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# Adapting Resource Road Infrastructure to Climate Change

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## ABSTRACT


The changes to climatic conditions in Canada are anticipated to have a significant impact on the Canadian forest industry. Resource roads are considered particularly vulnerable to the immediate and short-term impacts of climate change. Adaptation strategies for resource roads and infrastructure must be developed and implementation initiated to ensure that the road infrastructure required for forest access is maintained and made resilient to climatic impacts. This report presents the risks and vulnerabilities of resource roads to climate change and suggested adaptation methods and practices.


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# 1. INTRODUCTION

The management of resource roads and infrastructure continues to be an important activity for industries and governments across Canada. The planning, construction and maintenance of resource roads are required in support of various industrial and resource management activities and are often the primary access for remote communities and public recreational experiences.

Given the significance that resource roads have to economic and social well-being, efforts are required to understand the implications of climate change in order to adapt roads and infrastructure to the impacts of climate change.

Until recently, climate change discussions have been focused on the understanding of the challenges and efforts to mitigate climate change through reductions in the production of greenhouse gases, a primary contributor to climate change. The adaptation of resource roads to climate change is a relatively new concept and there currently exists very little information that identifies adaptation practices, assesses performance and recommends implementation practices that allow for mainstreaming of adaption for resource roads.

This paper aims to introduce the concepts of climate change adaptation for resource roads, specifically:

- Outlines the needs and challenges of climate change adaptation,
- Introduces the approaches for assessing for risk and vulnerability, and
- Offers solutions and best management practices for resource road adaptation.

# 2. CLIMATE CHANGE ADAPTATION NEEDS AND CHALLENGES

Climate change is anticipated to have important impacts to forest management in Canada principally as a result of expected changes in temperature and precipitation patterns. The degree of projected change varies considerably, but generally is expected to result in:

- Warmer summer and winter temperatures,
- Increase in high intensity and short duration rainfall events, and
- Increase or decrease in snowfall depending on the region.

These changes in climatic conditions are expected to result in increased forest disturbances, such as a change in the frequency, intensity and location of insect and disease outbreaks and forest fires, eventual shifts in tree species ranges, and availability of wildlife habitat and range. Some of these changes (e.g., insect outbreaks) are evident under current climatic conditions as a result of changes in historic climate patterns over the previous decades while others (e.g., tree species migration) are anticipated to become more pronounced over the long-term.

Climate change also is expected to have impacts on forestry operations, such as;

- Shortened winter harvesting operations,
- Reduced ability to construct winter roads,
- Increased demands on bridges and culverts to address more frequent, high intensity, short duration storms, and
- Alterations to transportation scheduling due to less frost and fewer mid-winter thaws.

Resource roads serve as the principle means of access to conduct forest and resource management and are, for the most part, managed as long-term permanent or semi-permanent assets with a low-cost approach. It is suggested that this management approach may create a state in which resource roads are especially vulnerable to climate change. The changing precipitation patterns and temperature regimes associated with climate change are expected to create impacts to resource roads that will affect the performance of infrastructure. Increased flooding, landslides and erosion can adversely impact the function or service life of roads and infrastructure while more frequent mid-winter thaws and rain-on-snow events, for example, will have a broader impact on operational planning and road construction standards.

A primary challenge with adapting Canadian resource roads to climate change is associated with changes to precipitation conditions and patterns and resulting impacts to runoff and streamflows. But unlike temperature regimes, long-term precipitation and resulting runoff and stream flow patterns are much more challenging to accurately forecast. Resource road managers will need to identify current and forecasted changes in temperature, precipitation and implications to resource road infrastructure and management, in order to be able to determine adaptation methods to create climate change resilient resource roads.

## Understanding adaptation

Climate change adaptation refers to any action that reduces the negative impact of climate change, and reduces the vulnerability of the value that is under management, in this case, resource roads and infrastructure. The adaptation of resource roads and infrastructure to climate change includes any administrative, policy, standards, planning, design, maintenance or construction activity that is implemented to address projected changes in the climate.

It is important to make the distinction between climate change adaptation and mitigation. Climate change mitigation consists of actions to limit the magnitude or rate of long-term climate change. Climate change mitigation has been the term most frequently referenced when discussing climate change, and refers to a human intervention to reduce the sources or sinks of greenhouse gases which contribute directly to climate change (IPCC, 2014). In forest operations, climate change mitigation measures may be focused on reducing the emissions from heavy vehicles through improved fuel economy or through the use of alternative fuels. In recent years, however, there has been an increase in research and focus on both climate change mitigation and climate change adaptation.

Adaptation provides a means in which these impacts are mitigated and vulnerability reduced through the implementation of practices or tools. Adaptation for resource roads and infrastructure can be classified as operational (changes to policies and procedures) or structural (direct changes to infrastructure).

The adaptation of resource roads and infrastructure to climate change involves the understanding of risks and vulnerabilities, identifying infrastructure components where risks are greatest, and creating a strategy to ensure that the road and infrastructure components are made resilient.

Implementing adaptation practices does not necessarily specify that significant changes to resource road management are required. There are many current practices that ensure resource roads function to required service levels that may also be considered as climate change adaptation practices. For example, effective erosion control and slope stabilization practices are already common best management practices. If a changing climate forecasts an increase in short duration, high intensity rainfall events, minor changes to the design specifications of current standard slope stabilization practices may be required to consider changes in peak flows and soil erosion events. There are adaptation practices that will require more significant changes to current resource road usage under certain climate forecasts. Milder winters and increased rain-on-snow events are expected in some regions of Canada which could reduce the use of winter-only roads, and will require significant adaptations in road construction and maintenance to allow continued road use.

