.C., representing a future climate particularly sensitive to small changes in precipitation over consecutive years. Ultimately, multi-year water shortages have occurred in B.C. several times in the past century, and their frequency is likely to remain similar or increase slightly from historical incidence.

**Likelihood Rating Drivers**

Type of risk event: Discrete

Climate change indicators:

- Number of dry days
- Moisture deficit
- Annual precipitation
- Annual average temperature

"Present day" period: Varies by indicator

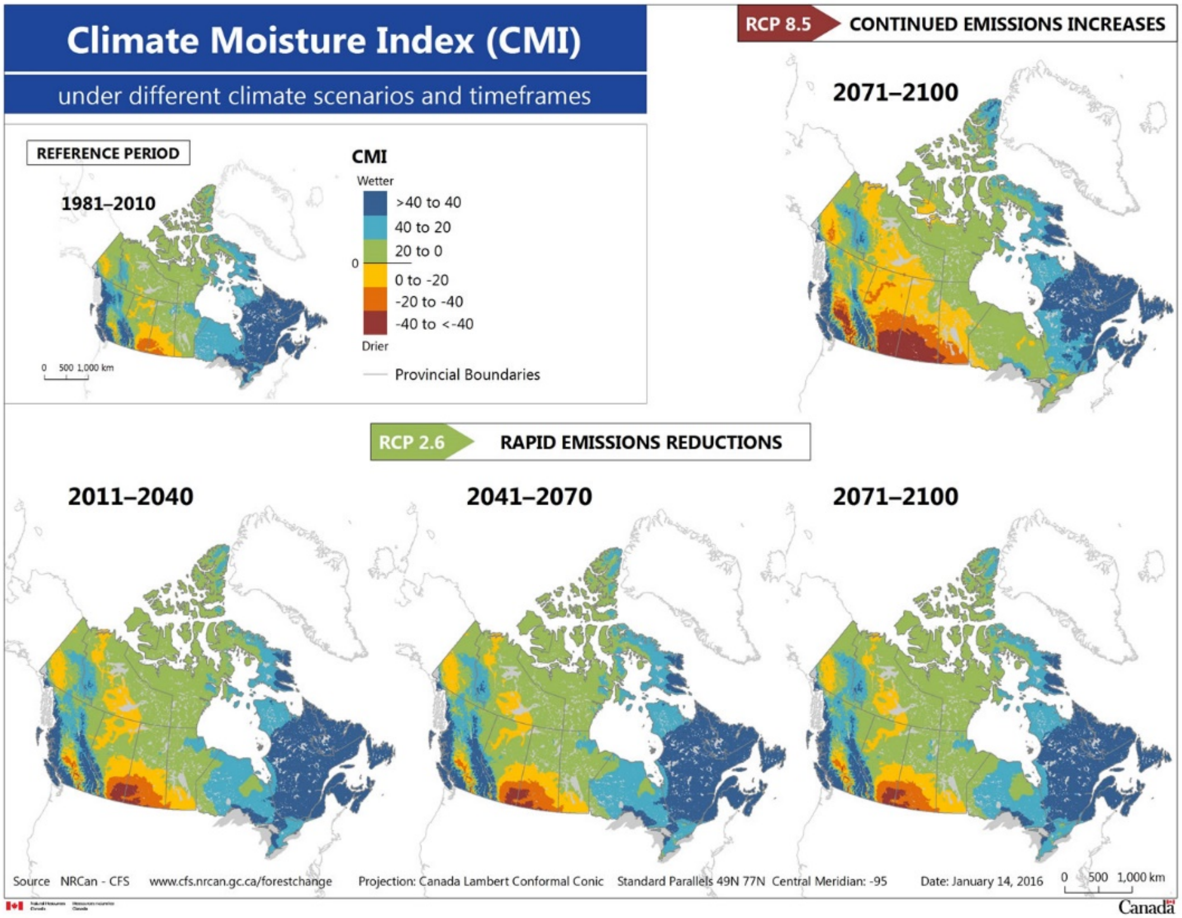
Source of 2050 projections: Varies by indicator

Emission scenario: Varies by indicator

The likelihood rating was determined based on the following findings:

- Projections show that the frequency and severity of water shortages will continue to increase in the Southern Interior of B.C. and the Prairies (NRCan, 2017), which exhibit similar levels of moisture deficit. Indicators of drought include:
  - Climate Moisture Index (CMI), which measures the difference between annual precipitation and potential evapotranspiration. Positive values indicate wet or moist conditions, while negative values indicate dry conditions. See **FIGURE 48.**
  - Soil Moisture Index includes daily or monthly weather records of precipitation and temperature, along with elevation and soil water-holding capacity. Lower values indicate drier conditions.
  - PDSI includes precipitation, temperature, moisture-holding capacity of the soil, and local infiltration. Positive and negative values represent conditions that are wetter and drier, respectively, than the long-term historical mean.

**FIGURE 48.** Projections of future conditions across Canada using the Climate Moisture Index (NRCan, 2017).




- The most recent scientific literature indicates that multi-year water shortages may become more frequent in the future, although there remains large uncertainty in model projections. For example:

- The extent and severity of water shortages are expected to increase (Bonsal & Regier, 2007). Future projections of the PDSI reveal that multi-year water shortages lasting at least 10 years are more likely in the future. Projections suggest that three such events could occur every 100 years, while approximately one has occurred every 100 years historically (Cohen, Koshida, & Mortsch, 2015; Yusa et al., 2015).
- The Canadian Regional Climate Model was used to evaluate potential changes in the frequency of dry days across Canada for the April to September period under the SRES A2 emission scenario.[57] The results indicated that the mean number of dry days and the maximum dry spell duration were projected to increase in southern Canada. The southern Prairies were identified as having a higher likelihood of drought conditions in the future (Warren & Lemmen, 2014).

[57] SRES A2 is a relatively high emissions scenario, although not the highest, that was used in IPCC AR4. This family of scenarios is characterized by heterogeneity and focus on regional change with continuous population increases (population reaches over 10 billion by 2050). Under this scenario, emissions are projected to be around 600 GtC, with concentrations of 575 ppm (NARCCAP, 2007) by mid-century.

- Multi-year water shortages result from a combination of climate factors. While below-average precipitation is a major factor, higher temperatures contribute significantly by increasing evaporation that exacerbates dry conditions. In years with low snowpack, which is associated with higher temperatures, seasonal river flow declines. Multi-year water shortages occur when anomalous seasonal water shortages continue without a substantial break (high precipitation and low temperature) for multiple seasons.
- In B.C., annual average temperature is projected to increase by 1.8°C (1.3°C to 2.7°C)[58] compared to the 1961 to 1990 baseline. While annual precipitation is projected to increase by around 6% (2% to 12%), seasonal precipitation varies greatly (Pacific Climate Impacts Consortium, 2012). Increases in evaporation due to higher temperatures are expected to outweigh increases in average precipitation (Yusa et al., 2015).
- GCMs project that the moisture deficit[59] will increase through mid-century, driven by rising summer temperatures and declining summer precipitation, potentially reaching levels exceeding the 1930s by the end of the century, when Canada experienced severe multi-year water shortages (Columbia Basin Trust, 2017). GCMs confirm warming will continue in B.C., which will increase evaporation. In combination, these factors will likely result in longer and more intense water shortages (Yusa et al., 2015; Bonsal & Regier, 2007).
- After several severe water shortages in the early 20th century, the subsequent water shortages and moisture deficits were relatively benign (Bonsal & Regier, 2007). However, studies indicate that the moisture deficit has increased again, bringing worsening drought conditions in the 21st century (Columbia Basin Trust, 2017). Regional trends across southern and western Canada indicate that more severe drought conditions are becoming more frequent (Warren & Lemmen, 2014).

**Confidence: Low**

There are several sources of evidence suggesting long-term water shortages could become more frequent and severe by mid-century. However, GCM simulations remain uncertain regarding future precipitation trends and scientists are generally unable to predict the occurrence of multi-year water deficits with certainty. In addition, longer duration events are more influenced by natural modes of variability, which are difficult to model and predict. Some of the data and examples included are based on droughts in other provinces to exemplify the type of water shortage B.C. could experience and its associated consequences.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (2+4+4+5+4+5+5+3)/8

Overall Consequence = 4.0

[58] This range represents the 10th and 90th percentile of model projections.
[59] The difference between precipitation inputs and losses through evaporation, which can be used as a measure of moisture needed for vegetation to avoid negative impacts (Columbia Basin Trust, 2017).

project team rated the overall consequence of this scenario as **4.0** out of 5.

## HEALTH

### *Loss of life: 2*

Based on the available evidence, there is low potential for multiple losses of life due to the direct impacts of long-term water shortages. While prolonged water shortages have been associated with mortality in low-income countries, communities in B.C. have the capacity to prepare in advance to protect communities from ill health effects. Long-term water shortages can have broader impacts to society by affecting surface and groundwater supplies, and food production. Although not accounted for here, compounding impacts due to extreme heat or wildfire may contribute to multiple deaths.

Supporting evidence includes:

- While no deaths have been directly attributed to water shortage in Canada, the effects of economic damage may have contributed to excess morbidity and mortality (Health Canada, 2008). Drought-related deaths have been documented in low-income countries (Yusa et al., 2015) but are unlikely in British Columbia.
- In the western U.S., some studies indicated that mortality risk increased during periods where extreme or exceptional drought conditions were worsening (i.e., becoming more severe on the U.S. Drought Monitor scale from one day to the next) for elderly adults between 2000 and 2013 (Berman, Ebisu, Peng, Dominici, & Bell, 2017).
- As an ongoing event, long-term water shortage will occur gradually as a series of seasonal water shortages, affecting groundwater supply and resulting in major desiccation. Since the event would happen gradually, there would be time to prepare and communities could find alternative water sources to meet basic needs. Health risks occur when people turn to contaminated water sources or cannot access safe supplies, which would be avoided except in extreme circumstances (Workshop feedback, 2019).
- Compounding factors that may accompany water shortages, such as more severe wildfire or extreme temperatures, could contribute to higher mortality (see Severe Wildfire Season and Heat Wave risk events).

**Confidence: Medium**

There is little literature documenting mortality due to water shortages, which could mean it is not well understood or not a major risk during water shortages. Assuming basic mitigative action is taken to supply water to affected communities, mortality would be low. Expert reviewers agree that there is a low likelihood for multiple deaths due to long-term water shortage.

### *Morbidity, injury, disease, or hospitalization: 4*

Water is vital for health and sanitation, so water shortages can negatively affect health if people turn to unsafe water sources. Contaminated groundwater and surface water, in addition to respiratory irritants, have the potential to expose hundreds of people to some level of illness during a multi-year water shortage. Ill effects could include bacterial infections from unsafe drinking water, water-borne and vector-borne diseases, or fungal diseases that become more prolific during the event. People living in rural areas or who are socioeconomically disadvantaged would likely experience disproportionate health impacts.

Supporting evidence includes:

- Approximately 78% of B.C.'s population depends on surface water supplies for drinking water. Since the 1980s, B.C.'s major urban centres have experienced several extreme water resource limitations. In the Capital Region District and Greater Vancouver Regional District, as well as smaller developing communities, drinking water supplies may become stressed during a water shortage (Walker & Sydneysmith, 2008).
- Reduced water levels in lakes and reservoirs, as well as lower streamflow during a shortage, can result in stagnation and increased concentration of nutrients and contaminants (Government of British Columbia, 2016; Yusa et al., 2015). Water shortage may lower water levels in wells and aquifers, increasing the concentration of contamination and dissolved matter (HealthLinkBC, 2018; Health Canada, 2008). For example:
  - In the U.S., water shortage is associated with elevated nitrates, chlorides, and sulphates in the groundwater supply (Yusa et al., 2015). Additionally, elevated phosphorus and nitrogen levels have been observed during water shortages in Alberta (Yusa et al., 2015).
  - Long-term water shortages can lower groundwater levels and streamflow, increase wind erosion, and cause cracks in cisterns and septic tanks, creating the potential for higher levels of sedimentation in water (Berry, Clarke, Fleury, & Parker, 2014).
  - Increased nutrient concentrations due to low flow conditions has contributed to cyanobacterial (algal) blooms in all provinces. Algal blooms can reduce drinking water quality (Orihel et al., 2012).
- Water shortages may increase the risk of water-borne disease (Ostry, Ogborn, Takaro, Bassil, & Allen, 2008). For example:
  - Increased concentrations of pathogens during low water levels in lakes are thought to increase the risk of infection to recreational water users exposed to water-borne pathogens. For example, leptospirosis cases have been associated with swimming in lakes in the U.S. during drought (Yusa et al., 2015).
  - Drought is associated with greater risk from water-borne diseases such as hepatitis A (Yusa et al., 2015).
  - Water shortages can also increase the concentration of Giardia and Cryptosporidium in groundwater sources and water storage locations, particularly in areas close to livestock farms (Yusa et al., 2015).
  - Several serious diseases are associated with dry conditions followed by a wet spring, including Campylobacteria and anthrax. Generally, there are only 0 to 2 cases in Canada each year, although incidence may become more prevalent (Yusa et al., 2015).
- Prolonged water shortages can result in respiratory issues, and illnesses related to exposure to toxins, rates of injury, and infectious diseases (food- and vector-borne diseases) (Yusa et al., 2015; Berry, Clarke, Fleury, & Parker, 2014; Frumkin, Hess, Luber, Malilay, & McGeehin, 2008). For example:
  - Extended water shortages tend to reduce air quality through impacts to soil moisture and loss of vegetation, increasing the chance of wind erosion becoming airborne (USGCRP, 2016). Wind erosion and dust storms can introduce irritants that contribute to respiratory issues (Berry, Clarke, Fleury, & Parker, 2014). Climate change may increase fine particulate matter, allergen, and dust concentrations in the air in drought-prone areas (Yusa et al., 2015). Inhalation of particles can irritate the lungs, resulting in chronic respiratory illnesses (USGCRP, 2016).
  - Some types of vector-borne diseases, including West Nile Virus and Eastern Equine Encephalitis, may spread more easily during water shortages (Berry, Clarke, Fleury, & Parker, 2014). Those who

spend time outdoors participating in recreation or due to their occupation are at a greater risk of contracting diseases (Yusa et al., 2015).

- Various fungi that can negatively affect health may become more prolific. For example, warm and dry conditions and low soil moisture promote colonies of Cryptococcus gattii in Canada. More than 100 cases of this disease were detected on Vancouver Island in 1999. Between 1999 and 2007, there were 218 reported cases in British Columbia, which has the largest infected population in Canada and the world (Yusa et al., 2015).

- Vulnerable populations, such as pregnant and nursing women, dialysis patients, immuno-compromised individuals, and those of lower socioeconomic status, could be disproportionately affected by water shortages (Yusa et al., 2015; Workshop feedback, 2019).
- Wastewater and drinking water treatment facilities are built for a certain level of water intake, and water shortage may present challenges for treating it to safe levels. In rural areas, people may drink septic water and get sick (Workshop feedback, 2019).
- During a multi-year water shortage, people may be pushed to use water sources that may be more highly contaminated (Workshop feedback, 2019).
- Compounding factors that may accompany long-term water shortage, such as more severe wildfire or extreme temperatures, could contribute to exacerbated health problems. See Severe Wildfire Season and Heat Wave risk events.

**Confidence: High**

There are multiple sources of high-quality evidence on the negative impacts of long-term water shortage on water and air quality that can result in negative health outcomes. However, more details are needed on the exact number of people who experienced these health outcomes in the past to understand the extent to which B.C. could be affected. Experts agree that the health consequence of a long-term water shortage could be widespread, potentially affecting even more than 1,000 people with some minor health impacts.

## SOCIAL FUNCTIONING

### *Psychological impacts: 4*

A multi-year water shortage could lead to severe, but localized, psychological impacts such as depression and loss of identity or way of life for individuals that have natural resource dependent livelihoods (e.g., farmers, fishermen, and cattle ranchers). The larger population may experience more moderate psychological impacts, such as anxiety and distress due to water restrictions or food security concerns. The extent of this impact depends on the location and severity of the water shortage, and on the resources provided to support people who are negatively affected.

Supporting evidence incudes:

- Small or private water systems may struggle to supply customers during a multi-year water shortage if streamflow and groundwater decrease. People dependent on these systems would experience major disruptions to life that could cause distress (Workshop feedback, 2019). Although most people connected to large water systems would likely have access to drinking water, most areas put in place water restrictions to reduce or prohibit outdoor water use for activities such as watering lawns, filling pools, or power washing. As the severity of the water shortage increases, the restrictions become stricter (City of Vancouver, 2019).

- Under a multi-year water shortage, the province may implement restrictions to water use to maintain environmental flows for fish. This may limit or cut off water use to some water users (i.e., junior licence holders or unauthorized use), particularly agricultural producers or industrial users (B.C. Ministry of Environment and Climate Change Strategy, 2018).
- A long-term water shortage would have more severe psychological impacts than a seasonal water shortage. For natural resource dependent communities, Indigenous communities, and those whose livelihood depends on accessing natural resources, long-term water shortage would necessitate changes in way of life. Some people could be displaced from their land or affected by lower property values (Workshop feedback, 2019).
- Common psychopathologies that manifest after disaster events include post-traumatic stress disorder, major depressive disorder, substance abuse disorder, general anxiety disorder, and prolonged grief disorder (Goldmann & Galea, 2014). The prevalence of these various mental health impacts from a long-term water shortage is unknown.
- In other countries, prolonged water shortages have had documented mental health impacts, particularly in rural areas (Hart, Berry, & Tonna, 2011; USGCRP, 2016). Although the severity of the impact would likely be mitigated by provincial support, these examples are indicative of the types of psychological impacts that could be experienced:
  - Negative impacts on mental health were identified for older women and Aboriginal groups in Australia, as well as rural youth, due to emotional stress from prolonged water shortages (Yusa et al., 2015).
  - Increased stress and mental health issues, particularly among farmers, have been linked to water shortages. For example, in Australia, prolonged water shortages caused pressures for farmers and a sense of loss (i.e. profitability, professional success, community status, physical well-being, etc.). Older farmers also felt discouraged from using mental health services (Polain, Berry, & Hoskin, 2011).
  - Farmers and ranchers could lose livestock and crops, which would result in psychological distress. If the water shortage persists, farmers and ranchers could abandon their way of life, which can be traumatic (Workshop feedback, 2019).
  - Farmers who lose their livelihoods and experience financial burdens may experience stress, anxiety, emotional and psychological distress, and grief (Yusa et al., 2015). In extreme cases, water shortage is associated with increased risk of suicide, particularly for agriculturally dependent rural populations (Hanigan, Butler, Kokic, & Hutchinson, 2012).
- Low income consumers could experience burdens associated with increased food costs and decreased availability of food, which may contribute to psychological distress (Yusa et al., 2015). Crop failures and economic hardship may lead to hunger, malnutrition and associated stress disorders (Health Canada, 2008). This will be relevant for local food production; however, the majority of food products are imported.
- Loss of property, livelihoods, displacement, and community disruption due to prolonged water shortage, or associated dust storms or wildfires, can cause stress (Health Canada, 2008). Chronic health issues from dust storms and wildfire smoke can contribute to exhaustion, depression, and

even suicide (Health Canada, 2008). The effects of wildfire are accounted for under the Severe Wildfire Season risk event.

**Confidence: Medium**

There are several sources of evidence that multi-year water shortage can contribute to psychological distress, depression, and even suicide. Additional information on reported cases during previous events and the duration of impacts in B.C. would help improve the assessment of risk. Experts expect that long-term water shortages could cause widespread and long-term psychological impacts due to people losing their ways of life.

*Loss of social cohesion: 5*

Multi-year water shortage could result a months-long disruption to daily life and permanent loss of livelihoods in localized areas, especially those in agriculturally dependent communities. Access to water resources may become more restricted. In addition, restrictions for water users creates "winners" and "losers," which could exacerbate social instability, although this impact is not expected to be widespread. Since water shortages may disproportionately affect vulnerable populations (e.g., socially disadvantaged persons, people dependent on natural resource-based livelihoods, and people without insurance), this could have severe implications for social cohesion.

Supporting evidence includes:

- Crop irrigation could be restricted or suspended, which would reduce crop productivity or even result in losses to irrigated crops (Crawford & Beveridge, 2013; Crawford & MacNair, 2012). In the worst case, agricultural producers could face major economic losses and workers could lose employment (Yusa et al., 2015), which could hurt the vitality of rural communities.
- Long-term water shortages may decrease social stability due to competition for resources, which has been documented during water shortages in Australia (Caldwell & Boyd, 2009).
  - For example, water shortages may increase tension due to competing water needs in the Okanagan, Kettle, and Coldwater-creek watersheds, including Indigenous communities, agriculture, rural communities, and ecosystem needs. When water supply is not adequate to meet authorized demand in B.C., users with senior water rights get to fulfill their licences and junior users may be regulated. This creates "winners" and "losers" (Workshop feedback, 2019).
  - The 2001 to 2002 drought led to the emergence of local water conflicts. During water shortages, fisheries may experience more water management conflicts with other users (e.g., hydroelectric power generation, irrigation, drinking water), particularly in the Southern Interior (Walker & Sydneysmith, 2008).
- When faced with a multi-year water shortage, people, particularly youth, may move away from rural communities to seek jobs in other industries. In some cases, water shortages may cause people to stop participating in community and volunteer activities, resulting in a higher degree of social isolation. Ultimately, water shortages may exacerbate alienation and distrust in institutions and governments (Alston & Kent, 2004).
- Small or private water systems may struggle to supply customers during a multi-year water shortage if streamflow and groundwater decrease. People would need to alter their behaviours to access water from a central distribution system or by purchasing bottled water (Workshop feedback, 2019). In

addition, the predicted decreases in water quality could increase the costs to obtain quality drinking water through either enhanced water treatment infrastructure or purchased drinking water.

- Many Indigenous communities rely on surface water flows and wells to meet water demands (Government of British Columbia, 2016). For several decades, some Indigenous communities have experienced issues accessing quality drinking water. As of 2008, 85 First Nation communities in Canada had water that was classified as "high risk" (CIER, 2008). In B.C. several First Nations, including Xeni Gwet'in and Lytton, have been under long-term water warnings because of polluted water (BBC, 2018; Ball, 2018). A multi-year water shortage could exacerbate these issues, particularly since many Indigenous communities are in remote areas and have limited economic means to maintain, refurbish, and replace infrastructure (CIER, 2008).
- Although most people connected to large water systems would likely have access to drinking water, most areas put in place water restrictions to reduce or prohibit outdoor water use for activities such as watering lawns, filling pools, or power washing. As the severity of the water shortage increases, the restrictions become stricter (City of Vancouver, 2019). These restrictions could disrupt people's routines.
- Water shortages may affect vulnerable populations disproportionately, including socially disadvantaged persons, agriculturally dependent communities, people without insurance, and people without financial resources (Yusa et al., 2015).

**Confidence: Medium**

There is limited evidence that water shortages have a negative impact on social stability in B.C. This could indicate that no past events were severe enough to reduce social stability or it may represent that this is not likely to manifest in the province. However, there are reasons to anticipate that water shortages could exacerbate inequality for vulnerable populations and produce a perception of "winners" and "losers" among water users. Expert reviewers suggest that people would need to adapt due to long-term water shortages, which would gradually result in a new steady state.

### NATURAL RESOURCES: 4

A multi-year water shortage in B.C. could cause extensive environmental damages, such as soil erosion, wetland loss, and habitat destruction. For example, water shortages could increase tree mortality and make forests more susceptible to insect outbreaks and wildfires. Additionally, temperature-sensitive species such as salmon could experience heat-stress and difficulties migrating due to low water levels. Depending on the severity of the water shortage, recovery of the resources could take decades.

Supporting evidence includes:

- Water shortages affect surface water by lowering lake and reservoir levels and reducing streamflow (Yusa et al., 2015). These impacts can cause environmental damages, such as reduced water quality, wetland loss, soil erosion and degradation, and aquatic habitat destruction (Bonsal & Regier, 2007). For example:

- B.C. has around 5.28 million hectares of wetlands that provide critical habitat for fish, birds, and other wildlife (Government of British Columbia, 2018b). Water shortage could damage wetlands by lowering water levels in riparian environments. Amphibian species could suffer due to reduced wetland area (Workshop feedback, 2019).

- Salmon spawn in streams in B.C. and migrate back and forth to the ocean. Lower flow conditions and changes in flow variability may make migration difficult (PSF, 2011).
- Lower flow conditions can increase river temperatures, resulting in negative impacts for fish and aquatic organisms including salmon and trout (Deitch, Van Docto, Obedzinski, Nossaman, & Bartsh, 2018; B.C. Ministry of Environment and Climate Change Strategy, 2018; National Park Service, 2018). The majority of Canadian sockeye salmon live in the Fraser River. Temperatures above 15°C can cause stress, depleting energy reserves and making salmon more susceptible to disease. Warmer river temperatures tend to reduce fitness, survival, and reproductive success of salmon (White, Wolf, Anslow, Werner, & Creative, 2016). Since environmental flows are prioritized, the extent of low flow is not known.
- Reductions in spring and summer flows in snowmelt-dominated watersheds could expose salmon eggs to scour, and increased water temperatures could shift migration and spawn time (Crozier, 2016).
- Damage to salmon populations can have large ecological repercussions, as they are vital to the food chain. Around 137 species rely on salmon, including bald eagles and bears (PSF, 2011; White, Wolf, Anslow, Werner, & Creative, 2016).
- Loss of forest cover and soil integrity may increase erosion into waterways, which can cause eutrophication and impacts on fisheries downriver. In addition, reduced flows could increase nutrient levels in surface water, which can result in algae growth. In turn, algae can decrease the dissolved oxygen concentration in water and threaten aquatic biota (Zheng & Paul, 2003).

- The effects of water shortage on forests and forest ecosystems will vary depending on the location of forests and the species of trees exposed (Mote et al., 2003). For example:

- Direct impacts of water shortage include reduced growth, increased tree mortality, and failure to regenerate (NRCan, 2017).
    - In the U.S. Pacific Northwest and Canada's boreal forests, forested ecosystems have already experienced mortality due to water shortages (Warren & Lemmen, 2014). Dieback of aspen-dominated woodland has been a persistent and possibly increasing phenomenon in western Canada, resulting in a 5 to 7% loss in biomass (Chang et al., 2014).
    - The 2001 to 2002 drought resulted in dramatic die-back in trembling aspen populations (over 20% greater mortality compared to the long-term average) (Warren & Lemmen, 2014).
- Water shortage may reduce rates of photosynthesis and tree growth (van der Kamp, 2016). Low soil moisture can reduce forest productivity and annual radial growth across species, including white spruce, black spruce, trembling aspen, and lodgepole pine (Warren & Lemmen, 2014; Hogg & Michaelian, 2014).
- Changes in hydrology could contribute to ecosystem shifts, which would change the ranges of BEC climate envelopes, which are the conditions associated with major forest types (Daust & Price, 2011).

- When forests are water stressed, they may be more susceptible to wildfires, insect infestations, and disease. For example:

- Water shortage may reduce tree vigour and make forests more susceptible to insect attack (Allen et al., 2010). Insects include bark beetles, spruce budworms, Douglas-fir beetles, Ips engraver beetles, lodgepole pine beetles, twig beetles, and elm bark beetle (Mote et al., 2003; van der Kamp, 2016; Joy & Maclauchlan, 2000). Beetle populations could increase to epidemic levels in B.C. due to warm, dry conditions (Woods, Heppner, Kope, Burleigh, & Maclauchlan, 2010).

- In B.C., there has been extensive tree mortality due to insects, particularly the mountain pine beetle, which have transformed the forests of the interior. In 1999, drought affected over 10,000 hectares of forest in the Kamloops region (Walker & Sydneysmith, 2008).
- Water shortages can also predispose trees to root disease (Woods, Heppner, Kope, Burleigh, & Maclauchlan, 2010).
- Persistent water shortages can pre-condition forests to burn due to wildfire by increasing die-off and the amount of flammable dead wood (van der Kamp, 2016). During a multi-year water shortage, lands are more susceptible to wildfire (Abbott & Chapman, 2018).
- The Loss of Forest Resources risk event provides more information on the risks due to forest loss.
- Multi-year water shortages may result in aquifer decline, due to lower surface water flows and reduced recharge to groundwater (Government of British Columbia, 2016).

**Confidence: High**

There are multiple sources of independent evidence reporting widespread damages to natural resources, particularly forests and salmon populations, due to long-term water shortages in British Columbia. However, the extent of damage to natural resources and recovery time will depend on the type of species, as some will be able to recover faster than others. Expert reviewers agree that recovery could take decades, although, depending on the magnitude of water shortage, experts anticipate that some natural resources may never recover.

## ECONOMIC VITALITY

### *Loss of economic productivity: 5*

A multi-year water shortage could reduce the productivity and economic contributions of major sectors, including agriculture, fishing, forestry, transportation, recreation, tourism, oil and gas, and other industries. Agriculture generates over $14 billion in annual revenue. Forestry and logging account for around $9 billion in annual revenue. If B.C. experiences a multi-year water shortage that affects a large portion of the province, losses in these sectors could easily exceed $1 billion in losses. Long-term disruptions and unemployment could also occur in the agriculture sector.

Supporting evidence includes:

Water shortages can reduce the productivity and economic contributions of many sectors, including agriculture, forestry, transportation, recreation and tourism, and energy (Moore, 2015b). For example:

- As of 2017, agriculture, forestry, fishing, and hunting accounted for 1.69% of B.C.'s GDP (Statista, 2018). Between 2014 and 2016, agriculture, seafood, and food and beverage processing produced revenues between $12 and $14 billion (AgriService BC, 2018).
- Losses to the agriculture, fisheries, and livestock sectors could include:
- Reduction in net farm income. For example, the 1961 drought led to a reduction in net farm income of 48% in Alberta and Saskatchewan (Asong, Wheater, Bonsal, Razavi, & Kurkute, 2018). Although not specific to B.C., these losses exemplify the types of risks B.C. could face because the Canadian Prairies and the interior of B.C. tend to be most susceptible to droughts.
- The 2001 to 2002 drought resulted in large economic losses across Canada, totaling a $5.8 billion reduction in GDP and $3.6 billion in agricultural losses over two years. In B.C., all drought losses occurred in 2002, totaling $42,955 and 224 lost jobs, with losses in agricultural production totaling

$30,001 (Swanson, Hiley, Venema, & Grosshans, 2007; Wheaton, Kulshreshtha, Wittrock, & Koshida, 2008).

- During the 2001-2002 drought, farmers in the Yakima basin (in Washington, USA) lost approximately US$130 million in revenue and farmers in the Klamath basin (in Oregon, USA) lost US$157 million in sales (Bumbaco & Mote, 2010).

- Increased unemployment in natural-resource-based sectors, including temporary displacement from agriculture (Yusa et al., 2015).
- Severely reduced agricultural and livestock production with resulting economic losses, as demonstrated by estimated losses from previous events (Health Canada, 2008). B.C.'s interior/Okanagan Valley is one of the driest places in Canada and vital for agricultural production. Negative consequences could include:
  - Loss of crop productivity. Water shortage can reduce crop growth and quality, resulting in smaller harvests, particularly for dryland production. Water shortages may decrease crop yields and increase costs (Crawford & Beveridge, 2013). For example, one report estimated that a multi-year water shortage reduces average crop yield by around two-thirds (Donahue, 2014).
  - Reduced water availability for livestock (Government of British Columbia, 2018a).
  - Lower pasture growth. Water shortages may reduce forage production, while simultaneously damaging pasturelands for livestock (Government of British Columbia, 2015) and reducing the productivity of grassland ranges.
    - Due to the 2001 to 2002 drought, large areas of pasture experienced poor growth, which contributed to feed supply shortages (Cherneski, 2018). If farmers lose forage crops and buy feed, this would increase production costs and reduce profits (Workshop feedback, 2019).
  - Water stress and quality impacts. Lower reservoir levels and wells that result from low precipitation or reduced flow from snowpack would reduce irrigation supplies (Moore, 2015b). In addition to surface water shortages, a multi-year water shortage would reduce water storage and groundwater supply for irrigation.
    - The compounding effects of higher temperatures would increase crop water requirements and evapotranspiration, which would add to crop stress during the water shortage. Many farmers may forgo planting because soil moisture would be reduced by a multi-year event.
    - Perennial cropping systems are particularly vulnerable when water use is restricted. Tree fruit, wine grapes, and berries take many years to mature and become productive. If water for irrigation is not available, extreme water shortages could result in major losses (MacNair, 2019). Droughts in 2001 and 2002 caused losses to perennial crops (high-value fruit trees and wine grapes, with some pasture and forage) (Neilsen et al., 2006).
  - Increased irrigation and management costs. Water shortages would push farmers to seek alternative sources of irrigation for water or make irrigation more efficient, incurring extra costs (Workshop feedback, 2019).
    - In the Okanagan River watershed, agriculture accounts for 75% of consumptive use and crops depend entirely on irrigation. Of the 18,416 hectares of irrigated agricultural land, 75% are irrigated with surface water and 21% draws on groundwater (BC Agriculture & Food Climate Action Initiative, 2016). Multi-year water shortages could disrupt the irrigation water supply from both sources, resulting in losses if farmers cannot meet crop water demands.
  - Altered soil properties and aeolian erosion. Water shortages can reduce soil fertility. For example, nitrogen and boron are vulnerable to low water availability. Crops that require nitrogen, such as corn and grasses, may accumulate high levels of nitrates when experiencing water stress, which can be

toxic to livestock (Moore, 2015a). However, these consequences are relatively minor compared to direct impacts to crops and livestock.

- Supply chain impacts. Restrictions to water withdrawals could force ranchers to buy hay and feed for their livestock. This could increase hay prices, which has implications for the cattle market and price of meat.

- Losses in the fisheries industry, as discussed under in the natural resources section. In a representative year, commercial salmon fishing in B.C. can bring in $30 million in value and $100 million in post-processing value (PSF, 2011).
- Loss of forestry output. In 2016, B.C.'s forest industry generated $32.96 billion in output and contributed $12.94 billion to the province's GDP. Forestry and logging accounted for around 28% of the industry's contribution (PwC, 2017). Other industries like pulp and paper mills also depend on healthy forest resources. As discussed in the section above, water-stressed trees are more susceptible to damages due to pests and wildfire. See Loss of Forest Resources risk event for additional information about the economic impacts of forest loss.
- Losses to urban forests, landscaping and horticulture, and the sod business (Workshop feedback, 2019).

- Water shortage could result in economic losses to the water-based tourism and recreation industry, including:

- Reduced quantity and quality of recreational water supplies (Yusa et al., 2015) could have negative economic impacts on communities that rely on water-based recreation and tourism (B.C. Ministry of Environment and Climate Change Strategy, 2018).
- Recreational fishing bans or reduced fish stocks, resulting in reduced expenditures and earnings in this sector. Recreational anglers spend over $550 million annually on fresh and saltwater sport fishing (PSF, 2011).
- Economic losses to communities near waterfronts or vacation areas (Alberta Water, 2018).
- Cancellation or closure of water-related recreational activities. During the 2001 to 2002 drought in Canada and the 1987 to 1992 drought in the U.S., water-related activities were closed (Alberta Water, 2018).
- Damage to orchards and wineries. For example, major water shortages and associated wildfires from 2001 to 2003 destroyed orchards and wineries in Okanagan and North Thompson valleys, which are popular tourist destinations. Regional hotel room revenues declined 3% (Walker & Sydneysmith, 2008).
- Reduced tourism revenue. For example, the 2005 drought in Washington State in the U.S. resulted in a loss of US$43 million in tourist revenue (Bumbaco & Mote, 2010).

- Fracking, mining, and other large industrial water users could face decreased production or increased costs due to prolonged water shortages. The B.C. Oil & Gas Commission (BCOGC) may suspend water withdrawals during water shortages (CAPP, 2018). In August 2018, BCOGC suspended water withdrawals for oil and gas companies fracking near the Peace River and Liard watersheds due to water shortage (The Council of Canadians, 2018).

- Properly functioning ecosystems provide an array of free benefits to humans in the form of ecosystem services. These services fall into the broad categories of supporting, provisioning, regulating, and cultural services, and may or may not be directly tied to market activity. Examples of these ecosystem services include: nutrient recycling and soil formation (supporting), timber and crops (provisioning), carbon sequestration and water purification (regulating), and spiritual significance and recreation (cultural). When these ecosystems are damaged by long-term water shortages, the services provided are often degraded or cease altogether, particularly those that rely on vegetation. These services must then be replaced by costly man-made facilities or processes that provide the same services (e.g., deployment of a soil retention structures as vegetation withers or dies). Long-term water shortages are likely to stress vegetation, specifically in forest and grassland ecosystems that remove pollutants from the air, sequester and store carbon, and provide flood protection.

- In B.C.'s Lower Mainland alone, it is estimated that the forest and grassland ecosystems provide $3.2 billion annually in ecosystem services ($1.5 billion in climate regulation, $0.4 billion in air purification, and $1.6 billion in flood protection) (Wilson, 2010).[60]
- Extrapolating to the entire province of B.C., grass and forested land provide ecosystem services valued at of $137 billion.[61]

**Confidence: High**

There are multiple sources of high-quality information on the severe impacts of a multi-year water shortage to agriculture, tourism, and industry. It is likely that these estimates do not represent the full range of economic consequences to the province and the exact costs to B.C. could differ (since some of these estimates are outdated or come from other provincial or national estimates). The evidence indicates, however, that a multi-year water shortage could result in losses that exceed $1 billion.

*Loss of infrastructure services: 5*

Multi-year water shortages may create prolonged disruptions of infrastructure services, including electricity production and water and wastewater treatment facilities. Historically, water shortages in Canada and the Pacific Northwest have reduced hydroelectricity production capacity, caused thermo-electric plants to shut down, and increased water treatment requirements due to higher turbidity.

Supporting evidence includes:

- Water could be unavailable for domestic use during a water shortage, particularly for small-scale water distribution facilities. There are 122 local water utilities in the province (Workshop feedback, 2019).
- Multi-year water shortage can reduce water supply for hydropower generation, which supplies around 90% of B.C.'s electricity. For example, the Columbia River Basin's hydropower production is vulnerable to lower water supply and changing river flow patterns (Walker & Sydneysmith, 2008). Lower streamflow (run-of-river production) or lower reservoir levels result in reduced power output from hydroelectric dams. During water shortages, hydroelectricity companies may change dam operations or purchase electricity from alternative sources. Reduced hydroelectricity could increase the costs to utilities and customers (U.S. Department of Energy & U.S. Department of Homeland Security, 2011). Previous events have resulted in a variety of impacts that can serve as a proxy for impacts to hydroelectric facilities and costs. For example:

- In 2010, severe drought in northeast B.C. reduced water supply in reservoirs, which forced B.C. Hydro to increase electricity imports at the cost of $220 million (U.S. Department of Energy & U.S. Department of Homeland Security, 2011).

[60] Values in present-day, 2018 CAD.
[61] This extrapolation was conducted by scaling the values for B.C.'s Lower Mainland (Wilson, 2010) to the entire area of British Columbia.

- Hydroelectricity accounts for approximately 18% of California's electricity supply. During the 2007 to 2009 drought and the 2012 to 2014 drought, electricity from hydropower dropped to 13% and 12%, respectively. From 2012 to 2014, the cost of electricity in the state increased by US$1.4 billion (Gleick, 2015).
- In 2005, Washington State estimated that the drought conditions increased the cost of supplying electricity by between US$200 and US$300 million, which would be equivalent to a 4 to 7% increase in the cost to consumers (U.S. Department of Energy & U.S. Department of Homeland Security, 2011).
- The 2001 to 2002 drought in the Pacific Northwest of the U.S. resulted in an estimated loss of between US$2.5 and US$6 billion in hydroelectric power (Harto et al., 2011).
- The 1988 North American drought decreased hydroelectric production by 25% in Manitoba (Xiao, Nijssen, & Lettenmaier, 2016).

- Thermo-electric plants require water for cooling. Water shortage, and associated higher water temperatures, can reduce energy production and efficiency. This can increase the probability of blackouts, which would negatively affect many industries (U.S. Department of Energy, 2012).
- During low flow conditions, water and wastewater treatment plants may become stressed. If water pressure drops, increased turbidity may increase the risk of water contamination and the need for greater water treatment. Bacteria and contaminants in greater concentrations will also increase the strain on treatment facilities, which are designed to manage a certain load. If well water levels decline, additional treatment would be required to treat alternative water sources to ensure that health is not at risk (Yusa et al., 2015).
- There could be stranded assets from industries that shut down due to water shortages (e.g., salmon industry, whale watching operations, and other wildlife viewing and nature-focused tourism) (Workshop feedback, 2019).

**Confidence: Medium**

There are multiple sources of evidence documenting high risks of severe water shortages to electricity production in Canada and the United States. The full consequence for B.C. is not known, since little research is available on the extent of impacts to the province from previous water shortages. The evidence indicates that disruptions could affect day-to-day life and last years, however.

### COST TO PROVINCIAL GOVERNMENT: 3

A multi-year water shortage would result in costs to the provincial government for emergency response and recovery funding to affected sectors, such as agriculture and forestry. Recovery payments to farmers from past water shortages reached hundreds of millions of dollars, some portion of which is provided by the provincial government. Although the costs to the province are not established, the costs to government are expected to be on the order of $375 million to $750 million.

Supporting evidence includes:

- Costs to government could include emergency response and recovery funding, and lost revenue from affected industries. Costs could include (Workshop feedback, 2019):
  - Public outreach to inform people about the water shortage
  - Payouts for crop insurance

- Water storage costs
- Lower tax revenue and water licence fees
- Decline in provincial angler and hunting licences
- Supplying water to communities without access to safe drinking water, including trucking in water
- Moving and supporting people who do not have access to water
- Relocating hospitals and health services to new areas

- Additional costs could be associated with developing drinking water protection plans, drought response plans, and preparing small water systems for water shortages. Environmental Health Officers may be required to work additional hours to conduct outreach to communities and water systems facing challenges (Workshop feedback, 2019).
- The project team was unable to precisely estimate the agriculture-related business risk management program costs for this scenario. However, assistance for the agriculture sector could include Production Insurance and funding through AgriStability. For AgriStability to respond, losses at the individual farm level would have to exceed a 30% margin decline for the whole farm (Agriculture and Agri-Food Canada, 2018b). Since Production Insurance and AgriStability would provide direct coverage for the types and levels of losses that could occur, it is highly unlikely that this event would trigger support through the AgriRecovery framework (Agriculture and Agri-Food Canada, 2018a). Historically, the governments of Canada and B.C. contributed to recovery funds for the agricultural sector. For example:

- In 1988, western Canada received Livestock Drought Assistance of $100 million and Crop Drought Assistance of $850 million through Federal-Provincial crop insurance (Cherneski, 2018).
- In 2002, crop insurance payments exceeded $2 billion (500% above the 10-year average) (Cherneski, 2018).
- Perennial tree fruit and grape crops are particularly vulnerable to water shortages, particularly when backup water supplies are depleted. In 2018, Okanagan Production Insurance coverage for grape and vine losses was $103 million and tree fruit coverage for quantity loss and tree loss was $245 million. Fraser Valley berry sector (blueberries, raspberries, cranberries, and strawberries) Production Insurance coverage was $50 million and berry plant coverage was $49.6 million (B.C. Ministry of Agriculture, 2019).

- The provincial government would likely be responsible for some portion of health care costs, although the project team could not determine the exact cost share between the federal and provincial government for the following estimates:

- Although the negative health outcomes of water shortage will vary, some people may require hospitalization. According to the Canadian Institute for Health Information, the cost of a standard hospital stay in B.C. is on average $6,135.[62] Although not all cases of morbidity, injury, or disease are likely to result in hospitalization, the estimated range of over 100 hospitalizations as a result of seasonal water shortage can be valued at over $613,500. Some portion of this cost would be covered by the provincial government.
- If a multi-year water shortage reaches disaster levels, an estimated 30% to 60% of affected populations will need some form of mental health-related assistance (NIST, 2017). Rates for severe, moderate, and mild mental illness can range between 6% to 26% up to 30 months

[62] The value is in 2017 CAD. This measure divides a hospital's total inpatient expenses by the number of hospitalizations it sees in a year. The number is adjusted for some differences in the types of patients a hospital sees to make it more comparable with other hospitals.

following a disaster (FEMA, 2012). Treatment costs for these mental illness cases are estimated at (FEMA, 2012):

- 12 months post disaster: US$822 per person
- 18 months post disaster: US$639 per person
- 24 months post disaster: US$567 per person
- 30 months post disaster: US$414 per person

- If the event is declared a large-scale natural disaster that triggers DFAA, some portion of the cost could be covered by the federal government (Public Safety Canada, 2019). However, it is unknown whether a long-term water shortage could qualify for DFAA.

**Confidence: Low**

There is limited reporting of the costs to B.C.'s government due to lost revenue and emergency response during past events. Additional data is needed to account for the full cost to the provincial government expected due to prolonged water shortage. In addition, it is unknown whether a long-term water shortage would qualify for DFAA, in which case the federal government could provide significant financial assistance.

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## Glacier Mass Loss

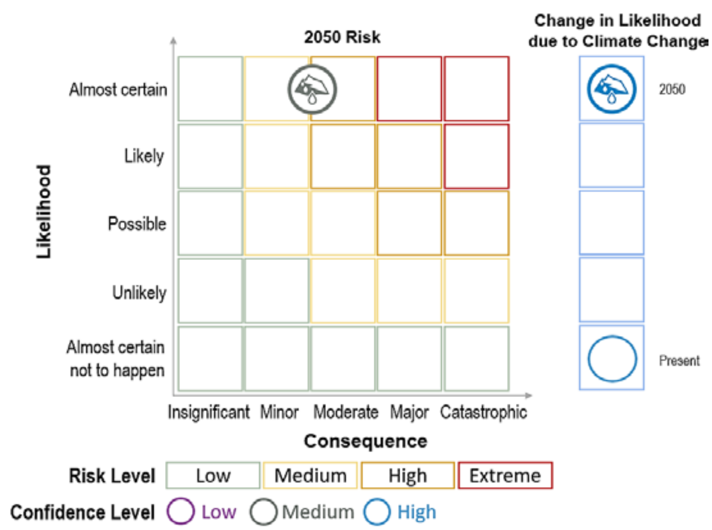
### Scenario

The specific risk event scenario analyzed is a 25% decline in glacier area within B.C. by 2050, relative to 2005. This event would be a province-wide, ongoing change driven by warming temperatures. Projected warming temperatures will cause glaciers to melt more quickly, losing a greater amount of area and volume. Similarly, higher temperatures are projected to increase the proportion of precipitation falling as rain rather than snow, which lowers the rate of glacier accumulation. Overall, this would result in the rate of glacier ablation outpacing accumulation. Other factors that contribute to glacier retreat are accumulation of snowpack, which also contributes significantly to runoff. In some cases, the distinction between how much glacier melt and snowmelt contribute to streamflow is unclear.

### Summary of Findings

B.C. has around 17,000 glaciers that cover approximately 25,000 km² or about 3% of the province. Glacier area declined by approximately 11% between 1985 and 2005. Due to projected increases in temperature, glacier area is projected to further decrease by 30 to 50% by 2050, relative to 2005.

**FIGURE 49.** Risk assessment findings for glacier mass loss scenario.




Glaciers represent a vital freshwater resource for the province, contributing to rivers that support communities, industry, hydroelectricity generation, irrigation, and ecosystems. By the 2050s, the contribution of glaciers to streams and rivers will decline and associated streamflow is projected to decrease. This change has already occurred in some basins, whereas others will experience a short-term increase in flow followed by a decline. Timing and amount of flow could affect natural ecosystems and communities. Particularly during summer months, water supply could be reduced for agriculture, power generation, and industry. This risk assessment focuses on the impact of glacier retreat by mid-century; evidence of the long-term reduction in water supply is included for reference to understand the trends of glacier decline.

**FIGURE 49** and **TABLE 26** summarize the risk assessment results for this scenario. The highest consequences relate to natural resources and loss of social cohesion. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 26.** Risk Rating Evaluation for Glacier Mass Loss Scenario

| GLACIER MASS LOSS: 25% DECLINE IN GLACIER AREA BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **1** | From 1985 and 2005, glacier area declined by approximately 11%, ranging from -24% to -8% across the province. | **5** | **Climate-related risk cause:** Projected temperature increases would likely increase glacier retreat in spring and summer and increase the proportion of precipitation falling as rain rather than snow.<br>**2050 projections:** By 2050, glacier area in western Canada is projected to shrink by 30 to 50% relative to 2005 and glacier volume is projected to shrink by 35 to 40%. Models show general agreement. | High |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **2** | There is low likelihood of multiple losses of life due to glacier mass loss in B.C. | Low |
| | Morbidity, injury, disease, or hospitalization | **2** | Reductions in freshwater supply and quality due to lower flows and higher sedimentation could pose minor health risks to communities. | Medium |
| **Social functioning** | Psychological impacts | **2** | People and communities with identities or livelihoods tied to glaciers may experience moderate psychological impacts. | Low |
| | Loss of social cohesion | **3** | Changes in seasonal water supply may reduce access to freshwater supplies for agriculture and other industries, resulting in seasonal loss of livelihood or way of life for a small population. | Low |
| **Natural resources** | Loss of natural resources | **5** | Streamflow and stream temperature could be permanently affected in some regions, particularly during dry summer months, which could have severe impacts on aquatic species, particularly salmon. | High |
| **Economic vitality** | Loss of economic productivity | **2** | Losses in agriculture, outdoor recreation, and sports fishing that could surpass $1 million. | Medium |
| | Loss of infrastructure services | **2** | Reductions in seasonal water supply could disrupt transportation, hydropower dams, agricultural assets, and other infrastructure services. Prolonged disruptions to services are not anticipated. | Medium |
| **Cost to provincial government** | | **2** | Potential costs include lost revenue, reduced hydroelectric capacity, and reduced water rental fees. | Low |
| **OVERALL RISK** | **CURRENT** | **LOW (2.5)** | | **MEDIUM** |
| | **2050** | **HIGH (12.5)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **2.5** out of 25, which equates to **low risk**, and the 2050 risk rating is **12.5** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

### Risk Calculation

Risk = Likelihood x Average Consequence

Present Risk = 1 x 2.5 = 2.5 (Low)

2050 Risk = 5 x 2.5 = 12.5 (High)

## Evidence Base

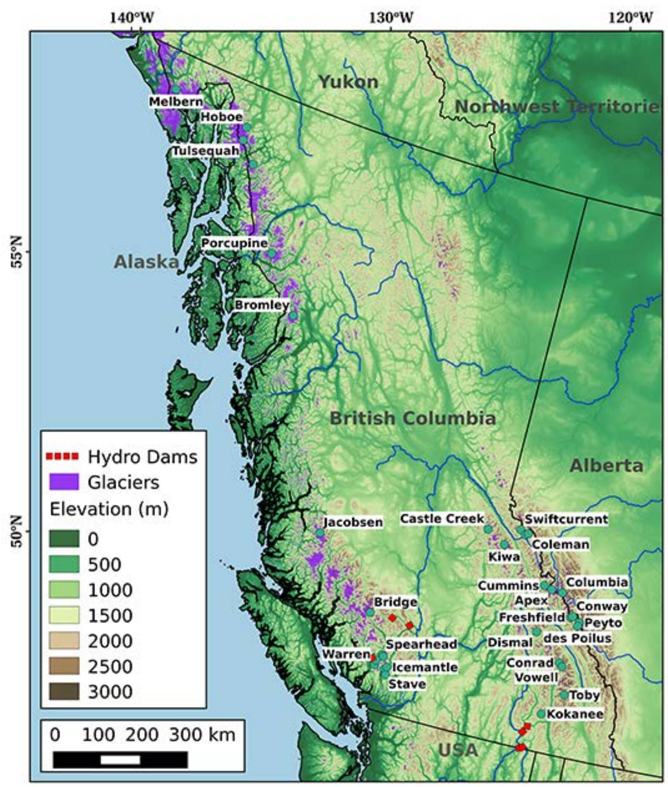
### *Risk Event Scenario*

This scenario represents one illustrative permutation of glacier loss within British Columbia. The consequence ratings are specific to this scenario, but many may be transferable to other related scenarios.

The specifics of this scenario were based on:

- Of the 200,000 glaciers on Earth, 17,000 are in British Columbia. Glaciers cover approximately 25,000 km² of the province, which is equivalent to 3% of the surface area (Jost & Weber, Potential Impacts of Climate Change on B.C. Hydro's Water Resources, 2012) (see **FIGURE 50**).

**FIGURE 50.** Glaciers in British Columbia (Pelto, 2017).

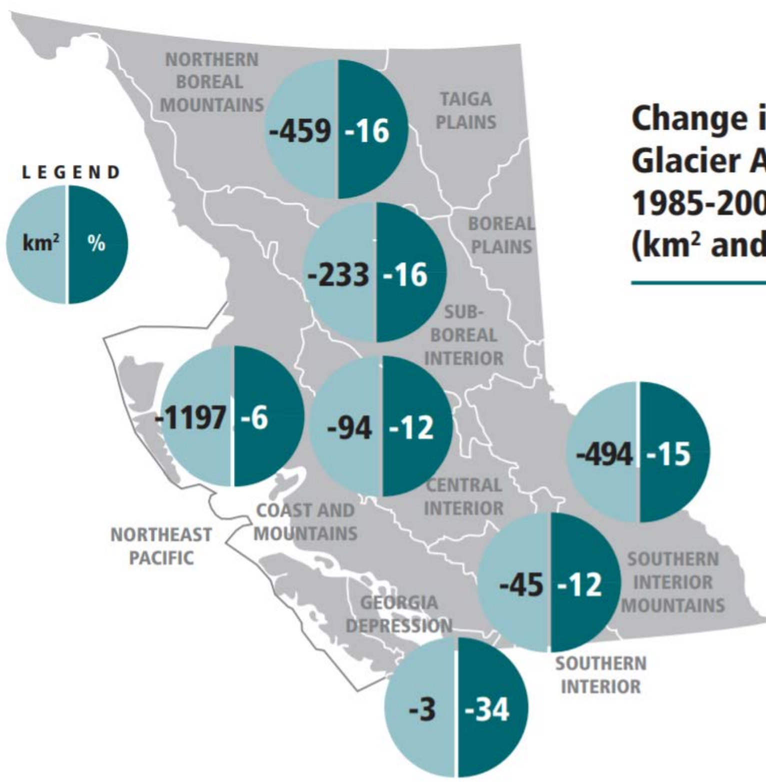



- Multiple studies indicate that glacier area and volume have already decreased in British Columbia. The extent of glacier loss varies across the province, with average area loss of around 11% from 1985 to 2005. Findings include:

- Across the province, glacier area declined by anywhere from 6 to 34% between 1985 and 2005, depending on the geography. The largest reduction (34%) was on Vancouver Island (White, Wolf, Anslow, Werner, & Creative, 2016). See **FIGURE 51**.
- Beedle et al. (2015) conducted a survey of 33 glaciers in the Cariboo Mountains of British Columbia. Between 1952 and 2005, the glaciers receded, losing a surface area of around 0.19% per year, resulting in total losses of 10.6 ± 2.9%. After 1985, the rate of retreat increased to around 0.41% per year (Beedle, Menounos, & Wheate, 2015).
- Bolch et al. (2010) found that glaciers in B.C. lost 10.8 ± 3.8% of their area between 1985 and 2005 (Bolch, Menounos, & Wheate, 2010).
  - The northern Interior Ranges experienced the largest ice loss in B.C. (−24.0 ± 4.6%), while glaciers in the northern Coast Mountains declined the least (−7.7 ± 3.4%) (Bolch, Menounos, & Wheate, 2010).

- White et al. (2016) assessed volume loss from B.C. glaciers during the period 1985 to 2005. All glaciers retreated during this period, decreasing at a rate of around 21.9 km³ per year, and reducing total glacier coverage by around 2,525 km² (White, Wolf, Anslow, Werner, & Creative, 2016).
  - The Georgia Depression on Vancouver Island had the greatest percentage loss (34%), although these glaciers are small in size, so the total area lost was only 3 km².
  - The Northern Boreal Mountains, Sub-Boreal Interior, and Southern Interior Mountains lost 15 to 16% of their area.
  - The Coast and Mountains region lost the largest volume (-15.4%) and area (-1197 km²).

**FIGURE 51.** Percent change in glacier area from 1985 to 2005 (White, Wolf, Anslow, Werner, & Creative, 2016).




- Snowpack also contributes significantly to runoff amount and temperature regulation in rivers. In some cases, the distinction between how much glacier melt and snowmelt contribute to streamflow is unclear. There has been a reduction in peak snow accumulation over the past 50 years, one half to two thirds of which is tied to natural variability, including ENSO and the PDO. Separated from natural variation, climate-driven snowpack decline is around 4% (Jost & Weber, Potential Impacts of Climate Change on B.C. Hydro's Water Resources, 2012). Since snowfall contributes to glacier accumulation, reduced snowfall could mean that glaciers will rebuild at a slower rate while melt occurs more quickly.
- Glaciers advance and retreat naturally due to inter-annual variability in accumulation. In order to understand climate change impacts, models seek to understand the long-term trend to see if it reveals instability beyond natural variability. Projected changes during the future period are expected to

follow the historical trends and hasten glacier loss in the future. Clarke et al. (2015) found that, by 2050, glacier area in western Canada could shrink by 30 to 50% and glacier volume could shrink by 35 to 40% relative to 2005 (Clarke G. K., Jarosch, Anslow, Radić, & Menounos, 2015). The selected scenario provides a conservative estimate of projected glacier area.

## *Likelihood rating*

The present-day likelihood of this scenario is **1** and the 2050 likelihood of this scenario is **5**. Glaciers in B.C. have experienced an increasing rate of retreat over the last century. Projected temperature increases by 2050 would negatively affect glaciers in two ways. First, glacier retreat would very likely increase during spring and summer. Second, higher winter temperatures would increase the amount of precipitation falling as rain, rather than snow, which would result in glacier ablation significantly outpacing accumulation. Multiple reputable sources of evidence indicate that glacier loss will likely be greater than 25% by mid-century and as much as 70 to 95% by the end of the century. The project team considered projected change in glacier area and volume for glaciers in Western Canada as primary indicators to evaluate the likelihood of the scenario. Additional climate drivers of glacier mass loss, such as temperature and precipitation projections, are also considered. Interpretation of the likelihood rating should consider geographic variability; glacier area will decline most rapidly for glaciers at lower elevations and in southern B.C. compared to more northern and mountainous regions.

