Developing a Climate Change Adaptation Interdependency Process with Economic Considerations

Supported by Natural Resources Canada's Climate Change Adaptation Program

VOLUME 1 A Consultation Process on Interdependencies for Climate Adaptation Projects

VOLUME 2 Methods for Interdependency Communication

VOLUME 3 A Financial Evaluation Process for Climate Adaptation Projects

VOLUME 4 Key Performance Indicators (KPIs) for Climate Adaptation Projects

VOLUME 5 Summary Case Study of the 2016 Pine Pass Flood

APPENDIX PCIC Climate Change Information

BRITISH COLUMBIA
Ministry of Transportation and Infrastructure

Developing a Climate Change Adaptation Interdependency Process with Economic Considerations

B.C. Ministry of Transportation and Infrastructure

Nodelcorp Consulting Inc.

Pacific Climate Impacts Consortium

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Supported by Natural Resources Canada's Climate Change Adaptation Program

Natural Resources Canada
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The BC Ministry of Transportation and Infrastructure (BCMOTI) is pleased to present the work in this report in response to a call for proposals from Natural Resources Canada's (NRCan) Climate Change Adaptation Program. This is to provide further insights into climate change adaptation in Canada, and in this case infrastructure interdependencies and economic analysis, using examples from the climate, weather and terrain conditions found in British Columbia.

Volumes in this study:
- Review of interdependencies;
- Methods for interdependency communication;
- Economic analysis for adaptation projects (including interdependent impacts);
- Key Performance Indicators (KPIs) for monitoring and reporting on the effectiveness of adaptation actions; and
- A case study example of interdependencies, communication, economic analysis and reporting metrics for Ministry climate adaptation initiatives.

In addition to the Volumes of work listed, BCMOTI also investigated mapping Provincial transportation infrastructure, other infrastructure and climate change information. A good way to identify potential interdependencies in infrastructure and to use mapping. As an example, mapping can depict BCMOTI infrastructure at a location and any other infrastructure present with potential interdependencies. Also, including climate change information, such as a climate change layer on a map, can help portray future climate change conditions and potential impacts on infrastructure.

As in other areas of Canada, BC typically designs infrastructure with climate information such as extreme weather. With changing climate there is more requirement for future projections of climate information such as extreme precipitation. Therefore, including relevant climate change projections would include parameters like changes in temperature, precipitation and streamflow, etc. that may affect infrastructure in the future. The goal in developing, providing and communicating this type of information is to contribute to designing infrastructure to be sustainable and resilient to future climate change conditions and extreme weather events.

Mapping of Infrastructure and Climate Changes

For the NRCan project BCMOTI further developed its in-house infrastructure mapping using internal as well as open source data. This mapping includes Ministry infrastructure and other infrastructure such as rail, utilities like power systems, pipelines, and forest service roads, as well as locations of municipalities and First Nations and their infrastructure. Thus, as the Ministry considers adapting its infrastructure for climate change it would be advisable to consider other types of infrastructure located in the vicinity in order to potentially share relevant adaptation information and thus consider a systematic approach to adaptation.

BCMOTI also partnered with the Pacific Climate Impacts Consortium (PCIC) at the University of Victoria as they provide climate change projections. This information is currently used by the Ministry to design infrastructure for future conditions and thus provide a sustainable and resilient transportation system. Sharing this information would allow other infrastructure owners to collaborate on developing climate resilient systems.

Since being established in 2008, PCIC has been developing climate science, data and tools in the climate change realm. This includes using Global Climate Model information and downscaling climate data to $10km^2$ grid size projections as this is more useful in designing local infrastructure for future climate conditions. PCIC have developed tools to portray this information on web interfaces such as Plan2Adapt and the newer PCIC Climate Explorer.

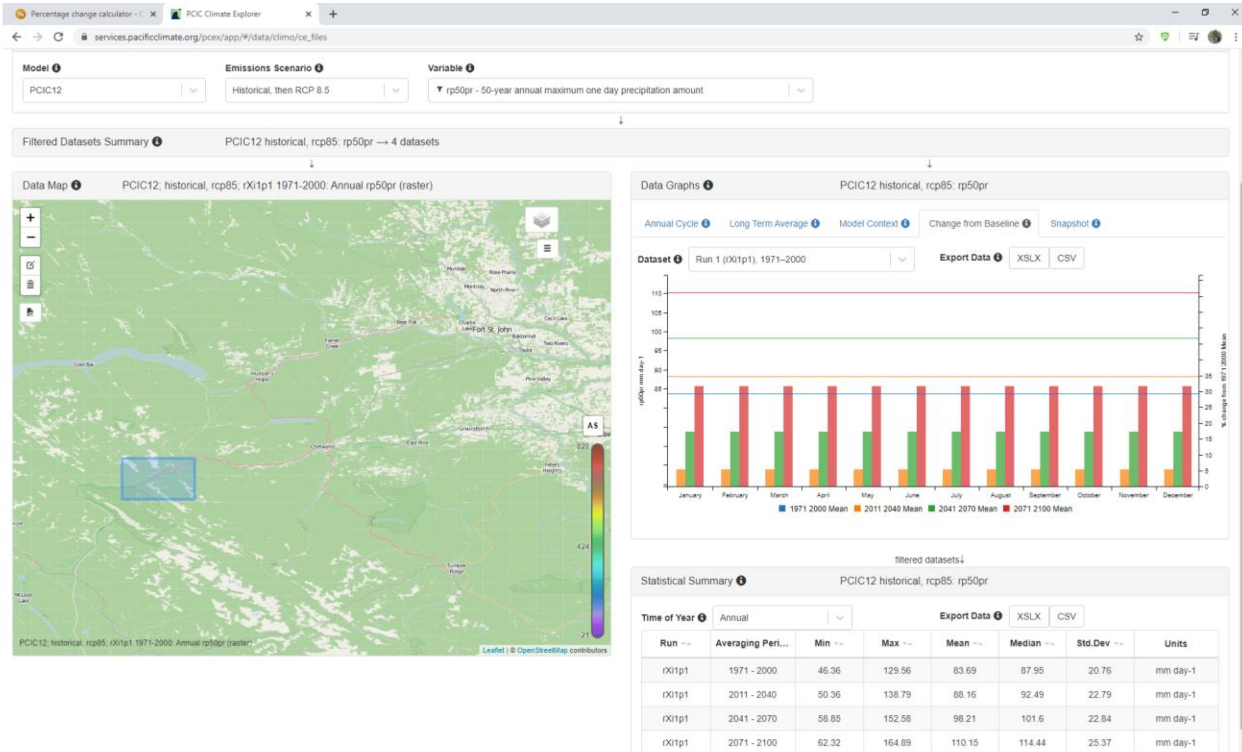
The latter has been developed with input from BCMOTI, for as of 2015 (updated in 2019), BCMOTI policy states that Ministry staff and consultants working for the Ministry are required to take changes in climate into consideration over the lifespan of the infrastructure they are designing. Over the years, this strong relationship with PCIC has enabled the Ministry to use climate change projections in design work, develop risk assessments of highway infrastructure, develop policy (as mentioned), and helped establish Ministry climate change adaptation design guidelines that BCMOTI has advanced in partnership with Engineers and Geoscientists BC.

The web page images below are taken from PCIC Climate Explorer and shows the map location of the case study for this report, in the Peace River area 80 Km to the west of Chetwynd, BC. The small blue rectangular box is the selected area along Highway 97 near the Pine River. The whole area along Highway 97 has experience sever flooding in past years, such as 2016, with bridge and culvert damage and road closures.

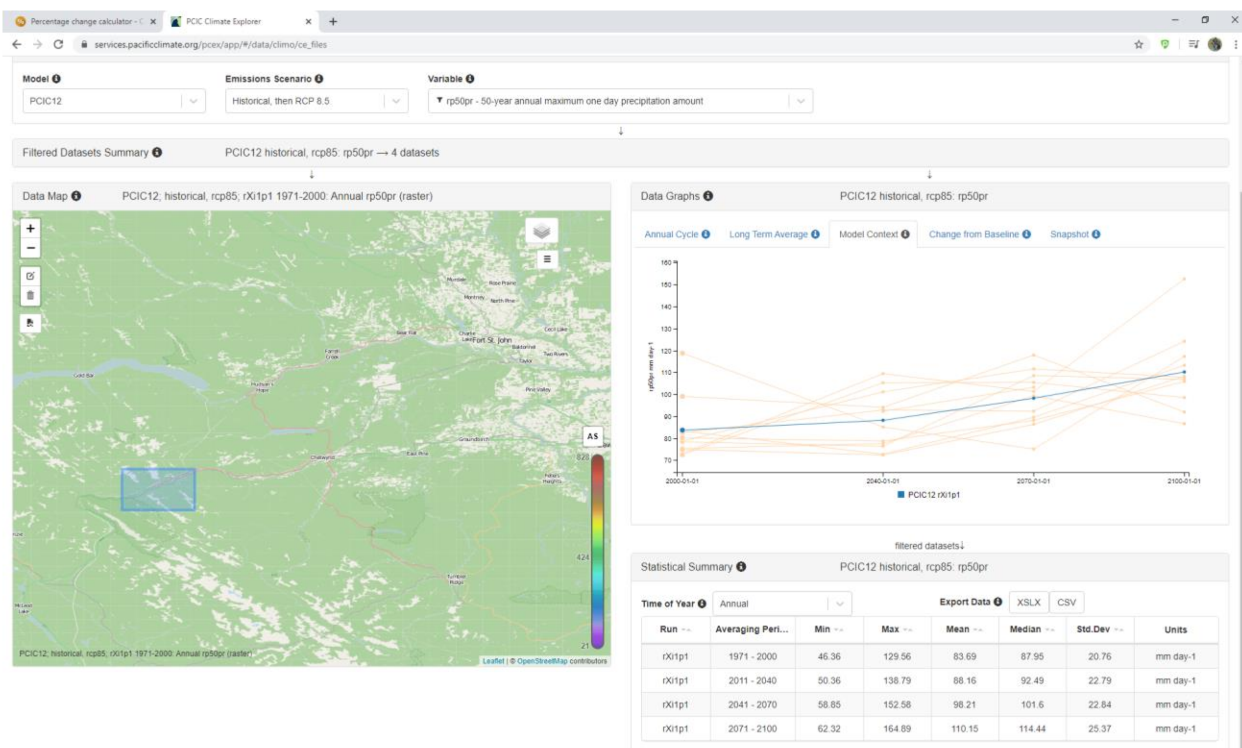
The images of climate change projections show output for the PCIC12 ensemble (an average of 12 climate models). The parameters for the modeling use RCP 8.5 and the 50-year return period for extreme precipitation in mm per day, for different periods up to 2100. The images show climate projections as a graph beside the map in the first image, and as table beside the map in the second image.

At present, PCIC provides projections for the 50-year return period for extreme precipitation (most extreme precipitation projected to occur in one of the years over a 50-year period). With advances in climate modeling and research it is anticipated that longer (100 and 200 year) return period projections for extreme events will be produced.

PCIC Climate Explorer – with change from baseline graph



PCIC Climate Explorer – with model context graph



This project initially proposed to combine infrastructure mapping developed by the Ministry with PCIC climate change projections. Thus, PCIC developed a way for the Ministry to access their pre-processed climate data files (see PCIC Appendix). Due to this project, and as this information is publicly available from PCIC, these files can now also be imported and used by others in applications such as digital mapping (with some programming knowledge). The Ministry can now import climate data into their mapping interface and portray climate information as a map layer, and therefore use this information for infrastructure design purposes.

While this is possible and can be done in the future, this step was not completed at this time. The reason is that some of the current Ministry information in its in-house mapping is proprietary and not used outside the Ministry. So, although the information would be useful to Ministry staff were it to be integrated, it would not be available for sharing with other organizations or consultants at this time. Therefore, other data sharing formats are being considered.

The spatial domain of available PCIC climate data is different depending on the data set. For example (as discussed in the PCIC Appendix), climate model output data are Canada-wide, the ClimDEX data are Canada-wide, the Degree Day data are mostly BC (with some data for western Alberta), the Return Period data are BC-only, and the gridded streamflow data are of the Peace River watershed only at this time.

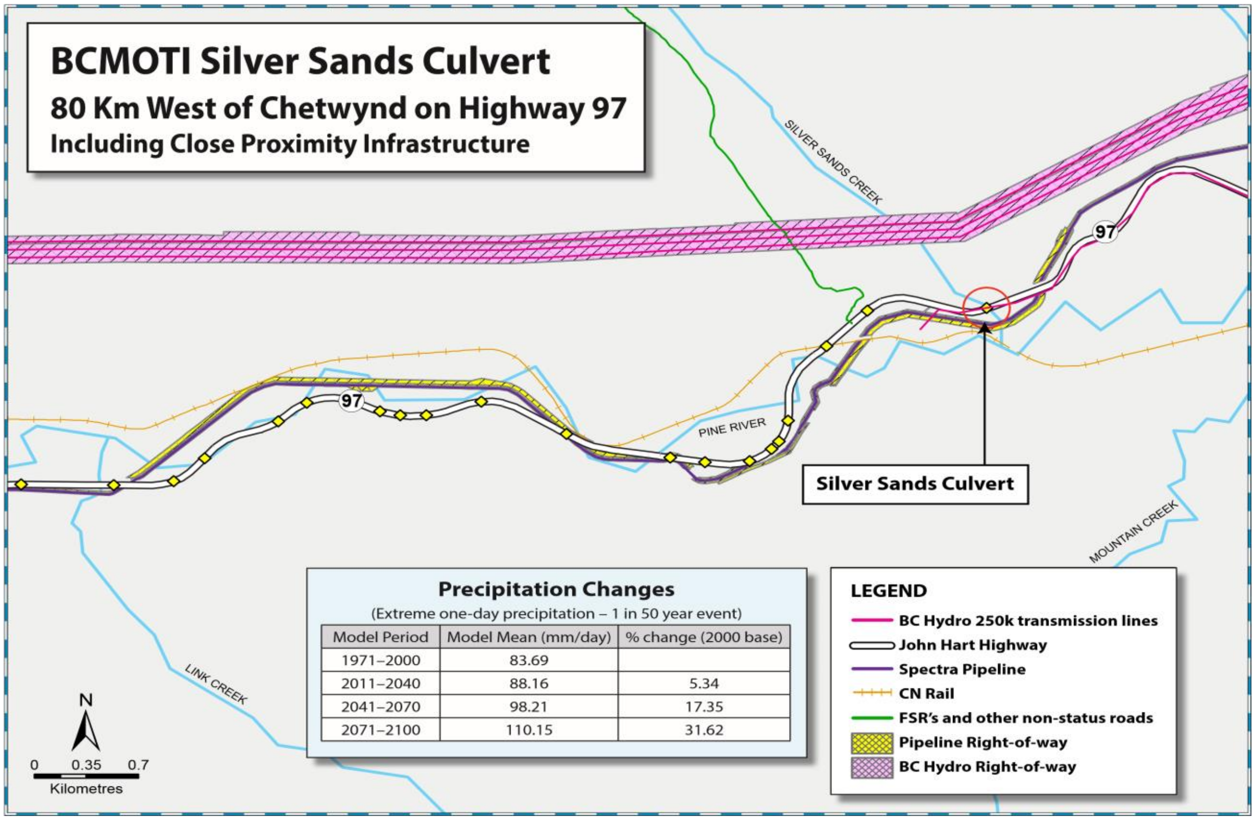
The next image shows an example of how information could be integrated into one map. This format makes it easier to visually see BCMOTI infrastructure (in this case, the Silver Sands culvert on Highway 97 west of Chetwynd, BC), and other agencies infrastructure. And also include future climate change projections, in this case, extreme precipitation for the 50-year return period for this location.

The box on the map illustrates the 1 in 50-year extreme precipitation model results from the base period to future periods. Thus, from the 1971-2000 period to the 2011-2040 period the 50-year extreme precipitation projected increase was 5%. From the base period to the 2041-2070 period there was a 17% increase projected, and from the base to the 2071-2100 period, the projected increase was over 31%. This would have implications for design or rehabilitation of infrastructure in the area and thus sustainability and reliability over its lifespan.

This type of information could be shared with relevant infrastructure owners potentially affected by future climate conditions at a location. They could then prepare and plan for these climatic changes that may affect their infrastructure in the future. Furthermore, joint projects among infrastructure owners could be considered.

These types of interdependent infrastructure situations could allow for a more comprehensive climate adaptation response to be developed. This would be a more inclusive approach potentially comprised of infrastructure owners from different groups such as highways, railways, and utilities (transmission lines, pipelines, etc.) forest service roads, etc. and possibly also any infrastructure of local governments or First Nations in the vicinity.

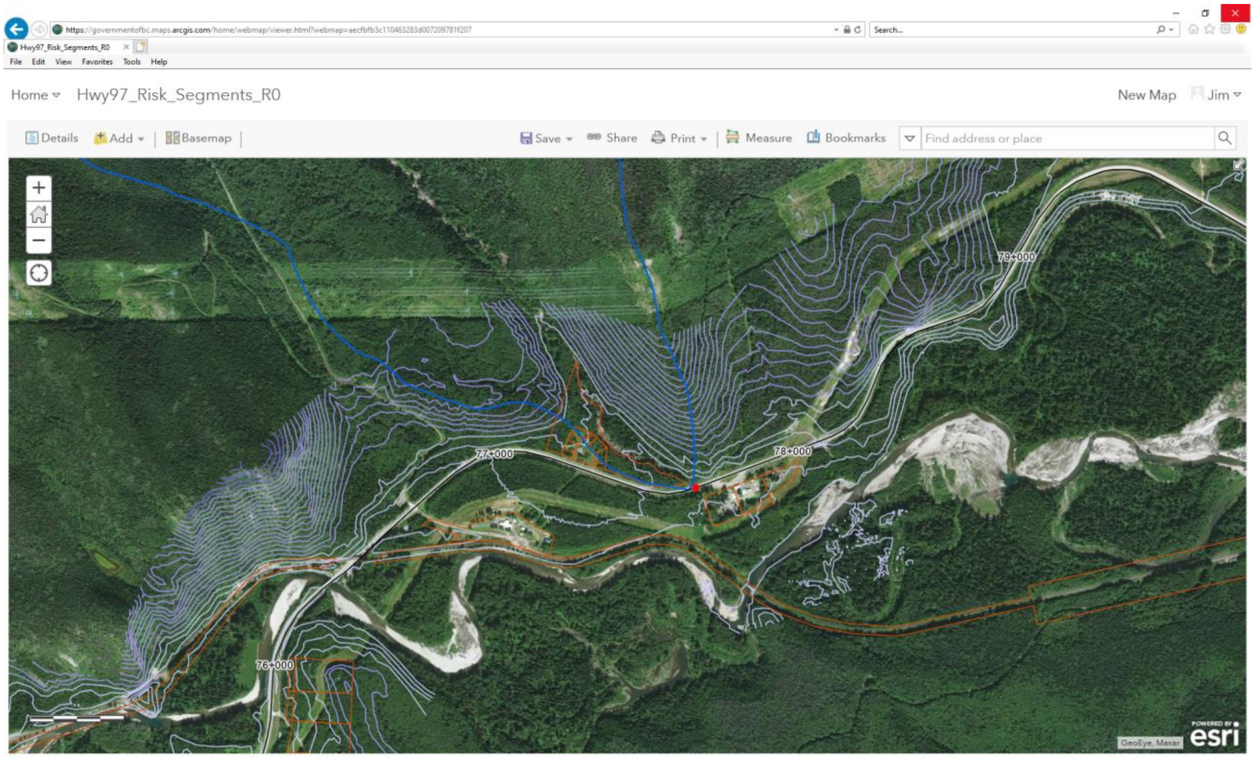
Highway 97 Culvert, other Infrastructure and Precipitation Changes



As another example of developing information in a format that could be shared with others, the Ministry developed a SharePoint based database. The information in this particular database pertains to Highway 97 bridges and culverts as many of these structures were damaged in 2016 storms, as mentioned. This project identifies current structures at risk from heavy precipitation events so they can be prioritised for repair or replacement.

The image below is from this database and shows the Silver Sands Creek Culvert as the red dot. This culvert is located at the west end of vulnerable segments identified along this Highway and is prioritized for improvement. When this image is compared to the map above, several nearby infrastructures can be identified. Thus, mapping tools like this are useful in showing potentially interdependent infrastructure and when this information is combined with climate projections and shared, this presents the context for infrastructure sustainability and resiliency planning.

Highway 97 Silver Sands Culvert, from Flood Risk GIS Database



Developing a Climate Change Adaptation Interdependency Process with Economic Considerations

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VOLUME 1

A Consultation Process on Interdependencies for Climate Adaptation Projects

BRITISH COLUMBIA

Ministry of Transportation and Infrastructure

Contents

Figures

1 Introduction

This report is a member of a family of documents prepared for the British Columbia Ministry of Transportation and Infrastructure (BCMOTI) and supported by Natural Resources Canada's Climate Change Adaptation Program. It is one element of an integrated project considering the interdependency between BCMOTI infrastructure, other infrastructure systems and climate adaption initiatives. Other infrastructure systems may include rail, power systems, gas pipelines, forest service roads, as well as municipal and indigenous infrastructure systems. Overall, the project is designed to include:

- Review of interdependencies (this volume);
- Methods for interdependency communication;
- Economic analysis for adaptation projects (including interdependent impacts);
- Key Performance Indicators (KPIs) for monitoring and reporting on the effectiveness of adaptation actions; and
- A case study example of interdependencies, communication, economic analysis for Ministry climate adaptation initiatives.

This volume of the project reviews response and recovery to emergency events affecting BCMOTI infrastructure and response and recovery issues of interdependent agents with impacted infrastructure to the same events. It draws on reflections of emergency events and the interdependency among agencies when they respond to emergency conditions.

This background will inform development of a process of informing others when Ministry climate adaptation projects are considered. Thus, it serves as information for developing workable communications methods among parties regarding climate adaptation initiatives. The aim is to increase infrastructure resilience and therefore reduce disaster risk scenarios to future climate change for Ministry and other infrastructure in a more comprehensive and integrated manner.

The project is iterative, with each phase of work feeding the next and back to the beginning of the cycle where results are refined based on the outcomes throughout the process. The case study serves as a real-world example of how the process would work based on experience gained through the Pine Pass Flood Mitigation and Adaptation Project.

Figure 1-1 shows how interdependency work fits within the overall sequence of the project workflow.

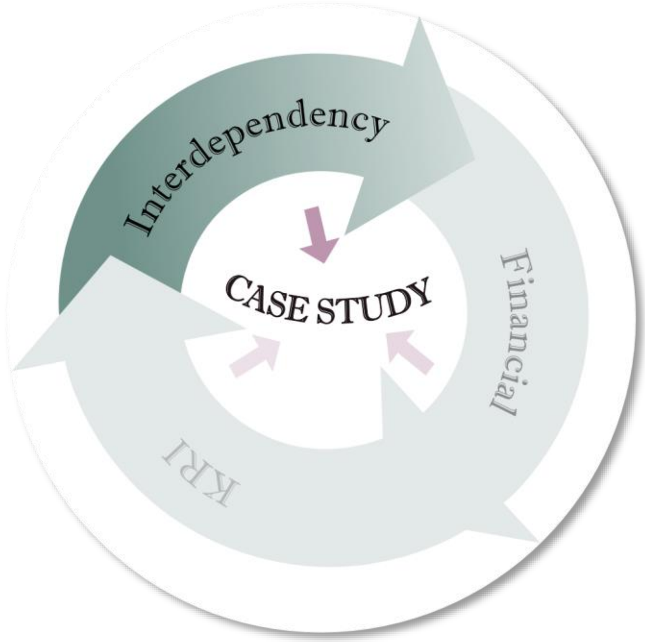

Figure 1-1 Interdependency Phase

2 Background

2.1 History of BCMOTI Climate Change Assessment Projects

BCMOTI has a long history of climate change assessment work, including risk assessments on five BC highway segments:

- Coquihalla Highway - *2010*
- Yellowhead Highway – *2011*
- Highway 20 – Bella Coola - *2014*
- Highway 37A – Stewart – *2014*
- Highway 97 – Pine Pass – *2014*

From this work, the Ministry developed climate change risk and adaptation information that they have since integrated into policies and guidelines.

The previous BCMOTI work comprised:

- Understanding the climate change context
- Collaborating with subject matter experts
- Identifying climate change risks
- Analyzing climate change risks;
- Evaluating climate change risks and producing assessment of risks;

- Developing policy and guidance documents to integrate and mainstream climate change adaptation considerations into design work.

These projects were the predecessors for the current work. They established the framework for BCMOTI to evaluate climate impacts throughout their highway infrastructure and develop adaptation measures. From this work, the Ministry developed a firm grasp of the climate change and extreme weather events that pose the most serious risks to Provincial Highways. They also established an understanding of potential climate change and extreme weather interactions affecting B.C. Highways and other infrastructure systems.

2.2 Where the Current Work Fits

This current project expands on the previous work to evaluate potential interdependencies among BCMOTI highway systems and other systems, considering the way these systems react and potentially interact before, during, and after extreme weather events.

This project conveys information from consultation with infrastructure stakeholders, based on infrastructure affected from the 2016 flood in the Pine Pass region. In addition, it evaluates a variety of approaches for assessing the financial, social, and environmental impacts of potential adaptation responses, particularly with reference to how those actions affect interdependent systems. The work was passed through the lens of the 2016 Pine Pass flood event to ground truth the results.

A monitoring process was developed for evaluating the ongoing performance of adaptation measures based on measurable key response indicator metrics.

These activities build on previous Ministry climate adaptation initiatives, expanding the boundaries of the work to cover broader social, economic and environmental impacts.

This volume of the report addresses consultation with stakeholders affected by the 2016 Pine Pass flood.

3 Consultation Context

3.1 Climate Impacts and Geography

The province of British Columbia (BC) experiences wide variations in climate because of geography and the influence of the Pacific Ocean.

The many facets of the Province's geography create a variety of natural hazards. For example, the mountain passes and mountain valleys experience wildfire, avalanches and floods. Other hazards include of earthquakes, severe storms, storm surges and tornadoes.

The mountain ranges pose extreme challenges to transportation. Mountain passes allow East-West ground passage. Many infrastructure systems use the mountain passes to provide Province-wide services. These include roads, highways, rail systems, pipelines, and power transmission. The flow of goods and services along the web of road infrastructure serve as a critical part of the supply chain that supports Canada's economy. Canada's central regions provide goods and require products from the west coast of BC. The flow of products and supplies depends on safe and efficient transportation corridors.

The challenge to the transportation corridors comes from the varied geography of the Province. Roads and rails must traverse foothills, high altitude mountain passes and valleys, more mountain passes, and finally downhill to the coast. Population clusters along transportation routes and the coastal zones. Cities and towns require food, fuel and other critical goods and services to support habitation and commerce.

Mountain passes often become pinch points to transportation along the supply chain. Changes in weather like snowfalls, rain, and drought can affect the serviceability of the transportation system. For some locations, damage to roadways can cause long detours resulting in additional time and costs for transportation of goods and services.

Along rural transportation corridors, different communities routinely use highways, secondary, and resource roads for travel, and transport of vital goods and services. For these communities, road accessibility is critical. In addition, these corridors and roads support key activities necessary to the economic wellbeing of the communities, such as tourism. In these cases, roads that have been designed to a specific purpose become important in in supporting other aspects of local communities' socio-economic wellbeing. These needs must be considered in climate adaptation work. A key example of affected groups includes First Nations communities.

BCMOTI must adapt the infrastructure under their management to respond to adverse conditions. The objective is to reduce loss of service and reduce other social and environmental costs arising from climate change and severe weather events. In addition to BCMOTI infrastructure. there are often other adjacent and connected infrastructure systems to consider. Thus, it is prudent for the Ministry to communicate climate adaptation measures to other infrastructure owners to ensure resilience and integrity of all infrastructure potentially impacted by adverse conditions.

Thus, the broader requirements for social, environmental. and economic cohesion include effective adaptation measures involving interrelated infrastructures and providing communication opportunities to achieve a state of climate resilience for the entire system.

3.2 Methodology

We interviewed agency representatives accountable for managing the June 2016 significant flood event in the northeast region of BC affecting Highway 97, the John Hart Highway. This highway extends eastward from Dawson Creek and connects with highways in Alberta. The road also extends northward to Fort St. John and Fort Nelson. Information was collected on damage from flooding and landslides arising from extreme rainfall swelling creeks and soaking mountain sides. Photographs are available to show the extent of response demands resulting from the event by (TranBC, 2016).

The interviews covered interactions of Ministry highway infrastructure with other interdependent infrastructure that share the same right-of-way. In addition, discussions covered related positive and negative consequences arising from the loss of highway access. For instance, how were pipelines, hydro, and rail responses to the event impacted by Ministry responses and actions?

The 2016 flood event formed the starting point for discussions with key players. We sought information about who to contact during severe climate events, emergency response, recovery operations, and lessons learned. We also discussed the results and knowledge base which form the basis for adaptation planning and preparedness training during the longer periods between extreme weather events.

3.3 Region of Study

The Project Team focussed on a small area in the northeast of the Province. This is part of the Peace River Basin, known as Pine Pass. The Rocky Mountain Trench separates the Province vertically. Transportation and services travel from west to east using narrow mountain passes through the challenging terrain. Highway 97 follows the Pine River along an east - west route through the mountainous region with bridges that traverse creeks and streams along the way as the route follows the winding terrain.

Many rivers and creeks feed the forests and often overflow their banks during high intensity rainfall periods. Any extensive rainfall can lead to road washouts and rockslides blocking road access.

Highway 97 is long and divides at several junctions. Therefore, the project limited the scope of the study to the highway between Dawson Creek and the town of Chetwynd. The area was appropriate, as extensive damage occurred in this region during the June 2016 flood. Availability of documentation and access to representatives from interrelated infrastructure systems allowed for high-level interviews covering the respondent's activities during the flood, those of Emergency Management BC (EMBC), and BCMOTI.

There were significant floods in this region in 2011 and 2016. In 2016, the flood and avalanche caused damage to 186 sites on six numbered highways (97 South, 2 at Dawson Creek, 29 South, 29 North, 52 North) and 40 side roads. There was serious devastation to infrastructure, homes, and personal property.

Pictures of the event demonstrate the extent of damage and traffic congestion from moving heavy equipment into the area for responding to the flooding. Different response teams competed for position to park their equipment along the limited undamaged road areas to repair their organization's infrastructures and restore service to their customers; services not only needed for nearby communities but also much farther downstream.

As high rainfall swelled rivers and creeks, the effect of the Mountain Pine Beetle infestation and large areas of dead forest growth caused high debris flow downstream. Clogged drainage and eroding structural components resulted in road washouts, and large holes exposing pipelines and other infrastructures.

The consultation identified the response actions of individuals from various agencies, and the lessons they learned from their experience. We sometimes posed the question: ***"What is your wish list?"*** to identify recommendations for action to mitigate and prepare for disaster risks, improve response coordination, and promote faster recovery for all.

3.4 Prevent - Reduce Disaster Risk

The United Nations Sendai Framework for Disaster Risk Reduction 2015-2030 (United Nations, 2015) outlines four priorities for actions to prevent new and reduce existing disaster risks. It aims for substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries and calls for ***all of society*** to share responsibility for reducing disaster risk (BC Ministry of Public Safety and Solicitor General, 2019).

