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2022
Canadian Consulting Engineering Awards

Category
B. Transportation

Alaska Highway

Adapting Infrastructure in the Face of Extreme Weather

TETRA TECH

Public Services and Procurement Canada
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Alaska Highway

Adapting Infrastructure in the Face of Extreme Weather Events

Introduction

The Alaska Highway is the primary transportation corridor connecting the contiguous United States, through Canada, with Alaska. Spanning over 2,000 km, the highway itself was constructed in 1942, during a time of crisis, in less than 8 months. The highway is of high strategic importance, providing a critical link to the north. The corridor travels through several ecological regions, crosses five mountain summits, and runs alongside portions of major rivers.

Over the past 75+ years, the transportation corridor has undergone many geometric improvements as well as upgrades to critical infrastructure including bridges, culverts, and geotechnical assets.

Despite these ongoing efforts, the highway infrastructure faces two key challenges:

1. Managing the replacement of a variety of aging infrastructure components, and
2. Increasing infrastructure vulnerability as a result of a changing climate.

Truck along the transportation corridor

An asset failure resulting in a road closure can lead to long detours and increaded routing costs

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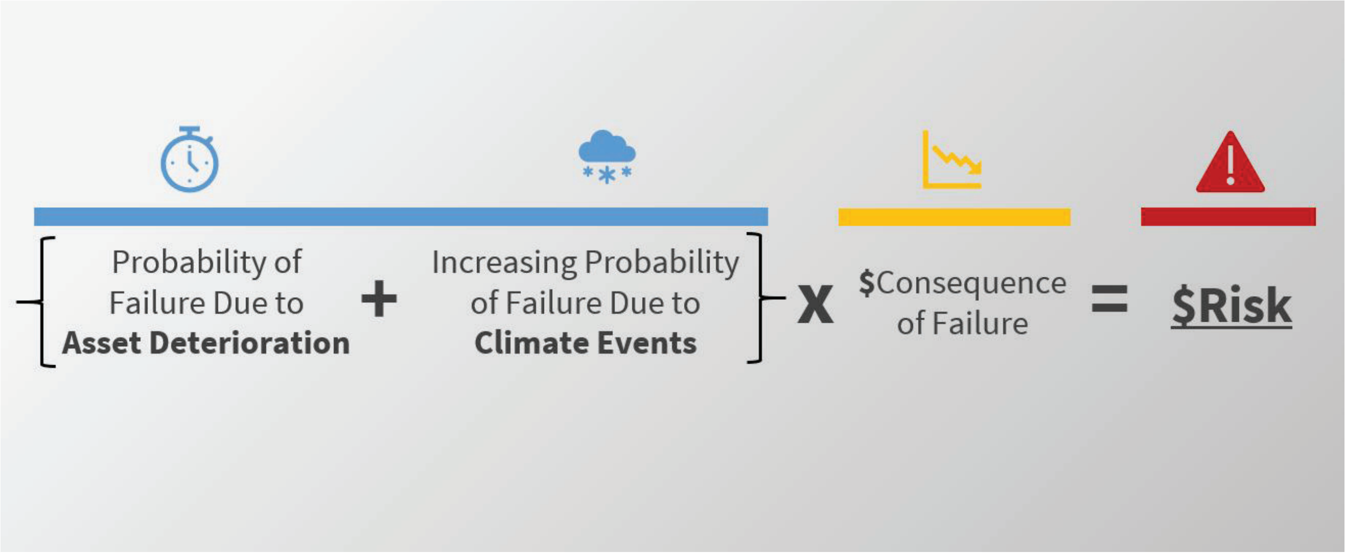
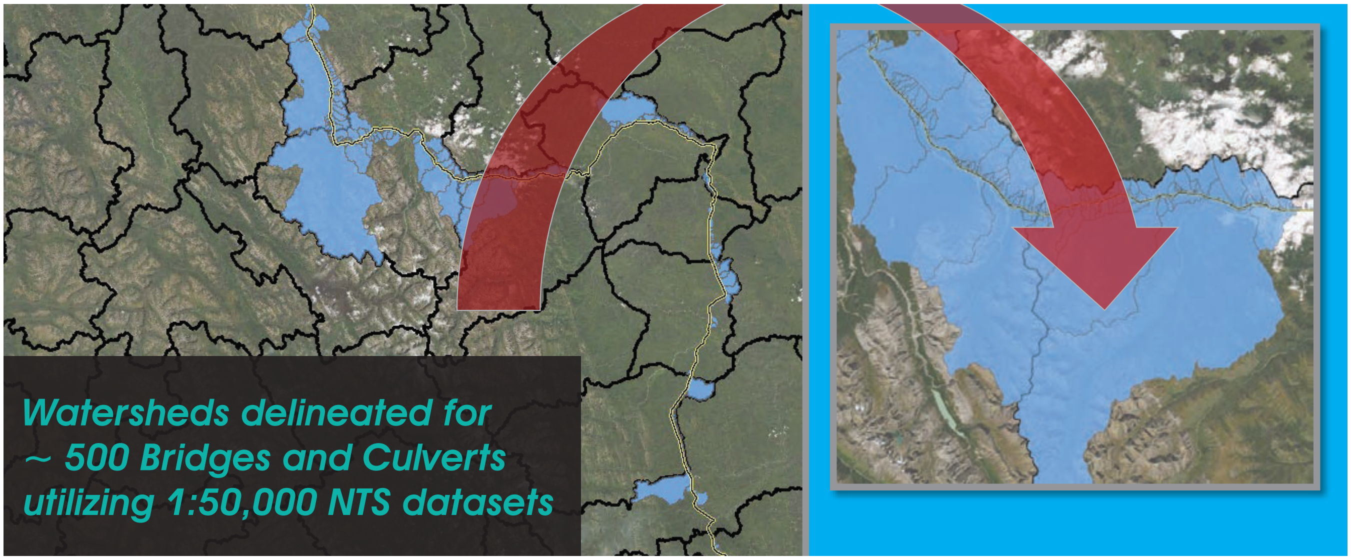