### Understanding resiliency

Through the implementation of climate change adaptation practices, a resilient resource road infrastructure and network system can be created. Resource road infrastructure resiliency *"is the capacity to withstand disruption, absorb disturbance, act effectively in a crisis, adapt to changing conditions and transform over time"*. (Hughes & Healy, 2014)

Long-term climate forecasting with the current climatic models utilizes a coarse landscape approach and, therefore, is best suited to analysing the impacts for large areas. For many engineers, designers, and planners of resource roads, there is a desire for more climate predictions for specific operating areas. Given the limitations in the modelling and data used in forecast development, there are uncertainties in the development of specific weather events and conditions for local areas. Given this uncertainly, it can be difficult to design and construct a road that is fully resistant to failures and hazards due to climate change.

A key element to consider for resiliency is that the intent is not to create infrastructure that is resistant to all hazards. Rather, the intent is to create infrastructure with the capacity to respond and adapt to climate change hazards and events while reducing the severity of damage.

## 3. IDENTIFYING THE RISKS AND VULNERABILITIES OF RESOURCE ROADS TO CLIMATE CHANGE

The impacts of climate change on sustainable forest management is expected to take many years or even decades to impact the Canadian forest industry. Impacts such as tree species migration, insect outbreaks, and increases in forest fires are large scale landscape impacts that will require long-term development and implementation of adaptation measures. Climate change events, such as increased precipitation and flooding, are having immediate impacts to resource roads and adaptation measures are required in the near-term.

In order to adapt resource roads to climate change, vulnerabilities and risks must be identified. Vulnerability is defined as an indication of the degree to which the infrastructure is susceptible or unable to cope with the negative impacts of climate change. Vulnerability to climate change is generally considered to be a function of three factors:

1. Exposure. The degree to which resource roads and infrastructure is forecasted to be exposed to climate change;
2. Sensitivity. The level or extent that resource roads will be impacted by a change in climatic events; and
3. Adaptive capacity. The ability of resource roads and infrastructure to adapt to the negative impacts of forecasted changes to the climate (IPCC, 2014).

Once the vulnerability is identified, an evaluation is performed to understand the risks to the system. When evaluating the risks to climate change, the probability of a negative impact must be considered, in addition to the severity of the impact if the event occurs. This may best be accomplished through a formal risk management process. In this case, the process considers and evaluates the exposure, sensitivity, adaptive capacity, and adaptation measures to resource road and infrastructure (Figure 1).

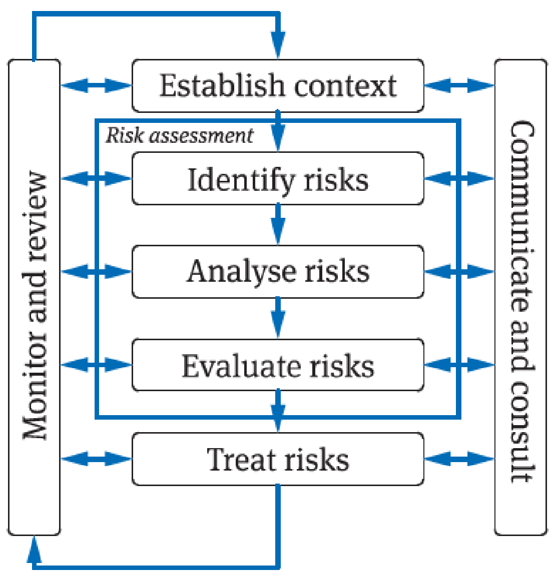


**Figure 1. The risk management process. Adapted from ISO31000:2009.**

## The PIEVC protocol

A variety of management processes are available to assess the vulnerability of engineered structures to climate change, however, a method commonly used in Canada is the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol. (Engineers Canada 2016). The PIEVC protocol is a civil engineering tool used to assess the vulnerability of engineered structures to climate change. A variety of data are required to conduct a vulnerability analysis including infrastructure age, condition and inspection data, traffic volumes, geotechnical and terrain information, extreme weather event data and its impact on infrastructure.

The PIEVC has created a five-step protocol to assess various infrastructure components, while focused on public and civil infrastructure; it also can be adapted to resource roads and infrastructure (Figure 2). The PIEVC protocol reviews historic climate data, and projects the nature, severity, and probability of future events for a specific region. This information is then used to conduct a risk assessment of existing or planned infrastructure to determine if and what management response is required. This also provides managers and planners an opportunity to understand or establish the adaptive capacity of infrastructure, as determined by design, operations, maintenance, and policies.