Sendai Framework priorities include:

1. Understanding disaster risk;
2. Strengthening disaster risk governance to manage disaster risk;
3. Investing in disaster reduction for resilience; and
4. Enhancing disaster preparedness for effective response, and to "build back better" in recovery, rehabilitation and reconstruction

EMBC is modernizing the Emergency Program Act (EPA) to support more effective management of emergencies in B.C. by incorporating international best practices (BC Ministry of Public Safety and Solicitor General, 2019). In October 2018, B.C. become the first Canadian province to adopt the Sendai Framework. One of its key tenets is an "all of society" approach to emergency management to help build resilience at the individual and community levels. In May 2019, BC adopted an Interim Disaster Recovery Framework to provide a governance and operational structure for recovery prior to development of the new legislation. According to EMBC the proposals outlined in the discussion paper will provide the legislative framework to build on these measures.

According to EMBC, the new Act will reflect the lessons learned from the unprecedented flood and wildfire seasons in 2017 and 2018, address all four pillars of emergency management (mitigation, preparedness, response and recovery), and place more emphasis on up-front disaster risk reduction in order to prevent events from happening and to lessen the impact when they do occur.

3.5 Four Pillars Approach to Emergency Management

The four-pillar approach for emergency management includes four phases;

1. Mitigation;
2. Preparedness;
3. Response; and
4. Recovery.

This approach is an internationally recognized system for defining and understanding different aspects of emergency management and is integral to the systems and processes used in BC to minimize exposure and vulnerability to hazards, prepare for and manage emergencies, and rebuild afterwards. While the existing EPA is strong on the preparedness and response pillars, there are significant gaps when it comes to mitigation (pre-emergency activities) and recovery (post-event activities).

With the continual shift to a new normal because of climate and weather changes, the response system might be more dynamically illustrated than four vertical pillars. A spiral, representing growth, actions and the shift to different realities may be a better representation of the dynamic nature of the process. Adaptive measures create new scenarios requiring slightly different responses and exposing the organization to a new range of possible consequences.

Figure 4-1 modifies the four pillars of emergency management to phases in a spiral for as the organization grows with experience and new data, the organization creates a continually evolving new environment, the "new normal".

Figure 3-1 Phases of Emergency Management and Changing Scenarios

The figure shows how the four phases evolve as new climate events occur and our response and recovery modify the infrastructure system and its operations.

3.5.1 *Mitigation*

Mitigation is the phase of emergency management in which proactive steps are taken to prevent a hazardous event from occurring by eliminating the hazard, or to reduce the severity or potential impact of such an event before it occurs. Mitigation protects lives, property, cultural sites, and the environment, and reduces vulnerabilities to emergencies and economic and social disruption.

Mitigation is one pillar that requires more emphasis in the recovery process and denotes efforts to reduce future harm or future damage. In general risk management, any action that reduces or prevents harmful impacts is called mitigation.

BCMOTI demonstrates climate change adaptation leadership by including mitigative or damage reduction measures in the rebuilding of damaged infrastructure where possible. As the Province's highways become more resilient to severe weather events, the Ministry reduces the costs to the highway infrastructure and other interdependent systems as well as to society and the environment.

3.5.2 *Preparedness*

Preparedness is the phase of emergency management during which action is taken to ensure readiness to undertake emergency response and recovery. It includes, but is not limited to, hazard, risk, and vulnerability assessment, planning, resource planning, volunteer management, training, exercises, public/stakeholder education, and continuous improvement.

3.5.3 *Response*

Response is the phase of emergency management during which actions are taken in direct response to an imminent or occurring emergency in order to prevent, limit and manage impacts. Response includes the initiation of plans and actions to support recovery and may include deployment of registered volunteer resources.

3.5.4 *Recovery*

Recovery is the phase of emergency management during which action is taken to re-establish social, cultural, physical, economic, personal and community well-being through inclusive measures that reduce vulnerability to emergencies, while enhancing sustainability and resilience. It includes taking steps to repair a community impacted by an emergency and restore conditions to a level that could withstand a potential future event or, when feasible, improve them to increase resilience in individuals, families, organizations, and communities.

The lessons from response and recovery from recent severe weather events form the basis for adaptation planning and rebuilding infrastructure. Continual communication between government departments and other users (stakeholders) of the infrastructure will inform the process and ensure the Ministry executes appropriate adaptation actions. In practice, the priority of adaptation actions depends on the sensitivity of the zones, such as high debris and flood areas, or avalanche sensitive zones.

The ***Interim Provincial Disaster Recovery Framework*** and planned legislation by the Government of BC for emergency management are examples of progressive risk mitigation and management. One main recommendation of the Disaster Recovery Framework states that "*the growing gap between Response and the other three pillars must shrink if British Columbia is to be better prepared for disaster in the future*". Thus, it becomes essential for BC government agencies and others to work together following the direction laid out in the framework.

This project considered the challenges in responding to weather induced infrastructure disruptions, and advice for reduction of impacts, and need for improved communication as ways to improve the climate adaptation process.

4 Consultation with Interdependent Infrastructure Owners

Stakeholder consultation began by considering the effects of service disruptions to road infrastructure and from there progressed to other issues important to users, infrastructure owners, and managers.

For this project, we consulted with the owners of potentially interdependent infrastructure systems to assess their sensitivity to Ministry climate change adaptation response options. We focused on identifying key interdependencies and the preferred process for consultation between the Ministry and affected interdependent system operators, when the Ministry plans activities to respond to high risk weather.

4.1 Consultation with Coordinating Agencies and BCMOTI Staff

Coordinating Agencies examples would be the provincial Emergency Management Agency (EMBC), as well as energy regulators such as the BC Oil and Gas Commission. Other regulatory agencies can be considered *Coordinating Agencies*. These include BC's Forest, Lands, Natural Resources Operations and Rural Development (FLNRORD). EMBC also "***provides recovery services and supports to First Nations communities on reserve, based on a delegated service delivery agreement supported by Indigenous Services Canada.***" (Government of British Columbia, 2019)

BCMOTI functions as one ministry of the British Columbia Government with many operating arms. Project team members consult with representatives from various regional project management staff. Each manager contributes to the response and recovery from extreme climate events. In our consultation, we also discussed emergency response funding sources and funding flow.

There are many mining and forest roads which connect to BCMOTI roadways that are outside of the jurisdiction of BCMOTI. Many of these are under the care of FLNRORD, with whom we consulted briefly.

EMBC manages response activities for disasters and played a central role in the flood events in the Pine Pass, Peace River area. They maintain up-to-date contact information of interconnected and proximate infrastructure emergency personnel. The organization also serves as a conduit for distribution of funding from the Federal Government's Disaster Financial Assistance Arrangement (DFAA). This federal government department is also the source for some adaptation action funding for activities that fall within their guidelines.

4.2 Consultation of Interconnected Infrastructures

Interconnected infrastructures are infrastructures that have structures in common, such as drainage appliances or are embedded underneath the highway on the right-of-way and include pipelines, telephone and transmission lines.

Interconnected infrastructures are external to the Government of BC management jurisdiction and operate independently from BCMOTI. However, their supply chain, and physical infrastructure, such as pipelines and transmission towers are beside or buried underneath the highway. Therefore, any damage to the highway such as an avalanche or sink holes from severe weather events may also impact these infrastructures.

Drainage infrastructure located downstream from the highway drainage structures such as culverts or bridges may react to changes affected by BCMOTI. Thus, any adaptation efforts by BCMOTI, such as installing larger culverts or bridges, will require similar actions from the downstream infrastructure to avoid debris jams and other unintended adverse outcomes.

Weather has become more favourable for the proliferation the Mountain Pine Beetle which kills wide swaths of BC's forests. Infected trees dry up and die providing ready tinder for wildfire and increased debris in times of heavy rainfall. Any mitigative measures, such as removing fallen trees and debris before heavy rainfall, can reduce the adverse impacts of flood and avalanche events.

Examples of interconnected infrastructure in the Pine Pass area include pipelines carrying natural gas and oil, railway tracks running beside the roadway, power transmission lines, and fibre-optic communication transmission towers that operate within the same right of way. The route is a conduit for many resources from central Canada to the BC coast for export or servicing the BC coastal population.

4.3 Consultation with Near-Proximity Infrastructure Operators

Near-proximity infrastructures are near to or abut to Ministry systems and depend on the transportation corridor.

Near-proximity infrastructure consists of adjacent rail lines as they often have adjacent drainage components, nearby communities, first nations, and logging and wood products operations. Local authorities may govern communities. Similarly, organizations such as the Oil and Gas Commission deal with issues associated with oil and natural gas sales and transportation. Local authorities often provide alerts to communities about climate and other emergencies. Commissions deal with permitting and provide valuable information about incidents and emergency response issues.

5 Findings

The consultation began with a discussion with respondents about their organization and their responsibilities and then progress to a discussion about the 2016 June flood event.

Many respondents indicated that their biggest challenge from flooding events was the limitation in space along the roadway during the event. Damaged roads limit or stop providing service, thus normal vehicular traffic was impeded, and limited access was provided for large equipment needed for repairing damaged infrastructure. This situation continued until BCMOTI could allow safe access to affected areas. However, much of the work necessary to restore service to interconnected infrastructures required the same heavy equipment access. All agencies require operation recovery as quickly as possible.

Unproductive and unsafe situations can occur when companies compete for access. Although some companies can monitor damage with helicopters, they may be unable to repair damage and regain service expeditiously when their heavy equipment cannot gain access.

The other challenge respondents mentioned was the extent of area flooded and the amount of infrastructure affected. Highways cross many rivers and creeks in mountainous terrain. Thus, infrastructure like bridges and drainage appliances such as culverts cover a wide span of age, size and condition.

Older infrastructure such as drainage appliances may not meet current engineering standards and may not have the capacity to accommodate the impacts of climate change. Sediment and debris from deadfall may clog culverts and require manual clearing. Thus, planning and prioritizing the primary response and recovery requires mapping the geography and infrastructure of the region and ideally, communicating with other infrastructure owners for solutions.

5.1 Jurisdictional Issues

The main highway jurisdiction belongs to BCMOTI and interconnected infrastructures often follow the roadway or use its right-of-way. However, crown corporations such as CN rail also have legal jurisdiction over the area supporting the railroad.

CN does not use the highway roadbed itself, but there are crossings and rail bridges that abut the highways. CN also manage their own drainage system of culverts and bridges along the right-of-way. In this study, they are designated as near-proximity Infrastructures. They also affect other infrastructures in the right-of-way, requiring space for repair work as their heavy equipment needs access to damaged areas. Recovery efforts can often be a case of who goes first and who has the jurisdiction to service the area first. Sometimes jurisdictional issues override recovery approaches.

Since CN has jurisdiction over rail infrastructure, they presume similar rights to access to damaged areas as BCMOTI. They also have the right to fell trees and remove deadwood as measures of debris control and flood damage reduction. Poor communication between agencies such as CN and BCMOTI team may lead to challenging situations for contractor personnel.

5.2 Management Issues during Preparation and Response Phases

Emergency management of events can provide opportunities for management actions that can vary depending on the phase of the emergency. Before an emergency arises, preparation is required for the response. Then the first moments of emergency require response management of the initial emergency event focusing on saving lives and assets. Better communication may help focus on balancing the needs of all affected Interdependent infrastructure owners during the four phases of emergency management.

Management decisions during the response period can determine the amount of damage to roads and other infrastructure. Local personnel must use their training to allow for access to the highest priority damaged infrastructure under urgent circumstances. They should also ensure that measures prevent growth in the extent of the damage.

Another example of management decision making regarding emergency response involves an engineer-manager who took personal job risk and ordered a surgical cut in the road section to allow for flood water to pass. This saved the area from further damage. As flooding receded, the crew resealed the cut within a week without damage to other infrastructure.

In this example, the supervisor confronted the underlying risk that the damage would grow, if left unmanaged. If the water broke through the roadway, sinkholes and extensive washouts would have occurred. The interrelated infrastructures like pipelines would be unsupported and in danger of rupture. Safety is a major concern with sour gas pipelines because the gas is extremely toxic. Maintenance of the underlying support for the pipelines is one of the urgent, high priority response actions.

Commercial and residential gas customers on the coast rely on pipeline delivery of this product, and even though traffic was disrupted for a short time, the supervisor resolved many issues and the integrity of the pipeline was ensured. The action safeguarded the pipeline and maintained safety for the immediate area. Highway service was returned fairly quickly.

If the supervisor did not cut the road (with the resulting stoppage of traffic) the road section may have suffered more extensive damage with more damage to other Interdependent infrastructures as well.

5.3 Management Priorities for Preparation and Response

At the onset of an emergency infrastructure owners must respond immediately and have an onus to protect people and assets. Safety of emergency work crews and community public safety should come first. Sometimes, protecting an organization's reputation and assets takes priority and can appear to override public safety requirements.

Physical geography constraints can add additional pressures on emergency management managers and teams. Limitations of space to bring in repair equipment can create a competitive environment where different infrastructure crews and contractors vie for priority to move heavy machinery on congested, and potentially damaged roadways. This can create a challenging mixture of environment, machinery and people.

To clarify roles of the interdependent players during an emergency, impartial and independent coordination would be beneficial. An independent coordinator would have information about the geography and jurisdiction issues to deploy repair crews effectively. This coordination is important for the safety of people, protecting the environment and improving response time and effort.

For example, preventing ruptured gas pipelines should take precedence over the repair of cell service or rail lines. Prioritizing the order of agencies for road access can help speed up the repair and ensure contingency services remain available until the emergency has passed.

5.4 Management Issues during Mitigation and Recovery Phases

After this phase, the recovery phase re-establishes infrastructure function. During calmer phases of mitigation and recovery, management actions can consist of adaptation of the physical structure to reduce damages from future events. To do this they must draw on the experience and learning gained from the emergency event.

Respondents also identified gaps resulting from differing styles of infrastructure management during mitigation and recovery. For example, different ministries may prioritize adaptation responses differently based on their core mandates. The priority of building and adapting for future climate events may not be deemed to be as critical. The priorities of BCMOTI may not be the same as those of private entrepreneurial organizations, like logging companies, as private company management may be focused on continuing their operations, keeping their staff working, and maintaining wages.

A respondent gave an example of a potential adaptation action that was planned though not completed. A logging company supervisor noted the instability of a hillside because of fallen logs that threatened a bridge structure. However, before he could undertake any action to address the situation, he required permission from various government departments such as Environment and Forest Roads Management. Any action to remove debris required analysis, studies, and permits from the various ministries. Ultimately, he got permission, but it was only valid for a small window of time, which was untenable for a logging firm because of market and cash flow conditions. The risk prevention project was never completed, leaving the bridge exposed during future extreme rainfall events.

First Nations communities in remote locations identified another risk prevention opportunity. Resource roads connected to BCMOTI secondary highways often service these communities. First Nations residents identified roadbed stability problems at the transition points between the secondary highway and the resource road. However, they experienced considerable confusion about the accountability for care and maintenance of this infrastructure. In essence, they had no clear contact point to report the issue. Thus, the infrastructure remains vulnerable to future flooding events. The roads are very important to these communities, and they would experience considerable social costs should the infrastructure fail, as the roads are used to transport children and elders to the community school.

The Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNRORD) has jurisdiction over resource roads used by industry in BC that can connect to Provincial highways. These smaller roads are used by vehicles engaged in forestry, mining, oil and gas or agriculture operations. In addition to resource industries, these roads often are used by the general public and commercial operators, such as ski hills or fishing lodges. They serve as crucial links for rural communities and access to recreational opportunities. Private companies can be issued permits for industrial use of other roads and thus they could be involved in road maintenance. However, the core business of these private companies does not necessarily include road operation and maintenance. Consequently, the priority to repair, maintain and mitigate disaster risk for future climate change events for FLNRORD permitted roads or private roads may not align with BCMOTI climate adaptation initiatives. Permitted and privately-owned roads are often neglected during unfavourable market conditions.

There is also an issue of addressing vulnerabilities from indirect impacts on the transportation corridor, such as events that could exacerbate damage from mudslides or flooding during a rainy period. For example, one respondent described an unstable resource road which adjoined a BCMOTI managed highway. Also mentioned was fallen logs on a hillside that could threaten bridge infrastructure downstream during extreme rainfall events.

5.5 Management Priorities for Mitigation and Recovery

A few of the respondents identified difficulty with bureaucratic layers necessary to obtain approval to undertake proactive mitigation work. Clarity is required around which government agency is responsible and what paperwork and forms and associate assessments are required to support requests. If not clear, this creates additional iterations and effort for mitigating hazards.

Securing funding to mitigate climate change vulnerabilities after emergency management response to large-scale events may depend on the availability of financing through Disaster Financial Assistance Arrangements (DFAA) offered by the federal government. In some cases, without funding, the Ministry may face higher risks of service interruptions and may require responses to hazards with alternative adaptation actions. These may include increased patrolling, monitoring and maintenance of existing infrastructure.

With effective climate adaptation planning organizations can develop resilience to extreme weather events enhancing disaster mitigation, recovery and resilience results from rebuilding to accommodate climate impacts by ***building back better or building elsewhere***. Infrastructure owners may wish to build stronger and larger. For example, highway adaptation measures can include larger culverts, more fortified bridges at vulnerable points along the highway, or investment in more personnel to patrol, monitor, and maintain infrastructure. All of these actions contribute to resilience.

Effective adaptation requires the active engagement of senior management to implement policies and secure funding. Ultimately, the goal is to prevent damage to infrastructure and communities from future extreme weather events.

6 Recommendations

6.1 Understand Disaster Risk Interdependencies

During emergency response, action depends on the impact of inaction, urgency, and the potential for an immediate and local problem to mushroom into a larger and more serious situation.

Organizations often disagree about which systems take priority for return to service. As one would expect, every organization believes that their service and customers are the most important, and they should have priority access to affect repairs. This issue was raised by several respondents. They stressed the importance of coming to a common understanding of which infrastructure repairs should go first, and the need to ensure that accessing repair sites aligns with this priority.

6.2 Manage Disaster Risk

One respondent recommended independent organisation and allocation of access through a central emergency coordinator who could impartially assess the seriousness, urgency, and potential for growth in each problem area.

Designating who is responsible for emergency management in each department and listing their contact points can significantly improve the timeliness of consultation and decision-making in urgent emergency management situations.

Within BCMOTI and other Government departments data acquisition times can be improved with enhanced coordination. During an emergency, important data such as the age of infrastructure and hydrological data of the area can be key to the ultimate effectiveness of response activities.

6.3 Invest in Resilience for Reducing Disaster Risk

Harm Reduction is a key consideration for infrastructure owners. Road managers and engineers understand the concept of increasing infrastructure resiliency through beefing up their infrastructure. Bigger culverts, stronger bridges, slope stabilization and trash racks are some physical measures to increase infrastructure response capacity.

The other aspect of risk management is ***Harm Prevention***. For road systems, common Harm Prevention activities include more frequent debris clearing from culverts and bridge openings and clearing deadfall from slopes.

6.4 Enhance Disaster Mitigation and Preparedness

The Ministry can enhance Harm Prevention activities by listening to and learning from infrastructure users, especially those directly affected by previous failures. If road users have a means to notify road engineers of unstable subsoil, or impending blockages from further upstream, the engineering team can proactively address the impact of future extreme rainfall events.

All levels of the infrastructure management team should receive training on the emergency response protocols. When all levels of management are familiar with the emergency management protocols, response times are reduced. Much like performing fire drills, emergency response training increases everyone's knowledge and familiarity with their roles and responsibilities during an emergency.

Different jurisdictions have different core missions and objectives. Planning for an emergency response framework must allow for constructive communication between parties to take advantage of the knowledge gained from previous events. The need to restore service during a disruption is a common objective.

A communication network including interdependent agents could reap rewards through developing mitigation and preparedness options and foster unifying cooperation for climate adaptation initiatives. Design and set-up of these communication networks can be developed in the periods between emergencies, when no urgency exists to respond and provide contingency measures.

Having an integrated system for identifying and accessing infrastructure information such as drawings, design information, and other features of infrastructure could as well as future climate projection data could be very useful to the interdependency communication process. One such tool could include a map-based system (such as GIS) where relevant information could be incorporated within different layers of the mapping system.

7 Conclusions

One result of this work is our increased understanding of the range of conflicting needs and priorities among various interdependent stakeholders when emergency management and infrastructure adaptation to climate change is considered. The needs and priorities vary depending on the mandate of the organization, the staff within the organization and their objectives which differ according to scope of their activities.

Any communication process involving interdependent agents should recognize the importance of the different phases of emergency management, so that after the response and recovery phases it is hoped that all would strive to develop resilient infrastructure in order to mitigate, prepare and adapt for future climate events.

Along with allocating financial resources for strengthening highway infrastructure, emphasis and consideration of social and environmental impacts inherent in climate adaptation initiatives would also be significant. This three-pronged, triple bottom line approach to adaption planning and investment would offer a more complete picture of the overall benefits of proposed adaptation action.

This findings in this volume of the project illustrates the requirement for a clear conduit of communication across owners of Ministry infrastructure, owners of interdependent infrastructure, owners of near proximity infrastructure, and coordinating agencies. This would allow significant and coordinated adaptation efforts and benefits from this enhanced communication. It would also support the collection of relevant data to focus, structure and prioritize adaptation work. Information shared with other government departments and interdependent infrastructure agents reduces gaps and duplication of adaptation efforts.

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Developing a Climate Change Adaptation Interdependency Process with Economic Considerations

Supported by Natural Resources Canada's Climate Change Adaptation Program

VOLUME 2

Methods for Interdependency Communication

British Columbia

Ministry of Transportation and Infrastructure

Contents

1 Purpose

The purpose of this document is to look at recent emergency management initiatives in BC and the Provincial climate change situation to develop a communication process for British Columbia Ministry of Transportation and Infrastructure (BCMOTI) when considering or planning climate adaptation for its infrastructure. Firstly, to let other infrastructure owners know what BCMOTI is considering so they can understand the ramifications for their infrastructure. Secondly to develop a process for this communication. Thirdly for developing stakeholder trust and confidence in adaptation efforts by BCMOTI.

From lessons learned from the unprecedented flood and wildfire seasons including, 2011, 2016, 2017 and 2018, and studies such as ***Addressing the New Normal: 21st Century Disaster Management in British Columbia***, April 30, 2018 - also known as the Abbott-Chapman report (Abbot & Chapman, 2018), BC will update and improve its emergency management program including its four pillars of emergency management (mitigation, preparedness, response and recovery). BC will place more emphasis on up-front disaster risk reduction in order to prevent events from happening and to lessen the impact when they do occur.

In addition, climate change poses increasing economic, environmental and social threats to BC from more extreme weather-related events such as flood and contributing factors to increased wildfire risk. The impacts of climate change are already being felt in the province and will likely increase in severity. In 2018, the BC government conducted an audit of the Province's ability to manage risks from climate change as contained in ***Managing Climate Change Risk: An Independent Audit***, November 2017. Therefore, these scenarios provide an opportunity for the Transportation Ministry to continue its climate adaptation initiatives and communicate to involve other infrastructure owners in consideration and planning of climate adaption actions.

2 Emergency Management

Emergency management is a universal term for the systems and processes used for preventing or reducing the impacts of emergencies on communities. Recent improvements to Emergency Management BC include:

- New Integrated Disaster Recovery Approach
- Emergency Support Services modernization
- Common Operating Picture enhancements
- Updated flood Response Plan (Spring 2019)
- Updated Evacuation Operational Guidelines (Spring 2019)
- Emergency Program Act modernization (2020)

In updating its emergency management program, the Province of British Columbia in 2018 adopted the concepts described in the ***United Nations Sendai Framework for Disaster Risk* Reduction** (Sendai Framework, UN, 2015). Essentially: "*The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.*" This represents a community wide initiative to reduce disaster risks.

Sendai Framework priorities include:

1. Understanding disaster risk;
2. Strengthening disaster risk governance to manage disaster risk;
3. Investing in disaster reduction for resilience; and
4. Enhancing disaster preparedness for effective response, and to “build back better” in recovery, rehabilitation and reconstruction

BC will incorporate the tenets of the Sendai Framework within its emergency management initiatives which use the internationally recognized system for defining and understanding emergency management conceptualized by four phases to minimize exposure and vulnerability to hazards, prepare for and manage emergencies, and rebuild afterwards:

1. Mitigation
2. Preparedness
3. Response
4. Recovery

The new recommendations for BC are centered on adopting a cross-sector approach that defines expectations with respect to the development of four-pillar emergency management planning documentation that is registered provincially, exercised, subject to audit, and integrated with government emergency plans. The intention of these activities is to enhance the resilience of critical infrastructure in British Columbia, as well as those that rely on its services. The resilience of critical infrastructure assets and systems is essential to the functionality of critical supply chains such as food, water, fuel, shelter, and medical supplies, and is also a vital component of efficient and effective response and recovery efforts. Furthermore, awareness of downstream risks (i.e., scenarios that may result in critical service losses) and interdependencies (where one critical infrastructure asset relies on another, or there is a mutual dependency) may also help the Province, Local Authorities, First Nations, and other critical infrastructure operators develop and update their emergency management planning documentation appropriately.

A modernized approach to emergency management would:

- Improve information sharing and coordination between critical infrastructure operators, the Province, Local Authorities, and First Nations; and,
- Establish minimum standards for emergency management and business continuity plans for critical infrastructure operators.

3 Response and Recovery Communication

Two of the worst flood and wildfire seasons the Province has ever seen were in 2017 and 2018. Tens of thousands of people were evacuated from their homes. Cities, towns and villages were affected in every corner of the province. Transportation routes were shut down, and some communities were cut off completely, with remote and First Nations communities disproportionally affected by these events.[(Modernizing BC's Emergency Management legislation, 2019) pp 3]

Information collected from previous flood or fire events and climate risk analyses can be shared with all ministries and others. This can facilitate developing a more consistent approach to climate adaptation using investment analysis, application of climate data and tools, and hydrological analyses. Sharing information across sectors of the Province will make climate adaptation analysis and investment more cost-effective. These efforts will also improve cross-sector collaboration and good will.

Sharing information where appropriate about the climate vulnerability and analyses of infrastructure systems with other user groups, and infrastructure owners will enable developing:

- A knowledge base of climate sensitivities;
- Collaboration among interdependent agents for enhancing decision-making; and
- Priorities for implementing adaptation actions.

A sister report, *Developing an Interdependent Infrastructure Communication Process* (Nodelcorp Consulting Inc., 2019) references examples of emergency management where the Ministry has been involved. That analysis is a background for developing a communication process to be used by the Ministry to connect with other infrastructure owners when considering climate adaptation work that could be cross-sectoral.

4 Education and Training

Education and training can reduce response and recovery time during a weather-related emergency. Public education is key to coordinated incident response. In cases of extensive wildfire or flooding, it may be necessary to evacuate a municipality, First Nations, or region. Training should be supported through commitment of resources and ongoing communication of desired incident response measures.

Training is fundamental to a safe and orderly response to emergency measures. Ongoing public outreach and education about their roles and responsibilities during a weather-related event, for example reduces anxiety and supports safe and timely response during an emergency. When people know what they need to do, where they need to go, and who is responsible, they can be receptive to response actions during emergency situations.

Training at all levels of the organization can significantly increase positive outcomes from severe weather-related events. Staff and supervisors benefit from training, to acquire useful skills to support consistent management direction during an emergency.

Educating the public regarding Ministry projects and the intent of adaptation measures informs citizens about the Ministry work does to increase transportation efficiency and adapt to new situations and conditions. This outreach can improve Ministry reputation and create opportunities for stakeholder input.

Communication and coordination of planned and ongoing projects and initiatives among ministries supports effective cross-department collaboration. These efforts create a relationship of trust between ministries and external stakeholders and improve BCMOTI ability to fulfill their service mandate.

Encourage disaster preparedness for all levels the organization to support consistent management and response during extreme weather events

Continue outreach to update public on adaptation planning and provide a mechanism to allow for stakeholder input, questions, and comments

5 Mitigation and Preparedness

The new BC approach for emergency management is contained in ***Modernizing BC's Emergency Management Legislation*** (Modernizing BC's Emergency Management legislation, 2019). Along with describing new processes for response and recovery phases of emergency management, it provides significant emphasis for mitigation and preparedness phases and collaborative action. By emphasising the latter, the goal is reducing risks caused by severe weather events and other disasters.

Understanding and assessing hazards, risks, vulnerabilities, and establishing adaptation plans can reducing risk when developing and building climate change resilient infrastructure. Information collected from previous flood or fire events and climate risk analyses can be shared with ministries and others. Sharing information where appropriate about the climate vulnerability and analyses of infrastructure systems with other user groups, and infrastructure owners will enable developing a knowledge base of climate sensitivities, developing collaboration among interdependent agents for enhancing decision-making, and developing priorities for implementing adaptation actions.

This can facilitate developing a more consistent approach to climate adaptation using investment analysis, application of climate data and tools, and hydrological analyses etc. Sharing information across sectors of the Province will make climate adaptation analysis and investment more cost-effective. These efforts will also improve cross-sector collaboration and good will. Thus, it is critical to promote collaboration and coordination to increase transparency about risk and enhance coordination and consolidation of risk assessments and hazard identification across the Province.

This will allow the Province to reduce risk exposure by developing cross-sector approaches to planning, assessing, and managing and strengthening infrastructure. This will aid in improving management policy and procedures to increase infrastructure resiliency. The involvement of cross-sector stakeholders in Ministry mitigation and adaptation planning programs to reduce emergency response and recovery efforts informs a more encompassing climate adaptation process, and also including and incorporating social, environmental and economic approaches along with engineering solutions can produce more inclusive resiliency projects.

BCMOTI is developing an approach that will align with the new Provincial emergency management initiatives. It involves more systematic management of infrastructure and social responsibilities through advising and networking with other independent infrastructure owners, community organizations, and First Nations to help the Ministry and others develop and maintain resilient infrastructure. Thus, a key feature will be to communicate the Ministry's considerations and plans for infrastructure climate adaptation to others for their consideration.

To address emergency management *mitigation* initiatives, it is useful to collect and share information about BCMOTI infrastructure climate adaptation projects that are being considered with other groups that may also have infrastructure in the area. Infrastructure under consideration may include roads, railways, pipelines, transmission lines, etc. This infrastructure such as resource roads may belong to *Ministry of Forests, Lands, Natural Resource Operations, and Dural Development* (FLNRORD) or others such as corporations or private owners.

In some cases, such as resource roads, it may be challenging to identify the owner of the infrastructure and the upkeep and maintenance of this type of infrastructure may not be a core operational requirement for an organization. However, issues such as debris buildup in culverts along these roads could lead to failures of these roads and subsequently affect other infrastructure. Thus, identifying the owners of these secondary type roads to include in adaptation planning may be challenging in some situations.

Sharing findings from data collection with owners of infrastructure including other ministries *such as FLNRORD* who manage forest service roads and corporations and private owners can promote communication and co-operation that will ultimately improve the resilience all infrastructure including BCMOTI and other systems. As well, extending the communication to communities and First Nations can lead to more proactive infrastructure management and therefore reduce the requirements for emergency response and recovery.

6 Communication

Clear and transparent communication and consultation help coordinate emergency management efforts particularly during the mitigation phase. Where climate adaptation is prudent, good communication allows improvement of interdependent or close proximity physical assets and promotes better governance of infrastructure. Stakeholders benefit by sharing options and this contributes to better decisions from cross-sectoral discussions. This can help develop relationships of trust necessary to address challenging demands and provide safe and secure infrastructure services despite the wide array of terrains and climate challenges in BC.

In promoting this approach, limitations of infrastructure should be kept in mind. For example, highway infrastructure covers long expanses, it can be at different stages of its service life in different sections of roadway, and the infrastructure can also vary in age and function. In addition, maintenance timing for highway sections and accompanying infrastructure can vary due to availability of contractors to perform tasks.