VRA Project Monetizing Risk

In 2019, Public Services and Procurement Canada (PSPC) teamed with Tetra Tech Canada Inc. (Tetra Tech) to develop a multi disciplinary study on the Infrastructure Vulnerability and Risk Assessment due to Changing Climate and Extreme Weather Events for the Alaska Highway. The project needed an innovative approach for compiling and assessing the variety of asset components (asset type, location and condition), and then incorporating a decision-making schema that could prioritize asset replacement – considering both asset condition and vulnerability, while also considering the potential effects of climate change. The project team's approach was unique in that it adopted and expanded on the methodology documented under the Vulnerability Assessment and Adaptation Framework developed by Federal Highway Administration, which provides a process for conducting a vulnerability assessment for the infrastructure assets. In addition, the approach expanded on a method previously developed by Tetra Tech and the US Army Corps of Engineers.

This method is based on "risk-based asset management" fundamentals. The approach incorporated a means for assessing and forecasting the risk, or probability of failure, of each individual asset, and assessed the consequence, in dollars, of the potential failure.

When applied to all Alaska Highway transportation assets, this approach provides a quantitative cost-benefit, or cost-risk measure, without any of the bias that often influences asset replacement decision making (i.e. bridges are more important than roads). The outcome is a detailed priority ranking of all of the corridor's assets, where asset replacement is categorized by benefit cost. This approach results in a genuinely optimal asset management plan, allowing for asset replacement planning based on an informed decision-making process, all while addressing the unique characteristics of the Alaska Highway corridor.



Typical Watershed Areas in ArcGIS

Innovation

First of its Kind Project

PSPC retained Tetra Tech in a first-of-its-kind study on Alaska Highway for climate change vulnerability assessment of its infrastructure assets. PSPC selected the application of the Vulnerability Assessment and Adaptation Framework (FHWA, 2017) for the vulnerability assessment after reviewing available literature, which is the first time the FHWA Framework is implemented in a climate resiliency study in Canada. The climate change vulnerability assessment is an emerging engineering and economics domain of assessing the resiliency of infrastructure assets in terms of economic metrics. The project is a first-of-its-kind project for Tetra Tech in Canada in the growing field.