**Likelihood Rating Drivers**

Type of risk event: Ongoing

Climate change indicator: Glacier area

Critical threshold: 25% decline

“Present day” period: 2005

Source of 2050 projections: Modeling study of projected glacier area in Western Canada

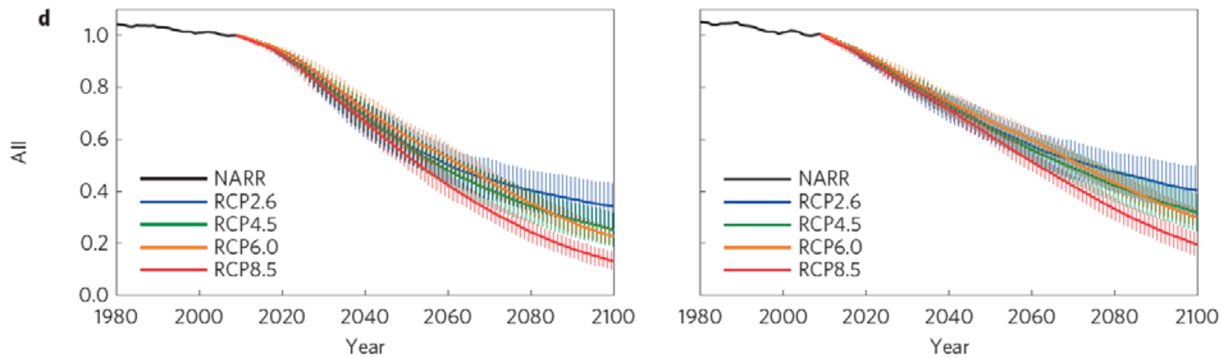
Emission scenario: RCP8.5

Supporting evidence includes:

- By 2050, average annual temperature is projected to increase by 1.8°C (1.3 to 2.7°C) relative to the historical baseline time period (Pacific Climate Impacts Consortium, 2012).[63] Temperature change is expected to increase to a greater degree in the northern regions of the province (White, Wolf, Anslow, Werner, & Creative, 2016).
- Glaciers are projected to continue retreat under all future emission scenarios. By 2050, glacier area in western Canada could shrink by 30 to 50% and glacier volume could shrink by 35 to 40% relative to 2005 (Clarke G. K., Jarosch, Anslow, Radić, & Menounos, 2015). Projections of glacier decline are consistent across emissions scenarios and climate models. **FIGURE 52** shows the projected change in area and volume of glaciers in western Canada under different emissions scenarios.

[63] The range of numbers represents the 10th to 90th percentile based on an ensemble of 15 climate models. The historical baseline period is 1961-1990.

**FIGURE 52.** Projected change in area (left) and volume (right) of glaciers in Western Canada for all glaciers under four different emissions scenarios (RCP2.6, RCP4.5, RCP6.0, RCP8.5) (Clarke G. K., Jarosch, Anslow, Radić, & Menounos, 2015).




- Coastal glaciers, which are predominant in B.C., receive higher amounts of precipitation, and models indicate a loss of 75% +/- 10% of ice area relative to 2005 and 70% +/- 10% of volume by 2100 (Clarke G. K., Jarosch, Anslow, Radić, & Menounos, 2015). Glacier loss for inland glaciers in the Rocky Mountains is projected to be greater, with ensemble models indicating losses exceeding 90% for all scenarios except RCP2.6 (Clarke G. K., Jarosch, Anslow, Radić, & Menounos, 2015).
- Studies of individual glaciers also show large projected losses, including:

- In the Mica Basin, approximately 60% of glacier cover is projected to disappear by 2050 and 85% by 2100, relative to 1961 to 1990. Some scenarios show a complete loss of glaciers in the region by 2100 (Jost & Weber, Potential Impacts of Climate Change on B.C. Hydro's Water Resources, 2012).
- The Illecillewaet Glacier, which feeds into the Columbia River, could lose approximately 0.6 metres per year of water equivalent under a 1°C warming. A 30% increase in winter precipitation would be needed to offset the decline in contributions to the river from glacier melt (Hirose & Marshall, 2013).
- Many small glaciers in southern B.C. are projected to disappear entirely (White, Wolf, Anslow, Werner, & Creative, 2016).

- Maximum rate of ice volume loss will occur around 2020 to 2040, meaning that peak flow would occur by mid-century, and runoff would continue to decline through the end of the century (Clarke G. K., Jarosch, Anslow, Radić, & Menounos, 2015). Once the glacier has disappeared, there will be no flow into rivers. Other sources report glacier-fed streams, including the Columbia River catchments, show negative trends, suggesting that peak flow has already passed (Stahl, Moore, Shea, Hutchinson, & Cannon, 2008).

**Confidence: High**

There are multiple sources of reputable evidence projecting major glacier retreat by 2050, exceeding 25% decline by mid-century and as much as 70 to 95% by the end of the century. By mid-century, the RCP scenarios consistently project changes by more than 25% with a high level of agreement. Other sources confirm that many glaciers have already passed this threshold and are in decline.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.5** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (2+2+2+3+5+2+2+2)/8

Overall Consequence = 2.5

### HEALTH

*Loss of life: 2*

The largest threat to life due to glacier retreat is from glacier outburst floods, which can cause catastrophic damage. Globally, glacier flooding and disasters related to the destabilizing effects of glacier retreat have caused deaths and severe injuries. However, due to the location of glaciers in B.C. and the characteristics of its glacier lakes, it is unlikely that glacier mass loss will contribute to multiple losses of life. According to experts, glacier lakes in B.C. can be monitored and stabilized through engineering mechanisms to manage flood risk. In addition, there are also few population centres located in close proximity to glaciers that would be affected by these types of events.

Supporting evidence includes:

- Carrivick and Tweed (2016) reports a lack of quality records on the number of deaths directly caused by glacier floods, globally. However, based on available records, glacier floods caused over 12,000 deaths; 88% of these occurred in two events: the 1941 Huaraz, Peru and the 2013 Kedarnath, India disasters.
- B.C. is unlikely to experience glacier outburst floods at the level experienced in other parts of the world. Lakes presenting a risk would likely be monitored and the province can apply engineering approaches to mitigate the risk. In most places where glacier dams exist, the lakes drain regularly, which does not create the risk of a major flood. In addition, the ability to form dams of glacier lakes decreases as glaciers recede (Clarke, 2019).
- The risks presented to people in B.C. would depend on proximity to at-risk areas. In B.C., most major glaciated areas are located far from population centres. Thus, there is a low potential for multiple losses of life.

**Confidence: Low**

There is little available evidence of glacier retreat contributing to mortality in B.C. historically, despite major glacier retreat. This score is based primarily on expert judgement that the risk of mortality due to glacier mass loss is low in British Columbia due to the location of major glaciers and the low likelihood of glacier lake outburst floods.

*Morbidity, injury, disease, or hospitalization: 2*

Although the extent of these impacts has not been quantified for B.C., changes in water quality or quantity due to glacier retreat could affect human health. For example, high sediment and nutrient contributions due to glacier retreat could reduce water quality and increase the strain on water treatment facilities. Overall, the resulting negative health outcomes are expected to be minor.

Supporting evidence includes:

- Communities that rely on glacier melt contributing to freshwater supply could face adverse health effects related to declining water quality and water quantity (Ostry, Ogborn, Takaro, Bassil, & Allen, Climate Change and Health in British Columbia, 2008).
- Reduced flow in glacier-fed streams and rivers could reduce freshwater availability for human consumption (see the natural resources section). People living in certain watersheds where glaciers provide a large portion of runoff will be most affected by these changes, particularly during dry summer months. However, the consequences of a 25% decline are unlikely to result in major water shortages.
- Glacier retreat may increase sediment and nutrients present in water, reducing water quality in the short term. However, as glacier runoff decreases, turbidity could decline (Milner et al., 2017). Additionally, since glaciers regulate water temperatures in rivers and streams, lower glacier melt contribution would result in higher water temperatures, which is considered a negative impact on water quality. These conditions may also be more conducive to water-borne illnesses. Reduced water quality and increased levels of contamination put stress on water treatment facilities that are designed to treat at a certain level (Workshop feedback, 2019).
- Those with limited economic resources or lack of access to alternatives including Indigenous communities would likely be the most severely affected, as decreasing water quality may increase the cost of obtaining drinking water.

**Confidence: Medium**

Several sources of evidence indicate that glacier retreat can contribute to reduced water quality, which may increase the risk of illness. However, expert reviewers anticipate that the number of people who will experience morbidity, injury, disease, or hospitalization will be low. The extent of this impact will depend on the number of people reliant on glacier-fed rivers, and their ability to access alternatives.

## SOCIAL FUNCTIONING

### *Psychological impacts: 2*

Glaciers are a key part of the landscape in some areas of the province. As glaciers melt, people and communities with identities or livelihoods tied to glaciers may experience moderate psychological impacts. People may experience fear, anxiety, and grief over observed losses in glacier mass as well as the prospect of continued glacial retreat. In addition, as glaciers continue to retreat past 2050, this could cause loss of identity/sense of place for individuals whose culture or livelihoods are heavily embedded in the land.

Supporting evidence includes:

- Glaciers are symbolic of Canada as a northern nation and some people have strong ties to them (Clarke, 2019). As glaciers retreat, communities with identifies linked to glaciers may experience negative psychological impacts, including distress due to environmental change or "ecological grief" (Cunsolo & Ellis, 2018; Cunsolo Willox, 2012). For example, communities that are named for glaciers in their area and have developed identities around that glacier may face new psychological challenges if the glacier disappears (MacKinnon, 2016). As glaciers retreat further or disappear entirely, these consequences have the potential to become more severe.

- For people with resource-dependent livelihoods, such as farmers or those in the oil and gas sector, reductions in water supply could result in increased pressures or loss of livelihoods. In addition, earlier melt and wet conditions can force oil and gas companies to halt operations (Lapp, 2019). If operations cease, people who depend on those industries for their livelihoods could experience depression (Workshop feedback, 2019).

**Confidence: Low**

There are limited quality sources of research in this area. Experts disagree about the extent of impact glacier retreat would have on psychology, ranging from insignificant for those who do not have a connection to glaciers to major impacts related to a permanent change to the landscape associated with anxiety and loss. Given the lack of available research, this rating relies heavily on expert judgment. Psychological impacts are expected to become more severe as glacier mass loss progresses beyond 2050.

*Loss of social cohesion: 3*

Changes in seasonal water supply from glaciers may reduce access to freshwater supplies for agriculture and other industries. In addition, fish habitat and migration patterns in glaciated river systems may change. Therefore, due to glacier retreat, people may experience seasonal loss of livelihoods or ways of life. Due to the relatively low contribution of glacier melt to most major river systems, this is likely to affect a small portion of the population by 2050.

Supporting evidence includes:

- Some communities in B.C. rely on seasonal water resources from glaciers (and snowpack) to supply freshwater and support habitat for salmon. Changes in glacier supply could disrupt food systems and networks of people with ties to natural resource patterns (Turner & Clifton, 2009). Melting glaciers could affect the natural resources upon which people depend, which may force people to change their way of life.

**Confidence: Low**

There is limited research in this area and the assessment is based primarily on documentation of effects and expert opinion. Expert reviewers disagree about the extent of impact glacier retreat would have on social cohesion, ranging from insignificant for those who do not feel a connection to glaciers to major impacts related to a permanent change to the landscape associated with loss of livelihoods. Given a decline of 25%, the impacts to social cohesion may be less, although they could become more severe as glacier mass loss progresses beyond 2050.

**NATURAL RESOURCES: 5**

The consequences of glacier melt will depend greatly on geographic area but could result in permanent changes for certain areas of the province (e.g., Vancouver Island). Especially during the dry summer months or during exceptionally dry years, glaciers help maintain streamflow and temperatures conducive for fish habitat in some river systems. After peak flow has passed, which has already happened in some river systems and could happen by mid-century in others, streamflow is expected to decline in glacier-fed systems, which could have severe impacts on ecosystem and aquatic health. Since glacier retreat could be permanent and irreversible, resources that depend on glaciers may never recover to current levels.

Supporting evidence includes:

- Glaciers (in addition to snowpack) provide critical water supplies to many major rivers in B.C., including the Cheakamus River, Pemberton Creek, Slesse Creek, Homathko River, Lilooet River, and Squamish River (White, Wolf, Anslow, Werner, & Creative, 2016). Although glaciers contribute far less to annual runoff than snowpack in the province, glaciers provide important streamflow during dry summer months (Moore et al., 2009).
- The retreat and thinning of glaciers affect both water supply and water temperature in glaciated systems (Hirose & Marshall, 2013; Stahl, Moore, Shea, Hutchinson, & Cannon, 2008). During warm, dry years, glaciers play an important role in maintaining streamflow (Stahl, Moore, Shea, Hutchinson, & Cannon, 2008), regulating downstream conditions (Stahl & Moore, 2006), and reducing inter-annual variability in streamflow (DeBeer, Wheater, Carey, & Chun, 2016; Jost & Weber, 2012). The reduction or disappearance of the glacier contribution to streamflow would increase the frequency of low-flow days and increase river temperatures (Pike et al., 2008; White, Wolf, Anslow, Werner, & Creative, 2016).
- In glacier-fed systems, the highest streamflow contribution tends to occur in early and mid-summer, and glacier runoff may contribute a significant portion of the water supply at that time (White, Wolf, Anslow, Werner, & Creative, 2016). For example:

- Between 1970 and 2007, glacier ice melt (excluding snow cover) supplied an average of 6% of annual flow to the Columbia River, increasing to as much as 25 to 35% of streamflow in August and September (DeBeer, Wheater, Carey, & Chun, 2016).
- From 2009 to 2011, the Illecillewaet Glacier contributed 25% of August streamflow. On average, glacier ice makes up 34% of discharge. However, during the driest year, glacier runoff made up 81% of August runoff (Hirose & Marshall, 2013).
- In the Mica sub-basin, although glaciers only cover 5% of the watershed, models indicate that meltwater from glacier ice contributes up to 25 to 35% of streamflow in August and September (Jost, Moore, Menounos, & Wheate, 2012).
- Glacier recession resulted in a decline in mean monthly streamflow of 9% in August and 11% in September downstream of Bridge Glacier. This indicates that Bridge Glacier may have passed peak water or may pass it soon (Moyer, Moore, & Koppes, 2016).

- Once peak flow has passed, stream and river flow in glacier-fed systems will likely decrease, especially during the summer, due to reduced glacier area and volume (White, Wolf, Anslow, Werner, & Creative, 2016; Jost & Weber, 2012; Rango, Martinec, & Roberts, 2008). For example:

- By 2050 (2041 to 2070), annual streamflow in the Fraser River is projected to increase, although summer flow is projected to decrease. However, increased streamflow is attributed to both glacier melt and projected increases in precipitation (White, Wolf, Anslow, Werner, & Creative, 2016).
- A hydrologic analysis of Bridge Glacier indicated a decrease in August streamflow of 37% by the 2050s. A study of the Columbia Basin projected a reduction of flow in the dry season of 10% to 25%, and a reduction of flow during the summer months of up to 90% by the 2050s (Pacific Climate Impacts Consortium, 2007).

- River piracy, which is defined as the diversion of headwaters of one stream into another, can have dramatic downstream impacts on ecosystems and sediment flow. In the Yukon, retreat of the Kaskawulsh Glacier was so abrupt that the river fed by meltwater changed directions and now feeds into a different ocean. While this type of event has occurred in the past, the current pace of glacier retreat may expedite the process in other areas (Shugar et al., 2017).

- In glacier-fed river systems, glacier runoff provides cooler water necessary to moderate river temperatures and maintain suitable habitat for aquatic species, including cold-water species such as salmon (Pacific Climate Impacts Consortium, 2007; Stahl & Moore, 2006). In the late summer (July, August, and September), glaciers and snowmelt can cool stream temperatures by around 0.6 to 1.2°C for each 10% increase in cover (Moore, 2006). If the glacier contribution declines, habitat for invertebrates and fish could decline in suitability due to warmer water temperatures and changes in flow (National Park Service, 2018; White, Wolf, Anslow, Werner, & Creative, 2016). For example:
  - Lower flow is also associated with poorer water quality and warmer water temperatures, which could threaten health of aquatic ecosystems and salmon habitat (White, Wolf, Anslow, Werner, & Creative, 2016).
  - Without glacier melt, summer water temperatures would rise, which can cause significant stress for temperature-sensitive species, including trout and salmon (National Park Service, 2018; Hirose & Marshall, 2013).
  - As air temperatures increase, particularly for extended periods of time, water temperatures also increase (Isaak, Wollrab, Horan, & Chandler, 2012). One study shows that water temperatures increase by about 0.6 to 0.8°C for every 1°C increase in air temperature (Morrill, Bales, & Conklin, 2001), although temperatures can be influenced by a variety of factors such as shading or glacier runoff. Warmer river temperatures tend to reduce fitness, survival, and reproductive success of salmon. Water temperatures above 15°C can cause stress, depleting energy reserves and making salmon more susceptible to disease. At temperatures above 18°C, salmon swimming ability becomes impaired (White, Wolf, Anslow, Werner, & Creative, 2016). Fish communities changed rapidly through transition zones at certain maximum weekly average temperature thresholds (12°C and 19°C) (Parkinson, Lea, Nelitz, Knudson, & Moore, 2015).
  - Projected changes in river flow volume may change salmon migration patterns and spawning success (White, Wolf, Anslow, Werner, & Creative, 2016).
  - Damage to salmon populations can have large ecological repercussions, as they are vital to the food chain. Around 137 species rely on salmon, including bald eagles and bears (PSF, 2011; White, Wolf, Anslow, Werner, & Creative, 2016).
  - As river temperatures rise, native warm-water species, such as smallmouth bass and yellow perch, may expand their range. Non-native invasive species may also thrive under warmer conditions (White, Wolf, Anslow, Werner, & Creative, 2016).

**Confidence: High**

There are multiple sources of high-quality independent evidence with widespread agreement about the impact of glacier retreat on water resources (streamflow amount, timing, and quality), as well as the impact on fish and aquatic ecosystems. However, there are challenges determining the impacts resulting from glacier loss only, as opposed to those also resulting from loss of snowpack. While the level of impact may be minor on some species, expert reviewers agree that the glacier retreat would have permanent consequences on any resource that relies on the resource, since it will be permanently depleted. As this trend continues after 2050, the impacts will become more severe.

## ECONOMIC VITALITY

### *Loss of economic productivity: 2*

Glacier loss could reduce economic productivity by reducing water availability for the agriculture sector, changing landscapes upon which recreation and tourism depend, affecting extractive industry operations, and endangering fish species that support a major industry. Losses associated with these wide-ranging impacts could exceed $1 million (though the full extent of these impacts has not been quantified). These impacts will be compounded by other changes that further diminish water supply.

Supporting evidence includes:

- River piracy could have negative impacts on downstream communities and water users, including hydropower, agriculture, and domestic users, who would lose access to water from the river (Shugar et al., 2017).
- Reduced glacier cover could present both challenges and opportunities the mining industry:
  - In glaciated areas, mining camps have difficulty building infrastructure on or around the glacier as it moves, which can make accessing the sites more difficult (Clarke, 2019). In addition, reduced river flows could necessitate stricter restrictions on effluent due to the reduced dilution capacity of the rivers, which would limit mining operations (Moore, 2019).
  - Due to glacier retreat, mining opportunities may become possible to exploit. For example, Goliath Resources Limited plans to open mining operations for gold, silver, and copper resources in the Golden Triangle in northwestern B.C. as glaciers retreat (Goliath Resources Limited, 2017).
- Changing streamflow from glacier retreat would change watershed hydrology, which could have implications for water availability for agriculture (Pike et al., 2008).
- Glacier retreat can affect glacier-related tourism. For example:
  - Some tourist locations, such as Glacier National Park of Canada or the Whistler Glacier, could experience a near-term peak in tourism due to the "last chance" effect (Stewart et al., 2016; Dawson et al., 2011), but decline thereafter.
  - Glacier retreat may reduce opportunities for activities, including skiing, snowmobiling, and dogsledding (Statistics Canada, 2008). National parks and alpine communities with industries centred on glaciated areas could experience economic losses (Clarke, 2019). Further costs could be incurred to businesses for maintaining conducive conditions for winter activities.
- Reduced native fish populations (see the natural resources section) could damage provincial tourism and fishing industries and affect Indigenous communities that rely on fish stocks (White, Wolf, Anslow, Werner, & Creative, 2016). Fishing contributes significantly to the economy, representing the scale of impacts glacier retreat could have. For example:
  - In 2010, freshwater recreational angling in B.C. generated a total of $957 million (FFSBC, 2012).
  - In 2011, sport fishing contributed $325.7 million to the economy (Stroomer & Wilson, 2012).
  - B.C.'s wild salmon exports generated $139 million in 2017 (AgriService BC, 2018). If salmon habitats and health are negatively affected by changes in river temperature or timing of flow, exports could decline.

**Confidence: Medium**

There is some exemplative evidence available to quantify the impacts of glacier retreat on economic productivity. However, these estimates do not represent the full range of possible consequences, yielding these findings incomplete. In addition, differentiating impacts due to glacier retreat from those due to other changes in streamflow or snowmelt contribution is challenging. Expert reviewers agree that the impacts overall will be minor.

*Loss of infrastructure services: 2*

As glaciers retreat in B.C., short-term higher river flow and rates of retreat may contribute to increased likelihood or magnitude of a variety of flood events, including glacier outburst floods and avalanches. However, experts expect that major floods are not expected to occur in the province. Changes in seasonal water supply could lead to disruptions to transportation, hydropower dams, agricultural assets, and other infrastructure services, although the overall decrease in glacier runoff could be counteracted by increases in precipitation. These impacts are not expected to result in prolonged disruptions to services.

Supporting evidence includes:

- Floods and debris flows could damage physical infrastructure and infrastructure services (Ostry, Ogborn, Takaro, Bassil, & Allen, Climate Change and Health in British Columbia, 2008). Glacier outburst floods occur when glaciers that dam lakes melt away or become overtopped, leading to a rapid draining of the lake. Moraine-dammed lakes are also susceptible to failure due to overtopping that occurs due to retreating glaciers (Evans & Clague, 1997).
  - Historically, a glacier outburst flood at the Tulsequah Lake damaged a mining bridge and caused flooding at a local airstrip (British Columbia Forest Service, 2000).
  - A glacier outburst flood at Queen Bess Lake caused dam overtopping, erosion, and ultimately dam failure (Emmer, 2017).
  - In 1961, Summit Lake near Salmon Glacier drained catastrophically (Evans & Clague, 1997). Mining operations had begun in the area, and roads and bridges were built to support mining. Summit Lake had never drained before so, when it flooded the first time, it washed out a bridge. The lake continues to fill and drain annually, and it has not caused any harm since the first flood (Clarke, 2019).
  - In 1994, a glacier outburst flood occurred at Farrow Creek, B.C.
  - Experts predict a low likelihood of major glacier outburst floods because formation and breakage of a large glacier dam could be anticipated and mitigated. As glaciers retreat, glacier outburst floods are less likely (Clarke, 2019).
- Glacier retreat has a destabilizing effect on mountain rock slopes, which could lead to avalanches or falling objects. Rock avalanches are common in areas where glaciers are retreating (Evans & Clague, 1997). Since 1855, 17 of the 31 avalanches occurred adjacent to glaciers that have experienced retreat (Evans & Clague, 1997).
  - In 2012, a large portion of Ghost Glacier in Jasper National Park fell from the mountain to a pond below. The event resulted in flooding for a parking lot and road at the base, and the part of the park where it fell was closed for an extended period. If people were present at the time of the event, people could have been injured (Plummer, 2013).
- Changes in summer flow quantity could affect hydropower production in British Columbia. For example:

- Hydroelectric power generation delivers approximately 90% of B.C.'s electricity, depending on water flow. By mid-century, B.C. Hydro expects to see a modest increase in annual water supply for power generation up until mid-century (Phillips L. , 2016). For example:
  - The headwaters for the Columbia River are in the interior region of B.C., which is one of the most glacierized parts of the Columbia River Basin. Glacier runoff contributes to the Mica Reservoir and other dams, which provide over 5GW of hydroelectric power (Clarke G. K., Jarosch, Anslow, Radić, & Menounos, 2015).
  - Although the glacier melt contribution is expected to decrease in the Mica Basin, increases in water supply are likely due to increases in precipitation (Jost & Weber, 2012).
  - Increased streamflow by mid-century is expected to increase hydroelectric power potential by 11%, while peak demand may only increase by around 2%. Thus, this would result in an increase in production of around 11 terawatt hours of available energy by 2050 (Parkinson & Djilali, 2015).
  - Even if overall capacity increases, seasonal changes in hydropower generation due to lower flows during the summer months may necessitate operational changes to dams to meet peak energy demands when flows decline.
  - By later in the century, flow will likely decline, which could reduce hydroelectric power capacity.

**Confidence: Medium**

There are several sources of high-quality independent evidence that glacier retreat could result in some risk of flooding, although this is not anticipated to be major in B.C. The evidence demonstrates major impacts to hydropower generation, although the direction of change is mixed and will depend on the system in question. Expert reviewers agree that the impacts overall will be minor.

### COST TO PROVINCIAL GOVERNMENT: 2

Glacier retreat could negatively affect the fisheries sector, which would cost the provincial government in terms of revenue from taxes, licences, and permits. It could also result in reduced hydroelectric capacity, requiring the province to turn to more expensive fuel alternatives. Some portion of water rental fees could also decline. Although the scale of economic impacts due to glacier retreat are not fully quantified, the cost to the provincial government is expected to be on the order of $375 million or less.

Supporting evidence includes:

- Reduced contributions to streamflow from glaciers and lower summer flow may increase stream and river temperatures beyond levels suitable for critical fish habitats (see the natural resources section). Damaged fish habitat and migration pathways in B.C. could reduce revenues from fishing and fish production. For example:
  - Commercial and sports fishing generate around $260 million annually for B.C. and the government collects around $12 million in annual revenue through licences and permits (Government of British Columbia, 2004).
  - Freshwater recreational angling provided provincial tax revenues of almost $55 million (FFSBC, 2012).
- In the near term, reduced glacier retreat may only have minor impacts on hydroelectric energy supply. However, in the long term, the consequence of reduced streamflow from reduced glacier runoff could be more severe.

- B.C. Hydro operates 12,051.6MW capacity of hydroelectric power generation, earning a revenue of $5,657 million in 2016 and $5,874 million in 2017 (B.C. Hydro, 2017).
- Other water use generates over $6 million in water rental fees paid to the government (Government of British Columbia, 2004).

**Confidence: Low**

There are varying amounts and quality of evidence to evaluate this consequence. The main areas of impact associated with glacier retreat are expected to be in reductions in the fisheries and angling sectors and lower to hydroelectric potential. However, this estimate does not account for the full range of costs to the government.

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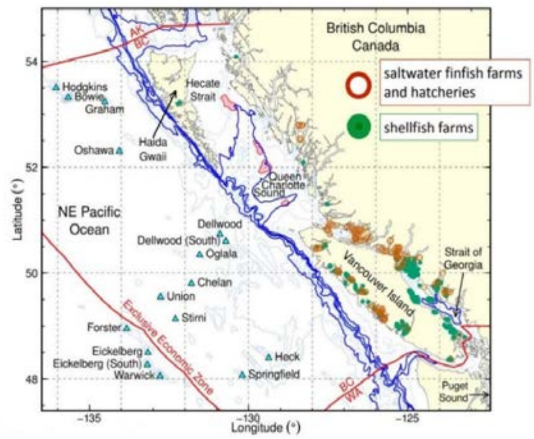
# Ocean Acidification

## Scenario

The specific scenario analyzed is ocean acidification, characterized by a 0.15 pH reduction along the B.C. coast by 2050 from present-day (1990 to 2010) levels. Acidification is caused by increased atmospheric carbon dioxide emissions. Ocean currents and upwelling also facilitate more acidic waters along the Pacific coast.

**FIGURE 53.** Map of shellfish farms along the B.C. coast (Haigh, Ianson, Holt, Neate, & Edwards, 2015).




## Summary of Findings

B.C.'s aquaculture industry represents more than half of total aquaculture production in Canada (Stocks, 2016). See **FIGURE 53** for a map of B.C. shellfish farms (shown in green).

However, ocean pH levels are at their lowest in 20 million years, threatening B.C.'s shellfish industry and other marine life (Canadian Climate Forum, 2017; Fisheries and Oceans Canada, 2012). For example, ocean acidification prevents or decreases the calcification of shells and skeletons, disrupting shellfish growth and development (Okey, Alidina, Lo, & Jessen, 2014; Haigh, Ianson, Holt, Neate, & Edwards, 2015; Washington State Blue Ribbon Panel on Ocean Acidification, 2012). A 0.15 reduction in pH would cause decreased calcification and population decline for a majority of marine shellfish, including oysters, clams, scallops, mussels, pteropods and snails (Parker et al., 2013).

**FIGURE 54.** Risk assessment findings for ocean acidification scenario.

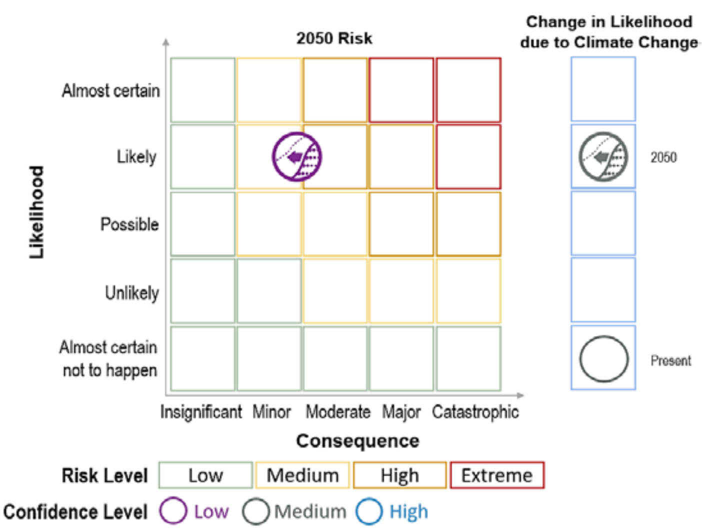



**FIGURE 54** and **TABLE 27** summarize the risk assessment results for this scenario. The highest consequence relates to natural resources, social functioning, and loss of economic productivity. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 27.** Risk Rating Evaluation for Ocean Acidification Scenario

| OCEAN ACIDIFICATION: 0.15 REDUCTION IN PH BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **2** | Current global surface ocean pH of 8.1 falls below the critical threshold of 7.95 but, given the variability of B.C.'s naturally low pH, there is some potential to temporarily cross the threshold. | **5** | **Climate-related risk cause:** Increased carbon dioxide emissions causes ocean acidification.<br>**2050 projections:** A decrease in pH of 0.15 units, which meets or surpasses the critical threshold of some bivalve and gastropod species. | Medium |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **1** | There is no evidence that ocean acidification causes loss of life. | Low |
| | Morbidity, injury, disease, or hospitalization | **1** | There is no evidence that ocean acidification causes morbidity, injury, disease, or hospitalization. | Low |
| **Social functioning** | Psychological impacts | **4** | For individuals directly connected to the ocean, ocean acidification could cause severe, long-term impacts (e.g., depression, loss of identity). | Low |
| | Loss of social cohesion | **4** | Ocean acidification could cause permanent loss of livelihoods or way of life for coastal communities and could affect food supplies, employment opportunities, and community culture and identity. | Low |
| **Natural resources** | Loss of natural resources | **5** | Shellfish and other marine life could experience decreased calcification and altered behavioural and chemical responses. These species will be weakened permanently and likely unable to recover. | Medium |
| **Economic vitality** | Loss of economic productivity | **4** | Economic impacts may include higher mortality of shellfish, decreased growth and productivity, and job losses. | Medium |
| | Loss of infrastructure services | **1** | There is no evidence that ocean acidification causes loss of infrastructure services. | Medium |
| **Cost to provincial government** | | **2** | Costs to government might include lost revenue and taxes as well as resources or programs to help the shellfish industry cope with acidification. | Low |
| **OVERALL RISK** | **CURRENT** | **LOW (5.5)** | | **LOW** |
| | **2050** | **HIGH (13.8)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **5.5** out of 25, which equates to **low risk**, and the 2050 risk rating is **13.8** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 2 x 2.8 = 5.5 (Low)

2050 Risk = 5 x 2.8 = 13.8 (High)

## Evidence Base

### *Risk Event Scenario*

The likelihood and consequence rating for this risk event are based on the scenario of ocean acidification along the B.C. coast characterized by a 0.15 pH reduction by 2050 from present day (1990 to 2010). The 0.15 reduction in pH is a critical threshold after which the majority of marine shellfish—including oysters, clams, scallops, mussels, pteropods and snails—will experience decreased calcification and population decline (Parker et al., 2013). Some species are more resilient to ocean acidification, including squid and cuttlefish, whose pH reduction threshold is 0.5 (Parker et al., 2013). Although direct impacts will be primarily on shellfish by 2050, there may be longer term ripple effects throughout the food web causing indirect effects on the marine species that feed on lower trophic levels species affected by acidification (e.g., krill, euphausids, shrimp, and pterapods).

This scenario represents just one example of the potential effects of climate change on oceans in British Columbia. Other examples include higher ocean temperatures or algal blooms. The likelihood and consequence ratings presented here are specific to this scenario, but many are likely transferable to other related scenarios.

The specifics of this scenario were based on the following information:

- Dissolved carbon dioxide from the atmosphere lowers ocean pH levels and reduces the concentration of calcium carbonate. The carbon dioxide gas reacts with water, forming carbonic acid, which then further breaks down into bicarbonate ions, carbonate ions, and hydrogen ions. The increase in hydrogen ions is what lowers the pH and increases acidity. In addition, some hydrogen ions will also bond with carbonate ions, decreasing the concentration of carbonate ions available to make calcium carbonate, which oysters, clams, mussels, and corals need to form their skeletons and shells (Canadian Climate Forum, 2017; Haigh, Ianson, Holt, Neate, & Edwards, 2015).
- The West Coast of the U.S. and Canada is characterized by upwelling of deep ocean water, which naturally has a lower pH (higher acidity) from decaying phytoplankton that have sunk from the ocean surface. As a result, the B.C. coast is naturally more acidic, making it even more vulnerable to ocean acidification (Canadian Climate Forum, 2017; Okey, Alidina, Lo, & Jessen, 2014; Haigh, Ianson, Holt, Neate, & Edwards, 2015).
- A series of experiments conducted to identify the pH threshold at which individual species experience ocean acidification impacts[64] revealed that pH thresholds vary widely by species (Parker et al., 2013). Reduction thresholds are relative to present-day (i.e. 1990 to 2010) global average pH levels. Based on these results, the project team identified a 0.15 reduction in pH as the critical

[64] Impact measurements varied by species, but included variables such as calcification, respiration, excretion, immune response, shell growth, shell density, shell weight, shell length, shell strength, shell thickness, shell dissolution, survival, tissue energy stores, stomatic growth, metabolic rate, abundance, and predator avoidance.

threshold at which the majority of bivalves and gastropods will experience decreased calcification and population decline:

- The pH threshold for bivalves (e.g., clams, oysters, scallops) ranges from 6.35 to 8.02 (sensitive to a decrease of 1.75 to 0.08 from global average of 8.1).
- The pH threshold for gastropods (e.g., pteropods, snails) ranges from 6.63 to 8.00 (sensitive to a decrease of 1.47 to 0.1 from global average of 8.1).
- The pH threshold for cephalopods (e.g., squid, cuttlefish) ranges from 7.1 to 7.62 (sensitive to a decrease of 1.0 to 0.48 from global average of 8.1).
- However, even if their critical threshold is not surpassed, many species may begin to experience preliminary impacts as demonstrated by existing acidification impacts to shellfish (Parker et al., 2013).

- A study of marine $CO_2$ patterns in the Northern Salish Sea projects that winter pH and spring and summer aragonite saturation state[65] will decrease below the biological threshold of 7.69 pH and 1.0 and 1.7 aragonite saturation states for many marine species by 2100, including Pacific oyster, Mediterranean mussel, California mussel, thecosome pteropod, and North Pacific krill (Evans et al., 2019).
- A vulnerability study of U.S. shellfisheries to ocean acidification found that the Pacific Northwest and Southern Alaska are expected to be exposed to a significant level of ocean acidification from 2006 to 2030. This implies that the B.C. coastline is on a similar trajectory. An aragonite saturation state of 1.5 was used as the critical threshold of exposure (Ekstrom et al., 2015).

## *Likelihood rating*

The present-day likelihood of a 0.15 reduction in pH levels along the B.C. coast is **2** and the 2050 likelihood of this reduction is **5**. The critical threshold (pH decrease of 0.15) is relative to present-day (1990 to 2010) global average pH levels of 8.1 (i.e., to pH levels of 7.95). In addition, the B.C. coast typically exhibits lower pH levels relative to the global mean, suggesting local ocean acidification may exceed the global average.

Given the natural variability and fluctuation of ocean pH along the B.C. coast, the project team assessed the current likelihood of crossing the 0.15 threshold as unlikely, but there is some potential to briefly cross the threshold during a period of particularly acidic conditions.

**Likelihood Rating Drivers**

Type of risk event: Ongoing

Climate change indicator: Change in ocean pH

Critical threshold: pH decrease of 0.15

“Present day” period: 1990-2010

Source of 2050 projections: IPCC global surface ocean pH projections

Emission scenario: RCP8.5

The project team used global surface ocean pH projections from IPCC AR5 (2014) as the primary indicator to evaluate this scenario. Additional indicators include a consideration of background B.C. ocean pH levels relative to the global average. The project team complemented IPCC projections with results from other studies investigating ocean pH reduction magnitudes in coastal subregions and for

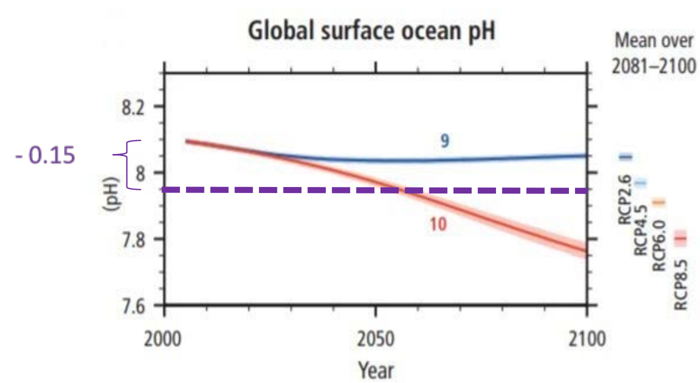
[65] A decrease in the saturation state makes it more challenging for some marine organisms to build skeletons and shells.

specific marine species. Ultimately, a preponderance of evidence and projections indicate that ocean pH will likely pass the critical threshold by 2050.

Supporting evidence includes:

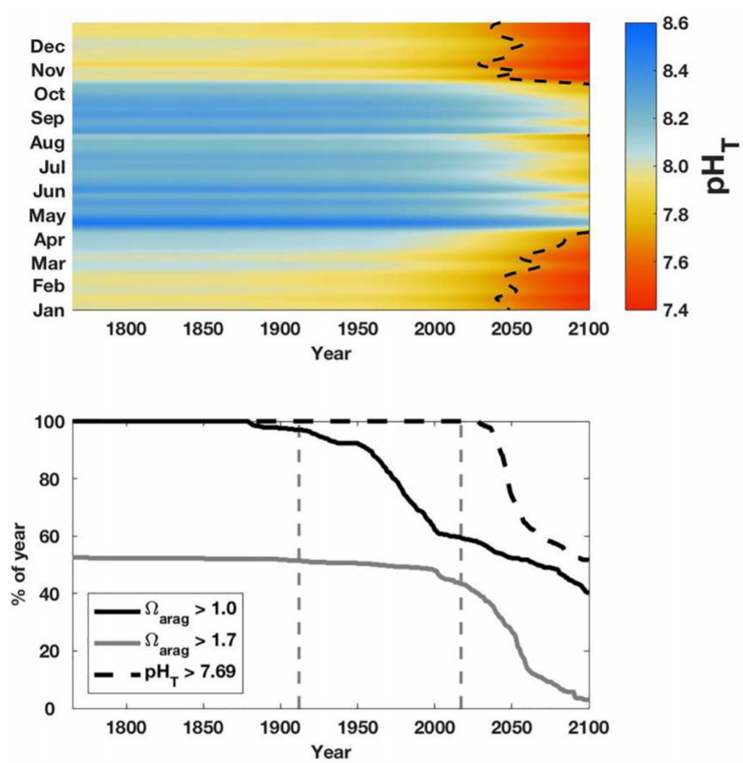
- Average global surface ocean pH has decreased by approximately 0.11 units since the preindustrial era (Feely, Doney, & Cooley, 2009).
- **FIGURE 55** shows IPCC AR5 projections that reveal global surface ocean pH will very likely reduce by 0.15 units through 2050, relative to 2005 levels (IPCC, 2014) under RCP8.5.
- While the current global average surface ocean pH is 8.1 (IPCC, 2014), the west coast of North America, including coastal B.C., is more acidic than the global average due to the influence of concentrated coastal upwelling and strong western boundary ocean currents (Canadian Climate Forum, 2017; Okey, Alidina, Lo, & Jessen, 2014; Haigh, Ianson, Holt, Neate, & Edwards, 2015). For example, a study of acidity along the California coast recorded pH levels as low as 7.43 (Chan et al., 2017). As carbon dioxide emissions increase over time and global mean pH of the ocean decreases, periods of anomalously low pH along the Canadian coastline are expected to become more frequent and extreme (Canadian Climate Forum, 2017). In addition, climate change may affect the timing, magnitude, and variability of upwelling events in coastal B.C. by affecting coastal wind patterns (Haigh, Ianson, Holt, Neate, & Edwards, 2015), which can episodically increase water acidification. Together, these indicators suggest that the B.C. coast is more likely than the global average to exceed the threshold of a 0.15-unit reduction in ocean pH by 2050.

**FIGURE 55.** Projected change in global surface ocean pH for scenarios RCP2.6 and RCP8.5 from 2006 to 2100 (IPCC, 2014). Purple dashed line (overlaid by project team) shows the critical threshold assumed for this risk assessment.



- A study of marine $CO_2$ patterns in the Northern Salish Sea projects that winter pH and spring and summer aragonite saturation state will decrease below a pH of 7.69 and aragonite saturation states of 1.0 and 1.7, which are identified as critical biological thresholds for many marine species by 2100 (**FIGURE 56**). By 2050 in particular, the annual percentage of time above a pH of 7.69 is projected to rapidly decrease from 100% to 80% (**FIGURE 56**) (Evans et al., 2019).
- NOAA estimates that under RCP8.5, global surface ocean waters could be 150% more acidic by 2100 (NOAA Pacific Marine Environmental Labratory Carbon Program, Undated; West Coast Ocean Acidification and Hypoxia Science Panel, 2016).

**FIGURE 56.** Projections from 1765 to 2100 for pH by month (top) and the percent of the year above key pH and aragonite saturation state thresholds from 1765 to 2100 (bottom) (Evans, et al., 2019).




**Confidence: Medium**

Although the B.C. coastline has a pH lower than the global average, available 2050 projections are based on the global average. In addition, local pH levels vary throughout the year and therefore there may periods of time where the pH is lower or higher than the projected level. As a result, more B.C.-specific literature is needed to better understand the influence of local conditions.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.8** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (1+1+4+4+5+4+1+2)/8

Overall Consequence = 2.8

### HEALTH

*Loss of life: 1*

There is no evidence that suggests ocean acidification causes direct loss of life. There is speculation, however, that ocean acidification may contribute to shellfish toxins, which could threaten health.

**Confidence: Low**

There is little evidence that ocean acidification causes direct health impacts to humans. Emerging research, however, suggests that high carbon dioxide concentrations could increase both the production of toxins from harmful algal blooms and the accumulation of toxins in shellfish from eating the algae (Braga et al., 2018; Haigh, Ianson, Holt, Neate, & Edwards, 2015). Shellfish toxins can cause health concerns, but there is limited evidence and disagreement among experts that ocean acidification is directly tied to shellfish toxins.

*Morbidity, injury, disease, or hospitalization: 1*

There is no evidence that ocean acidification causes morbidity, injury, disease, or hospitalization. There is speculation, however, that ocean acidification may contribute to shellfish toxins, which could potentially threaten health.

**Confidence: Low**

There is no evidence across multiple sources that ocean acidification causes health impacts to humans. Emerging research, however, suggests that high carbon dioxide concentrations could increase both the production of toxins from harmful algal blooms and the accumulation of toxins in shellfish from eating the algae (Braga et al., 2018; Haigh, Ianson, Holt, Neate, & Edwards, 2015). Shellfish toxins can cause health concerns, but there is limited evidence and disagreement among experts that ocean acidification is directly tied to shellfish toxins.

## SOCIAL FUNCTIONING

*Psychological impacts: 4*

Given that the ocean is a large part of B.C.'s identity, culture, and economy, ocean acidification could cause localized, severe, and long-term psychological impacts (e.g., depression, loss of identity), particularly for individuals whose lives are directly connected to the ocean. For the broader B.C. population, psychological impacts may be moderate or insignificant.

Supporting evidence incudes:

- Ocean acidification is an ongoing event that will get worse with time. Compared to other climate risks, it is also an event that the province has little control over given that it is a global issue that requires global effort to reverse, which may increase feelings of fear, anxiety, and depression (Workshop feedback, 2019). Psychological impacts will be most severe for individuals who are directly connected to the ocean via their work, community, or culture.
- The ocean is considered a large part of B.C.'s identity, culture, and economy. Many coastal communities are heavily reliant on the ocean for their way of life, including food resources, income, culture, travel, and recreational purposes (Stocks, 2016). Concerns over food security and job security could cause feelings of fear, stress, and anxiety, especially for individuals from coastal and Indigenous communities (Smithsonian Ocean Portal Team, 2018; Gattuso, Mach, & Morgan, 2013; Mathis et al., 2015).
- A survey of 86 individuals from the U.S. West Coast shellfish industry revealed that many people within the industry are concerned about ocean acidification and some have already experienced negative impacts (Mabardy, Waldbusser, Conway, & Olsen, 2015):

- Of those surveyed, 36% are extremely concerned about ocean acidification. In addition, 39% are very concerned and 20% are somewhat concerned. Only 5% reported little or no concern.
- Of the more than 50% of respondents who have already experienced negative impacts from ocean acidification, 97% reported financial damage and 68% reported emotional stress.

**Confidence: Low**

There is limited research on the psychological impacts of ocean acidification, especially in British Columbia. More information is needed on the potential for food security and job security concerns as well as the level of public concern about ocean acidification in both coastal and non-coastal communities. As a result, this rating relies heavily on expert judgment.

*Loss of social cohesion: 4*

Ocean acidification could cause localized, permanent loss of livelihoods or way of life for coastal communities and those reliant on the shellfish industry for food or employment. Ocean acidification could decrease food supplies, decrease employment opportunities, cause economic losses, and affect community culture and identity.

Supporting evidence includes:

- Many coastal communities are heavily reliant on the ocean for their way of life, including food resources, income, culture, travel, and recreational purposes (Stocks, 2016). In addition, the ocean is a large part of the identity of both the province and many individual communities (Workshop feedback, 2019).
- The effects of ocean acidification on shellfish and other seafood could cause food security concerns across the province and especially for coastal and Indigenous communities (Smithsonian Ocean Portal Team, 2018; Gattuso, Mach, & Morgan, 2013). The scale of food security concerns from this scenario are unknown.
- Job diversity in coastal communities and employment alternatives for people in the shellfish industry are two metrics that have been used to assess the risks of ocean acidification to Alaskan communities (Mathis et al., 2015; Ekstrom et al., 2015). The degree of job diversity or employment alternatives for B.C. communities is unknown.
- Ocean acidification could cause temporary (or permanent) closures of shellfish farms. A study on the effects of temporary fisheries closures on two coastal communities (Crescent City, California and Long Beach, Washington) from a 2015 harmful algal bloom offers insight on the potential effects of ocean acidification-driven disruptions (Ritzman et al., 2018):
  - The event caused significant economic losses both on the local and state scale.
  - The event occurred during peak crab season causing significant financial losses and long-term impacts to individual financial stability for fishers and others in the industry. In addition, there were limited alternative employment opportunities for those affected.
  - The financial challenges and uncertainty of the event caused elevated stress and decreased wellbeing.
  - The event also disrupted cultural traditions around crab and shellfish, threatening the identity of the community as well as tourism.

**Confidence: Low**

There is limited information available on social cohesion consequences for coastal communities. Better understanding of how certain indicators apply to B.C.—such as job diversity, employment alternatives, and food accessibility—would help support the rating. As a result, this rating relies heavily on expert judgment.

## NATURAL RESOURCES: 5

Shellfish and other marine life are particularly vulnerable to ocean acidification and are already showing signs of distress. By 2050, shellfish and other marine life could experience significant impacts, such as decreased classification for scallop, oyster, clam, limpet, periwinkle, and whelk. In addition, acidification can alter critical behaviours and chemical reactions in the bodies of fish that may affect their ability to survive. While these species may not be lost entirely, they will be weakened permanently and likely unable to recover if ocean acidification persists.

Supporting evidence includes:

- Acidification is expected to affect a wide variety of wild and farmed species:
  - Acidification causes disruptions to the production of carbonate hard body shells and skeletons for organisms such as phytoplankton, zooplankton, molluscs, crustaceans, gastropods, corals and sea urchins and other echinoderms (Canadian Climate Forum, 2017; Washington State Blue Ribbon Panel on Ocean Acidification, 2012).
  - A study of critical thresholds at which certain species begin to experience ocean acidification impacts[66] revealed that a 0.15 unit decrease in pH will cause the following species to surpass their critical threshold and experience primarily decreased calcification (Parker et al., 2013):
    - Argopecten irradians (scallop) – decreased calcification
    - Crassostrea virginica (oyster) – decreased calcification, decreased survival, decreased tissue energy stores, decreased stomatic growth
    - Mya arebaria (clam) – decreased calcification
    - Crepidula fornicata (limpet) – decreased calcification
    - Littorina littorea (periwinkle) – decreased calcification
    - Urosalpinx cinerea (whelk) – decreased calcification
  - A study of ocean acidification effects on wild and farmed species in B.C. found that (Haigh, Ianson, Holt, Neate, & Edwards, 2015):
    - Wild geoducks, clams, scallops, abalone, sea cucumbers, naked pteropods, shelled pteropods, microzooplankton, macroalgae, sea urchins, and other echinoderms are likely to be negatively affected by ocean acidification.
    - Farmed oysters, clams, scallops, and other shellfish are likely to be negatively affected by ocean acidification, while farmed Atlantic salmon and Pacific salmon could be negatively affected (low certainty) by the indirect effects of ocean acidification.
- Specific acidification impacts and ripple effects include:
  - Low concentrations of carbonate ions can cause deformities in new or existing shells and can even cause existing shells to dissolve. In addition, weaker shells may increase the vulnerability of shelled

[66] Impact measurements varied by species, but included variables such as calcification, respiration, excretion, immune response, shell growth, shell density, shell weight, shell length, shell strength, shell thickness, shell dissolution, survival, tissue energy stores, stomatic growth, metabolic rate, abundance, and predator avoidance.

organisms to predation (Canadian Climate Forum, 2017; Haigh, Ianson, Holt, Neate, & Edwards, 2015; Washington State Blue Ribbon Panel on Ocean Acidification, 2012).

- Building shells or skeletons in acidic water will require more energy use by the organism, which could otherwise be directed toward reproduction or other activities (Smithsonian Ocean Portal Team, 2018; Haigh, Ianson, Holt, Neate, & Edwards, 2015).
- Shellfish may experience decreased reproductive success as young offspring in particular struggle to develop strong shells (Government of Canada, 2016).
- A study of current pH conditions in the Puget Sound found that krill larvae are already experiencing developmental delays and decreased survival (McLasky et al., 2016).
- Acidification impacts to species such as krill may also have ripple effects on the larger food web, including decreased food availability for higher trophic levels or changes in the structure of the food web (West Coast Ocean Acidification and Hypoxia Science Panel, 2016; Fisheries and Oceans Canada, 2012; Canadian Climate Forum, 2017; Haigh, Ianson, Holt, Neate, & Edwards, 2015; Mathis et al., 2015). The specifics of potential food web impacts are unknown.
- In addition, acidification decreases the vertical habitat range for shellfish, which may have implications for population size and harvesting (Government of Canada, 2016). Shellfish are also less mobile than finfish, which further increases their vulnerability to a changing habitat (Johnson et al., 2018).

* For fish, higher acidity can alter chemical reactions in the body. For example, fish burn extra energy to maintain their body chemistry and pH, which takes energy away from other activities such as digesting food and reproducing. Furthermore, some fish and other aquatic organisms have exhibited behavioural changes, such as exhibiting a weaker sense of smell or hearing and reduced success at avoiding predators (Smithsonian Ocean Portal Team, 2018; West Coast Ocean Acidification and Hypoxia Science Panel, 2016; Williams et al., 2018). A study on the effects of high carbon dioxide concentrations on Coho salmon revealed that high carbon dioxide conditions affect olfactory senses, which all Pacific salmon are reliant on for predator avoidance and homing migrations (Williams et al., 2018). The implications of behavioural changes on the marine ecosystem remain unknown (Haigh, Ianson, Holt, Neate, & Edwards, 2015).

**Confidence: Medium**

There is strong evidence across multiple sources that acidification has a number of significant negative impacts on marine resources. However, the threshold pH level at which some of these impacts will occur is unknown. In addition, the severity of acidification in terms of the ability for populations to recover is not well understood. As the event is ongoing, ocean acidification could continue after 2050, which would exacerbate these impacts and impede recovery.

## ECONOMIC VITALITY

*Loss of economic productivity: 4*

The fish and shellfish industry is a critical component of B.C.'s economy. Based on the value of the industry and potential severity and extent of acidification impacts, the project team concluded that direct and indirect economic losses could total more than $100 million (the threshold for a score of 4). Impacts may include higher mortality of shellfish, decreased growth and productivity, and job losses. However, through certain management practices, farmers may be able to reduce shellfish exposure to more acidic ocean water, which could help lessen, but not prevent economic losses.

Supporting evidence includes:

- B.C. leads the country in sales of farmed and wild salmon, halibut, rockfish, hake, tuna and farmed oysters and clams. In 2017, total sales from all commercial fishing and aquaculture for the province were $1.2 billion, accounting for 0.2% of the provincial GDP. In 2017, 690 operations were licensed to farm finfish, shellfish, and marine plants in B.C. and 4,500 people were employed in the seafood industry (Government of British Columbia, 2017).
- A Government of Canada report on the marine impacts of climate change speculates that acidification impacts could cost the B.C. shellfish fishery industry millions of dollars (Government of Canada, 2016).
- The annual landed value of wild and farmed molluscs[67] harvested in B.C. is estimated at $63 million (Haigh, Ianson, Holt, Neate, & Edwards, 2015).
- As a result, acidification impacts are already beginning to cause operational disruptions for some shellfish farmers. Farmers are either relocating or investing in monitoring and control equipment to modify the pH levels in the hatcheries (West Coast Ocean Acidification and Hypoxia Science Panel, 2016). For example, a B.C. scallop farmer successfully increased the survival rate of his scallops by employing new best management practices following three years of devastating losses (St. Denis, 2015). Actions to reduce acidity within hatcheries and aquaculture facilities may help to lessen the severity ocean acidification on natural resources and economic productivity.
- In addition, ocean acidification could lead to job losses in coastal communities, particularly those reliant on the fishing industry and coastal tourism (West Coast Ocean Acidification and Hypoxia Science Panel, 2016).
- In the U.S., ocean acidification to date has cost the Pacific Northwest oyster industry nearly US$110 million and has directly or indirectly affected 3,200 jobs (Ekstrom et al., 2015).

**Confidence: Medium**

There is strong evidence across multiple sources that acidification has significant negative impacts on economic productivity. However, the precise magnitude of economic loss due to a 0.15 reduction in pH is unknown.

*Loss of infrastructure services: 1*

Ocean acidification is not expected to cause loss of infrastructure services. There is speculation that ocean acidification could affect the lifespan of critical infrastructure due to corrosion, but there is little evidence and the effect is likely to be small compared with that of other impacts to nearshore infrastructure. By the time gradual changes associated with ocean acidification manifest, the asset is likely to already be at the end of its useful life (Cooley, 2019; Workshop feedback, 2019).

**Confidence: Medium**

There is no evidence across multiple sources that ocean acidification causes loss of infrastructure services across the province. However, more information is needed about how pH levels could affect infrastructure and on what timeframe.

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[67] Molluscs by definition include abalone, clams, mussels, octopus, oysters, squid, scallops, and some snails.

### COST TO PROVINCIAL GOVERNMENT: 2

Costs of ocean acidification are expected to primarily affect the shellfish industry by 2050. Disruptions to the food web could also have cost implications for commercial fishing. However, costs to government could include lost revenue and taxes as well as resources or programs to help the shellfish industry cope with acidification. These costs are expected to be on the order of $375 million or less.