Infrastructure owners must be cognizant of limitations of addressing infrastructure issues in isolation rather than as part of a larger, integrated system. As warranted, it can be advantageous to develop adaptation actions for infrastructure, such as drainage appliances and other potentially interrelated assets when entities are potentially interrelated. Thus, a key recommendation to assist BCMOTI and other owners of infrastructure in managing adaptation practices is recognizing the importance of inclusive multi-party communication processes.

Information collected during climate emergencies can aid in planning, management, and proactive action to mitigate the severity of future events. There are significant savings gained from taking proactive adaptation action rather than fixing infrastructure, after an event. Much of the saving accrues from reduced response and recovery efforts that, in the best case, can be entirely eliminated. In addition, a climate event can cause disruption to the local economy, social services and cause environmental issues that may not be remedied immediately. As a side benefit, enhanced physical assets and management practices can improve the performance, reliability and serviceability of infrastructure.

Communication about ideas and initiatives and sharing observations about system vulnerabilities supports proactive risk mitigation and improves climate resilience. Thus, sharing knowledge and observations about systems can be invaluable among stakeholders who manage infrastructure.

6.1 Communication Methods

Discussions and information sharing on infrastructure improvements for emergency management disaster risk reduction through such things as adaptation to climate change are best framed in a fashion that allows respondents to provide input in open-ended replies, if possible. Discussion should stimulate a range of responses and allow for thoughts, observations and options for solutions to be explored.

Any consultation should be framed in a manner indicating an openness to entertain constructive responses. While stakeholders may not be comfortable exploring options for infrastructure adaptation through questionnaires, this may get the discussion started. However, where possible, person-to-person conversations with a representative group of interdependent stakeholders are often more productive. Also, to focus the direction and analysis when social (health and safety) and environmental issues are included in the evaluation, qualitative anecdotal information can often add to the discussion.

There are many options and applications for sharing information. These include developing dedicated themes and platforms to enable content for discussions or threads or even chat rooms. Specific topics in this context and include:

- Climate Adaptation;
- Pro-Active Risk Reduction Measures;
- Improved Maintenance Technique; and
- Others as appropriate.

Developing themes serves to roughly categorize topics and information that may be useful for cross-sectoral communication.

These types of communications can enhance the ability to collaboratively apply mitigation measures and, in some cases, apply for Federal funds to support adaptation initiatives. This communication can promote synergies in planning and implementation of adaptation initiatives.

Collect anecdotal information when interacting with interdependent infrastructure staff, senior management, and owners. Share findings as appropriate when considering the interdependency of adaptation regarding climate adaptation projects

Consider adopting the use of cross-sectoral chat room groups or online meeting rooms to exchange and brainstorm ideas for better climate risk management.

6.2 Collecting and Sharing Information

Methods and tools such as interviews, surveys and web portals can be useful tools to collect, disseminate and share specific information. Web portals should be structured for easy use. With the existence of many government web interfaces, clear guidance as to each site's specific purpose and procedures is helpful, allowing contributors get to the correct place to be effective. This will allow better planning for initiating joint climate adaptation programs for all potentially involved. Making information useable rather than difficult to develop and share, will reduce frustration and enhance the communication process.

A web portal for this purpose should be simple and direct and should allow information to be shared appropriately. To achieve this objective, users should be ideally offered menu categories and map layers of information. For example, climate adaptation information and mapping for BCMOTI and other infrastructures could include:

- Location in Province;
- Infrastructure type;
- Climate projections;
- Financial considerations;
- Previous risk analysis.
- Map layers including:
    - Structural (e.g. roads, culverts and bridges, etc.);
    - Environmental (rivers, streams, animal and fish populations, etc.);
    - Social (hospitals, schools, etc.);
    - Communities;
    - First Nations and finally;
    - Climate projections (temperature, precipitation, stream flow, etc.).

6.3 Communication Tools

It is useful to develop tools for communicating and sharing useful emergency information, operations data and adaptation tools with others with the aim to better prepare for climate events. Sharing of planned infrastructure improvements by BC government departments with external stakeholders will improve trust and increase emergency mitigation and facilitate climate adaptation planning.

Ministry of Transportation and Infrastructure can share specific alerts for highway sections under their management to notify road users of extreme weather events and road closure information. Fortunately, they are able to share this information through Drive BC (Government of British Columbia, 2020) to advise and inform the public through this service.

Continue using Drive BC to notify public of emergency alerts for extreme weather events and to publish road closures and detours and expected opening times.

Emergency management improvements include further developing communication tools such as the British Columbia Emergency Management Common Operating Picture (COP), which is a robust system aimed to assist in emergency response and also leading to creating resiliency in the Province. The use of this one common portal providing data, information and tools for emergency management will enhance situational awareness and decision making. The COP is accessible to all provincial agencies and external EMBC partner agencies that include First Nations, Local Authorities, Critical Infrastructure Owners, Federal Departments and NGOs.

Another example of tools to aid communication for infrastructure adaptation are the Pacific Climate Impacts Consortium's (PCIC) publicly available ***Plan2Adapt*** and the more technical ***Climate Explorer*** (Pacific Climate Impacts Consortium, 2019). These tools provide climate projections for BC for temperature, precipitation and will include more future climate data when available. The former is more general while the later can be challenging to use at first, especially for people without background in climate data and modelling. However, developing experience in working with this tool can provide valuable information for designing infrastructure for future climate conditions. Being aware of these tools and using them will help gain valuable understanding of climate trends and hydrological data necessary for effective climate adaption work.

Create information sharing systems including risk analysis and climate projections for climate disaster prevention and reduction for all Government of British Columbia departments and others

7 Planning of Physical Infrastructure and Financial Considerations

The complexity of building, operating and maintaining the extensive infrastructure and assets under the Province's care such as the BCMOTI highway system can be challenging and costly. As well, responding to emergencies can also be expensive. Therefore, planning, operating and maintaining large infrastructures with long lifespans requires robust socioeconomic investment analysis ideally including social, environmental and financial considerations.

There are also issues of climate change and adaptation that enter the mix and require addressing. In order to avoid the costs of extensive emergency response and recovery, it helps to prepare and mitigate future issues and also include climate change and adaptation in planning infrastructure projects. To do this in a system-wide and cross-sectoral way can make the system more robust to future conditions.

Benefits and cost and other financial investment analyses are useful inputs to a robust Triple Bottom Line analysis of social, environmental and financial impacts of adaptation projects. Obtaining and analysing financial information from infrastructure owners can help plan climate adaptation activities and interdependent collaboration for system-wide solutions. However, this sort of information may not always be readily available for all potentially financially sensitive areas. In this case, it may necessary to develop proxies.

Standard financial analysis based on the net present value and internal rate of return is a tried and true method to represent the value of investments. However, these numeric approaches can often overlook or undervalue environmental impacts, and social impacts, like community safety issues and vibrancy.

While standard financial-based methods can be applied to these aspects of a project, the analysis can be complicated and misunderstood. These misunderstandings can hamper effective communication and also investment in projects. Experience shows that these types of obstacles can be overcome through the application of a robust Triple Bottom Line (TBL) analysis including social, environmental and financial considerations. We describe a TBL process in *A Financial Evaluation Process for Climate Adaptation Projects* (Nodelcorp Consulting Inc., 2019).

Well-designed communication and consultation can be used to collect the necessary financial and proxy data required for developing efficient cross-sectoral TBL analysis for projects. This improves the scope and utility when designing and building projects. Moreover, connecting with various community groups and First Nations can improve relationships between them, other infrastructure owners and the Ministry. This can lead to improved design and ultimately reduced costs from building climate resilience into infrastructure projects, including interdependent cross-sectoral situations which can include highway infrastructure systems.

Developing information from groups with first-hand experience of past emergency events such as flooding can inform infrastructure climate adaptation options. Extending this process to communities and First Nations promotes connecting with these groups and benefits from their experiences. Interrelated infrastructures owners can communicate to produce well-coordinated preparedness and mitigation actions, by promoting sound climate change adaption and connecting information from their organizations to reduce emergency event risks and future asset damage, and costs while protecting lives.

Use surveys and interviews from focus groups to augment economic planning analyses and adaptation management

8 Conclusion

BCMOTI continues to demonstrate leadership in applying climate adaptation policy in developing climate resilient infrastructure to reduce climate risks. This aligns with newly proposed BC Government emergency management direction (Modernizing BC's Emergency Management legislation, 2019) to emphasize pro-active mitigation actions, to protect against disaster risks, including climate change risks and thus reduce the need for other emergency management actions including response and recovery.

As discussed, the Ministry is proposing to extend the climate adaptation approach to include more cross-sectoral communication to promote cooperative climate risk management. Thus, through coordinated efforts among owners to strengthen interdependent and localized infrastructure more systematically, this will help reduce costly response and recovery phases when confronted with severe climate events.

Also discussed are the importance that appropriate methods of communication among public and private organizations when undertaking cross-sector climate adaptation work. As climate impacts increase in severity across infrastructures causing increasing costs, there is an increased need for collaboration to support efforts to mitigate adverse impacts and adapt to climate change. Cross-sectoral outreach efforts and cooperative information sharing can foster greater pro-active asset resilience and enhance other aspects of the emergency management system to reduce weather related disaster impacts on Provincial infrastructure.

Some discussion was also provided regarding additional factors to include in analysis to estimate the full costs and benefits of reducing risk from disasters. This includes additional cost and benefit considerations in terms of society and the environment. Thus, to examine the full costs and benefits of climate adaptation involving across sectors at a location, the consistent valuation of social, environmental and financial costs of projects should be considered. This will inform funding considerations by governments and others at all levels to help to better adapt to climate change by promoting more resilient infrastructure which will enhance the protection and security of the economy and the people of B.C.

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Developing a Climate Change Adaptation Interdependency Process with Economic Considerations

Supported by Natural Resources Canada's Climate Change Adaptation Program

VOLUME 3

A Financial Evaluation Process for Climate Adaptation Projects

British Columbia
Ministry of Transportation and Infrastructure

Contents

Figures

Tables

1 Introduction

This report is a member of a family of documents prepared for the British Columbia Ministry of Transportation and Infrastructure (BCMOTI) and supported by Natural Resources Canada's Climate Change Adaptation Program. It is one element of an integrated project considering the interdependency between BCMOTI infrastructure, other infrastructure systems and climate adaption initiatives. Other infrastructure systems may include rail, power systems, gas pipelines, forest service roads as well as municipal and indigenous infrastructure systems. Overall, the project is designed to include:

- Review of interdependencies;
- Methods for interdependency communication;
- Economic analysis for adaptation projects (including interdependent impacts) (this volume);
- Key Performance Indicators (KPIs) for monitoring and reporting on the effectiveness of adaptation actions; and
- A case study example of interdependencies, communication, economic analysis and reporting metrics for Ministry climate adaptation initiatives.

This volume of the study covers financial analysis that practitioners may use when assessing climate adaptation projects. It draws on inputs from the interdependency work and serves as a starting point for developing workable key performance indicator (KPI) reporting metrics.

The project is iterative, with each phase of work feeding the next and back to the beginning of the cycle where results are refined based on the outcomes throughout the process. The case study serves as a real-world example of how the process would work based on experience gained through the Pine Pass Flood Mitigation and Adaptation Project.

Figure 1-1 shows how the financial analysis work fits within the overall sequence of the project workflow.

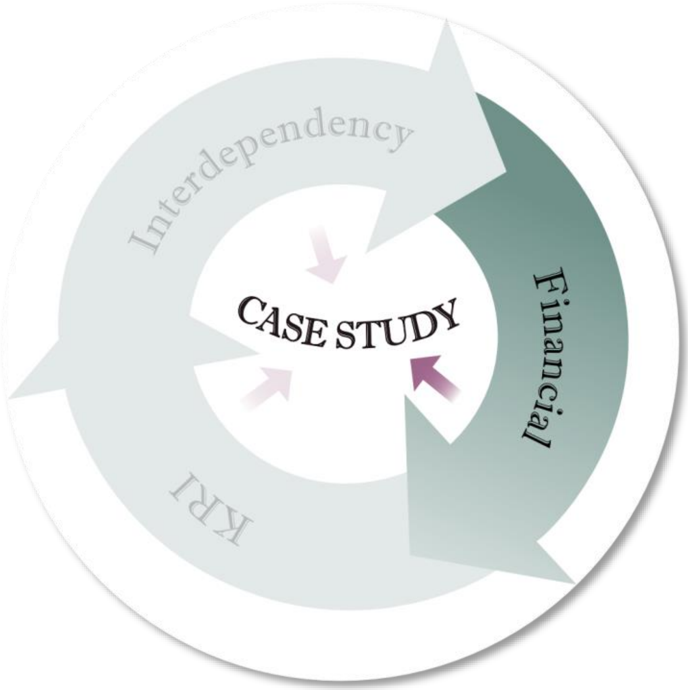

Figure 1-1 Financial Analysis Phase and Overall Work Sequence

2 Background

2.1 History of BCMOTI Climate Change Assessment Projects

BCMOTI has a long history of climate change assessment work, including risk assessments on five BC highway segments:

- Coquihalla Highway - *2010*
- Yellowhead Highway – *2011*
- Highway 20 – Bella Coola - *2014*
- Highway 37A – Stewart – *2014*
- Highway 97 – Pine Pass – *2014*

From this work, the Ministry developed climate change risk and adaptation information that they have since integrated into policies and guidelines.
The previous BCMOTI work comprised:

- Understanding the climate change context
- Collaborating with subject matter experts
- Identifying climate change risks
- Analyzing climate change risks;

- Evaluating climate change risks and producing assessment of risks;
- Developing policy and guidance documents to integrate and mainstream climate change adaptation considerations into design work.

These projects were the predecessors for the current work. They established the framework for BCMOTI to evaluate climate impacts throughout their highway infrastructure and develop adaptation measures. From this work, the Ministry developed a firm grasp of the climate change and extreme weather events that pose the most serious risks to Provincial Highways. They also established an understanding of potential climate change and extreme weather interactions affecting B.C. Highways and also other infrastructure systems.

2.2 Where the Current Work Fits

This current project expands on the previous work to evaluate potential interdependencies among BCMOTI highway systems and other systems, considering the way these systems react and potentially interact with each other before, during and after extreme weather events.

Progressively frequent extreme weather events present a set of potentially serious and costly impacts on aging and taxed infrastructure systems. With changing climate and increasing extreme events, organizations require tools and policies that help them continue to make informed decisions about how to invest limited financial resources.

This project conveys information from consultation with infrastructure stakeholders, based on infrastructure affected from the 2016 flood in the Pine Pass region. In addition, it evaluates a variety of approaches for assessing the financial, social, and environmental impacts of potential adaptation responses, particularly with reference to how those actions affect interdependent systems. the work was all passed through the lens of the 2016 Pine Pass flood event to ground truth the results.

These activities build on previous Ministry climate adaptation initiatives, expanding the boundaries of the work to cover broader social, financial and environmental impacts. This volume of the report addresses analysis for assessing social financial and environmental considerations for climate adaptation projects.

This study was developed to enable transportation decision makers to integrate economic analysis (including costs and benefits, etc.) of adaptation measures in preparation for extreme weather events and climate change. This will benefit practitioners when making planning and funding decisions in a fiscally constrained environment. Also, transportation agencies need effective economic analysis methodologies to develop plans (short and long-term) with partners and efficiently select between project alternatives, allowing them to prepare, respond, and recover quickly.

2.3 Background

Extreme weather events and a changing climate can increase costs to transportation agencies and the traveling public due to increases in travel delays and accidents. The World Meteorological

Association reports that the world is nearly five times as prone to weather-related disasters now as it was in the 1970's. (The Ecologist, 2014) Currently, in the USA 15 percent of highway congestion (U.S. Department of Transportation, 2020) and 21 percent of accidents (U.S. Department of Transportation, 2020) are weather-related. Also, the estimated cost of weather-related delays to trucking companies in the USA can be up to $3.5 billion dollars annually.

In British Columbia, there are increasingly significant impacts on Ministry operating budgets, which are absorbing costs for more road repairs from problems caused by extreme storms and floods affecting roads, bridges, and culverts. For example, in BC's South Peace District, a 2016 rain event damaged over 308 BCMOTI sites. Due to this event, the Ministry established the *Peace Flood Recovery Program* to restore the long-term safety and efficiency of highways affected. The Program had a notional budget of over $146 million, and by 2020, the Ministry had spent over $98 million on flood repairs, mostly on highway infrastructure restoration. The repairs along Highway 97 alone are estimated at $41 million.

As governments begin to experience impacts from increasing frequency of extreme weather events on their systems, many have started to evaluate factors such as criticality, traveler delays, economic impacts on freight, emergency management requirements, and safety. It is increasingly prudent to examine these factors when evaluating what the implications of climate change are on their systems and which improvements are cost effective.

For example, Washington State Department of Transportation studied a four-day storm-related highway closure in December 2007. Damage to state highways was estimated at $18 million. However total statewide freight-related economic impacts were estimated at a $47 million loss in economic output, $2 million loss in state tax revenues, and a reduction in personal income of $14 million (Washington State Department of Transportation, 2008).

To achieve the best possible results with limited resources in the face of extreme weather, transportation departments can employ available data and tools to help them make informed, timely decisions. Employing methods such as economics and financial type analyses of different feasible courses of action given situational constraints can shed light on options. Approaches such as Cost-Benefit Analysis (CBA), is an example of a tool that decision makers can use to evaluate if and how to incorporate climate change adaptation and extreme weather events into the design of a transportation asset or system.

3 Overview of Economic and Financial Analysis Approaches

Economic and financial type analysis (such as variations of Cost-Benefit Analysis (CBA)) are tools that can help inform and strengthen the case for making climate resilience investments. Particularly because peak benefits could be realized later in an infrastructure's life cycle. While analysis like CBA has some limitations, such as the problem of monetizing all benefits associated with a project or policy, these types of analysis tools can be useful in the transportation planning toolbox. These analyses can to help screen projects and adaptation approaches to identify those for further consideration of incorporation into a project. Thus, they allow users to evaluate whether climate or extreme weather adaptation measures are viable at the asset or corridor levels from a financial or economic - triple bottom line perspective.

Analysis (such as CBA) are formal ways of organizing evidence of the good and bad effects of projects and policies. They are processes that try to quantify things like benefits and costs of a project or policy using equivalent monetary value (for example in the case of CBA) in order to evaluate if projects meet financial and other criteria for implementation. The objective of something like a CBA may be to decide whether to proceed with the project, to place a value on the project, or to decide which of various possible alternatives would be the most beneficial.

Thus, economic and financial type analyses being discussed will be employed to be able to evaluate the trade-offs between different climate responses and adaptation measures and their effectiveness in terms of cost and other values. They provide an overview of options for assets at a specific location, experiencing a particular hazard or set of hazards, over a certain period of time.

3.1 Macro-Economics, Micro-Economics and Financial Analysis

Often, work in this area does not distinguish between micro and macro-economics when discussing financial analysis of climate change initiatives. In general terms, finance tends to center around topics that include the time value of money, rates of return, cost of capital, optimal financial structures and the quantification of risk.

Micro-economics is a subset of the broader economics discipline, and focusses on individuals and companies and their choices, often with only minimal reference to broader economy-wide macro themes. While micro-economics refers to the impacts of investment decisions on a business or organization, macro-economics covers the impacts on the broader economy of government decisions, the markets, population shifts, etc.

For this work, the expression financial analysis is used to refer to the economic analysis of business investments.

3.1.1 Factors Considered

For financial analysis in this study, inputs such as macro-economic indicators are employed. These are factors like projected interest rates, the rate of inflation, population growth projections, among others. These parameters are drawn from modelling outputs from credible external sources and applied within the financial analysis.

The purpose of this work is to enable risk-balanced financial analysis of climate adaptation measures, and thus climate impacts are also included in the analysis.

3.1.2 Determining Financial Boundary Conditions

In financial analysis clarity regarding boundary conditions of the analysis is necessary, specifying what factors are considered within the analysis and what are excluded. This ensures clarity about what the analysis concludes about different investment opportunities.

This project evaluated the effectiveness of adaptation measures from the perspective of BCMOTI. The ministry has guidance documents that specify key elements for this analysis, outlining those factors and the approach that addresses Ministry expectations (BCMoTI, 2014), (Apex Engineering, 2018).

Following these internal guidance documents has allowed inclusion of broader social and economic impacts in our financial evaluation. This includes factors such as the value of time for drivers forced to detour, GDP impacts, etc. These considerations are often excluded from financial analysis. However, in climate adaptation work for infrastructure systems affecting a broad range of users, impacts to these users are often incorporated in the analysis. The approach reflects the Ministry's mandate to support broader social activities. Accordingly, financial analysis was based on the cost-effective delivery of user services to the community.

3.1.3 Forms of Financial and Economic Analysis Applied in Climate Adaptation Work

OCCIAR and Golder Associates completed an extensive review of financial analysis for climate change impacts and adaptation measures in the Canadian mine industry (Rodgers, Douglas , Fabro, & Capstick, 2015). The detailed report comprises three volumes:

- Volume 1: Literature Review
- Volume 2: A Guide to Using the Climate Change Cost-Benefit Analysis Tool
- Volume 3: Final Report

While this report covered climate change impacts in the mining industry, the authors outlined an approach for financial analysis of climate change adaptation projects that is directly applicable to the current project for BCMOTI. The report outlined five principle techniques used for economic and financial analysis that were initially considered for application in this project:

1. Cost-Benefit Analysis (CBA)
   - NPV, IRR
   - Applicable for analysis of physical assets where monetary values can be estimated

2. Cost Effectiveness (CEA)
   - Applicable to situations where it may be difficult to estimate monetary benefits from an investment
   - For example, loss of life

3. Multi-Criteria Analysis (MCA)
   - Applicable for prioritization or broad-spectrum comparisons of investment opportunities
   - Triple Bottom Line Analysis, Multi-Factor Analysis, Weighted Decision Analysis

4. Partial Equilibrium and General Equilibrium Models
   - Macro-economic modelling

5. Ricardian/Physical Models
   - Macro-economic modelling

This project focussed on the financial analysis of climate adaptation options. It did not include Partial and General Equilibrium Modelling or Ricardian/Physical Modelling. These approaches are modelling exercises tailored to macro- economic analysis.

With this in mind, this work assessed CBA, CEA, and MCA. These approaches all have application in the analysis of climate adaptation measures.

These approaches are summarized in **Sections 5.2 through 5.5**.

4 Cost-Benefit Analysis (CBA)

The standard cost-benefit analysis (CBA) metrics are internal rate of return (IRR), and net present value (NPV). Often, as a short cut, organizations may employ simple return on investment (ROI), though finance specialists discourage this practice. In practice, analysts often confuse simple ROI with IRR, using the ROI acronym to describe both metrics. Caution must be exercised about this simplification in language, as the two metrics are calculated differently, and can yield conflicting results. For this reason, it is prudent to seek clarification about the actual metric and if the practitioner applied discounted cash flow analysis in the derivation of the metric.

Further guidance on the derivation of the three financial metrics in found in **Sections 4.1 to 4.6**.

4.1 Simple Return on Investment (ROI)

Simple ROI is based on ***Equation 1***.

$$ROI\ (\%) = \frac{Gain\ from\ Investment - Cost\ of\ Investment}{Cost\ of\ Investment} \times 100 \qquad (1)$$

This equation is silent about the number of years of the investment and only considers two input parameters:

- The cost for the investment (capital cost); and
- The gain in the investment over the life of the project.

Typically, for engineered systems, gains are derived from the avoided costs over the life of the project. So, ROI is the ratio of the amount of cost avoided over the life of the project and the original cost of investment. Simple ROI is a measure of the overall increase or decrease in value of the project over its useful life. The ratio contemplates the total value over the life of the project and does not consider annual returns.

Simple ROI doesn't consider the impact of inflation, discount rates, depreciation and other factors included in a more robust analysis. As a result, for projects with extended useful lives, the results from the analysis may significantly overstate the financial benefits for the investment. For short-term investments of one to five years the difference may be nonmaterial. However, for longer duration projects, like most infrastructure projects, neglecting these factors can lead to significant errors in the financial analysis.

To compensate for these deficiencies, practitioners often use an annualized ROI.

4.2 Annualized Return on Investment (ROI_A)

Typically, engineer practitioners will consider the avoided costs on an annual basis and calculate an annual ROI accordingly. On this basis, the annual ROI is derived using ***Equation 2***.

$$Annual\ ROI\ (\%) = \frac{\left(\frac{Gain\ from\ Investment - Cost\ of\ Investment}{n}\right)}{Cost\ of\ Investment} \times 100 \qquad (2)$$

Where:

n = number of years

This form of simple ROI considers the avoided costs to accrue equally, each year over the life of the project. This simplifying assumption is often incorrect, as avoided costs can be sporadic over the duration of the project. This "lumpiness" in the actual cash flow can yield dramatically different financial results, when properly accounted for.

Once again, the simple ROI can be useful for short duration projects, with even cash flows, but the analysis can significantly miss the impacts of uneven cash flows and the time value of money for long duration projects.

While common in engineering projects, ROI and Annual ROI both have significant weaknesses that could yield erroneous financial results.

Finally, some financial advisors use another form of Annualize ROI to compensate for the time value of money over the duration of a project. This form of Annualized ROI is presented in ***Equation 3***.

$$Annualize\ ROI\ (\%) = \left[(1 + ROI)^{1/n} - 1\right] \times 100 \qquad (3)$$

Where:

n = number of years

This form of Annualize ROI accommodates the effect of compound interest. The Annualized ROI is not the arithmetic average value. It is the value derived from a geometric series that would yield the overall ROI over the life of the project.

While a standard practice in financial analysis and in banking, this form of Annualized ROI is uncommon in engineering practice but is provided here to be complete. When speaking with financial advisors or banking professionals, being clear about language avoids misunderstandings that can lead to significant errors in completing an effective financial analysis for a project investment. This form of Annualized ROI has not been applied in the current financial analysis.

4.3 Discounted Cash Flow

Before discussing IRR and NPV, a foundation in discounted cash flow (DCF) is required. DCF is a valuation method that estimates the value of an investment based on its future cash flows. In DCF analysis the value of an investment today is determined, based on projections of how much money it will generate, or costs it will avoid, over its useful life.

In DCF analysis, the present value of expected future cash flows (or avoided costs) is determined using a discount rate. Then the present value estimate is used to test the merit of the investment. If the DCF value exceeds the current cost of the investment, the investment may be worthwhile.

DCF is calculated using ***Equation 4***.

$$DPV = \sum_{n=1}^{N} \frac{FV_n}{(1+r)^n} \qquad (4)$$

Where:

DPV = Discounted present value of future cash flow (FV)
FV = Value of cash flow or avoided cost in future period
r = Discount rate
n = Year
N = Total number of years in project

While the mathematics may look daunting, normally in practice spreadsheets are used to calculate the DPV based on estimates of future cash flows. Spreadsheet applications originated to simplify this financial calculation, so these applications all have integrated formulas to determine DPV.

4.4 Discount Rate

Discounting future cash flows tests the question:

> ***"How much money must I invest today, at a given rate of return, to yield the forecast cash flow, at its future date?"***

Discounting gives us the present value of future cash flows. The discount rate is the cost of capital that *appropriately* reflects the risk, and timing, of the cash flows.

The discount rate should incorporate:

1. Time value of money (or risk-free rate)

- Generally reflected in preferred interest rates at the time of the investment. This is what the investor could earn by simply leaving the money in the bank to collect interest. To be of any interest at all the project should at least yield a return exceeding the amount that could accrue by doing nothing with the money other than banking it.

2. Risk premium
   - Reflects the extra return the organization requires to compensate for the risk that the cash flow might not materialize. This risk adjustment offers a buffer against bad investments by increasing the hurdle rate that investments must achieve to be acceptable. Often, the organization's finance specialists and executives establish the risk premium based on the organization's risk tolerance.

Often, practitioners will refer to discount rate as the "real rate of interest". This translates into the nominal rate of interest minus the rate of inflation. In this way, discount rate and real rate of interest reflect the actual cost of long-term borrowing.

Many organizations establish standard discount rates that they require for DPV, NPV and IRR calculations. For example, BCMOTI uses a default discount rate of 6%, established in the *Benefit Cost Analysis Guidebook* (BCMOTI, 2014).

If the organization has not established a standard discount rate, a rate of 10% is often used. This is a conservative value, and it is relatively challenging for marginal projects. However, in this analysis it is better to err on the side of caution by establishing a more challenging discount rate, to ensure investments are not inappropriate.

4.5 Net Present Value (NPV)

Net present value is the difference between the present value of future cash flows (DPV) and the present value of the investment cost of the project (PVI). For us to deem a project acceptable, it must accrue a DPV that exceeds the PVI. Over the useful life of the project it must return financial benefits greater than the cost of the project. Thus, if:

- NPV = $0
  - The project will merely cover its original investment cost over its useful life, and just breaks even
- NPV > $0
  - The project will make a profit over its useful life
- NPV < $0
  - The project will lose money over its useful life

NPV is calculated using ***Equation 5***.

$$NPV = \sum_{n=1}^{N} \frac{R_n}{(1+r)^n} \qquad (5)$$

Where:

n = *Year*
N = *Total number of years in the project*
R_n = *Net cash flow during time period "n"*
= *Cash inflow – Cash outflow*
r = *Discount rate*

NPV has several advantages over simple ROI. NPV accounts for the time value of money. As NPV is based on a discount rate, it allows the flexibility to incorporate a risk premium into the evaluation. Thus, NPV can evaluate projects within the context of the organization's risk tolerance. In this way, projects must fit within the organization's risk profile to be acceptable. Investments that do not exceed the thresholds for the organization's cost of capital and risk margins, will not have positive NPV values and will therefore fail as acceptable investment opportunities.

NPV can also accommodate uneven, "lumpy" cash flows. Thus, the practitioner need not assume that the benefits of the investment accrue equally over each year of the project. While this may seem trivial, the timing of financial accruals has a significant bearing on the attractiveness of an investment. Investments with early returns are better. The organization can reinvest the savings or returns earlier. NPV accounts for these nuances, providing superior results for investments that have early returns.

These factors address earlier concerns about the weaknesses of simple ROI metrics. However, NPV has several potential weaknesses. First, the NPV calculation is sensitive to the assumptions applied to the cash flow analysis. If the practitioner isn't careful, they can skew results based on where they incorporate cash inflows and outflows during the project lifecycle.

Second, while NPV establishes that a project at least breaks even, it does not give a direct comparison of the investment with other options for placing the money, such as banks and bonds. For this comparison, decision-makers would prefer to see a percentage return, as they can then directly compare the returns with these other options.

NPV values tend to be larger for large projects and smaller for small projects. Thus, if the organization invests $100M, there is no direct way with NPV to compare the benefits of that project with a smaller opportunity that only requires $1M.

To address these potential weaknesses, finance experts will often quote both the NPV and IRR for an investment opportunity. The NPV provides insight about the ability of the project to break even; the IRR provides a metric to compare the investment with other opportunities that may require larger or smaller commitments of capital.