The project involved asset management for both drainage and geotechnical assets along the highway. The results of climate change resiliency assessment, such as benefits in terms of reduction in monetary risk and benefit-cost ratio (BCR), were used for cross-asset comparison since the economic metrics or performance indicators are equivalent for both types of assets. The cross-asset comparison using BCR is a non-conventional approach different from conventional cross-asset optimization, which only utilizes cross-asset optimization between pavement, bridge and road geometric improvements.

Non-Conventional Approach Climate Resiliency

Tetra Tech followed the Vulnerability Assessment and Adaptation Framework, which is different from the conventional approach of using a Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol across other Canadian regions. The PIEVC protocol provides a qualitative risk assessment process using a multi-disciplinary team's subjective risk rating, professional judgement and expert opinion. PSPC and Tetra Tech selected FHWA Framework due to its flexibility to integrate an innovative quantitative risk-based engineering assessment approach developed and refined in-house by Tetra Tech's Transportation Asset Management Group. The non-conventional approach used objective parameters such as traffic, detour length, agency consequence, user consequence etc., to minimize the role of heuristic bias and uncertainty in engineering judgement in conventional approaches.

Alaska Highway Multi-plate Culvert

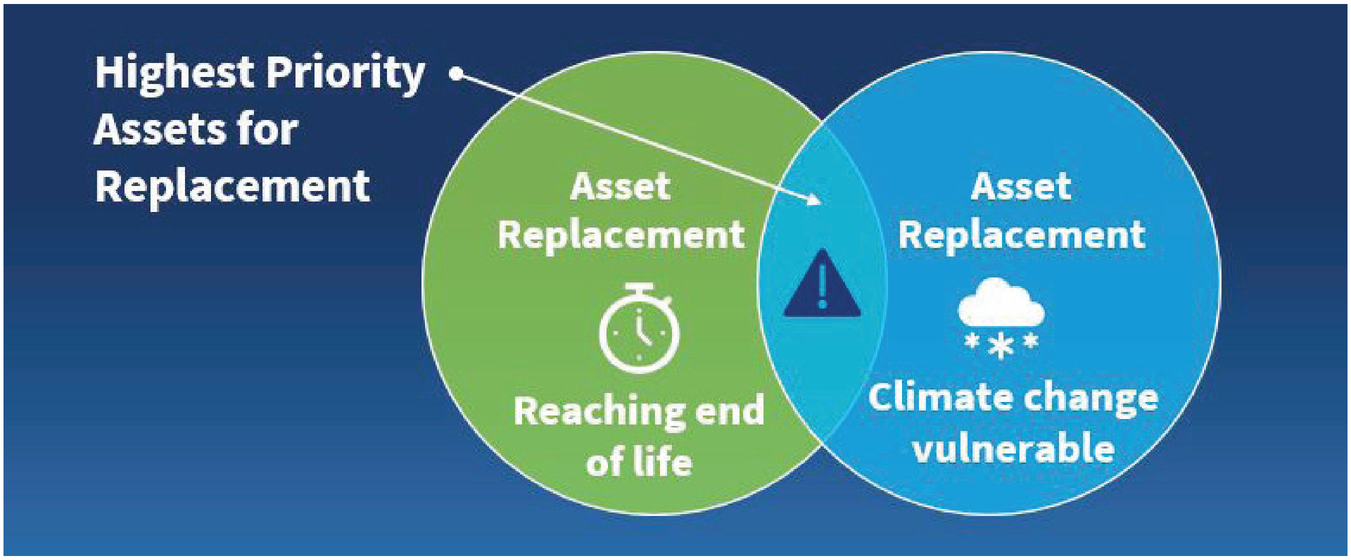
Innovative in-house Monetized Risk Assessment

The technique uses Tetra Tech's Intellectual Property, (in the form of business rules and predictive models), to be established in a commercial off the shelf software (COTS) solution to efficiently generate multiple alternative potential infrastructure resiliency improvements for each individual asset along with associated life-cycle costs and benefits, in terms of reduced $Risk. The innovation is that the cost/benefit of the changing climate and associated extreme weather events is both forecasted and included in the engineering economics-based Life-Cycle Cost Analysis (LCCA).