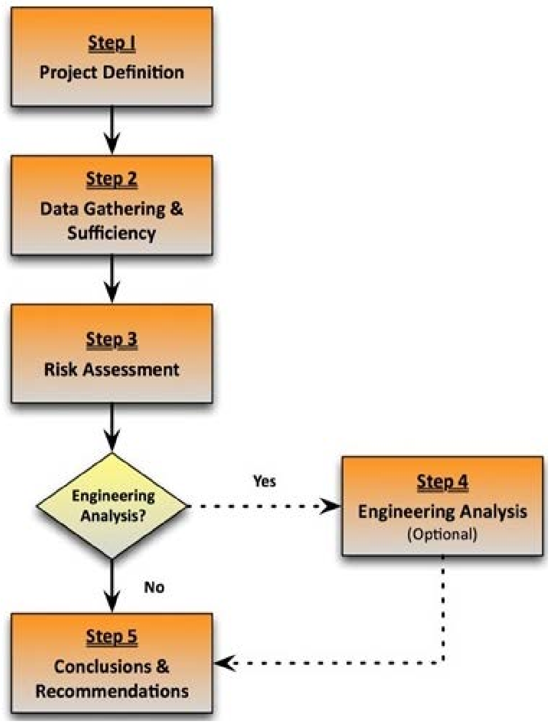


**Figure 2. Stages in the PIEVC protocol. Reproduced from Engineers Canada 2016.**

Step 1 - Defining the scope of the risk and vulnerability assessment is a crucial first step in ensuring that the analysis is effective, and that the conclusions and recommendations are relevant to the project objectives. The project definition includes identifying items such as the road segments to be studied, and stakeholders and road users to consult or consider.

Step 2 - During the data gathering and sufficiency step, it is important to consider which types of road and infrastructure components to gather data on (e.g., bridges, road surfacing, cut slopes), and which weather events historically occur in the area and directly influence the road and infrastructure components in strongly negative ways.

Step 3 - In the risk assessment step, weather metrics are selected which characterize the climatic changes of concern. These metrics, with assumptions for various climate change scenarios, are input into climate prediction models to forecast the frequency and intensity of future weather events and climatic conditions on a local basis.

A high level risk assessment is made for each infrastructure element identifying which, and by how much, each weather metric is likely to influence the performance of each type of road and infrastructure. The risk assessment can be conveniently arranged in a spreadsheet table that calculates a risk rating for the each pair of road/ infrastructure element and weather metric. This is calculated using the probability rating of the predicted weather metric, and a severity rating. The severity rating takes into consideration how the occurrence of each weather event or climatic condition would affect the functionality and service life of each road/ infrastructure element (taking into account how effectively current management responses mitigate these impacts).

Step 4 - The engineering analysis step has various components, including refining the climatic predictions, and assessing load capacity vulnerability. Those familiar with the design of the infrastructure elements review the design assumptions, material properties, etc. to assess the anticipated changes in performance given the climate changes predicted. If design changes are warranted to ensure safety or reliability, then these are recommended.

Step 5 – The final step is the development of conclusions and recommendations in respect to possible operational or management actions required to upgrade the infrastructure. The overall resiliency and vulnerability of the infrastructure to climate change is described as well as any need to conduct additional analysis or further data gathering.

## 4. ADAPTING RESOURCE ROADS TO CLIMATE CHANGE

Upon the completion of a climate change vulnerability assessment, the need to implement adaptation strategies will be highlighted. Once the need has been assessed the approach on how to mitigate the negative impacts must be evaluated. Generally, the adaptation strategies that mitigate the impacts of resource roads to climate change result in higher quality roads with increased performance levels, regardless of whether climate change occurs or not. This strategy of implementing adaptation practices that improve road infrastructure performance, whether or not the anticipated climatic changes or events occur, is referred to as a “no-regrets approach”. (Olsen, 2015). With limited capital resources available for the planning, construction and maintenance of resource roads, however, efforts and capital costs must be focused where adaptation strategies are most needed.

Effective adaptation to climate change requires the creation and implementation of an adaptation strategy that identifies the conditions for which adaption is required, and identifies the methods and practices to ensure that adaptations are occurring (Figure 3).