4.6 Internal Rate of Return (IRR)

The internal rate of return (IRR) is also commonly called the discounted cash flow rate of return (DFC-ROI). The IRR is the discount rate required by an investment to break even, based on a cash flow analysis. In simple terms, IRR is the discount rate where:

NPV = $0

IRR is calculated using ***Equation 6***.

$$0 = \sum_{n=1}^{N} \frac{R_n}{(1+r)^n} - R_0 \qquad (6)$$

Where:

n = *Year*
N = *Total number of years in the project*
R_n = *Net cash flow during period "n"*
= *Cash inflow – cash outflow*
R_0 = *Investment cost*
r = *Discount rate*

To determine the IRR, solve ***Equation 6*** for the value of "r". This is a complex mathematical task. However, the IRR can be calculated using a standard financial calculator or spreadsheet. Normally, a spreadsheet will require the "first guess" as a percentage, but the selected value doesn't matter. The application will then conduct thousands of iterations and yield the IRR as a simple output.

The historical complexity of the calculation is one reason engineering practitioners shied away from IRR as a standard financial metric, opting instead for simple ROI. However, with spreadsheets and financial calculators, this simplification is no longer necessary.

As IRR is based on NPV, it shares the advantages of that metric. It accounts for time value of money, and "lumpy" cash flows. Also, as it yields a percentage return, IRR can be used to evaluate the relative merits of investments of different sizes. The one weakness of IRR is that it does not give a sense of the magnitude of the profitability of an investment in absolute dollar terms. However, NPV provides this information. As a result, both IRR and NPV metrics are commonly used together for project investment analysis.

4.7 Why are NPV and IRR Recommend

Internal rate of return and net present value are the standard metrics used in project financial analysis. Both metrics rely on a detailed cash flow analysis over the life of the project, accommodate the time value of money, and account for "lumpy" cash flows.

To provide some context about the implications of "lumpy" cash flow and time value of money, a simple example calculation can show the differences in financial attractiveness predicted by Simple ROI, Annual ROI, NPV and IRR. For this example, assume:

- Ten-year project life;
- Capital expenditure of $10M in Year 1
- Avoided expenses of $10M in Year 10
- Inflation rate of 2%
- Discount rate of 10%

The cash flow analysis and calculated financial metrics appear in **Table 1**.

Table 4-1 Example Discounted Cash Flow Analysis for "Lumpy" Returns

	YEAR									
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Capital Cost	$ (10M)									
Avoided Cost										$10M
Annual Cash Flow	$ (10M)	$0	$0	$0	$0	$0	$0	$0	$0	$10M
Inflation	1.00	1.02	1.04	1.06	1.08	1.10	1.13	1.15	1.17	1.20
Cash Flow Adjusted for Inflation	$ (10M)	$0	$0	$0	$0	$0	$0	$0	$0	$8.4M
Simple ROI	100%									
Annualized ROI	10%									
IRR	-2%									
NPV (@10%)	$ (6.8M)									

For this example, there is a wide disparity of results depending on which financial metric is chosen. The Simple ROI and Annual ROI suggest the investment is very attractive. However, when accounting for time value of money and discount rate, the results are quite different. The discount analysis shows that the investment is actually unprofitable, losing $6.8M in real terms over the life of the project with a -2% IRR.

While this is an extreme example, it shows how accruing benefits later in a project can dramatically reverse the financial outcomes of an investment. These losses are missed by the Simple ROI metrics but are captured by NPV and IRR.

Therefore, it is strongly recommended is to avoid Simple ROI metrics when evaluating large investments, especially investments with uncertain or uneven cash flows over an extended period. Historically, when calculating NPV and ROI was a labour-intensive, mathematically demanding activity, using Simple ROI was justifiable. However, today with the ready availability of spreadsheets and financial calculators, avoiding the use Simple ROI should be avoided whenever possible.

Climate adaptation projects amplify these concerns as climate impacts accrue in a “lumpy” way, over a prolonged period. When evaluating these impacts on the financial performance of an adaptation investment, ensuring that the analysis is robust enough to capture the impacts of events that occur sporadically over the life of the investment ensures the best investment decisions.

5 Cost Effectiveness Analysis (CEA)

5.1 Why CEA?

Sometimes, the benefits of an investment cannot be monetized. Often, this happens when the purpose of the investment is a social benefit. As the proponent did not design the project to generate a profit, it can be difficult or impossible to assign a dollar value to the opportunity. In these situations, CBA is difficult, as it relies on monetary parameters to generate standard percentages and financial returns. When financial metrics cannot be calculated, CBA breaks down.

Often, in these cases practitioners will try to force-fit information into CBA analysis. For instance, they may arbitrarily assign a monetary value to an ecosystem or assign a dollar value to the price of a life.

While, some of these parameters are available through the insurance industry, their purpose is determining insurance premiums. They do not actually reflect the value of these intangibles. Rather, they are statistical parameters that quantity the costs borne by the insurance company to develop business, manage, litigate, pay out on claims, and cover other internal business contingencies for the policies covering these situations. These values only address the cost to the insurance company and do not reflect the overall value of the intangibles to victim’s families and to society as a whole. While subtle, this a very different lens from evaluating the overall value of a life.

The BCMOTI Default Values for Benefit Cost Analysis (Apex Engineering, 2018) provides a very good summary of costs that can be applied to the value of a life in cost-benefit analysis. This document draws from work conducted by Paul deLeur for the City of Edmonton (deLeur, 2010). DeLeur’s work is a risk tolerance balanced evaluation of the value of life for road work development and provides a reasonable cost of life value for CBA.

Numerical approaches for monetizing the value of a life all suffer from the inability to fully account for the emotional impact on loved ones and the community. As such, while they are very effective in CBA, it is advisable to be cautious about treating these values as a full account of the impact of injuries and death in broader terms. This approach can be misconstrued to imply that the practitioner simply didn't consider the full social impact of these events.

As such, while including the cost of life in a detailed CBA can be beneficial, it may only go part way towards addressing this complex issue in the context of a rigorous triple bottom line analysis, incorporating both monetizable and non-monetizable parameters.

Consequently, applying these types of monetizations in CBA can generate controversial results. Decision-makers can push back on assigning a monetary value to these intangibles. If made public, this approach can raise stakeholder concerns resulting in challenges to an organization's reputation. Thus, while the practitioner may have applied the CBA analysis with the best intentions, the approach can lead to adverse outcomes if not managed carefully.

Organizations that confront these types of dynamic social issues developed cost effectiveness analysis (CEA) as an alternative to CBA.

5.2 What is CEA?

Cost effectiveness analysis (CEA) is an alternative to cost-benefit analysis (CBA) that compares the costs with the outcomes of two or more investment opportunities.

CEA is most useful when the benefits accruing from an expenditure cannot be monetized. Commonly, healthcare professionals use CEA when it is difficult to put a dollar value on outcomes, but where they can count and compare the outcomes themselves. For example, health professionals may evaluate "the number of lives saved" through an expenditure.

There are several unstated assumptions in this metric. First, there is no monetary value assigned to a life, though the approach assumes that saving lives is inherently good and saving more lives with less expenditure is better.

CEA measures costs and the effectiveness of an expenditure. The effectiveness must be measurable, but it does not have to be monetary.

In CEA, calculating the ratio of costs to effectiveness can be done in one of two ways. First, to calculate the cost effectiveness (CE) ratio, use ***Equation 7***.

$$CE = \frac{C_x}{E_x} \tag{7}$$

Where:

x = *Option number*
C_x = *Cost of option "x"*
E_x = *Effect of option "x" in physical unites*

Conversely, to calculate the effectiveness cost (EC) ratio, use ***Equation 8***.

$$EC = \frac{E_x}{C_x} \tag{8}$$

Equation 7 provides the cost per unit of effectiveness (e.g. dollars spent per life saved). ***Equation 8*** provides the effectiveness per unit of cost (e.g. lives saved per dollar spent).

The ratios can be used to rank projects. The most cost-effective project will have the lowest CE ratio, or the highest EC ratio. As the ratios are simply the inverse of each other, choose the metric that best suits the situation. Practitioners use CEA in both ways, though they must be careful to understand the method correctly to interpret those values that show better cost effectiveness results.

CEA may be used to assess the cost-effectiveness of social or environmental benefits. For example, health professionals use CEA to evaluate the cost-effectiveness of different treatments. The World Health Organization (WHO) offers detailed guidance on CEA (World Health Organization, 2003), which has been applied to the current work on climate adaptation evaluations.

5.3 CEA and Climate Adaptation Investment Analysis

BCMOTI designs, builds and operates highway infrastructure for the benefit of the people of the Province of British Columbia. The standard financial metrics developed for profit-driven organizations may not completely capture the organization's objectives. Having an acceptable IRR, or NPV does not necessarily mean a proposed project addresses all organizational needs.

The BCMOTI guidance for CBA stresses the value of infrastructure user costs, time, and accident frequency (Apex Engineering, 2018). While this approach goes a long way to addressing the discrepancy between CBA and the Ministry's objectives, it is not the only way to approach this issue.

CEA addresses this by bypassing the monetization steps of CBA and directly measuring the impact of investment on achieving measurable objectives of an organization.

For example, there may be situations where a climate adaptation action results in reduced traffic delays on a highway, and the organization can determine the amount of reduction using traffic volume analysis. However, monetizing those values is often challenging.

Here, it is possible to calculate a CE ratio based on dollars spent to reduce delays on a section of the highway. This will yield a metric like ***$/hour-saved***. This can then be compared the impact of different project alternatives and prioritize spending based on those actions that lead to the largest "bang for the buck". In this way, the CE ratio is a way to prioritize project spending based on the cost effectiveness of the various alternatives.

To avoid the pitfalls associated with the time value of money, a discount rate should be included in the analysis. WHO suggests applying similar discount rates to those used in CBA to the non-monetizable parameters considered in the analysis. WHO argues that these parameters are just as time-sensitive as the dollars spent. In the work on this project the WHO's guidance was followed on this matter, accounting for inflation, standard discount rates, and population growth in the analysis.

An advantage of CEA is that it serves as an input into key performance indicator (KPI) analysis. Either the ratio or the non-monetizable parameters may be used as inputs to KPI analysis. These are numbers are measurable and can easily be translated into forms and templates for reporting. This is much more difficult for IRR and NPV values, as calculating these requires a solid foundation in cash flow analysis and finance that are not always skill sets of supervisors and managers who must use the forms. A detailed summary of KPI analysis is included in the companion report for this project (Nodelcorp Consulting Inc., 2020). This financial analysis report was focussed on reviewing available data and developing a set of CE ratios that provide meaningful insight into project investment opportunities.

6 Multi-Criteria Analysis

6.1 The Triple Bottom Line

Decisions about climate change adaptation projects should, as far as possible consider impacts involving a broad range of factors. The concept of sustainable development has evolved over the last thirty years to include full cost accounting of projects by integrating and estimating financial, environmental and social impacts of business decisions. The aim is achieving an appropriate balance that provides the best option to ensure a project is financially stable, environmentally sound, and socially equitable. Balancing these three aspects in project analysis is known as the triple bottom line (TBL) accounting framework.

The TBL analysis is an approach that helps organizations make decisions that best address sustainability objectives.

The PIEVC Protocol outlines a Triple Bottom Line (TBL) assessment process based on multifactor analysis and consultation with an appropriate range of stakeholders (Engineers Canada, 2013). In the current study, a multi-criteria analysis was used to achieve the same results.

6.2 The MCA Process

Multi-Criteria Analysis (MCA) is a method used to obtain an impartial understanding and evaluation of similar options or alternatives. The analysis provides greater insight into the strengths and weaknesses of various alternatives based on a set of common attributes.

The first step of an MCA is establishing the objectives and criteria to use in evaluating the project alternatives. Criteria must be chosen without bias favoring one alternative over the others. For this purpose, criteria are developed without reference to the alternatives being evaluated. Thus, the practitioner steps outside the project and views the criteria through three lenses; broader social, financial, environmental and organizational objectives. These criteria establish the measuring stick used to assess alternatives. The alternatives that better match these criteria achieve a higher ranking through the MCA process.

The following process might apply to the development of a policy, a programme or a project:

- Identifying objectives;
- Identifying options for achieving the objectives;
- Identifying the criteria to be used to compare the options;
- Analyzing the options;
- Making choices, and

- Soliciting feedback.

In MCA the criteria are split into two categories:

- Musts; and
- Wants.

6.2.1 Musts

In the first step of the MCA, criteria are established that are essential to the success of a project. These factors are deemed to be absolute minimums, below which the project cannot succeed. For example, minimum acceptable IRRs may be established that an alternative must achieve or be deemed unacceptable.

No score is applied to ***Must*** criteria they are treated as mandatory. If an alternative fails to satisfy even one ***Must*** criterion, it is excluded from further consideration.

6.2.2 Wants

In the second step of the MCA, the practitioner identifies the features desired in the best project. These are the ***Want*** criteria. These features are not mandatory but represent those factors that enhance the desirability of the project. For example, returning to the IRR criterion established as a ***Must***, the ***Want*** criterion may state that having met the minimum IRR for the project, the alternative should maximize the IRR above that threshold. An MCA can have many ***Want*** criteria covering the gamut of characteristics that a successful project should incorporate.

In MCA a weight is applied to each ***Want*** criterion to establish the relative importance of the criteria. Criteria that are more important are assigned a higher weight.

Once again, the ***Want*** criteria weightings are established with no reference to the alternatives that are being tested. The ***Want*** criteria should reflect broader social, environmental and organizational objectives without biasing the analysis towards one alternative over the others.

In MCA, the most important ***Want*** is assigned a weight of 10. The other ***Wants*** are compared to the most important and assigned a weight relative to 10 based on their importance. This is guided by posing the question:

Given that Want 1 is a 10, what weight would you assign Want 2 relative to Want 1?

6.2.3 Alternative Review Process

The next step in the analysis is to test the various alternatives against the ***Must*** criteria. As previously stated, failure to satisfy even one ***Must*** will exclude the alternative from further consideration.

Having completed the ***Must*** analysis, the remaining alternatives are tested against the ***Want*** criteria and against each other. This employs a step-by-step comparison of each alternative against each ***Want.***

The alternative that best satisfies a ***Want*** is assigned a *Raw Score* of 10. Note that this does not imply the alternative perfectly addresses the ***Want***. Rather, it says that of the range of alternatives being considered, this one ***best addresses*** the ***Want***. Having established the alternative that best addresses the ***Want,*** each of the other alternatives is tested against it. This is guided by posing the following question:

> *Given that Alternative 1 has a Raw Score of 10, what Raw Score would you assign Alternative 2 relative to Alternative 1?*

6.2.4 Weighted Score and Total Score

Next, the *Raw Score* for each ***Want*** is multiplied by the *Weight* to generate a *Weighted Score*. The *Weighted Scores* are summed to generate a *Total Score* for each alternative.

6.2.5 Analysis of the Total Score and Sensitivities

Having generated the *Total Score,* the alternatives are compared. Notionally, the highest scoring alternative is the best. However, it is good practice to review the *Raw Scores* and **Want** *Weights* to test the impact of changes in these values. This process is guided by posing the question:

> *Would a small change in the Raw Score or Weight cause a significant change in the result?*

If the answer to this question is "yes", it is prudent to review the thought processes and arguments guiding the selection of the raw scores and weights. Often, the best approach is inviting individuals who were not part of the original process to review the *Weights* and *Raw Scores*. Based on their input, an adjustment to the *Total Score may be required*.

Often, decision-makers will offer input about the raw scores and weights during their review of recommendations. While this may seem to compromise the integrity of the process, it is in fact a desirable outcome. Decision-makers often are better placed to assess overall organizational objectives than the practitioners that execute the MCA. Based on their review of the MCA, they can offer insights that may otherwise be missed in the analysis. In this way, their review strengthens the integrity of the MCA and leads to better decisions overall.

6.2.6 Strengths and Weaknesses of MCA

MCA has the advantage of constraining decision-makers to evaluate the ability of each alternative to address a range of predetermined objectives and criteria. In this way the process helps decision-makers be more objective in the selection process.

One possible weakness of the approach is that it has the appearance of quantification, suggesting that it is a more precise process than it actuality is. The selection of criteria, weights and raw scores is subjective. The process results in the best decision based on the user's perception of the situation. This perception can vary from person to person.

Based on these issues, it is best to use MCA as an aid to decision-making and not as the final arbiter between alternatives. Active discussion of the results of the analysis will frequently lead to a more dynamic understanding of the best overall alternative, even if it isn't the alternative with the highest score in the initial analysis.

MCA is a robust approach that yields good results. However, given the potential variability in results, any standard template or form prepared for this analysis must provide very strict criteria on scaling and scoring factors. It should never simply be left to one person to complete an MCA analysis. At its best, it is a brainstorming exercise designed to draw out professional judgment and document the results.

6.3 Modifying the MCA for TBL Analysis

Normally, MCA does not contemplate different classes of ***Want*** criteria, such as the Social, Environmental and Financial criteria considered in a TBL analysis. As well, MCA does not contemplate providing different emphasis for these categories of ***Want*** criteria. To accommodate these nuances, the MCA may be modified in two key areas to accommodate the requirements of TBL analysis.

6.3.1 Provision for Modifying Emphasis Placed on TBL Categories

In TBL analysis identify several ***Want*** criteria specifically related to the three sustainability categories:

- Social;
- Environmental; and
- Financial.

This adjustment allows the application of a specific emphasis on each of these categories. Normally, it is best to apply equal weighting to each category. However, some organizations place different weights on each of these factors. While not aligned with the accepted definition of sustainable development, which would apply equal weight to each factor (social, environmental, financial), it nonetheless reflects the real-world environment within which the decision-makers operate.

For example, in one study the practitioner initially suggested applying equal weighting for each category of ***Want*** criteria. However, industry experts at an MCA workshop emphasized that equivalent emphasis did not reflect the way their regulator actually evaluates these factors. They suggested that a more reasonable reflection of the "real world" in this case would be:

- Social: 5%
- Environmental: 5%
- Financial: 90%.

The ability to make this adjustment was included in the modified MCA forms developed for this project. The forms allow the practitioner to vary the weights applied to each category to assess the impact of adjusting these perspectives on the final recommendation.

6.3.2 *Modifications to Ensure Equality of TBL Categories*

Because TBL analysis demanded separate social, economic and environmental categories in the MCA, it was necessary to make other adjustment to the standard MCA. This is to ensure that the total weighted ***Want*** scores for each category are equivalent and guarantee that the analysis did not artificially overemphasize one category.

When the total score for each category is different, the categories with the highest raw scores are artificially favoured by the analysis. To adjust for this contingency, the total score for each of the categories is prorated to 100 points.

6.3.3 *Adjusted MCA for TBL Analysis*

When adjustments outlined in **Sections 6.3.1** and **Section 6.3.2** are both applied, the maximum possible score for any given alternative is 100 points.

The formatted MCA worksheet is presented in **Figure 6-1**. A fully functional MCA worksheet is provided in the supporting documentation for this report. A complete TBL analysis of the Pine Pass adaptation alternatives (alternatives listed in **Section 7.1.2**) applying this template is provided in **Section 7.4**.

Figure 6-1 MCA Worksheet for TBL Analysis

			Alternative 1			Alternative 2			Alternative 3		
	Description		Description			Description			Description		
	Must		Yes /No		Comments	Yes /No		Comments	Yes /No		Comments
M 1											
M 2											
M 3											
M 4											
M 5											
M 6											
	Wants	Weight									
	Social Factors	33.3%	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
S 1		10	8	80		7	70		6	60	
S 2		9	10	90		9	81		8	72	
S 3		5	10	50		0	0		0	0	
S 4		4	5	20		10	40		10	40	
	Total Possible Score	280					0			0	
	Sub Total Score			240			191			172	
	Sub Total out of 100			86			68			61	
	Score Adjusted by Social Factor Weighting			29			23			20	
	Environmental Factors	33.3%	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
EN 1		10	5	50		10	100		10	100	
EN 2		8	8	64		10	80		10	80	
EN 3		6	1	6		10	60		10	60	
	Total Possible Score	240									
	Sub Total Score			120			240			240	
	Sub Total out of 100			50			100			100	
	Score Adjusted by Environmental Factor Weighting			17			33			33	
	Economic Factors	33.3%	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
EC 1		10	1	10		6	60		8	80	
EC 2		9	2	18		5	45		5	45	
EC 3		8	2	16		10	80		10	80	
	Total Possible Score	270									
	Sub Total Score			44			185			205	
	Sub Total out of 100			16			69			76	
	Score Adjusted by Economic Factor Weighting			5			23			25	
	TOTAL Weighted Score		51			79			79		

7 Application of Financial Evaluation Approaches to the 2016 Pine Pass Flood Case

The areas surrounding the Pine Pass areas within the Peace River Regional District of BC have experienced several severe flooding events. Most recently, the 2011 and 2016 flood events caused significant damage to private, corporate and public infrastructure in the area. Highway 97and Highway 27 were both affected by the events and at some points were shut down due to damage from flooding. These flood events not only directly affect the health and safety of the local residences, but they also affect property, businesses, and infrastructure. Significant monies have been spent in the region as part of flood relief, repair and mitigation works. [(DWB Consulting Services Ltd. , 2019), pp 1]

In this section a summary is provided regarding testing financial evaluation approaches using real-world data related to Flood Event Loss Scenario Alternatives as proxies for adaptation measures proposed for the 2016 Pine Pass flooding event. BCMOTI is undertaking recovery work for this event that incorporates adaptation measures to provide resilience against expected future events, therefore the current analysis is retrospective. Fortunately, the Ministry has comprehensively documented this work, thus accessing this data allows conducting a detailed review of the three financial analysis techniques described. This enables an evaluation of the pros and cons of each approach for assessing proposed climate adaptation measures. In this case, climate adaptation proxy examples of Flood Event Loss Scenario Alternatives.

Previous **Sections 4, 5 and 6**, outlined the theoretical basis for the three key methods to evaluate the effectiveness of climate adaptation actions:

- Cost benefit analysis (CBA);
- Cost effectiveness analysis (CEA); and
- Triple Bottom Line (TBL) analysis.

7.1 Data Sources

7.1.1 Costing Data

BCMOTI has a rich data set to support this part of the project, and additionally two key reports prepared by Apex Engineering were also consulted. The first report was a background paper that Apex prepared to support a Ministry submission for funding from the Disaster Mitigation and Adaptation Fund (DMAF) (Apex Engineering, 2019). To support this work, Apex referred to their previous work for the Ministry providing default values for cost-benefit analysis (Apex Engineering, 2018) covering parameters such as the value of time spent in detours, collision costs, and the value of personal injuries. Apex then applied the cost-benefit procedures outlined in the Disaster Mitigation and Adaptation Fund Applicant's Guide (Infrastructure Canada, 2018).

Compliant with the Disaster Mitigation and Adaptation Fund Applicant's Guide, Apex applied a specific approach to the analysis of the "Recent Flood Loss Scenario Alternatives" listed in the background paper. This applied a constant capital cost across all the alternatives, which is not a standard financial analysis process. An ROI was calculated for this range of scenario alternatives:

- Federal DFAA Payment for 2016 Flood;
- Ministry Peace Flood Recovery Program;
- Ministry Cost of 2016 Flood along Highway 97; and
- Future Loss Projection.

While this approach is consistent with Federal – Disaster Financial Assistance Arrangement (DFAA) requirements, this is not an approach normally used to rank a range of alternatives. Normally, a range of project options are identified with different capital costs and the avoided costs for each alternative estimated.

Regardless, the Apex report provides a solid basis for cost-benefit analysis and a good starting point for this type of analysis. This work also provides a solid and robust description of various costs incurred during flooding events in the Pine Pass.

7.1.2 Scenario Alternatives

The Scenario Alternatives are examples of climate adaptation actions used to illustrate different methods of evaluation.

Alternative 1: Federal DFAA Payment for 2016 Flood
Based on DFAA payment for 2016 flood in Pine Pass area. (In the event of a large-scale natural disaster, the Government of Canada provides financial assistance to provincial and territorial governments through the Disaster Financial Assistance Arrangements (DFAA), administered by Public Safety Canada.)

Alternative 2: Ministry Peace Food Recovery Program
Based on Ministry flood recovery costs for Highway 97 and other highways in Peace Region.

Alternative 3: Ministry Cost of 2016 Flood along Highway 97
Based on Ministry costs along Highway 97 including proposed replacement of six bridges for climate resilience for this highway.

Alternative 4: Future Loss Projection
Based on a summary of the costs for a future flood event within the Pine Pass study area. The estimate includes the immediate response and the post disaster recovery plan including the replacement of three impacted structures.

Federal DFAA Payment for 2016: Repeats Alternative 4 Data

7.1.3 Climate Data

For a climate adaptation study in the Pine Pass region of B.C, information is required on baseline and projected climate conditions at that location. Fortunately, there are several good sources for this information, such as previously conducted detailed climate vulnerability and risk assessment work for Pine Pass (Nodelcorp, 2014). In addition to this data, the Pacific Climate Impact Consortium (PCIC) has a climate projection tool – BC Climate Explorer (PCIC, 2019).

Table 7-1 outlines climate data from the 2014 climate change risk assessment.

Table 7-1 Pine Pass Climate Data from 2014 Climate Change Risk Assessment

Regional Average Data (PCIC)	Historical (1971-2000)	Projected (2041-2070)	% Change
Annual Precipitation (mm/year)	**653**	**734**	**12**
Precipitation 10-year Return Period (mm/24hr)	**35**	**42**	**20**
Precipitation 25-year Return Period (mm/24hr)	**41**	**51**	**24**
5-Day Precipitation (mm)	**53**	**59**	**11**
Sustained Precipitation (events/year) 5 > days with >3.5 mm	**0.5**	**0.8**	**60**

Longer Precipitation (events/year) 10 > days with >5 mm rain	**0**	**0**	**NA**
3-Day Precipitation above 10-year Return Period Value (30y events)	**11**	**18**	**64**
Snow (events/year)	**4.3**	**5**	**16**
Chetwynd A (Environment Canada station data 1970-2005)	**Precipitation**	**Return**	
Storm 23 June 2011 (mm/24hr)	27.5	**-**	
Storm 24 June 2011 (mm/24hr)	72.0	**50y**	
Storm 25 June 2011 (mm/24hr)	25.8	**-**	
Total	**125.3**		
Storm 7 July 2011 (mm/24hr)	17.9	**-**	
Storm 8 July 2011 (mm/24hr)	43.6	**~5y**	
Storm 9 July 2011 (mm/24hr)	10.3	**-**	
Total	**71.8**		
Total 2 events	**197.1**		

Cross-checking the information in **Table 7-1** with BC Climate Explorer, confirmed the data is acceptable for the purposes of the current work.

The Pine Pass flooding events of 2011 and 2016 are assessed to be 1-in-100-year events and the time period for this risk event to occur in the future is estimated to be approximately 10 years. This is based on 1-in-100-year flood events having occurred in 1987, 2001, 2011, and 2016 with the number of years between these events being 14, 10, and 5 years. Therefore, BCMOTI assumed a 10-year return period for the precipitation event leading to the 2016 Pine Pass flood. [(DWB Consulting Services Ltd. , 2019), pp 9]

Based on the data outlined in **Table 7-1** and BC Climate Explorer, going forward the historic 10-Year return event is anticipated to occur with a 25% increase in frequency and 25% increase in intensity. For the purposes of this review of financial methods, these values are sufficient. Going forward, however, practitioners are encouraged to review their climate assumptions with a credible authority. As a minimum, they should review the most recent data outlined in ***BC Climate Explorer*** and the other PCIC tools, available online. For larger projects, practitioners should consult directly with credible climate specialists and apply the most up-to-date information in their analysis.

7.2 Cost Benefit Analysis

7.2.1 Results

A high-level summary of the cost-benefit analysis is presented in **Table 7-2**.

For this work an Excel workbook template was developed and is provided in the supporting documentation for this report. The template allowed for up to five cost-benefit analysis alternatives. As BCMOTI provided only with data for four alternatives, **Table 7-2** repeats data found in *Alternative 4* in *Alternative 5*. The data from *Alternative 4* was used to confirm the Excel template was fully functional across all five alternatives.

Table 7-2 High-Level Summary of Cost Benefit Analysis

BASE CASE

Default Values			Alternatives				
			1	2	3	4	5
			Federal DFAA	Ministry Peace Flood	Ministry Hwy 97	Loss Projection	Alt 5
	Capital Cost	$	$52,000,000	$52,000,000	$52,000,000	$52,000,000	$52,000,000
	Annual Avoided Costs	$/Y	$7,500,000	$14,500,000	$5,550,000	$4,400,000	$4,400,000
6.0%	Discount Rate	%	6%	6%	6%	6%	6%
2.5%	Inflation Rate	%	3%	3%	3%	3%	3%
	NPV	$	$22,460,688	$89,210,160	$3,866,192	($7,099,793)	($7,099,793)
	IRR	%	11%	25%	7%	4%	4%
	Simple ROI	%	14%	28%	11%	8%	8%

ACCOUNTING FOR CLIMATE CHANGE

Default Values			Alternatives				
			1	2	3	4	5
			Federal DFAA	Ministry Peace Flood	Ministry Hwy 97	Loss Projection	Alt 5
	Capital Cost	$	$52,000,000	$52,000,000	$52,000,000	$52,000,000	$52,000,000
	Annual Avoided Costs	$/Y	$7,500,000	$14,500,000	$5,550,000	$4,400,000	$4,400,000
25%	Frequency Change	%	25%	25%	25%	25%	25%
20%	Intensity Change	%	20%	20%	20%	20%	20%
	Climate Adjusted Avoided Cost	$/Y	11,250,000	21,750,000	8,325,000	6,600,000	6,600,000
6.0%	Discount Rate	%	6%	6%	6%	6%	6%
2.5%	Inflation Rate	%	3%	3%	3%	3%	3%
	NPV	$	$58,219,334	$158,343,542	$30,327,590	$13,878,613	$13,878,613
	IRR	%	19%	38%	13%	9%	9%
	Simple ROI	%	22%	42%	16%	13%	13%

7.2.2 Observations

Several conclusions may be drawn from the analysis presented in **Table 7-2**.

As discussed in **Section 4.7**, simple ROI and IRR supported by NPV can provide widely divergent results. For example, in *Baseline - Alternative 4,* Simple ROI supports the investment. However, IRR and NPV show the investment would not be sound. NPV indicates that over the life of the project the investment will lose upwards of $7M and IRR suggests that the investment barely covers the cost of interest. Meanwhile, Simple ROI suggests that the investment covers the cost of money and provides a bit of a profit.

Simple ROI doesn't account for the time value of money. *Alternative 4* is a case where this gap is significant and could lead to inappropriate investment decisions. Therefore, Simple ROI in cost-benefit analysis should be avoided if at all possible, as it can lead to unsound financial decisions.

Incorporating climate change considerations into the analysis significantly changes the financial attractiveness of these investment opportunities. **Table 7-3** highlights the impact of incorporating climate change impacts on the cost-benefit analysis.

Table 7-3 Impact of Climate Change on Cost-Benefit Outcomes

	Alternative 1			*Alternative 2*			*Alternative 3*			*Alternative 4*		
	Baseline	*Climate*	*Δ*	*Baseline*	*Climate*	*Δ*	*Baseline*	*Climate*	*Δ*	*Baseline*	*Climate*	*Δ*
			(%)			(%)						
NPV (M$)	$22	$58	**62**	89	158	**56**	4	30	**56**	(7)	14	**150**
IRR (%)	11	19	**42**	25	38	**34**	7	13	**46**	4	9	**10**

Including climate change impacts in the cost benefit analysis significantly improves the financial benefits of these climate adaptation projects. This is a reasonable outcome, as BCMOTI developed these projects to address severe flooding arising from extreme precipitation events. The analysis is very sensitive to the assumptions made regarding the timing and intensity of those events. Here, increasing the intensity of the events by 20% and the frequency by 25% has a direct impact on the results from the cost-benefit analysis.