The technique can efficiently compare the $Risk and $Risk reduction associated with the costs of multiple levels of potential infrastructure resiliency options across hundreds of different assets spanning multiple asset classes through a life cycle.

Original Research

Tetra Tech implemented an innovative in-house engineering-informed assessment approach based on the US Army Corps of Engineers published guide (USACE, 2011) to risk and reliability based engineering relying on the concept of monetizing the costs of consequences of asset failure. The in-house methodology was used along with multi-strategy life cycle cost analysis through a commercial software solution. The asset management software was populated with the asset inventory data for drainage and geotechnical assets required to complete the analysis. The vulnerability and risk assessment modelling of drainage and geotechnical assets was carried out using several input parameters related to asset location, hydrological parameters of assets, climate-change parameters, risk and reliability assessment parameters and treatment resets. The monetized risk of failure was calculated for each asset over a 50-year analysis period for multiple adaptation strategies.

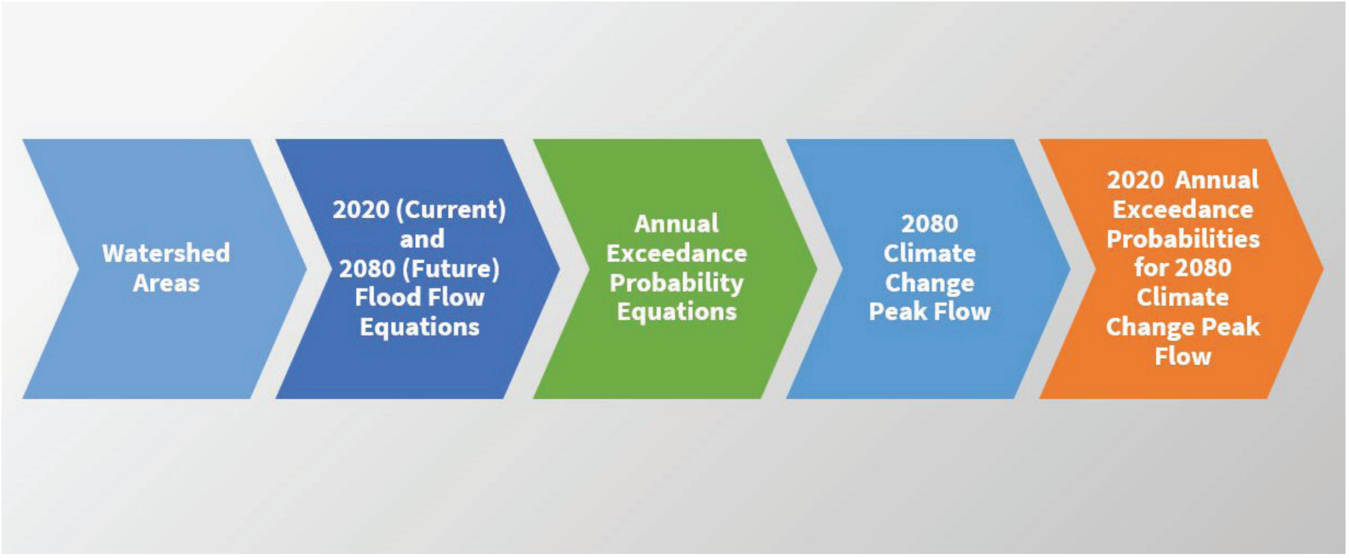


Incorporating Assessment Results in Decision Making

Complexity

The project solution was derived by working backwards from the final objective. Devise a methodology whereby the costs and benefits of improving resiliency of different asset types could be determined in such a way that these improvements could compete equitably for funding with all the other candidate improvements. This unique solution is possibly the first implementation of its kind relating to a transportation corridor - combining a monetized risk-and-reliability/climate change vulnerability asset management program. In the eyes of PSPC, the outcome provided a credible means for justifying capital expenditure decision making. Tetra Tech assembled a team of 10 specialists within the fields of climate science, hydrotechnical engineering, geotechnical engineering, GIS analysts, highway design and construction, as well as asset management engineers. This highly complex project included some of the following key considerations and project tasks:

- Future relevant climate parameters were established for the next 60 years.
- Data gathering from disparate sources, (images, LiDAR, bridge and culvert inspections, traffic, detour alternatives etc.) assembled into a project Geographic Information System (GIS).
- Mass delineation of watersheds through GIS based drainage modelling applications for the purposes of hydraulic modeling and evaluation on over 400 drainage structures.
- Geotechnical evaluations relating to 74 geotechnical assets were conducted.
- Condition deterioration models were developed for each asset.
- Determination of the societal impact of the failure of all the project assets.
- Up to five increased resiliency adaptations and associated costs were developed for each of these individual assets.
- Software development for the purpose of completing a multi-strategy 60-year Life Cycle Cost Analysis in the specially configured software.
- A ranked list of candidate projects was developed for inclusion with other corridor candidate projects.



Assessment of Vulnerability

Data Collection and Management

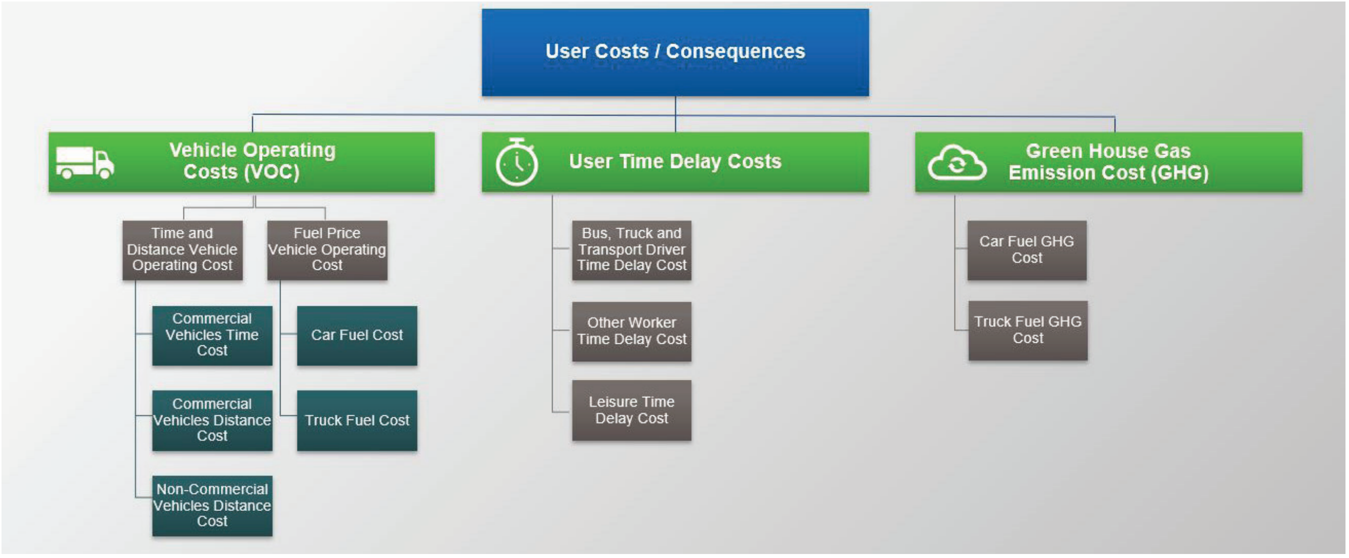
The vulnerability assessment tasks required unique approaches and innovative methods for compiling the required data such as location, physical characteristics of an asset (e.g. culvert diameter, slope height etc.), embankment geometry, condition, and climate-related data. Infrastructure vulnerability and risk assessment required utilizing the collected data to predict the expected conditions in 60 years due to climate change through modelling. The modelling at this large level required using commercial programmable asset management software to manage the data and predict the results in an efficient method.

Climate Change Model Scenarios

Tetra Tech provided a specific analysis of projected changes in temperature- and precipitation-related parameters as predicted by Global Circulation Models (GCMs, or climate change models) to establish a probable range of future climate conditions to which assets may be subjected. Projecting future climate change is a complicated undertaking that involves accounting for complex atmospheric and climatic processes and the interaction of these processes with global socioeconomic projections related to greenhouse gas emissions.