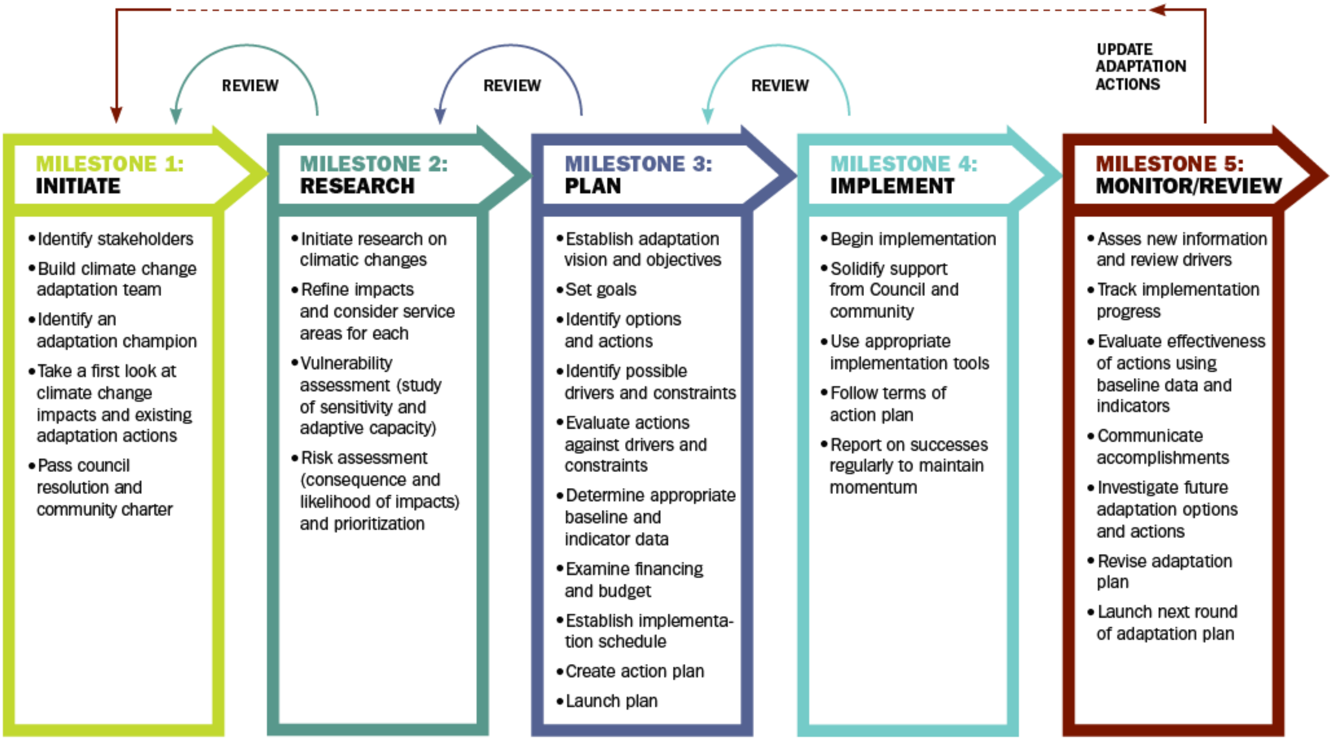


**Figure 3. A generalized approach to adaptation. Reproduced from Jackson, Barry & Morzak 2011.**

## Adaptation strategies

The approaches for adaptation can be broadly categorized into proactive and reactive adaptation strategies and both may be considered as planned approaches to adaptation. The decision about which adaptation strategy(s) to implement requires that the benefits from the strategy(s) outweigh the potential cost of climate change-induced damages and the costs of implementing the strategy(s).

Proactive adaptation, also known as anticipatory adaptation, is a planned approach that maintains the infrastructure to its designed performance levels before deterioration occurs. This approach may be a challenge to implement as an upfront investment in planning, forecasting and maintenance or construction is required. In general, the investment to create resilient infrastructure can create a positive cost-benefit as compared to solely implementing a reactive adaptation approach. (Schweikert, Chinowsky, Espinet & Tarbert 2014). This approach involves long-term decision making and climate forecasting to reduce the vulnerability of the structures to climate change and to increase their resiliency. Proactive adaptation requires that current operational practices be carefully analyzed and assessed for their effectiveness under a changing climate.

Reactive adaptation, also known as event-based adaptation or a "wait and see" approach, is a planned approach wherein management responses occur after the structure has been damaged or destroyed, or its performance degraded. The risk inherent with a reactive adaptation approach is that the performance levels of the road are permitted to decrease, possibly below operational and safety thresholds.

A reactive adaptation approach can be costly as the need for maintenance and replacement interventions are unplanned and, therefore, can have a significant negative effect on budgeting. Reactive adaptation must also consider long-term climate forecasting, and not just current or historical conditions, when interventions are planned.

# 5. RESOURCE ROAD ADAPTATION METHODS AND PRACTICES

The development and implementation of adaptation strategies is a new discipline, and is an ongoing effort to both identify effective strategies as well as future needs and responses. This is particularly true of resource road and infrastructure adaptation where very little has been published about adaptation strategies. The weather events that are associated with climate change, such as heavy precipitation, are not new concerns for resource road managers but, it is rather the duration and intensity of these events. As a result, there are many existing resource road management strategies that, with an increased focus or alteration, could become effective climate change adaptation practices.

Creating resilient resource roads and infrastructure will require adaptation measures to be identified and implemented throughout all stages of the components' service life including planning, construction, and maintenance.

## Planning, design, and construction

The planning and design stage of a resource road represents the first opportunity where climate change adaptation strategies can be identified and implemented. Implementing strategies effectively requires that the risks and vulnerabilities have been identified, and that the future climate conditions have been recognized. The following are practices that could be considered for adapting resource roads to climate change during the planning, design, and construction phases:

1. Create an accurate inventory, condition and performance assessment of existing resource road infrastructure.
2. Perform a vulnerability assessment of existing resource road infrastructure.
3. Anticipate near- and far-future infrastructure needs, and build adaptation strategies into existing resource road planning, where necessary.
4. Create and implement an inspection plan, and a document management plan for all infrastructures. The inspection plan should include both a schedule for regular inspections, and procedures for inspections during or immediately following storms and extreme weather events.
5. Consider implementing a "safe to fail" design approach that allows the infrastructure to fail in a controlled and predicted manner. Designing resource roads and infrastructure to be able to resist all storm or flood events is not practical or economically feasible.
6. Road networks should be designed to remain functional during extreme weather events. Planners should identify routes for emergency access and evacuation, and prioritize funding to improve the resiliency of roadway and infrastructure on these routes.
7. Design and build roads and infrastructure to minimize the potential negative impacts from failures. Examples would include minimizing fill volumes, constructing with erosion resistant materials, and locating roads in lower risk areas.