Supporting evidence includes:

- A Government of Canada report on the marine impacts of climate change speculates that acidification could cost the B.C. shellfish fishery industry millions of dollars (Government of Canada, 2016).
- In the U.S., ocean acidification to date has cost the Pacific Northwest oyster industry nearly US$110 million and has directly or indirectly affected 3,200 jobs (Ekstrom et al., 2015).
- The extent of costs on the provincial government is unknown, but likely to include lost revenue and taxes from the shellfish industry.
  - In 2017, total sales of commercial fishing and aquaculture were $1.18 billion. The GDP was $338 million or 0.2% of B.C.'s total GDP (Government of British Columbia, 2017).
  - In 2017, B.C.'s commercial shellfish was valued at $143 million, including clams, shrimp, crab, sea cucumber, and sea urchin (Fisheries and Oceans Canada, 2019).
  - In 2016, shellfish revenue totaled $24 million, including oysters ($14.8 million), clams ($5.7 million), and other shellfish ($3.5 million) (B.C. Stats, 2018).
- Other potential costs to government include:
  - Job trainings, resources, and other support for those in the shellfish industry (Workshop feedback, 2019).
  - Relocation of the shellfish industry to other coastal areas (Workshop feedback, 2019).
  - Mental health programs and resources (Workshop feedback, 2019).

**Confidence: Low**

There is limited information available on costs to government from ocean acidification. Beyond a limited ability to quantify potential lost tax revenues, large uncertainty relates to whether the provincial government would be required to offer additional financial or other assistance to the industry. As a result, this rating relies heavily on expert judgment.

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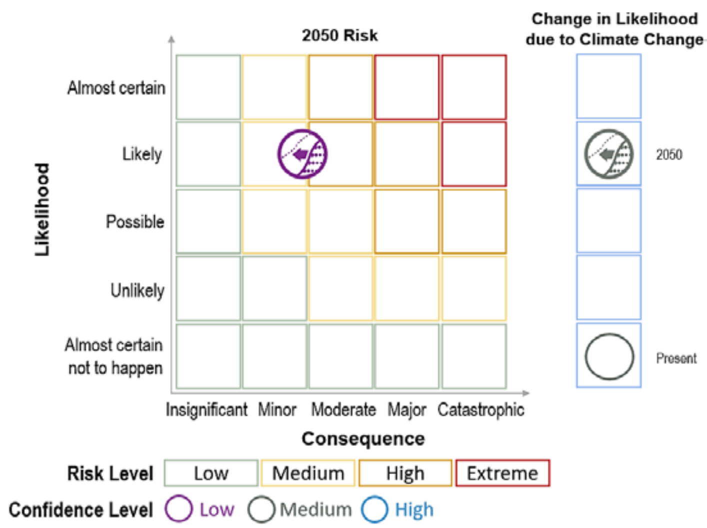
# Saltwater Intrusion

## Scenario

The specific scenario analyzed is at least seasonal saltwater intrusion into the Fraser River delta and surrounding communities, including Richmond, Delta, and Surrey, B.C., caused by 0.5 m of sea level rise by 2050 from present day (2000) levels. Saltwater intrusion is most likely to affect irrigation water availability from August to October.[68] The position of the salt wedge in the Fraser River is driven by sea level rise, tides, river flow, and water use.

## Summary of Findings

**FIGURE 57.** Risk assessment findings for saltwater intrusion scenario.




Over the course of the 21st century, sea level rise is expected to eventually lead to coastal inundation of low-lying areas. By 2050, the freshwater/saltwater interface is expected to extend farther up the Fraser River, which may also cause saltwater intrusion of groundwater and freshwater aquifers[69] in low-lying areas of the Fraser River delta region (Government of British Columbia, 2016). The research collected for this risk event deals primarily with encroachment of the freshwater/saltwater interface due to sea level rise. Saltwater intrusion is expected to have the most significant impacts on agriculture and freshwater supplies. Agriculture is a significant component of the delta's economy, accounting for $170 million in total gross farm receipts[70] for 2010 (BC Agriculture & Food Climate Action Initiative, 2013).

**FIGURE 57** and **TABLE 28** summarize the risk assessment results for this scenario. The highest consequence relates to loss of economic productivity. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

[68] August to October is the critical period for irrigation when Fraser flow has declined from Freshet conditions.
[69] Aquifer salinization can occur from above due to inundation or storm surge, laterally due to encroachment of the freshwater/saltwater interface, or from below due to pumping (Klassen & Allen, 2016; Werner, et al., 2013).
[70] Gross farm receipt refers to the gross farm receipts of the agricultural operation in the year prior to Census or the last complete accounting (fiscal) year. This includes receipts from all agricultural products sold, program payments and custom work receipts. It does not include sales of forestry products (firewood, pulpwood, logs, fence posts, pilings, etc.), of capital items (quota, land, machinery, etc.), or receipts from the sale of any goods purchased only for retail sales. It is gross receipts before deducting expenses (Statistics Canada, 2018).

**TABLE 28.** Risk Rating Evaluation for Saltwater Intrusion Scenario

| SALTWATER INTRUSION: AT LEAST SEASONAL SALTWATER INTRUSION INTO THE FRASER RIVER DELTA AND SURROUNDING COMMUNITIES BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **1** | This scenario does not occur today. | **4** | **Climate-related risk cause:** Sea level rise will drive the salt wedge farther upstream in the Fraser River.<br>**2050 projections:** Sea level rise is projected to increase between 0.5 to 0.6 m by 2050. | Medium |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **1** | There is no evidence that seasonal saltwater intrusion causes loss of life. | High |
| | Morbidity, injury, disease, or hospitalization | **1** | There is no evidence of other health risks as long as freshwater is accessible from alternative sources. | Low |
| **Social functioning** | Psychological impacts | **2** | Impacts to agriculture operations and irrigation could cause moderate and temporary psychological impacts, such as stress or anxiety, for farmers. | Low |
| | Loss of social cohesion | **3** | Agricultural communities may experience seasonal losses of livelihoods and potentially a loss of trust in the government or water utility. | Low |
| **Natural resources** | Loss of natural resources | **3** | Short-term impacts include a decline in plant health and soil fertility. Longer-term impacts include a gradual, but permanent change in ecosystem composition and health near the saltwater/freshwater interface. | Low |
| **Economic vitality** | Loss of economic productivity | **5** | Economic impacts include decreases in agricultural productivity, increased soil salinity, a potential change in the type of crops grown in the region, and a reduction in ecosystem services. | Medium |
| | Loss of infrastructure services | **3** | There may be a permanent loss of existing freshwater wells and aquifers. The high mineral content of saltwater could corrode pipelines and pumps used to extract freshwater. | Low |
| **Cost to provincial government** | | **2** | Costs might include management of sensitive ecosystems and protected areas or even supplying emergency water supplies to affected communities. | Low |
| **OVERALL RISK** | **CURRENT** | **LOW (2.5)** | | **LOW** |
| | **2050** | **MEDIUM (10.0)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **2.5** out of 25, which equates to **low risk**, and the 2050 risk rating is **10.0** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 1 x 2.5 = 2.5 (Low)

2050 Risk = 4 x 2.5 = 10.0 (Medium)

## Evidence Base

### *Risk Event Scenario*

The likelihood and consequence rating for this risk event are based on the scenario of at least seasonal saltwater intrusion in the Fraser River delta from August to October when irrigation demand is high and the Fraser River flow is low. A half-metre rise in sea level is expected to increase saltwater intrusion and both local groundwater and substrate salinity by both decreasing the hydraulic gradient between the ocean and inland groundwater, and pushing the salt wedge farther upstream in the Fraser River (BC Agriculture & Food Climate Action Initiative, 2013; Klassen & Allen, 2016; Klassen, Allen, & Kirste, 2014; PGL Environmental Consultants, 2016).

This scenario represents one illustrative permutation of saltwater intrusion in the province. This saltwater intrusion scenario considers the impacts to both the salinity of the Fraser River and the salinity of groundwater in the delta region. The delta, however, is not heavily reliant on groundwater supply. Most of the delta has been integrated into Metro Vancouver's water system and irrigation water is typically pulled directly from the Fraser River (Metro Vancouver, 2018). Saltwater intrusion is possible in other coastal areas of B.C., including the Gulf Islands where there is a greater dependence on groundwater supply. The consequence ratings are specific to this scenario, but many may be transferable to other related scenarios.

The specifics of this scenario were based on:

- *B.C. Agriculture and Climate Change Regional Adaptation Strategies Series: Delta* identifies changing hydrology and the effects on water supply and salinity levels as one of four priority climate impact areas in Delta, B.C. (BC Agriculture & Food Climate Action Initiative, 2013). Irrigation demand is expected to increase by 2050 due to higher average temperatures and higher rates of evapotranspiration, although more research is needed to quantify the scale of increase.
- *Modelling Effects of Climate Change and Dredging on Availability of Irrigation Water for Delta Farmers* predicts that sea level rise will push the salt wedge[71] upstream and significantly lessen the availability of fresh water[72] from August to October[73] in Delta, B.C. for irrigation by 2050 (Tetra Tech EBA, 2016). Irrigation water intakes located in the Fraser River are affected by the position of the salt wedge, which is influenced by sea level rise, tides, and river flow. High tide and periods of low flow advance the wedge farther upstream.
- Other studies in Delta, B.C. find that increasing saltwater intrusion may have a greater impact on agriculture than overland saltwater flooding (BC Agriculture & Food Climate Action Initiative, 2014,

[71] The salt wedge a wedge-shaped mass of saline water that extends up the Fraser River estuary from the ocean. During times of lower water flow, the salt wedge extends farther upriver than in times of high river discharges (BC Agriculture & Food Climate Action Initiative, 2014).

[72] For irrigation purposes, water must have a salinity of 0.34 parts per trillion or less.

[73] August to October is the critical period for irrigation when Fraser flow has declined from Freshet conditions.

citing Bomke et al. 1996). This is due in part to the ability of heavy precipitation and freshet floods to flush salt out of the soil from an overland event.

## *Likelihood rating*

The present-day likelihood of seasonal saltwater intrusions in the Fraser River delta is **1** and the 2050 likelihood of this scenario is **4**. The key indicator is a critical threshold of 0.5 m of sea level rise.

**Likelihood Rating Drivers**

Type of risk event: Ongoing

Climate change indicator: Relative sea level rise in the Fraser River delta

Critical threshold: 0.5 m relative sea level rise

"Present day" period: 2000

Source of 2050 projections: NOAA et al. 2017

Emission scenario: Upper limit projection

The frequency of saltwater intrusion is dependent on a range of underlying processes acting on a range of timescales. Sea level rise and lower river flows increase the likelihood and frequency of coastal saltwater intrusions, while heavy precipitation can abate intrusions by increasing runoff into the ocean. To evaluate the scenario likelihood, the project team focused on several indicators, including local sea level rise and precipitation projections and observations of saltwater wedge extents in the Fraser River.

Sea level rise is expected to meet or exceed 0.5 m by 2050 at multiple sites within the Fraser River delta. In addition, water availability for irrigation is expected to significantly decrease under just 0.3 m of sea level rise.

Supporting evidence includes:

- Projections estimate sea level rise of between 0.5 to 0.6 m by 2050[74] in the Fraser River delta relative to the historical baseline (NOAA et al., 2017). These values are based on the most recent and best available localized projections for the delta that account for several contributing factors to sea level rise, including changes in land-ice mass, freshwater additions from land-ice melt or precipitation changes, and vertical land movement. The two available gauges are:
  - Steveston (located at the mouth of the Fraser River) – projected rise of 0.6 m by 2050, with a 66th percentile "likely" range of 0.5 to 0.6 m (USACE, 2017).
  - New Westminster (located upstream) – projected rise of 0.5 m by 2050, with a 66th percentile "likely" range of 0.4 to 0.5 m (USACE, 2017).
- Currently, saltwater extends up to 16 km upstream of the Fraser River outlet during periods of average to low river flow. At one site in Richmond, B.C., the salt wedge extends 500 m inland from the river and its top is 10 m below ground. The extent of the salt wedge is dependent on saltwater density, sediment permeability, and fresh water flow (Neilson-Welch & Smith, 2001).
- A study modeling water availability from August to October[75] in Delta, B.C. for irrigation under different climate change scenarios revealed a decrease in freshwater[76] availability over time, indicating an increase in water salinity concentration throughout the Fraser River delta (Tetra Tech EBA, 2016):

[74] Baseline year is 2000, using an upper limit projection assuming more extreme sea level contributions from ice sheets as modelled by Pfeffer et al. (2008). This is consistent with the RCP8.5 projections used throughout this risk assessment.
[75] August to October is the critical period for irrigation when Fraser flow has declined from Freshet conditions.
[76] For irrigation purposes, water must have a salinity of 0.34 parts per trillion or less.

- Assuming present-day (2000 to 2015) sea level, the salinity requirement is met 24 hours/day under normal and high flow conditions. Under low flow conditions, water is available for irrigation for 3.6 to 7.9 hours/day (depending on intake site).
- With 0.3 m of sea level rise (expected within 10 to 25 years), the salinity requirement is met 14 to 18 hours/day under high flow conditions and 2 to 6 hours/day under low flow conditions (depending on intake site).
- With 1 m of sea level rise (expected by 2100), the salinity requirement is met 0 hours/day under low flow conditions, 0.8 to 3.8 hours/day under normal conditions, and 21.1 to 23.6 hours/day under high flow conditions (depending on intake site).

- The modeled changes in water availability for irrigation are due in part to a predicted decrease in the Fraser River flow rate of 5.4% to 28.6% by 2050 relative to the baseline time period of 2005 to 2014,[77] which allows the salt wedge to extend farther upstream (Tetra Tech EBA, 2016). Climate change is expected to cause higher river flows earlier in the irrigation season, and lower river flows later in the season when irrigation demand is at its peak (PGL Environmental Consultants, 2016; BC Agriculture & Food Climate Action Initiative, 2013).
- Precipitation and runoff may also affect the position of the salt wedge. High precipitation and runoff can flush soils of salt and push the salt wedge farther from the coast (BC Agriculture & Food Climate Action Initiative, 2013). Alternatively, low precipitation in the summer months can decrease groundwater recharge, which is necessary for decreasing salt concentrations (Klassen & Allen, 2016). Climate projections for the Greater Vancouver from 1961 to 1990 baseline to 2050 include (Pacific Climate Impacts Consortium, 2012):

- Increase in annual precipitation of 7% (10$^{th}$ to 90$^{th}$ percentile: -2% to +11%)
- Decrease in summer precipitation of 15% (10$^{th}$ to 90$^{th}$ percentile: -25% to +3%)
- Increase in winter precipitation of 6% (10$^{th}$ to 90$^{th}$ percentile: -4% to +15%)

**Confidence: Medium**

There are several sources of high-quality independent evidence, and general agreement that the likelihood of saltwater intrusion will significantly increase by 2050. However, there are many natural (e.g., river flow) and anthropogenic (e.g., groundwater usage) factors besides sea level rise that influence saltwater intrusion, making the exact duration and frequency of saltwater intrusion events difficult to project.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings,

### Consequence Calculation

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (1+1+2+3+3+5+3+2)/8

Overall Consequence = 2.5

[77] Tetra Tech EBA calculated the ensemble average based on the daily flow results from eight different climate change models, each appropriately downsized to produce Fraser River flows at Hope, and averaged to produce daily flows over the indicated time periods. The emission scenario modeled is SRES A1B. A1B is a lower emission scenario than the RCP8.5 used, where possible, throughout this risk assessment, though they are comparable around 2050.

the project team rated the overall consequence of this scenario as **2.5** out of 5.

### HEALTH

#### *Loss of life: 1*

Seasonal saltwater intrusion would not cause loss of life, assuming freshwater is accessible from other sources during the duration of the intrusion event.

**Confidence: High**

There is no evidence across multiple sources that seasonal saltwater intrusion would cause loss of life. This assessment assumes that freshwater is accessible from other sources during the duration of the intrusion event.

#### *Morbidity, injury, disease, or hospitalization: 1*

As long as freshwater is available from other sources, saltwater intrusion is not expected to cause cases of morbidity, injury, disease, or hospitalization other than through unforeseeable misadventure.

Supporting evidence includes:

- Saltwater intrusion of drinking water sources may cause water to be unsuitable for consumption (Huppert, Moore, & Dyson, 2008; Government of British Columbia, 2016). The Canadian drinking water quality guideline is a chloride concentration of less than 250 mg/L (Government of British Columbia, 2016). However, most of the delta region has been integrated into Metro Vancouver's water system (Metro Vancouver, 2018). In addition, as long as other water sources are available, saline water does not pose a significant risk for morbidity, injury, disease, or hospitalization.
- Other potential implications of seasonal saltwater intrusion that may indirectly affect health include buying unhealthy substitutes for water (e.g., soda) or having less healthy foods available due to agricultural impacts (Workshop feedback, 2019).

**Confidence: Low**

There is little information available on the health consequences saltwater intrusion. As a result, this rating is based on expert judgment and assumes that freshwater is accessible from other sources during the duration of the intrusion event.

### SOCIAL FUNCTIONING

#### *Psychological impacts: 2*

Farmers may experience moderate and temporary psychological impacts due to seasonal saltwater intrusion. Impacts to irrigation and operations in particular could cause stress or anxiety.

Supporting evidence includes:

- Farmers may experience mental health challenges due to loss of agricultural productivity and impacts to their operations (Berry et. al, 2011).
- For example, a study modeling water availability from August to October in Delta, B.C. for irrigation under different climate change scenarios revealed a decrease in water availability over time, which could cause stress or anxiety (Tetra Tech EBA, 2016).

- Under present day conditions, the salinity requirement for irrigation is met 24 hours/day under normal and high flow conditions. Under low flow conditions, water is available for irrigation for 3.6 to 7.9 hours/day (depending on intake site).
- In the next 10 to 25 years, 0.3 m of sea level rise will decrease the availability of water for irrigation to 14 to 18 hours/day under high flow conditions and 2 to 6 hours/day under low flow conditions (depending on intake site).

**Confidence: Low**

There is limited information available on the psychological impacts of saltwater intrusion. As a result, this rating is based primarily on expert judgment. Impacts are expected to primarily affect farmers who rely on irrigation water, since most of the delta region has been integrated into Vancouver's water system (Metro Vancouver, 2018). However, other coastal areas of B.C. that are heavily reliant on groundwater supply, such as the Gulf Islands, may be more vulnerable. The percentage of the Fraser River delta that is reliant on groundwater supply is unknown.

*Loss of social cohesion: 3*

Agricultural communities within the Fraser River delta will be affected by seasonal loss of livelihood due to saltwater intrusion. In addition, impacts to freshwater supplies could result in some erosion of public trust in the government or the water utility.

Supporting evidence includes:

- Seasonal saltwater intrusion can limit the availability of freshwater for irrigation. Depending on the length of disruption, crops could be affected (e.g., loss of quality or quantity). This may cause a seasonal loss of livelihood for farmers (Workshop feedback, 2019).
- If the government or water utility is unable to provide fresh drinking water, there could also be erosion of trust in the government or the water utility (Workshop feedback, 2019). The scale of disruption to drinking water supplies is unknown, but expected to be small considering the delta has a lower dependence on groundwater supplies than other areas of British Columbia.

**Confidence: Low**

There is limited information available on loss of social cohesion due to saltwater intrusion. As a result, this rating is based primarily on expert judgment. Impacts are expected to primarily affect agricultural communities who are reliant on irrigation water.

## NATURAL RESOURCES: 3

Short-term impacts of saltwater intrusion include a decline in plant health and soil fertility, especially for sensitive and salt-intolerant species or ecosystems. Recovery for these species and ecosystems could take years. Longer-term changes in water and soil salinity could lead to a gradual, but permanent change in ecosystem composition and health near the saltwater/freshwater interface as species redistribute based on salt tolerance. Despite these changes, it is unlikely that natural resources would be lost permanently.

Supporting evidence includes:

- This scenario can cause ecosystem stress, declines in plant health, declines in soil fertility, and the redistribution of species based on salt tolerance (Werner et al., 2013; Groulx, Mosher, Luternauer, & Bilderback, 2004; Government of British Columbia, 2016; PGL Environmental Consultants, 2016).
- Due to reduced water availability in saline soils, salt-intolerant plants could experience increased water stress as sea level rises, pushing the range of these species farther inland. Meanwhile, salt-tolerant species will likely expand in range. Changes in soil and water salinity could also facilitate the spread of salt-tolerant invasive species (Workshop feedback, 2019).
- In addition, given the urbanized nature of the delta, sensitive or rare species and ecosystems may have limited ability to move or adapt (Workshop feedback, 2019).
- Changes in ecosystem composition and health near the saltwater/freshwater interface will also negatively affect ecosystem services provided by these species. See the loss of economic productivity section for more information.

**Confidence: Low**

There is limited information available on how saltwater intrusion may affect natural resources. In addition, the severity of consequences depends on the duration and extent of the saltwater intrusion event as well as what species and ecosystems are affected. As a result, this rating relies on expert judgment.

## ECONOMIC VITALITY

### *Loss of economic productivity: 5*

Significant losses in water availability for irrigation as well as increased soil salinity could lead to long-term decreases in agricultural productivity. Higher salinity may also cause a shift in the types of crops grown in the region. In addition, saltwater intrusion may affect ecosystem services. When coastal or riverine ecosystems are damaged by direct human use, natural disasters, or climate change, the services provided are often degraded or cease altogether. These services must then be replaced by costly man-made facilities or processes that provide the same services (e.g., the construction of a water treatment plant or shipments of topsoil if forests and vegetation are lost).

Supporting evidence includes:

- The Fraser River delta is a provincially significant agricultural region, producing 14% of B.C.'s total farm gate receipts on 2.2% of the land (BC Agriculture & Food Climate Action Initiative, 2014). Saltwater intrusions can be profoundly detrimental to coastal agriculture through soil and irrigation water salination. Ongoing research on the effects of saltwater intrusion on B.C.'s agriculture sector indicate that there could be close to $800 million in impacts and that effects will persist for several years (Workshop feedback, 2019).
- The primary crops for this region have varying levels of vulnerability to salinity and flooding (BC Agriculture & Food Climate Action Initiative, 2014):
  - Blueberries are very sensitive to salt and excessive moisture. In addition, recovery would take years as it takes five years for blueberries to become established and eight to 10 years to reach peak productivity.
  - Grasses (particularly perennial Ryegass and Orchardgrass) are relatively tolerant of salt and flooding, but not for long periods of time.

- Potatoes are moderately sensitive to salinity and highly vulnerable to flooding.
- Cranberries are relatively tolerant of salt if the salt can be flushed out of the root zone. Cranberries are also tolerant of flooded soils, but do require good drainage for optimum productivity. Like blueberries, recovery would take several years.

- A study modeling water availability in Delta, B.C. from August to October[78] under different climate change scenarios indicates that irrigation needs may not be met under future climate conditions due to saltwater intrusion. The study projects a significant decrease in available water that meet the salinity requirement of 0.34 ppt or less (Tetra Tech EBA, 2016). As a result, this scenario could cause permanent or seasonal losses in productivity on Agriculture Reserve Lands due to increased water stress (BC Agriculture & Food Climate Action Initiative, 2013).
  - For example, farmers on Westham Island are already experiencing periodic saltwater intrusion and decreased agricultural productivity. From June to September, salinity is typically too high for irrigation due to lower freshwater levels. In addition, saline soils are found in this area, although most saline soils are currently below the depths of plant and crop roots (PGL Environmental Consultants, 2016).
- Farmers may also have increased maintenance or repair costs for irrigation ditches and corroded equipment (Workshop feedback, 2019).
- In addition, as high salinity conditions become more prevalent, farmers may need to shift to more salt-tolerant and non-irrigation crops, which may lead to permanent changes in the type and variety of crops grown in the Fraser River delta region (Burrows, 2011).
- Properly functioning ecosystems provide an array of free benefits to humans in the form of ecosystem services. These services fall into the broad categories of supporting, provisioning, regulating, and cultural services, and may or may not be directly tied to market activity. Examples of these ecosystem services include: nutrient recycling and soil formation (supporting), timber and crops (provisioning), carbon sequestration and water purification (regulating), and spiritual significance and recreation (cultural).
  - In B.C.'s Lower Mainland alone, it is estimated that ecosystems provide $5.4 billion worth of benefits per year.[79] The top three ecosystem services include: climate regulation ($1.7 billion annually), water supply ($1.6 billion annually), and flood protection ($1.2 billion annually) (Wilson, 2010).
  - Extrapolating to the entire province, ecosystem services provide an estimated annual value of $32 billion.[80]
- Saltwater marshes, sea grass beds, and coral reefs provide coastal protection and lower the risk of storm surge. Salt marshes dissipate wave and tidal energy thereby reducing the need for flood defence measures. During flooding, these ecosystems absorb and slowly release floodwaters afterwards, which also prevents flooding. Quantification of the value of these ecosystems on preventing flooding and saltwater intrusion is rare, but some studies have estimated the value at $0.6 to $1.1 million per hectare (Wilson, 2010).

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[78] August to October is the critical period for irrigation when Fraser flow has declined from Freshet conditions.
[79] Values in present-day, 2018 CAD.
[80] This extrapolation was conducted by scaling the values for B.C.'s Lower Mainland (Wilson, 2010) to the entire area of British Columbia.

**Confidence: Medium**

Although multiple independent sources support that loss of economic productivity could be high, an exact estimate for the agricultural sector is not available. In addition, impacts to other economic sectors are unknown.

*Loss of infrastructure services: 3*

As sea level rise and saltwater intrusion become increasingly chronic, there may be a permanent loss of existing freshwater wells and aquifers. In addition, the high mineral content of saltwater could corrode pipelines and pumps used to extract freshwater. Existing wells may need to be relocated higher up the river to collect adequate freshwater for irrigation.

Supporting evidence includes:

- This scenario may cause reduced or temporarily discontinued use of wells to allow the wells to recharges (Government of British Columbia, 2016). Severe or permanent saltwater intrusion due to sea level rise could lead to permanent discontinued use (Huppert, Moore, & Dyson, 2008).
- Saltwater intrusion has already occurred on the Gulf Islands of B.C. primarily in coastal wells that are at depths near the saltwater interface (Klassen & Allen, Risk of Saltwater Intrusion in Coastal Bedrock Aquifers: Gulf Islands, B.C., 2016).
- The high mineral content of saltwater could also cause corrosion of pipelines and well pumps that are used to extract freshwater from the aquifers (Huppert, Moore, & Dyson, 2008). This may mean more frequent replacement of wells, pumps, and pipelines.
- Although not particularly relevant for the Fraser River delta, it is also worth noting that aquifers may become permanently contaminated by saltwater intrusion due to sea level rise, in which case they would never recover. Aquifers experiencing temporary periods of saltwater intrusion can take several years to recover (Government of British Columbia, 2016). If there is saltwater in an aquifer, it is generally below a layer of freshwater. The depth of the freshwater layer varies seasonally depending on precipitation recharge and freshwater extraction (Government of British Columbia, 2016). Sea level rise will further limit the depth of the freshwater layer, which may affect the availability of freshwater.

**Confidence: Low**

There is limited information available on impacts to infrastructure services. Knowledge gaps include the number of wells and aquifers at risk of temporary or permanent inundation from 0.6 m of sea level rise and the severity of affected wells and aquifers on the delta's overall freshwater supply.

### COST TO PROVINCIAL GOVERNMENT: 2

The costs of saltwater intrusion are expected to fall primarily on individual water users or water suppliers. Costs to the provincial government could include management of sensitive ecosystems and protected areas or in extreme cases supplying emergency water supplies to affected communities. Although the costs to the provincial government are not well understood, costs are expected to be on the order of $375 million or less.

Supporting evidence includes:

- Costs of treating or replacing freshwater sources are likely to fall primarily on individual water users or the water suppliers. For example, a risk analysis of saltwater intrusion in the Gulf Islands of B.C. estimated the cost of replacing a household water source due to groundwater intrusion at $25,000 to $50,000 (the estimated cost of installing a rainwater collection system) or $6,000 per year (the estimated cost of importing freshwater) (Klassen & Allen, 2016). In addition, implementing a reverse osmosis system to combat saltwater intrusion could cost $100,000. The number of individuals in the delta that may need to replace their household water source due to groundwater intrusion is unknown, but expected to be small.
- In extreme cases, the government may need to supply water to communities that do not have access, which depending on the scale and duration of the event, could be costly (Workshop feedback, 2019).
- Other potential costs to government include the management of sensitive ecosystems and protected areas (Workshop feedback, 2019).

**Confidence: Low**

There is limited information on cost to the provincial government from saltwater intrusion, especially in the delta region. Knowledge gaps include the number of individuals reliant on groundwater supplies in the delta and whether there are any provincial government costs associated with impacts to irrigation water supply. As a result, this rating relies heavily on expert judgment.

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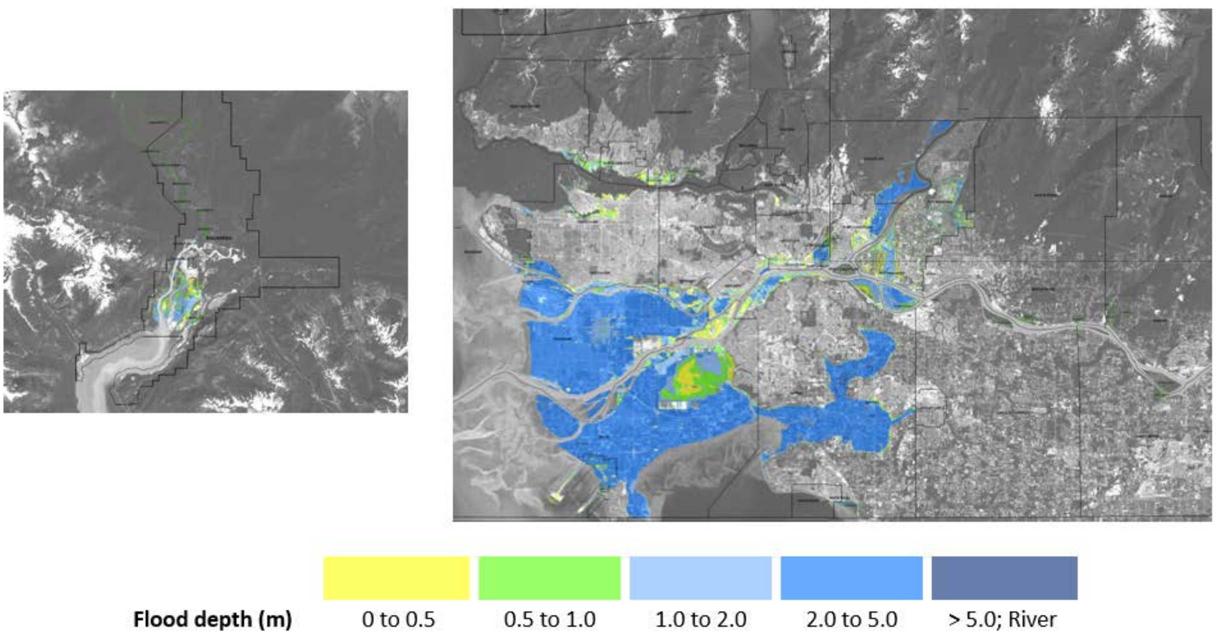
## Severe Coastal Storm Surge

### Scenario

The specific scenario analyzed is a storm surge of at least 3.9 m (caused by today's "500-year" winter storm with 3.4 m of surge plus 0.5 m of sea level rise), arriving during a king tide[81] along the B.C. coast. In this scenario, flood depths[82] could reach up to 5 m in some locations (see **FIGURE 58**) and last for two days.

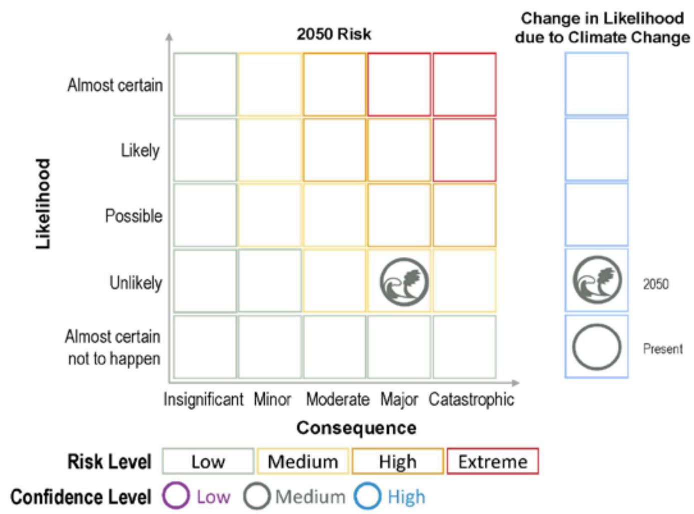
**FIGURE 58.** Severe storm surge scenario: flood depths under present-day 500-year coastal storm and 1 m sea level rise (equivalent to 0.5 m sea level rise coinciding with king tide).




[81] King tide is defined as an infrequent, but predictable high tide event without exacerbation from an accompanying storm. King tides occur on average two to three times a year typically during the winter months.
[82] Based on coastal flood mapping from Squamish to White Rock completed for the Lower Mainland Flood Management Strategy for a 500-year coastal event and 1 m sea level rise (Northwest Hydraulic Consultants, 2016). The Lower Mainland Flood Management Strategy of a 500-year coastal event and 1 m of sea level rise is the best available data source. Because sea level rise projections for 2050 are 0.5 m, the project team decided to modify the 500-year and 1 m sea level rise scenario for the purposes of this risk assessment, where the 1 m represents a combination of 2050 sea level rise (0.5 m) and the king tide. As a result, inundation is likely to be less than projected, however this mapping does not take into account wave run up, wind setup or land subsidence.

## Summary of Findings

**FIGURE 59.** Risk assessment findings for severe storm surge.




B.C. has more than 27,200 km of coastline and already experiences some coastal flooding when storms arrive during king tide events (Government of Canada, 2016; Northwest Hydraulic Consultants, 2016).

A present-day 500-year winter storm arriving at king tide, combined with 0.5 m of sea level rise, would result in significant flooding along the B.C. coast. In addition, this event threatens the integrity of existing flood management infrastructure (e.g., dikes). A 2016 flood vulnerability assessment for the lower mainland revealed that a major coastal flood event would become the costliest natural disaster to date in Canadian history (Northwest Hydraulic Consultants, 2016). Approximately four out of five B.C. residents live in coastal areas, increasing the risk of significant impacts to critical infrastructure and daily life (Government of Canada, 2016).

**FIGURE 59** and **TABLE 29** summarize the risk assessment results for this scenario. The highest consequences relate to social functioning and economic vitality. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 29.** Risk Rating Evaluation for Severe Storm Surge Scenario

| SEVERE COASTAL STORM SURGE: 3.9 M STORM SURGE DURING A KING TIDE ALONG THE B.C. COAST | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **1** | The 500-year coastal storm surge event has a 0.2% chance of occurring in any year. | **2** | **Climate-related risk cause:** Sea level rise due to increasing temperatures and glacial melt as well as king tides and El Niño cycles.<br>**2050 projections:** Although there is uncertainty regarding how climate change may affect coastal storms over time, sea level is projected to rise by up to 0.5 m by 2050 in B.C., which will increase the depth and frequency of significant coastal flood events. | Medium |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **4** | Ten to 100 deaths could occur from fast-moving floodwaters or limited medical/emergency care. | Medium |
| | Morbidity, injury, disease, or hospitalization | **4** | More than 100 people are at risk of harm due to fast-moving floodwaters, debris, disease, limited access to critical infrastructure and services, or environmental contamination. | Low |
| **Social functioning** | Psychological impacts | **5** | Severe psychological impacts are expected for individuals who experience damage to or loss of property or livelihood, evacuation, or loss of family member. Moderate impacts could be widespread. | Medium |
| | Loss of social cohesion | **5** | Direct recovery and clean up from flood damage could take months. Damages could also cause localized impacts to livelihoods. | Medium |
| **Natural resources** | Loss of natural resources | **2** | Natural resources could experience erosion, temporary saltwater intrusion, or contamination due to flooding; recovery could take months. | Low |
| **Economic vitality** | Loss of economic productivity | **5** | Total economic losses are estimated at $24.7 billion, including agriculture, transportation, and energy. | Medium |
| | Loss of infrastructure services | **5** | Infrastructure and institutional losses are estimated at $1.8 billion. Disruptions to critical infrastructure services could last for months. | Medium |
| **Cost to provincial government** | | **3** | Costs to government might include flood response, post-event cleanup, health services, ecosystem recovery, Disaster Financial Assistance, and AgriRecovery, among others. | Medium |
| **OVERALL RISK** | **CURRENT** | **LOW (4.1)** | | **MEDIUM** |
| | **2050** | **MEDIUM (8.3)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **4.1** out of 25, which equates to **low risk**, and the 2050 risk rating is **8.3** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 1 x 4.1 = 4.1 (Low)

2050 Risk = 2 x 4.1 = 8.3 (Medium)

## Evidence Base

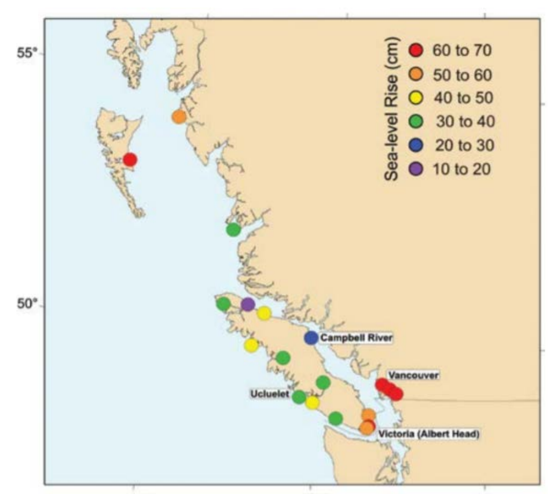
### *Risk Event Scenario*

This scenario represents one illustrative permutation of a storm surge event in British Columbia. The consequence ratings are specific to this scenario, but many may be transferable to other related scenarios.

The specifics of this scenario were based on:

- The project team reviewed many resources showing different coastal storm modeling permutations (AECOM, 2015; Northwest Hydaulic Consultants, 2014; B.C. Ministry of Forests, Lands and Natural Resource Operations, 2014), but chose to use the Lower Mainland Flood Management Strategy (Kerr Wood Leidal Associates Ltd, 2015; Northwest Hydraulic Consultants, 2016).
- *Lower Mainland Flood Management Strategy: Analysis of Flood Scenarios* estimated coastal flood levels for several communities (Kerr Wood Leidal Associates Ltd., 2015). One of the scenarios modeled flooding for the present-day 500-year storm event with stillwater ocean state and 1 m sea level rise, representing a year 2100 scenario. The project team used this available modeling to approximate flood extent depth under a mid-century sea level rise amount of 0.5 m (B.C. Ministry of Environment and Climate Change Strategy, 2011), but occurring during a king tide.[83] The report does not specify the flood duration, but assumes a two-day flood duration in its loss estimates (Northwest Hydraulic Consultants, 2016). Therefore, the project team applied the same assumption here.
  - The B.C. Ministry of Environment and Climate Change Strategy uses a standard projection of 1 m of sea level rise by 2100 for planning, relative to 2000 (B.C. Ministry of Environment and Climate Change Strategy, 2011), and this value is used in multiple local flood risk assessments (Kerr Wood Leidal Associates Ltd, 2015; Northwest Hydraulic Consultants, 2016; Lyle, Long, & Beaudrie, 2015; AECOM, 2015). Similarly, the recommended planning scenario for 2050 is 0.5 m of sea level rise by 2050 (B.C. Ministry of Environment and Climate Change Strategy, 2011).
- Relative sea level rise along the B.C. coast has been less than the global mean due to residual glacial and isostatic effects (Northwest Hydaulic Consultants,

**FIGURE 60.** Sea level rise projections for the year 2100 under a high-emission scenario (RCP8.5) (Government of Canada, 2016).




[83] Half a metre is a conservative estimate of king tide elevations. For example, Mean Sea Level at the Bellingham (WA) tide gage is 1.5 m above mean lower low water. Highest observed tide is 3.2 m (NOAA, 2018).

2014). Due to varying levels of subsidence and uplift along the B.C. coast, sea level rise will not affect all areas of the coast equally. **FIGURE 60** illustrates the local variability in sea level rise projections due to difference in vertical land movement (Government of Canada, 2016).

## *Likelihood rating*

The present-day likelihood of this scenario is **1** and the 2050 likelihood of this scenario is **2**. A present-day 500-year coastal flood with a 3.4 m storm surge, by definition, has a 0.2% annual chance of occurring. By 2050, sea level rise, king tides, and El Niño cycles are assumed to influence the likelihood of this scenario, and the project team evaluates these as indicators for the scenario. Unlike riverine flood events, there is larger uncertainty regarding whether coastal storm events will increase in frequency or intensity over time. However, climate change will increase the likelihood of significant local sea level rise by 2050 and, in turn, the depth and frequency of large flooding events when contemporaneous with large storms and/or king tides. Therefore, the project team judges that the 2050 scenario has a higher likelihood than the present-day scenario.

### Likelihood Rating Drivers

Type of risk event: Discrete

Climate change indicator: Relative sea level rise along the B.C. coast

"Present day" period: 2000

Source of 2050 projections: NOAA et al. 2017

Emission scenario: Upper limit projection

Supporting evidence includes:

- A 1-in-500-year coastal flood event, by definition, has a 0.2% annual chance of occurring.
- Recent coastal flood events during king tides occurred in December 2012, December 2014, and early 2016 (Smith, 2015; Northwest Hydraulic Consultants, 2016). Currently, there is no discernable trend on whether king tides are becoming higher or more frequent over time. There is also large variability in the size of king tides from year to year (Smith, 2015).
- Sea level rise is expected to increase the extent of inundation from coastal storms. The B.C. Ministry of Environment and Climate Change Strategy in *Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use* defines recommended sea level rise projections for B.C. land use policies, including 0.5 m for 2050 (B.C. Ministry of Environment and Climate Change Strategy, 2011).
- Projections estimate sea level rise of between 0.5 to 0.6 m by 2050[84] in the Fraser River delta relative to the historical baseline (NOAA et al., 2017). These values are based on the most recent localized projections for the delta that account for several contributing factors to sea level rise, including changes in land-ice mass, freshwater additions from land-ice melt or precipitation changes, and vertical land movement. These sea level rise projections are most relevant for the Fraser River delta. Other areas of the B.C. coastline are experiencing uplift (Government of Canada, 2016).
- Storm-surge flooding is recognized as a greater threat to the coast than sea level rise alone—in part because of upward vertical land movement in parts of B.C., which counterbalance the impacts of sea level rise (Government of Canada, 2016).

[84] Baseline year is 2000, using an upper limit projection assuming more extreme sea level contributions from ice sheets as modelled by Pfeffer et al. (2008). This is consistent with the RCP8.5 projections used throughout this risk assessment.

- Finally, El Niño events are known to be associated with more intense and frequent winter storms, storm surges, and waves (Abeysirigunawardena & Walker, 2010). Therefore, the likelihood of this scenario occurring increases during El Niño. The Intergovernmental Panel on Climate Change (IPCC) has low confidence in how the frequency and magnitude of El Niño will change in the future (Intergovernmental Panel on Climate Change, 2013).

**Confidence: Medium**

There are several sources of high-quality independent evidence, with some degree of agreement. In addition, sea level rise projections vary along the B.C. coastline. While relative sea level may rise 0.5 m through 2050 in the Fraser River delta due to local land subsidence, rates will be smaller in most other locations that experience tectonic-driven coastal uplift (e.g. **FIGURE 60**). The likelihood rating should, thus, be considered most relevant to coastal areas analogous to the Fraser River delta and Vancouver Metro area.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **4.1** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (4+4+5+5+2+5+5+3)/8

Overall Consequence = 4.1

### HEALTH

*Loss of life: 4*

Due to the magnitude and location of the event, 10 to 100 people could lose their lives from either direct or indirect causes. Direct loss of life could occur if people are caught in fast-moving floodwaters. In addition, limited medical or emergency care or loss of vital services such as power or clean water during and following the event could cause indirect loss of life. If warnings or evacuation orders are not issued in a timely manner, loss of life could even exceed 100 people.

Supporting evidence includes:

- Approximately four out of five B.C. residents live in coastal areas (Government of Canada, 2016). In metro Vancouver alone, 245,000 people are located in areas at risk of sea level rise (Government of Canada, 2016).
- On average, floodwaters become unsafe at flow depths of 0.8 to 0.9 metres (Shu, Han, Kong, & Dong, 2016). However, low-height, high-velocity floodwaters may be more hazardous to people than high-height, low-velocity floodwaters (Gomez, Kure, Udo, & Mano, 2016).
- Public Safety Canada assessed that coastal flooding “could result in more than 50 fatalities” (Public Safety Canada, No date). Similarly, a study found that hurricanes on the Atlantic coast caused an average of 50 deaths per year between 1963 and 2012. Storm surge was responsible for 49% of these deaths (Rappaport, 2014).

- Other factors that could influence loss of life include accessibility of medical or emergency care during the event and availability of utility services such as power and clean water.

**Confidence: Medium**

Loss of life is dependent on a number of variables, including how quickly flood waters rise, how much time people are given to evacuate, and how many people need to be evacuated. In addition, there are varying amounts and quality of evidence regarding the flood mortality rate for Canada and B.C. specifically. A more detailed analysis would be necessary to compute precise mortality risk for the B.C. coast based on extent and depth of modeled flooding, population demographics (including age and gender), timing of warning, evacuation behaviour, and other factors.

*Morbidity, injury, disease, or hospitalization: 4*

Coastal storm surge and flooding can cause health hazards beyond fatalities, such as injury, disease, or hospitalization from fast-moving floodwaters or debris, limited access to critical infrastructure and services, or environmental contamination. For example, storm surge can damage water supply systems, create conditions for water-borne diseases, or impair hospital or emergency response capacity. More than 100 people could experience ill health effects due to this scenario. If warnings or evacuation orders are not issued in a timely manner, this number could exceed 1,000 people.

Supporting evidence includes:

- Approximately four out of five B.C. residents live in coastal areas, including many populations vulnerable to flooding such as elderly populations, low-income populations, and immigrant populations. Indigenous populations could also be vulnerable to flooding (Government of Canada, 2016; Public Safety Canada, No date). In metro Vancouver alone, 245,000 people are located in areas at risk of sea level rise (Government of Canada, 2016).
- Severe coastal surge and flooding can cause many threats to public health and safety, including:
  - Damage to water supply systems or exceedance of treatment capacity, which may result in a Boil Water Notice (Government of British Columbia, No date).
  - Environmental contamination especially in areas near agricultural land, transportation and industrial sites, and hazardous waste storage facilities (Northwest Hydraulic Consultants, 2016). Agricultural contaminates may include manure, deceased livestock, or chemical inputs such as pesticides.
  - Limited access to critical infrastructure and services that may limit immediate access to medical treatment and inflate health impacts. Under this scenario, six ambulance stations and three hospitals are vulnerable to coastal flooding, which may limit immediate access to medical treatment and inflate morbidity, injury, disease, hospitalization, or death (Northwest Hydraulic Consultants, 2016).
  - Diseases spread through food contamination or insects, carbon monoxide positioning, and mental health effects (see the psychological impacts section for more information on mental health) (Government of Canada, 2018).
- Public Safety Canada assessed that injury from severe coastal surge will be high and widespread and will require federal support or intervention (Public Safety Canada, No date).

**Confidence: Low**

There are varying amounts and quality of evidence regarding cases of morbidity, injury, disease, and hospitalizations specific to Canada or B.C. from coastal storm surge. The number of people affected is ultimately dependent on a number of unknown variables, including where along the coast the surge event occurs, how much time people are given to evacuate, how many people evacuate, and what critical infrastructure services are affected.

## SOCIAL FUNCTIONING

### *Psychological impacts: 5*

Severe coastal storm surge could cause widespread and severe psychological impacts such as PTSD or depression for coastal populations as well as some interior populations that are directly affected by the event (e.g., people experiencing damage to or loss or property, mandatory or voluntary evacuation, loss of family members or friends). More moderate psychological impacts such as stress and anxiety are also possible for those who do not experience the storm directly, but are affected by limited transportation or utility services.

Supporting evidence includes:

- The key determining factors for post-disaster mental health issues are the degree and severity of exposure as well as post-disaster life stressors and level of social support (Goldmann & Galea, 2014). For flood-related disasters, the severity of flooding is the most significant factor for determining mental health effects (Foudi, Oses-Eraso, & Galarraga, 2017).
  - Common psychopathologies that manifest after disasters (e.g., hurricanes, terrorist attacks) include post-traumatic stress disorder, major depressive disorder, substance abuse disorder, general anxiety disorder, and prolonged grief disorder (Goldmann & Galea, 2014). The prevalence of these various mental health impacts from coastal flooding-related disasters are unknown.
  - Suffering material, physical, or intangible damage negatively affects mental health. Material damage (e.g., structural damage or damage to household contents) has the smallest effect (Foudi, Oses-Eraso, & Galarraga, 2017).
  - Key risk factors that may increase vulnerability to disasters include age, low socioeconomic status, minority ethnic status, previous mental health issues, and low social support (Goldmann & Galea, 2014). The relative importance of these factors for coastal flooding-related disasters is unknown.
- The Public Safety Canada flood risk assessment for B.C. identifies that more than 15% of the population is in flood-prone areas and may be displaced for more than six months (Public Safety Canada, No date).
  - In the Lower Mainland alone, this scenario would inundate 12 of 20 First Nation reserves and treaty lands (Northwest Hydraulic Consultants, 2016).
  - In Vancouver alone, this scenario could result in:
    - 4,000 displaced households and 11,900 people seeking space at public shelters. Many emergency shelters are in areas of flood risk, which may cause additional stress for those displaced and seeking shelter (Northwest Hydaulic Consultants, 2014; Lyle, Long, & Beaudrie, 2015).
    - More than 800 damaged buildings, the majority of which are residential (Northwest Hydaulic Consultants, 2014; Lyle, Long, & Beaudrie, 2015).
- A surge event of this magnitude will likely have ripple effects that last beyond six months and affect greater than 15% of the population:

- Disruptions to ferry and barge terminals may significantly affect the delivery of goods to Vancouver Island and other coastal communities, adding to individual and community stress (Northwest Hydraulic Consultants, 2016). In addition, impacts to agriculture and aquaculture could affect food security (Workshop feedback, 2019).
- Disruptions to utility services may further delay recovery and the ability of evacuated individuals to return home, increasing stress and anxiety. See the loss of infrastructure services section for more details.
- Psychological impacts related to agriculture are likely to be significant due to loss of agricultural livelihoods and assets, difficulty relocating livestock and possible associated losses (e.g., dairy animals), limited ability to transport critical agricultural inputs (e.g., feed) and outputs (e.g., crops), and increased stress or anxiety from farm management challenges and complexities (MacNair, 2019). See the loss of economic productivity section for projected losses of agricultural crops from this scenario. Agricultural impacts could lead to food security concerns (Workshop feedback, 2019).

**Confidence: Medium**

There are several high-quality sources detailing potential mental health effects from flooding, including post-disaster stressors such as disruptions to transportation or agriculture. Although the majority of the literature pertains to riverine flooding, the project team assumes that the findings are generally applicable to coastal flooding as well. More specific research on psychological impacts of coastal flooding in B.C. is needed to better understand the scope and extent of impacts.

*Loss of social cohesion: 5*

For those directly affected by storm surge (e.g., flooded home, flooded workplace or route to work), disruptions to daily life could last for months. Damages could also cause localized impacts to livelihoods (e.g., aquaculture and agriculture). There are also likely to be lingering after-effects to infrastructure services and institutions that could last for months after a coastal storm surge event. Given the potential for widespread disruptions to many critical institutions and services (e.g., wastewater treatment), even individuals who do not experience direct damage could experience at least a weeks-long disruption to daily life in terms of available services.

Supporting evidence includes:

- In the Lower Mainland, coastal flooding under this scenario could disrupt day-to-day life due to:
- Potential inundation of all wastewater treatment facilities in metro Vancouver and the Fraser Valley Regional District. These facilities serve the entire urban population base, including some areas that may be directly affected by flooding (Northwest Hydraulic Consultants, 2016).
- Possible flooding of vulnerable police stations (6), fire halls (12), ambulance stations (6), and hospitals (3), which may limit access to emergency help and medical care (Northwest Hydraulic Consultants, 2016).
- Possible flooding of 95 vulnerable schools, the majority of which are located in Richmond, Delta, Chilliwack, and Abbotsford (Northwest Hydraulic Consultants, 2016).
- Disruption to individual and commercial fishing, especially for Indigenous and rural communities. A decrease in fishing for Indigenous communities affected by a dam breach in 2014 resulted in a

shift in diet, physical activity, and cultural practices as well as a decrease in community income and employment opportunities (Shandro et al., 2016).

- In the Capital Region District, almost all municipalities include at least one key community, transportation, or business asset that would be temporarily inundated under this scenario (AECOM, 2015).
- In Vancouver, this scenario is not expected to affect social services (e.g., homeless shelters), but could cause:
  - Flooding to commercial services (Northwest Hydaulic Consultants, 2014; Lyle, Long, & Beaudrie, 2015).
  - Flooding and debris accumulation at coastal recreation-oriented public spaces (e.g., pools, rinks, sports fields), as well as at museums, historic buildings, etc. (Northwest Hydaulic Consultants, 2014; Lyle, Long, & Beaudrie, 2015).
- Public Safety Canada assessed public sensitivity impacts from coastal flooding as a sustained, long-term loss of trust, confidence, reputation, or public perception of public institutions (Public Safety Canada, No date). The failure of critical infrastructure (e.g., dikes, wastewater treatment) is expected to be the main driver of lost confidence in government and institutions during a coastal event.

**Confidence: Medium**

There are several high-quality sources on potential impacts to social cohesion. Loss of social cohesion is dependent on the extent of damage and number of people and institutions affected. Impacts to drinking water systems and elements of local government infrastructure are largely unknown as are the extent of damage and timeline for recovery for all infrastructure services. This rating assumes a significant portion of the population will experience disruptions that last beyond the duration of the event.

### NATURAL RESOURCES: 2

Given that coastal environments are generally resilient to coastal storm events, natural resources could recover within months of the event. Ecosystems in the affected area could experience erosion, temporary saltwater intrusion, or contamination due to flooding of agricultural, industrial, transportation, and hazardous waste sites.

Supporting evidence includes:

- Coastal ecosystems (e.g., wetlands) and the species that reside in those ecosystems are generally resilient to storm surge and would be able to bounce back relatively quickly following a coastal event (Government of Canada, 2016; The Ocean Foundation, 2017). However, surge may increase the rate of coastal erosion (Government of Canada, 2016). In addition, the Lower Fraser River estuary, for example, supports many unique and fragile ecosystems (Public Safety Canada, No date). The impacts of a severe coastal event on these ecosystems are unknown.
- An extreme coastal storm surge event can cause temporary saltwater intrusion, damaging soils and ecosystems (Government of British Columbia, 2016; BC Agriculture & Food Climate Action Initiative, 2014).
- The Public Safety Canada flood risk assessment for B.C. rated environmental impacts at the highest risk level, primarily due to contamination concerns (Public Safety Canada, No date). Locations near agricultural land, transportation, industrial sites, and hazardous waste storage facilities have an

elevated risk of contamination during a surge event. A surge can carry chemicals, fertilizers, petroleum products, raw sewage, or other contaminants, which can affect ecosystem health, human health, and agricultural productivity (Public Safety Canada, No date).

- Impacts to coastal ecosystems can also negatively affect ecosystem services provided by these species. See the loss of economic productivity section for more information.

**Confidence: Low**

There is limited information regarding how storm surge will affect natural resources along the B.C. coast. In addition, recovery time will vary depending on the affected species and ecosystems as well as local conditions. As a result, this rating relies heavily on expert judgment.

## ECONOMIC VITALITY

### *Loss of economic productivity: 5*

Total economic losses could be an estimated $24.7 billion. Damages to multiple industries, including agriculture, transportation, and energy are estimated above the catastrophic threshold of $1 billion each. In addition, coastal storm surge may affect ecosystem services. When coastal ecosystems are damaged by direct human use, natural disasters, or climate change, the services provided are often degraded or cease altogether. These services must then be replaced by costly artificial facilities or processes that provide the same services (e.g., the construction of a water treatment plant or shipments of topsoil if forests and vegetation are lost).

Supporting evidence includes:

- The Public Safety Canada flood risk assessment for B.C. identifies that greater than 15% of the local economy could be affected by riverine or coastal flooding (Public Safety Canada, No date).
- Total economic losses under this scenario are estimated at $24.7 billion, which includes direct building losses, agricultural losses, transportation losses, and infrastructure/institutional losses (Northwest Hydraulic Consultants, 2016):
  - Modelling using Hazus indicated $19.1 billion in building losses, including 8,200 buildings damaged and 3,700 buildings destroyed. Most of the losses are attributed to residential and commercial buildings (Northwest Hydraulic Consultants, 2016).[85]
  - Transportation losses are estimated at $3.6 billion (Northwest Hydraulic Consultants, 2016).[86]
  - Agricultural losses are estimated at $200 million, including:[87]
    - Damage to agricultural buildings is estimated at $40.9 million,
    - Damage to agricultural equipment is estimated at $14.6 million, and

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[85] Hazus-related building losses are based on default recovery times ranging from 1 to 33 months. Hazus (Hazus-MH 2.1) was developed by FEMA and adapted for Canadian conditions by Natural Resources Canada. Building-related loss projections encompass the cost of repair or replacement of residential, commercial, industrial, and public/institutional buildings damaged or destroyed by flood, and include losses relating to inventory, relocation, and wages.

[86] Loss projections for transportation revenues from delays and cancellations in cargo shipping. Losses from interruptions to rail traffic were estimated based on freight transshipped through Port Metro Vancouver. Interruptions to highway traffic and to Vancouver International Airport were discussed but not quantified. Transportation losses assume two weeks of disruptions for coastal floods.

[87] Agricultural losses were estimated based on Land Use Inventory information and Stats Canada's 2011 Census of Agriculture data. Farmer losses from Hazus data were based on flood inundation exceeding a two-week critical period. Loss projections for agriculture include agricultural buildings and equipment damaged or destroyed, lost farm gate sales, and replanting costs.