When including the climate impacts in the analysis, projecting changes in both intensity and frequency of the events driving the flooding, the alternatives are all more financially attractive. This makes sense as these changes directly affect the events and therefore designs to accommodate them. This provides a more accurate measure of the effectiveness of alternatives and a realistic measure of each.

Practitioners should consider climate change impacts on key assumptions embedded in the analysis. This is another reason to strongly prefer IRR and NPV for this analysis, as this evaluates future conditions that are projected to differ greatly from the current baseline analysis. Therefore, incorporating cash flow analysis over the life of the project will provide superior results, more reflective of the real world. The analysis allows consideration of the impact of timing on the finances of the project and more accurately aligns the financial analysis with real-world conditions.

7.2.3 Cost-Benefit Analysis Results Summary and Analysis

Several observations may be drawn from the CBA analysis presented in **Table 7.2**.

7.2.3.1 Base Case

Of the four alternatives, **Alternative 4** is financially marginal, especially when the analysis does not consider climate change impacts. The other three alternatives at least meet normally accepted financial hurdles, exceeding readily available rates for bank interest and bonds.

With these financial projections, any of **Alternatives 1, 2, or 3** would be financially viable. **Alternative 2** offers the best financial results overall with an IRR of 25% and generating positive cash flow of over $89M over the life of the project. Even so, any one of these alternatives would cover their construction costs and generate positive cash flows over their useful life.

Under Base Case conditions, **Alternative 4** has an IRR of 4% and, over the life of the project projects losses of over $7M. This wold not be a financially sound investment under these conditions. This alternative also demonstrates the weakness of Simple ROI in this analysis, as the Simple ROI suggests that the project would be marginally profitable or at least break even. Under Base Case conditions, this could result in the approval of a project that would be unprofitable in real-world conditions.

7.2.3.2 Accounting for Climate Change

The situation is altered somewhat when climate change impacts are integrated into the analysis. In this case, all four alternatives are financially viable meeting normally accepted financial hurdles, exceeding readily available rates for bank interest and bonds. While **Alternative 4** is still the least financially attractive, it still covers its costs and generates a respectable cash flow of approximately $14M over the life of the project.

The other three alternatives become very attractive financially, generating very high IRRs and NPVs.

Under these conditions, any of these alternatives are financially viable.

These results should not be surprising. These projects were conceived and designed to accommodate severe climate change driven precipitation events. As such, they have built in capacity to accommodate those expected changes. This approach typically increases the capital cost of projects, as they are designed with incremental capacity to address conditions over and above the baseline. When climate change is taken into account in the financial analysis, there is better alignment between the infrastructure design and projected cash flows based on the real-world conditions within which the system will operate. As such, including climate change impacts in the analysis provides a more accurate picture of the financial performance the project.

7.2.3.3 Implications for Climate Adaptation Interdependency and Communication

Internally, financial analysis provides key information to decision-makers about the financial viability of projects. The process offers standard methodologies and metrics to evaluate the financial integrity of projects and compare project alternatives. Care must be exercised, however, to avoid basing project decisions solely on these metrics.

Standard financial analysis is not designed to address far-reaching socio-economic and environmental impacts of projects. These “softer” factors are difficult to monetize. While BCMOTI’s default values incorporate costing for some socio-economic factors, it does not contemplate environmental factors, impacts on quality of life, and other intangibles.

When communicating with decision-makers about financial analysis, care must be taken to ensure that the strengths and weakness of the process are clearly stated. Then, decision-makers will be equipped to apply their professional judgment to assess the effect of softer issues on the project to make more robust project decisions. When this is done, often decision-makers select a notionally less attractive financial investment, opting for alternatives that both address minimum financial criteria and also the softer socio-economic and environmental factors.

Externally, these financial metrics allow the organization to demonstrate prudent financial management of taxpayer dollars. The metrics show that the projects avoid ongoing, unmanaged emergency response costs and demonstrate the Ministry is effectively managing climate impacts on operations.

When dealing with interdependent infrastructure owners, municipalities and First Nations, the financial metrics are only one element of the communication process. Care must be exercised in this potentially sensitive communication, as impacted stakeholders may object to decisions based solely on financial performance.

The Ministry can demonstrate through the financial analysis that the project design addresses future impacts that could affect third parties, because the cash flow analysis contemplates these impacts. In this regard, the financial analysis can be a starting point in the communication process to allow the development of a more robust cash flow analysis. The Ministry can consult with interdependent infrastructure owners to incorporate third-party costs into the analysis, as appropriate.

The analysis presented in **Table 7.2** can be used to demonstrate that the Ministry is basing project decisions on prudent financial analysis that incorporates monetizable social costs. When climate change is considered any one of the alternatives is viable. This could be used as a mechanism to solicit interdependent infrastructure owner input to revise project cash flow analysis. This would allow a broader financial analysis that addresses third-party impacts, as appropriate.

7.3 Cost Effectiveness Analysis

7.3.1 Analysis

BCMOTI designs, builds and operates highway infrastructure for the benefit of the people of the Province of British Columbia. The standard financial metrics outlined in the BCMOTI guidance on cost-benefit analysis may not completely capture the social and environmental benefits of a project. As such, achieving a good IRR, or NPV does not necessarily mean a proposed project answers all of the financial, social, or environmental factors the organization wishes to project to address.

Also, the need to monetize all the input data is a drawback of cost-benefit analysis. Not only is quantitative information required, but there is also a need to assign dollar values to that data. Sometimes this is not possible.

The BCMOTI guidance for CBA stresses the value of infrastructure user costs, time, and accident frequency. This addresses some gaps in the ability of cost-benefit analysis to assess broader social and environmental factors. However, gaps remain, as it may not be easy to monetize completely things like livability, ecosystem health, and quality of life.

Cost effectiveness analysis attempts to address these gaps by bypassing the monetization steps of cost-benefit analysis, directly measuring the impact of project spending on achieving measurable objectives.

This project evaluated several possible cost effectiveness parameters. The analysis considered the ability of the parameter to provide a broader perspective of the social and environmental benefits of the four project alternatives considered in the cost-benefit analysis. The possibilities included:

- GDP per dollar spent;
- Greenhouse gas emission savings per dollar spent;
- Lives saved per dollar spent;
- Detour hours avoided per dollar spent;
- Injuries avoided per dollar spent;
- Collision costs avoided per dollar spent; and
- Total costs avoided per dollar spent.

As outlined in **Section 5.3**, discount analysis was applied to each parameter based on projected population growth in the Pine Pass region and for inflation as appropriate.

Based on numerical analysis of the six possibilities, it was concluded that the optimum parameters for cost effectiveness analysis from the available data were:

- GDP per dollar spent;
- Greenhouse gas emissions avoided per dollar spent; and
- Detour hours avoided per dollar spent.

The other possibilities either yielded results to small or too insensitive to dollars spent to be useful in project evaluation. While avoided costs and collision costs were somewhat more useful, these parameters were more accurately covered in the cost benefit analysis. In these cases, cost effectiveness analysis provided no incremental value over and above cost-benefit analysis.

7.3.2 Results

Results for the three best cost effectiveness parameters are outlined in **Tables 7-4 to 7-6**. Discussion and synthesis of the results presented in the tables is provided **in Sections 7.3.3 and 7.3.4**.

An Excel workbook template to guide this work is provide in the supporting documentation for this report. The template allows up to five cost effectiveness analysis alternatives. BCMOTI provided only data for four alternatives. Therefore, **Tables 7-4 to 7-6** repeat the data for *Alternative 4* in *Alternative 5*. Data from *Alternative 4* was used to confirm the Excel template was fully functional across all five alternatives.

The Apex report did not provide data regarding the detour times for each alternative, though they did provide a detailed analysis of the costs associated with a future event with a 15-day detour. Therefore, this work employed adjustments for the other alternatives to reflect a different detour time depending on the magnitude of the event.

The work was guided by assuming the duration of the detour could be directly related to the overall cost of the event covered in the alternative. While this is not a perfect correlation, and costing each of these events from the ground up would be preferable, the approach provided a reasonable approximation of the differences in detour time associated with each alternative. The approximation was sufficient for the purposes of this work, which was indented to show the impact of different costing and pricing options on cost effectiveness results for adaption options.

Table 7-4 GDP Cost Effectiveness Analysis

GDP							
			Alternatives				
			1	**2**	**3**	**4**	**5**
Default Values			***Federal DFAA***	***Ministry Peace Flood***	***Ministry Hwy 97***	***Loss Projection***	***Alt 5***
	Capital Cost	$	$52,000,000	$52,000,000	$52,000,000	$52,000,000	$52,000,000
	Number of Incident Days	d	26	49	19	15	15
	Population	#	15,600	15,600	15,600	15,600	15,600
6%	Discount Rate	%	6%	6%	6%	6%	6%
3%	Inflation Rate	%	3%	3%	3%	3%	3%
1%	Population Growth Rate	%	1%	1%	1%	1%	1%
33%	% of Population Affected	%	33%	33%	33%	33%	33%
$57,000	Per Capita BC GDP	$/y	$57,000	$57,000	$57,000	$57,000	$57,000
10%	Frequency	%	10%	10%	10%	10%	10%
25%	Climate Frequency Change	%	25%	25%	25%	25%	25%
20%	Climate Intensity Change	%	20%	20%	20%	20%	20%
2.5	Indirect Cost Factor	#	2.5	2.5	2.5	2.5	2.5
	GDP CEA Ratio	$/$	$0.87	$1.65	$0.64	$0.50	$0.50
	GDP CEA Ratio (CC)	$/$	$1.31	$2.47	$0.96	$0.76	$0.76

Table 7-5 Greenhouse Gas Cost Effectiveness Analysis

Greenhouse Gases

Default Values							
	Incremental Travel Distance	km	495	495	495	495	495
	Veicles per Day	v/d	1,500	1,500	1,500	1,500	1,500
	Annualized Incident Days	d/y	2.60	4.90	1.90	1.50	1.50
35%	Faction Cars	%	65%	65%	65%	65%	65%
65%	Fraction Trucks	%	35%	35%	35%	35%	35%
0.0977	Fuel Economy Cars	l/km	0.0977	0.0977	0.0977	0.0977	0.0977
0.4272	Fuel Economy Trucks	l/km	0.4272	0.4272	0.4272	0.4272	0.4272
2.634	GHG Emission Factor Cars	kg/l	2.634	2.634	2.634	2.634	2.634
2.824	GHG Emission Factor Trucks	kg/l	2.824	2.824	2.824	2.824	2.824
	GHG Emissions	kg/y	1,138,062	2,144,809	831,661	656,574	656,574
	GHG CEA Ratio	kg/$	0.646	1.218	0.472	0.373	0.373
	GHG CEA Ratio (CC)	kg/$	0.969	1.827	0.708	0.559	0.559

Table 7-6 Detour Hours Cost Effectiveness Analysis

Detour Hours

Default Values							
85	Avearage Detour Speed	kph	85	85	85	85	85
	Total Detour Time	h/y	22,712	42,803	16,597	13,103	13,103
	Detour Time Cars	h/y	14,763	27,822	10,788	8,517	8,517
	Detour Time Trucks	h/y	7,949	14,981	5,809	4,586	4,586
$18.49	Value of Time Car Passengers	$/h	$18.49	$18.49	$18.49	$18.49	$18.49
1.2	Car Occupancy	person/v	1.2	1.2	1.2	1.2	1.2
	Total Value Cars	$/h	$22.19	$22.19	$22.19	$22.19	$22.19
$31.25	Value of Time Truck Drivers	$/h	$31.25	$31.25	$31.25	$31.25	$31.25
1.0	Truck Occupancy	person/v	1.0	1.0	1.0	1.0	1.0
	Total Value Trucks	$/v/h	$31.25	$31.25	$31.25	$31.25	$31.25
	Cost of Detour - Cars	$/y	$327,554	$617,313	$239,366	$188,973	$188,973
	Cost of Detour - Trucks	$/y	$248,410	$468,157	$181,530	$143,313	$143,313
	Total Cost of Detour	$/y	$575,964	$1,085,470	$420,896	$332,287	$332,287
	Time Saved CEA Ratio	h/K$	12.9	24.3	9.4	7.4	7.4
	Time Saved CEA Ratio (CC)	h/K$	19.3	36.5	14.1	11.2	11.2
	Value of Time Saved	$/K$	$241	$454	$176	$139	$139
	Time Saved CEA Ratio (CC)	$/K$	$361	$681	$264	$209	$209

7.3.3 General Observations of Results Presented in Tables 7.4 to 7.6

After reviewing a wide range of cost-effectiveness ratios, the analysis finally settled on only four useable ratios, based on the available data. Some parameters were very insensitive to changes in the input values. This would undermine the value of the indicator and its ability to measure small differences between potential investment alternatives.

Some ratios were relatively easy to quantify, but upon closer scrutiny, standard cost benefit analysis parameters such as IRR and NPV already consider them. The practitioner is better served with standard financial metrics, where available. Decision-makers are more likely to have a passing familiarity with the meaning of standard financial metrics, thus eliminating the need to explain the results derived from less common cost-effectiveness parameters.

Cost-effectiveness factors also suffer from having no external benchmark for comparison. For example, comparisons can be made for NPV and IRR values with bank rates and standard discount rates. Thus, it is possible to assess the financial viability of even a single alternative by comparing its forecast performance against these standard benchmarks. Conversely, it is not possible to compare cost effectiveness parameters to a standard benchmark, at least not early in the implementation. The organization has no basis to evaluate the effectiveness of a single project based on previously established metrics.

Cost-effectiveness ratios can be very useful for ranking several alternatives for a specific project application. Using these ratios, the practitioner can prioritize alternatives based on the relative magnitude of the ratios for each project. In this way, cost-effectiveness ratios can be very useful input data for a triple bottom line analysis, as outlined in **Section 7.4**.

7.3.4 Numerical Considerations of Results Presented in Tables 7.4 to 7.6

Cost effectiveness ratios are very useful for prioritizing investment opportunities. Of the four effectiveness ratios considered, all clearly demonstrated the impact of varying the benefits associated with constant investment dollars. In this way, the practitioner can discern the impact of investment on the four key parameters considered, with better results achieved when larger benefits accrue due to the investment. While this may seem trivial, if an effectiveness ratio is to be of any use, it must be relatively sensitive to changes in benefits and investment dollars. In the worked example, *Alternative 2* showed the highest effectiveness ratios across the board because of the assumption that the $52M investment offset a much longer shutdown period resulting from the scale of the interruption.

Considering climate change impacts has a significant impact on the results, showing improved effectiveness ratios across the board when including projected impacts of climate on future events. Following from the work on cost benefit analysis, this outcome was not surprising. Rather, this can be viewed as an indication that the effectiveness ratios responded appropriately to the input data.

Table 7-7 presents a direct comparison of cost effectiveness ratio results.

Table 7-7 Cost Effectiveness Ratio Comparison

	Alternative 1			*Alternative 2*			*Alternative 3*			*Alternative 4*		
	Baseline	*Climate*	Δ (%)	*Baseline*	*Climate*	Δ (%)	*Baseline*	*Climate*	Δ	*Baseline*	*Climate*	Δ
GDP ($/$)	.87	1.31	**34**	1.65	2.47	**32**	.64	.96	**33**	.5	.76	**34**
GHG (kg/$)	.646	.969	**33**	1.218	1.827	**36**	.472	.708	**33**	.373	.559	**33**
Time Saved (hr/K$)	12.9	19.3	**33**	24.3	36.5	**33**	9.4	14.1	**33**	7.4	11.2	**34**
Value of Time Saved ($/K$)	241	361	**33**	454	681	**33**	176	264	**33**	139	209	**33**

Based on the results from the worked example, the investments would be prioritized as:

1. Alternative 2
2. Alternative 1
3. Alternative 3
4. Alternative 4

Overall, the effectiveness ratios provided a slightly different investment prioritization than obtained from the cost-benefit analysis. The cost-benefit analysis would place *Alternative 1* above *Alternative 2* in order of priority. This difference results from placing somewhat less emphasis on financial results and increasing the emphasis of the social and environmental benefits from each alternative.

Cost effectiveness analysis often don't yield identical results as cost benefit analysis, as CBA places a very high priority on financial outcomes, while CEA places more emphasis on directly measuring social and environmental outcomes. The is one of the primary reasons why CEA is applied, as it allows the incorporation of non-financial considerations into the analysis.

Both cost effectiveness and cost-benefit analysis produce useful results, casting the investment decision through different lenses. Triple Bottom Line analysis allows blending cost effectiveness and cost-benefit outcomes into a single analysis. As well, triple bottom line analysis offers the ability to incorporate parameters that cannot be quantified into the analysis, providing a balanced analysis.

The triple bottom line analysis is discussed in **Section 7.4**.

7.4 Triple Bottom Line Analysis

Metrics derived in **Sections 7.1 through 7.2** were used as input values for the triple bottom line (TBL) analysis worked example. Several non-numeric factors were added into the TBL analysis to show how the process accommodates softer, judgment-based, data. **Table 7-7** and **Table 7-8** outline the results from the worked example. Discussion and synthesis of the results presented in the tables is provided **in Section 7.4.1**.

Table 7-8 Baseline TBL Analysis

#	Description		Alternative 1			Alternative 2			Alternative 3			Alternative 4		
			Federal DFAA			Ministry Peace Flood			Minsitry Highway 97			Loss Projection		
	Must		Yes /No		Comments	Yes /No		Comments	Yes /No		Comments	Yes /No		Comments
M 1	IRR ≥ 5%		Yes		11%	Yes		25%	Yes		7%	No		4%
M 2	NPV ≥ $0		Yes		$22M	Yes		$89M	Yes		$4M	No		($7M)
M 3	Simple ROI ≥ 5%		Yes		14%	Yes		28%	Yes		11%	Yes		8%
M 4	Be Technically Feasible		Yes			Yes			Yes			Yes		
M 5	Meet all current design standards		Yes			Yes			Yes			Yes		
	Wants	**Weight**												
	Social Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
S 1	Largest Reduction in Service Interruption	10	5	45		10	90		4	36			0	
S 2	Address surrounding community needs	9	9	90		10	100		8	80			0	
S 3	Best Time Saved CEA Ratio	8	6	54	12.9 hr/K$	10	90	24.3 hr/K$	5	45	9.49 hr/K$		0	
	Total Possible Score	270					0			0			0	
	Sub Total Score			189			280			161			0	
	Sub Total as a Percentage of Total Possible Score			70%			104%			60%			0%	
	Score Adjusted by Social Factor Weighting			**23**			**34**			**20**			**0**	
	Environmental Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
EN 1	Best GHG CEA Ratio	10	5	50	0.646 kg/$	10	100	1.218 kg/$	4	40	0.472 kg/$		0	
EN 2	Biggest reduction in fisheries impacts	8	10	100		10	100		10	100			0	
EN 3	Minimize environmental footprint	6	10	100		10	100		10	100			0	
	Total Possible Score	240												
	Sub Total Score			250			300			240			0	
	Sub Total as a Percentage of Total Possible Score			104%			125%			100%			0%	
	Score Adjusted by Environmental Factor Weighting			**34**			**41**			**33**			**0**	
	Economic Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
EC 1	Maximize IRR	10	4	40	11%	10	100	25%	3	30	7%		0	
EC 2	Maximize NPV	10	3	30	$22M	10	100	$89M	1	10	$4M		0	
EC 3	Maximize Simple ROI	6	5	30	14%	10	60	28%	4	24	11%		0	
EC 4	Best GDP CEA Ratio	8	5	40	0.87 $/$	10	80	1.65 $/$	4	32	0.64 $/4		0	
EC 5	Best Cost of Time Saved CEA Ratio	5	5	25	241 $/K$	10	50	454 $/K$	4	20	176 $/K$		0	
EC 6	Minimizes annual operations and maintenance bugets	4	10	40		10	40		10	40			0	
	Total Possible Score	390												
	Sub Total Score			205			430			156			0	
	Sub Total as a Percentage of Total Possible Score			53%			110%			40%			0%	
	Score Adjusted by Economic Factor Weighting			**17**			**36**			**13**			**0**	
	TOTAL Weighted Score		**75**			**112**			**66**			**0**		

Table 7-9 Climate Change TBL Analysis

#	Description		Federal DFAA			Ministry Peace Flood			Minsitry Highway 97			Loss Projection		
	Must		Yes /No		Comments	Yes /No		Comments	Yes /No		Comments	Yes /No		Comments
M 1	IRR ≥ 5%		Yes		19%	Yes		38%	Yes		13%	Yes		9%
M 2	NPV ≥ $0		Yes		$58M	Yes		$158M	Yes		$30M	Yes		$14M
M 3	Simple ROI ≥ 5%		Yes		22%	Yes		42%	Yes		16%	Yes		9%
M 4	Be Technically Feasible		Yes			Yes			Yes			Yes		
M 5	Meet all current design standards		Yes			Yes			Yes			Yes		
	Wants	**Weight**												
	Social Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
S 1	Largest Reduction in Service Interruption	10	5	45		10	90		4	36			0	
S 2	Address surrounding community needs	9	9	90		10	100		8	80			0	
S 3	Best Time Saved CEA Ratio	8	5	45	19.3 hr/K$	10	90	36.5 hr/K$	4	36	14.1 hr/K$	3	27	11.2 hr/K$
	Total Possible Score	270					0			0			0	
	Sub Total Score			180			280			152			27	
	Sub Total as a Percentage of Total Possible Score			67%			104%			56%			10%	
	Score Adjusted by Social Factor Weighting			**22**			**34**			**19**			**3**	
	Environmental Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
EN 1	Best GHG CEA Ratio	10	5	50	0.969 kg/$	10	100	1.827 kg/$	4	40	0..708 kg/$	3	30	0.559 kg/$
EN 2	Biggest reduction in fisheries impacts	8	10	100		10	100		10	100		10	100	
EN 3	Minimize environmental footprint	6	10	100		10	100		10	100		10	100	
	Total Possible Score	240												
	Sub Total Score			250			300			240			230	
	Sub Total as a Percentage of Total Possible Score			104%			125%			100%			96%	
	Score Adjusted by Environmental Factor Weighting			**34**			**41**			**33**			**32**	
	Economic Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
EC 1	Maximize IRR	10	5	50	19%	10	100	38%	3	30	13%	2	20	9%
EC 2	Maximize NPV	10	4	40	$58M	10	100	$158M	2	20	$30M	1	10	$14M
EC 3	Maximize Simple ROI	6	5	30	22%	10	60	42%	4	24	13%	2	12	9%
EC 4	Best GDP CEA Ratio	8	5	40	1.31 $/$	10	80	2.47 $/$	4	32	0.96 $/$	3	24	0.76 $/$
EC 5	Best Cost of Time Saved CEA Ratio	5	5	25	361 $/K$	10	50	681 $/K$	4	20	264$/K$	3	15	209 $/K$
EC 6	Minimizes annual operations and maintenance bugets	4	10	40		10	40		10	40		10	40	
	Total Possible Score	390												
	Sub Total Score			225			430			166			121	
	Sub Total as a Percentage of Total Possible Score			58%			110%			43%			31%	
	Score Adjusted by Economic Factor Weighting			**19**			**36**			**14**			**10**	
	TOTAL Weighted Score		**75**			**112**			**66**			**45**		

7.4.1 Observations of Results Presented in Tables 7.8 and to 7.9

TBL analysis provides a mechanism to combine cost-benefit analysis (CBA), cost effectiveness analysis (CEA), and non-quantifiable parameters. The analysis is robust, as it allows a step-by-step review of each ***Must*** and ***Want*** throughout the analysis. It provides an effective way to prioritize project alternatives.

In the worked example, the priorities derived from all three analyses are consistent. This outcome was expected, as the BCMOTI guidance for cost-benefit analysis incorporates a wide range of social costs not normally included in traditional cost-benefit work. Thus, the BCMOTI CBA approach largely covers the social emphasis normally derived from CEA and TBL analysis.

It is worth noting, however, that the BCMOTI CBA method does not allow for including non-quantifiable parameters that are often critical for making appropriate investment decisions. For example, while the approach provides a very good assessment of social costs, it cannot discern the impact of social acceptability, public opinion and environmental impacts that are often key factors in a project's success. TBL analysis is a useful approach to integrate these softer factors into the decision analysis.

Incorporating climate change into the TBL analysis can affect the results. In the Baseline analysis, *Alternative 4* was eliminated because it did not exceed the IRR and NPV hurdles established in the analysis. However, in the Climate Change case, *Alternative 4* passed all the Musts and was carried into the Want analysis.

TBL analysis appears to be a quantitative approach, as it provides numerical scoring for each alternative. However, the scoring often is based on professional judgment. Thus, TBL analysis is subjective at its core. There are two conclusions that may be drawn from this observation. First, small changes in judgment-based scores can change the outcome of the analysis. Second, it is best to use a team approach to conduct the analysis.

As the process is founded on professional judgment, it is best conducted in a facilitated environment drawing on the combined expertise of an entire team. In particular, the analysis benefits from a wide range of expertise and experience. Technical staff can ground the analysis on the demands of design standards and guidelines. Climate and risk professionals can ensure that the analysis follows robust industry standards. Finally, decision-makers can provide a more holistic perspective of how the proposed project fits within broader organizational objectives. The synthesis of these perspectives into one robust TBL analysis ensures the best outcomes from the process.

7.4.2 TBL Analysis Results Summary and Analysis

Several observations may be drawn from the TBL analysis presented in **Tables 7.8 and 7.9**.

7.4.2.1 Base Case

In the Base Case, only three alternatives would be deemed viable. **Alternative 4** failed to meet the minimum IRR of 5% and positive NPV Must criteria. Of the remaining three alternatives, **Alternative 2** offered the highest overall TBL score. Depending on the structure of the team conducting the analysis, this would notionally make **Alternative 2** the optimal choice, as it addresses all the quantifiable financial criteria and, overall best addresses the softer socio-economic and environmental factors.

7.4.2.2 Accounting for Climate Change

The Climate Change Case yields similar results overall. This arises from the structure of the Must and Want criteria applied in the analysis. In this example, the Must criteria hurdles for IRR and NPV were the same as in the Base Case.

Alternative 4 would meet minimum financial criteria in the Climate Change Case and is now included in the overall analysis. Even so, given its relatively poor financial performance compared to the other alternatives, it still has the lowest overall score in the TBL analysis.

The other alternatives received the same relative soring.

A TBL team may opt for different hurdle rates in the Climate Change case to reflect higher uncertainties and perceived risks in that scenario. These adjustments were not made in this example, as the project team did not have sufficient data to support such an adjustment. In practice, TBL teams can bring their expertise to bear on the analysis and make adjustments to the criteria accordingly.

7.4.2.3 Implications for Climate Adaptation Interdependency and Communication

Care should be exercised in interpreting these results, as the structure of the team can have a significant bearing on the scoring. Overall, it is best to have a team with the broadest representation. If that team includes all of the relevant technical and operational expertise and also the professional judgment of decision-makers, it may be fair to conclude that **Alternative 2** is the best project decision. However, if there are any gaps in the team, the results of the TBL analysis can change when it reviewed by different team members through different organizational lenses.

The TBL is an ideal process for soliciting input and engaging with stakeholders. Internally, it allows gathering broad organizational input into key decisions and is especially effective when TBL teams have decision-maker representation. Externally, the TBL facilitates broad stakeholder input, incorporating a wide range of potential impacts into the decision process.

Both internally and externally, the success of the TBL process depends on stakeholder engagement and buy-in. To encourage this, the process should start with broad stakeholder input on Must and Want criteria and on the relative weighing applied to those criteria. This will ensure that the entire group both understands the process and also agrees with the factors applied to finally make a decision.

When broad stakeholder input is included in TBL analysis, it provides a robust assessment of quantifiable and unquantifiable parameters that best address the needs of the organization and affected stakeholders, including interdependent infrastructure systems.

8 Conclusions

From the foregoing analysis, several conclusions can be drawn regarding the application of financial analysis in climate change adaptation projects.

1. Simple ROI is an unreliable measure of project financial performance. It can provide misleading results, especially for projects that have uneven cashflows over their useful life.

2. NPV and IRR are superior metrics for measuring the financial impacts of a climate change adaptation project.

3. Most NPV and IRR approaches do not include external social or environmental benefits. However, the BCMOTI Guidance on cost-benefit analysis provides Ministry approved methods for costing these social and environmental benefits that makes the Ministry CBA method far more robust for climate adaptation work than traditional CBA methods that exclude the valuation of external social costs.

4. Cost effectiveness analysis is a good way to incorporate non-monetizable metrics into a climate change adaptation financial analysis. However, the parameters still must be quantifiable. The approach does not allow the valuation of softer, more subjective factors within the analysis.

5. TBL analysis provides a useful mechanism to blend CBA, CEA and more subjective, non-quantifiable parameters within a consistent, rigorous and unified analysis.

6. TBL analysis is a very powerful tool for evaluating climate adaptation project alternatives. And can include financial, social and environmental aspects of projects in the evaluation.

7. TBL analysis is best conducted using a facilitated, team approach.

8. CBA and CEA analyses do not provide a complete picture of the overall benefits of climate adaptation projects, as they only include parameters that can be quantified. While these parameters can be measured, they often do not provide a comprehensive picture of the overall benefits of an adaptation project, as they omit broader social and environmental factors that may not easily be quantified.

9. CBA and CEA metrics are useful input data for a TBL analysis.

10. While CBA analysis can establish that a project exceeds internal financial hurdles, CEA and TBL analysis are more useful in ranking project alternatives. CEA and TBL allow the inclusion of non-monetizable parameters in the analysis that a practitioner can use to differentiate between multiple project alternatives.

11. Including the impact of climate change within all three analyses provides a better projection of project performance. Neglecting climate change impacts can disqualify otherwise sound projects.

9 Recommendations

1. Practitioners should use NPV and IRR as their primary financial metrics for evaluating the financial integrity of climate change adaptation projects.

2. BCMOTI should refer to the internal Ministry guidance on cost-benefit analysis to establish input data for NPV and IRR calculations, as this approach establishes a firm basis for incorporating social costs within the financial analysis.

3. Practitioners should as much as possible consider the "real" environment within which the project will operate, and this should include consideration of climate change impacts.

4. Practitioners should use CBA and CEA metrics as input data for a robust TBL analysis of climate change adaptation projects.

5. Practitioners should use multiple approaches to establish climate adaption project viability. CBA can establish that the project addresses financial objectives. CEA can establish that which projects better address quantifiable social and environmental measures, and TBL can establish how well each alternative addresses broader social and environmental concerns. The multi-factor approach is depicted in **Table 9-1**.

Table 9-1 Multi-Factor Approach to Project Evaluation

	Analysis Approach		
	CBA	***CEA***	***TBL***
Best Application	Financial Analysis Monetizable input data	Direct comparison of alternatives Quantifiable input data	Holistic evaluation of quantifiable and non-quantifiable financial, social and environmental parameters
Benefits	Can be compared with standard benchmarks Familiar to decision-makers	Avoids the need to monetize socially sensitive factors Familiar to health professionals	Draws on best professional judgment of the team

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Developing a Climate Change Adaptation Interdependency Process with Economic Considerations

Supported by Natural Resources Canada's Climate Change Adaptation Program

VOLUME 4

Key Performance Indicators (KPIs) for Climate Adaptation Projects

British Columbia
Ministry of Transportation and Infrastructure

Contents

Figures

Tables

1 Introduction

This report is a member of a family of documents prepared for the British Columbia Ministry of Transportation and Infrastructure (BCMOTI) and supported by Natural Resources Canada's Climate Change Adaptation Program. It is one element of an integrated project considering the interdependency between BCMOTI infrastructure, other infrastructure systems and climate adaption initiatives. Other infrastructure systems may include rail, power systems, gas pipelines, forest service roads, as well as municipal and indigenous infrastructure systems. Overall, the project is designed to include:

- Review of interdependencies;
- Methods for interdependency communication;
- Economic analysis for adaptation projects (including interdependent impacts);
- Key Performance Indicators (KPIs) for monitoring and reporting on the effectiveness of adaptation actions (this volume); and
- A case study example of interdependencies, communication, economic analysis for Ministry climate adaptation initiatives.