8. Be familiar with hauling regulations, allowable truck weights and truck haul configurations. Regulations such as spring haul restriction periods and winter weight premiums can be important factors when planning heavy vehicle hauls and management of the resource road infrastructure during certain periods of the year.
9. Consider the use of tire pressure control systems (TPCS) and widebase tires on gravel and other trucks to reduce their impacts to the road surface, and to prolong road use during periods of marginal road conditions.
10. Optimize the amount of roads, often measured as roaded area or road density, to ensure that the least amount of road is constructed and maintained in order to support the required economic, recreational, and community access activities in a given area. Reduced road density ensures effective use of economic resources, minimizes short and long-term negative impacts of climate change, and reduces environmental impact.
11. Ensure that all road managers in a defined area, such as a watershed, implement solutions that meet their specific needs and the broader needs of the road users in a given area. For example, if roads located at higher elevations adapt to climate change by providing for increased storm flows and debris passage, roads located in lower elevations must also adapt to the increased water flows and debris levels that may occur.
12. Locate new roads in areas that are considered to be of low-risk to climate change-induced influences. For example, locate roads at higher elevations in a watershed where stream flow levels are lower or prevent the location of new roads in areas that are of higher risk to flooding.
13. Consider upgrading winter roads to be all-season roads so that access is reliably provided during all times of the year.
14. If climate forecasts predict increased precipitation, the drainage requirements for new and existing resource roads will increase and must be achieved through building and maintenance practices. Constructing and maintaining road crowns to 3% -5%, and outsloping steep roads when possible, will ensure that water is evacuated quickly and effectively from the road surface.
15. Certain regions are anticipated to have lower levels of precipitation and increased temperatures. These conditions may promote high road dust levels which can lead to collisions and reduced vehicle travel speeds. In these regions, it would be prudent to surface roads with a well graded material that remains compact and relatively dust free, and be prepared to implement an enhanced dust abatement program.

## Water crossings

In many regions of Canada climate change is expected to bring changes in precipitation patterns. This could result in more frequent, short duration, high intensity rainfall events, or other changes, that will alter stream peak flows and the times of year in which they occur. These changes will require a specific analysis of the hydraulic capacity of water crossing structures, as well as their projected needs to mitigate the risks to these structures. The following practices may address these concerns:

1. Evaluate the needs of current culverts and bridges to adequately pass or accommodate flood conditions and increased flows of water, bedload and debris. In areas where groundwater retention capabilities are low, higher peak flows can be expected to occur as a result of higher precipitation levels. Where needed, remediate or replace existing structures with higher capacity structures.
2. For new culverts, consider implementing streambed simulation designs to determine sizing rather than a standard hydraulic design, which merely considers the passage of storm flows. Streambed simulation considers the fish passage requirements and geomorphology of the site to determine culvert size, shape, and installed elevation. Culverts installations based on streambed simulation designs have been shown to be more resistant to flooding and peak flows.
3. On watercourses where high amounts of bedload movement and debris are anticipated, consider installing upstream trash racks and catch basins to intercept materials before they can reach the crossing structure. Prior to and after large storms, inspect and clean out bedload deposits and debris from upstream reaches, trash racks, and catch basins.
4. Consider the increased use of low water bridges and vented fords in locations where these types of structures are deemed appropriate. Low water bridges and vented fords provide additional peak flow passage by allowing high water, large debris and bedload to pass over top with a minimum of damage to the structure.
5. Remove water crossing structures if a road is expected to be inactive for an extended period of time. If ongoing maintenance of the water crossing and drainage structures in a road won't or can't be performed, consider removing all or some of the structures to prevent increased maintenance issues and road washouts.
6. Ensure that water crossings on winter roads are able to accommodate flows from early thaws or from rain-on-snow precipitation events. In many regions, climate change can be expected to increase the frequency of mid-winter thaws and winter rain events which can alter the water passage requirements of existing infrastructure.
7. Ensure that water crossing structures are oriented with the natural stream channel, and avoid installing the structure so that the natural stream channel is diverted. This allows the water to follow its natural path and provides for a consistent water velocity, important factors to aid in minimizing structure blockages, erosion or scouring of the structure and stream banks.
8. Design the structure to include the least amount of fill material as possible. This can be accomplished by evaluating structure shapes such as round, arch or low-profile arch, and estimating fill requirements based on site characteristics. A structure containing less fill will create less of an environmental hazard if it fails, and will have lower repair and maintenance costs.
9. Consider the use of full span structures without mid-span piers. Depending on the design and location, these types of structures may be more likely to be able to pass debris and will have a lower risk of blockage.

## Drainage and water management

The management of water across the forested landscape is expected to be a greater challenge in response to predicted changes in climate in many areas of Canada. These changes could bring increases in rain-on-snow events, spring and fall seasonal precipitation, and warmer winters with increased snowmelt runoff. These changes in landscape water movement and seasonal timing could stress existing resource road drainage infrastructure. Adaptation for future conditions could include:

1. Review current guidelines on cross-drain culvert placement, spacing and sizing. If necessary, increase the number of cross-drain culverts as well as their diameter. Increasing the size and spacing frequency can accommodate higher flows and more debris and, thereby, reduce the likelihood of washouts. A further benefit of enhanced drainage is less concentration of flows in the ditch leading to less erosion and sedimentation.
2. Ensure that erosion resistant materials and slope stabilization methods are implemented in and around cross drain culverts. Short duration, high intensity, rainfall events can increase the risk of soil erosion and subsequent culvert blockage.
3. Avoid sole reliance on ditches and cross drains to provide road drainage. Review current use of alternative road surface and ditch drainage methods, such as outsloping roads, broad-based dips and waterbars.
4. Incorporate additional water passage structures to supplement the capabilities of installed drainage or water crossing structures. For example, in a road embankment crossing a floodplain, additional cross drain culverts or armoured dips in the road surface, will pass flood waters and help protect the integrity of the water crossing structure and its approach road.
5. In landslide prone areas, implement enhanced erosion and stabilization techniques, such as armoring and vegetating slopes, and, especially, the toes of slopes. Deepen ditches of roads across talus slopes and other rock fall zones to prevent more ravelling rock from reaching the road surface. Shallow retaining walls for the cut slope will intercept raveling cut slope materials, and will create a more stable cut slope by reducing its angle. If needed, install warning signs and road closure gates at the extents of the high risk landslide areas.
6. At rock faces adjacent to roads, where there is evidence of past or impending rock falls, consider installing rock anchors, wire curtains, or rock fall barriers. In some regions, increases in freeze-thaw conditions are predicted and these conditions can be expected to increase the risk of rock falls.
7. Where roads cross debris flow routes, consider installing upstream containment structures, and replacing existing crossing structures with more robust structures. Containment options include diversion channels, and excavated pits in front of containment dams. Debris flow-resistant structures can include vented geotextile reinforced soil (GRS) embankments and vented fords.
8. After mass movements (e.g., debris flows) occur, inspect the channel for residual blockages and bed load accumulations. Inspect containment structures and crossing structures for damage and reduced capacity. Clean out bed load accumulations and effect repairs, as needed. If indicated, create plans to excavate deposited materials from the streambed when the risk to fish values is low.

9. Reduce the erosive capacity of roadside ditch water through the effective use of off-take and diversion ditches to evacuate the water away from the road. Ensure the use of adequately sized check dams (ditch blocks) in ditches to direct ditch water into cross drains and prevent its concentration in ditches where it would erode ditch and road side slopes.
10. Incorporate water management structures into winter roads during construction, when soils are not frozen and are easily worked. Structures, such as log culvert bundles, can be removed during deactivation to create cross ditches; and, structures, such as off-take ditches and ditch blocks, can be left in place during deactivation for subsequent years.
11. Ensure effective road surface drainage at the time of construction, and with regular maintenance interventions. In-slope or outslope the road surface or crown the road at 3% - 5% to provide for rapid evacuation of water off of the road surface. Ensure that best grading practices are implemented to remove surface drainage obstructions, such as unbroken roadside berms.

## Road maintenance

Ensuring that road and infrastructure maintenance practices are identified and implemented is critical in obtaining a resource road that functions to its required performance and service levels. It can be a challenge to effectively implement recurring maintenance in current resource road operations but with forecasted changes in climate the importance of increased maintenance activities will be heightened to ensure road infrastructure resilience. The following are a few adaptation practices that can be considered:

1. In regions where prolonged droughts and dry conditions exist, review dust abatement strategies to ensure road safety and desired vehicle travel speeds. If necessary, increase the use of dust abatement products, and have the road surface material tested for gradation, plasticity of the fines content, and aggregate durability. A well graded road surface material, containing some low plasticity clay fines, will compact and seal well. This will provide a smooth, impervious, running surface that supports higher travel speeds, reduces maintenance requirements, and optimizes the performance of dust abatement products.
2. Implement an ongoing road inspection performance and condition assessment process to document rates of road and infrastructure degradation. Use this information to prioritize the form, timing, and location of maintenance activities, and to anticipate maintenance changes in the future.
3. After landslides have occurred, inspect the rock slope for unstable formations that may fall later on their own or in response to vibrations caused by the excavation of deposits from the road. Make the landslide site safe by removing or stabilizing unstable formations. Once the landslide slopes are deemed stable, clear away rock deposits from the road and its ditches, and shape the upslope deposits into a stable arrangement. Increase the frequency of site inspections and road cleaning until the stability of the slope is confirmed. Install warning signs if rock continually ravels onto the road.

4. Bridges and other stream crossings should be inspected before and (or) after heavy storms to identify erosion concerns, scouring, evidence of overtopping, and accumulations of debris and bedload in and around the structures. Remove bedload and debris accumulations that substantially reduce hydraulic capacity of the crossing structure. When erosion, overtopping, or deposition concerns arise make note of the weather event(s) leading up to with them. This information can be useful for adapting structures to climate changes.
5. Repair or upgrade rip-rap armouring to protect vulnerable parts of the crossing structure and adjacent stream channel. If heavy storm flows move rip rap from armoured surfaces, this is an indication that the rip rap is undersized.

# 6. SUMMARY

Changes to the global climate are widely recognized to be occurring due to the production of greenhouse gases caused by human activities and development. With this recognition, the global discussion on climate change is beginning to include not only strategies to mitigate the negative impacts that human activities can have on the climate but also how human activities must adapt to the changes that are occurring.

The changes to climatic conditions in Canada are expected to have a significant impact on Canadian forests and industry. Long-term adaptation needs are principally associated with changes in hydrologic regimes resulting in increased forest fires and insect outbreaks, regional shifts in native tree species ranges and wildlife migration. Short-term impacts of a changing climate are of immediate interest for forest operations as winters become milder with more precipitation. These changes in weather patterns are expected to increase the frequency and intensity of flooding in many regions of Canada. Resource roads are considered particularly vulnerable to the immediate and short-term impacts of climate change. Adaptation strategies for resource roads and infrastructure must be developed and implementation initiated to ensure that the road infrastructure required for forest access is maintained, and made resilient to climatic impacts.