- Lost farm gates sales and replanting costs are estimated at $144.5 million (Northwest Hydraulic Consultants, 2016).[88]
  - Infrastructure/institutional losses are estimated at $1.8 billion (Northwest Hydraulic Consultants, 2016). See the loss of infrastructure services section for more details.
- In addition to agricultural building and equipment losses, this scenario could also lead to:
  - Coastal inundation of farmland causing waterlogged soils and higher soil salinity. Salt in the soil from a winter flood event, however, will likely be flushed out during heavy winter or spring precipitation events, decreasing the impacts of salinity on agricultural productivity compared to a spring coastal flooding event (BC Agriculture & Food Climate Action Initiative, 2014; Government of Canada, 2014).
  - Decreased water quality for irrigation due to saltwater intrusion (Tetra Tech EBA, 2016). Permanent loss of freshwater supplies is possible in some areas. In the Gulf Islands, some low-lying aquifers could be inundated by seawater, resulting in permanent loss of the aquifer (Klassen & Allen, 2016). This could have implications for irrigation as well as household use.
  - Agricultural losses per crop category[89]: 10% forage, 5% annuals, 10% perennials, and 2% dairy[90] (Northwest Hydraulic Consultants, 2016).
- Another study modeling the economic impacts of storm surge and sea level rise for the period 2009 to 2054 found that capital damage costs to dwellings in B.C. range from $2.2 billion to $53 billion, depending on the scenario.[91] In addition, agricultural land damages in B.C. range from $105,000 to $621,000 and forest land damages range from $300,000 to $1,360,000 (Withey, Lantz, & Ochuodho, 2016).
- Loss of life also has an economic impact. The range of loss of life from 10 to 100 can be valued at $52 to $520 million, based on the number of lives projected to be lost (Treasury Board of Canada Secretariat, 2007).[92,93]
- Properly functioning ecosystems provide an array of free benefits to humans in the form of ecosystem services. These services fall into the broad categories of supporting, provisioning, regulating, and cultural services, and may or may not be directly tied to market activity. Examples of these ecosystem services include nutrient recycling and soil formation (supporting), timber and crops (provisioning), carbon sequestration and water purification (regulating), and spiritual significance and recreation (cultural).
  - In B.C.'s Lower Mainland alone, it is estimated that ecosystems provide $5.4 billion worth of benefits per year.[94] The top three ecosystem services include climate regulation ($1.7 billion annually), water supply ($1.6 billion annually), and flood protection ($1.2 billion annually) (Wilson, 2010).

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[88] Estimated losses based on two-day coastal week flood durations.
[89] The agricultural loss estimates assume that coastal flooding occurs between December and January and lasts for two days.
[90] Livestock estimates assume that most livestock would be moved to higher ground prior to an impending flood. Any losses due to insufficient time to complete evacuations are not accounted for.
[91] The scenarios include: current sea level rise and storm surge conditions; sea level rise and storm surge conditions under IPCC's B1 emission scenario; and sea level rise and storm surge conditions under IPCC's A2 emission scenario.
[92] Value in 1996 CAD.
[93] The Treasury Board of Canada Secretariat expects departments to use a VSL of $5.2 million adjusted for inflation since 1996.
[94] Values in present-day, 2018 CAD.

- Extrapolating to the entire province of B.C., ecosystem services provide an estimated annual value of $232 billion.[95]

- Salt marshes, sea grass beds, and coral reefs provide coastal protection and lower the risk of storm surge. Salt marshes dissipate wave and tidal energy thereby reducing the need for flood defence measures. During flooding, these ecosystems absorb and slowly release floodwaters afterward, which also prevents flooding. Values on the value of these ecosystems on preventing flooding and saltwater intrusion are rare, but some studies have estimated the value at $0.6 to $1.1 million per hectare (Wilson, 2010).

**Confidence: Medium**

Although is it difficult to estimate the total cost to economic productivity, several sources of high-quality independent evidence indicate costs will be significantly above the $1 billion threshold. Indirect costs as well as impacts to the tourism industry are largely not accounted for in the literature, suggesting that the estimates presented are conservative estimates for costs to economic productivity.

*Loss of infrastructure services: 5*

Disruptions to critical infrastructure services (e.g., transportation, communications, energy, and wastewater treatment) could last for months depending on the extent and depth of flood damage. Estimated losses to infrastructure and institutional from this event are $1.8 billion. Impacts could include inundation of key transportation infrastructure, loss of electrical services, and dike failure, among others.

Supporting evidence includes:

- This scenario would result in infrastructure/institutional losses of $1.8 billion (Northwest Hydraulic Consultants, 2016),[96,97] including inundation of the following infrastructure in the lower mainland (where modeling data are available):

- 23 hydro substations, which could result in loss of electrical service for an undetermined amount of time (Northwest Hydraulic Consultants, 2016).
- Five airports, including Vancouver International Airport.
- Various port facilities and terminals, although the degree of vulnerability is dependent on the specifics of each facility (e.g., the location of electric motors) (Northwest Hydraulic Consultants, 2016). The Port of Metro Vancouver is Canada's largest, busiest, and most diverse port and is therefore critical to the province and Canada's economy (Public Safety Canada, No date).
- All three Class 1 railways and some passenger railways. This could mean losses of freight and cargo shipments and loss or reduction of freight services, affecting supply chains and causing cascading effects.
- Five wastewater treatment plants are in the coastal floodplain, which could be compromised during a flood event or cause contamination. Even if an area is not directly affected by a coastal

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[95] This extrapolation was conducted by scaling the values for B.C.'s Lower Mainland (Wilson, 2010) to the entire area of British Columbia.
[96] Infrastructure and institutional buildings are defined as substations, airports, marine facilities, rail lines, critical highway routes and arterial roads, rapid transit lines, wastewater treatment plants, police and emergency services, hospitals, municipal halls and work yards, and other structures.
[97] Infrastructure/institutional losses are order of magnitude estimates based on rough assumptions and replacement costs by FEMA. They do not incorporate durations.

flood event, indirect impacts from disruptions to the wastewater treatment system can still affect these areas (Public Safety Canada, No date).

- A present-day storm surge at high tide can overtop existing infrastructure (even without sea level rise considerations). The Public Safety Canada flood risk assessment for B.C. rated the impacts to transportation and energy and utility infrastructure as the highest risk level (Public Safety Canada, No date).
- In addition, a B.C. Dike Assessment revealed that the average condition rating for coastal dikes protecting the lower mainland ranges from "fair to poor" and "poor to unacceptable," meaning many dikes are susceptible to breaching during a coastal flood event, which would exacerbate flooding (Northwest Hydraulic Consultants, 2016). In addition, breached dikes could cause daily impacts from high tide in the weeks to months following the event until the dike is repaired (Workshop feedback, 2019).
- In the Capital Region District, sea level rise and storm surge concerns are largely focused on disruptions to transportation networks, such as ferry services and the wharves as well as Victoria's Inner Harbour (tourism hub) and Canadian Forces Base Esquimalt (base of Canada's Pacific Fleet) (Government of Canada, 2016).
- In Vancouver, infrastructure is expected to be relatively resilient to this scenario, but could cause the following impacts (Northwest Hydaulic Consultants, 2014; Lyle, Long, & Beaudrie, 2015):

- Damage to more than 800 buildings, some of which are industrial.
- Inundation of three evacuation and access routes.
- Some disruptions to roads and bridges.
- Flooding at one B.C. Hydro substation.
- Storm sewer overflows.
- Shutdown of the Neighbourhood Energy Utility, potentially for several weeks.
- Flooding of portions of the rapid transit service. Commuter rail, port, and heliport may also be affected by flooding.

- Repair and replacement costs for critical infrastructure could also accumulate. For example, the costs of erosion for Port Metro Vancouver include (Smith, 2015):

- Engineering survey = $2 to $4 per linear metre
- Engineering design = unknown cost
- Minor repair costs = $70 to $150 per linear metre
- Moderate repair costs = $400 to $600 per linear metre
- Major repair costs = $1,500 to $3,000 per linear metre
- Replace costs = $6,000 per linear metre

- In addition to storm surge, coastal storm events can cause widespread wind damage and loss of trees, which can also take months to clean up (Woo, 2019).

**Confidence: Medium**

Multiple risk assessments have been completed for B.C. to evaluate the consequences of a severe coastal storm surge event, including assessing potential impacts to a variety of infrastructure. The extent of damage and timeline for recovery, however, are unknown and dependent on the specifics of the storm surge event (e.g., duration and extent of inundation for each infrastructure asset).

## COST TO PROVINCIAL GOVERNMENT: 3

A 500-year coastal storm surge event is estimated to be the costliest natural disaster in Canadian history to date, indicating a significant cost to the provincial government. However, assuming that this event would trigger significant financial assistance from the Government of Canada through DFAA, the cost to the provincial government is expected to be on the order of $375 million to $750 million. The provincial government could bear costs including flood response, post-event cleanup, health services, ecosystem recovery, Disaster Financial Assistance, and AgriRecovery and other business risk management programs, among others.

Supporting evidence includes:

- The level of expected damage from this scenario would be costlier than any disaster to date in Canadian history (Northwest Hydraulic Consultants, 2016; Public Safety Canada, No date). The scenario is expected to result in $24.7 billion in total economic losses[98] (Fraser Basin Council, 2016).
- Economic modeling of storm surge and sea level rise scenarios found that B.C. could experience GDP losses of $81.11 billion under 0.85 m of sea level rise and associated storm surge conditions between 2009 and 2054[99] (Withey, Lantz, & Ochuodho, 2016).
- Costs to the provincial government would include flood response, post-event cleanup, and AgriRecovery and other business risk management programs (e.g., Production Insurance, AgriInvest, AgriStability).
  - Although total evacuation costs are unknown, a coastal event would displace 11,900 people in Vancouver alone. At a per diem cost of roughly US$380, the cost of a single-day evacuation of 11,900 people is US$4,522,000 (U.S. Department of State, 2019).
  - The project team was unable to precisely estimate the agriculture-related business risk management program costs for this scenario. However, if all or a majority of the existing flood mitigation infrastructure failed, this event would likely trigger a federal-provincial recovery initiative under the AgriRecovery policy framework (Agriculture and Agri-Food Canada, 2018a). For AgriStability, losses at the individual farm level would have to exceed a 30% margin decline for the whole farm (Agriculture and Agri-Food Canada, 2018b).
- The provincial government would likely be responsible for some portion of health care costs, although the project team could not determine the exact cost share between the federal and provincial government for the following estimates:
  - According to the Canadian Institute for Health Information (2017), the cost of a standard hospital stay in B.C. is on average $6,135.[100] Although not all cases of morbidity, injury, or disease are likely to result in hospitalization, the estimated range of 100 to 1,000 hospitalizations as a result of severe flooding can be valued at $613,500 to $6,135,000. Some portion of this cost would be covered by the provincial government.

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[98] This figure includes residential, commercial, industrial, public/institutional buildings, interrupted cargo shipments, infrastructure, and agriculture losses. Building-related loss projections encompass the cost of repair or replacement of residential, commercial, industrial, and public/institutional buildings damaged or destroyed by flood, and include losses relating to inventory, relocation, and wages. Loss projections for interrupted cargo shipments is based on revenues from delays and cancellations in cargo shipping. Loss projections for agriculture include agricultural buildings and equipment damaged or destroyed, lost farm gate sales, and replanting costs.

[99] The scenario used for this study is based on IPCC's A2 global emissions scenario and assumes 0.85m of sea level rise. It represents slightly less sea level rise than the scenario evaluated in this risk assessment.

[100] The value is in 2017 CAD. This measure divides a hospital's total inpatient expenses by the number of hospitalizations it sees in a year. The number is adjusted for some differences in the types of patients a hospital sees to make it more comparable with other hospitals.

- An estimated 30 to 60% of affected populations will need some form of mental health-related assistance following a disaster (NIST, 2017). Rates for severe, moderate, and mild mental illness can range between 6 to 26% for up to 30 months following a disaster (FEMA, 2012,). Treatment costs for these mental illness cases are estimated at (FEMA, 2012):
  - 12 months post disaster: US$822 per person
  - 18 months post disaster: US$639 per person
  - 24 months post disaster: US$567 per person
  - 30 months post disaster: US$414 per person

- Other potential costs to government include:
  - Restoration of natural resources (e.g., clearing debris, contaminants) (Workshop feedback, 2019).
  - Replacement of lost or damaged infrastructure (Workshop feedback, 2019).
  - Lost revenue or taxes due to disruptions to businesses and tourism (Workshop feedback, 2019).

- If the Government of B.C. declares a natural disaster eligible[101] for Disaster Financial Assistance, local government bodies, homeowners, residential tenants, small business owners, charities, and farmers can apply for monetary assistance from the Government of B.C. for uninsurable losses (Wadhwani, 2018; Huffpost Canada, 2015; Government of British Columbia, 2018).
  - For individuals, the province will cover up to 80% of uninsurable disaster-related damages greater than $1,000, to a maximum claim of $300,000 (Government of British Columbia, 2018).
  - For local governments, the province will cover up to 80% of recovery measures greater than $1,000 to replace essential materials, including rebuilding or replacing essential public infrastructure (Government of British Columbia, 2018).
  - The province will also cover 100% of the cost to local governments to run emergency operations centres (Wadhwani, 2018).

- For a large-scale disaster such as a 500-year coastal storm surge event, the Government of Canada would likely provide financial assistance through the DFAA, which would significantly lower the burden on the provincial government (Public Safety Canada, 2019). For example:
  - For a disaster totaling $1.5 billion, the Government of Canada would provide $1.3 billion in financial assistance to the Government of British Columbia. The province would be responsible for $179 million.
  - For a disaster totaling $500 million, the Government of Canada would provide $421 million in financial assistance to the Government of British Columbia. The province would be responsible for $79 million.
  - For a disaster totaling $50 million, the Government of Canada would provide $19 million in financial assistance to the Government of British Columbia. The province would be responsible for $31 million.

**Confidence: Medium**

There are several sources of evidence regarding cost to the provincial government from a coastal storm event of this severity. There is a knowledge gap regarding the cost of business risk management programs and emergency assistance programs. The cost to the provincial government is ultimately dependent on the location of the storm event and the severity of damages. In addition, this rating

[101] Eligibility is determined between the provincial and local government.

assumes significant financial assistance from the Government of Canada. If the province were responsible for the total cost of the disaster, it could exceed the "catastrophic" threshold.

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# Heat Wave

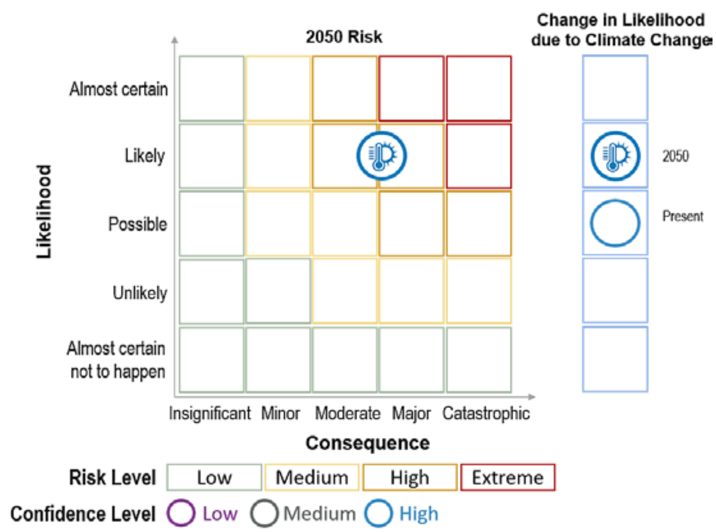
## Scenario

The specific risk event scenario analyzed is a heat wave of at least three days in several regions across the province, resulting in significant consequences to human health. Other factors such as humidity/wet bulb temperature, Heat Index measurements, nighttime temperatures, and regional variations in relative extreme temperatures will play a role in the magnitude of a heat wave event.

## Summary of Findings

Heat waves are extended periods of time with relatively high temperatures for a given location. A provincially significant heat wave would be one that would have severe negative outcomes for human health. For example, in 2009, B.C. experienced a heat wave that brought temperatures above 31°C in coastal areas and above 36°C inland. This event contributed to approximately 200 additional deaths and a total cost estimated at around $120 million (Henderson & Kosatsky, 2012; Stewart et al., 2017).

**FIGURE 61.** Risk assessment findings for heat wave scenario.




Heat waves are defined in many different ways, often as a relative extreme temperature compared to average temperatures. In this assessment, the likelihood of 3+ days above 32°C was chosen. As heat waves become more frequent and severe, the effects could be more significant, leading to a range of negative impacts. The largest risk is to human health. People tend to become adapted to gradually rising temperatures, but extreme heat events can manifest in dire health consequences. In addition, a heat wave could result in stress to infrastructure and transportation systems, economic productivity, and ecosystems.

**FIGURE 61** and **TABLE 30** summarize the risk assessment results for this scenario. The highest consequences relate to loss of life; morbidity, injury, disease, or hospitalization; and psychological impacts. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 30.** Risk Rating Evaluation for Heat Wave Scenario

| HEAT WAVE: HEAT WAVE OF AT LEAST THREE DAYS THAT AFFECTS HUMAN HEALTH | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **3** | Event is expected to happen about once every 11 to 50 years. | **4** | **Climate-related risk cause:** Increase in average and extreme temperatures.<br>**2050 projections:** Extreme heat days (particularly days above 32°C) are projected to become more common. An extreme heat wave could be expected to happen about once every 3 to 10 years. | High |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **5** | Over 100 excess mortalities could occur in B.C. | High |
| | Morbidity, injury, disease, or hospitalization | **5** | Over 1,000 people could experience negative health impacts, ranging from dehydration to heat stroke and respiratory illnesses. Urban populations are particularly vulnerable because of the heat island effect. | High |
| **Social functioning** | Psychological impacts | **5** | Extreme heat events can trigger and exacerbate mental, behavioural, and cognitive disorders, causing widespread and severe psychological impacts. Widespread moderate impacts may also occur. | High |
| | Loss of social cohesion | **3** | A heat wave could exacerbate marginalization of vulnerable populations and increase the possibility of violent crime. Disruptions to daily life could last the duration of the heat wave. | High |
| **Natural resources** | Loss of natural resources | **2** | Heat stress could result in minor damages to wildlife, forests, and fish. Recovery could occur in months. | Medium |
| **Economic vitality** | Loss of economic productivity | **4** | Economic losses in agriculture (crops and livestock), damage to fish populations, reduced labour productivity, and increased costs of electricity could exceed $100 million. | High |
| | Loss of infrastructure services | **3** | Disruptions to energy systems and transportation infrastructure could last multiple days, impeding day-to-day activities. | Medium |
| **Cost to provincial government** | | **2** | Potential costs include emergency management and response, short-term reductions in tax revenue, and losses in productivity for city workers. | Low |
| **OVERALL RISK** | **CURRENT** | **MEDIUM (10.9)** | | **HIGH** |
| | **2050** | **HIGH (14.5)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **10.9** out of 25, which equates to **medium risk**, and the 2050 risk rating is **14.5** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 3 x 3.6 = 10.9 (Medium)

2050 Risk = 4 x 3.6 = 14.5 (High)

## Evidence Base

### *Risk Event Scenario*

This scenario represents one illustrative permutation of a severe heat wave in British Columbia. Heat waves could have varying duration and severity, as well as geographic footprints. The consequence ratings are specific to this scenario, but many may be transferable to other related scenarios.

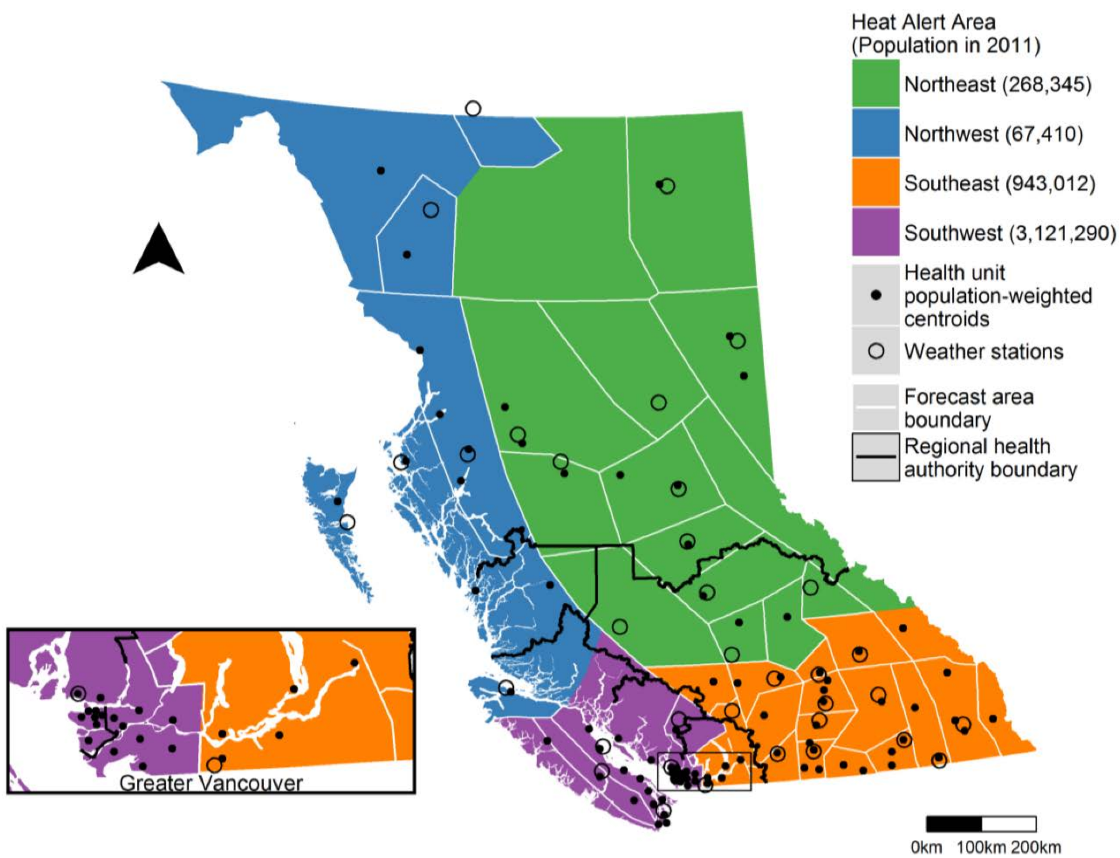
The specifics of this scenario were based on:

- There is no standard definition of a heat wave, and the consequences depend on a variety of factors including average temperatures, humidity, and location. Existing definitions of heat wave from the literature include:
  - Three or more consecutive days with temperatures above 32°C (definition used by Environment Canada and HealthLink BC) (Phillips D. , 2013; Hansen et al., 2008; HealthLink BC, 2018). This threshold is evaluated explicitly in the likelihood section below.
  - A marked unusual hot weather over a region persisting at least two consecutive days during the hot period of the year based on local climatological conditions (WMO, 2016).
  - Two-day average temperatures exceeding 29°C on the coast and 34°C inland (Stewart et al., 2017).
  - A period of at least 48 hours during which neither the overnight low nor the daytime heat index falls below the National Weather Service heat stress thresholds (26.7°C and 40.6°C) (Stewart et al., 2017).
  - Wet bulb temperatures (combination of humidity and temperature factors) exceeding 35°C, at which the human body can no longer cool through perspiration (Sarofim et al., 2016).
  - A period when maximum temperature and minimum temperature are over the 90$^{th}$ percentile of the monthly distribution for at least two days (Health Canada, 2012).
  - The heat threshold relevant for human health is around the 95$^{th}$ percentile for summer temperatures, which varies depending on local conditions (Henderson, Wan, & Kosatsky, 2013).
- Despite these definitions, adverse effects have been noted at lower temperatures and in shorter-duration events, and not all events with conditions over these thresholds result in catastrophic impacts (Stewart et al., 2017). Therefore, the project team defined this heat wave scenario in terms of its impacts on human health.
- The correlation between temperature and mortality is most severe in northern B.C., where summers are typically mild and hot days are rare. In the North, there is a 19% increase in mortality at 30°C. However, people in B.C.'s southern Dry Plateau are more adapted to hotter temperatures and mortality only increased by 4% at 30°C (Henderson, Wan, & Kosatsky, 2013).
- Within B.C., one study found increased risk of mortality and morbidity at maximum temperatures as low as 14°C in the north and as high as 22°C in the south (McLean et al., 2018). **FIGURE 62** shows the four regions considered in the study.

- Observed daily lows from 2004 to 2016 ranged from -14.5°C to 26.6°C across B.C., and observed highs ranged from 0.5°C to 42°C. Temperatures are generally higher in the south than in the north of the province.
- The study established the following thresholds for mortality and morbidity, which are based on two consecutive daytime high temperatures and the overnight low temperature in between:
  - Southwest: Two consecutive days of 29°C with an overnight low of 16°C
  - Southeast: Two consecutive days of 35°C with an overnight low of 18°C
  - Northeast: Two consecutive days of 29°C with an overnight low of 14°C
  - Northwest: Two consecutive days of 28°C with an overnight low of 13°C

- The application of the 32°C temperature threshold to gridded data likely underestimates the number of occurrences compared to using higher resolution bias-corrected or station data. This is because some locations within the grid (~10 km) may be hotter than the 32°C average, particularly in areas with complex topography.

**FIGURE 62.** Map of heat alert areas, forecast areas, weather stations, health united population-weighted centroids, and Regional Health Authority Boundaries in B.C. (McLean et al., 2018).




## *Likelihood rating*

The present-day likelihood of three consecutive days with 32°C heat is **3** and the 2050 likelihood of this scenario is **4**. Although there is no standard definition of a heat wave affecting human health, as

### Likelihood Rating Drivers

Type of risk event: Discrete

Climate change indicators: Annual days above 32°C

"Present day" period: 1980-1999

Source of 2050 projections: Project team analysis of downscaled GCM data from PCIC

Emission scenario: RCP8.5

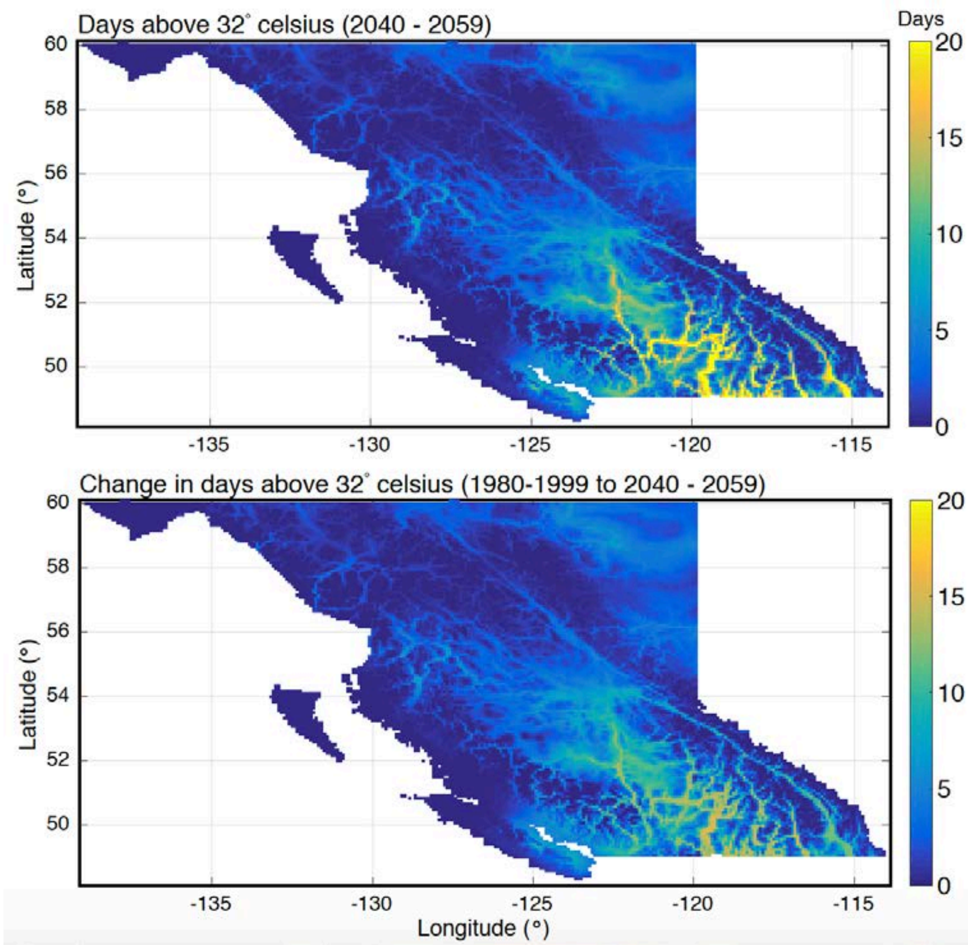
described above, the project team selected a primary climate change indicator to evaluate the change in likelihood of this scenario: days above 32°C. This threshold was chosen as particularly significant for health risks in British Columbia (Phillips D. , 2013; Hansen et al., 2008; HealthLink BC, 2018).

In order to evaluate this scenario, the project team calculated the number and change in days per year above this threshold for mid-century (2040 to 2059) relative to the baseline time period (1980 to 1999) using bias-corrected, downscaled output from the CanESM2 Global Climate Model (GCM) and assuming RCP8.5 for the entire province. Cooler regions of British Columbia could experience heat wave conditions at temperatures lower than 32°C. For example, while the historical 95th percentile maximum temperature in the Central Plateau region is approximately 32°C, historical maximum temperatures in coastal B.C. and Rocky Mountains can be as low as 27°C (Henderson et al., 2013). As a result, the likelihood and consequence ratings should be viewed through this lens of regional variability. However, it is clear that B.C. will experience broad increases in maximum temperatures through mid-century, independent of location. In this scenario, projected increases in the magnitude of heat across the province are assumed to indicate the increasing likelihood of heat waves by mid-century. The project team used additional historical datasets and projections, often with varying baseline time periods, to support this evaluation.

The likelihood rating was determined based on the evaluation of the number of province-wide extreme heat days by mid-century and supplementary regional historical temperature trends and future projections:

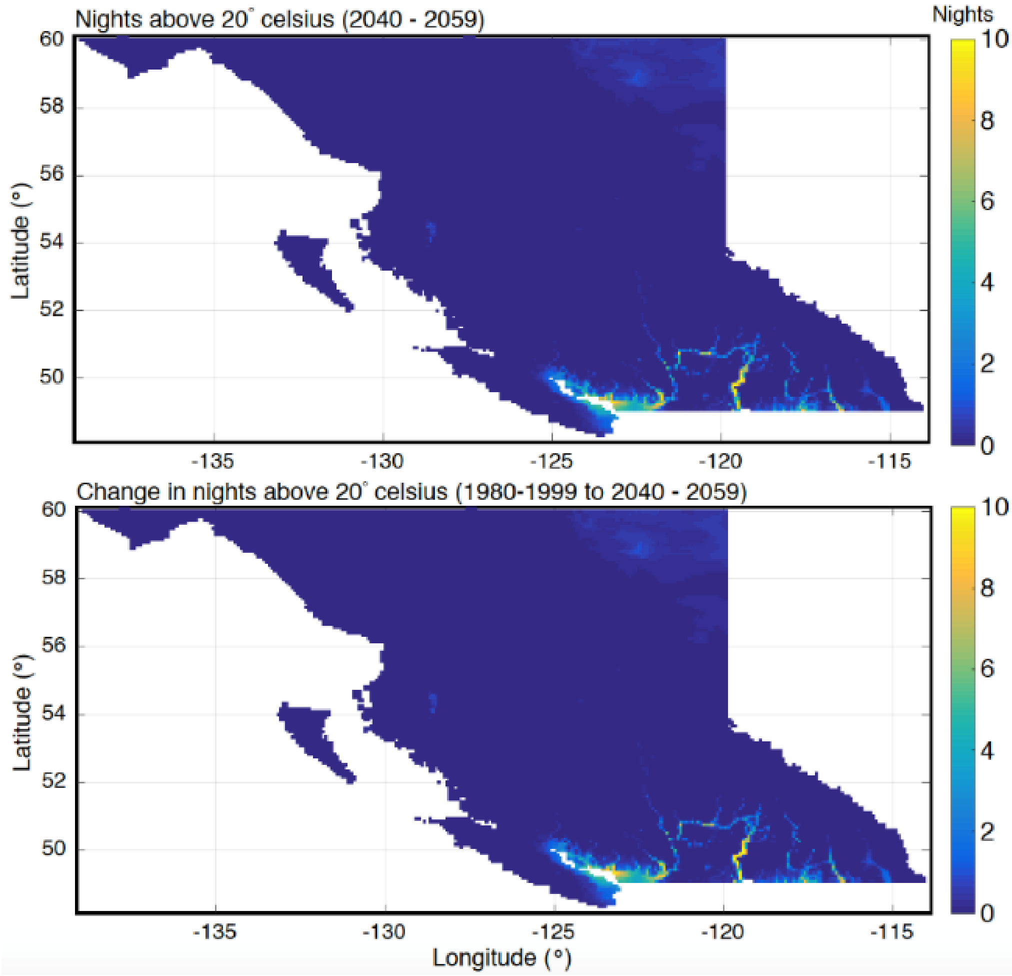
- **FIGURE 63** shows the mean number of extreme heat days exceeding 32°C per year across B.C. for mid-century (2040 to 2059) and the change in the number of days exceeding 32°C between the baseline time period (1980 to 1999) and mid-century (2040 to 2059) (Pacific Climate Impacts Consortium, 2012). These maps reveal a future characterized by widespread and more prevalent extreme heat. In particular, the inland valleys and central plateau regions could see more than 15 days greater than 32°C by mid-century. Other regions are very likely to see similar increases but for maximum temperature ranges below 32°C. The increase in the number of extreme heat days strongly suggests an increased likelihood of three-day heat waves occurrence by mid-century.
- **FIGURE 64** shows the mean number of daily low temperatures exceeding 20°C per year across B.C. for mid-century (2040 to 2059) and the change in the number of daily low temperatures exceeding 20°C between the baseline time period (1980 to 1999) and mid-century (2040 to 2059) (Pacific Climate Impacts Consortium, 2012). In addition to more frequent extreme heat days by mid-century, these maps reveal that nighttime low temperatures will also become increasingly hot, particularly in coastal areas including Vancouver and valley communities in southern B.C. Increasing nighttime temperatures present increased health risks during heat waves.

**FIGURE 63.** (top) Mean number of extreme heat days exceeding 32°C per year across B.C. for mid-century (2040 to 2059).[102] (bottom) Change in the number of days exceeding 32°C between the baseline time period (1980 to 1999) and mid-century (2040 to 2059) (data from Pacific Climate Impacts Consortium, 2018).




[102] Mapped data use downscaled (~10km) CanESM2 GCM projections assuming RCP8.5.

**FIGURE 64.** (top) Mean number of daily low temperatures exceeding 20°C per year across B.C. for mid-century (2040 to 2059).[103] (bottom) Change in the number of daily low temperatures exceeding 20°C between the baseline time period (1980 to 1999) and mid-century (2040 to 2059) (data from Pacific Climate Impacts Consortium, 2018).




- British Columbia is currently experiencing a long-term warming trend in observed daily maximum and minimum temperatures due to climate change. Based on ensemble mean GCM projections, annual temperatures are expected to increase by 1.3 to 2.7°C (10th to 90th percentile) by mid-century, relative to the 1961 to 1990 historical baseline (Pacific Climate Impacts Consortium, 2012), which will very likely result in more frequent warm summer days and an increase in significant heat waves (Bush, Loder, James, Mortsch, & Cohen, 2014). Additional regional historical trends and temperature projections include:

- In Victoria, between 1951 and 1980, an average of three days per year were warmer than 30°C. In the 21st century, days above 30°C are expected to more than quadruple, to 13 days per year (White, Wolf, Anslow, Werner, & Creative, 2016).

[103] Mapped data use downscaled (~10km) CanESM2 GCM projections assuming RCP8.5.

- In Metro Vancouver, the 1-in-20 hottest temperature is projected to increase from 34°C to 38°C by the 2050s relative to the 1971 to 2000 (Metro Vancouver, 2016).
- In Metro Vancouver, the number of summer days above 25°C and 30°C are expected to increase from 22 to 55 days per year and 3 to 17 per year by the 2050s, respectively, relative to the 1971 to 2000 baseline (Metro Vancouver, 2016). In addition, the annual hottest temperature for the region is expected to increase from 31°C to 35°C by the 2050s (Metro Vancouver, 2016).
- In Canada, the 1-in-20-year hottest day is likely to become a 1-in-2-year event by the end of the century (Warren & Lemmen, 2014).
- Hot days will be most frequent in the Lower Mainland and the interior of British Columbia (White, Wolf, Anslow, Werner, & Creative, 2016).

- Across much of the U.S. and Canada, both relative and absolute extreme heat events have increased since 1980, meaning there are more extremely hot days during the summer and more extremely hot days relative to historical monthly averages. There is some evidence that early-season events or unseasonable extremes pose a greater health risk to humans, especially vulnerable populations (Sheridan & Lee, 2018).
- By mid-century, heat waves are "very likely" to increase in duration, frequency, and/or intensity (Warren & Lemmen, 2014). Over the next century, climate models predict that heat waves will occur more frequently, particularly in urban areas, where buildings and pavement absorb and retain heat.

**Confidence: High**

There is a preponderance of evidence that extreme heat days and, in turn, heat waves will increase by the 2050s. While the extent to which heat waves will affect health and the economy depends, in part, on adaptive measures, heat waves will likely have profound negative impacts on B.C. by mid-century.

### *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **3.6** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (5+5+5+3+2+4+3+2)/8

Overall Consequence = 3.6

## HEALTH

*Loss of life: 5*

In Canada, extreme heat events are the leading weather-related cause of death. During past extreme heat events in B.C., over 100 excess mortalities occurred. Since the frequency and severity of heat waves in B.C. will likely be higher than historical events, more than 100 mortalities could occur again in British Columbia.

Supporting evidence includes:

- Extreme heat is a leading cause of illness and death from weather-related hazards in Canada (McLean et al., 2018). Heat waves exceed all other weather events in terms of the number of deaths (Stewart et al., 2017).

- There is an established relationship between temperatures and mortality. At a certain point, considered the "inflection temperature," the population experiences a spike in morbidity and mortality. Usually, the temperatures that become damaging to human health are around the 95th percentile of summer temperatures. The relationship varies widely depending on location because human health is affected by high *relative* temperatures.
- The literature agrees that extreme heat can lead to premature deaths, particularly in areas where summers are generally mild (Ostry, Ogborn, Takaro, Bassil, & Allen, 2008; Stewart et al., 2017; Sarofim et al., 2016). Examples from previous events include:
  - The 1936 heat wave resulted in the worst heat-related death toll on record in Canada, accounting for 780 deaths (Phillips D. , 2013).
  - In Chicago, the 1995 heat wave (temperatures exceeded 31.5°C for more than two days) resulted in 465 to 700 excess deaths, many of which occurred to individuals over 65 years of age (Dematte et al., 1998; Ostry, Ogborn, Takaro, Bassil, & Allen, 2008).
  - In Metro Vancouver, the 2009 heat wave[104] was linked with elevated mortality, ranging from 122 to 156 excess deaths and increased emergency room visits (Henderson & Kosatsky, 2012). Only 1% of the 398 recorded deaths were formally attributed to heat but this could be due to the way cause of death was documented (Stewart et al., 2017).
    - From July 27 to August 2, 2015, there were 398 non-accidental deaths recorded, compared to an average of 290 weekly deaths during the summer months from 2001 to 2009 (Stewart et al., 2017).
    - For eight consecutive days (July 27 to August 3), temperatures at Vancouver airport measured as high as 34.4°C (Kosatsky T. , 2010). During this period, the Fraser and Vancouver Coastal Health Authorities registered 455 deaths compared to 321 during the same period from 2004 to 2008 (Kosatsky T. , 2010).
  - In B.C., the highest relative mortality experienced due to extreme heat occurs in the North, where hot days are rare. However, in the Dry Plateau where summers are consistently hot, people are better-adapted to heat. Based on observed data, the highest number of mortalities were seen in the Coastal area where there is a denser population and little access to air conditioning (Henderson, Wan, & Kosatsky, 2013).
  - Stewart et al. (2017) reports that 18 deaths during the 2015 extreme heat event were attributed to self-harm or accidental overdoses, which was significantly higher than expected. This also demonstrates the potential for negative mental health outcomes due to extreme heat.
- Heat waves have a disproportionate impact on mortality for vulnerable populations, particularly the elderly, very young, those with pre-existing conditions, and those with disabilities (Stewart et al., 2017; Health Canada, 2012). Examples include:
  - Excess deaths from heat waves are largely confined to the elderly (those older than 64) (Stewart et al., 2017). The elderly may have physiological impairments, including reduced cognitive ability and mobility, reduced thirst sensation, low fitness levels, as well as susceptibility to dehydration, that make them more susceptible to extreme heat (Stewart et al., 2017). During the 2009 heat wave in Vancouver, persons aged 65 to 74 were 47% more likely to die than those older than 85, with more deaths occurring in homes than in hospitals and institutions (Kosatsky, Henderson, &

[104] Two-day average maximum temperatures reached >31°C at Vancouver International Airport (coastal) and >36°C at Abbotsford International Airport (inland). Nighttime temperatures and humidity were also high with minimum temperatures on July 30 being greater than 24°C at both locations. Such temperatures are unusual for this region.

Pollock, 2012). This may suggest that this relationship occurred because more individuals of advanced age lived in facilities with air conditioning or were protected from the heat in other ways. In some parts of B.C., there are efforts to move people out of hospitals and long-term care facilities into homes, which could inadvertently increase the vulnerability of certain groups (Workshop feedback, 2019).

- Risk of death is higher for those with known medical conditions or for those who are confined to bed, living alone, and/or living on the top floor of a building (Semenza et al., 1996). Individuals with lung or heart conditions, weakened immune systems, kidney disease, and those who are pregnant, or overweight are also more vulnerable during heat waves (Stewart et al., 2017).
- Certain medications, including diuretics, high blood pressure medication, antidepressants, antipsychotics, and illicit substances such as alcohol and cocaine can exacerbate vulnerability to heat (Stewart et al., 2017; Auger, Bilodeau-Bertrand, Emmanuelle Labesse, & Kosatsky, 2017; Misset et al., 2006).
- Daily maximum temperatures above 29°C increase the likelihood of sudden infant death syndrome (SIDS) (Stewart et al., 2017; Auger, Fraser, Smargiassi, & Kosatsky, 2015).

- Individuals of lower socioeconomic standing, marginalized ethnicities, or certain types of jobs may be more vulnerable to death during a heat wave. For example:

- People working outdoors, the socially isolated and economically disadvantaged, those with chronic illnesses, as well as communities of colour, are especially vulnerable to heat-related death or illness (Sarofim et al., 2016; Stewart et al., 2017).
- Disadvantaged populations without access to resources, such as air conditioning, cooling refuges, swimming, or transportation are at a greater risk of mortality (Stewart et al., 2017).

- Location can also influence vulnerability to heat waves. The impact of heat is magnified in urban areas due to the heat island effect, which can make urban temperatures as much as 11°C warmer than the surrounding area (Ostry, Ogborn, Takaro, Bassil, & Allen, 2008). The impact of the urban heat island effect is magnified in the very young and the elderly, particularly those living in poverty (Ostry, Ogborn, Takaro, Bassil, & Allen, 2008). There is also a correlation between population density and risk of mortality during heat waves (Stewart et al., 2017).

**Confidence: High**

There are multiple sources of evidence with widespread agreement that heat waves can contribute to excess mortality for greater than 100 people. There is some difficulty accounting for the actual number of deaths due to historical events because medical records do not indicate the conditions at the time of the event, which means related deaths may not be attributed to extreme heat. In addition, there are other factors that influence the risk of mortality, including changes in population density or demographics, and compounding factors related to other diseases that can be exacerbated by heat. Despite these knowledge gaps, the literature and expert reviewers agree that there is a catastrophic level risk of mortality due to heat waves.

*Morbidity, injury, disease, or hospitalization: 5*

Heat waves can contribute to a range of medical conditions beyond fatalities when people are unable to maintain acceptable body temperatures. Impacts range from heavy sweating and dehydration to heat stroke and chronic cardiac disease. Particularly acute negative health outcomes could occur for vulnerable populations, including the elderly, infants, socioeconomically disadvantaged, pregnant women, people experiencing homelessness, and those with preexisting conditions. Given that heat waves could occur over large areas (including in urban areas), it is likely that over 1,000 people could be affected by some type of heat-related illness, although the severity of impact will vary.

Supporting evidence includes:

- Extreme heat can result in a variety of health disorders, including:
  - Increased hospital admissions for cardiovascular, kidney, and respiratory disorders (Sarofim et al., 2016). For example, the Chicago 1995 heat wave contributed to 3,300 excess emergency room visits (Chicago's population in 1995 was around 3 million).
  - Increased premature mortality and morbidity due directly to heat-related illnesses (heat stroke, heat syncope, heat edema, etc.) and a range of cardiovascular, respiratory, kidney and other illnesses (Takaro & Henderson, 2015).
  - Increased risk of respiratory and cardiac issues due to reduced air quality from increased atmospheric ozone and particulate matter (Stewart et al., 2017; Health Canada, 2012; Ostry, Ogborn, Takaro, Bassil, & Allen, 2008). Respiratory illnesses among the elderly have commonly been reported during extreme heat events (Sarofim et al., 2016).
  - Heat cramps, heat exhaustion, heat stroke, hyperthermia, and other illnesses resulting from reduced ability to regulate body temperature (Stewart et al., 2017).
    - Symptoms of heat-related illnesses can range from mild to severe, including: pale skin, heavy sweating, intense thirst, muscle cramps, heat rash, swelling, exhaustion, loss of consciousness, dizziness, headaches, nausea and/or vomiting, fever, confusion, decreased mental alertness, hallucinations, seizures, and unconsciousness/coma (Health Canada, 2012; Stewart et al., 2017; B.C. CDC, 2017).
    - Heat stroke occurs when body temperature rises above 40°C and can result in negative impacts to the central nervous system, such as delirium, convulsions, and even comas. If untreated, heat stroke can result in multi-organ dysfunction and failure that leads to death (Stewart et al., 2017). Multi-organ dysfunction with neurologic impairment, renal insufficiency, intravascular coagulation, and acute respiratory disease were all documented during the 1995 Chicago heat wave (Dematte et al., 1998).
- Some populations are at higher risk during heat waves and could experience more severe health complications. For example (Health Canada, 2012; Stewart et al., 2017; Takaro & Henderson, 2015; Kenny, Yardley, Brown, Sigal, & Jay, 2010):
  - People with pre-existing respiratory disease, such as asthma, chronic obstructive pulmonary disease, lung cancer, influenza, pneumonia, bronchitis, tuberculosis, and cystic fibrosis may be more vulnerable to heat exposure.
  - The elderly (older than 65 years of age) may have physiological impairments, including reduced cognitive ability and mobility, reduced thirst sensation, low fitness levels, as well as susceptibility to dehydration, that make them more susceptible to extreme heat. During heat waves, most morbidity and mortality is experienced by elderly persons, even in typically moderate climates like Vancouver.
  - Pregnant women are susceptible to high ambient temperatures and heat waves because their ability to regulate internal body temperature is compromised.
  - Infants could experience low birth weight.
  - Individuals experiencing homelessness are more exposed to extreme heat events.

- People of low socioeconomic status are less likely to be able to follow adaptive procedures to protect themselves from heat-related illnesses or may have jobs that require them to be exposed to high temperatures.
- People who are socially isolated may not receive proper directions to handle extreme heat or be able to access care.
- People with mobility restrictions or mental impairments may not take necessary precautions or be able to avoid heat waves.
- People taking certain medications or under the influence of drugs and alcohol may have a compromised ability to regulate internal temperatures, making them more susceptible to heat-related illnesses.
- Individuals who work outside, such as construction workers, farmers, and those engaging in strenuous physical activity, are at greater risk from extreme heat.

- Urban populations are particularly vulnerable because of the heat island effect, which results in magnified temperatures above those of the surrounding area (Kuehn & McCormick, 2017; Ostry, Ogborn, Takaro, Bassil, & Allen, 2008).
- Additional health complications may occur in the days after the heat wave that may not be captured as heat-related complications. For those that survive the heat wave, their health could be compromised in the long term (Workshop feedback, 2019).

**Confidence: High**

There are multiple sources of high-quality evidence indicating the varied health risks of extreme heat. It can be difficult to attribute illnesses to extreme heat, but it is a clear contributing or exacerbating factor to a myriad of illnesses. While the full extent of emergency room visits and increased morbidity is not available for B.C., a heat wave could reasonably result in negative health consequences for over 1,000 people. Expert reviewers agree that the health impacts can be catastrophic.

## SOCIAL FUNCTIONING

### *Psychological impacts: 5*

Extreme heat waves can trigger or exacerbate mental, behavioural, and cognitive disorders ranging from negative feelings of exhaustion or stress to suicide. Psychological impacts would likely be more severe for those with underlying mental health issues or for those experiencing other life stressors (e.g., low socioeconomic status, minority ethnic status, age). Thus, a heat wave is expected to cause widespread and severe psychological impacts. Many people could also experience indirect effects due to loss of livelihood, electricity service disruptions, or distress due to concern for family members experiencing negative health outcomes due to extreme heat.

Supporting evidence incudes:

- The key determining factors for post-disaster mental health issues are the degree and severity of exposure as well as post-disaster life stressors and level of social support. Common psychopathologies that manifest after disasters include post-traumatic stress disorder, major depressive disorder, substance abuse disorder, general anxiety disorder, and prolonged grief disorder. Key risk factors that may increase vulnerability to disasters include age, low socioeconomic status, minority ethnic status, and previous mental health issues (Goldmann & Galea, 2014).

- People coping with mental illness can be particularly sensitive to heat exposure, such as heat exhaustion and heat stroke. Medications like anti-depressants can impede the body's ability to regulate temperature, increasing risk of heat-related morbidity or mortality, particularly for older adults (Martin-Latry et al., 2007). The use of antipsychotics, antidepressants, diuretics, and illicit substances can interfere with natural temperature regulation, making people more susceptible to heat waves (McLean et al., 2018).
- Mental, behavioural, and cognitive disorders can be triggered or exacerbated by heat waves, including dementia, mood disorders, neurosis and stress, and substance abuse. For example:
  - In Toronto, a study found that mean daily temperatures above 28°C were associated with increased emergency room visits for mental and behavioural disorders, such as schizophrenia and mood disorders (Wang, Lavigne, Ouellette-kuntz, & Chen, 2014).
  - One study in Australia found that hospital admissions for mental and behavioural disorders increased by 7.3% during heat waves above 80°F (around 27°C) for illnesses such as dementia, mood disorders, neurotic, stress-related, and somatoform disorders, and senility (Sarofim et al., 2016).
  - Mortalities attributed to mental and behavioural disorders increased during heat waves for individuals between 65 and 74 years of age for persons with schizophrenia, schizotypal, and delusional disorders. Dementia deaths increased for those over 65 years of age (Hansen et al., 2008).
  - In Australia, extreme heat events contributed to deterioration in mental wellbeing equivalent to the negative association between unemployment and mental wellbeing. The cumulative effects of heat remained significant for up to three months after an event. In addition, women were more vulnerable to overall heat impacts than men (Ding, Berry, & O'Brien, 2015).
  - In the U.S., a study found that temperatures above 21°C correlated with reduced wellbeing, with people reporting fewer positive emotions and increased negative ones, like stress and anger, and increased fatigue (Noelke et al., 2016).
- Although the relationship is not fully understood, one systematic review found strong evidence that the risk of suicide increased with heat and that there were greater numbers of mental health-related hospital admissions at higher temperatures (Thompson, Hornigold, Page, & Waite, 2018).
- Heat waves result in indirect impacts as well. For example, the subsequent impacts of a heat wave-induced brownout on individuals with limited resources (e.g., not having the resources to replace spoiled food) may cause additional stress and anxiety. A heat wave could also negatively affect people's livelihoods by inducing heat stress on livestock or crops, further increasing stress and anxiety after the initial event. In addition, family members of those who become sick or deceased, as well as marginalized groups, could experience negative mental health impacts (Workshop feedback, 2019).

**Confidence: High**

There are many reported and studied correlations between extreme heat and psychological disorders, although reports are not available for British Columbia. It is also unclear how long these impacts persist after a heat wave. Expert reviewers unanimously agreed that psychological impacts from a heat wave can be widespread and severe.

*Loss of social cohesion: 3*

A three or more days-long heat wave could cause many disruptions to daily life (e.g., limited outdoor exposure, school cancellations, traveling to a cooling centre, checking in on neighbours). On the more extreme end, heat waves can exacerbate marginalization for racial and ethnic minorities, those who are socially isolated, homeless persons, etc. In addition, many studies indicate that the rate of violent crime increases during heat events. These incidents have the potential to erode public trust and disrupt community cohesion for the duration of the event.

Supporting evidence includes:

- Disruptions to daily life during the duration of a heat wave include (Workshop feedback, 2019):

- Limited outdoor exposure
- School cancellations, which could also mean finding last minute daycare service
- Traveling to a cooling centre or finding alternative ways to keep cool
- Checking in on neighbours
- Changes in behaviour due to disruptions in electricity supply

- Heat waves could exacerbate marginalization. As mentioned in the previous sections, extreme heat events have disproportionate impacts on vulnerable and marginalized populations, including the elderly, infants, socioeconomically disadvantaged, people experiencing homelessness, etc. which could exacerbate social tensions and social inequity (Stewart et al., 2017; Sarofim et al., 2016). Race, ethnicity, and socioeconomic status affect vulnerability, which could contribute to a higher risk of comorbidities and disparities in access to air conditioning, land cover characteristics, or environmental justice issues (Sarofim et al., 2016).
- Heat waves could also exacerbate social isolation for individuals who remain indoors and forgo visiting friends and family or avoid participating in organized social outings during the heat wave (Stewart et al., 2017).
- Many studies indicate that uncomfortably high temperatures increase aggressive and violent behaviour, coined the "heat hypothesis." Thus, an extreme heat wave could contribute to a higher incidence of violent crimes such as rape, murder, riots, and assaults (Stewart et al., 2017; Sarofim et al., 2016).
- Heat waves affect urban and rural areas differently, due to socioeconomic and health disparities. Studies indicate that those living in rural areas tend to be worse off during heat waves because they are generally poorer, less educated, and have greater rates of unemployment (Ostry, Ogborn, Bassil, Takaro, & Allen, 2010). In addition, cooling centres and other emergency services needed during an event are more likely to be centred in urban locations. Thus, heat waves could exacerbate urban-rural tensions (Workshop feedback, 2019).

**Confidence: High**

The literature suggests that extreme heat can have negative implications for social cohesion due to disproportionate impacts on already marginalized groups, heightened aggressive and violent behaviour, and urban-rural tensions related to inequalities in access to resources. Expert reviewers agree that these disruptions to social cohesion would likely persist throughout the length of the heat wave.

### NATURAL RESOURCES: 2

A heat wave could stress wildlife and ecosystems that are not accustomed to extreme temperatures. In general, long periods of above average temperature could result in damages to ecological systems, such as heat-stress to aquatic ecosystems and susceptibility of forests to wildfire and insect outbreaks. However, a three-day event would likely result in minor damages and resources could recover quickly. Extreme temperatures occurring simultaneously with water shortages or contributing to wildfire could result in much greater compounding damages.

Supporting evidence includes:

- In a warmer climate, diverse insects could move to higher latitudes and altitudes. These pests could feed on forest or animal hosts. For example:
  - Heat accumulation could accelerate the lifecycle of the spruce beetle to just one year, which could increase the population size and contribute to more intensive outbreaks (Woods, Heppner, Kope, Burleigh, & Maclauchlan, 2010).
- Trees exposed to extreme temperatures, particularly when paired with drought, can become more susceptible to disease, insect outbreaks, and wildfire.
- Wildlife, including birds and bats, may suffer during a heat wave. High temperatures can lead to dehydration or heat stress for animals, particularly young animals (Wildlife Rescue association, 2017). Amphibians may also be at risk, particularly if water sources are compromised (Amphibian and Reptile Conservation, 2019).
- As air temperatures increase, particularly for extended periods of time, water temperatures also increase (Isaak, Wollrab, Horan, & Chandler, 2012). One study shows that water temperatures increase by about 0.6 to 0.8°C for every 1°C increase in air temperature (Morrill, Bales, & Conklin, 2001), although temperatures can be influenced by a variety of factors such as shading or glacier runoff. Warmer water temperatures can be damaging to aquatic species health, particularly salmon (Mote et al., 2003; White, Wolf, Anslow, Werner, & Creative, 2016; Fisheries and Oceans Canada, 2018). For example:
  - Several salmon species return to spawn each year during the summer when water temperatures warm most rapidly. If a heat wave affects water temperatures, the migrations could be disrupted as fish seek colder water. "Thermal events" have been documented where hundreds or thousands of adult salmon die because their heat tolerance is exceeded (Isaak, Wollrab, Horan, & Chandler, 2012).
  - Damage to salmon populations can have larger ecological repercussions, as they are vital to the food chain. Around 137 species rely on salmon, including bald eagles and bears (PSF, 2011; White, Wolf, Anslow, Werner, & Creative, 2016).

**Confidence: Medium**

There are several sources of evidence pointing to the detrimental impacts of extreme heat on wildlife and aquatic species. However, there could be additional impacts not documented here and the length of time taken to recovery is not described. In general, many of the consequences of high heat would result from a prolonged period of above-average temperatures and may not occur due to a short event. Considering a trend toward warmer temperatures, expert reviewers anticipate that recovery time could be even longer for some natural resources because resources may not be able to recover from a single heat event.

## ECONOMIC VITALITY

### *Loss of economic productivity: 4*

During a heat wave, major losses occur due to reduced agricultural productivity, heat stress to livestock, damage to fish populations, reduced labour productivity, and increased cost of electricity. For example, the 2009 heat wave contributed to costs exceeding $120 million. By the 2050s, the potential direct and indirect economic losses of a heat wave in B.C. could contribute to economic losses of well over $100 million.