This volume of the study covers indicators for monitoring and reporting on effectiveness of adaptation actions. It draws on inputs from the interdependency and financial analysis work as a starting point for developing workable key performance indicators (KPIs).

The project is iterative, with each phase of work feeding the next and back to the beginning of the cycle where results are refined based on the outcomes throughout the process. The case study serves as a real-world example of how the process would work based on experience gained through the Pine Pass Flood Mitigation and Adaptation Project.

Figure 1-1 shows how the KRI work fits within the overall sequence of the project workflow.

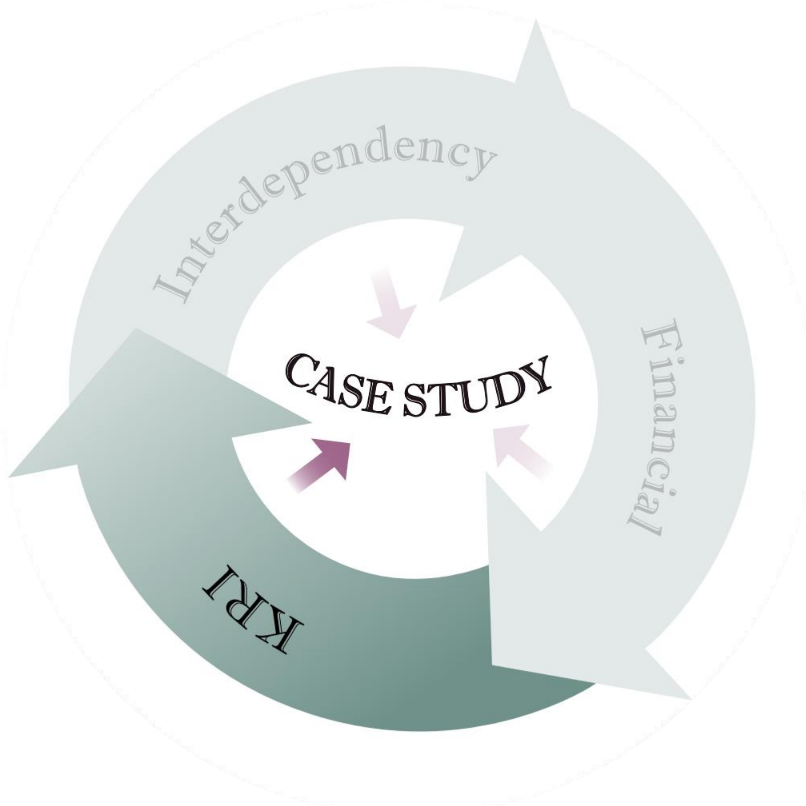

Figure 1-1 KRI Phase wrt Overall Work Sequence

2 Background

2.1 History of BCMoTI Adaptation Projects

BCMoTI has a long history of climate adaptation work, including risk and vulnerability assessments on five BC highway segments:

- Coquihalla Highway - *2010*
- Yellowhead Highway – *2011*
- Highway 20 – Bella Coola - *2014*
- Highway 37A – Stewart – *2014*
- Highway 97 – Pine Pass – *2014*

From this work, the Ministry developed climate change risk and adaptation information that they have since integrated into policies and guidelines.

The previous BCMOTI work comprised:

- Understanding the climate change context;
- Collaborating with subject matter experts;
- Identifying climate change risks;
- Analyzing climate change risks;
- Evaluating climate change risks and producing assessment of risks; and
- Developing policy and guidance documents to integrate and mainstream climate change adaptation considerations into design work.

These projects were the predecessors for the current work. They established the framework for BCMOTI to evaluate climate impacts throughout their highway infrastructure and develop adaptation measures. From this work, the Ministry developed a firm grasp of the climate change and extreme weather events that pose the most serious risks to Provincial Highways. They also established an understanding of potential climate change and extreme weather interactions affecting B.C. Highways and other infrastructure systems.

2.2 Where the Current Work Fits

This current project expands on the previous work to evaluate potential interdependencies among BCMOTI highway systems and other systems, considering the way these systems react and potentially interact before, during, and after extreme weather events.

This project conveys information from consultation with infrastructure stakeholders, based on infrastructure affected from the 2016 flood in the Pine Pass region. In addition, it evaluates a variety of approaches for assessing the financial, social, and environmental impacts of potential adaptation responses, particularly with reference to how those actions affect interdependent systems. The work was passed through the lens of the 2016 Pine Pass flood event to ground truth the results.

These activities build on previous Ministry climate adaptation initiatives, expanding the boundaries of the work to cover broader social, economic and environmental impacts.

This volume of the report addresses KPIs for climate adaptation projects.

3 Key Results Indicators vs Key Performance Indicators

An indicator is a qualitative or quantitative factor or variable that provides a simple and reliable mean to express achievement, the attainment of a goal, or the results stemming from a specific change.

Academic business literature outlines a range of opinion regarding the nomenclature and application of Key Results Indicators (KRIs) and Key Performance Indicators (KPIs). However, decision-makers often use the terms interchangeably. While many business academics worry about the nuances of these indicators, in practice the ultimate success of any indicator depends on three factors:

- The organization's ability to access meaningful data to support the indictor;
- The organization's ability to assign responsibility to departments to ensure that the indicator is maintained over time; and
- Responsible staff's ability to control the processes measured by the indicator's input parameters.

When the indicator satisfies these criteria, it usually succeeds. If the indicator does not address even one of these criteria, the indicator fails. While not placing too much emphasis on nomenclature in this work, some understanding the nuances of KRIs and KPIs can be helpful in providing clarity in the application of indicators to support climate adaptation projects.

Jordan Zenko provides a nice summary of the principal differences between KRIs and KPIs (Zenko, 2019), which is summarized in **Sections 3.1 and 3.2**. David Parmenter provided additional context about the nuances of KPIs and KRIs in his whitepaper, ***How to Implement Winning KPIs*** (Parmenter, 2014).

3.1 What is a Key Result Indicator (KRI)?

A key result indicator (KRI) measures the quantitative results of business actions to help companies track progress and reach organizational goals. KRIs offer an overview of past performance, help corporate management unify information on a company or department's performance and provide insight on what steps leaders should take to make improvements.

Key results indicators can address financial or nonfinancial measures. Normally, organizations measure and report KRIs on a regular schedule, monthly, quarterly or annually. KRIs rarely reflect an individual activity. As KRIs focus on results, generally they identify a single performance value reflecting the combined effects of a range of business activities. Typical examples of KRI included:

- Profit;
- Monthly sales; and
- Amount of a product produced;

More often, KRIs are lagging, providing a snapshot of activities during a previous reporting period. As a result, they may not easily be actionable, as they reflect operating conditions that may no longer be in place.

3.2 What is a Key Performance Indicator (KPI)?

A Key Performance Indicator is a measurable value that demonstrates how effectively a company is achieving key business objectives. Organizations use KPIs at multiple levels to evaluate their success at reaching targets. High-level KPIs may focus on the overall performance of the business, while low-level KPIs may focus on processes in departments such as sales, marketing, HR, support and others.

Typically, KPIs reflect nonfinancial values. For example, the number of calls a salesperson made as opposed to revenue generated from those calls. They are measured and reported on a regular schedule, monthly, quarterly, or annually.

The KPI is the result of an individual activity. Consequently, they are more easily actionable, as they discreetly measure the outcomes of a single action or process. These indicators are generally leading, or forward-looking, in that the parameter can be monitored continuously, allowing adjustments in real-time to ensure that the organization achieves its targets. As KPIs are based on a single parameter that can be monitored in real time, staff generally understand the measure and can participate directly in moving the organization toward its targets.

3.3 KRI vs KPI for Climate Adaptation Work

The key differences between KRIs and KPIs are:

- KRIs are global, providing a snapshot of the combined impacts of a range of initiatives and processes, while KPIs reflect the impact of only one activity or initiative;
- KRIs are lagging indicators while KPIs are leading indicators; and
- KRIs are useful for reporting the results from previous periods, KPIs are useful for making real-time adjustments to processes and activities to support achieving targets; so

- KRIs tell and organization how it did, KPIs help organizations meet their objectives for the current period.

With these distinctions in mind, the more appropriate tools to assess climate adaptation actions would be KPIs. Effective KPIs for climate adaption work should have several attributes to support their successful application. These include:

- The organization has ready access to the data needed to calculate the indicator, in real-time;
- The indicator reflects the impact of only one key activity or process;
- Staff understand the indicator and know how use it to make real-time adjustments to the activity or process;
- The organization can apply the KPI at all levels; and
- Responsibilities for meeting targets apply down to the departmental level, and even to individual positions.

3.4 Cautionary Notes

While KPIs are very useful tools to help an organization meet its objectives, they may have some downsides in their application.

Organizations establish KPIs to drive the behaviour of staff to support key targets and objectives. They often provide rewards for staff that achieve those objectives. While this reinforces positive behaviours, it can have unintended outcomes. Staff can make inappropriate decisions to meet the KPI target that have other negative outcomes.

For example, an organization can set a KPI that establishes maximum detour times for a specific road repair. Knowing that the organization monitors performance with this KPI, staff can prematurely open a road to meet the KPI target and expose the public to adverse road conditions. Clearly, this is not the outcome the organization intended, as road safety would be a priority. So, when choosing KPIs, the organization must ensure they establish the context for the indicator and its priority relative to other organization objectives.

4 Suggested BCMoTI KPIs

A detailed review of KPIs was completed in Volume III of this work. (Nodelcorp, 2019) That volume identified four possible cost effectiveness indicators:

1. GDP impact per dollar spent;
2. GHG impact per dollar spent;
3. Time saved per dollar spent; and
4. Value of time saved per dollar spent.

The work outlined in Volume III determined that all four of these Indicators had value for evaluating the financial impacts of an adaptation action. However, cast through the lens of effective KPI criteria, only time saved would suit as a useful organizational KPI for adaptation projects. The rationale for this observation is outlined in **Table 4-1**.

Table 4-1: Comparison of Possible KPI Options

	Ready Access to Data	One Process or Activity	Easy to Understand	Applies at All Levels	Can Assign Responsibility	Comments
GDP	**No**	**No**	**No**	**No**	**No**	GDP is a universal metric that captures the impact of a wide range of inputs. While reported routinely in the media, it is very difficult to parse out the impact of a single activity on GDP.
GHG	**No**	**Yes**	**No**	**Yes**	**No**	GHG emissions vary vehicle to vehicle, depending on age, wear and tear, and the current weather conditions. GHG emission calculations apply standard emission factors to a type of vehicle and require the application of professional judgment. It is difficult to assign the impact of a single action on GHG emissions.
Time Save	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	Time saved is relatively easy to calculate based on traffic volumes, which BCMoTI monitors, the distance of the detour, and the average speed through the detour. While easy to determine on a per vehicle basis, it is difficult to assess the impact on the number of people affected, as that measure would require a deeper knowledge of the number of people in each vehicle.
Value of Time Saved	**No**	**Yes**	**Yes**	**Yes**	**Yes**	Value of time saved is based on the time saved metric and relies on data relative to the number of people in each vehicle, and the types of drivers and passengers. Thus, while the metric addresses most of the criteria defined for an effective KPI, staff cannot readily access the data needed to calculate the indicator.

5 Observations

In the detailed review outlined in Volume III of this study, there were four possible indicators identified for evaluating the effectiveness of climate adaptation projects. The work evaluated the possibility of applying one or more of those indicators as a measure of the success of the adaptation action. Of the four, only one indicator satisfied the requirements for an effective KPI, the amount of time saved by the initiative.

BCMoTI routinely monitors traffic volumes, so staff has easy access to information about the number of vehicles affected by road repairs and detours. Staff can readily convert this information into a detour time value.

In practice, BCMoTI could establish a target of, for instance, zero detour hours on a segment of highway after the adaptation action occurred. If another, similar failure should occur, staff could monitor detour traffic count using available meters and report detour time through the chain of command. The ministry could use this information to monitor progress on road repairs arising from climate events, and also to test the assumptions that were originally used to assess the financial performance of the adaptation action. Staff could capture data with readily available traffic counting devices, so they are not diverted from their core function during a road closure for repairing the highway.

By monitoring detour hours, and targeting keeping those hours to a minimum, the Ministry could gather data allowing them to assess the effectiveness of climate adaptation actions. Also, they would be better equipped to evaluate future adaptation measures, as they would have real-world data on the impact of older initiatives. They could use this information to inform ongoing climate mitigation actions and to support consultation with interdependent infrastructure systems.

6 Conclusion

BCMoTI can support climate adaptation initiatives by closely monitoring traffic counts and detour times on highway segments where they have completed previous climate adaptation work. They can use this information to evaluate the effectiveness of historic work, inform new climate adaptation initiatives, and support consultation with interdependent infrastructure owners and users.

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Developing a Climate Change Adaptation Interdependency Process with Economic Considerations

Supported by Natural Resources Canada's Climate Change Adaptation Program

VOLUME 5

Summary Case Study of the 2016 Pine Pass Flood

British Columbia

Ministry of Transportation and Infrastructure

Contents

Figures

Tables

1 Introduction

This report is a member of a family of documents prepared for the British Columbia Ministry of Transportation and Infrastructure (BCMOTI) and supported by Natural Resources Canada's Climate Change Adaptation Program. It is one element of an integrated project considering the interdependency between BCMOTI infrastructure, other infrastructure systems and climate adaption initiatives. Other infrastructure systems may include rail, power systems, gas pipelines, forest service roads as well as municipal and indigenous infrastructure systems. Overall, the project is designed to include:

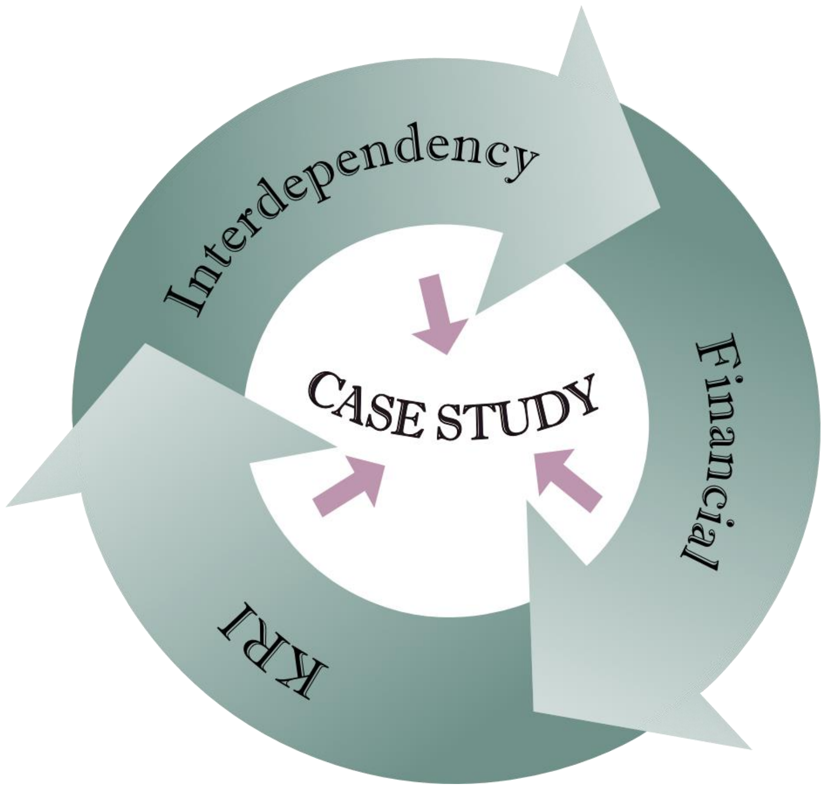
- Review of interdependencies;
- Methods for interdependency communication;
- Economic analysis for adaptation projects (including interdependent impacts);
- Key Performance Indicators (KPIs) for monitoring and reporting on the effectiveness of adaptation actions; and
- A case study example of interdependencies, communication, economic analysis and reporting metrics for Ministry climate adaptation initiatives (this volume).

This volume of the study covers a case study to demonstrate Ministry climate adaptation processes and considerations when other infrastructure owners could be engaged. It draws on inputs from other volumes under this project including understanding interdependencies and communication, economic analysis, in developing climate adaptation processes and considerations incorporating these areas and reporting metrics for projects.

The project had iterative features, with some phases of work feeding the next and back to the beginning of the cycle where results were refined based on the outcomes throughout the process. This case study serves as a real-world example of how the process would work based on experience gained through the Pine Pass Flood Mitigation and Adaptation Project.

Figure 1-1 shows how the case study fits within the overall sequence of the project workflow.

Figure 1-1 Case Study wrt Overall Work Sequence



2 Background

2.1 History of BCMOTI Climate Change Assessment Projects

BCMOTI has a long history of climate change assessment work, including risk assessments on five BC highway segments:

- Coquihalla Highway - *2010*
- Yellowhead Highway – *2011*
- Highway 20 – Bella Coola - *2014*
- Highway 37A – Stewart – *2014*
- Highway 97 – Pine Pass – *2014*

From this work, the Ministry developed climate change risk and adaptation information that have since integrated into policies and guidelines.

The previous BCMOTI work comprised:

- Understanding the climate change context
- Collaborating with subject matter experts

- Identifying climate change risks
- Analyzing climate change risks;
- Evaluating climate change risks and producing assessment of risks;
- Developing policy and guidance documents to integrate and mainstream climate change adaptation considerations into design work.

These projects were the predecessors for the current work. They established the framework for BCMOTI to evaluate climate impacts throughout their highway infrastructure and develop adaptation measures. From this work, the Ministry developed a firm grasp of the climate change and extreme weather events that pose the most serious risks to Provincial Highways. They also established an understanding of potential climate change and extreme weather interactions affecting B.C. Highways and other infrastructure systems.

2.2 Where the Current Work Fits

This current project expands on the previous work to evaluate potential interdependencies among BCMOTI highway systems and other systems, considering the way these systems react and potentially interact with each other before, during and after extreme weather events.

The project covers a telephone consultation with a range of potentially affected infrastructure systems, and stakeholders, based on the 2016 flood in the Pine Pass region. In addition, evaluated a variety of approaches for assessing the financial, social, and environmental impacts of potential adaptation responses, particularly with reference to how those actions affect interdependent systems. The work was passed through the lens of the 2016 Pine Pass flood event to ground truth the results.

We also reviewed a key performance indicator approach for evaluating the ongoing performance of adaptation measures.

These activities build on previous Ministry climate adaptation work, expanding the boundaries of the work to cover broader social, economic and environmental impacts.

3 Flooding in the Peace

3.1 Two Recent Flooding Events

The Peace River region of British Columbia has a history of flooding due to extreme rainfall events. The two most recent events occurred in July 2011 and in June 2016. This case study focuses on mainly the June 2016 event. However, both the 2011 and 2016 events affected infrastructure owners, municipalities, local residents and First Nations, and were referenced by those stakeholders in the engagement process.

3.2 The Peace Region

This case study considers the impact of the 2016 flood event on a 76 km section of Highway 97 north of Prince George. The area known as Pine Pass, is located between Mackenzie (Highway 39 junction) and Chetwynd extending from Honeymoon Creek to Fisher Creek in Highway 97. The area is prone to flooding during extreme weather events or heavy spring floods due to a lack of hydraulic capacity. (Apex Engineering 2019)

The communities of Chetwynd (pop 2,600) and Dawson Creek (pop. 13,000) depend on Highway 97 for access to Prince George and southern BC. If the highway is closed, traffic must detour an additional 495 km through Alberta to get to Prince George.

Along with Highway 97 there are a number of other services such as rail, transmission lines, and pipelines that share the corridor and supply Southern BC. These include:

- CN Rail main line linking Fort St John and Dawson Creek to southern BC.
- Electricity - The WAC Bennett, Peace Canyon and Site C dam (under construction) are linked to users in southern BC by way of three 500 kv overhead transmission lines adjacent to and served by Highway 97.
- The Plateau Oil Pipeline follows Highway 97 and links Fort St John to the Trans Mountain Pipeline in Kamloops, refineries in Prince George (12,000 bbl/day), Burnaby (55,000 bbl/day) and to export terminals in Vancouver.
- Westcoast Energy Pipeline - There are 2 gas pipelines in this corridor linking the gas fields in Northern BC to end users in southern BC and the export terminals at Kitimat and Vancouver.

Outages to these services from flooding damage can directly impacts 3 million end users in Vancouver and the lower Mainland comprising over 60% of the Province's population.

Figure 3-1 presents a map of the general case study location.

Figure 3-1 Map of Case Study Location

3.3 The 2016 Peace Flood

The events and responses to the 2016 Peace flood were viewed through the lens of infrastructure and social interdependencies. **Figure 3-2 is** an aerial photograph of the infrastructure affected at Commotion Creek on June 15, 2016 (BCMOTI 2016).

Figure 3-2 Commotion Creek Interdependencies - June 15, 2016

This photograph presents an overview of some interdependency issues. In this narrow right of way. There are three different critical infrastructure systems affected by the same extreme weather event:

1. On the extreme right of the photo, power lines are undermined and collapsing;
2. In the middle, the flooding cuts and undermines the highway in multiple locations;
3. On the left, the flooding undermines the railroad and leaves the tracks bridging a newly created gap; finally
4. A residence is inundated, with residents using backhoes to combat the flooding.

Greater insights about the impact on local residents may be glean through Facebook posts at the time of the flooding. **Figure 3-3** outlines an example.

Figure 3-3 Facebook Post from Local Resident at Commotion Creek – 2016

> **Kayla Strachan** So, this is my house and I thank every pilot in the air during this time because they not only saved my husband but my brother as well. He stayed behind and saved our home. If you were there. There is no way boots can be on the ground. Especially when it came to getting people in and out safely 🙂 koodos to all the pilots, machine works and highways for keeping the people safe

Figure 3-4 presents an image of the same Commotion Creek location during the repair work, following the flood.

Figure 3-4 Road Repairs at Commotion Creek – June 2016

BCMOTI responded to the highway infrastructure damage and had the roads open within eleven days. This was achieved through round-the-clock construction and repair work. **Figure 3-5** presents a photograph of nighttime construction work at the same Commotion Creek location.

Figure 3-5 Nighttime Repair Work at Commotion Creek – June 2016

3.4 Overall Impact of the 2016 Peace River Flood

In June 2016, a total of 135 mm of rain fell over a two-day period in the Chetwynd area. A massive storm surge passed through the Peace region impacting the southern areas of Dawson Creek, south and western areas of Chetwynd, and Pine Pass. The event caused significant damage to highway infrastructure and communities.

A section of Highway 97 was closed. The is he only route that connects the region of Peace River to the rest of the Province. The district of Chetwynd declared a local state of emergency. The city of Dawson Creek had approximately 100 mm of rain, destroying one bridge and submerging two others submerged, cutting the city in half and compromising power supply and effective emergency response.

Over 308 BCMOTI sites were damaged. The Ministry established the ***Peace Flood Recovery Program*** to restore the long-term safety and efficiency of roads in the South Peace District affected by the event. The Program had a notional budget of **over $146 million**. By 2020, the Ministry had spent **over $98 million** on the 2016 flood, mostly on highway infrastructure restoration. The repairs along Highway 97 alone are estimated at **$41 million.** (Apex Engineering 2019)

4 Four Pillar Approach to Emergency Management

Emergency Management is typically categorized into four phases:

1. Mitigation;
2. Preparedness;
3. Response;
4. Recovery.

4.1 Response

Immediately after a climate event, such as the 2016 flood, emergency responders and critical infrastructure personnel respond to the region. Their first priority is protecting human health and safety, making sure that people are evacuated from any further risk, and preventing unauthorized access to the area. If the event is short in duration, such as severe windstorms, this phase will be short. However, if the event occurs over many days, such as many flooding events, the response period expands accordingly. During the response phase, very few people are allowed access to the area, including many infrastructure repair teams, as allowing early access can put personnel and equipment in harms way.

4.2 Recovery

Once the immediate threat is over, activities begin to focus on returning the affected area back to normal operation. While human health and safety remain a key priority, work now begins on repairing damaged infrastructure and returning people to their homes and jobs, as quickly as possible. For example, highway infrastructure is critical to be open to allow free access to and through the region. While roads may not be fully operational, they can be repaired sufficiently and permit access. It is important to recognize that conditions rarely return to the pre-existing state after an extreme climate event. Rather, conditions return to a “new normal” that may continue from that point forward.

While quick recovery is normally a priority, the recovery period can extend for lengthy periods. That noted, after the 2016 Pine Pass flood, highway recovery activities were completed in a matter of weeks, though highway access was allowed relatively early during the recovery phase.

4.3 Preparedness

Upon completion of the ***Recovery Phase***, organizations generally focus on planning for future events. Commonly, organizations debrief about the steps taken during the response and recovery. What worked and what didn't? How could things be done better next time? Based on this information, they revise emergency response and recovery plans to address the lessons learned from the past event, build on successes and fill gaps in the process.

The ***Preparation Phase*** is often a ***Planning, Engineering and Construction Phase***. Preparing for future emergency events, such as flooding and wildfire, can encompass a wide range of adaptation measures, including:

- New procedures;
- Procuring new equipment;
- Designing systems to better respond to similar events; and
- Constructing new facilities based on the new designs.

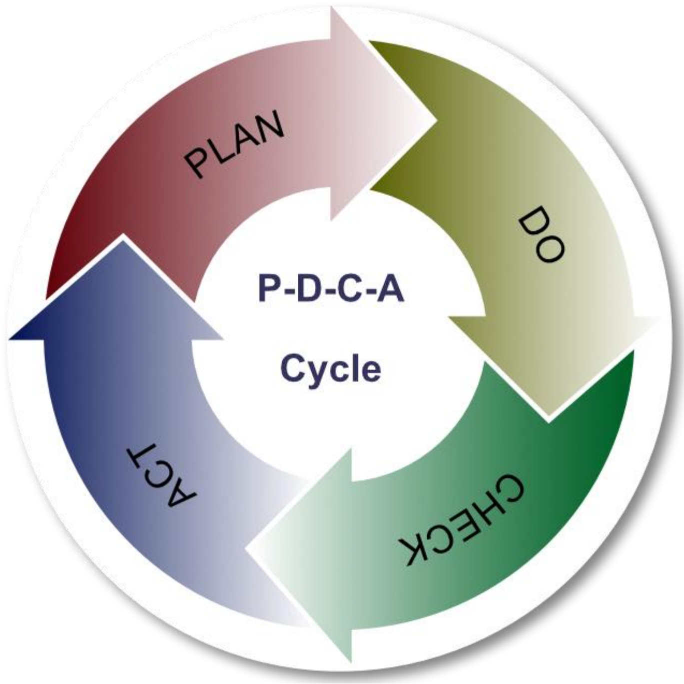
The ***Planning, Engineering and Construction Phase*** can carry on for years, with considerable time and effort devoted to design and construct new facilities, such as bridges. In some cases, securing necessary funding to support work is a lengthy process, especially with budget cycles that must address a wide range of priorities.

4.4 Mitigation

Developing new procedures, equipment, and/or facilities to reduce the hazard risk from occurring again are put in place so organizations can develop sustainable and effective adaptation options and actions for future events. Optimally, mitigation actions and monitoring and review of these should not wait until the next emergency event. Over time, many smaller less critical events can occur that may provide insight on the effectiveness of initiatives. The organization can use the intelligence gathered from ongoing monitoring to tweak and enhance the resilience of the adapted infrastructure system.

The preparedness and mitigation phases are cyclical and linked creating a continuous improvement or ***PDCA Cycle***. In ***a PDCA Cycle***, organizations plan and implement actions, then monitor outcomes against key performance indicators and, as required take action to tweak initiatives for enhanced effectiveness. Finally, all of the information gathered through the process is input in the planning for the next phase of activity and can be applied to reduce risk under in similar circumstances in other projects. A graphic of a typical ***PDCA Cycle*** is presented in **Figure 4-1**.

Figure 4-1 Typical PDCA Cycle



5 Lessons Learned from the 2016 Pine Pass Flood Event

Based on work completed during the 2016 Pine Pass flooding event and follow-up activities, this assessment identified three factors that will help integrate BCMOTI's response to extreme weather events with others. Specifically, the analysis considered approaches the Ministry can employ to ensure that interdependent infrastructure system and stakeholder needs are considered and, as appropriate included in ongoing climate change adaptation efforts.

Using this as our case study, we evaluated how three new or revised approaches can provide greater assurance that the Ministry accommodates potential interdependencies in future climate work. These include:

1. Enhanced communication during the Preparedness and Mitigation Phases of the PDCA Cycle;
2. Application of standardized financial metrics during the Planning Phase; and
3. The application of targeted key performance indicators (KPIs) to assess the effectiveness of adaptation measures during the Mitigation Phase.

Observations based on this case study are presented in **Sections 5.1 through 5.3.**

5.1 Preparation and Mitigation Phase Communication

5.1.1 Case Study Observations

A comprehensive survey of interdependent infrastructure owners and affected stakeholders for the 2016 Pine Pass flood event is outlined in the companion report for this case study (Nodelcorp Consulting Inc 2019). This review provides additional guidance for effective, ongoing climate adaptation in a methods document that can be used to inform the development of Preparation and Mitigation Phase communication initiatives (Nodelcorp Consulting Inc. 2019).

The survey concluded that Emergency Management British Columbia (EMBC) has superior communication procedures and systems that were applied effectively during the 2016 Pine Pass flood.

During the Response and Recovery Phases of the event, EMBC maintained open lines of communication between emergency management personnel, residents, municipalities, and key infrastructure staff. While there are always some communication glitches, EMBC maintained effective oversight and control of the situation, coordinating evacuation and access, and ensured that key stakeholders were kept informed. Following the flood, EMBC participated in debriefing sessions, gathered insight on what worked and what didn't work during the event, and applied this intelligence to improve their approaches going forward.

The EMBC communication model establishes a solid foundation for communication during the Response and Recovery Phases of emergency management. However, once the immediate emergency has been addressed, EMBC's coordinating roll is complete.

Communication during the Preparation and Mitigation phases is more dispersed. There are no established procedures to ensure coordinated climate change adaptation planning. While the EMBC model can serve as a template for ongoing communication, different parties must be involved. For example, responsibility passes from emergency management and first responder staff to planning, engineering, and management personnel. These people may not have had any involvement during Response and Recovery operations. They may have been denied access, being deemed non-essential emergency response staff. Accordingly, they may not have a complete picture of what happened on the ground during the event, information that could influence decisions during Preparation and Mitigation activities.

The work clearly demonstrates the need to adopt an ongoing, coordinated climate adaptation communication process, outside of emergency situations. Further, the EMBC communication process would be a good starting point for the development of this process. It would be necessary to identify key contacts for each interdependent system and stakeholder group involved in the process, as they will likely be different from the parties involved in Response and Recovery work.

As BCMOTI moves forward in their climate change adaption work, it will need to identify key personnel, infrastructure owners and other stakeholders to consult at each stage of the adaptation work. This communication will ensure that adaptation plans accommodate the needs of interdependent systems, and that activities undertaken across all systems work together to ensure overall regional resilience.