Ensuring that the development and implementation of adaptation strategies occur for resource roads across Canada will be a challenge. The following key elements must be considered in these adaptation strategies:

***Understand what adaptation is***

The adaptation of resource roads to climate change includes any planning, maintenance or construction activity that reduces the negative impacts of climate change to a resource road. Adaptation provides a means in which these negative impacts are mitigated through the implementation of practices or tools. The adaptation of resource roads and infrastructure to climate change involves the understanding of risks and vulnerabilities, identifying the infrastructure components with the greatest vulnerability, and implementing strategies to ensure that the road and infrastructure components are made resilient.

### *Know the climate changes to which you are adapting*

The type, duration, and frequency of changes to the Canadian climate are wide ranging and variable at both the local and regional levels. But, in general, the Canadian climate is expected to result in warmer summer and winter temperatures, increases in high intensity and short duration rainfall events and increases or decreases in snowfall depending on the region. These changes are broad indicators of a changing climate but, of themselves, are not specific enough to provide guidance on how to adapt resource roads. Effective adaptation will require practitioners to combine their experiences under current climatic conditions with long-term modelling forecasts of future conditions. Increased knowledge of the current and expected climatic conditions can help to focus efforts on adaptation strategies and to justify to stakeholders why these changes and initiatives are needed.

### *Develop an understanding of adaptation tools and practices*

There are a variety of adaptation strategies that can assist in creating and developing a resilient resource road, and these strategies are often grouped as proactive and reactive strategies. Proactive strategies, are planned and anticipatory, and are implemented before the deterioration or damage from a climate event occurs. Reactive strategies also can be planned but are considered event-triggered strategies that are implemented after a structure is negatively impacted by a weather event. Proactive strategies are recognized to have a stronger influence on reducing long-term impacts, although an effective adaptation strategy needs to include both proactive and reactive strategies.

### *Recognize that adaptation needs to happen at a local level*

The impacts to a changing climate often are presented at the broad or regional level; however, adaptation strategies must be developed and implemented at the local or site level to ensure the development of a resilient road network. For this reason, there are not a suite of adaptation strategies that can be assured to be effective in all sites or environments. Practitioners must use the suite of adaptation tools and strategies, local knowledge of terrain and landscape conditions, and current and long-term climatic modelling to create effective adaptation strategies.

### *Be aware that adaptation strategies are evolving*

The identification and development of adaptation strategies for resource roads is a very recent initiative. The focus of the discussion on climate change for many years was on mitigation strategies to reduce the production of greenhouse gases that are driving a changing climate. With the recognition that changes to the climate are already occurring, the focus has recently shifted to include the development of strategies that not only mitigate the impacts of human activities on the global climate but also mitigate the negative impacts of the climate on human activities. The development and recognition of adaptation strategies will continue to evolve as knowledge and awareness of this issue grows.

## 7. MOVING FORWARD

The adaptation of resource roads to climate change is a relatively new concept and there currently exists very little information that identifies adaptation practices, assesses performance and recommends implementation practices that allow for mainstreaming of adaption for resource roads. Resource roads are considered particularly vulnerable to the immediate and short-term impacts of climate change. Adaptation strategies for resource roads and infrastructure must be developed and implementation initiated to ensure that the road infrastructure required for forest access is maintained, and made resilient to climatic impacts.

In order to support adaptation strategies for resource roads there is a need to increase the understanding of forecasted climate conditions and resource road management practices. There are knowledge gaps that remain to be filled including developing a better understanding of:

- Forecasted medium to long term changes to climate parameters due to climate change.
- Identification of the key climate parameters with the greatest contribution to the vulnerability of resource roads.
- Identification of the key resource road infrastructure components that are most critically impacted by climate change.
- Climate change adaptation actions and strategies that result in resilient resource roads.
- Management strategies, including cost benefit analysis to support reactive and proactive adaptation strategy implementation.
- The effectiveness of adaptation strategies through short-long term monitoring efforts.

Resource roads are an important component that supports not only forest management throughout Canada but also access for other resource based industries and community and recreational access. Governments and industry throughout Canada will need to continue to further the understanding of forecasted climate change, its related extremes and the development and implementation of adaptation practices and strategies in order to ensure the resiliency of resource roads.

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# 10. APPENDIX A: BRITISH COLUMBIA GOVERNMENT CONSULTATION

In order to support the adaptation of resource roads and infrastructure to climate change, the government of British Columbia requested that FPInnovations perform consultations with government staff across the province. In response, FPInnovations completed four consultations by phone in March 2017 to discuss key issues with government staff such as:

- What are the prominent concerns and impacts, if any, of climate change on resource roads.
- What have been your observations and what are you doing to address.
- What climate change adaptation practices (formal or informal) have occurred.
- Are adaptations being driven by environmental needs, economic needs or both.
- Are there information gaps preventing adaptations from being implemented.
- Where do you think climate change impact and adaptation efforts should be focused to support your work.

The consultations were supported by FLNRO's Chief Engineer, who coordinated teleconferences with government personnel. Through the consultations FPInnovations was able to connect with 15 government staff that provided input.