Supporting evidence includes:

- Total cost of the 2009 heat wave was estimated at $120 million, which includes an estimated $50 million loss in output (daily GDP losses of around 5%), in addition to health and electricity costs of $66 million and $4 million, respectively (Stewart et al., 2017).
- Extreme heat can reduce agricultural and livestock productivity, with resulting economic losses. However, in most production systems, this heat wave scenario would likely result in losses within normal production loss levels. For example:
  - Loss of yield and agricultural productivity. Crop yields could decline due to heat stress (Kulshreshtha & Wheaton, 2013). For example:
    - Higher temperatures earlier in the season can affect germination and establishment for some vegetables. Conversely, high temperatures could cause berries to ripen too quickly, creating pressure to harvest quickly.
    - In 2012, the heat wave in Ontario caused fruit trees to blossom five weeks earlier than usual and a subsequent frost destroyed the blossoms, resulting in estimated losses of $100 million to the fruit industry (Warren & Lemmen, 2014).
    - For some commodities, such as mushrooms, high temperatures would increase the costs for climate control (Fraser Valley Regional District, 2017).
    - Some plants experience physiological stress at temperatures above 30°C. During a heat wave, plants may suffer from heat stress and sun scalding (Metro Vancouver, 2016).
  - Heat stress for livestock and poultry may reduce animal welfare. Livestock and dairy can be affected by extreme heat more than an increase in average temperatures (Walthall et al., 2013). Extreme heat can stress cattle, reducing animal appetite, reducing weight gain, causing heat-related illnesses, and even leading to mortality (Cattlemen B.C.). Dry heat waves can decrease animal weight gain, reduce milk production, and reduce reproductive success, whereas warm and wet conditions can result in more pests and diseases, such as ticks, mosquitoes, parasites, and bacteria. Ranchers will need to implement additional air conditioning and cooling adaptations to protect animals (Warren & Lemmen, 2014; Campbell, Durant, Hyatt, & Hunter, 2014). Extreme heat can be hazardous to poultry, reducing productivity and heat-related illnesses (B.C. Ministry of Agriculture, 2016).
  - Change in pests/diseases. Warmer temperatures could increase the threat to crops and livestock from more pests and diseases (Scholefield, Dessureault, Ibarra, & Meberg, 2017).
  - Losses to seafood supply due to stress on aquatic species and commercial fish stocks. In a representative year, commercial salmon fishing in B.C. can bring in $30 million in value and $100

million in post processing value. Higher water temperatures during a heat wave could lead to losses in the fisheries industry, as discussed in the natural resources section.
- Water contamination due to increased water temperature, which promotes the growth of blue-green algae that makes the water toxic for cattle (Boon, 2019).
- Reduced worker productivity. During a heat wave, workers may experience fatigue, dehydration, and heat-related illnesses or injury that reduce productivity (Spector et al., 2016). Workers may require more frequent breaks or adjusted working hours.
- Increased energy consumption or costs for cooling/ventilation for livestock, storage, transportation, etc. (Walthall et al., 2013).

- In 2016, B.C.'s forest industry generated $32.96 billion in output and contributed $12.94 billion to the province's GDP. Forestry and logging accounted for around 28% of the industry's contribution (PwC, 2017). The timber industry could experience losses due to large die-off of forests. As discussed in the natural resources section, extreme temperatures make trees more susceptible to damages due to pests and wildfire.
- Outdoor workers, including agricultural workers, construction workers, mining workers, and electricity and pipeline utility workers will be more exposed to heat stress. Risks include:

- Heightened risk of heat-related illnesses.
- Reduced worker productivity through lower cognitive and physical performance (Costa, Floater, Hooyberghs, Verbeke, & De Ridder, 2017).
- Dehydration and need for more frequent breaks. Work could be suspended if heat becomes severe (Sarofim et al., 2016).
- Lost productivity, labour hours, and wages that will poorly affect the economy.

- Increased costs for electricity during heat waves due to higher demand from the use of fans and air conditioning. B.C.'s electricity needs are projected to increase by 20 to 40% over the next 20 years due to industrial activity, general economic growth, and electrification. This change could increase reliance on non-hydro generation, which has a higher marginal cost (Stewart et al., 2017). For example:

- During the 2009 heat wave, electricity consumption increased during the event as more people used air conditioning. The estimated output due to the heat wave was 48 million kW. Using the current average cost of electricity ($0.09 per kWh), additional power would cost about $4.3 million (Stewart et al., 2017).

- Reduced visitors to outdoor attractions due to a heat wave could reduce revenue for tourist destinations, parks, and other outdoor attractions.
- Loss of life also has an economic impact. The loss of life of over 100 people can be valued at $520 million, based on the number of lives projected to be lost (Treasury Board of Canada Secretariat 2007).[105,106]

**Confidence: High**

Ample literature indicates that extreme heat can cause losses to a variety of economic sectors, particularly natural resource-based industries. This rating does not account for the full range of

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[105] Value in 1996 CAD.
[106] The Treasury Board of Canada Secretariat expects departments to use a VSL of $5.2 million adjusted for inflation since 1996.

disruptions B.C. could experience and is likely a conservative estimate of the full economic consequences. Expert reviewers agree that economic losses could be well over $100 million.

*Loss of infrastructure services: 3*

Due to a severe heat wave, infrastructure services such as electricity and transportation could be disrupted for multiple days, impeding day-to-day activities. For example, extreme heat reduces the capacity of power plants to produce energy, reduces transmission efficiency, and increases demand for electricity, all of which can increase the likelihood of power outages. Loss of infrastructure services during a heat wave could have significant implications for human health and the economy that could last several days.

Supporting evidence includes:

- Higher demand for electricity for fans, air conditioners, and increased refrigeration needs increases the strain on the electric grid and can result in power outages (Sarofim et al., 2016). Higher temperatures also reduce the efficiency of electrical transmission (Stewart et al., 2017). Blackouts, particularly during a heat wave, can have extensive implications for human health and the economy, producing compounding losses. For example, people would not have access to air conditioning in their homes and cooling centres would no longer be effective (Adler, Harris, Krey, Plocinski, & Rebecchi, 2010).
  - The use of air conditioning in B.C. has more than tripled from 10% in 2001 to 34% in 2017 (B.C. Hydro, 2018).
  - B.C. Hydro broke the record for summer power consumption in 2018, with peak hourly demand of 7,800 MW. The heat wave increased electricity demand (B.C. Hydro, 2018). If combined with drought, increased peak energy demand could stress the system, as low flow conditions would limit energy production capacity.
- Thermo-electric power plants require additional water for cooling the plant. During summer heat waves, low flow and higher water temperatures can put pressure on plants to remain cool and may require operational changes (Warren & Lemmen, 2014). Heat waves, and corresponding droughts, could force power plants to reduce operations or shut down, which could result in losses to other industries (U.S. Department of Energy, 2012).
- Heat waves can damage transportation infrastructure, such as pavement rutting and cracking, increased maintenance costs, and increased risk of accidents. Railroad tracks may expand or buckle, increasing the risk of train derailments, slow orders, or cargo damages (Stewart et al., 2017; Andrey, Kertland, & Warren, 2014).
- Climate-related disasters can disrupt supply chains and affect food prices (Ostry, Miewald, & Beveridge, 2011).

**Confidence: Medium**

There are several sources of evidence demonstrating the range of negative impacts of heat waves on electricity production and transmission, and transportation systems. This rating does not account for the full range of disruptions B.C. could experience. Depending on the severity of the heat wave and time to recover, the disruption to infrastructure services could be more severe. Evidence indicates that the disruptions could last several days.

## COST TO PROVINCIAL GOVERNMENT: 2

The Government of British Columbia would incur additional costs for emergency management and response, healthcare, and short-term reductions in tax revenue due to a heat wave. The productivity of city maintenance and operations could decrease, and the government may need to shift schedules or provide more frequent breaks to workers. There could also be costs related to public education to reduce the public health risk associated with extreme heat. Although the cost has not been quantified in B.C., added costs are expected to be on the order of $375 million or less.

Supporting evidence includes:

- Before and during a heat wave, the Government of B.C. will face additional costs, including (Workshop feedback, 2019):
  - Public education about how to prepare and protect health during extreme heat events
  - Emergency management and response, such as setting up cooling stations
  - Healthcare associated with heat-related illnesses and mental health
  - Reduced productivity of government staff, and slower city maintenance
  - Higher operational budgets for buildings
  - Reductions in short-term tax revenue
  - Protecting wildlife and sensitive habitats through actions such as releasing reservoir storage to manage stream temperatures
- The provincial government would likely be responsible for some portion of health care costs, although the project team could not determine the exact cost share between the federal and provincial government for the following estimates:
  - Although the negative health outcomes of a heat wave will vary, some people may be hospitalized. According to the Canadian Institute for Health Information, the cost of a standard hospital stay in B.C. is on average $6,135.[107] Although not all cases of morbidity, injury, or disease are likely to result in hospitalization, the estimated costs could be greater than $6,135,000. Some portion of this cost would be covered by the provincial government.
  - An estimated 30 to 60% of affected populations will need some form of mental health-related assistance following a disaster (NIST, 2017). Rates for severe, moderate, and mild mental illness can range between 6 to 26% up to 30 months following a disaster (FEMA, 2012). Treatment costs for these mental illness cases are estimated at (FEMA, 2012):
    - 12 months post disaster: US$822 per person
    - 18 months post disaster: US$639 per person
    - 24 months post disaster: US$567 per person
    - 30 months post disaster: US$414 per person
- The project team was unable to precisely estimate the agriculture-related business risk management program costs for this scenario. However, for AgriStability to respond, losses at the individual farm level would have to exceed a 30% margin decline for the whole farm. However, there is no historical precedent of significant increases in claims resulting from heat waves, and losses would likely remain under deductible levels (Agriculture and Agri-Food Canada, 2018).

[107] The value is in 2017 CAD. This measure divides a hospital's total inpatient expenses by the number of hospitalizations it sees in a year. The number is adjusted for some differences in the types of patients a hospital sees to make it more comparable with other hospitals.

- Examples from other cities also provide a benchmark for possible costs to government. Estimated yearly costs of climate change to the City of Philadelphia, Pennsylvania (which is a little over twice the size of Vancouver), included increased maintenance costs and costs of providing services. For example (Philadelphia Mayor's Office of Sustainability and ICF International, 2015):
  - Increased annual electricity costs of US$1 million for additional air conditioning demand.
  - Increased roadway maintenance costs from rutting and cracking due to high temperatures, estimated at US$2 to $4 million.
  - Double or triple the annual cost, currently around US$20,000, to run Heatline, a helpline service to help during heat emergencies.
  - Increased cost for water treatment when warmer temperatures increase algae, which can change the colour, taste, or odour of drinking water.
- If the event is declared a large-scale natural disaster that triggers DFAA, some portion of the cost could be covered by the federal government (Public Safety Canada, 2019).

**Confidence: Low**

There is no evidence available on the costs to government from historical heat events. Based on the types of costs that the government could incur and comparisons to other cities, the costs of a heat wave are expected to be moderate. The costs of heat waves have not been quantified for B.C. and this estimate is based on expert judgment and the consequences across other consequence categories. In addition, it is unknown whether a long-term water shortage would qualify for DFAA, in which case the federal government could provide significant financial assistance.

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# Severe Wildfire Season

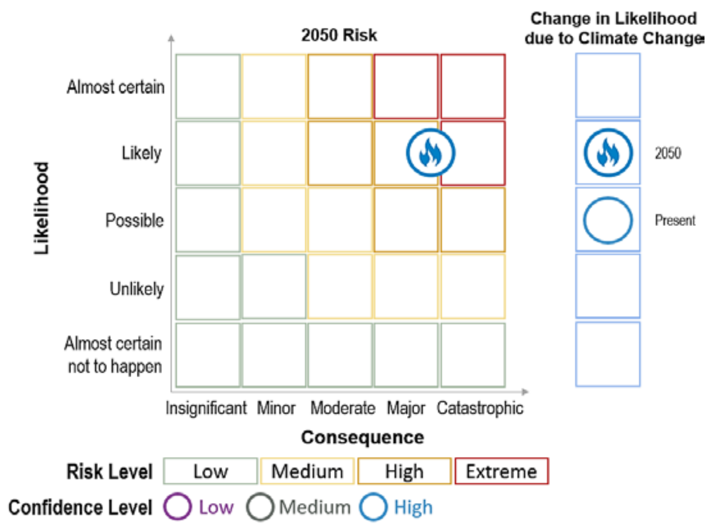
## Scenario

The specific risk event scenario analyzed is a severe wildfire season that burns at least one million hectares and affects human settlements and significant infrastructure (e.g., occurs in the Wildland Urban Interface or Industry/Critical Infrastructure Interface). In B.C., humans and lightning cause the majority of wildfire starts. However, climate factors such as higher temperatures and drought contribute to conducive conditions for large and prolonged fire seasons. Other key contributors to severe wildfire include the amount of fuel, fuel load, fuel distribution, and fuel moisture.

## Summary of Findings

The 2017 and the 2018 wildfire seasons set new records for area burned in B.C., becoming the first fires to burn over one million hectares since 1950. These events produced significant consequences across the province. With projected increases in temperature and decreases in summer precipitation, in addition to an abundance of dry fuel, conditions in some areas could be more conducive for severe wildfires in the future. Annual area burned is projected to increase by up to 4% by 2050, exceeding 9 million hectares across Canada. As this trend continues through the end of the century, B.C. could experience extreme wildfires more frequently.

**FIGURE 65.** Risk assessment findings for severe wildfire season scenario.




The consequences of wildfires for the provincial government are greater when they occur in the Wildland Urban Interface (WUI) because human settlements are more likely to be affected. Severe wildfires could contribute to negative health outcomes for residents across the province, due to direct exposure to smoke, particulate matter, and other hazardous substances (e.g., polycyclic aromatic hydrocarbons, volatile organic compounds). The results can be particularly dangerous for pregnant women, infants, and those with pre-existing health conditions. Displacement due to wildfires, along with loss of possessions and livelihoods, could contribute to extreme psychological distress and long-term impacts to health as well as economic losses to individual citizens.

Additionally, severe wildfires may disrupt operations and damage infrastructure across multiple industries, including tourism, timber, mining, and agriculture, resulting in economic losses. Wildfires may disrupt infrastructure systems such as transportation, electricity supply, telecommunications, water treatment, and sewage systems.

**FIGURE 65** and **TABLE 31** summarize the risk assessment results for this scenario. The highest consequences relate to morbidity, injury, disease, and hospitalization; psychological impacts; loss of social cohesion; and loss of economic productivity. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 31.** Risk Rating Evaluation for Severe Wildfire Season Scenario

| **SEVERE WILDFIRE SEASON: AT LEAST ONE MILLION HECTARES BURNED THAT AFFECT HUMAN SETTLEMENTS** | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **3** | This scenario currently has a 50-year recurrence interval. | **4** | **Climate-related risk cause:** Higher temperatures and low precipitation.<br>**2050 projections:** Projected changes in precipitation and temperature may create conditions more conducive for wildfires, increasing the likelihood to a 10 to 50% chance of annual occurrence. | High |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **4** | Ten to 100 possible mortalities due to direct and indirect effects of wildfire and associated smoke, and limited emergency and medical care. | Medium |
| | Morbidity, injury, disease, or hospitalization | **5** | Over 1,000 people could experience health effects due to smoke inhalation, air pollution, and limited access to critical infrastructure and services. | High |
| **Social functioning** | Psychological impacts | **5** | Uncertainty regarding evacuations and the spread of the fire can cause fear and anxiety, while people that lose their homes, loved ones, or ways of life could experience long-term psychological impacts. | High |
| | Loss of social cohesion | **5** | Tens of thousands of people could experience disruptions to daily life that last for months to years. Populations dependent on agriculture or forestry could lose their livelihoods. | High |
| **Natural resources** | Loss of natural resources | **4** | Forests and forest ecosystems could be damaged, displacing wildlife and transforming landscapes. Ash and debris may degrade water quality and cause damage to aquatic habitats. | High |
| **Economic vitality** | Loss of economic productivity | **5** | Economic losses could surpass $1 billion and result in long-term disruptions. Valuable ecosystem services could be lost. | High |
| | Loss of infrastructure services | **4** | Wildfire could disrupt transportation, electricity supply, telecommunications, and water treatment and sewage systems for weeks or months. | Medium |
| **Cost to provincial government** | | **4** | Potential costs include costs for fire suppression and emergency management and response for affected communities. | Medium |
| **OVERALL RISK** | **CURRENT** | **HIGH (13.5)** | | **HIGH** |
| | **2050** | **HIGH (18.0)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **13.5** out of 25, which equates to **high risk**, and the 2050 risk rating is **18.0** out of 25, which equates to **high risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence
Present Risk = 3 x 4.5 = 13.5 (High)
2050 Risk = 4 x 4.5 = 18.0 (High)

## Evidence Base

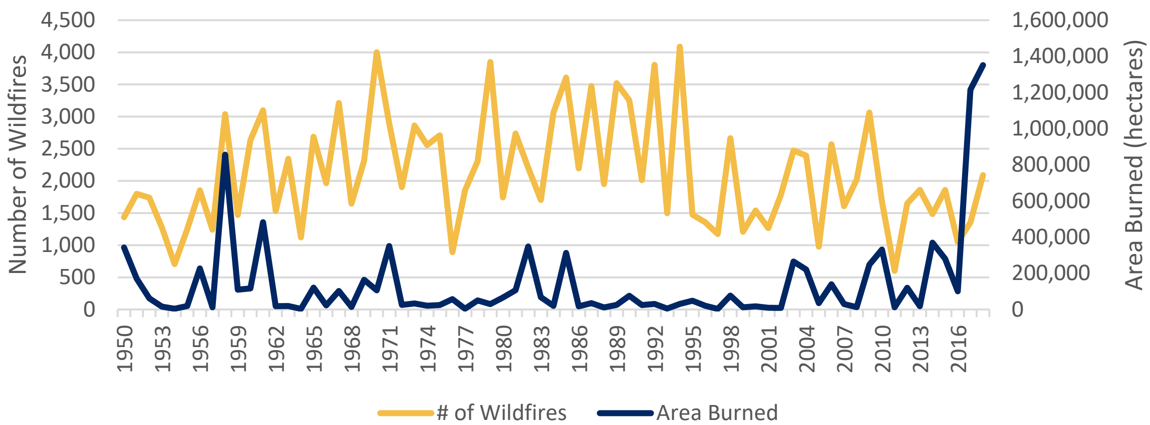
### *Risk Event Scenario*

This scenario represents one illustrative permutation of severe wildfire in British Columbia. The consequence ratings are specific to this scenario, but the types of consequences may be transferable to other related scenarios, such as more severe wildfire seasons, individual fires, or years with back-to-back severe seasons.

The specifics of this scenario were based on:

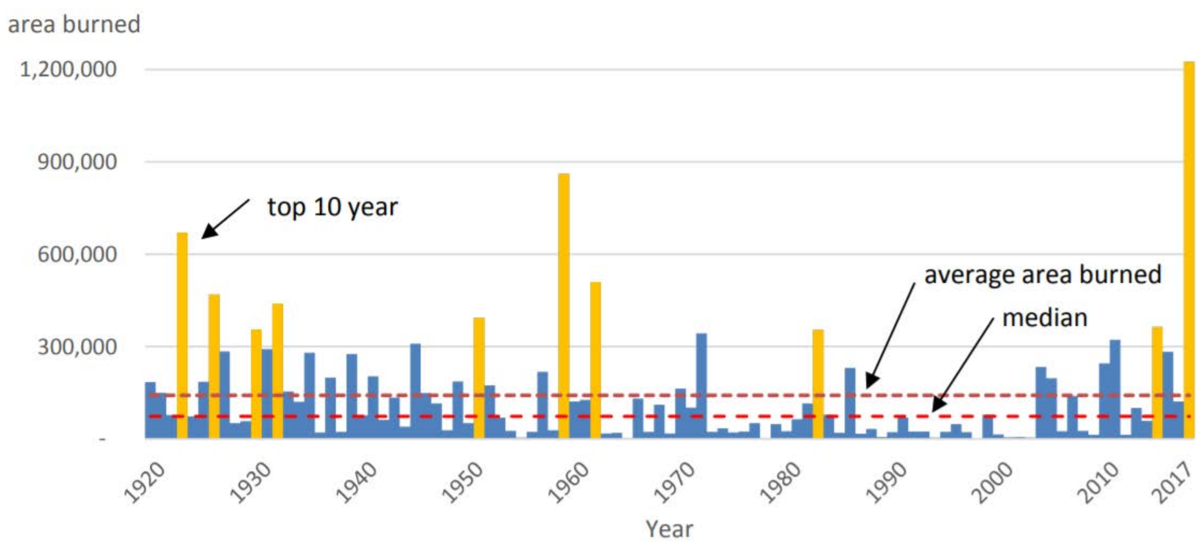
- Wildfires in western North America and B.C. have increased in severity and frequency, a trend that is expected to continue in the future due to climate change (CIER, 2008). Drought is expected to exacerbate the impacts, particularly in combination with extreme heat (Yusa et al., 2015).
- Several climate factors, including temperature, precipitation, wind, atmospheric moisture, and lightning contribute to wildfire.
- Higher temperatures and lower summer precipitation may increase fire activity by making the season longer and drier. Lower precipitation and higher temperatures will also drive a decrease in snowpack and an increase in evaporation. Overall, these conditions make fuel more flammable and increase the susceptibility of forests to wildfire (Flannigan, 2018).
- The area burned is projected to be greatest under a warm and dry scenario, although the area burned is projected to increase even if annual precipitation increases (Flannigan, 2018).
- Each year, Canada experiences more than 8,000 forest fires that together burn between 0.7 and 7.6 million hectares (Health Canada, 2008). Despite high year-to-year variability in the number of fires, the area burned does not always coincide with the number of fires (see **FIGURE 66**). Since 1960, the area burned has been relatively low (around 400,000 hectares) in comparison to the large increase in recent years (over one million hectares). Note that, in addition to representing fire activity, area burned partly reflects human suppression of wildfires and forest management techniques, which can influence wildfire fuel availability.

**FIGURE 66.** Number of wildfires and area burned in B.C. between 1950 and 2018 (B.C. Wildfire Service, 2018).




- As shown in **FIGURE 67**, 2017 was anomalous in terms of area burned. The 10 largest wildfire years in the last century account for around 40% of the total area affected (B.C. Ministry of Forests, Lands and Natural Resource Operations and Rural Development, 2018).

**FIGURE 67.** Area burned compared to long-term average (B.C. Ministry of Forests, Lands and Natural Resource Opertations and Rural Development, 2018).




- The 2017 and 2018 fire seasons, each of which burned over one million hectares of land, were provincially significant in their effects, including economic losses, health impacts, displacement of tens of thousands of people, and damage to infrastructure. If these disasters become more common, the impacts will likely result in provincially significant consequences across sectors.
- The scenario of one million hectares of burned area is unlikely to result from a single fire, but instead the confluence, or merging, of multiple fires. A similar scenario occurred during the Plateau Complex fire in 2017, when multiple fires joined to burn 545,151 hectares (Government of British Columbia, 2017b).

### *Likelihood rating*

The present-day (i.e., 2000 to 2020) likelihood of this scenario is **3** and the 2050 likelihood of this scenario is **4**. The likelihood rating is based on indicators including projections of annual area burned, wildfire frequency, and wildfire increases attributed to human-induced climate change over the historical record. To put these indicators in context, the assessment of likelihood considers projected changes in underlying climate-related causes, such as air temperatures, precipitation, and snowmelt. The assumption is that absolute magnitude changes associated with the range of indicators is indicative of likelihood increases through mid-century. Ultimately, climate change could amplify the risk of severe wildfires, and, coupled with the expected growth of the wildland-urban interface (the area where human settlements and wildland vegetation intermingle), drive increased likelihood of a catastrophic one million hectares wildfire toward mid-century. The 2017 and 2018 wildfire seasons both surpassed one million hectares burned in total, which far exceeds the 70-year average and suggests that unprecedented fire seasons may become more common.

**Likelihood Rating Drivers**

Type of risk event: Discrete

"Present day" period: 2010 to 2020

Climate change indicators:

- Projected change in annual area burned
- Winter precipitation
- Average annual temperatures

Source of 2050 projections: Varies by indicator

Emission scenario: Varies by indicator

The likelihood rating was determined based on the following findings:

- Present-day likelihood is based on recent research that found that, due to climate change that has already occurred, a wildfire season in B.C. that burns an area of 1 million hectares has approximately a 50-year return period as of 2017 (Kirchmeler-Young, 2019). The study also concluded that climate change has made wildfire-prone weather 2 to 4 time more likely from an earlier baseline of 1960 to 1970 to present-day (2010 to 2020).
- Expansion of the WUI over time would increase likelihood of fires near human settlements regardless of climate change. Climate change further exacerbates this risk through several mechanisms, including:

- Increases in wildfire fuel availability from heightened winter and spring precipitation, which promotes vegetation growth and, in turn, the amount of flammable material available to wildfires. With a projected increase in winter precipitation by around 8% by mid-century[108], fuel availability is expected to increase (Pacific Climate Impacts Consortium, 2012).
- Arid conditions and warm temperatures during the summer drive landscape desiccation and increase wildfire risk. Province-wide mean annual temperatures are expected to increase by 1.8°C and summer precipitation is expected to decrease by 1% through mid-century (Pacific Climate Impacts Consortium, 2012). As a result, wildfire-conducive conditions could become more common. Similarly, increased drought risk could amplify the amount of dry fuel load available to feed wildfires.

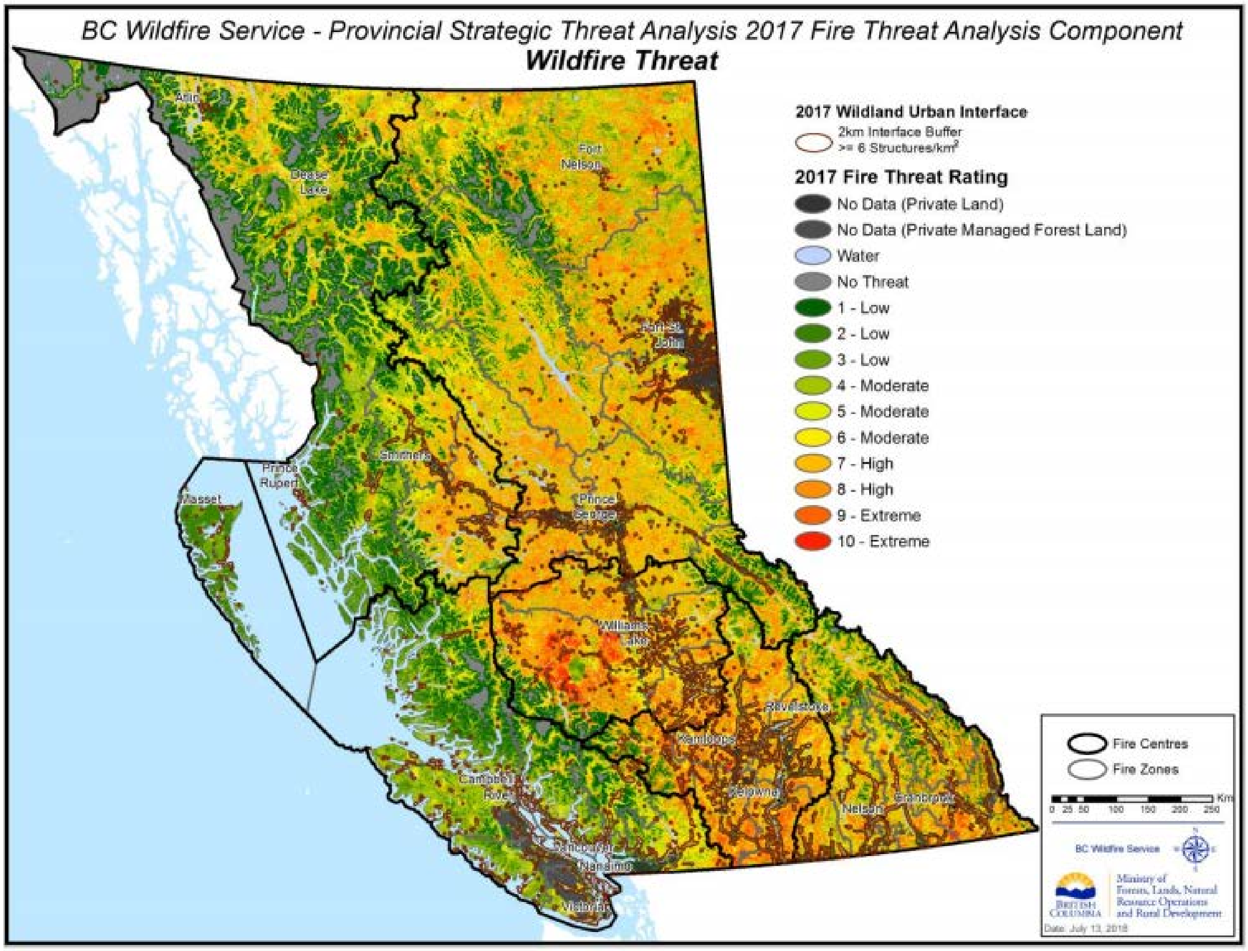
[108] Climate projections are based on ensemble medians from the Pacific Climate Impacts Consortium standard set of Global Climate Models (GCMs) relative to the baseline time period (1961 to 1990) and assume RCP8.5.

- Snowfall in the winter and spring is expected to decrease by 10% and 58%, respectively, across B.C. (Pacific Climate Impacts Consortium, 2012), which will deplete the amount of regional runoff and, in turn, amplify water shortage conditions.
- Wildfire ignition is largely dependent on lightning strikes, but also instances of human intervention. The likelihood of change in lightning or human-caused wildfires is difficult to project.

- Looking forward, annual area burned by wildfire in B.C. is expected to increase by around 4% by 2050 relative to the baseline time period between 1981 to 2010 (Natural Resources Canada, 2017). Annual area burned across Canada is projected to exceed 9 million hectares per year by 2050, increasing the area burned due to wildfire threefold (Natural Resources Canada, 2017), assuming RCP8.5.[109] Projections indicate that fires will occur most frequently in the boreal forest; however, communities within the Central Plateau region and the southern Columbia Mountains will be particularly susceptible to amplified wildfire risk through mid-century (Natural Resources Canada, 2017).
- Under RCP8.5, all provinces are projected to experience an increase in the frequency of extreme fires (area burned greater than the 90th percentile) by the end of the century. B.C. is projected to experience extreme wildfires in two out of every three years. Low fire years, which currently occur 25% of the time, are projected to occur less than 1% of the time by 2071 to 2100 (Hope, McKenney, Pedlar, Stocks, & Gauthier, 2016).
- In Western North America and Canada, wildfires are projected to become more frequent and severe due to warmer winters, increases in extreme weather, increases in frequency and severity of drought. Additionally, insect outbreaks are predicted to increase due to climate change, which increases the number of dead trees more susceptible to wildfire (CIER, 2008; Ostry, Ogborn, Takaro, Bassil, & Allen, 2008).
- In B.C., there are, on average, 2,000 wildfires each year between March and September (Natural Resources Canada, 2013). While most of the land burned is wildlands, a smaller percentage occur at the wildland-urban interface (WUI), the area where homes and other infrastructure border wildland vegetation. WUI fires result in greater damages to communities and associated infrastructure and increase the number of evacuations. Fighting interface fires is more challenging and expensive.
- B.C. has a more extensive WUI than other provinces (see **FIGURE 68**). In recent years, human development has expanded closer to forests, widening the interface at the edge of areas with highly flammable vegetation (Abbott & Chapman, 2018). B.C. estimates that about 1.107 million hectares on Crown land within two kilometres of built-up areas are at "high risk" as of 2017 (B.C. Wildfire Service, 2017). As urban areas expand, and people build more homes in wilderness areas, the WUI is expected to expand, which would result in greater damages due to wildfires because residential areas would be more exposed, resulting in more evacuations and property damages (Natural Resources Canada, 2013).

[109] A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory used by the IPCC to identify future projections. Four pathways (2.6, 4.5, 6.0, and 8.5) are used in climate modeling and research. RCP8.5 is the highest scenario, consistent with emissions continuing throughout the 21st century.

**FIGURE 68.** Wildland-Urban-Interface areas in B.C. (outlined in brown) (B.C. Wildfire Service, 2017).




**Confidence: High**

There are multiple sources of evidence supporting the projection that severe wildfires could become more likely. In addition, wildfire activity due to climate change factors can vary spatially and behave randomly. While the scenario is province-wide, forested and historically wildfire prone areas including the Interior, Central Plateau, and Rocky Mountains are more likely to experience catastrophic wildfires in the future compared to coastal locations.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **4.5** out of 5.

### Consequence Calculation

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (4+5+5+5+4+5+4+4)/8

Overall Consequence = 4.5

## HEALTH

### *Loss of life: 4*

Wildfires could result in loss of life if individuals are caught in affected areas, or indirect loss of life in the aftermath due to limited medical or emergency care or exposure to harmful smoke inhalation. Historically, the literature documents few direct deaths in B.C. due to wildfire. However, the inhalation of fine particulate matter in smoke can have severe repercussions for human health. By mid-century, loss of life due to intense wildfires could increase, particularly if fires occur closer to the wildland-urban interface. Although there is uncertainty about how this consequence could change in the future, mortality could fall in the range of 10 to 100 people during the wildfire season. More deaths may occur if emergency response does not have sufficient time or support to ensure everyone is evacuated or if evacuation routes are cut off.

Supporting evidence includes:

- In B.C., evidence indicates that few fatalities have occurred directly due to wildfire. In 2003, three pilots died while trying to put out the fires (Finlay, Moffat, Gazzard, Baker, & Murray, 2012). No deaths were attributed directly to wildfires or evacuations in 2017 (Maguet, 2018). However, the 2018 fires in California have taken the lives of around 90 people, as of November (Winsor, 2018). Fatalities could increase if wildfire intensity or severity increases, though population density is lower in B.C. than in California (which could lower the likelihood of deaths). Only eight of B.C.'s 29 regional districts have a population density of more than 10 people per $km^2$, while the density in Butte County and Paradise, California, is 51 per $km^2$ and 552.5 $km^2$, respectively (Environmental Reporting BC, 2018; U.S. Census Bureau, 2015).
- It is possible that more deaths could occur in B.C. than in wildfires historically. If people are not able to evacuate, more deaths could occur similar to those caused by structure fires. If wildfires cut off evacuation routes, additional deaths may occur. In addition, if the wildfire goes through more populated areas, such as Vancouver or Kelowna, mortality could be higher (Workshop feedback, 2019).
- Indirect deaths may occur due to health complications resulting from exposure to wildfire smoke and associated poor air quality. For example:

- The primary cause of death due to wildfires is from smoke inhalation. Wildfire smoke, which can travel over long distances, contains pollutants such as NOx, CO, and fine particulate matter (PM2.5 and PM10), as well as ozone. Exposure to these pollutants, particularly PM2.5 can exacerbate general respiratory morbidity, cardiovascular morbidity, and all-cause mortality (Maguet, 2018).
- Fine particulate matter (PM2.5) can exacerbate heart and lung disease and cause premature death, particularly among vulnerable populations, such as those with pre-existing conditions (B.C. CDC, 2018). Other complications due to exposure to hazardous chemicals and smoke inhalation can result in deaths (see the morbidity, injury, disease, or hospitalization section below).
- Globally, exposure to landscape fire smoke is responsible for around 339,000 deaths annually, primarily due to exposure to small particulate matter (Johnston et al., 2012). A study in the U.S. found that mortality attributable to wildfire-related PM2.5 is expected to increase from around 17,000 deaths per year in 2000 to around 32,000 deaths per year in 2050 (Ford et al., 2017).

- Exposure to extreme temperatures, toxic substances, and particulate matter while fighting fires could increase premature death of firefighters. A study on the causes of death of firefighters between 2000 and 2017 found that cancer made up 86% of fatality claims (50 per 100,000 firefighters); traumatic injuries accounted for 90% of time-loss claims (about 50 firefighters each year); mental health issues such as anxiety, post-traumatic stress disorder and depression were the third leading cause of time-loss claims (one in 50 firefighters); cardiovascular disease (previously the leading cause of firefighter death) accounted for around 5% of fatality claims; and respiratory disease accounted for around 2% (Garis, 2018). Since firefighters are exposed to a wide variety of dangers throughout their professional encounters, these health outcomes are not only due to exposure during wildfires.
- Though no literature was found on the topic, the advisory committee also raised concern that there could be deaths as a result of displacement or disruption to health care services.

- The health effects of wildfire disproportionately affect vulnerable populations, including:

- People with pre-existing conditions such as asthma, chronic obstructive pulmonary disease (COPD), heart disease, or diabetes (Corneil, 2018).
- Infants, the elderly, and pregnant women (Corneil, 2018).
- Firefighters and emergency personnel who are exposed to smoke and heat (Health Canada, 2008).
- Indigenous communities (Ostry, Ogborn, Takaro, Bassil, & Allen, 2008).

**Confidence: Medium**

Limited literature was found on the likelihood of increased mortality rates in B.C. However, there is evidence of deaths in other locations that could be extrapolated to estimate that some deaths could occur in B.C. due to severe wildfires. While direct deaths may be avoided, indirect deaths due to exposure to wildfire smoke could be more widespread, although quantifying this impact is difficult. Expert reviewers raised uncertainties regarding potential for loss of life; some consider the risk to life to be lower, while others suggested that more deaths could occur under specific circumstances (e.g., where evacuations are hindered).

*Morbidity, injury, disease, or hospitalization: 5*

Wildfire can create many health effects beyond fatalities, including risk of disease or hospitalization due to smoke inhalation, air pollution, and limited access to critical infrastructure and services after the event. Given the widespread effects to air quality, over 1,000 people could experience ill health effects due to a one-million-hectare fire, particularly if it is near population centres. Some portion of these effects could be more severe, such as burns or major smoke inhalation. In addition, a larger number of people could be affected by health effects due to air pollution and exposure to fine particulate matter. Some people could experience acute respiratory and cardiovascular symptoms, while others could experience short-lived irritation due to smoke exposure. Vulnerable populations, particularly infants, the elderly, pregnant women, and those with pre-existing conditions are at greater risk of morbidity and disease related to wildfire.

Supporting evidence includes:

- Wildfires degrade air quality by releasing toxins and particulate matter into the air. For example:

- Wildfire smoke contains toxic air pollutants (Health Canada, 2008). Forest fire emissions include carbon monoxide, atmospheric mercury, ozone-forming chemicals, and volatile organic compounds, which can affect local air quality and also travel long distances (Province of British Columbia, 2018).

- Wildfires also produce fine particulate matter, and a variety of gases such as nitrogen oxides and sulphur dioxide that reduce lung capacity, heart function, and blood flow (Corneil, 2018). Particulate matter, particularly small matter less than 2.5 micrometres in size (PM 2.5), is linked to serious health effects. In 2017, Kamloops had fine particulate matter concentrations higher than the provincial objective (25 μg/m3) for 33 of the 72 days of the state of emergency, reaching a maximum concentration of 274μg/m3. In Prince George, the maximum 1-hour concentration exceeded 1000μg/m3 (B.C. Lung Association, 2018).
- Ash from wildfires can contain carcinogenic and mutagenic hydrocarbons, which pose a health risk (Kane, 2018).
- When combined with higher temperatures, air pollution may be exacerbated (Ostry, Ogborn, Takaro, Bassil, & Allen, 2008).

• People who experience smoke inhalation or exposure to fine particulate matter may experience a variety of negative health outcomes, and exposure may occur inside or outside of buildings, as many of the gases can penetrate buildings (Interior Health, 2012). Negative outcomes include:

- Acute and chronic health effects, including pain, irritation, cough and phlegm, increases in mediation dispersion, and more doctor and emergency room visits (Takaro & Henderson, 2015).
- Smoke inhalation, irritation to nose and respiratory system, trouble breathing and reduced oxygen intake (Berry, Clarke, Fleury, & Parker, 2014).
- Hypothermia and dehydration, as well as physical and mental exhaustion (Health Canada, 2008).
- Long-term respiratory, cardiovascular, ophthalmic illnesses (Finlay, Moffat, Gazzard, Baker, & Murray, 2012; Interior Health, 2012).
- Low birth weights and lifelong health implications for babies in utero during a wildfire whose mother is exposed to pollutants (Takaro & Henderson, 2015).
- More emergency room visits, hospital stays, and deaths (B.C. CDC, 2018). In wildfire smoke-affected areas, emergency room visits for respiratory symptoms increase. Patients are likely to visit with asthma, bronchitis, dyspnea, chronic obstructive pulmonary disease (COPD), and otitis media, among others (Yao, Eyamie, & Henderson, 2016; Black, Tesfaigzi, Bassein, & Miller, 2017)). For example, during the 2003 forest fires in B.C., the Kelowna and Kamloops region experienced five weeks with elevated particulate matter. One community experienced an increase in doctor's visits of 46 to 78% for respiratory diseases (Moore et al., 2006). Further, access to medical services could be limited due to fires (Berry, Clarke, Fleury, & Parker, 2014).
- An increase in dispensation of medicines to treat asthma and other respiratory issues has been documented during wildfires (Elliott, Henderson, & Wan, 2013), which demonstrates that wildfire smoke can cause at least some mild symptoms to a large number of people.

• Wildfires can reduce drinking water quality in streams, rivers and lakes. Burned land and forest debris may wash downstream, increasing turbidity. A buildup of ash, soil erosion, and debris from fires can change the taste, colour, and smell of drinking water. Water chemistry may change, including buildups of iron and manganese. Additionally, fire retardants used to fight the flames can contaminate water supplies with nitrates and nitrites. These contaminants put an additional strain on water treatment systems, which may increase costs for additional filters and chemicals (HealthLinkBC, 2018). At the same time, water infrastructure and treatment plants could be destroyed due to wildfire, increasing the risk to populations dependent on that water supply (Workshop feedback, 2019).

- More moderate health effects could be experienced by people who forgo physical activity and remain inside during wildfires, which can have health effects due to remaining sedentary (Workshop feedback, 2019).
- The health effects of wildfire disproportionately affect vulnerable populations, including:
  - People with pre-existing conditions such as asthma, chronic obstructive pulmonary disease (COPD), heart disease, or diabetes (Corneil, 2018).
  - Infants, the elderly, and pregnant women (Corneil, 2018).
  - Firefighters and emergency personnel who are exposed to smoke and heat (Health Canada, 2008).
  - Indigenous communities (Ostry, Ogborn, Takaro, Bassil, & Allen, 2008).

**Confidence: High**

There are many sources of quality evidence about the health impacts of wildfire that agree on the types of diseases and impacts likely to occur. The results will depend on the location of the wildfire, which influences the number of people that could be exposed to negative health outcomes. Expert reviewers suggested that more than 1,000 people could experience some negative health outcome due to a major wildfire near a populated area, although of the affected persons could experience only minor illness.

## SOCIAL FUNCTIONING

### *Psychological impacts: 5*

Depending on the location of the wildfire, disturbances could be widespread and result in loss of people's homes, belongings, and well-being. Uncertainty regarding evacuations and the spread of the fire can cause fear and anxiety, while people that lose their homes, loved ones, or ways of life could experience long-term psychological impacts such as post-traumatic stress disorder (PTSD).

Supporting evidence incudes:

- Natural disasters, including wildfires, can cause distress, which can have psychosocial and mental health impacts (Berry, Clarke, Fleury, & Parker, 2014). For example:
  - People face great uncertainty and anxiety during the pre-evacuation and evacuation process regarding whether they will need to evacuate, when they will need to evacuate, preparing belongs to leave, and uncertainty about when or if they can return and what types of damages they will see when they do return (Workshop feedback, 2019).
  - Loss of property, infrastructure, homes, and ways of life can have negative impacts on mental health (Yusa et al., 2015). Those who lose their homes or are evacuated may experience trauma from the wildfire and associated displacement (Health Canada, 2008).
  - In the medium or long-term, wildfires may induce mental exhaustion, anxiety, depression, and PTSD related to loss of friends, relatives, homes, and livelihoods (Berry, Clarke, Fleury, & Parker, 2014). After the Kelowna fire in 2003, there were more cases of mental and physical exhaustion and some people exhibiting PTSD symptoms (Ostry, Ogborn, Takaro, Bassil, & Allen, 2008).
  - People experiencing physical health complications due to wildfires (e.g., asthma attacks due to smoke; injury from debris; disruptions to routine medical care) may experience additional psychological distress (Berry, Clarke, Fleury, & Parker, 2014).

- Due to wildfires, people are often displaced until their homes can be recovered or rebuilt, which may last for an extended period. On average, 5,500 people across Canada are evacuated each year. In 2017, 65,000 people were displaced in B.C. alone, and the province declared a 10-week state of emergency. Long-term displacement is associated with stress, isolation, and social/cultural disruption, all of which create patterns of anxiety and depression (Pearce, Murphy, & Chretien, 2017).
- Wildfires can have significant psychological impacts for people whose homes and livelihoods are simultaneously affected, such as agricultural operators and ranchers. In the ranching community in particular, individuals may be involved in suppression or response and/or need to re-enter areas during a wildfire event. These experiences, as well as losses to their herds or impacts to family farms can be traumatic (Boon, 2019; MacNair, 2019).
- People with special needs, including cognitive disabilities, diabetes, dementia, pregnant women, and those in hospice care, may experience more adverse effects after a wildfire or evacuation due to loss of care (Pearce, Murphy, & Chretien, 2017).
- Firefighters, emergency personnel, and first responders are especially prone to experience stress-related disorders and post-traumatic stress syndrome (Health Canada, 2008).
- For at-risk groups, evacuations can cause disproportionate trauma, including PTSD and revival of negative memories from the past (Abbott & Chapman, 2018). If these issues go unaddressed, they could lead to family violence, drug and alcohol abuse, attempted and actual suicides, and recruitment into criminal activity (Pearce, Murphy, & Chretien, 2017). Living through a disastrous wildfire may be a 'tipping point' for some people, driving them into harmful behaviours (Abbott & Chapman, 2018).
- After the Cariboo-Chilcotin fires in 2017, mental health was highly affected in both the short- and long-term. In surveys, residents noted a drop in their mental health by 31% during the wildfires, and maintained a 7% drop from their pre-wildfire normal after the event (Conrad, 2018).
- After wildfires in B.C., the Red Cross provides mental health services. For example, in 2017, there was a 200 to 600% increase in mental health referrals following the wildfire (Workshop feedback, 2019). The Red Cross indicates that psychosocial recovery from a disaster could take 5 to 6 years (Babineau, 2018).
- People who experienced trauma and who were forced to evacuate during a wildfire may experience distress triggered by subsequent wildfire seasons (CBC, 2018).

**Confidence: High**

Multiple reputable sources agree that wildfires contribute to serious psychological impacts for affected people. It is widely understood in the literature and among expert reviewers that disasters such as major wildfires can have catastrophic consequences on mental health and can cause long-lasting trauma.

*Loss of social cohesion: 5*

Wildfires could lead to months- to years-long disruptions to daily life. Displacement could cause disruptions to employment and education. In addition, those dependent on timber or agriculture may experience long-term loss of livelihoods, and Indigenous communities may experience significant disruptions to traditional ways of life.

Supporting evidence includes:

- Wildfires are a common occurrence across Canada and they put large numbers of people at risk. On average, 20 communities with a total of 70,000 people are threatened by wildfire in Canada each year, and 10 communities totaling around 5,500 people are evacuated (Berry, Clarke, Fleury, & Parker, 2014).
- Between 2003 and 2011, wildfires forced 113,996 people across Canada to evacuate (Berry, Clarke, Fleury, & Parker, 2014).
- In recent years (2017 and 2018), over 1 million hectares of land burned, which displaced tens of thousands of people. In some cases, communities may not be rebuilt, or people may relocate permanently, disrupting social structures. In 2017, B.C. evacuated 65,000 people and declared a 10-week state of emergency due to the wildfires (Abbott & Chapman, 2018).
- People who return after a disaster may find communities that may have changed dramatically: the landscape and buildings burned, wildfire-impacted natural environments, the smell of smoke, ash covering large areas, familiar landmarks missing, spoiled food and damaged belongings, changes to the social structure based on those who move permanently, etc. (Canadian Red Cross, 2016).
- Displacement and evacuations affect Indigenous communities in Canada disproportionately.
  - The inter-connectedness between First Nation communities and their lands increase the effects of trauma experienced due to wildfires (Abbott & Chapman, 2018).
  - A study found that, in 30 years, the chance of being evacuated during wildfire was 33 times greater for those living on a First Nations reserve (Yumagulova, 2018).
  - In 2016, the wildfire in Fort McMurray, Alberta forced nearly 90,000 people to evacuate their homes, many of whom were Indigenous persons (Austen & Levin, 2016).
  - These relocations can have negative implications for community cohesion and mental well-being. Evacuations can exacerbate physical, mental, spiritual, and social impacts of a wildfire (Pearce, Murphy, & Chretien, 2017).
  - Displacements often result in isolation due to distance from their social network, lack of access to traditional foods, lack of stable educational opportunities, job insecurity, and overall poor psychological health (Pearce, Murphy, & Chretien, 2017).
  - Indigenous communities may experience disenfranchisement during the evacuation process due to issues with jurisdiction between the national government and provincial government. The national government is responsible for Indigenous communities and the provincial government is responsible for fire suppression activities. Historically, there have been logistical difficulties communicating evacuation orders to remote reservations and evacuating residents (Abbott & Chapman, 2018; Kane, 2018).
  - In 2018, the Nadleh Whut'en lost approximately 22% of their territory to wildfires. The corresponding losses of animals and plants will have long-term effects on the people. The Nadleh did not have access to traditional food, medicine, and firewood due to destruction (Sharp & Krebs, 2018). The Nadleh Whut'en evacuees, who were moved to the City of Prince George, were not welcomed. Many Nadleh members suffered abuse and were treated with disrespect by hotel operators and restaurant staff (Sharp & Krebs, 2018).

**Confidence: High**

There is ample evidence of significant displacement due to wildfires and the permanent impacts that wildfires can have on livelihoods and traditional ways of life. The length of displacement and the extent to which communities will be able to recover will depend on adaptive capacity, location, and ability to prepare.

## NATURAL RESOURCES: 4

While fire plays in important role in the health and re-establishment of some ecosystems, a severe fire season could cause extensive damage to forests and forest ecosystems. Wildfires could destroy wildlife habitat, displacing animals and causing health problems due to burns and smoke inhalation. Some resources, such as annual plants, will recover quickly, while others, such as old growth forest, could take decades to recover from major disruptions. In some cases, new species and ecosystems may move in after the event, resulting in ecological transformations. Additionally, the soil erosion, ash, and debris washed into waterways can degrade water quality, causing damage to habitat for fish and aquatic life.

Supporting evidence includes:

- Wildfires play an important role in shaping the B.C. environment and are a natural part of ecosystem cycles. However, future warming and drying may predispose forests in B.C. to more frequent wildfires that will have severe negative consequences to species and ecosystems. For example, forest fires may change forest ecology and encourage growth of new species. Even if natural resources recover, significant wildfire activity can lead to ecological transformations when severe fires are followed by the introduction of new species that could be aligned to a warmer climate (van der Kamp, 2016).
- Increased air pollutants, including ozone, can damage vegetation growth and reduce photosynthesis. Thus, wildfire could reduce ecosystem productivity overall (Yue & Unger, 2018).
- Damage to forest ecosystems leads to habitat fragmentation and displacement of animals (Harvey, Axelson, & Smith, 2018). For example, wildfires may fragment early winter caribou habitat in the North Columbia Mountains near Mount Revelstoke and Glacier National Parks in British Columbia (Hansen, Franklin, Woudsma, & Peterson, 2001).
- In addition to destroying habitat, wildfire smoke can cause health problems for wildlife, similar to those experienced by humans, including difficulty breathing, eye irritation, inflammation of throat and mouth, nasal discharge, fatigue or weakness, disorientation, and stumbling. Birds are particularly susceptible to smoke (American Veterinary Medical Association, 2019; McGlashen, 2017).
- Fires may interact with other impacts of climate change, including insect outbreaks. For example, changing conditions may increase infestation by the mountain pine beetle in B.C., which increases the number of dead trees. This may increase wildfire risk and, with additional dead trees, spring water runoff is exacerbated (Ostry, Ogborn, Takaro, Bassil, & Allen, 2008). During past events, wildfire patterns have followed the path of insect outbreaks because dead trees are more flammable fuel for wildfire (Workshop feedback, 2019).
- Wildfire disturbances can reset plant communities and create an environment conducive for invasive species to take over without competition from native plants that take longer to regenerate (U.S. NPS, 2015; Zouhar, Kapler Smith, & Sutherland, 2008). Invasive species are nonnative plants that grow quickly and outcompete native species for resources (U.S. NPS, 2015). Invasive species can be detrimental to wildlife and ecosystems, in addition to creating a fuel load that could exacerbate the following fire season (Invasive Species Council of BC, 2011). This type of habitat type conversion

can have implications for wildlife species that depend on native plants for sustenance (Western Association of Fish & Wildlife Agencies, 2017).

- Post-fire salvage logging and firefighting operations can lead to disturbances that affect the hydrologic system, including alteration of natural flow paths, soil disturbance, removal of vegetation, etc. Loss of forest cover following a wildfire can result in increased precipitation reaching the ground, decreased transpiration, increased soil moisture, and increased runoff (Winkler, 2018). Runoff can increase due to hydrophobic soils and increased nutrient loading can lead to algae blooms. In addition, ash in the air can wash into rivers and streams when rains follow fires, contaminating rivers. Heavy metals could be washed into water supplies and fire retardants can also negatively affect water quality (RDNO, 2018). Due to wildfires, water quality may be degraded, which could negatively affect fish and aquatic ecosystems downstream (Winkler, 2018; van der Kamp, 2016).

**Confidence: High**

There are several sources of high-quality evidence documenting wildfire impacts to forests, wildlife, aquatic life, and soil and water quality. Expert reviewers agree that recovery could take decades to centuries, and the ecosystems could transform during the recovery process.

## ECONOMIC VITALITY

### *Loss of economic productivity: 5*

Wildfires may bring about closures for many businesses, including those in agriculture, tourism, timber, and mining. Additionally, wildfires cause physical damage to land, buildings, and other infrastructure necessary to support productivity. Although the full extent of these impacts has not been quantified, available evidence suggests potential direct and indirect economic losses could easily surpass $1 billion and result in long-term disruptions to certain economic sectors such as the timber industry.

Supporting evidence includes:

- The 2017 wildfire season cost $568 million in direct fire suppression costs, $20 million in aid to ranchers, as well as other indirect economic losses. These figures do not account for lost tourism revenue, economic disruption, and other social costs (Abbott & Chapman, 2018).
- Disruptions to travel and damage to tourism destinations could reduce tourism activity, along with associated jobs and revenue. Wildfires may also discourage outdoor recreation, which contributes substantially to B.C.'s economy. For example:

- In 2016, tourism generated $17 billion in revenue in British Columbia (Destination British Columbia, 2018). A study of recreational sites and trails in B.C. found that they contributed around $15 million to GDP and user spending generated almost $100 million (Norris Penny, 2011).
- Poor air quality and reduced access to certain wilderness areas during and after a wildfire discourages outdoor activity and recreation, which may reduce tourism. Local businesses that receive customers from nearby outdoor activities could see significant declines in revenue. Since fires are prevalent during summer months, they overlap with the tourist season (Workshop feedback, 2019; WorkSafe BC, 2017).

- Destruction of agricultural land and products could decrease food supply, affect the food value chain, and agricultural commodities (U.S. EPA, 2017; FAO, 2015). Losses to the agriculture sector alone could surpass $0.5 billion in some areas (Workshop feedback, 2019).
  - Agricultural Land Reserve land could be vulnerable to permanent or seasonal loss of productivity
  - Yields could decline due to smoke cover, as well as dust or ash on crops
  - Soil and water quality could be affected by washouts and erosion due to loss of trees and vegetation (MacNair, 2019)
  - Reduced quality and quantity of crops harvested (lower yields due to reduced sunlight, smoky taste in grapes)
  - Supply chain disruption (e.g., farm inputs, transportation)
  - Changes in soil characteristics
  - Competition for agricultural water supply due to firefighting activities
  - Economic losses to farm communities
  - Farm infrastructure damage (machinery and fences)
- Fires can devastate farming operations, killing animals and destroying thousands of dollars in woodlots, forage, equipment, and infrastructure. Even if the wildfire does not hit the farm directly, smoke inhalation can be damaging to animals' respiratory systems (B.C. Ministry of Agriculture, 2016).
- Relocation, negative health outcomes, and mortality for livestock could cost the cattle industry millions of dollars.
  - B.C. has approximately 4,086 ranches, making up 5% of the national cattle supply and using around 5 million acres of private land. In 2017, the B.C. cattle industry lost approximately 1 million acres of land, including prime grazing land, in the Fraser plateau of the interior and the Thompson plateau (Blennerhassett, 2017).
  - During the 2017 fire season, 25,000 to 30,000 heads of cattle of the 545,000 in the province were affected by evacuation orders and fires (Blennerhassett, 2017). Wildfires can lead to potential mortality and negative health impacts due to poor air quality and burns, in addition to costs and production losses for relocating and housing animals away from the wildfire zone (CAI, 2015). Cattle who have inhaled smoke must be sold at a discount or euthanized if they do not recover (Blennerhassett, 2017).
  - Wildfires also contribute to significant property damage for ranchers, including burning miles of fences, pastures, hay crops, and hay bales. The burned pastures could recover in one year, but other infrastructure is more difficult to repair, and some may be irreplaceable (Blennerhassett, 2017).
- Timber operations and mills near active fires may shut down, losing money due to lost operations and long-term impacts related to reduced harvest.
  - In 2016, B.C.'s Forest Industry generated $32.96 billion in output and contributed $12.94 billion to the province's GDP. Forestry and logging accounted for around 28% of the industry's contribution. This sector could be negatively affected by severe wildfires (PwC, 2017).
  - The 2017 fire season burned 609,000 hectares in Cariboo that are used for timber harvesting. Due to damage, the total timber harvest was reduced. The area burned was about eight times larger than the average annual area burned and 17 times larger than the long-term median (see **FIGURE**

**67**) (B.C. Ministry of Forests, Lands and Natural Resource Opertations and Rural Development, 2018).

- Loss of timber inventory produced long-term disruptions for timber companies that had to find alternative timber sources to maintain mill operations (Abbott & Chapman, 2018). In addition to losses due to timber sales and business interruption, the timber industry experienced material damage to infrastructure. One operator reported that replacing a burned mill would cost the company up to $140 to $145 million (Sagan, 2017).
- During the 2017 wildfire, an estimated 30 to 40 companies shut down because they were not able to log or transport products (Workshop feedback, 2019). Sawmills, plywood and wallboard plants (operated by Norbord Inc., Tolko Industries Ltd., and West Fraser Timber Co. Ltd., among others) in fire zones shut down and some logging contractors assist in the firefighting efforts (Jang & Cryderman, 2017; Penner, 2017; Government of British Columbia, 2017a).