5.1.2 Key Communication Considerations

With these thoughts in mind, the work identified nine key considerations for the proposed climate adaptation communication network.

5.1.2.1 Response and Recovery Phases

1. Continuing the use of Drive BC to notify public of emergency alerts for extreme climate events and to warn the public of road closures and detours.

    - When possible, Transportation and Infrastructure managers may be able to share alerts for the section under their management to notify road users of extreme climate events and road closure information. BCMOTI already Drive BC in place for this purpose. It may be advantageous to advertise and inform public continuously to promote user interest and subscription in Drive BC.

2. Encouraging drills and disaster preparedness for all levels the organization to support consistent management and response during extreme weather events.

    - Training and education can reduce response and recovery time during a climate emergency. Training should be supported through commitment of resources and ongoing communication of desired incident response measures. This applies to all levels of the organization and can significantly reduce confusion, errors, and unintended consequences during the heat of a climate event.

3. Collecting anecdotal information about experiences in emergency management risk events through use of interviews with interdependent infrastructure staff, senior management, and owners and sharing findings with the appropriate managing authority or departments.

    - Anecdotal information can add focus to the direction of financial analysis and contribute non-numerical data on human health, safety, and environmental issues that must be considered during Preparation and Mitigation activities.

    - Disaster response time can be reduced by collecting data about sensitive locations in the infrastructure.

5.1.2.2 Preparedness and Mitigation Phases

4. Continuing outreach activities to update public on road construction and climate change adaptation planning and providing mechanisms to allow for stakeholder input, questions, and comments.

    - Consistent Ministry publication of new construction zones, detours and even the intent of climate change adaptation measures updates residents about the work BCMOTI does on their behalf keeps the populous informed. This sort of outreach can improve Ministry reputation and also create opportunities for dialogue stakeholder input.

- Coordination of current outreach efforts between ministries supports effective cross department collaboration. These efforts create a relationship of trust between ministries and external stakeholders and improve BCMOTI's ability to fulfill their service mandate.

5. Creating information sharing systems for climate disaster prevention and reduction for all Government of British Columbia departments.

    - Information collected from previous flood or fire events under the control of one ministry can be shared internally with all ministries. In this way, each ministry may benefit from a consistent approach to climate adaptation, investment analysis, application of climate data and tools, and hydrological analyses. Sharing information across all ministries and regions of the Province will make climate change adaptation analysis and investment more cost effective. These efforts will also improve cross-ministry collaboration and good will.

6. Providing clear and specific input parameters to direct infrastructure owners and stakeholder input to appropriate ministries or departments.

    - Web portals should be simple and direct, ideally one external facing portal that can collect information or queries for appropriate action. To achieve this objective, users should be offered a menu of input categories that map the information flow to the correct government ministry.

7. Using surveys and interviews from focus groups to augment economic planning analyses and climate change adaptation management.

    - A well-designed consultation can collect important non-numeric data. Moreover, connecting with various community groups can improve relationships between the community and the ministry. This can lead to improved design and ultimately reduced costs from building potentially expensive climate resilience into road infrastructure systems.

8. Sharing useful adaptation tools or operations data with other ministries with the aim to better prepare for climate events. This should also incorporate sharing planned infrastructure improvements by BC government departments with external stakeholders to improve trust and reduce errors in climate change adaptation and greenhouse gas mitigation planning.

    - Coordinate and collaborate on climate change adaptation Preparedness and Mitigation actions.

9. Adopting the use of secure inter-departmental chat groups or online meeting rooms to exchange and brainstorm ideas for better climate risk management.

    - Sharing information in cloud-based portals is convenient. However, outreach should be conducted through secure applications.

Information sharing and outreach can foster initiatives to enhance the stewardship function of the Province's infrastructure and enhance the emergency management system when disaster strikes.

Clear communication between all private and public organizations plays a key role in this work. As climate change impacts increase in costs and severity, continued collaboration to support efforts to deal with adverse impacts of climate change are necessary.

5.2 *Financial Metrics for the Preparation and Mitigation Phases*

5.2.1 Cost-Benefit Analysis Overview

This case study included conducting a detailed assessment of financial analytics for climate adaptation projects. A detailed analysis and findings are included in companion report for this case study (Nodelcorp Consulting Inc. 2019). That work considered three different approaches for financial analysis of the Pine Pass flooding mitigation project alternatives. These approaches were:

1. Cost-benefit analysis (CBA);
2. Cost effectiveness analysis (CEA); and
3. Triple Bottom Line (TBL) analysis.

The analyses incorporated real-world data related to adaptation measures proposed for Pine Pass after the 2016 flooding. BCMOTI is advancing recovery work for this event that incorporates adaptation measures to provide resilience against expected future events. With this in mind, the analysis is retrospective.

Simple Return on Investment (ROI) and Internal Rate of Return (IRR) supported by Net Present Value (NPV) can provide widely divergent results. Simple ROI doesn't account for the time value of money and this gap could lead to inappropriate investment decisions. Since these cases cannot be identified without completing the analysis, relying soling on simple ROI in cost-benefit analysis is strongly discouraged, as this can lead to unsound financial decisions.

The work clearly demonstrated that incorporating climate change considerations into the financial analysis significantly changes the attractiveness of investment opportunities. In many cases, including climate change impacts in the cost-benefit analysis will significantly improve the financial benefits of climate change adaptation projects.

In the example here, when including climate impacts in the analysis and projecting changes in both intensity and frequency of precipitation events driving flooding, the alternatives all become more financially viable. This makes sense. When including these changes, the analysis directly assesses the events for which the adaptation measures are designed. This provides a more accurate measure of the effectiveness of alternatives that includes the conditions they are intended to address.

With this in mind, practitioners should consider climate change impacts on key assumptions embedded in the analysis. This is another reason to rely mainly on IRR and NPV for evaluating the financial impacts of projects that address future conditions projected to differ greatly from the current baseline analysis. An analysis that incorporates cash flow over the life of the project will provide superior results, more reflective of the real world. This type of analysis allows consideration of the impact of timing on the finances of the project and more accurately aligns the financial analysis with real-world conditions.

5.2.2 Scenario Alternatives

The Scenario Alternatives are examples of climate adaptation actions used to illustrate different methods of evaluation.

Alternative 1: Federal DFAA Payment for 2016 Flood
Based on DFAA payment for 2016 flood in Pine Pass area. (In the event of a large-scale natural disaster, the Government of Canada provides financial assistance to provincial and territorial governments through the Disaster Financial Assistance Arrangements (DFAA), administered by Public Safety Canada.)

Alternative 2: Ministry Peace Food Recovery Program
Based on Ministry flood recovery costs for Highway 97 and other highways in Peace Region.

Alternative 3: Ministry Cost of 2016 Flood along Highway 97
Based on Ministry costs along Highway 97 including proposed replacement of six bridges for climate resilience for this highway.

Alternative 4: Future Loss Projection
Based on a summary of the costs for a future flood event within the Pine Pass study area. The estimate includes the immediate response and the post disaster recovery plan including the replacement of three impacted structures.

Alternative 5: Repeats Alternative 4 Data

Table 5-1 provides a high-level summary of our cost benefit analysis for the Pine Pass flood mitigation alternatives.

Table 5-1 High-Level Summary of Cost Benefit Analysis

BASE CASE

Default Values			Alternatives 1	2	3	4	5
			Federal DFAA	*Ministry Peace Flood*	*Ministry Hwy 97*	*Loss Projection*	*Alt 5*
	Capital Cost	$	$52,000,000	$52,000,000	$52,000,000	$52,000,000	$52,000,000
	Annual Avoided Costs	$/Y	$7,500,000	$14,500,000	$5,550,000	$4,400,000	$4,400,000
6.0%	Discount Rate	%	6%	6%	6%	6%	6%
2.5%	Inflation Rate	%	3%	3%	3%	3%	3%
	NPV	$	$22,460,688	$89,210,160	$3,866,192	($7,099,793)	($7,099,793)
	IRR	%	11%	25%	7%	4%	4%
	Simple ROI	%	14%	28%	11%	8%	8%

ACCOUNTING FOR CLIMATE CHANGE

Default Values			Alternatives 1	2	3	4	5
			Federal DFAA	*Ministry Peace Flood*	*Ministry Hwy 97*	*Loss Projection*	*Alt 5*
	Capital Cost	$	$52,000,000	$52,000,000	$52,000,000	$52,000,000	$52,000,000
	Annual Avoided Costs	$/Y	$7,500,000	$14,500,000	$5,550,000	$4,400,000	$4,400,000
25%	Frequency Change	%	25%	25%	25%	25%	25%
20%	Intensity Change	%	20%	20%	20%	20%	20%
	Climate Adjusted Avoided Cost	$/Y	11,250,000	21,750,000	8,325,000	6,600,000	6,600,000
6.0%	Discount Rate	%	6%	6%	6%	6%	6%
2.5%	Inflation Rate	%	3%	3%	3%	3%	3%
	NPV	$	$58,219,334	$158,343,542	$30,327,590	$13,878,613	$13,878,613
	IRR	%	19%	38%	13%	9%	9%
	Simple ROI	%	22%	42%	16%	13%	13%

5.2.3 Cost-Benefit Analysis Results Summary and Analysis

Several observations may be drawn from the CBA analysis presented in **Table 5.1**.

5.2.3.1 Base Case

Of the four alternatives, **Alternative 4** is financially marginal, especially when the analysis does not consider climate change impacts. The other three alternatives at least meet normally accepted financial hurdles, exceeding readily available rates for bank interest and bonds.

With these financial projections, any of **Alternatives 1, 2, or 3** would be financially viable. **Alternative 2** offers the best financial results overall with an IRR of 25% and generating positive cash flow of over $89M over the life of the project. Even so, any one of these alternatives would cover their construction costs and generate positive cash flows over their useful life.

Under Base Case conditions, **Alternative 4** has an IRR of 4% and, over the life of the project projects losses of over $7M. This would not be a financially sound investment under these conditions. This alternative also demonstrates the weakness of Simple ROI in this analysis, as the Simple ROI suggests that the project would be marginally profitable or at least break even. Under Base Case conditions, this could result in the approval of a project that would be unprofitable in real-world conditions.

5.2.3.2 Accounting for Climate Change

The situation is altered somewhat when climate change impacts are integrated into the analysis. In this case, all four alternatives are financially viable meeting normally accepted financial hurdles, exceeding readily available rates for bank interest and bonds. While **Alternative 4** is still the least financially attractive, it still covers its costs and generates a respectable cash flow of approximately $14M over the life of the project.

The other three alternatives become very attractive financially, generating very high IRRs and NPVs.

Under these conditions, any of these alternatives are financially viable.

These results should not be surprising. These projects were conceived and designed to accommodate severe climate change driven precipitation events. As such, they have built in capacity to accommodate those expected changes. This approach typically increases the capital cost of projects, as they are designed with incremental capacity to address conditions over and above the baseline. When climate change is considered in the financial analysis, there is better alignment between the infrastructure design and projected cash flows based on the real-world conditions within which the system will operate. As such, including climate change impacts in the analysis provides a more accurate picture of the financial performance the project.

5.2.3.3 Implications for Climate Adaptation Interdependency and Communication

Internally, financial analysis provides key information to decision-makers about the financial viability of projects. The process offers standard methodologies and metrics to evaluate the financial integrity of projects and compare project alternatives. Care must be exercised, however, to avoid basing project decisions solely on these metrics.

Standard financial analysis is not designed to address far-reaching socio-economic and environmental impacts of projects. These "softer" factors are difficult to monetize. While BCMOTI's default values incorporate costing for some socio-economic factors, it does not contemplate environmental factors, impacts on quality of life, and other intangibles.

When communicating with decision-makers about financial analysis, care must be taken to ensure that both the strengths and weakness of the process are clearly stated. Then, decision-makers will be equipped to apply their professional judgment to assess the effect of softer issues on the project to make more robust project decisions. When this is done, often decision-makers select a notionally less attractive financial investment, opting for alternatives that both address minimum financial criteria and also the softer socio-economic and environmental factors.

Externally, these financial metrics allow the organization to demonstrate prudent financial management of taxpayer dollars. The metrics show that the projects avoid ongoing, unmanaged emergency response costs and demonstrate the Ministry is effectively managing climate impacts on operations.

When dealing with interdependent infrastructure owners, municipalities and First Nations, the financial metrics are only one element of the communication process. Care must be exercised in this potentially sensitive communication, as impacted stakeholders may object to decisions based solely on financial performance.

The Ministry can demonstrate through the financial analysis that the project design addresses future impacts that could affect third parties, because the cash flow analysis contemplates these impacts. In this regard, the financial analysis can be a starting point in the communication process to allow the development of a more robust cash flow analysis. The Ministry can consult with interdependent infrastructure owners to incorporate third-party costs into the analysis, as appropriate.

The analysis presented in **Table 5.1** can be used to demonstrate that the Ministry is basing project decisions on prudent financial analysis that incorporates monetizable social costs. When climate change is considered any one of the alternatives is viable. This could be used as a mechanism to solicit interdependent infrastructure owner input to revise project cash flow analysis. This would allow a broader financial analysis that addresses third-party impacts, as appropriate.

5.2.4 Triple Bottom Line Analysis Overview

Triple Bottom Line (TBL) analysis provides a mechanism to combine cost-benefit analysis (CBA) incorporating non-quantifiable parameters. The analysis is robust, as it allows a step-by-step review of parameter throughout the analysis. It provides an effective way to prioritize project alternatives.

In the Pine Pass flood example, the priorities derived from CBA and TBL analysis are consistent. This outcome was expected, as the BCMOTI guidance for cost-benefit analysis incorporates a wide range of social costs not normally included in cost-benefit work. Thus, the BCMOTI CBA approach largely covers the social emphasis normally covered by TBL analysis.

It is worth noting, however, that the BCMOTI CBA method does not allow for including non-quantifiable parameters that are often critical for making appropriate investment decisions. For example, while the approach provides a very good assessment of social costs, it cannot discern the impact of social acceptability, public opinion and environmental impacts that are often key factors in a project's success. TBL analysis is a useful approach to integrate these softer factors into the decision analysis.

TBL analysis appears to be a quantitative approach, as it provides numerical scoring for each alternative. However, the scoring often is based on professional judgment. Thus, TBL analysis is subjective at its core. Several conclusions may be drawn from this observation. First, small changes in judgment-based scores can change the outcome of the analysis. Second, it is best to use a team approach to conduct the analysis.

As the process is founded on professional judgment, it is best conducted in a facilitated environment drawing on the combined expertise of an entire team. In particular, the analysis benefits from a wide range of expertise and experience. Technical staff can ground the analysis on the demands of design standards and guidelines. Climate and risk professionals can ensure that the analysis follows robust industry standards. Finally, decision-makers can provide a more holistic perspective of how the proposed project fits within broader organizational objectives. The synthesis of these perspectives in one robust TBL analysis ensures the best outcomes from the process. **Table 5-2 and 5-3** provide detailed summaries of baseline and climate projection TBL analyses.

Table 5-2 Baseline TBL Analysis

#	Description	Weight	Alternative 1			Alternative 2			Alternative 3			Alternative 4		
#	Description		Federal DFAA			Ministry Peace Flood			Minsitry Highway 97			Loss Projection		
	Must		Yes /No		Comments	Yes /No		Comments	Yes /No		Comments	Yes /No		Comments
M 1	IRR ≥ 5%		Yes		11%	Yes		25%	Yes		7%	No		4%
M 2	NPV ≥ $0		Yes		$22M	Yes		$89M	Yes		$4M	No		($7M)
M 3	Simple ROI ≥ 5%		Yes		14%	Yes		28%	Yes		11%	Yes		8%
M 4	Be Technically Feasible		Yes			Yes			Yes			Yes		
M 5	Meet all current design standards		Yes			Yes			Yes			Yes		
	Wants	**Weight**												
	Social Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
S 1	Largest Reduction in Service Interruption	10	5	45		10	90		4	36			0	
S 2	Address surrounding community needs	9	9	90		10	100		8	80			0	
S 3	Best Time Saved CEA Ratio	8	6	54	12.9 hr/K$	10	90	24.3 hr/K$	5	45	9.49 hr/K$		0	
	Total Possible Score	270					0			0			0	
	Sub Total Score			189			280			161			0	
	Sub Total as a Percentage of Total Possible Score			70%			104%			60%			0%	
	Score Adjusted by Social Factor Weighting			**23**			**34**			**20**			**0**	
	Environmental Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
EN 1	Best GHG CEA Ratio	10	5	50	0.646 kg/$	10	100	1.218 kg/$	4	40	0.472 kg/$		0	
EN 2	Biggest reduction in fisheries impacts	8	10	100		10	100		10	100			0	
EN 3	Minimize environmental footprint	6	10	100		10	100		10	100			0	
	Total Possible Score	240												
	Sub Total Score			250			300			240			0	
	Sub Total as a Percentage of Total Possible Score			104%			125%			100%			0%	
	Score Adjusted by Environmental Factor Weighting			**34**			**41**			**33**			**0**	
	Economic Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
EC 1	Maximize IRR	10	4	40	11%	10	100	25%	3	30	7%		0	
EC 2	Maximize NPV	10	3	30	$22M	10	100	$89M	1	10	$4M		0	
EC 3	Maximize Simple ROI	6	5	30	14%	10	60	28%	4	24	11%		0	
EC 4	Best GDP CEA Ratio	8	5	40	0.87 $/$	10	80	1.65 $/$	4	32	0.64 $/4		0	
EC 5	Best Cost of Time Saved CEA Ratio	5	5	25	241 $/K$	10	50	454 $/K$	4	20	176 $/K$		0	
EC 6	Minimizes annual operations and maintenance bugets	4	10	40		10	40		10	40			0	
	Total Possible Score	390												
	Sub Total Score			205			430			156			0	
	Sub Total as a Percentage of Total Possible Score			53%			110%			40%			0%	
	Score Adjusted by Economic Factor Weighting			**17**			**36**			**13**			**0**	
	TOTAL Weighted Score		**75**			**112**			**66**			**0**		

Table 5-3 Climate Change TBL Analysis

#	Description	Weight	Federal DFAA			Ministry Peace Flood			Minsitry Highway 97			Loss Projection		
	Must		Yes /No		Comments	Yes /No		Comments	Yes /No		Comments	Yes /No		Comments
M 1	IRR ≥ 5%		Yes		19%	Yes		38%	Yes		13%	Yes		9%
M 2	NPV ≥ $0		Yes		$58M	Yes		$158M	Yes		$30M	Yes		$14M
M 3	Simple ROI ≥ 5%		Yes		22%	Yes		42%	Yes		16%	Yes		9%
M 4	Be Technically Feasible		Yes			Yes			Yes			Yes		
M 5	Meet all current design standards		Yes			Yes			Yes			Yes		
	Wants	**Weight**												
	Social Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
S 1	Largest Reduction in Service Interruption	10	5	45		10	90		4	36			0	
S 2	Address surrounding community needs	9	9	90		10	100		8	80			0	
S 3	Best Time Saved CEA Ratio	8	5	45	19.3 hr/K$	10	90	36.5 hr/K$	4	36	14.1 hr/K$	3	27	11.2 hr/K$
	Total Possible Score	270					0			0			0	
	Sub Total Score			180			280			152			27	
	Sub Total as a Percentage of Total Possible Score			67%			104%			56%			10%	
	Score Adjusted by Social Factor Weighting			**22**			**34**			**19**			**3**	
	Environmental Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
EN 1	Best GHG CEA Ratio	10	5	50	0.969 kg/$	10	100	1.827 kg/$	4	40	0..708 kg/$	3	30	0.559 kg/$
EN 2	Biggest reduction in fisheries impacts	8	10	100		10	100		10	100		10	100	
EN 3	Minimize environmental footprint	6	10	100		10	100		10	100		10	100	
	Total Possible Score	240												
	Sub Total Score			250			300			240			230	
	Sub Total as a Percentage of Total Possible Score			104%			125%			100%			96%	
	Score Adjusted by Environmental Factor Weighting			**34**			**41**			**33**			**32**	
	Economic Factors	**33.0%**	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments	Score	Wtd Score	Comments
EC 1	Maximize IRR	10	5	50	19%	10	100	38%	3	30	13%	2	20	9%
EC 2	Maximize NPV	10	4	40	$58M	10	100	$158M	2	20	$30M	1	10	$14M
EC 3	Maximize Simple ROI	6	5	30	22%	10	60	42%	4	24	13%	2	12	9%
EC 4	Best GDP CEA Ratio	8	5	40	1.31 $/$	10	80	2.47 $/$	4	32	0.96 $/$	3	24	0.76 $/$
EC 5	Best Cost of Time Saved CEA Ratio	5	5	25	361 $/K$	10	50	681 $/K$	4	20	264$/K$	3	15	209 $/K$
EC 6	Minimizes annual operations and maintenance bugets	4	10	40		10	40		10	40		10	40	
	Total Possible Score	390												
	Sub Total Score			225			430			166			121	
	Sub Total as a Percentage of Total Possible Score			58%			110%			43%			31%	
	Score Adjusted by Economic Factor Weighting			**19**			**36**			**14**			**10**	
	TOTAL Weighted Score		**75**			**112**			**66**			**45**		

5.2.5 TBL Analysis Results Summary and Analysis

Several observations may be drawn from the TBL analysis presented in **Tables 5.2 and 5.3**.

5.2.5.1 Base Case

In the Base Case, only three alternatives would be deemed viable. **Alternative 4** failed to meet the minimum IRR of 5% and positive NPV Must criteria. Of the remaining three alternatives, **Alternative 2** offered the highest overall TBL score. Depending on the structure of the team conducting the analysis, this would notionally make **Alternative 2** the optimal choice, as it addresses all the quantifiable financial criteria and, overall best addresses the softer socio-economic and environmental factors.

5.2.5.2 Accounting for Climate Change

The Climate Change Case yields similar results overall. This arises from the structure of the Must and Want criteria applied in the analysis. In this example, the Must criteria hurdles for IRR and NPV were the same as in the Base Case.

Alternative 4 would meet minimum financial criteria in the Climate Change Case and is now included in the overall analysis. Even so, given its relatively poor financial performance compared to the other alternatives, it still has the lowest overall score in the TBL analysis.

The other alternatives received the same relative soring.

A TBL team may opt for different hurdle rates in the Climate Change case to reflect higher uncertainties and perceived risks in that scenario. These adjustments were not made in this example, as the project team did not have sufficient data to support such an adjustment. In practice, TBL teams can bring their expertise to bear on the analysis and make adjustments to the criteria accordingly.

5.2.5.3 Implications for Climate Adaptation Interdependency and Communication

Care should be exercised in interpreting these results, as the structure of the team can have a significant bearing on the scoring. Overall, it is best to have a team with the broadest representation. If that team includes all of the relevant technical and operational expertise and also the professional judgment of decision-makers, it may be fair to conclude that **Alternative 2** is the best project decision. However, if there are any gaps in the team, the results of the TBL analysis can change when it reviewed by different team members through different organizational lenses.

The TBL is an ideal process for soliciting input and engaging with stakeholders. Internally, it allows gathering broad organizational input into key decisions and is especially effective when TBL teams have decision-maker representation. Externally, the TBL facilitates broad stakeholder input, incorporating a wide range of potential impacts into the decision process.

Both internally and externally, the success of the TBL process depends on stakeholder engagement and buy-in. To encourage this, the process should start with broad stakeholder input on Must and Want criteria and on the relative weighing applied to those criteria. This will ensure that the entire group both understands the process and also agrees with the factors applied to finally make a decision.

When broad stakeholder input is included in TBL analysis, it provides a robust assessment of quantifiable and unquantifiable parameters that best address the needs of the organization and affected stakeholders, including interdependent infrastructure systems.

5.2.6 Conclusions and Observations about Financial Analysis

5.2.6.1 Conclusions

The Pine Pass Case Study analysis supports several conclusions about the application of financial analysis in climate change adaptation projects.

1. Simple ROI is an unreliable measure of project financial performance. It can provide misleading results, especially for projects that have uneven cashflows over their useful life.

2. NPV and IRR are superior metrics for measuring the financial impacts of a climate change adaptation project.

3. Most NPV and IRR approaches do not include external social or environmental benefits. However, the BCMOTI Guidance on cost-benefit analysis provides Ministry approved methods for costing these social and environmental benefits that makes the Ministry CBA method far more robust for climate adaptation work than standard CBA methods that exclude the valuation of external social costs.

4. Cost effectiveness analysis is a good way to incorporate non-monetizable metrics into a climate change adaptation financial analysis. However, the parameters still must be quantifiable. The approach does not allow the valuation of softer, more subjective factors within the analysis.

5. TBL analysis provides a useful mechanism to blend CBA, CEA and more subjective, non-quantifiable parameters within a consistent, rigorous and unified analysis.

6. TBL analysis is a very powerful tool for evaluating climate adaptation project alternatives that includes financial, social and environmental aspects of projects in the evaluation.

7. TBL analysis is best conducted using a facilitated, team approach.

8. CBA and CEA analyses do not provide a complete picture of the overall benefits of climate adaptation projects, as they only include parameters that can be quantified. While these parameters can be measured, they often do not provide a comprehensive picture of the overall benefits of an adaptation project, as they omit broader social and environmental factors that may not easily be quantified.

9. CBA and CEA metrics are useful input data for a TBL analysis.

10. While CBA analysis can establish that a project exceeds internal financial hurdles, CEA and TBL analysis are more useful in ranking project alternatives. CEA and TBL allow the inclusion of non-monetizable parameters in the analysis that a practitioner can use to differentiate between multiple project alternatives.

11. Including the impact of climate change within the analyses provides a better projection of project performance. Neglecting climate change impacts can disqualify otherwise sound projects.

5.2.6.2 Recommendations

1. Practitioners should use NPV and IRR as their primary financial metrics for evaluating the financial integrity of climate change adaptation projects.

2. BCMOTI should refer to the internal Ministry guidance on cost-benefit analysis to establish input data for NPV and IRR calculations, as this approach establishes a firm basis for incorporating social costs within the financial analysis.

3. Practitioners should as much as possible consider the “real” environment within which the project will operate, and this should include consideration of climate change impacts.

4. Practitioners should use CBA and CEA metrics as input data for a robust TBL analysis of climate change adaptation projects.

5. Practitioners should use multiple approaches to establish climate adaption project viability. CBA can establish that the project addresses financial objectives. CEA can establish that which projects better address quantifiable social and environmental measures, and TBL can establish how well each alternative addresses broader social and environmental concerns. The multi-factor approach is outlined in **Table 5-4**.

Table 5-4: Multi-Factor Approach to Project Evaluation

	Analysis Approach		
	CBA	CEA	TBL
Best Application	Financial Analysis Monetizable input data	Direct comparison of alternatives Quantifiable input data	Holistic evaluation of quantifiable and non-quantifiable financial, social and environmental parameters
Benefits	Can be compared with standard benchmarks Familiar to decision-makers	Avoids the need to monetize socially sensitive factors Familiar to health professionals	Draws on best professional judgment of the team

5.3 *Monitoring Phase KPIs*

A detailed assessment of key performance indicators (KPIs) for climate adaptation projects is provided in a companion report to this case study (Nodelcorp Consulting Inc. 2019).

5.3.1 KPI Observations

A detailed review of the Pine Pass flood data identified four possible indicator metrics for evaluating the effectiveness of climate adaptation projects. The evaluation included the possibility of applying one or more of those metrics as a measure of the success of the adaptation action. Of the four, only one metric satisfied the requirements for an effective KPI, ***the amount of time saved by the initiative.***

BCMOTI routinely monitors traffic volumes, so staff has easy access to information about the number of vehicles affected by road repairs and detours. Staff can readily convert this information into a detour time metric.

In practice, BCMOTI could establish a target, for example zero detour hours on a segment of highway after the adaptation action occurred. If another, similar failure occurred, staff could monitor detour traffic count using available meters and report detour time through the chain of command. The ministry could use this information to monitor progress on road repairs arising from climate events, and also to test the assumptions that were originally used to assess the financial performance of the adaptation action. Staff can capture date with readily available traffic counting devices, so they are not diverted from their core function during a road closure, repairing the highway.

By monitoring detour hours, and targeting to keep those hours to a minimum, the Ministry could gather data allowing them to assess the effectiveness of climate adaptation actions. Also, the Ministry would be better equipped to evaluate future adaptation measures, data would be available on the impact of older initiatives. The Ministry could use this information to inform ongoing climate mitigation actions and support consultation with interdependent infrastructure systems.

Table 5-5 provides a summary analysis of the four potential KPIs considered in the analysis.

Table 5-5 Comparison of Possible KPI Options

	Ready Access to Data	One Process or Activity	Easy to Understand	Applies at All Levels	Can Assign Responsibility	Comments
GDP	No	No	No	No	No	GDP is a universal metric that captures the impact of a wide range of inputs. While often reported, it is very difficult to parse out the impact of a single activity on GDP.
GHG	No	Yes	No	Yes	No	GHG emissions vary vehicle to vehicle, depending on age, wear and tear, and current weather conditions. GHG emission calculations apply standard emission factors to a type of vehicle and require the application of professional judgment. It is difficult to assign the impact of a single action on GHG emissions.
Time Saved	Yes	Yes	Yes	Yes	Yes	Time saved is relatively easy to calculate based on traffic volumes, which BCMOTI monitors, such as the distance of a detour, and the average speed through a detour. While easy to determine on a per vehicle basis, it is difficult to assess the impact on the number of people affected, as that metric would require a

	Ready Access to Data	One Process or Activity	Easy to Understand	Applies at All Levels	Can Assign Responsibility	Comments
						deeper knowledge of the number of people in each vehicle.
Value of Time Saved	No	Yes	Yes	Yes	Yes	Value of time saved is based on the time saved metric and relies on data relative to the number of people in each vehicle, and the types of drivers and passengers. Thus, while the metric addresses most of the criteria defined for an effective KPI, staff cannot readily access the data needed to calculate the metric.

5.3.2 Conclusion Drawn from Pine Pass Case Study

BCMOTI can support climate change adaptation initiatives by closely monitoring traffic counts and detour times on highway segments where climate adapted infrastructure is in place. The Ministry can use this information to evaluate the effectiveness of the work, inform new climate adaptation initiatives, and support consultation with interdependent infrastructure owners and users.

6 *Final Thoughts*

The volumes of this study were based on information from the 2016 Pine Pass flood. The work included:

- Detailed review of the infrastructure risks and damages based on communication with other interdependent infrastructure system owners;
- Methods of financial analysis related to adaptation options to extreme weather events for events like the Pine Pass flooding; and
- Ways of monitoring the effectiveness of climate adaptation actions.

The study aimed at developing a communication process that could be use by the Ministry and other interdependent infrastructure owners to proactively develop climate change adaptation options among those potentially affected from climate change and extreme weather events. The aim is to put more emphasis on the Mitigation or risk reduction phase of the Emergency Management framework. This can reduce the resources required for other phases such as response and recovery.

The work also included financial analysis covering the triple bottom line that incorporates financial, social, environmental factors. This approach was applied to the evaluation of proposals for climate change adaptation options.

The Pine Pass case study links these aspects and hopes to provide direction for methods to connect with others to information when developing climate change adaptation options.