Many GCMs have been developed by climate researchers and consortiums around the world, and no two models predict the exact same future. Tetra Tech analyzed output from a model ensemble most appropriate to provide the widest spread in projected future climate for the study area.

For this project, in particular, Tetra Tech divided the Alaska Highway between Km133 and Km967 into 170 grid cells based on the grid resolution of the downscaled GCM output. For each grid cell, climate change data from 12 different GCMs most appropriate for Western North America were gathered and analyzed over a 147-year period between 1950 and 2096. Two future GHG concentration scenarios were assessed (RCP4.5 and RCP8.5), providing for a total of 24 moderate to conservative daily projections per grid cell. The data analysis involved approximately 670 million data points, from which a mean, 75th percentile and 90th percentile trend were developed for the climate parameters most relevant to engineering design and asset assessment such as daily and annual rainfall and snowfall, number of annual free-thaw cycles, daily minimum and maximum temperature, etc.



Calculating User Costs / Consequences

Future Projections for Geotechnical and Hydrotechnical Assets

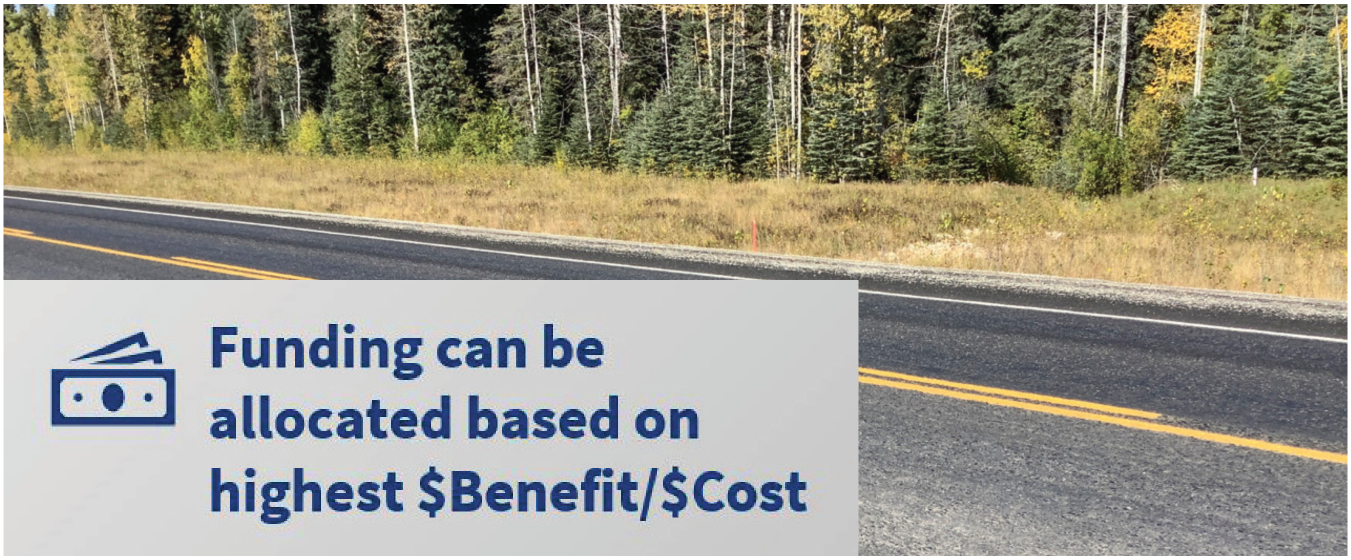
An adjusted annual probability of failure was assigned for each geotechnical asset due to climate change. The hydrotechnical portion of this assessment aimed at quantifying the flood flow magnitudes at each of the evaluated watercourse crossings. Flows were estimated for both present-day and future projections capturing the anticipated effects of climate change. These flows were then used to evaluate the hydraulic performance of the existing bridges and culverts. The risk was then quantified by comparing the magnitudes of flood flows to the capacity of the crossing.