- The Fort McMurray wildfire caused major economic losses, which exemplify the level of impact a future event could have. For example (Snowdon, 2017):

- The oilsands industry reduced output by 1.2 million barrels per day for two weeks, resulting in losses of more than $985 million.
- Lost labour income during the evacuation was estimated at $458.4 million.
- More than 20,000 individuals sought mental health support after the wildfire, costing around $4.8 million.

- Due to the 2017 fire season, the mining industry reduced operations. For example, Imperial Metals Corp reduced operations at the Mount Polley open pit copper and gold mine (Sagan, 2017).
- Wildfires can result in major damage to private property, although data was not found on the extent of these losses (Workshop feedback, 2019).
- Wildfires may damage homes and infrastructure on reservations. In some cases, infrastructure is not up to national standards and may not be insured, which may mean that the wildfire has disproportionate long-term impacts, making recovery more difficult and costly (Kane, 2018).
- Indigenous communities lose ties to cultural land if they are dislocated by fires, in addition to loss of income from foraging for non-timber forest products. Members of Indigenous communities would be disproportionately affected due to their strong ties to the natural environment (The Canadian Chamber of Commerce; Workshop feedback, 2019).
- Properly functioning ecosystems provide an array of free benefits to humans in the form of ecosystem services. These services fall into the broad categories of supporting, provisioning, regulating, and cultural services, and may or may not be directly tied to market activity. Examples of these ecosystem services include: nutrient recycling and soil formation (supporting), timber and crops (provisioning), carbon sequestration and water purification (regulating), and spiritual significance and recreation (cultural). When these ecosystems are damaged by wildfire, these services are often degraded or cease altogether. These services must then be replaced by costly man-made facilities or processes that provide the same services (e.g., the construction of a water treatment plant or shipments of topsoil if forests and vegetation are lost).

- In B.C.'s Lower Mainland alone, it is estimated that ecosystems provide $5.4 billion worth of benefits per year.[110] The top three ecosystem services include: climate regulation ($1.7 billion

[110] Values in present-day, 2018 CAD.

annually), water supply ($1.6 billion annually), and flood protection ($1.2 billion annually) (Wilson, 2010).
- Extrapolating to the entire province of B.C., ecosystem services provide an estimated annual value of $232 billion.[111]

- When ecosystems are damaged by a wildfire, and vegetation is destroyed, the ecosystem services normally provided are disrupted. One way to measure this loss is through the assessment of vegetation loss (one measure is Basal Area loss). Relationship of vegetation loss to ecosystem service loss can be categorized as (Batker et al., 2013):
  - Vegetation loss: 0% - ecosystem service function capacity: 100%
  - Vegetation loss: 0 to 25% - ecosystem service function capacity: 90%
  - Vegetation loss: 25 to 75% - ecosystem service function capacity: 50%
  - Vegetation loss: 75 to 100% - ecosystem service function capacity: 10%
- One example of wildfire damage is the Rim Fire in California, which burned 256,000 acres (10,360 sq km) in 2013 and resulted in first-year ecosystem service losses of US$736 million (Batker et al., 2013). The damages to these ecosystem services can then take decades to fully recover.
- Loss of life also has an economic impact. The range of loss of life from 10 to 100 can be valued at $52 to $520 million, based on the number of lives projected to be lost (Treasury Board of Canada Secretariat 2007).[112,113]

**Confidence: High**

There are multiple sources of high-quality evidence indicating that wildfires can cause losses to a variety of major economic sectors. This rating does not account for the full range of disruptions B.C. could experience and is likely a conservative estimate of the full economic consequences. In addition, the value of losses will depend on the area of the province affected and the industries in those locations. Expert reviewers agree that economic losses could be well over $1 billion.

*Loss of infrastructure services: 4*

Depending on the size and location of the wildfire, the extent of losses in infrastructure services could vary. Impacts may include damage to electricity infrastructure, telecommunications, roads and bridges, water treatment and sewage systems, private property, and require building modifications to overcome declining air quality. These damages to infrastructure could disrupt services to people in affected areas for weeks or months at a time.

Supporting evidence includes:

- Wildfires cause electricity/power outages that can cause disruptions and damages (HealthLinkBC, 2018). Extreme heat exposure can damage transmission lines and towers, jeopardizing electricity supply. Gas distribution lines, electric lines, and fibre optic lines can also be damaged (Workshop feedback, 2019).
- Telecommunications infrastructure may be damaged, interrupting communication. For example, the 2017 wildfires burned down a cellphone towner near Cache Creek and cut off mobile service to the

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[111] This extrapolation was conducted by scaling the values for B.C.'s Lower Mainland (Wilson, 2010) to the entire area of British Columbia.
[112] Value in 1996 CAD.
[113] The Treasury Board of Canada Secretariat expects departments to use a VSL of $5.2 million adjusted for inflation since 1996.

Ashcroft Indian Band. When towers are damaged and communications are cut off, emergency response becomes more difficult (Abbott & Chapman, 2018).

- Critical infrastructure, including roads and bridges, may be damaged, which could have severe consequences for evacuation. For example:
  - Major highways, logging roads, and some bridges within the wildfire zone could be affected, preventing access. This could also inhibit emergency response (Workshop feedback, 2019).
  - In 2017, highways closed, which cut off access for emergency vehicles to reach communities. In addition, hospitals must be protected to ensure that medical care is available for those affected (Abbott & Chapman, 2018).
- Wildfires can increase the patient loads for health care centres to handle immediate injuries such as burns and delayed injuries to lungs and airways from smoke inhalation. For example, in B.C., particulate matter levels above 10 µg/ m3 in the PM2.5 were associated with a 4% increase in salbutamol dispensations and days with levels above 25µg/m3 in the PM2.5 were associated with an increase in visits to health care professionals (Government of Northwest Territories, 2016).
- Due to the 2017 wildfire, Interior Health faced many stresses that resulted in 19 facility closures, over 250 calls received to the emergency hotline, $2.7 million spent on wildfire response, 182 helicopters and planes deployed, and over 2,000 air filters changed every 2 to 3 weeks to protect air quality (Workshop feedback, 2019). Although no literature was found on the effects of wildfire on health care infrastructure, if it was damaged, patients would need to be moved to new facilities. This puts additional pressure on health care services in other areas to meet the needs of displaced persons.
- Wildfires cause damage to structures (e.g., buildings, water intake valves, water well heads, treatment systems, piping, etc.) (HealthLinkBC, 2018). These damages may disrupt normal water treatment practices or cause loss of water pressure, allowing pollution to enter the system or leading to stagnant water lines (HealthLinkBC, 2018). Also, ash may clog water treatment and sewer systems, increasing maintenance requirements.
- HVAC systems may need to be installed or updated to remove particulates and chemicals that could pose dangers to people inside buildings (WorkSafe BC, 2017).
- Wildfires can reduce drinking water quality in streams, rivers and lakes. A buildup of ash, soil erosion, and debris from fires can change the taste, colour, and smell of drinking water. Additionally, fire retardants used to fight the flames can contaminate water supplies with nitrates and nitrites. These contaminants put an additional strain on water treatment systems, which may increase costs for additional filtration and chemicals (HealthLinkBC, 2018).
- Wildfires can strain water treatment facilities, requiring more intensive treatment, increased transport costs and sludge production, potential increase in disinfection byproducts, increase in toxins, and increased treatment costs to address all water quality impacts (RDNO, 2018).

**Confidence: Medium**

There are varying amounts and quality of evidence across sectors. The full loss of services is likely not accounted for in this summary, but the evidence exemplifies the types of disruptions to infrastructure services. Evidence indicates disruptions could last for weeks to months.

## COST TO PROVINCIAL GOVERNMENT: 4

The provincial government is responsible for fire suppression costs, which could exceed $500 million in a large fire season like 2017. Based on the literature, the costs could increase by at least 50%, which would increase fire suppression costs to around $850 million to $1 billion. There could be other costs unaccounted for that would bring the costs of preparedness and recovery up to a higher level. Some portion of these costs would likely be covered by the Government of Canada, if this event would trigger the DFAA. Total costs to the province are expected to be on the order of $750 million to $1.5 billion.

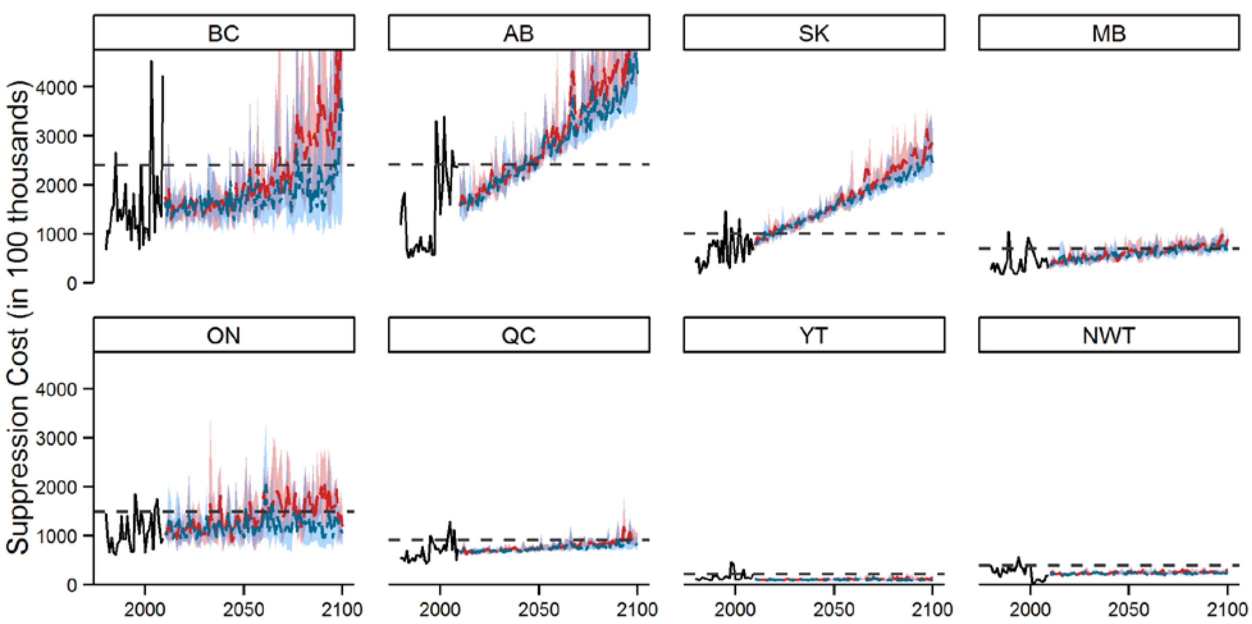
Supporting evidence includes:

- Over the period from 1970 to 2009, national annual fire suppression costs ranged from $216 million (2009 dollars) to over $1 billion, with an annual average of $537 million (Hope, McKenney, Pedlar, Stocks, & Gauthier, 2016).
- Direct costs of fire suppression from past wildfires in B.C. have included:

- 2003: $700 million in property losses and fire suppression costs (Government of British Columbia, 2004b).
- 2017: $568 million in direct fire suppression costs, plus $20 million in aid to ranchers, as well as other indirect economic losses. These figures do not account for lost tourism revenue, economic disruption, and other social costs (Abbott & Chapman, 2018).
- 2018: The provincial government will be matching all Red Cross donations up to $20 million to help people affected by B.C. wildfires (Crawford, 2018).

- Annual variable costs of fire suppression in B.C. are projected to increase by up to 145% by 2071 to 2100. B.C. is projected to experience extreme costs (above the 90th percentile value from 1980 to

**FIGURE 69.** Total suppression costs forecasted under RCP2.6 (Blue) and RCP8.5 (Red) for All GCMs, with the black dashed line representing the extreme fire year threshold (Hope, McKenney, Pedlar, Stocks, & Gauthier, 2016).



2009) roughly one out of every two years, with maximum costs of $1.07 billion projected by 2099 (Hope, McKenney, Pedlar, Stocks, & Gauthier, 2016). **FIGURE 69** shows projected costs of fire suppression between 2009 and 2100. It should be noted that the estimated increase in suppression costs is based on an average from before 2009. Suppression costs of more recent fire seasons would likely change these estimates. Even a 50% increase in suppression costs by 2050 would bring costs up to $1 billion and $850 million, compared to the 2003 and 2017 fire seasons respectively.

- Research from the U.S. found that the cost of protecting an additional 125 homes would cost $1 million for one fire of average duration (Headwaters Economics, 2008). With the expansion of the WUI, additional costs could occur for fire suppression (Natural Resources Canada, 2013).
- In 2017, 65,000 people were displaced in B.C. from wildfire. At a per diem cost of US$316, the cost of a single-day evacuation is US$20,540,000 (U.S. Department of State, 2019).
- The provincial government would likely be responsible for some portion of health care costs, although the project team could not determine the exact cost share between the federal and provincial government for the following estimates:

- Health response could include support for the Red Cross. Due to the 2018 wildfire season, the Canadian Red cross provided $38.6 million (Public Safety and Emergency Preparedness Canada, 2018) and the provincial government matched donations to help people affected by B.C. wildfires up to $20 million (Crawford R. , 2018).
- Health-related costs due to emergency department visits, respiratory and cardiac hospital admission, asthma symptom days, and acute respiratory symptoms. For example:
  - According to the Canadian Institute for Health Information (2017), the cost of a standard hospital stay in B.C. is on average $6,135.[114] Although not all cases of morbidity, injury, or disease are likely to result in hospitalization, the estimated range of over 1,000 hospitalizations as a result of sever wildfires can be valued at $6,135,000. Some portion of this cost would be covered by the provincial government.
  - In Alberta, the estimated health-related costs resulting from the 2001 fire were $9 million to $12 million for affected population of 1.1 million (Embrey, Remais, & Hess, 2012). There could be additional long-term healthcare costs.
  - In Kelowna, B.C., there was a 46 to 78% increase in physician visits for respiratory illnesses during a 3-week forest fire period (Youssouf et al., 2014). The government of B.C. would bear the cost of additional treatment.
  - In California, a study found that the average individual cost of illness is US$9.50 per exposed person per day due to the Station Fire (Richardson, Champ, & Loomis, 2012).
- Costs to evacuate long-term care facilities and hospitals, and costs to establish treatment capacity in locations to which people are relocated (Workshop feedback, 2019).
- Due to the 2017 wildfire season, the government contributed $100 million to the Canadian Red Cross.
- An estimated 30 to 60% of affected populations will need some form of mental health-related assistance following a disaster (NIST, 2017). Rates for severe, moderate, and mild mental illness can range between 6 to 26% up to 30 months following a disaster (FEMA, 2012). Treatment costs for these mental illness cases are estimated at (FEMA, 2012):

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[114] The value is in 2017 CAD. This measure divides a hospital's total inpatient expenses by the number of hospitalizations it sees in a year. The number is adjusted for some differences in the types of patients a hospital sees to make it more comparable with other hospitals.

  - 12 months post disaster: US$822 per person
  - 18 months post disaster: US$639 per person
  - 24 months post disaster: US$567 per person
  - 30 months post disaster: US$414 per person

- The project team was unable to precisely estimate the agriculture-related business risk management program costs for this scenario. Costs to government for recovery of agriculture after wildfires could include:
  - AgriStability support – if losses at the individual farm level exceeds 30% for the whole farm, AgriStability funds could be used (Agriculture and Agri-Food Canada, 2018).
  - AgriRecovery – this event would likely trigger a federal-provincial recovery initiative under the AgriRecovery, which has occurred in past events. For example:
    - The 2017 Canada-British Columbia Wildfires Recovery Initiative provided up to $9 million to assist agricultural producers with the costs incurred to recover from the wildfire. The costs were shared 60:40 between the Government of Canada and Government of B.C. (B.C. Ministry of Agriculture, 2019)
    - Due to the 2018 fire season, the government started the British Columbia Wildfire Recovery Initiative, which set aside $5 million in federal aid to cover costs related to: animal health and safety; feed supply; shelter and transportation costs for livestock; and reestablishing perennial crops on damaged lands (GFM Staff, 2018). However, to date, total indemnities paid are less than $1 million, and are not expected to exceed $1.5 million (B.C. Ministry of Agriculture, 2019).
  - Crop insurance payouts (B.C. Ministry of Agriculture, 2018).
  - In 2017, the provincial government committed $6.2 million to support the replacement of cattle infrastructure destroyed by wildfires (Blennerhassett, 2017).
  - Disaster financial assistance and unemployment to farmers, businesses, and private individuals who file claims (Workshop feedback, 2019).
- Wildfire damages to economically productive sectors, such as timber and tourism, could contribute to loss of revenue for B.C.'s government. For reference:
  - The B.C. Forest Industry pays a total of $198 million in municipal taxes (PwC, 2017).
  - The operation of recreation sites and trails in B.C. generate $3.78 million in revenues per year for the federal, provincial, and municipal governments and user spending generates $18.5 million (Norris Penny, 2011).
  - B.C. Parks are forced to close parks due to wildfire activity, which results in negative economic impacts to the park system. Eight parks remain closed or partially closed due to the 2017 and 2018 wildfire activity (B.C. Parks, 2018).
  - Historical and archaeological sites may require additional investment in preservation and fire protection, including emergency water tanks, sprinklers, fire breaks, and clearing fuels. Combined with reduced visitor numbers, these costs make it increasingly difficult to operate many heritage properties in areas with high wildfire risk (Linzey, 2019).
- The full extent of expenses for emergency management on First Nations reserves are not tracked. However, unaudited records indicate that around $448 million was allocated to First Nations for emergency management between 2009 and 2013 (Cullingford, 2018). In 2017, First Nations called on the federal government to create a $200 million emergency preparedness fund for Indigenous communities (Kane, 2018).

- For a large-scale disaster such as a severe wildfire season, the Government Canada would likely provide financial assistance through the DFAA, which would lower the burden on the provincial government (Public Safety Canada, 2019). For example, the federal government paid $175 million in DFAA for the 2018 wildfire season. Wildfire suppression and firefighting costs, however, are not eligible for reimbursement under DFAA. For example:

- For eligible costs totaling $1.5 billion, the Government of Canada would provide $1.3 billion in financial assistance to the Government of British Columbia. The province would be responsible for $179 million.
- For eligible costs totaling $500 million, the Government of Canada would provide $421 million in financial assistance to the Government of British Columbia. The province would be responsible for $79 million.
- For eligible costs totaling $50 million, the Government of Canada would provide $19 million in financial assistance to the Government of British Columbia. The province would be responsible for $31 million.

**Confidence: Medium**

There are several sources of high-quality independent evidence documenting the high costs of fire suppression, emergency response, and recovery due to wildfires, historically. The exact cost sharing between the provincial and federal government depends on the significance of the wildfire and this is not fully documented in the evidence base. Also, there are likely additional costs to government due to wildfire not documented in this estimate. Under certain circumstances, the total cost to the provincial government could exceed the "catastrophic" threshold.

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# Loss of Forest Resources

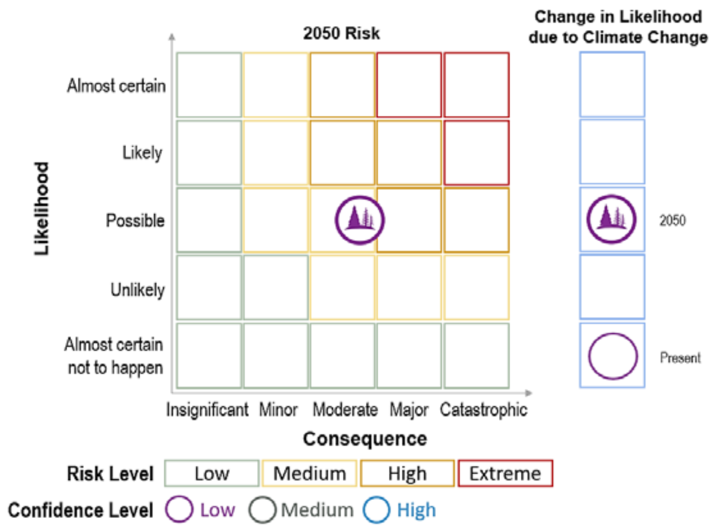
## Scenario

This scenario represents loss in forest resources, measured as a 25% decline in timber growing stock, in B.C. from 2010 to 2050. Forest loss could be exacerbated due increased temperatures and seasonal changes in precipitation, in addition to major disruptions (wildfire and pest outbreaks).

## Summary of Findings

Since the 1990s, B.C. has lost millions of hectares of forest to the mountain pine beetle (MPB) epidemic. Droughts in 2001 and 2002 also took a toll on forest resources, making them more susceptible to disease and wildfire. With warmer temperatures and more frequent or severe droughts, B.C.'s forests could experience greater losses due to pests and wildfire in the coming decades.

**FIGURE 70.** Risk assessment findings for forest resource loss scenario.




Loss of B.C.'s forest resources could have detrimental effects to natural resources and economic productivity. Many of B.C.'s species depend on forests for habitat and ecosystem regulation, which could decline if forests are compromised or die. Additionally, forestry and forestry-supported industries contribute significantly to the economy. Loss of resources could result in rising unemployment and loss of livelihood for forestry-dependent communities.

**FIGURE 70** and **TABLE 32** summarize the risk assessment results for this scenario. The highest consequences relate to loss of economic productivity. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 32.** Risk Rating Evaluation for Forest Resource Loss Scenario

| LOSS OF FOREST RESOURCES: 25% DECLINE IN TIMBER GROWING STOCK BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **1** | This scenario has not occurred. | **3** | **Climate-related risk cause:** Warmer temperatures and changes in precipitation patterns.<br>**2050 projections:** Between 2010 and 2080, timber growing stock on the total land base could decline by as much as 14% due to decreased growth, increased decay, and a greater risk of wildfire. Decline is projected on the timber harvesting land base, while forests may expend in other areas. | Low |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **1** | Loss of life is unlikely to occur. | Low |
| | Morbidity, injury, disease, or hospitalization | **2** | A small number of people could experience mild health impacts, resulting from increased pollen and allergens, reduced water quality, and disruptions to ecosystem services. | Low |
| **Social functioning** | Psychological impacts | **4** | Mild effects could be widespread due to a loss of aesthetic value and natural areas for recreation. People with forest-dependent livelihoods could experience severe psychological impacts. | Low |
| | Loss of social cohesion | **4** | Communities reliant on forestry industries could experience localized, permanent losses of livelihood. | Medium |
| **Natural resources** | Loss of natural resources | **4** | Forest loss will contribute to reduced habitat and biodiversity, increased erosion and sedimentation, and a decline in ecosystem services. | High |
| **Economic vitality** | Loss of economic productivity | **5** | Expected losses in the forestry and logging industry, downstream forest-dependent industries, and nature-based tourism could exceed $1 billion. | Medium |
| | Loss of infrastructure services | **3** | Rural communities may experience major impediments to daily life or incur major costs associated with loss of maintained roads. | Low |
| **Cost to provincial government** | | **3** | Costs include losses in tax revenue, stumpage fees, and tourism revenue. | Low |
| **OVERALL RISK** | **CURRENT** | **LOW (3.3)** | | **LOW** |
| | **2050** | **MEDIUM (9.8)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **3.3** out of 25, which equates to **low risk**, and the 2050 risk rating is **9.8** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence
Present Risk = 1 x 3.3 = 3.3 (Low)
2050 Risk = 3 x 3.3 = 9.8 (Medium)

## Evidence Base

### *Risk Event Scenario*

This scenario represents one illustrative permutation of loss in forest resources in British Columbia. The consequence ratings are specific to a 25% decline in timber growing stock, but the types of consequences may be transferable to other related scenarios.

The specifics of this scenario were based on:

- To address the likelihood and consequences for this scenario, the project team defines forest resources as timber stock, with the expectation that timber stock reductions are indicative of alternative measures and definitions of forest resources, including forest area and species composition.
- B.C.'s 67 million hectares of forest resources provide forest products and ecosystem services for the province.
- Climate change is expected to negatively affect forest resources through several mechanisms, including driving forest species conversion, migration, and disruptions from wildfire, pests, and disease. For example:
  - Climate change will affect tree growth rates, mortality rates, disturbance patterns, and the distribution of tree species (Johnston et al., 2010).
  - Changes in temperature and precipitation could alter forest composition. Some habitats may disappear or shift northward or to higher elevations (Natural Resources Canada, 2017).
  - Drought could increase forest die off and make tress more vulnerable to wildfire and pest outbreaks (Johnston et al., 2010).
  - Increases in wildfire frequency and intensity could increase the area of forest burned (Natural Resources Canada, 2017).
- Environmental damage due to climate change would include negative effects on forest resource values, such as soils, visual quality, timber, forage and associated plant communities, water, fish, wildlife, biodiversity, recreation resources, resource features, and cultural heritage resources (B.C. Ministry of Forests, Lands and Natural Resource Opertations, 2013).
- Metsaranta et al. (2011) estimate the loss of forest resources in B.C. under different climate scenarios. Using the most pessimistic scenario as a conservative case for assessing risk, the scenario assumes that annual growth rate decreases, decay increases, and annual area burned doubles by 2080, relative to 2010. This scenario is used as a basis for the likelihood assessment.

## *Likelihood rating*

Based on these findings and the likelihood rating criteria, the present-day likelihood of this scenario is rated as **1** (i.e., almost certain not to cross critical threshold) and the 2050 likelihood of this scenario is rated as **3** (i.e., just as likely to cross critical threshold or not). The project team used the decline in timber stock due to climate change as the primary indicator to evaluate this scenario and, additionally, considers a range of underlying climate-related causes, including increasing air temperatures, drought and wildfire risk, and beetle infestation. Between 2010 and 2080, timber growing stock across all of B.C. could decline by as much as 14%, resulting in major consequences for natural resources, cultural resources, and the economy (Metsaranta, Dymond, Kurz, & Spittlehouse, 2011). Forest resources have already seen large reductions in British Columbia; the Mountain Pine Beetle epidemic alone is estimated to have destroyed millions of hectares of pine forest since the 1990s.

**Likelihood Rating Drivers**

Type of risk event: Ongoing

"Present day" period: 2010

Critical threshold: 25% loss in timber growing stock

Climate change indicator: Projected change in timber growing stock (supplemented with projections of a variety of climate indicators)

Source of 2050 projections: Study of projected change in timber harvesting land base (Metsaranta et al., 2011)

Emission scenario: IPCC SRES A2

At the same time, timber stock decline will vary across the province due to regional differences in projected climate. Faster tree growth rates have been measured in B.C. forests where moisture is plentiful, potentially offsetting losses locally. However, because climate is expected to warm significantly, and warmer and drier conditions may exacerbate the risk of pest outbreaks, resulting in an accelerated decline of B.C.'s forests by mid-century.

Supporting evidence includes:

- Metsaranta et al. (2011) consider several projections for forest resources over the next century. Under the most severe forest loss scenario, annual tree growth rate decreases, decay increases, and annual area burned doubles by 2080, relative to 2010. Projected changes from 2010 to 2080 are as follows:
  - Forecasts predict a decline in timber growing stocks on the timber harvesting land base (THLB) and an increase on non-THLB under all scenarios. Specifically, by 2080, the timber growing stock on the THLB is projected to decrease under all scenarios, ranging from a decline of 26 to 62% of the growing stock relative to 2010. However, growing stock on non-THLB could increase under all scenarios (Metsaranta et al., 2011).
  - Under different scenarios, timber growing stock on the total land base (both THLB and non-THLB) may increase by up to 9% (optimistic scenario) or decrease by as much as 14% (pessimistic scenario), relative to 2010 (Metsaranta et al., 2011).
  - The total ecosystem carbon stock for the total land base is projected to decrease by 8.3% (Metsaranta et al., 2011).
- Other studies also suggest that forests are expected to decline in the province. For example:
  - Due to climate change, timber quantities in B.C. are projected to fall between 5% and 8% in B.C. by the 2050s (NRTEE, 2011).
  - Forest cover may decrease in dry areas of the Southern Interior of British Columbia (Johnston et al., 2009).

- Spruce-dominated forests in the central and Southern Interior of B.C. could decline, and beyond 2050, serious declines are predicted in the south and at lower elevations (Johnston et al., 2009).

- Tree species will likely shift due to changes in suitable habitat. One study found that tree species with their northern range in B.C. could gain potential habitat at a rate of around 100km per decade. Conifer species, on the other hand, are expected to lose a large portion of suitable habitat in the province (Hamann & Wang, 2006).
- Increasing drought and air temperatures are linked to a widespread increase in tree mortality across many forest types in Canada. In turn, increased tree mortality limits forest regeneration and increases forest susceptibility to pest outbreaks and wildfire (Pacific Institute for Climate Solutions, 2017). For example:
  - A severe drought in 2001 to 2002 led to the dieback and decline of aspen forests across large areas of western North America. Although future tree mortality is hard to project, it is expected to continue to increase with climate change, particularly due to drought (Natural Resources Canada, 2017).
  - Hot and dry summers and mild winters correlate with more widespread infestation by the MPB, which has been traditionally limited in B.C. due to the climate (Embrey, Remais, & Hess, 2012). Unusually warm winters increase larvae survival, resulting in increasing populations and higher levels of outbreak in the spring (Natural Resources Canada, 2018; Embrey, Remais, & Hess, 2012).
    - The MPB epidemic started in B.C. in the early 1990s. Between 2000 and 2013, B.C. lost 18.6 million hectares of forest to the MPB. NRCan projected that, by the time the infestation had largely subsided in 2017, the province would have lost 752 million cubic metres of timber that would otherwise have been sold in commercial markets (NRCan, 2017). Other studies estimated that pine volume in B.C. decline. by more than three quarters by 2015 (Johnston et al., 2009).
    - A large portion of B.C.'s forests have been decimated by these infestations. Higher temperatures could contribute to even more losses due to infestations.
  - Drought, especially when it coincides with high temperatures, increases the risk of wildfire. In addition, due to drought and insect outbreaks, forests may be more susceptible to wildfire, resulting in larger areas burned (Pacific Institute for Climate Solutions, 2017). Wildfires cause major forest loss.
- There is a high degree of uncertainty as to where and when problems will occur, the degree of mortality, and the magnitude of gains and losses in forest ecosystems (Dymond et al., 2015). The degree of forest loss expected is hard to estimate, particularly due to the positive and negative changes occurring simultaneously (Spittlehouse, 2019).

**Confidence: Low**

Several scientific studies predict continued forest decline due to a variety of climate factors. However, deconvolving the attribution of forest reduction to primary contributors such as temperature and precipitation change and related factors, such as pest outbreaks and wildfire, remains challenging. In some cases, forests will regrow, while elsewhere trees will fail to re-establish. Sources acknowledge the great uncertainty in projections of how climate change could affect forests, given the many stressors and interactions. Additional data constraining the cause of tree mortality is necessary to improve the project team's assessment.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **3.3** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (1+2+4+4+4+5+3+3)/8

Overall Consequence = 3.3

### HEALTH

*Loss of life: 1*

Loss of forest resources is not expected to cause loss of life. However, there are some secondary and compounding risks for mortality, due to events such as wildfire and landslides, which could be exacerbated due to forest resource loss.

**Confidence: Low**

There is no literature connecting forest resource loss directly to mortality. Although expert reviewers estimate that there could be a possibility for loss of life due to indirect consequences related to forest decline, it is difficult to account for deaths outside of those due to major landscape disturbances such as wildfires.

*Morbidity, injury, disease, or hospitalization: 2*

While the loss of ecosystem services from damaged forest resources could affect a large proportion of the B.C. population, effects could be relatively minor. The drivers of morbidity, injury, and disease would include the quantity or type of pollen and allergens in the air causing respiratory illnesses or poor water quality increasing risk of water-borne illness. However, there are some secondary and compounding risks to health due to events such as wildfire and landslides, which could be exacerbated due to forest resource loss.

Supporting evidence includes:

- The impacts of lost forest resources will not be evenly distributed. Some populations will face higher risks because of their location, association with climate-sensitive environments, and economic, political, and cultural characteristics (Workshop feedback, 2019).
- Declining forest health or extent could increase erosion and sedimentation, which contributes to turbidity in rivers and streams. Increased turbidity can negatively affect water quality, requiring more treatment or caution prior to human consumption (Embrey, Remais, & Hess, 2012). Ecosystem disruption may have significant direct and indirect health effects resulting from increased runoff, surface water turbidity, and forest fires, along with associated waterborne disease and respiratory disease impacts (Embrey, Remais, & Hess, 2012).
- Warming temperatures could shift the expanse of certain trees and change pollination patterns, which could increase exposure to allergens. With warmer temperatures and higher levels of $CO_2$, plants produce more pollen and grow more prolifically. In Canada, more people might suffer seasonal allergies triggered by pollen, causing symptoms including watery eyes, runny nose, sneezing, and coughing (Schmidt, 2016).

- Forests provide vital ecosystem services, such as regulating water, air, and soil quality; nutrient regulation; climate stabilization; and biomass production. Loss of forest resources could reduce these services, resulting in health impacts due to reduced air and water quality (Embrey, Remais, & Hess, 2012). Other disturbances such as wildfire and landslides can also disrupt the ecosystem services.
- Any health outcome due to loss of forest resources is likely to affect vulnerable populations, including the elderly, young, and those with pre-existing conditions, disproportionately.
- Additional morbidity, disease, or hospitalization could occur due to compounding impacts associated with wildfires, landslides, and flooding, which could be exacerbated due to forest resource loss.

**Confidence: Low**

In general, the literature agrees on a various health impacts of ecosystem disruption but the specific impacts of forest resources in B.C. is not fully understood. Expert reviewers agree that the impacts to health are low, although there are major research and data gaps to understand these consequences.

## SOCIAL FUNCTIONING

### *Psychological impacts: 4*

For people and communities that depend on forest resources for their livelihoods, psychological impacts could be severe. Changes in the forest industry, unemployment, and loss of identity or purpose could have cascading effects on psychological wellbeing. Forest resources also provide psychological values due to positive feelings associated with the aesthetic of forests and spending time in nature. Thus, the broader population could experience more moderate psychological impacts such as anxiety or grief due to changes in the beauty of nature areas that people enjoy.

Supporting evidence incudes:

- The impacts of lost forest resources will not be evenly distributed. Some populations will face higher risks because of their location, association with climate-sensitive environments, and economic, political, and cultural characteristics (Workshop feedback, 2019).
- Serious psychological distress could occur due to loss of property or livelihoods, displacement, or damages incurred due to wildfire. An increase in perceived risk of forest fire has been reported to negatively affect mental health by increasing public concern (Embrey, Remais, & Hess, 2012). See Severe Wildfire Season risk event for quantification of this impact.
- Due to psycho-social pressures from lost livelihoods, there is a potential for deaths due to suicide in communities reliant on the forest industry, although this is not documented in the literature (Workshop feedback, 2019).
- Forests and ecological diversity are associated with psychological value that could be lost (Johnston et al., 2010). For example:
  - Lost forest areas may contribute to distress due to environmental change or "ecological grief" (Cunsolo & Ellis, 2018; Cunsolo Willox, 2012).
  - Areas affected with pine beetles could lose aesthetic quality where people experience contact with nature, and people may lose access to places that contribute positively to mental and physical health (Embrey, Remais, & Hess, 2012).

**Confidence: Low**

While the literature suggests potential for negative mental health outcomes, the value of forest aesthetic for mental health is not well quantified. In addition, it is difficult to estimate whether forest losses expected by 2050 would be severe enough to trigger negative mental health outcomes. Therefore, it can be difficult to understand the significance of lost forest resources on mental health and the number of people affected. Expert reviewers identified the strong emotional and economic ties to forest resources that could result in severe disturbances due to forest loss, particularly when tied to loss of livelihood.

### *Loss of social cohesion: 4*

Loss of forest resources could affect some populations disproportionately, particularly communities reliant on forestry industries. Thus, a major loss of forest resources could cause a localized, permanent loss of livelihoods for these communities.

Supporting evidence includes:

- The impacts of lost forest resources will not be evenly distributed. Some populations will face higher risks because of their location, association with climate-sensitive environments, and economic, political, and cultural characteristics (Workshop feedback, 2019).
- While all communities could face issues due to forest loss, forest-dependent communities and Indigenous communities would likely be the first to feel the impacts of reduced timber supplies or loss of other forest values (Natural Resources Canada, 2017; Government of British Columbia, 2016).
  - For example, the MPB epidemic disrupted timber-dependent communities in B.C.'s interior, contributing to unemployment (Woods, Heppner, Kope, Burleigh, & MacLauchlan).
  - Economic downturn in 2008, combined with lower timber supply, resulted in thousands of lost jobs in the forestry sector. Many communities, particularly in the Central Interior, rely on timber-based industries and are vulnerable to downturns in product markets and the impact of forest decline. As of 2005, 8% of the provincial labour income was derived from the forest sector (B.C. Ministry of Forests, Mines and Lands, 2010).
- The following factors could exacerbate community vulnerability to forest loss (Johnston et al., 2010):
  - Strong ties to surrounding climate-sensitive forest landscapes
  - Economic or personal reliance on local wood supply
  - Reduced competitiveness of businesses
  - Constraints to adaptation such as small and undiversified economies or a specialized labour force unable to transition into other industries
  - Increased risks due to expected increases in wildfire activity
  - Lack of consideration of climate change in forest management decisions and forestry institutions that may ultimately lead to higher impacts manifesting at the community level

**Confidence: Medium**

There are multiple sources of evidence indicating that forest-dependent livelihoods could be disrupted due to climate impacts on forest resources. More information is needed on how compounding factors like wildfire contribute to loss of social cohesion and how many people depend on forest-based industries in British Columbia. Some experts claim this could cause catastrophic and widespread loss of livelihood for communities across the province.

### NATURAL RESOURCES: 4

Forest ecosystems, as an important natural resource, may be lost due to a variety of climate impacts. On some sites, forests could take decades or centuries to recover after a disruption, while trees may fail to re-establish on others. In addition, biodiversity and wildlife supported by these forest environments would likely experience decline and some species dependent on certain tree species could go extinct or need to migrate to new ecozones. Forest loss would impede ecosystem services, including carbon sequestration. However, this does not account for potential positive outcomes resulting from shifts to different ecosystems (e.g., grasses replacing forested areas), which would lower the overall impact on natural resources by providing new intact habitats and maintaining some ecosystem services.

Supporting evidence includes:

- Due to ecological shifts, the appropriate climate conditions for subalpine and alpine areas will diminish in most locations while those for grasslands, shrub-steppe, and dry forested ecosystems are expected to expand. Many species, including trees, will not be able to migrate quickly enough to keep pace with shifting climate zones. During this time, ecosystems will be heavily influenced by disturbances and invasive plants (Government of British Columbia, 2016).
- Forests support biodiversity, including diverse ecosystems and wildlife habitat (Johnston et al., 2010). Thus, loss in forest area or shifts in range could result in loss of forest habitat and species loss. For example:
  - About 33% (1,345) of plant and animal species in B.C. rely on forests for some portion of their life cycle. While most of B.C.'s forest-dependent species are healthy, 116 vascular plants and vertebrates are red-listed, meaning they are extirpated, endangered, or threatened. For example, the White-headed Woodpecker and mountain beaver are at the northern limits of their natural range (B.C. Ministry of Forests, Mines and Lands, 2010).
  - Many streams that support fish species depend on forested areas and organic debris in streams for channel stability, erosion control, shading, and temperature modification (B.C. Ministry of Forests, Mines and Lands, 2010).
  - Caribou, ungulates, mountain goats, and bighorn sheep use pine stands for winter shelter (Wong, 2008). Grizzly bears could lose habitat and face pressures due to forest loss (Workshop feedback, 2019).
  - Red squirrels have been affected negatively by forest loss due to MPB outbreaks (Saab et al., 2014).
  - Birds that nest in the forest canopy would likely be disrupted, while those birds and small mammals that live in tree cavities may benefit or face limited disturbance (Wong, 2008; Saab et al., 2014).
  - Alterations of freshwater environments could affect fish. Changes to the aquatic environments could include changes in water flow, peak flow, dissolved oxygen levels, more sediments in water, increased water temperature, and changes to aquatic plant growth. Some fish may benefit, while others may not (Wong, 2008).
- Forests help maintain soil integrity through the root system. Declining forest health or extent could increase erosion and sedimentation, which contributes to turbidity in rivers and streams (Embrey, Remais, & Hess, 2012). This could reduce water quality, which could damage riverine ecosystems downstream. In addition, forest soils store and filter fresh water, playing a vital role in protecting the

quantity, quality, and timing of river flows. Forests provide stream bank stability, shade, organic materials, and nutrients for aquatic communities, which might decline or be lost (B.C. Ministry of Forests, Mines and Lands, 2010).

- Forest disturbances can significantly affect snowmelt processes in certain watersheds. With reduced canopy, the amount of snowmelt increases and could occur earlier in the year, which will change hydrologic features of snowmelt driven watersheds (Davis, Boon, Winkler, Spittlehouse, & Pomeroy, 2011; Redding et al., 2008). When snowmelt occurs in the spring, it may happen earlier and more abruptly, resulting in higher flow volumes during certain periods, risks due to fast increases in water level during storms, and more intense flows from forest soils to streams and rivers (Wong, 2008).
- Historically, B.C.'s forests acted as a carbon sink, reducing atmospheric carbon dioxide. However, high tree mortality, and disruptions from insects and wildfire, reversed this trend. Canada's managed forests have become a net source of carbon since the year 2002 (Embrey, Remais, & Hess, 2012; Johnston et al., 2010; B.C. Ministry of Forests, Mines and Lands, 2010). According to B.C. Ministry of Forests, Mines and Lands (2010), B.C.'s forests are projected to become a net sink again after 2020.
- Major forest die-off supplies excess fuel, exacerbating the risk of wildfires. Wildfires cause major disruptions and damages to natural resources. Since this is a compounding impact, these damages are not included in the risk rating here. Refer to the Severe Wildfire Season section and the Interactions between Risk Events section for additional details.

**Confidence: High**

Since forests are a natural resource, loss of forest itself is a detriment. There are multiple sources of evidence reporting the negative consequences of forest loss on ecosystem services, water quality, and habitat for various species. There is significant uncertainty around these consequences, which could be greater or less severe depending on a variety of factors. Some experts identified that the consequence to habitat and species may be lower if ecosystems shifted to different functional ecosystems. However, if forests are lost completely rather than shifting, certain species and ecosystems may suffer.

## ECONOMIC VITALITY

### *Loss of economic productivity: 5*

Loss of forest resources could have a detrimental impact on the economy of B.C., including direct losses to the forestry industry and indirect losses to nature-based tourism. In the short-term after a disturbance, there is an increase in productivity due to salvage logging, which will collapse in the long term. There would also be downstream effects on industries supported by forestry, including pulp and paper processing. Based on estimates from the literature, B.C. could experience losses in the timber industry of $5 to 32 billion from 2010 to 2080. Assuming around half of these losses occur by 2050, this would range from $2.5 to 16 billion. Rural communities reliant on forest industries could collapse due to forest resource loss.

Supporting evidence includes:

- The impacts of lost forest resources will not be evenly distributed. Some populations will face higher risks because of their location, association with climate-sensitive environments, and economic, political, and cultural characteristics (Workshop feedback, 2019).

Loss of forest resources could affect multiple economic sectors, including forest and timber, agriculture, tourism, and ecosystem services.

- Forest and timber industry impacts include:
  - In 2016, the forest industry accounted for $22 billion of Canada's GDP, and, in 2015, it employed more than 200,000 people. More than 170 rural municipalities depend on the forest sector to support the economy (Natural Resources Canada, 2017). The forestry and logging sector contributed $1.65 billion to provincial GDP in 2012 and the revenue from forest-related goods produced more than $16 billion (Corbett, Withey, Lantz, & Ochuodho, 2016).
  - Forest resource loss could be analogous to the losses due to the MPB epidemic, which resulted in major economic losses. For example:
    - B.C.'s mountain pine beetle is projected to result in a loss of around 23% of provincial timber volume (NRTEE, 2011). B.C. estimated that the MPB epidemic cost $2.5 billion losses in manufacturing activity and 27,000 lost jobs (Embrey, Remais, & Hess, 2012).
    - The MPB epidemic in B.C., which affected more than 53% of the merchantable pine, resulted in major losses to the timber industry. Estimated economic impacts from 2009 to 2054 show cumulative present value loss of $57.37 billion in GDP (roughly 1.34%) and a $90 billion decline in welfare, based in 2009 Canadian dollars. A large portion of these losses are due to jobs lost (Corbett, Withey, Lantz, & Ochuodho, 2016).
  - Additional loss of forest resources could cause major economic losses to the forest industry, including timber, logging, and associated manufacturing and paper industries. For example:
    - Provincial GDP could fall by 0.2 to 0.4% by the 2050s with a 5 to 8% decline in timber quantity (NRTEE, 2011).
    - Reduction in forest resources would contribute to losses to the wood, pulp, and paper industry (Climate Atlas, 2018).
    - Nationally, the cumulative costs of changes in timber supply over the next 70 years range from $25 billion to $176 billion. In B.C., this could result in costs ranging from $5 to 32 billion from 2010 to 2080 (NRTEE, 2011).
    - If timber supplies fall by 5% and correspond to a decrease in GDP contribution by the same amount, this would also exceed $1 billion. Losses to the forest industry alone could exceed $1 billion, and there are other economic losses not accounted for in this estimate.
  - As with the MPB infestations and tree mortality, communities dependent on timber resources could experience major shifts in supply. Immediately after a disruption, timber harvests increase to collect dead trees and then decreases significantly, resulting in unemployment and socioeconomic decline (Embrey, Remais, & Hess, 2012). For example:
    - The annual allowable cut in Vanderhoof Forest District changed from around 2 million $m^3$ in 2000 to around 6.5 million $m^3$ to salvage damaged pines. Under a worst-case projection, timber harvests in the district could drop to around 1 million $m^3$ by 2070 (Johnston et al., 2010).
    - In response to the MPB epidemic, the Government of B.C. increased the annual allowable cut for salvage harvest of lodge pole pine trees. While the harvest increased in the near term, the longer-term impact will be a reduction in available timber over the next several decades, as stands will take decades to regrow (Corbett, Withey, Lantz, & Ochuodho, 2016).
  - Reduced timber supply can cause an increase in saw log prices, although this will not offset the significant effect of the timber supply decrease (Corbett, Withey, Lantz, & Ochuodho, 2016).

- Changes in forest supply can also have significant employment impacts in the forestry industry. Jim Girvan and International Wood Markets published a report forecasting that, due to the MPB epidemic, B.C. would have to close 16 sawmills and/or plywood production facilities in the interior permanently by 2018 (Logging and Sawmilling Journal, 2009). Other sawmills have reduced production. Hundreds of sawmill workers have been laid off already as sawmills closed due to high log prices and low supplies resulting from MPB outbreaks and wildfires (Bennett, 2018).

• Many Indigenous communities engage in economic activity that could decline due to forest resource loss (Natural Resources Canada, 2017; Government of British Columbia, 2016; B.C. Ministry of Forests, Mines and Lands, 2010). For example, the Pacheedaht First Nation on Vancouver Island, B.C. has 163,000 hectares of fir, hemlock, red cedar, yellow cedar, and other forest types that are valued and have been used for thousands of years. In recent years, the Nation has received licences to manage and co-manage a large portion of the forest and operate a sawmill. The Pacheedaht First Nation manages trees over the lifespan over the 400 years it requires to reach the length required for certain cultural practices.

• Agriculture industry impacts include:

- Loss of forest cover changes hydrology, which can negatively affect agriculture. Without trees holding water within the soils, more precipitation runs off of the land, contributing to erosion, flood risks, and general soil quality degradation that affect agricultural areas (MacNair, 2019).
- Forested Crown land is often used for pasture and foraging (e.g., mushrooms and berries), which contribute to the livelihoods of supported communities (Workshop feedback, 2019). These activities could be disrupted due to forest loss.

• Tourism industry impacts include:

- Forests provide aesthetic value and outdoor recreational opportunities. In B.C., residents engage in around 310 to 350 million user-days of outdoor recreation. Expenditures on tourism and forest recreation are estimated to be $13 billion per year with about $4 billion for forest recreation in parks and Crown land. It is estimated to contribute around $7 billion to GDP and employ nearly 150,000 people directly (B.C. Ministry of Forests, Mines and Lands, 2010). Forest-based recreational opportunities could be lost or shift to different locations, which could have economic implications for some communities (Johnston et al., 2010).
- Reduced aesthetic appeal could reduce tourism to certain areas of British Columbia (Climate Atlas, 2018). For example, in Grand County, CO, property values declined by US$648, US$43, and US$17 for every tree killed by pest infestation within 0.1, 0.5, and 1.0 km from the property, respectively. People have reported that MPB infestation has reduced tourism and recreation revenue and contributed to greater unemployment in infested communities (Embrey, Remais, & Hess, 2012). Similar evidence was not found for the B.C. MPB epidemic.

• Ecosystem services impacts include:

- Forests provide vital ecosystem services, such as regulating water, air, and soil quality; nutrient regulation; climate stabilization; and biomass production (Embrey, Remais, & Hess, 2012). Loss of forest resources will reduce the capacity to provide ecosystem services. Although it is widely acknowledged that these services have an economic value, studies differ in quantifying the value of ecosystem services. One study estimated that North American forests provide ecosystem services worth around US$300 billion annually (Embrey, Remais, & Hess, 2012).

- In B.C.'s Lower Mainland alone, forested land is estimated to provide more than $6 billion in ecosystem services annually.[115] This includes (Wilson, 2010):
  - $1.5 billion in climate regulation in the form of carbon sequestration and storage
  - $0.4 billion in air regulation (the removal of pollutants from the air)
  - $1.25 billion in flood protection from water retention and soil stabilization
  - $1.5 billion in clean water from pollution filtration
  - $0.2 billion in habitat for pollinators
  - <$0.1 billion in recreation
- Extrapolating to the entire province of B.C., these forest ecosystem services provide an estimated annual value of $219 billion.[116]

**Confidence: Medium**

There are several sources of high-quality evidence documenting the costs of forest decline in British Columbia, which already surpass $1 billion in losses due to the MPB epidemic. This account does not include all potential losses due to forest resource loss. However, the evidence found provides information about the type and range of costs that could be experienced across resource-dependent sectors.

*Loss of infrastructure services: 3*

Rural communities may experience major impediments to daily life or incur major costs to continue using roads that were previously maintained by the forest service or forest industry.

Supporting evidence includes:

- Due to changes in hydrology from lost forest cover (increased runoff during precipitation events), the capacity of culverts may be exceeded, resulting in flooding. Additional infrastructure damage could occur due to higher velocity river flows during storms (Spittlehouse, 2019).
- The forest industry supports infrastructure services in communities where they operate. Over 620,000 kilometres of roads in B.C. are "resource roads" and are a highly valued part of the transportation network. These roads are used primarily by industrial vehicles for forestry, mining, oil and gas, and agriculture operations. They can also be used to access skiing areas, fishing, other outdoor activities, and rural communities (Government of British Columbia, 2019). If forest industries shut down, communities including rural and Indigenous communities would become responsible for maintaining forest access roads. Abandoned forest roads must be decommissioned to avoid erosion (Workshop feedback, 2019).
- Access to outdoor recreation areas may be lost because roads are not maintained (Workshop feedback, 2019).

**Confidence: Low**

Due to the lack of evidence on infrastructure services, the rating was based on expert judgement. No evidence was found to document other types of service or infrastructure disruptions that could occur due to forest resource loss.

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[115] Values in present-day, 2018 CAD.
[116] This extrapolation was conducted by scaling the values for B.C.'s Lower Mainland (Wilson, 2010) to the entire area of British Columbia.

### COST TO PROVINCIAL GOVERNMENT: 3

Cost to the provincial government from a decline in forest resources would include lost revenue from stumpage fees and tax revenue from businesses and individuals dependent on forest resources. Damages to the timber industry from the MPB resulted in a loss of $250 million; loss of forest resources could have an impact of similar scale. Additional costs could include losses in tourism and forest recreation and costs to decommission roads previously maintained by the forest industry. As a result, the costs to government are expected to be on the order of $375 million to $750 million.

Supporting evidence includes:

- Most of the forest land in Canada is publicly owned and the right to harvest timber is sold to private companies (Johnston et al., 2010). About 95% of B.C.'s 55 million hectares of forest are owned by the provincial government (Xu, Smyth, Lempriere, Rampley, & Kurz, 2018). Timber harvesting on public lands provides revenue to the provincial government in the form of stumpage fees[117] (Johnston et al., 2010). Timber losses from the MPB epidemic in B.C. resulted in a loss of $250 million in government stumpage and royalty revenues (Embrey, Remais, & Hess, 2012). The provincial government could lose revenue from taxes and stumpage fees due to loss of forest resources.
- The provincial government received around $990 million in revenue from forests for 2017 to 2018 (B.C. Stats, 2018). Some portion of this revenue could be lost. If the relationship is considered linear, 25% decline would result in losses of approximately $250 million.
- Tourism and forest recreation contribute around $1.4 billion to provincial tax revenue per year, which could decline if forest resources are lost (B.C. Ministry of Forests, Mines and Lands, 2010).
- Immediately after a large forest dieback, timber harvests increase due to the large amount of wood that needs to be salvaged. However, after the initial harvest, the available harvestable wood decreases, which can result in higher unemployment and socioeconomic decline. As a result, the government could lose tax revenues from affected communities (Embrey, Remais, & Hess, 2012).
- If the forest industry pulls out of certain areas due to forest loss, the government could incur costs for decommissioning roads that are no longer in use (can be as much as $10,000/km). The forest service is responsible for maintaining around 60,000 km of road (Workshop feedback, 2019).

**Confidence: Low**

While there are several sources that document the costs of pest and disease damage in B.C. during previous outbreaks, these estimates may not account for the full extent of costs associated with losses in revenue, tourism, or additional costs for recovery of communities facing economic changes from lost forest industries. As a result this rating relies on

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[117] Stumpage fees refer to the price charged by the government to companies for the right to harvest timber on public land (Embrey, Remais, & Hess, 2012).

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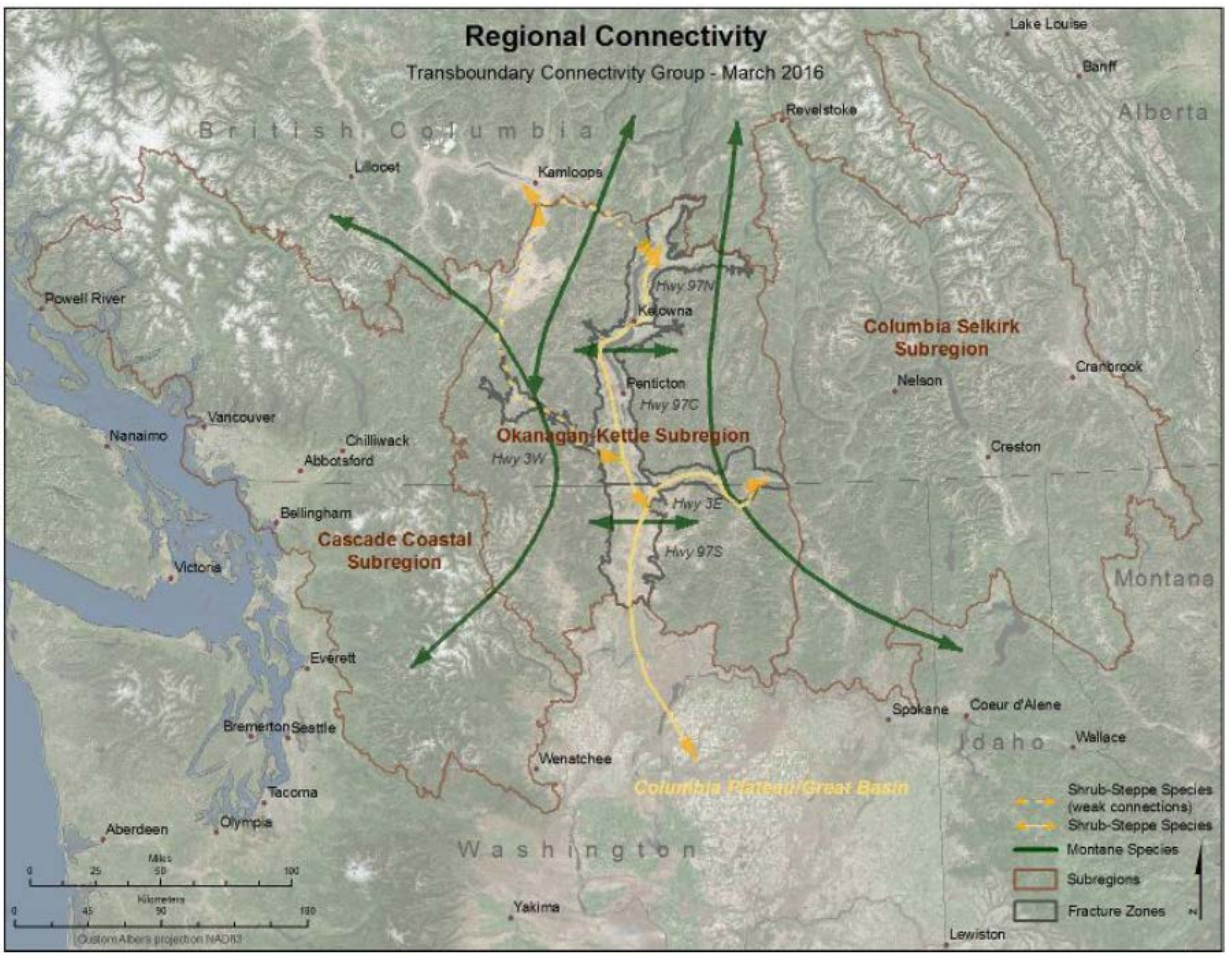
# Reduction in Ecosystem Connectivity

## Scenario

The specific scenario analyzed is reduction in ecosystem connectivity[118] in the Okanagan-Kettle region (see **FIGURE 71**), caused by changes in temperature and precipitation that result in wildfires, floods, pests, ecosystem shifts, and other stressors. Although this assessment focuses on climate drivers, human development is another factor that can affect ecosystem connectivity. For the purposes of this assessment, a reduction in ecosystem connectivity is defined by a negative change from present conditions.