6.1 Climate Change and Extreme Weather Emergency Management is a Process

Generally, responding and adapting to climate change and extreme weather emergencies follows a four-step process. When an event occurs the first priority is responding and providing emphasis on public health and safety. Once the event is finished the process transitions to a recovery mode, where the priority is returning infrastructure systems and living conditions of those affected back to order as soon as possible. Once this is complete, organizations and communities start to focus on Preparedness and planning for the next possible climate emergency; addressing issues that arose and hardening assets to better accommodate anticipated extreme weather conditions. Finally, the process enters a Mitigation phase. Ideally, the organization or municipality keeps track of the effectiveness of initiatives and tweaks systems and procedures on an ongoing basis to be better prepared for the next climate change and extreme weather emergency.

When a new event occurs, the process starts over, with new information. While weather emergencies are anything but normal, emergency management and should be a routine activity for organizations and communities.

6.2 Enhanced Communications for Preparedness and Mitigation Phases

The case study demonstrated that communication during emergency response and recovery was very effective. The communication processes developed for emergency response and recovery form a solid foundation for further developing communication programs during the Preparedness and Mitigation stages of emergency management. While, the system may include a different group of stakeholders, the overall model and methodology is sound, and would ensure developing greater resilience of infrastructure to avoid weather related climate change emergencies. This process will ensure that system interdependencies are considered in climate change adaptation planning, be more effective, and provide initiatives that reduce downstream climate change impacts that could affect other interdependent systems.

6.3 Choosing Proper Financial Metrics

Often, when organizations evaluate climate change adaptation options during the planning phase, they must justify and secure budgetary funding to support the work. This requires effective financial metrics that demonstrate the options support organizational financial objectives. In the case study, we demonstrated that the most effective financial metrics for this work are internal rate of return (IRR) and net present value (NPV) that include climate change impacts in the analysis.

The case study revealed nuances associated with applying these metrics to BCMOTI proposals. Standard financial metrics typically show that investments meet profitability targets established by an organization. For organizations solely focussed on profitability, this is relatively straightforward. These organizations conduct the analysis based on budgets and financial returns. Social and environmental factors are often excluded, unless there is a direct and measurable financial impact.

BCMOTI is a public organization. The Ministry builds, maintains, and operates highways in B.C. for the benefit of the residents of the Province. Normally, IRR and NPV are less meaningful for this type of organization, as standard profitability measures may not apply. However, the Ministry recognizes this nuance, and has published internal guidance on incorporating social parameters within standard financial analysis. Following this guidance, the Ministry is well positioned to apply these metrics to evaluate climate change adaption projects.

The Ministry can enhance this process through Triple Bottom Line (TBL) analysis. TBL analysis allows the inclusion in the analysis of parameters that are not easily quantified, including many social and environmental factors.

6.4 Ongoing Performance Monitoring

Once a project is built, the organization is wise to continue monitoring its effectiveness. The case study showed that the best metric for BCMOTI for measuring climate adaptation project performance is ***time saved relative to a baseline***. For example, if the Ministry includes justification based on reducing detour times from ten days to three days, detour times can be monitored along that particular segment of highway to compare actual performance with the design assumptions.

Effective monitoring parameters must be easy to measure, and the data must be readily available to all levels of the organization. For instance, the Ministry routinely monitors traffic counts, so there is ready access to the number of vehicles that use a detour during a road closure, and the length of the closures. This data is a foundation for the avoided traffic delay metrics identify in the case study.

6.5 Pine Pass Case Study Demonstrates Good Emergency Management Practices

The analytical basis for this case study can be found in companion documents and supporting spreadsheets. Overall, the Pine Pass flood event was a good example of the four phases of emergency management. Analysis of this event demonstrated the value of:

- Good interdependent communication during the response and recovery stages of the emergency management process;
- Robust financial metrics that include social and environmental considerations;
- Ongoing monitoring; and
- Sharing information among interdependent organizations

By developing these approaches BCMOTI will be able communicate with other infrastructure owners about the potential interdependencies between Ministry climate adaptation initiatives and other infrastructure systems, including those operated by municipalities and First Nations.

7 Works Cited

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Developing a Climate Change Adaptation Interdependency Process with Economic Considerations

Supported by Natural Resources Canada's Climate Change Adaptation Program

APPENDIX

PCIC Climate Change Information

British Columbia | Ministry of Transportation and Infrastructure

Climate Information, Projections and Process for use in the Ministry Highway Maintenance Renewal Data Mapping Tool

Pacific Climate Impacts Consortium

2020-04-30

Introduction

In FY 2019-2020 the Pacific Climate Impacts Consortium (PCIC) and the Province of British Columbia's Ministry of Transportation (MoTI) and Infrastructure collaborated together through Agreement #820LA0005. The goal of the project was to develop and incorporate climate information mapping via Open Geospatial Consortium (OGC) compliant services and protocols such as Web Map Service (WMS) or Web Feature Service (WFS) into the Ministry highway maintenance renewal data mapping tool.

The motivation for supplying climate change information via OGC-compliant services can be partially attributed to the fact that the data requirements for storing climate change scenarios are quite large and beyond the capabilities for many organizations to effectively store and manage. Storing the data in a single place, and providing access via a service oriented architecture represents a much more efficient method of distributing information than would replicating hundreds of terabytes of data across multiple organizational units.

In addition to the issues of data size, even summaries of climate change information are highly complex. PCIC's tool sets maintain data for dozens of variables, from a dozen different global climate models, for multiple scenarios, across multiple multidecadal periods. Certainly, not all of this data will be necessary for each specific transportation and infrastructure use case. So a sensible solution is for PCIC to maintain the datasets, while allowing on-demand access to the necessary datasets at the time of analysis.

A substantive goal of this project was to pioneer the use of PCIC's climate data Application Programmer Interfaces (APIs) in a hybrid setting. The objective was for MoTI to be able to combine certain sensitive and proprietary information in their internal system (assets and infrastructure) with data that is publicly available from PCIC. This is another huge advantage of the service oriented architecture; the ability to mix and match data in an authorization-required decision support system.

Example work flow

A variety of typical workflows for the PCIC Climate Explorer (PCEx) can be found in Chapter 2 of `climate-explorer-backend` manual found in the appendices.

In general, the workflow involves:

1. Making a call to the `/multimeta` API endpoint which provides a programatically readable list of all of the data available from the services.
2. Using keys/dataset IDs found in this list for calls to:
   1. Request a map
   2. Request data across the seasons of a climatological year
   3. Request data for a specific season across multiple multi-decadal periods
3. Plotting data returned from the service in whatever tools are available to the requester.

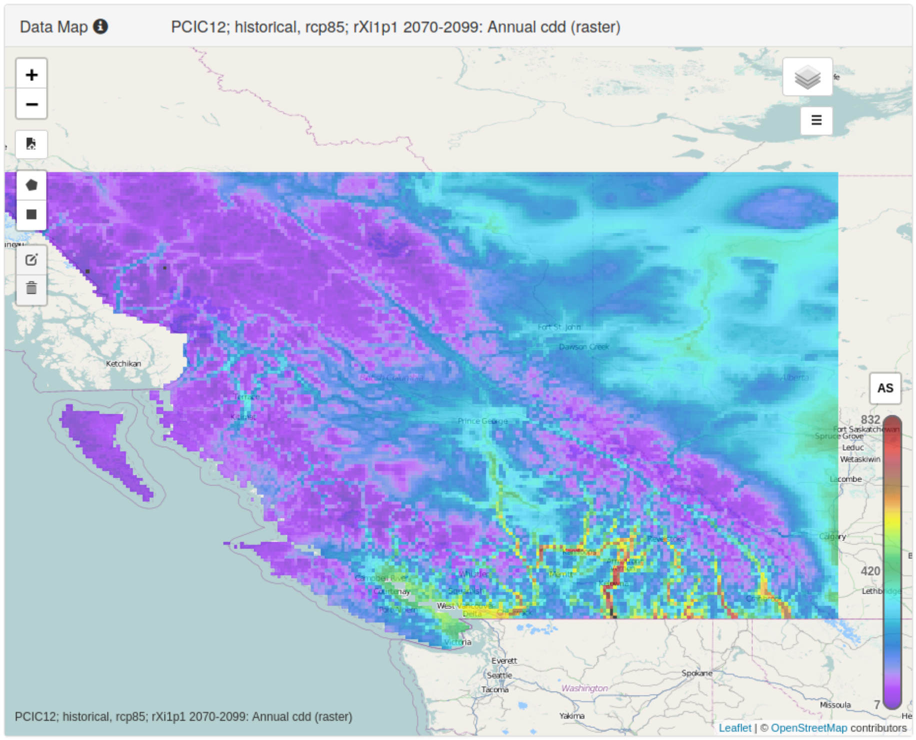
See the `climate-explorer-backend` manual for further details.

New Data Products

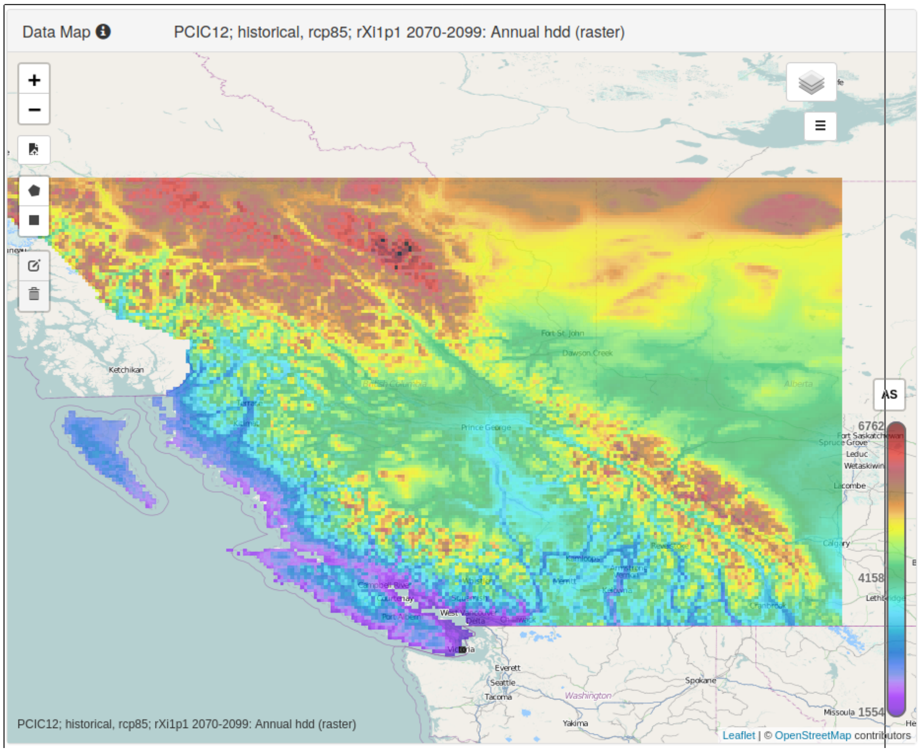
Over the course of this project, PCIC created a large number of new summary data products (around 8500). These data have all been deployed to the PCEx and are publicly available through an *Application Programmer Interface (API)*. The data can now be analyzed interactively with the PCEx user interface, or they can be incorporated into other decision support tools.

Degree days

Several derived variables that can be conveniently grouped together as "degree day" variables have been produced and added to the PCEx as part of this project. These variables are commonly sought by users because of their close ties to climate impacts and applications. Heating degree days (`hdd`) and cooling degree days (`cdd`) are commonly used in building and engineering applications while growing degree days (`gdd`) and freezing degree days (`cdd`) are frequently used in agricultural application.



Screenshot of the PCEx map for annual Cooling Degree Days, 2080s, under RCP8.5



Screenshot of the PCEx map for annual Heating Degree Days, 2080s, under RCP8.5

Return periods

As described below in the first appendix, a return period variable describes extreme temperature or precipitation events that would be expected to occur once during a specified "return period," for example once every 20 years. These datasets are highly useful for engineering applications, when one wants to relate a specific infrastructure lifetime to a design value. As part of this project, PCIC added 5, 20, and 50 year return period values for variables daily minimum temperature (`tasmin`), daily maximum temperature (`tasmax`) and daily precipitation (`pr`).

"PCIC12" Ensemble averages

Each different climate model has different strengths, weaknesses and biases. Robust climate impacts analysis typically requires using an ensemble of multiple climate models. Model ensembles are expensive to produce, since they require a multiplicative increase in the resources required for a single model.

For example, to produce a 12 model ensemble average of downscaled climate model output requires 12 times more data storage of global climate model output that would using a single model. It also requires 12 times as much computation for post-processing the output to high-resolution downscaled scenarios, and 12 times more storage for the high-resolution output.

However, using model ensembles for analyses is quite valuable, so PCIC maintains the output from an ensemble of 12 global climate models for which we have produced statistically downscaled climate scenarios across all of Canada. This ensemble is succinctly nicknamed the "PCIC12".

As part of this project, PCIC computed and made available PCIC12 ensembles over BC and western Alberta for our baseline variables (`tasmin`, `tasmax`, `pr`), our degree day variables (`hdd`, `cdd`, `gdd`, `fdd`), and return period variables (`rp5pr`, `rp20pr`, `rp50pr`, `rp5tasmax`, `rp20tasmax`, `rp50tasmax`, `rp5tasmin`, `rp20tasmin`, `rp50tasmin`). All of these variables are defined and explained in the appendix.

Routed streamflow in the Peace

As part of this project, PCIC has also piloted a process for producing a *gridded* streamflow dataset across a single watershed. This is a dataset that contains streamflow projections at each model grid cell across the entire Peace River watershed. Grid cells are 1/16-degree squared (roughly 30 km^2 at the latitudes covered) and there are 7484 grid cells within the area of approximately 200,000 km^2. This dataset is able to support decision making requiring future streamflow projections at any arbitrary, scale-appropriate point.

It should be noted that the technique used in this project to support instantaneous streamflow queries at arbitrary locations was to compute streamflow at *every* point in the Peace watershed. This technique makes a trade-off: dramatically increasing the overall computational and storage expense in order to provide the user with results in under a couple seconds. Realistically, there is not infrastructure that would require decision support within every single grid cell, so precomputing the entire watershed is not necessary. For future work, PCIC will be developing on-demand compute capabilities for such an application (allowing a user to select an arbitrary point in *any* watershed that PCIC has modeled, without having to precompute routed flow across the entire modelling domain). In the mean time, this pilot gives hydrotechnical engineers an important dataset and information to be able to work within the Peace watershed.

The specifics of the routed streamflow variable and an example workflow of requesting such data are documented in the appendices below.

New mapping layers and GIS

PCIC has ensured that each of the 8500 or so datasets that have been produced as part of this project are all available to visualise through PCIC's web mapping server. Each dataset map contains multiple separate timesteps for the various climatological times of year: e.g. annual, each season, and each month. Effectively this means that the 8500 datasets available work out to there being $\approx$ 48,000 new mapping layers available.

PCIC's mapping server is an instance of the `ncWMS` software and is available at the base URL: https://services.pacificclimate.org/pcex/ncwms.

By making these climate mapping layers available through `ncWMS`, users are able to programmatically access the layers using the Open Geospatial Consortium's (OGC) Web Mapping Service (WMS) standard.

While PCIC displays the climate mapping layers using a web-based map on the PCEx (with the JavaScript library Leaflet), one can use any traditional desktop GIS system like ArcGIS or QGIS. Any software that supports OGC's WMS protocal would be able to map the PCEx's climate mapping layers.

Workflow for requesting maps

To request a map from ncWMS, one needs several pieces of information:

- A layer ID which is itself composed of:
  - a dataset ID and
  - a variable name
- A string describing the timestep to request
- Map parameters (bounding box and spatial reference system, usually provided by your mapping software)
- Output parameters (image format and size)
- Styling parameters
  - colour scale
  - colour range
  - logrithmic scale (optional)

All of the dataset specific information can be discovered by using the PCEx's `/mulitmeta` and `/metadata` API calls. The identification string of the file of interest can be determined from the `/multimeta` query, which lists all files available in a collection. And the `/metadata` API endpoint response contains all of the timesteps available for a given dataset.

For example if one wanted to request a map of the annual average Cooling Degree Days (`cdd`) over 1961-1990 for the PCIC12 model ensemble, you could issue a `GetMap` request for `layer_id=cdd_aClimMean_BCCAQv2_PCIC12_historical-rcp85_rXi1p1_19610101-19901` `time=1977-07-02T00:00:00Z`, across a certain spatial domain (in this example we use 48 to 54 degrees latitude and -133 to -115 degrees longitude, but normally your mapping software will do this for you).

This request would look like this:

```
https://services.pacificclimate.org/pcex/ncwms?service=WMS&request=GetMap&
layers=cdd_aClimMean_BCCAQv2_PCIC12_historical-rcp85_rXi1p1_19610101-19901231_Canada%2Fcdd&
styles=default-scalar%2Fx-Occam&format=image%2Fpng&transparent=true&version=1.1.1&
time=1977-07-02T00%3A00%3A00Z&srs=EPSG%3A4326&width=512&height=512&
bbox=-133,48,-115,54
```

There are many, many options for styling, map projection, image format, color scale, etc. Full discussions of using the WMS protocol and the ncWMS implemenation options are beyond the scope of this document. Please refer to the ncWMS documentation for more details.

API Calls

As part of this project, PCIC designed, implemented and deployed a brand new API that provides quantitative statistics for the modelled watersheds. This information can accompany the modelled streamflow output to be incorporated into decision making by hydrotechnical engineers.

Watershed

The `/watershed` API endpoint accepts two parameters:

1. An `ensemble_name` where the basin information files can be found (currently they are all located in the `hydro_files` ensemble), and
2. `station` which should be a single point that serves as the basin outlet, encoded as a WKT POINT geometry.

The endpoint returns a variety of statistics about the modelled watershed, such as area, cell count, min/max elevation, a polygon of the watershed and its mouth.

For example, requesting the watershed that ends at the latitude/longitude location 56, -121 would look like this:

```
$ curl -s 'https://services.pacificclimate.org/pcex/api/watershed
          ?ensemble_name=hydro_files&station=POINT(-121%2056)' | python -m json.tool
```

```
{
    "area": {
```

```
    "units": "m2",
    "value": 26986103.504903063
},
"boundary": {
    "geometry": {
        "coordinates": [
            [
                [
                    -120.9375,
                    56.0
                ],
                [
                    -120.9375,
                    56.0625
                ],
                [
                    -121.0,
                    56.0625
                ],
                [
                    -121.0,
                    56.0
                ],
                [
                    -120.9375,
                    56.0
                ]
            ]
        ],
        "type": "Polygon"
    },
    "properties": {
        "mouth": {
            "geometry": {
                "coordinates": [
                    -120.96875,
                    56.03125
                ],
                "type": "Point"
            },
            "type": "Feature"
        }
    },
    "type": "Feature"
},
"debug/test": {
```

```
        "watershed": {
            "cell_count": 1,
            "time": 0.0038528619334101677
        }
    },
    "elevation": {
        "maximum": 774.0,
        "minimum": 774.0,
        "units": "m"
    },
    "hypsometric_curve": {
        "area_units": "m2",
        "cumulative_areas": [
            0,
            0,
            0,
            0,
            0,
            0,
            0,
            26986103.504903063,
            0,
...
            0
        ],
        "elevation_bin_start": 0,
        "elevation_bin_width": 100,
        "elevation_num_bins": 46,
        "elevation_units": "m"
    }
}
```


Full documentation on its usage can be found in the API docs.

Appendices

API Docs

Documentation of the `climate-explorer-backend` is currently available upon request, and will soon be available via the PCEx web interface.

An API in general is a computing interface to a software component, system or data that defines how other software components can use it.

In this context, the `climate-explorer` API is a way for a client to make programmatic data requests to PCIC's climate resource archive. The client of an API is typically a programmer who is writing computer software to fulfill a business requirement. Making API requests programmatically allows the client to dynamically request, manipulate and display the data according to the client's own business rules and logic.

Source code

All code developed for the PCEx are available as Free and Open Source Software, released under the GNU General Public License. The relevant repositories containing the entire history of revisions are as follows:

1. `https://github.com/pacificclimate/climate-explorer-data-prep`
2. `https://github.com/pacificclimate/climate-explorer-backend`
3. `https://github.com/pacificclimate/climate-explorer-frontend`

Data available in PCEx

There are five types of data available in PCEX: model output, ClimDEX (discussed below in section "ClimDEX (climate extremes indices)"), degree days, return periods and routed streamflow.

Model output

Daily temperature and precipitation data output by global or regional climate models based on a combination of historical data and possible future greenhouse gas projections. The data is averaged by month over thirty year periods; there are six such periods from 1960 to 2100. This data is available for all of Canada.

- **`pr`**

Precipitation at ground level

- **`tasmax`**

Daily maximum near-surface air temperature

- **`tasmin`**

Daily minimum near-surface air temperature

- **`prsn`**

Precipitation at ground level while mean daily temperature is below freezing

ClimDEX (climate extremes indices)

Measures of weather extremes calculated from model output. ClimDEX defines 27 climate extremes indices, encompassing extreme precipitation, extremes of temperature, or lack thereof in different ways. This is a heterogeneous dataset; a given extreme may be calculated either as a monthly index averaged over thirty year periods from 1960 to 2100, or an annual index calculated individually for each year from 1950 to 2100. This data is available for all of Canada.

Many of the ClimDEX variables measure lengths of certain events, e.g. the number of sequential days with no precipitation. This length of time is referred to as a "spell". In the strict definition of these indices, spells are not allowed to span the calendar year boundary; i.e. from a beginning time in one year to an ending time in a subsequent year. In practice, however, this frequently happens. Most "spell" variables have an alternate definition which does allow spells to cross the annual boundary.

The formal definition of all ClimDEX variables can be from the Expert Team (ET) on Climate Change Detection and Indices (ETCCDI).

- **`altcddETCCDI`**

Dry spell duration index spanning years: Maximum number of consecutive days in one year with less than 1 mm of precipitation.

This is an alternative version of the ClimDEX variable `CDD`. It represents the full length of continuous dry spells that extend across the (artifical) December-January boundary of a calendar year.

- **`altcsdiETCCDI`**

Cold spell duration index spanning years: Count of days with at least 6 consecutive days when daiy minimum temperature < 10th percentile.

This is an alternative version of the ClimDEX variable `CSDI`. It represents the full length of continuous cold spells that extend across the (artificial) December-January boundary of a calendar year.

- **`altcwdETCCDI`**

Maximum length of wet spell spanning years: Maximum number of consecutive days with at least 1 mm of precipitation.

This is an alternative version of the ClimDEX variable `CWD`. It represents the full length of continuous wet spells that extend across the (artificial) December-January boundary of a calendar year.

- **`altwsdiETCCDI`**

Warm spell duration index spanning years: Count of days with at least 6 consecutive days when daily maximum temperature > 90th percentile.

This is an alternative version of the ClimDEX variable `WSDI`. It represents the full length of continuous warm spells that extend across the (artificial) December-January boundary of a calendar year.

- `cddETCCDI`

Maximum length of dry spell: Maximum number of consecutive days with less than 1 mm of precipitation.

- `csdiETCCDI`

Cold spell duration index: Annual count of days with at least 6 consecutive days when daiy minimum temperature $<$ 10th percentile.

- `cwdETCCDI`

Maximum length of wet spell: Maximum number of consecutive days with at least 1 mm of precipitation.

- `dtrETCCDI`

Mean diurnal temperature range: Monthly mean difference between daily maximum temperature and daily minimum temperature.

- `fdETCCDI`

Number of frost days: Annual count of days when daily minimum temperature. $>$ 0°C.

- `gslETCCDI`

Growing season length.

- `idETCCDI`

Number of icing days: Annual count of days when daily maximum temperature. $<$ 0°C.

- `prcptotETCCDI`

Annual total precipitation in wet days.

- `r10mmETCCDI`

Annual count of days with at least 10 mm of precipitation.

- `r1mmETCCDI`

Annual count of days with at least 1 mm of precipitation.

- `r20mmETCCDI`

Annual count of days with at least 20 mm of precipitation.

- `r95pETCCDI`

Annual total precipitation when daily precipitation exceeds the 95th percentile of wet day precipitation

- `r99pETCCDI`

Annual total precipitation when daily precipitation exceeds the 99th percentile of wet day precipitation

- `rx1dayETCCDI`

Annual Maximum 1-day Precipitation

- `rx1dayETCCDI`

Monthly Maximum 1-day Precipitation

- `rx5dayETCCDI`

Annual Maximum Consecutive 5-day Precipitation

- `rx5dayETCCDI`

Monthly Maximum Consecutive 5-day Precipitation

- `sdiiETCCDI`

Simple precipitation intensity index.

- `suETCCDI`

Number of summer days: Annual count of days when daily maximum temperature > 25°C.

- `tn10pETCCDI`

Percentage of days when daily minimum temperature is below the 10th percentile.

- `tn90pETCCDI`

Percentage of days when daily minimum temperature is above the 90th percentile

- `tnnETCCDI`

Annual minimum of daily minimum temperature

- `tnnETCCDI`

Monthly minimum of daily minimum temperature

- `tnxETCCDI`

Annual maximum of daily minimum temperature

- `tnxETCCDI`

Monthly maximum of daily minimum temperature

- `trETCCDI`

Number of tropical nights: Annual count of days when daily minimum temperature) exceeds 20°C.

- `tx10pETCCDI`

Percentage of days when daily maximum temperature is below the 10th percentile

- `tx90pETCCDI`

Percentage of days when daily maximum temperature is above the 90th percentile

- `txnETCCDI`

Annual minimum of daily maximum temperature

- `txnETCCDI`

Monthly minimum of daily maximum temperature

- `txxETCCDI`

Annual maximum of daily maximum temperature

- `txxETCCDI`

Monthly maximum of daily maximum temperature

- `wsdiETCCDI`

Warm spell duration index: Count of days with at least 6 consecutive days when daily maximum temperature > 90th percentile.

Degree-day variables

Calculated from model output, a degree-day variable counts how many days fall below or above a given temperature threshold multiplied by how many degrees the threshold is exceeded, over a period of a season or year. The data is averaged over six thirty year periods between 1960 to 2100, namely 1961-1990, 1971-2000, 1981-2010, 2010-2039, 2040-2069, and 2070-2099. This data is available for all of British Columbia.

A degree-day is a measure of how much the actual temperature (usually the mean average temperature) falls either above or below a threshold temperature that represents a temperature of interest (e.g., freezing, temperature at which cooling is required). For a given degree-day measure, the difference is only counted when the actual temperature is either above or below the threshold, the condition (above, below) being given as part of the measure's definition. One degree day is one day with a temperature difference from threshold of 1 degree (in Canada, °C). A day with a temperature difference of 3 degrees represents 3 degree-days. The total degree-days over a given period (e.g., a month, a year) is the total degree-days for each day in that period, always respecting both the threshold and the condition (above, below) in counting each day. This means that when both seasonal and annual degree day data are viewed in a chart or table, the annual values will be larger, as they represent the sum of the seasonal values.

- `cdd`

Cooling Degree Days: Degree-days during the specified time period above 18°C.

- **hdd**

Heating Degree Days: Degree-days during the specified time period below 18°C.

- **gdd**

Growing Degree Days: Degree-days during the specified time period above 5°C.

- **fdd**

Frost Degree Days: Degree-days during the specified time period below 0°C.

Return period variables

A return period variable describes extreme temperature or precipitation events that would be expected to occur once during a specified "return period," for example once every 20 years. These datasets are calculated from model output using a generalized extreme value (GEV) distribution and the R packages `ismev` (to fit GEVs using maximum likelihood estimation) and `extRemes` (to obtain magnitudes for given return periods). A further description of the GEV process can be found in Cannon et al. 2015.

It should be noted that the scientific literature and guidance on how to properly use projections for return period variables is rapidly and substantively evolving. There are many caveats, limitations and uncertainties present in these data and using them requires the use of significant expert judgment. At present, these data should *not* be used verbatim, without the involvement of and guidance from climate scientists.

These data are available for four thirty year climatological periods from 1970 to 2100, namely 1971-2000, 2011-2040, 2041-2070, and 2071-2100. These data are available for all of British Columbia.

- **rp5pr**

5-year annual maximum one day precipitation amount

- **rp20pr**

20-year annual maximum one day precipitation amount

- **rp50pr**

50-year annual maximum one day precipitation amount

- **rp5tasmax**

5-year annual maximum daily maximum temperature

- **rp20tasmax**

20-year annual maximum daily maximum temperature

- **`rp50tasmax`**

50-year annual maximum daily maximum temperature

- **`rp5tasmin`**

5-year annual minimum daily minimum temperature

- **`rp20tasmin`**

20-year annual minimum daily minimum temperature

- **`rp50tasmin`**

50-year annual minimum daily minimum temperature

Routed Streamflow

- **`streamflow`**

Simulated daily streamflow data calculated from model output, soil geography, and topology. Runoff and baseflow data within each grid square were generated from model outputs using the Variable Infiltration Capacity (VIC) model coupled to a glacier model. Streamflow is then routed between grid squares with the RVIC postprocessor. This data is averaged by month over thirty year periods, and is currently available for the Peace River watershed in British Columbia.

Global Climate Models (GCMs)

In PCEX, global climate models are indentified by short codes. The following table gives the full name and provenance of these models.

- `GFDL-CM3`: U.S. Geophysical Fluid Dynamics Laboratory Coupled Physical Model CM3
- `GFDL-ESM2G`: U.S. Geophysical Fluid Dynamics Laboratory ESM2G model
- `GFDL-ESM2M`: U.S. Geophysical Fluid Dynamics Laboratory ESM2M model
- `HadGEM2-AO`: U.K. Met Office HadGEM2 AO (Troposphere, Land Surface & Hydrology, Aerosols, Ocean & Sea-ice) model
- `HadGEM2-ES`: U.K. Met Office HadGEM2 ES (Troposphere, Land Surface & Hydrology, Aerosols, Ocean & Sea-ice, Terrestrial Carbon Cycle, Ocean Biogeochemistry, Chemistry) model
- `HadGEM2-CC`: U.K. Met Office HadGEM2 CC (Troposphere, Land Surface & Hydrology, Aerosols, Ocean & Sea-ice, Terrestrial Carbon Cycle, Ocean Biogeochemistry)
- `MRI-CGCM3`: Japan Meteorological Research Institute CGCM3 model

- `CNRM-CM5`: France Centre National de Recherches Météorologiques (National Centre for Meteorological Research) CNRM-CM5 model
- `CCSM4`: U.S. National Center for Atmospheric Research CCSM4 4.0 model
- `CSIRO-Mk3-6-0`: Australia Commonwealth Scientific and Industrial Research Organisation CSIRO-Mk3.6.0 model
- `inmcm4`: Russia Institute for Numerical Mathematics Climate Model Version 4
- `bcc-csm1-1-m`: China Beijing Climate Center Climate System Model version 1.1 (m)
- `FGOALS-g2`: China LASG (Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics) FGOALS-g2 model
- `CanESM2`: Canadian Centre for Climate Modelling and Analysis ESM2 (Earth System Model ver. 2)
- `MIROC5`: Japan Agency for Marine-Earth Science and Technology; Atmosphere and Ocean Research Institute; Centre for Climate System Research - National Institute for Environmental Studies MIROC5 (Model for Interdisciplinary Research on Climate, ver. 5)
- `MIROC-ESM-CHEM`: Japan Agency for Marine-Earth Science and Technology; Atmosphere and Ocean Research Institute; Centre for Climate System Research - National Institute for Environmental Studies MIROC-ESM-CHEM (Model for Interdisciplinary Research on Climate Earth System Model with Atmospheric Chemistry)
- `MPI-ESM-LR`: Germany Max Planck Institute ESM (Earth System Model) Low Resolution
- `ACCESS1-0`: Australian Community Climate and Earth System Simulator coupled model