There were many common themes that were presented during the consultation meetings. The biggest challenges that were identified to resource roads from climate change were the management of water and the changing seasonal temperature and precipitation events. Of particular concern in many areas of the province were more frequent rain-on-snow events and freeze-thaw events as this was described to have a significant impact on road maintenance, such as freezing of culverts, and a reduction in the use of winter roads.

While there appears to be adaptation measures currently being adopted in many regions throughout the province there is no widespread recognition of the effectiveness of these measures or the range of adaptation measures that may be available. Current adaptation measures are focused on the immediate concerns with smaller culverts not being able to handle the increased water and debris flows that are occurring.

The recognition of climate change is still occurring, especially for field and operational staff, so there have not been focused resources to identify current and future adaptation practices. Those practices that have been proposed to adapt to climate change are principally focused on alternative water crossing structures, such as fords, or modifications to existing structure types, such as portable bridges.

There was strong recognition that there is a knowledge gap that is preventing engineers and road designers from making decisions in their day to day work. Guidance principles have been suggested by various agencies but many practitioners desire more detailed data that can be used to make the required decisions but also to provide a decision process which can be justified. There was also a general need identified that field and operational staff need to be aware of the concerns and risks of resource roads to climate change and that documentation and literature needs to be developed with these staff in mind.

The following presents in further detail the principal issues, concerns and suggestions that were provided by the B.C. government staff during the consultation sessions.

## Climate change impacts to resource roads

- Main issues seem to be landslides, slope instabilities and historical development problems (roads in bad place).
- Slumping, mass wasting events and debris flows are more frequent in some regions.
- Rain-on-snow events are more frequent in some regions.
- Freeze/thaw events more prevalent and this results in culverts becoming frozen, unable to pass flows during melt events.
- Frozen culverts are of increased concern, warmer winters result in rains in January, followed by freeze/thaw cycle results in ditches and small culverts getting iced in.
- Freeze/thaw cycles result in more winter grading activities.
- Milder winters are resulting in road bans occurring at different times of year in the north.
- Decreased snow falls are also allowing for continued winter logging and hauls which the roads were not originally built, this wasn't anticipated.
- More slippery days in winter with rain on frozen roads causing icing of surface.
- Water comes faster and earlier in the spring, water flows earlier in the year and can't be absorbed into the soil due to frozen soil conditions.
- Roads may need more erosion resistant material, more ballast and shotrock.
- Modelling shows wetter springs, winter and fall.
- Older structures are main problem.
- Peak rainfall events have increased erosion on road surface.
- Drier areas can't handle the new peak flows like the naturally wet areas that have stabilized.
- North has experienced drier summers.
- Storms more intense, annual rainfall about the same but falling in intensified events.
- Storms more localized but very intense.
- More rain is saturating soils, results in every subsequent rainfall creating creeks everywhere resulting in drainage culverts and ditches being overwhelmed.
- Seeing more harvesting and haul operations shutdown in the fall due to wet weather.

## Adaptation methods currently being practiced

- There is a belief that some regions and operations may be oversizing culverts but this is not widespread.
- Examples where culvert diameters have increased by adding 10% to design for peak flow events as has been suggested by APEGBC.
- Rip rap sizing increasing but not a lot of info/data/field data to help in design.
- Peak rainfall events are problems and engineers are starting to take in account larger peak flows.
- In some regions minimum culvert size has changed from 450mm to 600mm to allow for better debris passage.
- Small culverts are sized using the California method, average size 3x for Q100 calculation but have moved to 3.1 for small culverts.
- Increased use of fords in response to difficulty in maintaining smaller culverts.
- Modified fords being tried.
- Heavily walled culverts being used.
- Increased dredging activities have occurred as components of sediment management plans with respect to structures where deposition has occurred.

## Adaptation methods considered or suggested for implementation

- Roads may be decommissioned and reforested; this can be considered as a mitigation method.
- Reduced road density can help a road network adapt to climate change.
- Modified fords may become more common.
- Fords not common in north but may become more common to support recreational access.
- Fords can be a solution, shut down when there is flow.
- Portable/temporary bridges may be installed and then removed in the winter. This reduces risk of complete structure failure in times of flooding or debris.
- The BC interior uses maintained waterbars but additional water management practices such as swales may be needed.
- The BC interior may benefit from water management practices being used on the coast.
- Importance of road maintenance will increase.

## Information and knowledge gaps

- Culvert design tables need upgrading including rainfall intensities, duration, frequency and debris accommodation, and how to consider that in water crossings.
- Need guidance on culvert sizing, not only hydrological design data but confirmation and feedback on the effectiveness of current general guidance principles, such as 10% increase of peak flows.
- Rain-on-snow events, what are they going to look like, what are concerns that need to be considered, what do we need to do differently, streamflow data and trends.
- Engineering capacity lacking to determine landslide risks, as an example.
- Lacking detailed inventory and long-term plans of existing infrastructure.
- Rip rap sizing is increasing but not a lot of information to aid in the design.
- Lack of information for engineers to make decisions in day to day design.
- How can freeze/thaw cycles affect road design or maintenance and materials used.
- How much to spend on adaptive techniques vs risk and impacts.
- There is a need to classify the landscape features, such as streams, by their the risk and vulnerability.
- Need to increase awareness of climate change, its impacts and adaptation practices that are relevant and specific to climate change, aimed at on the ground personnel.
- How to change standards and policy locally or provincially to support climate change challenges.
- Need climate modelling at the district level to support climate change adaptation.

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