**FIGURE 71.** Movement patterns for shrub-steppe and montane species in the Okanagan-Kettle Region (Transboundary Connectivity Group, 2016).

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118 Ecosystem connectivity is defined to include both connectivity between ecosystems within the region and connectivity with ecosystems in surrounding regions.

## Summary of Findings

Ecosystem connectivity is vital for facilitating movements of wildlife populations, maintaining species diversity, and maintaining high-quality habitats. Disconnected habitat fragments can lead to habitat isolation and population decline.

Climate change and human development threaten ecosystem connectivity in the Okanagan-Kettle region by disconnecting and changing species' habitat and causing ecosystem shifts. For areas with decreasing habitat suitability for a species, these changes can cause further isolation of habitats and decline of habitat quality. For areas with increasing habitat suitability for a species, however, climate change could help expand the ecosystem and increase connectivity. All of these shifts could have larger implications for ecosystem services and biodiversity.

**FIGURE 72.** Risk assessment findings for ecosystem connectivity scenario.

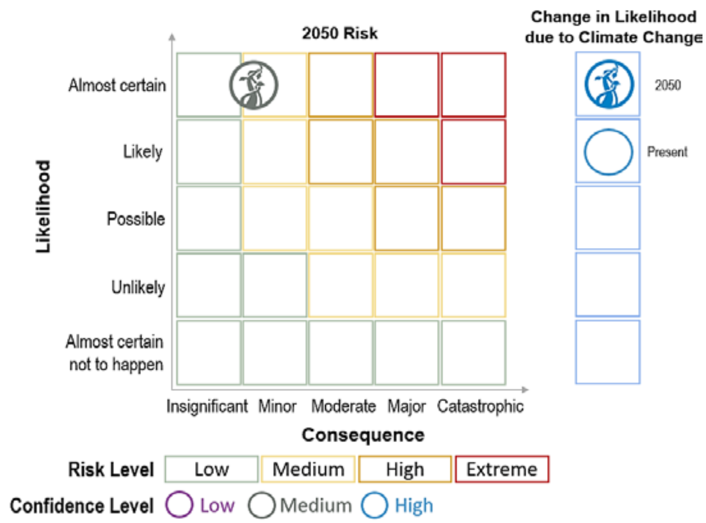



**FIGURE 72** and **TABLE 33** summarize the risk assessment results for this scenario. The highest consequences relate to loss of economic productivity. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 33.** Risk Rating Evaluation for Ecosystem Connectivity Scenario

| REDUCTION IN ECOSYSTEM CONNECTIVITY: REDUCTION IN ECOSYSTEM CONNECTIVITY IN THE OKANAGAN-KETTLE REGION BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **3** | At present, persistent bioclimate envelopes support ecosystem connectivity. | **4** | **Climate-related risk cause:** Changes in temperature and precipitation.<br>**2050 projections:** Climate projections for bioclimate envelopes indicate that ideal climate conditions for high-elevation and high-latitude ecosystems will contract and become more fragmented while climate conditions for low-elevation and low-latitude ecosystems will expand. | Low |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **1** | There is no evidence of loss of life. | High |
| | Morbidity, injury, disease, or hospitalization | **1** | There is no evidence for morbidity, injuries, diseases, or hospitalizations. | High |
| **Social functioning** | Psychological impacts | **2** | Reduction in ecosystem connectivity could cause moderate psychological impacts, and lead to loss of identity or sense of place for some individuals or communities. | Low |
| | Loss of social cohesion | **4** | The scenario could lead to localized and permanent loss of livelihood for some communities. | Low |
| **Natural resources** | Loss of natural resources | **4** | All ecosystems within the Okanagan-Kettle region will experience some degree of climatic shift and change in ecosystem connectivity, which could have implications for ecosystem services and biodiversity. | Medium |
| **Economic vitality** | Loss of economic productivity | **5** | Reduction in ecosystem connectivity could cause long-term disruption and potential job losses for the agriculture, forestry, and tourism industries. | Low |
| | Loss of infrastructure services | **2** | A loss of ecosystem services benefits could require infrastructure as an alternative (e.g., water filtration or flood control). | Low |
| **Cost to provincial government** | | **2** | Costs to government might include replacing lost ecosystem services, damage compensation for increased wildlife pressure on agricultural land, and recovery efforts for declining species or ecosystems. | Low |
| **OVERALL RISK** | **CURRENT** | **MEDIUM (7.9)** | | **LOW** |
| | **2050** | **MEDIUM (10.5)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **7.9** out of 25, which equates to **medium risk**, and the 2050 risk rating is **10.5** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 3 x 2.6 = 7.9 (Medium)

2050 Risk = 4 x 2.6 = 10.5 (Medium)

## Evidence Base

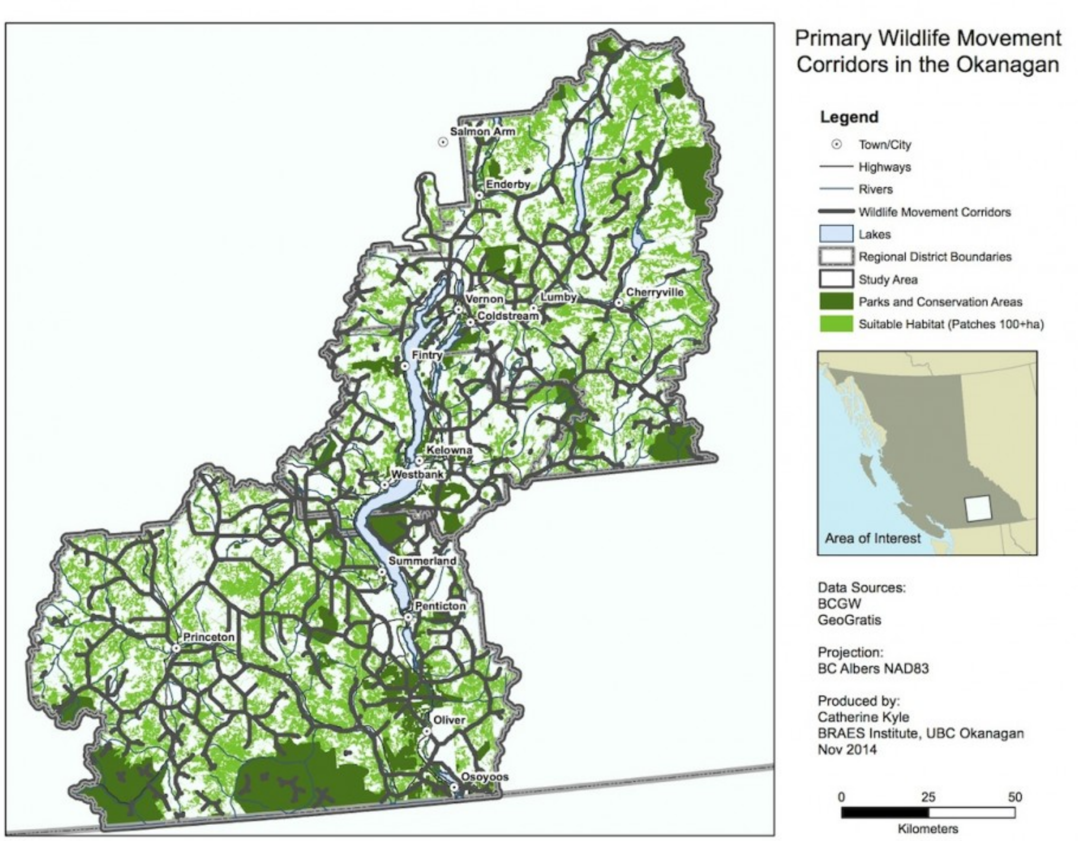
### *Risk Event Scenario*

This scenario represents one illustrative permutation of reduction in ecosystem connectivity in British Columbia. The consequence ratings are specific to this scenario in the Okanagan-Kettle region, but many may be transferable to other related scenarios, such as reductions in connectivity in other regions. Many key species at risk in B.C. are facing ecosystem connectivity challenges across the province, such as Caribou where habitat loss has been compounded by climate change.

The specifics of this scenario were based on:

- The Okanagan-Kettle region is critical for providing north-south connectivity between B.C. and Washington and east-west connectivity between two mountainous areas (Cascade Range to the west and the Monashee Mountains and Kettle Range to the east) (see **FIGURE 71**) (Transboundary Connectivity Group, 2016). The Okanagan-Kettle region currently exhibits a variety of forest habitats at higher elevations and shrub-steppe or grasslands at lower elevations. Lands in the B.C. portion of this region are either Crown lands (parks and protected areas), private land, or Colville Confederated Tribal lands (Transboundary Connectivity Group, 2016).
- Okanagan Valley, located between the Cascade Range and the Columbia Mountains, has experienced extensive human development, which is already beginning to cause ecosystem connectivity issues. For example, montane species are having a harder time crossing the Valley to get from one mountainous environment to another due to losses in grassland environments (Transboundary Connectivity Group, 2016).
- The primary wildlife movement corridors in the Okanagan are shown in **FIGURE 73**.

**FIGURE 73.** Primary wildlife movement corridors in the Okanagan. The corridors are not species-specific and represent routes that the majority of species might use to move across the valley (Parrott, 2014).




- The location of bioclimate envelopes (i.e., ecological and climate distributions) reflects local and regional climate, such as mean annual temperature, which generally corresponds to elevation and latitude (Utzig, 2012). Thus, shifts in temperature or precipitation due to climate change can result in shifts in the location of bioclimate envelopes, which may alter ecosystem connectivity. The project team identified a negative change from present conditions as an appropriate threshold to evaluate reduction in ecosystem connectivity by 2050. Insufficient data precludes consideration of a more specific threshold with certainty. The project team relied on the following studies to assess changes in bioclimate envelopes:

*Washington-British Columbia Transboundary Climate-Connectivity Project* (University of Washington Climate Impacts Group, 2016a): The project included climate modeling of future (2080) vegetation changes in the upland areas of the Okanagan-Kettle region and evaluated the connectivity implications for terrestrial species, including American Marten, Black Bear, Canada Lynx, Lewis's Woodpecker, Mule Deer, Tiger Salamander, White-tailed Ptarmigan, Wolverine, and Bull Trout.

- *Ecosystem and Tree Species Bioclimate Envelope Modeling for the West Kootenays* (Utzig, 2012): The project included modeling of bioclimate envelope shifts by 2050 (2041 to 2070) compared to a 1961 to 1990 baseline in the West Kootenay region, which is directly east of the Okanagan-Kettle region.

- *Projecting future distributions of ecosystem climate niches: Uncertainties and management applications* (Wang T. , Campbell, O'Neill, & Aitken, 2012): The project included modeling of the current (2000 to 2009) and future (2041 to 2070) distributions of 16 bioclimate envelope shifts at the provincial sclae.

## *Likelihood rating*

The present-day likelihood of this scenario is **3** and the 2050 likelihood of this scenario is **4**. At present, persistent bioclimate envelopes (i.e., ecological and climate distributions) support ecosystem connectivity throughout B.C. (Utzig, 2012).

To assess the likelihood of change, the project team evaluated several bioclimate envelope projections as an indicator of future ecosystem dispersion and reduced connectivity in the Okanagan-Kettle region. The project team focused on the bioclimate envelopes supporting Ponderosa Pine Forest, Engelmann Spruce-Subalpine Fir Forest, and Cedar Hemlock Forest because these species are particularly susceptible to climate change and represent an integral part of the regional landscape.

### Likelihood Rating Drivers

Type of risk event: Ongoing

“Present day” period: 1961-1990

Critical threshold: Any reduction in connectivity

Climate change indicator: Projections of bioclimatic envelopes supporting Ponderosa Pine Forest, Engelmann Spruce-Subalpine Fir Forest, and Cedar Hemlock Forest

Source of 2050 projections: Utzig, 2012

Emission scenarios: B1, A1B, A2, and A1FI

However, projected shifts in bioclimate envelopes represent a shift in optimal climate conditions rather than a shift in species location. While existing vegetation will experience increasing stress due to bioclimate envelope shifts, permanent forest change will take decades to complete. As a result, the magnitude of connectivity reduction will likely be low through mid-century, even if some reductions are likely to occur.

The project team additionally considered projected changes to wildfire risk and pests as secondary indicators of ecosystem dispersion and connectivity. These events can act as local tipping points by quickly clearing existing vegetation and facilitating accelerated ecosystem shifts within the affected area.

Ultimately, climate projections for bioclimate envelopes indicate that ideal climate conditions for high elevation and latitude ecosystems (e.g., alpine) will contract and become more fragmented while climate conditions for low elevation and latitude ecosystems will expand. Although the timescales on which ecosystem connectivity may change are not well constrained, the project team assumes that some reduction is likely to occur by 2050. The project team notes more significant changes are likely through the second half of the 21st century. The magnitude of change and whether or not there is a net reduction in ecosystem connectivity is additionally dependent on human development, management practices, and the magnitude of impacts to each ecosystem and the species of interest.

Supporting evidence includes:

- Climate modeling of future (2080) vegetation changes in the upland areas of the Okanagan-Kettle region completed as part of the Washington-British Columbia Transboundary Climate-Connectivity Project found:
  - Reduction of alpine and sub-alpine forest;

- Expansion of mid-elevation needle-leaf forest and temperate mixed-needle and broad-leaf forest; and
- Expansion of drier grassland-shrub habitat (University of Washington Climate Impacts Group, 2016m).

• To the east of the Okanagan-Kettle region, bioclimate envelope modeling for the West Kootenays offers insights on how bioclimate envelopes might similarly shift in the Okanagan-Kettle region (Utzig, 2012). The study used a suite of GCMs to simulate both wet and dry climate change scenarios to project significant bioclimate envelope shifts in the West Kootenay region by 2050 compared to a 1961 to 1990 baseline[119] (Utzig, 2012). In summary, climate change will drive significant bioclimate shifts in the West Kootenays that will affect ecosystem connectivity through mid-century:

- Bioclimate envelopes are generally projected to shift upward in both elevation and latitude as temperatures increase and precipitation patterns change. For example:
  ▪ Projections show a dramatic shift from Subalpine forest and Sub-boreal spruce forest bioclimate envelopes to more Interior Cedar Hemlock forest and grassland bioclimate envelopes.
  ▪ 2080 model projections also show that under the driest climate scenarios, the most common ecosystem climate envelope will shift from Interior Cedar Hemlock to grassland.
- New bioclimate envelopes may also emerge as climate changes, but more research is needed on this topic.

• The Utzig (2012) findings by region and elevation of the West Kootenays for Ponderosa Pine (PP), Interior Cedar-Hemlock Forest (ICH) and Engelmann Spruce-Subalpine Fir Forest (ESSF) are summarized in **TABLE 34**.[120] PP and ICH represent climate envelopes projected to increase by 2050, while ESSF represents one of the climate envelopes projected to decrease by 2050.

**TABLE 34.** Summary of Projected Ecosystem Climate Envelope Shifts for Ponderosa Pine (PP), Interior Cedar-Hemlock Forest (ICH), and Engelmann Spruce-Subalpine Fir Forest (ESSF) in the West Kootenays

| REGION OF WEST KOOTENAYS | ELEVATION BAND | BASELINE MAPPING (1961 TO 1990) | 2050 PROJECTIONS (2041 TO 2070) |
|---|---|---|---|
| North | <1000m | Dominantly ICH | ICH; minor PP |
| North | 1000 to 1500m | Mainly ICH; some ESSF | Mainly ICH |
| North | 1500 to 2000m | Dominantly ESSF | Mostly ESSF; minor ICH |
| North | >2000m | None | Mainly ESSF |
| Mid | <1000m | Dominantly ICH | Very minor ICH and PP |
| Mid | 1000 to 1500m | Dominantly ICH; very minor ESSF | Mainly ICH; very minor PP |
| Mid | 1500 to 2000m | Dominantly ESSF; minor ICH | Some ICH; minor ESSF |
| Mid | >2000m | None | ESSF |
| South | <1000m | Dominantly ICH; very minor ESSF | PP |
| South | 1000 to 1500m | Dominantly ICH, very minor ESSF | Some ICH |

[119] The main results and discussion of this report are focused on 2080 bioclimate projections using the B1, A1B, and A2 emissions scenarios. Appendix 3 provides 2020, 2050, and 2080 bioclimate projections using the A1FI emissions scenario (Utzig, 2012).
[120] The results shown in **TABLE 34** are for the A1FI emission scenario.

| | | | |
|---|---|---|---|
| South | 1500 to 2000m | Dominantly ESSF; minor ICH | Minor ICH |
| South | >2000m | Minor ESSF | Minor ESSF |

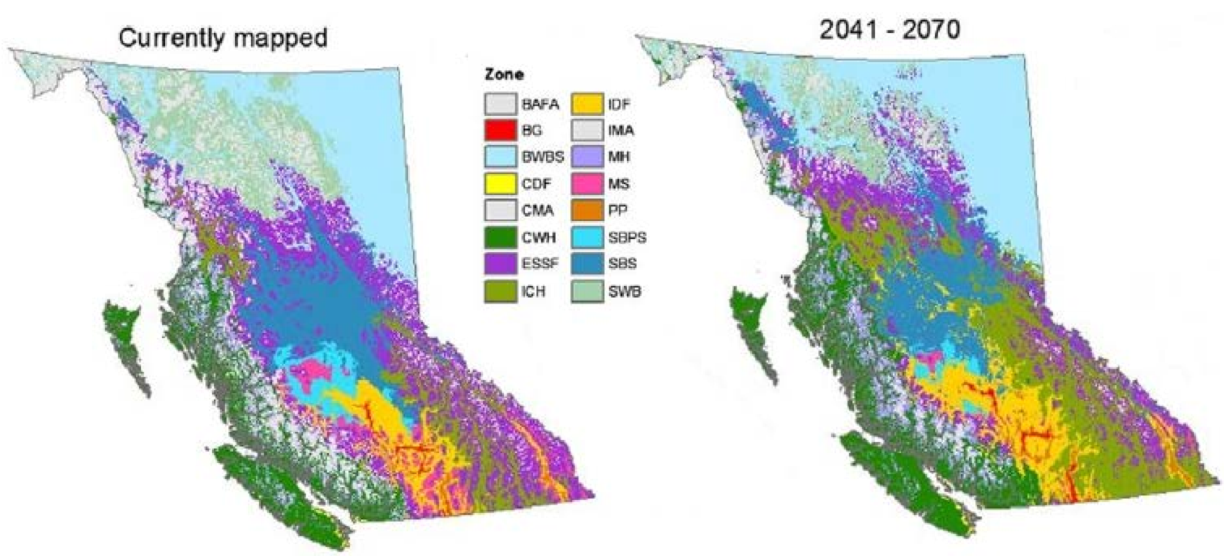
- Changes in hydrology in the Okanagan-Kettle region are also expected to have both positive and negative implications for aquatic and riparian habitat connectivity. The net effect of the following changes on aquatic and riparian habitats is unknown (University of Washington Climate Impacts Group, 2016m):
  - An increase in spring precipitation may increase water availability for ponds and wetland areas, but an increase in spring evapotranspiration may reduce water availability for ponds and wetland areas;
  - A decrease in summer precipitation and spring and summer runoff may reduce water availability for ponds and wetland areas, but a decrease in summer evapotranspiration may increase water availability for ponds and wetland areas;
  - An increase in runoff from extreme precipitation events may decrease habitat quality by causing scour or removing trees and vegetation; and
  - An increase in frost-free days by 2080 in both the valley and upland areas May decrease the amount of runoff reaching ponds and wetland areas. Frost decreases the permeability of soil and allows more runoff to reach ponds and wetland areas.
- Climate projections for the Okanagan-Kettle region also include an increase in the frequency and severity of summer drought, which in turn increases wildfire risk. Wildfires could decrease forest cover areas and potentially cause a shift from forest habitat to grassland and shrub habitat. In addition, changes in temperature, precipitation, and wildfire frequency could facilitate the spread of some invasive species, potentially further degrading preexisting ecosystems and their connectivity (or decrease the prevalence of other invasive species) (University of Washington Climate Impacts Group, 2016m).
- At a provincial scale, **FIGURE 74** shows a map of the current and future distribution of 16 bioclimate envelopes[121] based on climate conditions for the province.
  - The study found that based on historical data, 23% of the province has shifted to climate characteristics of a different ecosystem zone since 1970 (compared to the historic baseline of 2001 to 2009) (Wang T. , Campbell, O'Neill, & Aitken, 2012):
    - The most significant reduction of suitable habitat (46 to 59% of total area) has occurred in Interior Mountain-heather Alpine, Montane Spruce, Sub-Boreal Pine-Spruce, and Spruce-Willow-Birch ecosystem zones.
    - The most significant expansion of suitable habitat (51 to 77%) has occurred in Interior Douglas-fir, Ponderosa Pine, Bunchgrass, and Interior Cedar Hemlock ecosystem zones.
  - For 2050, the 2041 to 2070 map suggests that climate change will continue to exacerbate a shift in climate characteristics, generally in the northward direction, which may alter ecosystem composition (Wang T. , Campbell, O'Neill, & Aitken, 2012). Species located in regions that are

[121] The study includes 16 ecosystem zones and climate envelopes: Boreal Altai Fescue Alpine (BAFA), Bunchgrass (BG), Boreal White and Black Spruce (BWBS), Coastal Douglas-fir (CDF), Coastal Mountain-heather Alpine (CMA), Coastal Western Hemlock (CWH), Engelmann Spruce-Subalpine Fir (ESSF), Interior Cedar-Hemlock (ICH), Interior Douglas-fir (IDF), Interior Mountain-heather Alpine (IMA), Mountain Hemlock (MH), Montane Spruce (MS), Ponderosa Pine (PP), Sub-Boreal Pine-Spruce (SBPS), Sub-Boreal Spruce (SBS), and Spruce-Willow-Birch (SWB).

expected to experience a shift in climate may experience increased stress. The degree to which species will shift with their climate envelope by 2050 is unknown.

- By 2100, over 80% of area climatically suitable for high-elevation (Boreal Altai Fescue Alpine, Interior Mountain-heather Alpine, and Montane Spruce) and sub-boreal (Sub-Boreal Pine-Spruce, Sub-Boreal Spruce, and Spruce-Willow-Birch) ecosystems is projected to be lost.
- Alternatively, area climatically suitable for grasslands (Bunchgrass), dry forested ecosystems (Ponderosa Pine and Interior Douglas-fir), and Interior Cedar Hemlock ecosystems are projected to expand by 2100. Area suitable for Interior Cedar Hemlock ecosystem (ICH in **FIGURE 74**), in particular, is projected to expand three-fold and become the most common climate envelope by 2080 (Wang T. , Campbell, O'Neill, & Aitken, 2012).

**FIGURE 74.** Current geographic distribution of ecosystem zones (1960 to 1991) and projected climate envelope and for 2050 (Wang T. , Campbell, O'Neill, & Aitken, 2012).




### Confidence: Low

Although there are multiple high-quality sources of information, the likelihood of reduction in ecosystem services is dependent on which species and habitats are most of value to B.C., which requires expert judgment. In addition, experts have pointed to flaws in the Wang study that suggest the projected change may be greater than modeled. In particular, the study used a best fit approach and only used ecosystems that currently exist in British Columbia. As a result, future projections may not represent the full scale of change, including any new ecosystem types that could be introduced to the province. Similarly, the bioclimate envelope modeling by Utzig (2012) only considered ecosystems in the West Kootenay region. However, the project team considers that study to be a reasonable analog to the neighbouring Okanagan-Kettle region because it features a similar range of topography and geography.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.6** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (1+1+2+4+4+5+2+2)/8

Overall Consequence = 2.6

### HEALTH

*Loss of life: 1*

Reduction in ecosystem connectivity is not expected to cause loss of life.

**Confidence: High**

There is no evidence across multiple sources that reduction in ecosystem connectivity directly causes loss of life. An indirect effect of reduction in ecosystem connectivity on loss of life, however, could be suicide.

*Morbidity, injury, disease, or hospitalization: 1*

Reduction in ecosystem connectivity is not expected to cause morbidity, injury, disease, or hospitalization.

**Confidence: High**

There is no evidence across multiple sources that reduction in ecosystem connectivity directly causes morbidity, injury, disease, or hospitalization.

### SOCIAL FUNCTIONING

*Psychological impacts: 2*

Reduction in ecosystem connectivity has the potential to cause moderate psychological impacts within the Okanagan-Kettle region, such as feelings of fear, anxiety, and grief over observed changes in ecosystem connectivity as well as the prospect of continued change. In addition, a reduction in ecosystem connectivity could lead to loss of identity/sense of place for individuals whose culture or livelihoods are heavily embedded in the land.

Supporting evidence includes:

- For Indigenous and rural communities that are more connected to and reliant on the environment, psychological impacts could be significant depending on reduction in ecosystem connectivity in that specific location (e.g., loss of certain species or habitats).
  - For example, Indigenous communities who rely upon wildlife and natural foods as an important component of their diet may experience stress or anxiety as food supplies change (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019).
  - Research shows that loss of cultural continuity within Indigenous communities can increase suicide risk (Chandler and Lalonde, 2008).

- Reduction in ecosystem services could also disrupt fishing, especially for Indigenous and rural communities, which may have ripple effects on wellbeing. For example, a decrease in fishing for Indigenous communities affected by a dam breach in 2014 resulted in a shift in diet, physical activity, and cultural practices as well as a decrease in community income and employment opportunities (Shandro et al., 2016).
- Reduction in ecosystem connectivity is likely to continue to increase wildlife pressures on agricultural lands. As habitat suitability and connectivity change, species may become more or less prevalent on agricultural lands (MacNair, 2019).

**Confidence: Low**

There is limited information available on the relationship between reduction in ecosystem connectivity and psychological impacts. In addition, impacts depend on which ecosystems are of value. While higher elevation ecosystems are generally expected to decrease in range, lower elevation ecosystems have the potential to increase in range due to climate change. As a result, this rating relies heavily on expert judgment. Psychological impacts are expected to become more severe as reduction in ecosystem connectivity progresses beyond 2050.

*Loss of social cohesion: 4*

Reduction in ecosystem connectivity has the potential to cause localized and permanent loss of livelihood or way of life, particularly for individuals whose culture or livelihoods are heavily embedded in the land. For example, reduction in ecosystem connectivity could change access to certain species or habitats, which could have implications for traditions or employment opportunities.

Supporting evidence includes:

- For Indigenous and rural communities that are more connected to and reliant on the environment, impacts to social cohesion could be significant depending on reduction in ecosystem connectivity in that specific location (e.g., loss of certain species or habitats). In addition, the ongoing nature of this risk event will cause generational impacts that may alter livelihoods and traditions (Workshop feedback, 2019).
- Indigenous communities who rely upon wildlife and natural foods as an important component of their diet may be challenged to find alternative food sources (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019).
- In addition, reduction in ecosystem connectivity could change employment opportunities tied to natural resources (e.g., fishing) (Shandro et al., 2016).
- As habitat suitability and connectivity change, species may become more or less prevalent on agricultural lands. For example, there would likely be shifts in pollinators, vegetation types, wildlife, and pest populations. These shifts will result in a complex changing production environment for farmers and ranchers, which could affect social cohesion (MacNair, 2019).

**Confidence: Low**

There is limited information available on the relationship between reduction in ecosystem connectivity and social cohesion. In addition, impacts depend on which ecosystems are of value. While higher elevation ecosystems are generally expected to decrease in range, lower elevation ecosystems have the potential to increase in range due to climate change.

## NATURAL RESOURCES: 4

A reduction in ecosystem connectivity could lead to the decline of some ecosystem types and species, particularly those at higher elevations. However, climate suitability for other ecosystems coud expand under climate change, which could increase the abundance and connectivity of some species. Overall, as climate changes, the distribution of species across the region will change, which may negatively affect connectivity, ecosystem services, and biodiversity, especially if species are relocating at different paces or in different directions. Recovery of ecosystem connectivity could take decades, but for high elevation ecosystems, climate change could eventually result in permanent losses.

Supporting evidence includes:

- As the climate changes, the migration of habitats or elements of habitats will cause some species to migrate faster than others. Disjointed migration may decrease habitat quality and negatively affect ecosystem connectivity, especially for species that are reliant on one another (e.g., predator/prey relationships or a specific vegetation type for food or shelter) (Transboundary Connectivity Group, 2016). As a result, reduction in ecosystem connectivity could disrupt ecosystem services and biodiversity.
- In addition, although the Okanagan region accounts for 0.8% of B.C.'s land area, it is home to over 30% of the red listed species in the province and 46% of the blue listed species (Parrott, 2014). These vulnerable species may be threatened by changes in climate and ecosystem connectivity.
- Climate change could have the following influences on climate suitability and ecosystem connectivity:
  - In the Okanagan-Kettle region, climate change may cause the region to become warmer and drier, which overtime may result in a shift from forests areas to shrub-steppe areas. Due to development in grassland areas, the current connectivity between shrub-steppe environments is limited. A shift to more shrub-steppe areas would increase connectivity and movement of shrub-steppe species, but decrease connectivity in forest areas (Transboundary Connectivity Group, 2016).
  - Hotter and drier summers as well as a longer frost-free season are also expected to negatively affect the connectivity of wetland and riparian areas in the Okanagan Valley (Transboundary Connectivity Group, 2016).
  - Climate change can also increase the frequency of disturbances, including extreme events (e.g., wildfires) and the prevalence of pests and disease, which can damage habitats and decrease ecosystem connectivity across the region (Transboundary Connectivity Group, 2016).
  - There are likely to be many ecological cascade effects from reduction in ecosystem connectivity, the specifics of which are unknown (National Round Table on the Environment and the Economy, 2011).
- The Washington-British Columbia Transboundary Climate Connectivity Project assessed the current and future connectivity of a variety of individual terrestrial species using a climate suitability analysis for 2080. The results are summarized in **TABLE 35** and described in further detail in the bullets below.

**TABLE 35.** Washington-British Columbia Transboundary Climate Connectivity Project Summary Findings

| SPECIES NAME | FUTURE CHANGE IN ECOSYSTEM CONNECTIVITY |
|---|---|
| **American Marten** | Negative |

| | |
|---|---|
| **Black Bear** | Negative |
| **Canada Lynx** | Unknown |
| **Lewis's Woodpecker** | Unknown |
| **Mule Deer** | Unknown |
| **Tiger Salamander** | Unknown |
| **White-tailed Ptarmigan** | Negative |
| **Wolverine** | Negative |
| **Bull Trout** | Negative |
| **Whitebark Pine** | Negative |
| **Shrub-steppe Vegetation** | Positive |

- The American Marten (University of Washington Climate Impacts Group, 2016f) and the Black Bear (University of Washington Climate Impacts Group, 2016g) primarily reside in high elevations, using low elevations for movement between core habitats. Projected changes in habitat include:
  - Low-elevation habitat and corridor areas are projected to decrease by 2080, which will increase habitat fragmentation and decrease connectivity and movement between populations on either side of the valley.
  - High-elevation habitat areas are projected to increase by 2080. However, shifts in forest cover and changes in fire and pest prevalence could also cause habitat fragmentation at high elevations.
  - In addition, snow cover is projected to decrease by 2080, which could also affect habitat suitability for both species. The marten relies on snow cover for hunting and thermal insulation. For the black bear, less snow cover may increase the length of the hunting season and shorter hibernation, resulting in more human-bear interactions.
- The Canada Lynx (University of Washington Climate Impacts Group, 2016e) is primarily found in coniferous forests and presently exhibit low habitat connectivity. Projected changes in habitat include:
  - Low- and mid-elevation habitat and corridor areas of the Columbia, Monashee, and Selkirk Mountains, as well as low-elevation habitat and corridor areas of Colville National Forest, river valleys, and Okanagan Valley are all projected to decrease by 2080. A decline in these areas, which are used by lynx to move between key habitats indicates increased fragmentation and isolation of high-elevation areas separated by low-elevation areas. The amount and duration of snow cover in these areas is also projected to decrease, which could decrease the lynx's total habitat and increase fragmentation.
  - However, climate suitability for some areas west of Okanagan Valley is projected to increase by 2080.
  - Although changes in forest cover and species are expected by 2080, the lynx's current range is projected to remain mostly coniferous forest.
  - In addition, although wildfire risk is expected to increase by 2080, lynx prefer regenerating forests and therefore could benefit from an increase in the frequency of wildfire events.
- The Lewis's Woodpecker (University of Washington Climate Impacts Group, 2016i) nests primarily in the transboundary region's ponderosa pine forest during the spring and summer breeding season. Projected changes in habitat include:

- Climate suitability for Okanagan Valley and the lower Monashee Mountains is projected to decrease by 2080.
- Climate suitability for mid-elevation areas east and west of Okanagan Valley is not projected to change by 2080.
- Climate suitability for some high-elevation areas in the Purcell and Rocky Mountains is projected to increase by 2080.
- In addition, although moderate intensity fires are beneficial to ponderosa pine forests, an increase in the frequency and intensity of wildfires by 2080 could be damaging to the habitat. Furthermore, an increase in the prevalence of pests such as mountain pine beetles, spruce budworm, and western pine beetle could also damage the forests.

• The Mule Deer (University of Washington Climate Impacts Group, 2016h) is found in a variety of habitat types and currently exhibits high habitat connectivity.

- Climate suitability modeling for 2080 indicates that the current habitat range in the Okanagan-Kettle region will remain climatically suitable with the exception of the Purcell Mountains.
- However, decreased water availability in ponds and streams as well as increased wildfire risk could cause habitat quality and available vegetation to decrease.

• The Tiger Salamander (University of Washington Climate Impacts Group, 2016j) primarily resides in grassland, shrub-steppe, and open forest areas near water bodies. Tiger salamanders migrate between breeding ponds, foraging areas, and hibernation sites, but only during rainfall events. Projected changes in habitat include:

- Climate suitability of the salamander's current range is projected to remain steady. In addition, climate suitability is projected to increase into higher elevations areas of the Columbia Plateau and Okanagan Valley. However, the salamander has low dispersal ability so it is unknown whether or not it would be able to expand its range.
- Although climate suitability for shrubs and grasslands are projected to remain stable in Okanagan Valley, forest encroachment may also occur, which would decrease habitat connectivity.
- In addition, climate change may decrease the number of breeding ponds or increase the distance between ponds, further decreasing habitat connectivity. Shallow water bodies are particularly at risk.
- Finally, increasing temperatures and decreasing summer precipitation may limit the ability of salamanders to migrate to forage and hibernation sites.

• The White-tailed Ptarmigan (University of Washington Climate Impacts Group, 2016c) is found in high-elevation alpine areas year-round. Habitat connectivity is already low due to scattered patches of alpine habitat. Projected changes in habitat include:

- The overall habitat range is projected to decrease due to loss of alpine habitat as other species shift northward. The rising tree line may also increase existing habitat fragmentation between patches of open alpine habitat.
- Snow cover is also projected to decrease, but the net effect of loss of snow cover on nesting and reproduction is unknown.

• The Wolverine (University of Washington Climate Impacts Group, 2016b) is found primarily in alpine and subalpine habitat and requires deep snowpack for denning and reproduction. Projected changes in habitat include:

- Climate suitability of the majority of the wolverine's current habitat is projected to decrease significantly by 2080. However, some high-elevation habitat areas in the Cascade Range and east of Okanagan Valley are expected to persist, but may become more fragmented.
- In addition, vegetation is projected to shift north and reduce open alpine areas, which wolverines prefer in the summer months.
- Finally, spring snowpack is projected to decrease, which is expected to significantly affect wolverine habitat and result in fewer and more fragmented patches.

- The Bull Trout (University of Washington Climate Impacts Group, 2016k) is found in cold-water streams and is sensitive to changes in stream temperature. Projected changes in habitat include:

- Available habitat is projected to significantly decrease by 2080 causing an increase in habitat fragmentation. Habitat loss is due to lower summer streamflows (decrease in summer precipitation), higher summer stream temperatures (increase in air temperature and decrease in snowmelt runoff), increased egg loss (more frequent and intense rain events), and decreased vegetation to shade the stream (increased frequency and severity of summer drought and wildfire risk).

- Another study finds that warmer water temperatures are similarly expected to decrease the range and abundance of lake trout, which are also sensitive to water temperature (National Round Table on the Environment and the Economy, 2011).
- Whitebark Pine (University of Washington Climate Impacts Group, 2016d) is found in upper subalpine and tree line forests. Projected changes in habitat include:

- Overall climate suitability and habitat availability is projected to decrease by 2080.
- Areas in the Cascades, Coast Range, and the Purcell and North Columbia Mountains are expected to remain climatically suitable, but may become more fragmented.
- Encroachment of other tree species and the spread of many pests and diseases are also expected to decrease habitat connectivity.

- Shrub-steppe vegetation (University of Washington Climate Impacts Group, 2016l) is a key habitat for many species in the region, but has become more fragmented due to development. Projected changes in habitat include:

- Current big sagebrush[122] habitat is projected to remain climatically suitable, while adjacent upland areas are projected to become more climatically suitable for big sagebrush by 2080.
- However, vegetation models also project that some forest vegetation could encroach on the Okanagan Valley and displace shrub-steppe vegetation.
- In addition, an increase in the frequency and intensity of wildfires could prevent seedling establishment and regrowth.
- Shrub-steppe is also threatened by invasive species such as Cheatgrass although the impacts of climate change and wildfire risk on Cheatgrass as well as the implications for shrub-steppe vegetation are unknown.

- Changes in ecosystem connectivity for various species and ecosystems will also negatively affect the ecosystem services provided by these natural resources. See the loss of economic productivity section for more information.

[122] Big sagebrush is a dominant shrub-steppe species.

**Confidence: Medium**

There is an abundance of high-quality research with some degree of agreement. However, the net effect of changes in ecosystem connectivity to various species within the Okanagan-Kettle region is difficult to assess. In addition, existing literature reflects only a small subset of species found in the Okanagan-Kettle region.

## ECONOMIC VITALITY

*Loss of economic productivity: 5*

Reduction in ecosystem connectivity could cause long-term disruptions and potential job losses for the agriculture, forestry, and tourism industries. In addition, there may be significant losses in ecosystem services. When the size or shape of these ecosystems are distorted, whether by direct human use, natural disasters, or climate change, the services provided are often degraded or cease altogether. These services must then be replaced by costly man-made facilities or processes that provide the same services (e.g., the construction of a water treatment plant or shipments of topsoil if forests and vegetation are lost).

Supporting evidence includes:

- The key economic sectors in Okanagan Valley are agriculture, tourism, retail trade, manufacturing, forestry, and construction (Okanagan Valley Economic Development Society, 2013). Agriculture, tourism, and forestry could be particularly affected by changes in ecosystem composition and connectivity.
- Agricultural impacts include:
  - Reduction in ecosystem connectivity could negatively affect agricultural productivity, specifically aquaculture (e.g., salmon) and wild and country foods. As a result, the region may experience a decrease in local supply and sales. At a provincial scale, exports and trade markets could also be affected (Pacific Institute for Climate Solutions, 2011).
  - In addition, reduction in ecosystem connectivity could affect pollinator species, which are important for fertilizing agricultural crops (Mitchell et al, 2013).
  - Increased wildlife pressure on agricultural land due to declining habitat could cause economic damage and loss of productivity (Workshop feedback, 2019).
- Forestry impacts include:
  - Changes in forest composition or increased stress due to climate change could lower forest resilience to other stressors such as pests. As a result, forests may become less productive and less valuable (Johnston et al., 2010).
- Recreational and tourism impacts include:
  - Reduction in ecosystem connectivity could also alter the biodiversity and landscape of recreational and ecotourism areas (e.g., national parks), leading to decreased recreation and tourism revenue (National Round Table on the Environment and the Economy, 2011).
  - If connectivity of streams and aquatic environments decline, recreational angling may also decline, which is an important economic driver especially for rural communities (Morgan, 2018).
  - For example, recreational benefits of natural areas in the Fraser Valley (e.g., wildlife viewing) are estimated at $53.45 per hectare per year (Simon Fraser University Adaptation to Climate Change Team, 2009).

- Properly functioning ecosystems provide an array of free benefits to humans in the form of ecosystem services. These services fall into the broad categories of supporting, provisioning, regulating, and cultural services, and may or may not be directly tied to market activity. Examples of these ecosystem services include: nutrient recycling and soil formation (supporting), timber and crops (provisioning), carbon sequestration and water purification (regulating), and spiritual significance and recreation (cultural).
  - In B.C.'s Lower Mainland alone, it is estimated that ecosystems provide $5.4 billion worth of benefits per year.[123] The top three ecosystem services include: climate regulation ($1.7 billion annually), water supply ($1.6 billion annually), and flood protection ($1.2 billion annually) (Wilson, 2010).
  - Extrapolating to the entire province, ecosystem services provide an estimated annual value of $232 billion.[124]
  - Ecosystem services for the Okanagan region are estimated at $6.7 billion in 2007 dollars (Parrot and Kyle, 2014).
  - It has been shown that decreased connectivity has a negative impact on the provision of ecosystem services, particularly on pollination and pest regulation services, but few studies have attempted to quantify this impact (Mitchell et al, 2013).
- Alternatively, unique and vulnerable species may also move northward from the U.S., which could add new existential value and ecosystem services (Workshop feedback, 2019).

**Confidence: Low**

It is inherently challenging to assign a value to ecosystem services and connectivity. As a result, this rating relies heavily on expert judgment.

*Loss of infrastructure services: 2*

Reduction in ecosystem connectivity may cause a loss of ecosystem services benefits that require infrastructure as an alternative (e.g., water filtration or flood control). The scale of impact will vary depending on local conditions.

Supporting evidence includes:

- If an affected ecosystem provides water filtration services to a community, the loss or decline of that ecosystem may require more water treatment infrastructure to filter the water (Workshop feedback, 2019).
  - For example, water filtration benefits from Fraser Valley wetlands are estimated at $452 to $1,270 per hectare per year (Simon Fraser University Adaptation to Climate Change Team, 2009).
- In addition, certain ecosystems can help with flood control and erosion. The loss or decline of these ecosystems may require more flood control infrastructure (Workshop feedback, 2019).

**Confidence: Medium**

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[123] Values in present-day, 2018 CAD.
[124] This extrapolation was conducted by scaling the values for B.C.'s Lower Mainland (Wilson, 2010) to the entire area of British Columbia.

There is limited evidence that directly links reduction in ecosystem connectivity to loss of infrastructure services. In addition, the scale of loss is dependent on local conditions and access to alternatives.

### COST TO PROVINCIAL GOVERNMENT: 2

Reduction in ecosystem connectivity could cause a loss of key ecosystem services, which the government may be responsible for replacing (e.g., filter air and water, capture runoff, fertilize plants). Given the gradual nature of ecosystem shifts, a significant reduction in ecosystem services is not expected by 2050. Other costs could include damage compensation from increased wildlife pressure on agricultural land and recovery efforts for declining species or ecosystems. As a result, costs to government are expected to be on the order of $375 million or less.

Supporting evidence includes:

- Ecosystem services in the Okanagan region are estimated at $6.7 billion per year. Therefore, a loss of ecosystem services could cost the government up to $6.7 billion to replace the services provided by a fully functioning ecosystem (e.g., filter air and water, capture runoff, fertilize plants, etc.) (Parrot and Kyle, 2014; Okanagan Institute for Biodiversity, Resilience and Ecosystem Services, 2016). The portion of ecosystem services that would be lost by 2050 is unknown.
- Due to increased wildlife pressures on agricultural land, the government may be responsible for Agricultural Wildlife Damage Compensation. In 2014, the province contributed about $1 million while the Government of Canada contributed about $1.5 million (B.C. Ministry of Agriculture, 2013).
- Another potential cost to the provincial government is recovering populations of endangered species that have lost ecosystem connectivity (Workshop feedback, 2019).

**Confidence: Low**

There is limited information available on costs to government from reduction in ecosystem connectivity. As a result, this rating relies heavily on expert judgment.

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# Increase in Invasive Species

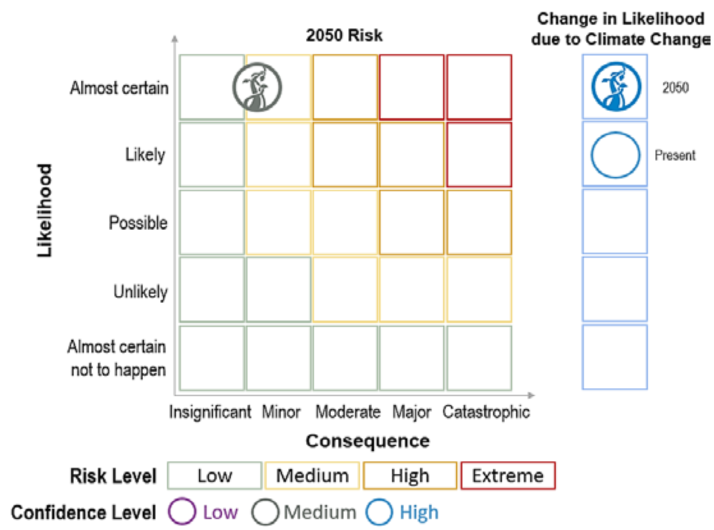
## Scenario

The specific scenario analyzed is the expansion of invasive knotweed (i.e., Japanese Knotweed, Giant Knotweed, Bohemian Knotweed,[125] and Himalayan Knotweed) across B.C. caused by increasing temperatures. Knotweed is tolerant of a range of soil types and climate conditions and is currently found in southern B.C., including Vancouver Island, Central Coast, Sunshine Coast, North Coast, Lower Mainland, Nechako, Cariboo, Thompson-Okanagan, and the Kootenays.

## Summary of Findings

Knotweed is identified by the International Union for Conservation of Nature as one of the world's 100 worst invasive species (Invasive Species Council of B.C., 2017). Knotweed is native to Asia and was first introduced to B.C. as an ornamental plant (Invasive Species Council of B.C., 2017). Knotweed is now one of the primary invasive species B.C. is working to control, in part due to its ability to grow through concrete and asphalt, which can cause significant damage to infrastructure (Invasive Species Council of B.C., 2017).

**FIGURE 75.** Risk assessment findings for invasive species scenario.




All four species of knotweed found in B.C. are invasive, but Bohemian Knotweed is the most aggressive in terms of its dispersal ability and the difficulty involved in killing and removing it (Schaefer, 2015). Knotweed currently occupies only a small fraction of its total potential range, but as temperatures increase knotweed is expected to expand its range by 2050, which may have negative consequences for infrastructure integrity and the health and abundance of native species. However, the potential consequences of knotweed expansion can be managed as long as its spread is controlled.

**FIGURE 75** and **TABLE 36** summarize the risk assessment results for this scenario. The highest consequences relate to loss of natural resources. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

[125] Bohemian Knotweed is a hybrid of Japanese Knotweed and Giant Knotweed and the fastest spreading of the four species due to its ability to spread via both fragment regeneration and wind-dispersed seeds.

**TABLE 36.** Risk Rating Evaluation for Invasive Species Scenario

| INCREASE IN INVASIVE SPECIES: EXPANSION OF KNOTWEED BY 2050 | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **4** | Knotweed occupies a small percentage of its current potential range and is already likely to spread at present. | **5** | **Climate-related risk cause:** Increased temperatures.<br>**2050 projections:** Increasing temperatures, precipitation, and growing degree days are almost certain to facilitate spread of knotweed and further expand potential range without control measures. | High |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **1** | There is no evidence that knotweed causes loss of life. | High |
| | Morbidity, injury, disease, or hospitalization | **2** | Fewer than 10 people could experience injury or hospitalization as a result of poor knotweed management. | Medium |
| **Social functioning** | Psychological impacts | **2** | The invasion of knotweed into homes or businesses could cause localized and moderate feelings of fear and anxiety given the potential extent of damage and difficulty and expense of treatment. | Low |
| | Loss of social cohesion | **2** | Knotweed control could minimally affect daily life. In addition, if knotweed is poorly managed, there could be minor erosion of public trust in government. | Low |
| **Natural resources** | Loss of natural resources | **3** | Knotweed can quickly outcompete existing vegetation and may be detrimental to certain species or ecosystems. Prolonged herbicide treatment could damage the surrounding ecosystem. | Medium |
| **Economic vitality** | Loss of economic productivity | **1** | Loss of economic productivity is assumed to be low. If knotweed is untreated, it could damage business infrastructure or disrupt agriculture and the movement of goods. | Low |
| | Loss of infrastructure services | **1** | Knotweed management could be a nuisance to transportation asset owners, but would not cause disruptions to infrastructure services or daily life unless severely untreated. | Low |
| **Cost to provincial government** | | **2** | Costs to government would include knotweed treatment and disposal costs on Crown lands. | Low |
| **OVERALL RISK** | **CURRENT** | **MEDIUM (7.0)** | | **MEDIUM** |
| | **2050** | **MEDIUM (8.8)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **7.0** out of 25, which equates to **medium risk**, and the 2050 risk rating is **8.8** out of 25, which equates to **medium risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 4 x 1.8 = 7.0 (Medium)

2050 Risk = 5 x 1.8 = 8.8 (Medium)

## Evidence Base

### *Risk Event Scenario*

Knotweed is designated as "provincially noxious" under the Weed Control Act[126] and regulated under the Forest and Range Practices Act[127] and the Community Charter[128] (Invasive Species Council of B.C., 2017). Knotweed is just one example of an invasive species that could expand in B.C. due to climate change. Other invasive species could include, for example, cheatgrass or puncture vine. The likelihood and consequence ratings here are specific to this scenario.

The specifics of this scenario were based on:

- **Habitat:** Knotweed is found primarily in moist areas such as riparian areas and low-lying areas, but also on derelict land, road and railway rights of way, ditches, irrigation channels, forest edges, and gardens. Knotweed is tolerant of challenging environmental conditions, including shade, high salinity, high heat, and drought. Although knotweed can tolerate a range of soil types and climate conditions, it most prefers moist soil and full or partial sun (Invasive Species Council of B.C., 2017; Invasive Species Council of B.C., 2016; Invasive Species Council of B.C., 2018; Metro Vancouver and the Invasive Species Council of Vancouver, 2018).
- **Reproduction:** Knotweed reproduces rapidly either by regeneration from root and stem fragments or by viable seed. The root system from one parent plant can spread up to three metres deep and 20 metres wide. For Bohemian Knotweed in particular, reproduction can also occur via wind-dispersed seeds. Germination rates for Bohemian Knotweed seeds are nearly 100% in some areas. As a result, knotweed can spread easily and quickly (Invasive Species Council of B.C., 2017).
- **Dispersal:** Knotweed fragments and seeds are spread via contaminated equipment and soil, improper disposal of removed plant material, wind, wildlife, cutting and mowing, flooding events, and the sale, purchase, or trade of knotweed plants (Invasive Species Council of B.C., 2017).
- **Control:** Knotweed can be managed and controlled through herbicide treatment and other methods. However, there are some limitations to knotweed treatment: for example, knotweed in riparian zones cannot be legally treated with herbicides due to the highly sensitive nature of riparian environments (B.C. Ministry of Forests and Range, 2010).

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[126] The Weed Control Act requires all land occupiers to control the spread of provincial and/or regional noxious weeds on their land and premises (Invasive Species Council of B.C., 2016).
[127] The Forest and Range Practices Act requires forest and range managers to specify and implement measures that prevent the introduction or spread of invasive plants within their forest stewardship plans, woodlot license plans, range use plans, and range stewardship plans (Invasive Species Council of B.C., 2016).
[128] The Community Charter enables municipalities to impose legislation for the control of invasive plants (Invasive Species Council of B.C., 2016).

### *Likelihood rating*

**Likelihood Rating Drivers**

Type of risk event: Ongoing

"Present day" period: 1980-1999

Climate change indicator: Degree days above 0

Critical threshold: 2,505 degree days above 0

Source of 2050 projections: Project team analysis of downscaled GCM data from PCIC

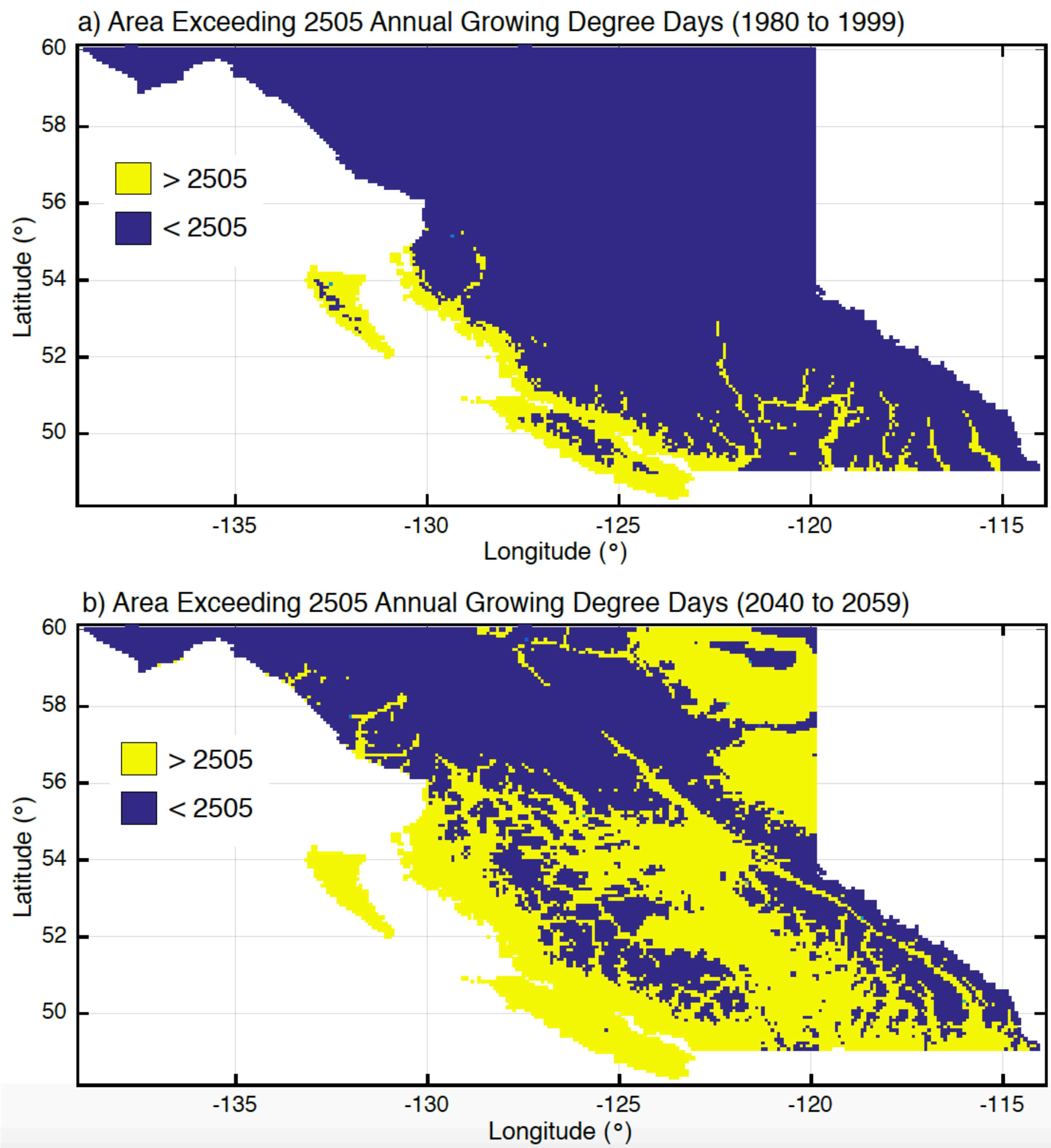
Emission scenario: RCP8.5

The present-day likelihood of this scenario is **4** and the 2050 likelihood of this scenario is **5**. Knotweed currently occupies only 25% to 36% of its potential range. As a result, the spread of knotweed is likely, even under the current climate. To evaluate the likelihood of further knotweed expansion, the project team considered climate thresholds determining current and future knotweed range, including a threshold based on annual degree days above 0°C. The project team also evaluated changes in underlying climate-related causes for knotweed expansion, including increasing air temperatures and precipitation. The geographic extent considered in this scenario is confined to regions where climate is conducive to knotweed habitat. This includes the majority of southern B.C. (approximately south of 54°N latitude), including coastal B.C., large swaths of the Central Plateau, and low-lying valley locations in the Rocky Mountains and Coastal Range. Looking forward, increasing annual temperature, precipitation, and growing degree days will almost certainly facilitate the spread of knotweed across the province by mid-century.

Supporting evidence includes:

- There are three key climate thresholds for determining the potential range of Japanese Knotweed. Japanese Knotweed requires (Bourchier & Van Hezewijk, 2010):
  - At least 2,505 annual degree days above 0°C
  - At least 735 mm of annual precipitation
  - Minimum annual temperatures above 30.2°C
- The annual degree day threshold produces the smallest range of Japanese Knotweed and therefore represents the most conservative estimate for its future range. Using the degree-day threshold of 2,505 degree days, 12% of B.C. is suitable for Japanese Knotweed based on temperature observations over the historical baseline time period (1971 to 2000). Of the suitable habitat area, about 50% has been colonized (Bourchier & Van Hezewijk, 2010). Alternatively, 26% and 36% of B.C. is currently suitable for Japanese Knotweed based on the minimum temperature and precipitation thresholds, respectively (Bourchier & Van Hezewijk, 2010).
- Climate models project that the number of growing degree days favourable to knotweed growth will increase dramatically by mid-century (see **FIGURE 76**). During the baseline period (1980 to 1999), conditions favourable to knotweed were confined to low-lying coastal and southern valley locations. By mid-century, the majority of the central plateau, northeast, and coastal British Columbia will experience temperatures supporting at least 2,505 annual growing degree-days relative to 0°C. This increase will potentially facilitate widespread expansion of knotweed in these regions.

**FIGURE 76.** Projected areal extent for annual growing degree days (GDD) base 0°C exceeding 2,505 for the baseline time period (1980 to 1999) and mid-century (2040 to 2059). Yellow shading represents areas exceeding the 2,505 GDD threshold. Analysis uses the CanESM2 GCM and assumes RCP8.5.

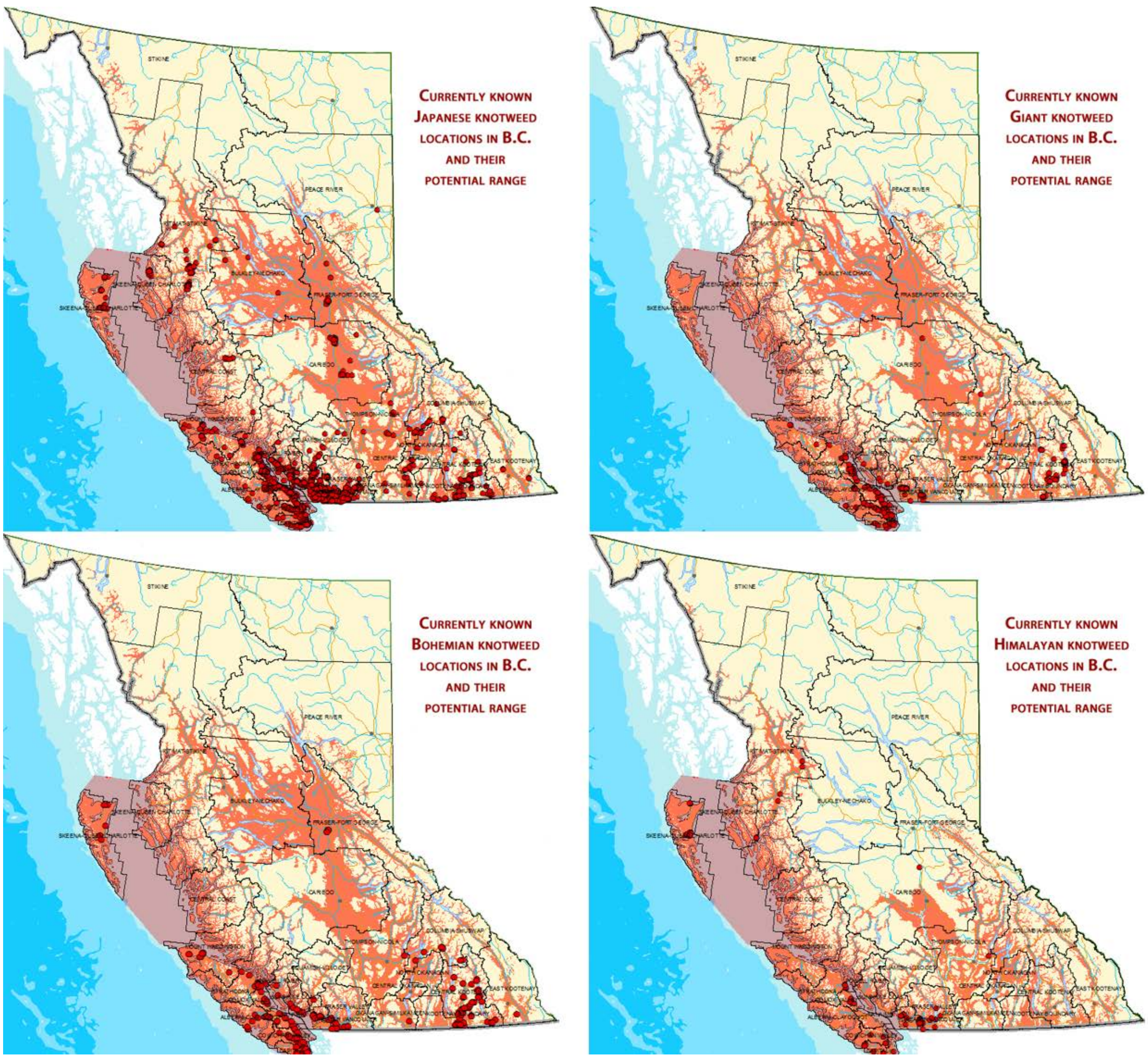



- **FIGURE 77** summarizes another study assessing the current and potential ranges for all four knotweed species (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural

Development Invasive Plant Program, No date). These maps are based on a study of habitat suitability, which revealed that:

- 36% of the province offers suitable habitat for Japanese Knotweed, Giant Knotweed, and Bohemian Knotweed. However, the current ranges are only 739 ha, 15.5 ha, and 15.8 ha, respectively, of the potential 36,581,112 ha.
- 25% of the province offers suitable habitat for Himalayan Knotweed. However, the current range is only 14.7 ha of the potential 25,573,705 ha.

**FIGURE 77.** Known and potential ranges of Japanese Knotweed (top left), Giant Knotweed (top right), Bohemian Knotweed (bottom left), and Himalayan Knotweed (bottom right). The red dots indicate currently known locations of



knotweed and the orange shading indicates potential range (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development Invasive Plant Program, No date).

- Temperature, precipitation, and growing degree day projections all suggest climate in B.C. will be more favourable to an extended knotweed range by mid-century relative to the 1961 to 1990 baseline (Pacific Climate Impacts Consortium, 2012), including an increase in annual mean temperature (and associated growing degree-days and minimum temperatures), and annual precipitation.

**Confidence: High**

There is widespread agreement among multiple sources of independent evidence that knotweed will expand its range by 2050.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **1.8** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (1+2+2+2+3+1+1+2)/8

Overall Consequence = 1.8

### HEALTH

*Loss of life: 1*

Knotweed expansion is not expected to cause loss of life.

**Confidence: High**

There is no evidence across multiple sources that knotweed causes loss of life.

*Morbidity, injury, disease, or hospitalization: 2*

Although knotweed is not expected to cause direct harm, less than 10 people could experience injury or hospitalization as a result of poor knotweed management. For example, if herbicide application regulations are not followed properly or if transportation corridors, septic systems, and other infrastructure are not maintained to clear excess vegetation, there is a minor possibility for harm (e.g., traffic accidents due to obstructed sightlines).

Supporting evidence includes:

- Chemical control of knotweed using herbicides is the most effective treatment method of knotweed. Although herbicide exposure could potentially cause negative health consequences, the chemical treatment of knotweed is highly regulated to ensure a low risk to the environment and public health (B.C. Ministry of Transportation and Infrastructure and B.C. Ministry of Forests, Lands, and Natural Resource Operations, 2016; Metro Vancouver and the Invasive Species Council of Vancouver, 2018).

- Significant overgrowth of knotweed can obstruct sightlines and road signs along transportation corridors, which could result in traffic accidents and related injuries or hospitalizations (Invasive Species Council of B.C., 2017).
- Infrastructure damage to homes (e.g., foundation, septic system) also has the potential to cause minor health and safety risks if not maintained (Invasive Species Council of B.C., 2016).

**Confidence: Medium**

Existing literature and expert input support limited potential for harm unless knotweed is poorly maintained. The potential for obstructed sightlines or herbicide exposure is dependent on individual behaviour and whether knotweed is being appropriately treated or maintained.

## SOCIAL FUNCTIONING

### *Psychological impacts: 2*

The invasion of knotweed into homes or businesses could cause localized and moderate feelings of fear and anxiety for those with knotweed on or near their property given the potential extent of damage and difficulty and expense of treatment.

Supporting evidence incudes:

- Knotweed can cause significant damage to homes or businesses by growing through building foundations, concrete retaining walls, septic systems, and drains (Invasive Species Council of B.C., 2017; Invasive Species Council of B.C., 2016). This may cause stress or anxiety for property owners that have knotweed on or near their property.
- Knotweed on private property is the responsibility of the property owner to treat, which can be difficult and expensive. In addition, treatment can last for 3 to 5 years, which may cause ongoing stress or anxiety (Wallin, 2019; B.C. Ministry of Transportation and Infrastructure, 2018). See the cost to provincial government section for additional details on management costs.
- In the United Kingdom, the presence (or nearby presence) of knotweed can decrease property values and may prevent homeowners from securing a mortgage (Invasive Species Council of B.C. , Undated). Although this is not yet documented in Canada, there are concerns that the presence of knotweed will decrease property values and make it more difficult to sell land in the future (Wallin, 2019).

**Confidence: Low**

There is little information available on the psychological impacts of knotweed. As a result, the rating relies heavily on expert judgment.

### *Loss of social cohesion: 2*

Although knotweed is a nuisance to treat, it is generally the responsibility of the individual property owner and therefore would only minimally affect social cohesion. The government is, however, responsible for treating knotweed on Crown land so there is a minor possibility for erosion of public trust in government if knotweed is poorly managed. There is some evidence that knotweed could affect daily life, but only under extreme circumstances and for a limited number of people.

Supporting evidence incudes:

- Potential impacts to daily life include:
  - Significant overgrowth of knotweed can obstruct sightlines and road signs along transportation corridors (Invasive Species Council of B.C., 2016). However, if knotweed is being treated or maintained along roadways, this is not an issue.
  - Knotweed can cause significant damage to homes or businesses by growing through building foundations, concrete retaining walls, septic systems, and drains, which would disrupt daily life for the property owner to repair the damage (Invasive Species Council of B.C., 2017; Invasive Species Council of B.C., 2016). However, if knotweed is treated or maintained before significant damage occurs, these impacts can be avoided.
  - Inadequate treatment of knotweed on neighbouring land could lead to tension between neighbours, business owners, or the government depending on the owners of the two neighbouring parcels of land (Workshop feedback, 2019).
  - Many Indigenous communities are located in riparian zones and are already experiencing the impacts of knotweed on community infrastructure and reserve lands (Wallin, 2019). Herbicide treatment is not allowed within riparian zones, making knotweed more challenging to control (B.C. Ministry of Forests and Range, 2010).
- Minor erosion of public trust in government is possible if knotweed is poorly managed on Crown lands (Miller, 2019).

**Confidence: Low**

Evidence across multiple sources supports that knotweed generally causes only minimal disruptions to daily life for most people (e.g., obscured traffic signs). However, this rating assumes that knotweed is not growing uncontrollably in communities. Significant damage to property or significant overgrowth on municipal or Crown lands may cause more significant erosion in public trust of government and social cohesion.

### NATURAL RESOURCES: 3

Knotweed can quickly overtake and outcompete existing vegetation and therefore can be detrimental to certain species and ecosystems. In addition, knotweed is difficult to control and may require multiple applications of herbicide, which could damage surrounding ecosystems. As a result, removal of knotweed and recovery of native species could take years.

Supporting evidence includes:

- Knotweed can grow three metres tall in one growing season, quickly outcompeting local and native vegetation for sunlight and other resources (Schaefer, 2015; Invasive Species Council of B.C., 2017).
- In addition to the impacts directly related to its rapid growth, knotweed releases allelopathic substances (biochemicals) to suppress the growth of surrounding plants, often completely displacing native vegetation (Murrell et al., 2011).
- As a result, knotweed creates dense monocultures, which reduce available habitat for other species and decrease biodiversity (Invasive Species Council of B.C., 2017; Metro Vancouver and the Invasive Species Council of Vancouver, 2018).
- Knotweed growth can also destabilize riverbanks (Murrell et al., 2011). Knotweed prefers to grow in riparian areas, but the roots do not bind to the soil so they cause erosion and stream sedimentation

near waterways (Invasive Species Council of B.C., 2017). In addition, knotweed in riparian zones cannot be legally treated with herbicides due to the highly sensitive nature of riparian environments (B.C. Ministry of Forests and Range, 2010). As a result, it is difficult to curb knotweed growth in these areas.

- Finally, herbicide use to control knotweed may negatively affect surrounding plants and wildlife, especially if it is used improperly (Metro Vancouver and the Invasive Species Council of Vancouver, 2018). Eradication of knotweed using chemical controls or another approach typically requires a multi-year management plan since small fragments have the ability to regenerate (Invasive Species Council of B.C., 2017). For example, herbicides will need to be applied multiple times to successfully kill the plant. As a result, as knotweed spreads, more natural resources may be vulnerable to chemical exposure.

**Confidence: Medium**

Although there are several supporting resources regarding impacts to natural resources, the typical recovery time for various affected ecosystems remains a knowledge gap. In particular, knotweed in riparian areas cannot be treated with herbicides. The implications of this policy in terms on loss of natural resources in riparian areas due to knotweed are unknown.

## ECONOMIC VITALITY

### *Loss of economic productivity: 1*

If knotweed is left untreated, it has the potential to damage business infrastructure or disrupt agriculture and the movement of goods. However, loss of economic productivity from knotweed alone is assumed to be low. The consideration of multiple noxious weeds or multiple invasive species would likely warrant a higher rating.

Supporting evidence includes:

- Knotweed could cause significant damage to businesses by growing through building foundations, concrete retaining walls, septic systems, and drains (Invasive Species Council of B.C., 2017; Invasive Species Council of B.C., 2016). Long-term maintenance or treatment could detract from business profits.
- Knotweed could pose an increasing challenge for agricultural producers in their efforts to manage and clean drainage ditches (Workshop feedback, 2019).
- Knotweed could also disrupt the movement of goods and services via damage to transportation infrastructure (Invasive Species Council of B.C., 2017). Long-term maintenance or treatment of knotweed could add to maintenance costs.

**Confidence: Low**

There is limited information available on the economic costs of knotweed. An economic analysis on specific costs to agriculture, transportation, and other sectors is necessary to better quantify the impact. However, based on existing literature and expert judgment, loss of economic productivity is assumed to be low.

*Loss of infrastructure services: 1*

Knotweed would not disrupt infrastructure services unless it is uncontrolled or untreated and causes significant damage. However, asset managers are likely to maintain infrastructure and treat knotweed before it becomes a significant problem. As a result, knotweed can be considered a nuisance to transportation asset owners and would not cause disruption to daily life.

Supporting evidence includes:

- Knotweed can grow through concrete and asphalt, which can cause significant infrastructure damage if left untreated. Knotweed can cause reduced stability and integrity to (Invasive Species Council of B.C., 2017):
  - Bridge foundations and abutments
  - Roadways
  - Rail beds
  - Pipes
- Municipalities and private landowners are likely to be responsible for most of these costs (Wallin, 2019).

**Confidence: Low**

There is limited information available on the impacts of knotweed to infrastructure services. This rating assumes that asset owners will control knotweed before it can cause significant damage.

### COST TO PROVINCIAL GOVERNMENT: 2

An expanded range for knotweed due to climate change indicates that control costs could increase over time. While most of these costs will be borne by municipalities and private landowners, the province is responsible for knotweed management on Crown lands. Based on costs of knotweed control for Metro Vancouver, the extrapolated cost to the provincial government at the provincial scale is more reasonably around $1,000,000 and therefore costs are expected to be on the order of $375 million or less.

Supporting evidence includes:

- The province is only responsible for knotweed treatment costs on Crown lands. As a result, municipalities and private landowners will also bear a significant portion of the knotweed control costs (Wallin, 2019).
- Knotweed treatment can take 3 to 5 years to complete (Invasive Species Council of B.C., 2017). Average control costs are about $300 per site for infestations along roadsides and a minimum of $500 per site for locations along waterbodies that require additional preparation, permitting, and specialized treatment approaches (Miller, 2019). Treatment costs can reach as high as $1,000 to $5,000 for herbicide treatment and $30,000 to $200,000 for excavation (B.C. Ministry of Transportation and Infrastructure, 2018).
- In 2018, Crown land sites accounted for approximately 45% of total knotweed sites treated in British Columbia. Waterbody sites account for about 5% of Crown sites treated to date (Miller, 2019).
- Types of treatment and disposal costs include:
  - Herbicide treatments;
  - Excavation and extraction;

- Repairs for infrastructure damage; and
- Proper disposal (Wallin, 2019).

- Knotweed control efforts in 2016 for Metro Vancouver from both local and provincial governments totaled more than $660,000 (Metro Vancouver and the Invasive Species Council of Vancouver, 2018). To approximate the rough order of magnitude of the total cost to the provincial government, the project team calculated and extrapolated the following figures from the 2016 cost to Metro Vancouver:
    - The cumulative cost to Metro Vancouver over the next 35 years assuming no increase in control costs would be $23,100,000.
    - A 4% increase in costs for Metro Vancouver would meet the $1,000,000 threshold for a 2 rating, while a 43% increase in costs would meet the $10,000,000 threshold.
    - If costs scale by population, the project team also extrapolated the cost to Metro Vancouver for B.C. using population data from the 2016 census for Metro Vancouver and British Columbia. Using this method, the annual cost of knotweed control to B.C. would be approximately $1.3 million and the cumulative cost over the next 35 years assuming no increase in control costs would be about $44 million.
    - Based on these estimates for the province, a mere 2% increase in knotweed control costs for B.C. would meet the $1,000,000 threshold, while a 22% increase in costs would meet the $10,000,000 threshold.
    - Therefore, the project team estimated that the cumulative increase in knotweed control costs by 2050 due to climate change would be between $1 million and $10 million, and justify a rating of 2.
- In the United Kingdom, the annual control cost of Japanese Knotweed is estimated at $3 billion (Invasive Species Council of B.C., 2017).
- Other potential costs include the recovery of sensitive species and ecosystems (Workshop feedback, 2019).

**Confidence: Low**

There is little public information available on cost to the provincial government at the provincial scale. As a result, the rating is based on data extrapolation and expert judgment.

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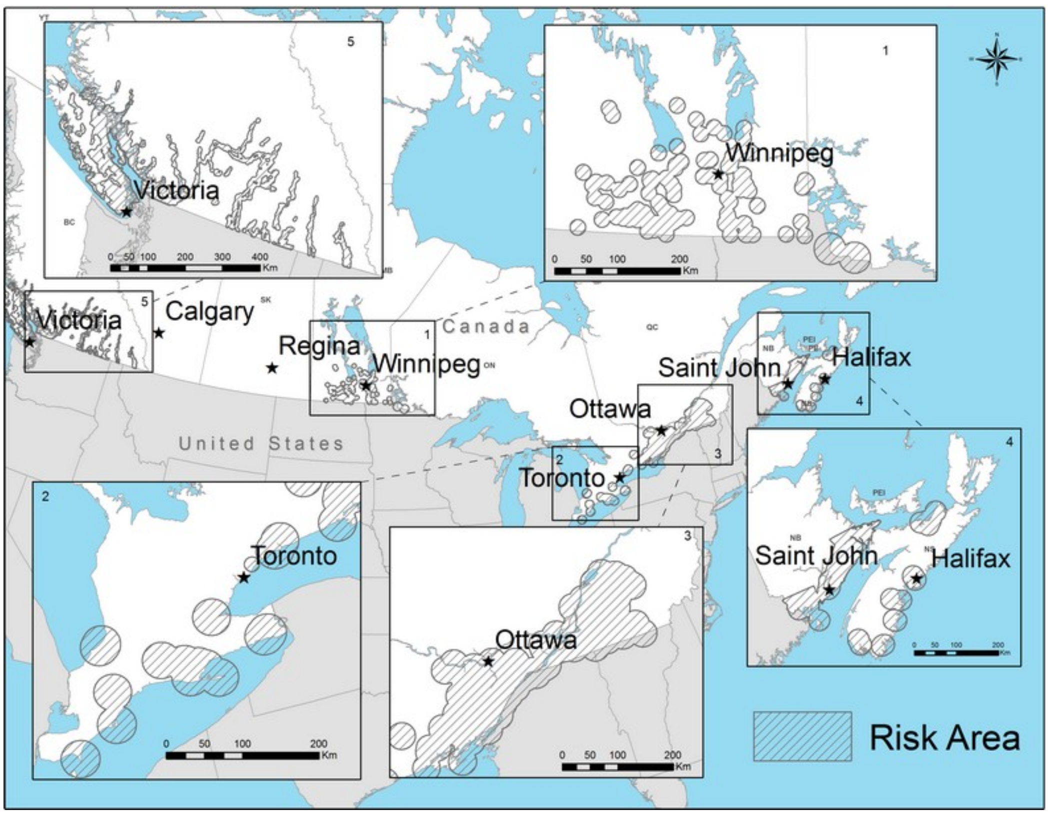
# Increased Incidence of Vector-borne Disease

## Scenario

The specific risk event scenario analyzed is at least a doubling of Lyme disease cases within B.C. over three years, occurring before 2050. Changes in temperature and precipitation[129] could allow *Ixodes pacificus* ticks to spread across the province of British Columbia, primarily starting in the areas currently supporting tick populations (the lower mainland and southern Vancouver Island) and moving eastward and northward. **FIGURE 78** shows the areas of the country where Lyme disease is already a risk. In B.C., this is primarily in the southwestern corner of the province.

**FIGURE 78.** Lyme disease risk areas in Canada (Government of Canada, 2018b).

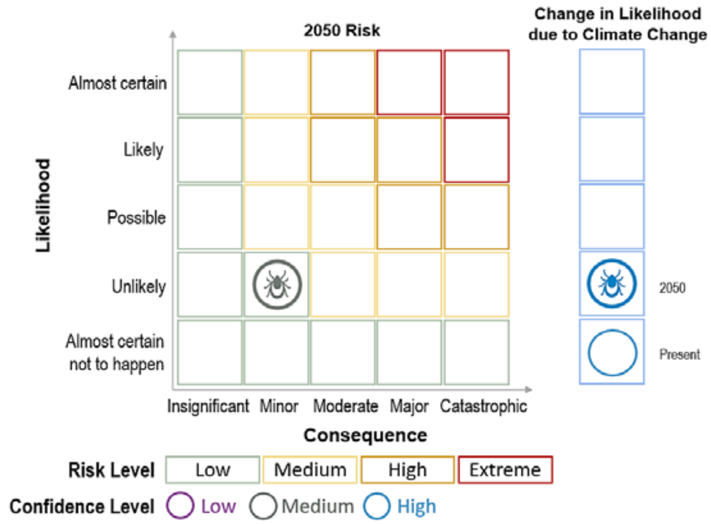



[129] Little research is available on the climate drivers for *Ixodes pacificus*, and how ticks may be affected by climate change, as confirmed by expert interviews.

## Summary of Findings

The risk of Lyme disease in B.C. has remained relatively low while it has spread rapidly in the eastern part of the country. At least a doubling in the number of cases of Lyme disease within a three-year period would reflect a rapid increase in infection similar to what has occurred in eastern Canada. However, the likelihood of a doubling in Lyme disease is low according to available evidence and expert opinion.

**FIGURE 79.** Risk assessment findings for vector-borne disease scenario.




Lyme disease can lead to severe and chronic health symptoms. In addition, those affected could experience disenfranchisement and depression due to misdiagnosis or persistent morbidity. Individuals affected by Lyme may not be able to participate in school, work, or other elements of society, contributing to economic losses and loss of well-being. The costs to government to treat Lyme patients and increase prevention activities could also increase.

**FIGURE 79** and **TABLE 37** summarize the risk assessment results for this scenario. The highest consequences relate to morbidity, disease, and hospitalization; and psychological impacts. Additional details on the likelihood of the scenario, its consequences, and the supporting evidence base for these ratings are provided in the sections below.

**TABLE 37.** Risk Rating Evaluation for Lyme Disease Scenario

| INCREASED INCIDENCE OF VECTOR-BORNE DISEASE: AT LEAST A DOUBLING OF LYME DISEASE CASES | | | | |
|---|---|---|---|---|
| **LIKELIHOOD** | | | | |
| **CURRENT RATING** | **JUSTIFICATION** | **2050 RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **1** | The risk in B.C. is low (<0.5 cases per 100,000 population, <1% tick infection rate). The rate of infection has been stable for decades. | **2** | **Climate-related risk cause:** Temperature and precipitation influence tick behavior and range.<br>**2050 projections:** Warmer conditions could increase host-seeking activity, change the life cycle, or expand suitable habitat for *Ixodes pacificus* ticks. However, significant change in infection is not expected given the characteristics of this tick vector and the fact that many of the populated areas of B.C. are already exposed to *Ixodes pacificus*. | High |
| **CONSEQUENCE** | | | | |
| **CATEGORY** | **CONSEQUENCE** | **RATING** | **JUSTIFICATION** | **CONFIDENCE** |
| **Health** | Loss of life | **2** | There is low potential for multiple losses of life due to Lyme disease, except in extreme circumstances. | Medium |
| | Morbidity, injury, disease, or hospitalization | **4** | 22 to 120 people per year could experience symptoms of Lyme disease, ranging from mild fever, headaches and rash to severe and chronic neurological, musculoskeletal, and cardiac issues. | Medium |
| **Social functioning** | Psychological impacts | **4** | People with untreated Lyme disease may present symptoms similar to psychiatric disorders. Misdiagnosis and chronic issues could cause distress for patients. | Low |
| | Loss of social cohesion | **2** | A doubling of Lyme could cause some erosion to public trust. | Low |
| **Natural resources** | Loss of natural resources | **1** | No evidence of impacts to natural resources. | Low |
| **Economic vitality** | Loss of economic productivity | **1** | Affected individuals could have reduced economic productivity. Outdoor recreation and tourism revenue could be lost. Overall costs expected to be less than $1 million. | Medium |
| | Loss of infrastructure services | **1** | No evidence of impacts to infrastructure services. | High |
| **Cost to provincial government** | | **2** | Potential costs include additional costs to the health system (approximately $88,000-$480,000), losses in revenue, and costs for public outreach. | Medium |
| **OVERALL RISK** | **CURRENT** | **LOW (2.1)** | | **MEDIUM** |
| | **2050** | **LOW (4.3)** | | |

Additional engagement with Indigenous communities would be needed to understand potential consequences from their perspectives.

Overall, the present-day risk rating is **2.1** out of 25, which equates to **low risk**, and the 2050 risk rating is **4.3** out of 25, which equates to **low risk**. See the Risk Calculation text box at right.

**Risk Calculation**

Risk = Likelihood x Average Consequence

Present Risk = 1 x 2.1 = 2.1 (Low)

2050 Risk = 2 x 2.1 = 4.3 (Low)

## Evidence Base

### *Risk Event Scenario*

This scenario represents one illustrative permutation of an increased incidence of vector-borne disease driven by climate change. In light of the impacts associated with the rapid increase in Lyme disease in eastern Canada, the potential for a similar rapid spread of Lyme in B.C. is cause for concern. Lyme disease, however, is just one example of a vector-borne diseases that could expand in (or be introduced to) B.C. due to climate change. Other examples include West Nile Virus and Malaria. The likelihood and consequence ratings here are specific to this Lyme disease scenario.

The specifics of this scenario were based on:

- Lyme disease is the most commonly reported vector-borne disease in the U.S. and Canada (Eisen, Eisen, Ogden, & Beard, 2016).
- Lyme disease is caused by the bacteria *Borrelia burgdorferi*, which is carried and transferred by several species of tick, including *Ixodes pacificus*, *Ixodes scapularis, and Ixodes angustus*. Most commonly, *Ixodes scapularis* is found in the northeastern U.S. and eastern Canada, while *Ixodes pacificus* and to a lesser degree *Ixodes angustus* are found along the Pacific Coast and in B.C. (B.C. Centre for Disease Control, 2018). The western blacklegged tick, *Ixodes pacificus*, is indigenous along the west coast of North America from Baja California to British Columbia (Scott et al., 2017).
- The different types of ticks present different levels of risk because they differ in their likelihood of becoming infected and their effectiveness in spreading the disease to humans. In terms of infection risk, the ticks are ranked (highest to lowest) as *Ixodes scapularis*, *Ixodes pacificus*, and *Ixodes angustus* (Morshed, 2018).
- In B.C., ticks (*Ixodes pacificus*, *Ixodes agustus*, and other minor types) are already present over a large geographic area, including the most heavily populated regions of the province (Morshed, 2018). Most *Borrelia burgdorferi* infected ticks are found in the southwestern part of the province, including Vancouver Island, the Gulf Islands, the Sunshine Coast, Greater Vancouver, and Fraser Valley (B.C. Centre for Disease Control, 2018). The areas in B.C. currently identified to be at risk for Lyme disease include Vancouver Island, the Southern Mainland, the coast of B.C. facing Vancouver Island, and river valleys across the southern part of the province (Government of Canada, 2018b).
- Reported Lyme disease cases in eastern and central Canada grew six-fold from 2009 to 2015 due to changes in climatic conditions and the range of the host population (Gasmi et al., 2017), which has increased concern about the risk of Lyme disease nationwide. Although the historical rate of Lyme disease in western Canada has remained low and stable, B.C. remains concerned that climate change could drive an increase in disease (as it has in the eastern part of the country). A catastrophic incidence level of Lyme disease would be and exponential (three- to five-fold) increase in the number of cases over several years (Galanis, 2018). The selected scenario is more conservative than this change in order to capture a larger range of risk.

- The scenario is based around cases contracted in British Columbia, rather than a spread of the disease elsewhere.

## *Likelihood rating*

**Likelihood Rating Drivers**

Type of risk event: Ongoing

"Present day" period: 2010s

Climate change indicators: Average annual temperature, days below 20°C and above -40°C. and winter precipitation all relate to tick range. However, these climate factors are secondary to other considerations about the likelihood of human exposure to ticks and incidence of infection in B.C. over time.

Critical threshold: Not available

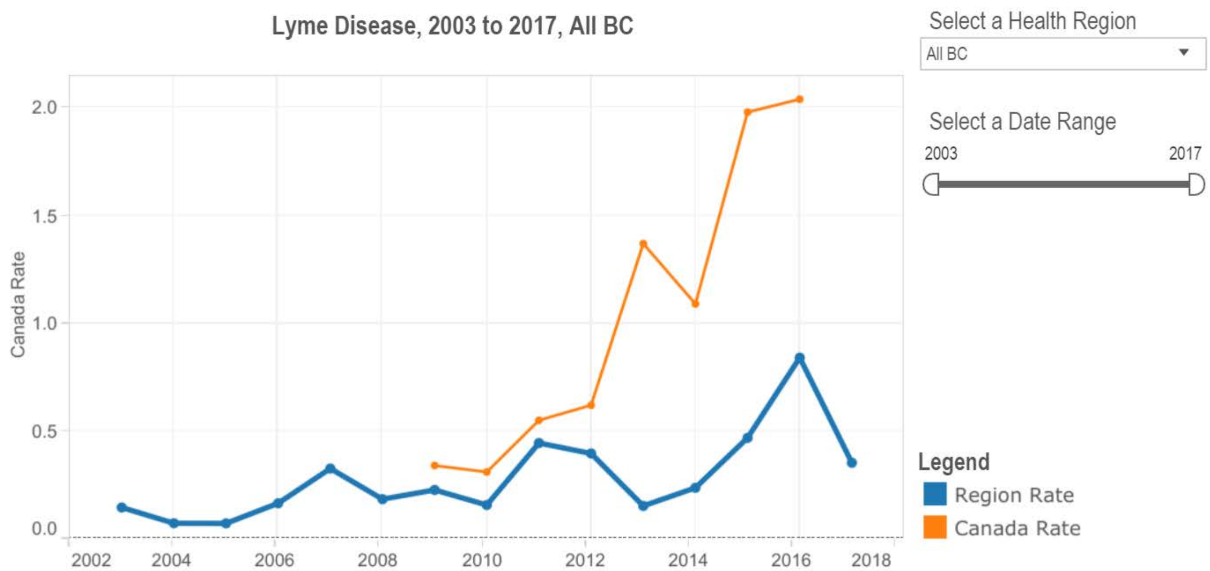
The present-day likelihood of this scenario is **1** and the 2050 likelihood of this scenario is **2**. The scenario is ongoing with a threshold defined as a doubling of Lyme disease cases in three years. Given that the ticks that carry Lyme disease are more prolific under warming conditions, higher temperatures due to climate change could increase host-seeking activity or change the habitat range, contributing to a rise in the number of Lyme disease cases. However, despite warming over the past several decades, the rate of infection in B.C. has remained low and stable. Given that many of the populated areas of B.C. are already exposed to *Ixodes pacificus*, it appears unlikely that Lyme disease cases in B.C. will double within a 3-year period by 2050. However, the projected impact of future warming on tick populations and distribution is not fully understood. To evaluate the likelihood of this scenario, the project team considered both the historical incidence rate of Lyme disease and changes to climate-related controls on its host population and range, including air temperatures and precipitation.

The likelihood rating was determined based on the following factors:

**Incidence Rate**

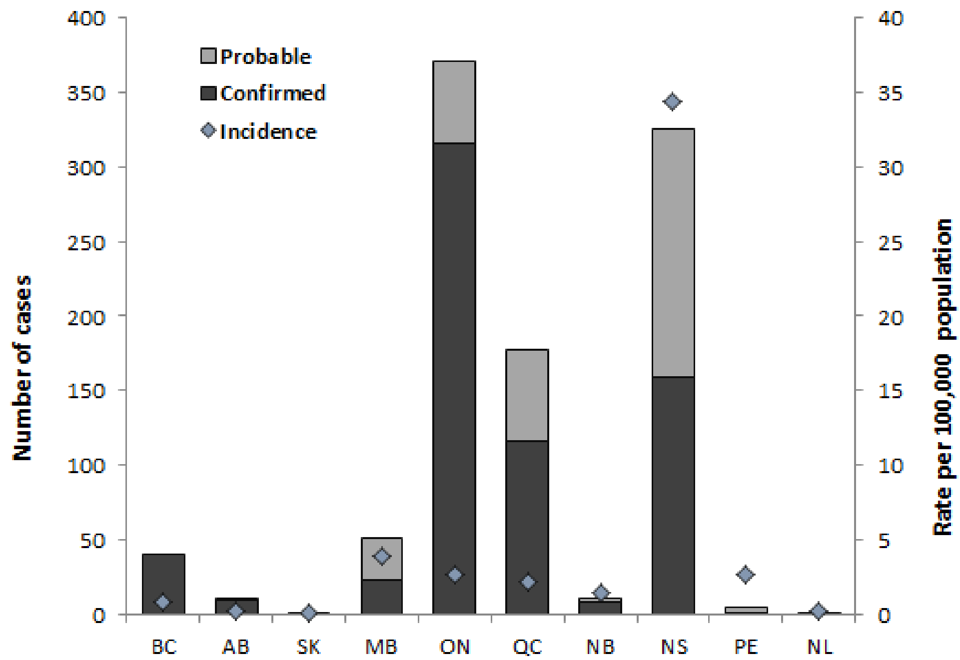
- The risk of contracting Lyme disease in B.C. is low. Less than 1% of ticks tested in the province carry Lyme disease and the incidence of the bacteria in ticks has remained relatively constant for the past decade (B.C. Centre for Disease Control, 2018). This is consistent with the number of reported Lyme disease cases in B.C., which has also remained low and stable over the past decade (Morshed, 2018).
- There are 7 to 40 cases of Lyme disease reported in B.C. each year (see **FIGURE 80**). Since 2003, there has been a relatively low rate of Lyme disease across B.C., roughly between 7 and 20 cases. However, in 2016, there was an increase in reported incidence (40 cases), which has been attributed to new diagnostic tests, implemented at the B.C. Centre for Disease Control Public Health Laboratory and the National Microbiology Laboratory, that are more sensitive, and a higher volume of tests due to greater awareness about the disease. Most of these cases were likely contracted outside of the province (B.C. Centre for Disease Control, 2019).

**FIGURE 80.** Reported cases of Lyme disease in B.C. from 2003 to 2017 (B.C. Centre for Disease Control, 2019).




- The disease remains underreported nationally (B.C. Centre for Disease Control, 2019). One study suggested a minimum of 10.2 to 28-fold under-detection of Lyme disease (Lloyd & Hawkins, 2018). Ninety-three cases were identified between 1997 and 2008; however, based on models, the expected number of cases during that period was 142 (95% confidence interval: 111 to 224), equating to a maximum incidence of 0.5 per 100,000 population (Henry & Muhamad, 2011; Henry et al., 2011). Thus, modeling indicates that there is an expected rate that is 1.5 times larger than the number of cases identified in this period. On the other hand, Henry et al. (2012) found that doctors who responded to surveys reported diagnosing 221 cases of Lyme disease in 2007 while only 13 cases were reported to public health authorities (6%) (Henry, Crabtree, Roth, Blackman, & Morshed, 2012).
- In 2012, of the Canadian cases for which information is available, 22.1% were acquired outside of Canada (Government of Canada, 2015). Within B.C., experts estimate that up to one-third to one-half of reported cases are acquired outside of the province (Galanis, 2018; Morshed, 2018). Thus, even an increase in the number of cases does not necessarily equate to cases attributed to a changing risk of disease within British Columbia.
- Throughout Canada, the number of Lyme disease cases increased from 144 in 2009 to 992 in 2016. In 2016, 88% of the cases were in Ontario, Quebec, and Nova Scotia (Government of Canada, 2018c) (see **FIGURE 81**).

**FIGURE 81.** Number of probable and confirmed Lyme disease cases (bars), and incidence rate per 100,000 population by province in 2016 (Government of Canada, 2018c).




- Compared with high rates of Lyme disease in the northeastern U.S. and spreading into eastern Canada (29 cases per 100,000 and 40% tick infection rate), the risk in B.C. is low (<0.5 cases per 100,000 population, <1% tick infection rate) (Henry & Muhamad, 2011).

- Evidence suggests that conditions on the West Coast are not suitable for *Ixodes scapularis* (Brownstein, Holford, & Fish, 2003). In addition, the large geographic distance and the barrier presented by the Rocky Mountains make it unlikely that infectious ticks from the east will spread to B.C. as a result of climate change (Morshed, 2018).

- Areas where *Ixodes pacificus* predominates generally have lower rates of Lyme disease infection. This is due, in part, to the fact that *Ixodes pacificus* is a less competent vector than *Ixodes scapularis*, is less abundant, and is less likely to feed on deer mice, a carrier for the disease. In addition, deer mice in Western Canada are less competent at harbouring and transferring Lyme disease, which further decreases the rate of infection relative to that in Eastern Canada (Morshed, 2018). It is also thought that *Ixodes pacificus* sits closer to the ground in leaf litter and rarely climb higher vegetation, which makes it less likely than *Ixodes scapularis* to bite humans and other large mammals (Eisen, Eisen, Ogden, & Beard, 2016).

- In B.C., tests of deer mice and ticks have yielded low rates of infection with *B. burgdorferi*, the bacteria that causes Lyme disease (Henry & Muhamad, 2011). Since 1993, the British Columbia Public Health Microbiology and Reference Laboratory has been testing ticks for *B. burgdorferi* across British Columbia. From 1993 to 1996, 10,056 ticks were tested, demonstrating an infection prevalence of 0.40%; from 1997 to 2007, 8,602 ticks were tested with a prevalence of 0.35% (Henry & Muhamad, 2011). From 2013 to 2014, studies of mice and ticks in British Columbia found *B. burgdorferi* DNA in

5 out of 359 tick pools (0.014%), and 41 out of 483 mice (0.085%) (Morshed et al., 2015). These studies demonstrate a low and stable level of infection in B.C. within host species.

- The B.C. Ministry of Health has reported a plateau in the number of infected tick populations in the past decade, despite rising rates across the rest of Canada. This is likely because the western blacklegged ticks spread into B.C. earlier than the eastern species spread into Canada, the optimal tick habitat is limited in the province, and far fewer of the western blacklegged ticks are infected with the Lyme disease bacterium (Government of Canada, 2018b).

**Climate Factors**

- There is great uncertainty about how climate change could influence tick behaviour and survival, due to the complexity of relevant factors (Eisen, Eisen, Ogden, & Beard, 2016).
- Hahn et al. (2016) modeled suitable habitat for *Ixodes pacificus* in the western U.S. and concluded that ticks are already present within much of the range classified as "suitable."[130] This suggests that *Ixodes pacificus* may have reached the extent of its niche in that region (Hahn, Jarnevich, Monaghan, & Eisen, 2016).
- Since *Ixodes pacificus* is present in most heavily populated areas of B.C., the southern part of the province, expansion northward may not produce a major increase in infection because the new range would be sparsely populated, thereby presenting limited risk to human populations (Henry & Muhamad, 2011; Morshed, 2018).
- Temperatures play a role in habitat suitability for ticks. Ticks prefer temperatures warm enough that they can survive during the winter, but high maximum temperatures can be damaging.

- Generally, warmer temperatures are more suitable for *Ixodes pacificus* habitat, yet temperatures greater than 20°C tend to reduce suitability (Hahn, Jarnevich, Monaghan, & Eisen, 2016).
- Higher temperatures could increase tick survival rates, and may affect host-seeking behaviour of nymphs (Morshed, 2018; Eisen, Eisen, Ogden, & Beard, 2016).
- Eisen et al. (2016) found the abundance of *Ixodes pacificus* nymphs to be negatively correlated with maximum air temperature (Eisen, Eisen, Ogden, & Beard, 2016).
- The population density of *Ixodes pacificus* nymphs declines between 21 and 23°C and when mean maximum daily relative humidity decreases below 83% to 85% (Eisen, Eisen, Ogden, & Beard, 2016).
- Longer summers due to warmer temperatures increase the length of the feeding season, which increases the time for the tick to become infected with the bacteria. Higher temperatures increase tick development and hatching rates but reduce tick survival and reproductive success. Overall, climate change could accelerate the tick life cycle (Beard et al., 2016).

- When temperatures are particularly cold, ticks will hide in the leaf litter. They can survive temperatures as low as -40°C (Morshed, 2018). However, tick activity and survival are inhibited below minimum temperature thresholds (Eisen, Eisen, Ogden, & Beard, 2016). As minimum temperatures rise, suitable habitat for ticks increases and the range expands northward (Beard et al., 2016).

[130] Suitable habitat considers climate and land cover predictors, including precipitation seasonality, minimum temperature of the coldest month, precipitation of the coldest quarter and warmest quarter, isothermality, annual mean temperature, mean temperature of driest quarter, mean diurnal temperature range, cumulative growing degree days in December, maximum temperature of the warmest month, percent forest cover, and vapor pressure in July (Hahn, Jarnevich, Monaghan, & Eisen, 2016).

- Ticks also thrive in humid conditions. Reduced rainfall in some areas could limit their geographic distribution, while increases in other areas may benefit ticks. The extent of these impacts is not well understood.
- Eisen et al. (2016) found the abundance of *Ixodes pacificus* nymphs to be positively correlated with rainfall (Eisen, Eisen, Ogden, & Beard, 2016). Between 300 and 600 mm of precipitation during the coldest quarter of the year may be conducive to ticks. However, extreme precipitation can reduce habitat suitability for *Ixodes pacificus* (Hahn, Jarnevich, Monaghan, & Eisen, 2016).

**Life Cycle Changes**

- Adult *Ixodes pacificus* populations studied in northwestern California became active after the first rain of the season in the fall; populations peaked in January and then declined throughout the spring. Ticks in the nymph stage appeared in January and remained active until October. Thus, the potential for infection from nymph and adult ticks was present in the study area nearly year-round, which means the potential for Lyme disease infection may extend for a greater period of time and provide more likelihood of infection (Salkeld et al., 2014)
- According to Beard et al. (2016), there is high confidence that ticks capable of carrying the bacteria that cause Lyme disease and other pathogens will show earlier seasonal activity and will expand northward due to increasing temperatures (Beard et al., 2016).

**Other Key Factors**

- Other key factors that affect Lyme disease include local ecology, vector competence, availability and type of hosts, type of vegetation, diagnostic test, physician and public awareness, and the clinical spectrum of illness.
- Juvenile tick density highly relates to host availability and habitat characteristics, such as dense leaf litter (MacDonald et al., 2017). Incidence may be related to the range of the host (rodents), which is expanding due to climate change (Morshed, 2018). These drivers are not fully understood.

**Confidence: High**

There are multiple sources of evidence indicating that the rate of Lyme disease in B.C. has remained stable and that the incidence of infected ticks is quite low. Compared to the extreme growth in Lyme disease cases in Eastern Canada, a similarly rapid increase seems unlikely in British Columbia. Additional information on the climate drivers of tick and host behaviour, as well as more information about diagnoses, would be helpful in improving this assessment.

## *Consequence ratings*

The overall consequence rating is an average of the individual consequence ratings (see the Consequence Calculation text box at right). Details on each individual consequence rating are provided below. Based on these findings, the project team rated the overall consequence of this scenario as **2.1** out of 5.

**Consequence Calculation**

Overall Consequence = Average of Individual Consequence Ratings

Overall Consequence = (2+4+4+2+1+1+1+2)/8

Overall Consequence = 2.1

## HEALTH

### *Loss of life: 2*

There is no evidence of deaths attributed to Lyme disease in Canada. Proper diagnosis can be challenging, which means deaths may have been incorrectly attributed. However, most people who would be infected with Lyme disease in B.C. could experience negative health outcomes unlikely to result in death. There is a low potential for multiple losses of life in B.C. due to Lyme disease.

Supporting evidence includes:

- Deaths due to Lyme disease are rarely reported. For example:
  - Based on a study of death certificates in the U.S., Lyme disease was listed as a cause of death on 114 death records (1999 to 2003). However, only one record was consistent with clinical symptoms of Lyme disease, demonstrating the rarity of Lyme disease as a cause of death (Kugeler et al., 2011).
  - According to the U.S. CDC, there were nine deaths due to Lyme carditis, a rare complication, reported worldwide between 1985 and 2018 (U.S. Centers for Disease Control and Prevention, 2018).
  - Three sudden cardiac deaths associated with Lyme carditis occurred in the U.S. between 2012 and 2013 (Government of Canada, 2018a). There may have been compounding health complications in these cases, however.
- Some patients are misdiagnosed with chronic Lyme disease and treated for it without evidence that they have the bacterial infection. This can lead to mis-documentation and health complications (Marzec et al., 2017). Alternatively, Lyme disease is often misdiagnosed due to symptoms that mimic other diseases.

**Confidence: Medium**

The literature also acknowledges that attributing the cause of death to Lyme disease is often difficult. Multiple published sources and experts in the field report low mortality due to Lyme disease, nationally. Within B.C., there is a lack of research and public documentation on the number of deaths due to Lyme disease.

### *Morbidity, injury, disease, or hospitalization: 4*

A doubling of Lyme disease could result in approximately 22 to 120 people who experience negative health impacts. Some portion of those people will suffer few or mild symptoms that can be treated, such as fever, headaches, and a skin rash. However, if left untreated, Lyme disease can lead to severe neurological, musculoskeletal, and cardiac issues that can result in chronic symptoms. Consequences are significant but, due to the suspected low level of reporting and difficulties diagnosing the disease, analyzing the full extent of infection is difficult. The risk of morbidity, disease, or hospitalization will be the most significant consequence due to Lyme disease.

Supporting evidence includes:

- A doubling of Lyme disease would result in an infection rate of approximately one case per 100,000 population. With a population of about 4.8 million, this would result in 48 cases in British Columbia. Alternatively, if the current rates of Lyme are underreported (at least 1.5 times more infections than the 7 to 40 reported) and closer to 11 to 60 people are infected, there could be 22 to 120 people or more infected per year if the rates at least doubles.

- Early symptoms of Lyme disease include fever, headache, fatigue, and a bullseye skin rash. Most cases can be treated within a few weeks with antibiotics (CDC, 2018).
- Those who do not get treated early, either due to misdiagnosis or by failure to notice early symptoms, may experience lifelong complications. Untreated Lyme disease can lead to neurological, musculoskeletal, and cardiac issues including:

- Up to 5% of untreated patients develop chronic neurological complaints (B.C. Centre for Disease Control, 2018). Complications include septic meningitis, cranial neuritis, Bell palsy, radiculoneuritis, and encephalopathy affecting memory and concentration (Henry & Muhamad, 2011; Healthwise BC, 2017).
- About 60% of untreated patients have bouts of arthritis, particularly in large joints (B.C. Centre for Disease Control, 2018). Patients may also experience swelling, migratory joint and muscle pains, and chronic arthritis (Henry & Muhamad, 2011; Healthwise BC, 2017).
- Lyme disease may also lead to heart disease, rare atrioventricular block, and acute myocarditis ( Galanis, 2018; Henry & Muhamad, 2011).

- More information on the stages of the disease can be found online at https://www.canada.ca/en/public-health/services/diseases/lyme-disease/health-professionals-lyme-disease.html.

**Confidence: Medium**

There are several sources of high-quality independent evidence, with some degree of agreement on the short-term and long-term effects of Lyme disease on human health. This score reflects the top end of our range of possible morbidity. Expert reviewers agree with the risk score rating.

## SOCIAL FUNCTIONING

### *Psychological impacts: 4*

In some cases, people infected with Lyme disease may experience various symptoms akin to psychiatric disorders, including depression, anxiety, schizophrenia, and bipolar disorder. Additionally, chronic Lyme can manifest in symptoms that mimic other diseases. The resulting misdiagnosis or chronic issues without proper care can exacerbate distress and anxiety of patients. While the psychological impacts of Lyme disease are severe, the affected population is likely small.

Supporting evidence includes:

- Many academic articles report that Lyme disease is associated with a variety of neurological and psychiatric symptoms. For example:

- A European study found that a significant proportion of people suffering psychiatric morbidity may be suffering from Lyme disease (Hájek et al., 2002).
- Lyme disease has been associated with psychiatric symptoms such as depression, anxiety, panic attacks, and autism spectrum disorders (Fallon & Nields, 1994).
- According to Mattingley and Koola (2015), 8% to 45% of Lyme disease patients report depression (Mattingley & Koola, 2015).

  - Multiple studies report that Lyme disease can present symptoms similar to schizophrenia and bipolar disorder (Fallon & Nields, 1994; Bransfield R. , 2018; Mattingley & Koola, 2015).
  - Some studies have found a connection between the psychiatric symptoms of Lyme disease and suicide risk (Bransfield R. C., 2017; Bransfield R. , 2018).

- However, the literature acknowledges that the neurological and psychological symptoms related to Lyme disease are not well understood. While studies like those cited above discuss psychiatric symptoms associated with chronic Lyme, other studies insist that psychiatric and psychological symptoms have been inaccurately ascribed to the disease. Although the medical literature does not report evidence of Lyme disease persisting after antibiotic therapy, four to 40% of patients report physical, cognitive, and/or mood symptoms after therapy (Hassett, Radvanski, Buyske, Savage, & Sigal, 2009). Many patients diagnosed with "chronic Lyme disease" either have no objective evidence of an infection with the disease or should be classified as having post-Lyme disease syndrome, which is when symptoms relapse in a patient who was previously treated for Lyme disease (Marques, 2008).
- Lyme disease is easiest to diagnose during the early periods of infection when rashes appear, whereas serologic tests must be used later (CDC, 2019). Otherwise, Lyme disease is often difficult to diagnose because the symptoms mimic other diseases and disorders and the diagnosis tests are not always effective (CDC, 1991). Thus, people are often misdiagnosed, or diagnosis takes a prolonged period of time. Not receiving proper treatment or diagnosis could take a toll on mental health, as people may feel helpless or dismissed.

**Confidence: Low**

There are several sources of evidence reporting similar psychological symptoms associated with chronic Lyme disease. However, the literature acknowledges that these symptoms and their drivers are not well understood and there is some level of disagreement about how or if Lyme disease is truly responsible for these symptoms.

*Loss of social cohesion: 2*

If the rate of Lyme disease were to double within a short period of time, there could be greater pressure on the government as well as outrage from advocacy groups. This could result in erosion of public trust in the government. However, a doubling of Lyme disease cases in B.C. is a small portion of the population and may not result in the level of outrage observed in other regions of Canada.

Supporting evidence includes:

- Many people have experienced personal suffering due to chronic Lyme disease regardless of whether there is evidence of an infection with *B. burgdorferi*. The medical community does not always agree with these diagnoses. Many patients have the perception that the medical community has failed to effectively explain or treat their illnesses. In addition, the advocacy community commonly argues that Lyme disease is grossly underdiagnosed and is responsible for an enormous breadth of illness; they also argue that scientific and public health professionals ignore or even obscure evidence related to Lyme disease (Lantos, 2015).
- Lyme disease has drawn national attention due to public concern from advocacy groups pushing for greater awareness about the risks of the disease and outrage about cases of misdiagnosis. For those affected and their families, the illness can be devastating. Some patients have experienced

disenfranchisement with diagnosis and treatment, which contributes to frustration and anger with the healthcare system and the government (CanLyme, 2019; CanLyme, 2014).

**Confidence: Low**

Little research was found to evaluate the consequences of Lyme disease on social cohesion. There is significant controversy in the public opinion about the severity of Lyme disease risk and how it is managed by the government. Expert reviewers confirm that little information is known about this consequence.

### NATURAL RESOURCES: 1

Lyme disease is not expected to have a substantive impact on natural resources in British Columbia.

**Confidence: Low**

No evidence was found to evaluate the consequence of Lyme disease on natural resources. Expert reviewers attest that there is little impact of Lyme disease to natural resources.

### ECONOMIC VITALITY

#### *Loss of economic productivity: 1*

Due to illness, more than 100 people could become unable to continue pursuing their education, career, and personal objectives, resulting in losses in productivity and societal costs. However, given the individualized nature of the impacts, the overall economic losses across the province due to a doubling of Lyme disease would be relatively small. There may also be losses in revenue for outdoor recreation and tourism if people limit time outside.

Supporting evidence includes:

- Due to illness, individuals may become unable to pursue their normal educational, career, and personal life trajectories and objectives. Costs to the individual can include loss of income; loss of tuition payments for patients made incapable of attending school; loss due to pain and suffering; and costs of transportation, relocation, and dependency on family or other caregivers. These impacts can represent a loss to society from the lost contributions of individuals with Lyme disease to the economy. Other societal costs include increasing welfare costs, loss of productivity, loss of tax revenue to local and national governments, and the potential breakup of families due to the emotional and financial stress of this disease (DellaSala, Middelveen, Liegner, & Luche-Thayer, 2017).
- Perceived risks of contracting Lyme disease on average cause a person in the Northeastern U.S. to forgo eight 73-minute outdoor trips per year, costing them about nine hours of outdoor time per year. Although the cost of individual lost trips is small—about US$2.75 to $5—the total cost equates to roughly US$2.8 to $5 billion annually due to the large number of people in the region (Yale School of Forestry & Environmental Studies, 2017). The results are unlikely to become this high in B.C. given the much lower incidence of Lyme disease, but it provides a sense of scale of the possible economic impacts due to lost activity.

**Confidence: Medium**

There are several sources of evidence reporting losses to economic productivity due to Lyme disease. However, the full extent of these impacts is not well documented in B.C. and would depend on the number of people experiencing debilitating symptoms. Expert reviewers agree that the consequence to economic productivity would be low.

*Loss of infrastructure services: 1*

Lyme disease is not expected to result in losses to infrastructure services in British Columbia.

**Confidence: High**

No evidence was found to connect Lyme disease with disruption of infrastructure services. Expert reviewers attest that there is no apparent impact of Lyme disease to infrastructure services.

### COST TO PROVINCIAL GOVERNMENT: 2

The primary cost to the provincial government is healthcare services, which are shared between the federal and provincial government. For 22 to 120 cases of Lyme disease, health care costs are estimated at $88,000 to $480,000. There could also be additional costs to the health system, losses in productivity, and efforts required to educate the public about Lyme disease prevention and treatment. These costs are expected to be on the order of $375 million or less.

Supporting evidence includes:

- Lyme disease is associated with US$2,968 higher total healthcare costs, as measured by medical claims, (95% CI: 2,807 to 3,128, $p<0.001$) and 87% more outpatient visits (95% CI: 86% to 89%, $p<0.001$) over a 12-month period. It is also associated with 4.77 times greater odds of having any post-treatment Lyme disease syndrome (PTLDS)-related diagnosis, as compared to a control group. Among those with Lyme disease, having one or more PTLDS-related diagnosis is associated with $3,798 higher total health care costs and 66% more outpatient visits over a 12-month period, relative to those with no PTLDS-related diagnoses (Adrion, Aucott, Lemke, & Weiner, 2015).
- A study by researchers at Johns Hopkins Bloomberg School of Public Health estimated that the U.S. health care system spends $712 million to $1.3 billion a year (about US$3,000/patient) to treat symptoms of patients in the year following their Lyme disease diagnosis (DellaSala, Middelveen, Liegner, & Luche-Thayer, 2017). Since costs are not available for B.C., US$3,000 can be a reasonable benchmark for treatment costs, although costs could be lower in Canada due to differences in the health care system ( Galanis, 2018).The project team estimated the costs based on a per-patient cost of US$2,968 (approximately CAD$4,000) for 22 to 120 cases of Lyme disease. This would cost the government approximately $88,000 to $480,000.[131]
- The Government of B.C. invested $2 million to create the Complex Chronic Disease Program at the B.C. Women's Hospital to treat several chronic diseases, including Lyme disease (Fayerman, 2011).
- Economically, this debilitating multisystem disease costs society billions of dollars in loss of schooling, employment, and health, especially for medical travel, doctor visits, diagnosis, testing, and treatment. In the U.S., the cost is calculated to be US$1.3 billion, with extrapolated costs for Canada estimated to be CAD$130 million per year (Scott et al., 2017). At the national level, the Canadian

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[131] This estimate is based on costs in the U.S., which are difficult to extrapolate to Canada. Including data from B.C. would improve the estimate of costs. Estimate based on exchange rate as of 5 November 2018.

government is spending $4 million on research into Lyme disease and developed a framework for fighting the disease (Harris, 2017).

- Costs are associated with public health, awareness raising, and surveillance. If people are not treated quickly and do not know how to identify the symptoms, they have a greater likelihood of experiencing long-term impacts (Workshop feedback, 2019).

**Confidence: Medium**

There are several sources of high-quality independent evidence, with some degree of agreement about the costs associated with Lyme disease. There is a high level of uncertainty on the extent of the costs borne by government because evidence is drawn from cases in the U.S., which are loosely extrapolated to the B.C. context. In addition, there are likely addition costs to healthcare infrastructure and long-term healthcare costs. The exact cost will depend on how costs are shared between the federal and provincial government.

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