The adaptation treatment for culverts consists of upgrading the flow capacity with multiple culverts of the existing size, upgrading the flow capacity with larger size single or multiple culverts, and replacing the culvert with the same size culvert to end of service life. Each asset was considered for a range of viable mitigation options based on the previous experiences with projects under similar conditions along the highway. Mitigation strategies were developed for each site ranged from no initial construction to the most significant construction option (e.g. highway realignment).

Monetized Risk-based LCCA

Economic analysis was carried out to identify and select the most efficient strategy alternative, including a do nothing scenario. The adaptation options were evaluated through economic analyses, as it monetizes the costs and benefits associated with adaptation strategies over a specific analysis period to be compared. The economic analysis for climate change adaptation options quantifies the extent of cost and benefit of adaptation options under each climate change scenario.

The costs considered in the LCCA include both "direct costs," the cost directly incurred by the PSPC, and "user costs," costs that users of the road would incur rather than the PSPC. The consequences for all assets were accounted for in the analysis in terms of owner and user consequences. The multi-strategy life-cycle cost analysis for implementing each adaptation strategy and do-nothing strategy were calculated. The cost-benefit analysis results indicated geotechnical assets with a high benefit-cost ratio and would merit additional investigation. The high benefit-cost ratio is due to the relatively high failure consequence compared to other assets and the uncertainty of the remediate options' potential costs. The study results were presented to the PSPC team and incorporated in the Strategic Asset Management Plan. The PSPC will complete project-level investigations to a list of select assets.



Incorporate Assessment Results in Decision Making

Social and/or Economic Benefits

Alaska highway is key to the economic prosperity of the northern part of British Columbia, and it also ensures local communities have access to reliable infrastructure assets. Improved travel and transportation of goods across the region through Alaska Highway benefits the local economy and improves residents' quality of life in nearby communities. The continuous operation of Alaska Highway is vital to provide the only link to several northern towns and cities with the rest of Canada and the United States. The impact on the movement of goods and services through the transportation corridor is potentially catastrophic – with travel distances increased by over 1000 km as a result of the ensuing detour. With risk being comprised of the product of the probability of an event happening and the cost of the consequences, a monetized societal benefit can be established based on the probability reduction of risk.

The benefit of proactively planning to reduce the risk of isolating communities and associated supply chain disruptions is self-evident. The methodology employed required a calculation of the societal costs of a failure of the asset in its existing condition, the societal cost of failure resulting from added resiliency (the difference being the societal benefit of the added resiliency), and the construction cost of the added resiliency. Establishing the costs of adding resiliency (larger capacity, more protection etc.) is straight forward. Establishing a societal cost of current, and potentially increasing vulnerability due to increasing frequency of extreme weather, is a more complicated cost to determine. The latter involves determining the current and potentially increasing likelihood of asset failure due not only to the increased probability of extreme events, but also to the natural deterioration of the asset over a long (in this case 60 year) planning horizon. This, in addition to establishing a monetary value to the societal costs of such an asset failure and the reduced societal costs of any improved resiliency allow us to calculate a true benefit cost ratio to justify adding resiliency. As an example, a washout of a culvert carries a much higher monetized consequence of failure than simply the cost of the culvert itself. In fact, a washout due to an under-capacity culvert can result in a road closure of several days or weeks.

Targeted investing in vulnerable transportation infrastructure is vital to support uninterrupted growth of economic activity in the northern region. By mitigating the risk of failure, this study results will ensure that the traffic keeps moving along the Alaska Highway with minimal delay or closure while utilizing the capital expenditure in the most efficient way possible. The long-term infrastructure risk assessment for over 50 years safeguards the network with the sudden unanticipated rise in the capital construction and maintenance cost.

A washout of a culvert carries a much higher monetized consequence of failure than simply the cost of the culvert

Environmental Benefits

Building resilience to the impacts of climate change requires technical assessments, the understanding of potential impacts, and the development of creative solutions within policy and programming at regional and local levels. As part of this project Tetra Tech developed and applied a range of tools to assess climate change vulnerability and risks and supported the critical process of linking these assessments to implementation decisions that will ultimately improve climate change resilience to the infrastructure of the Alaska Highway.

As part of calculating the reduction in societal costs that can be achieved through added resiliency, the potential for reduction in green house gas emissions was quantified. If a road segment is closed, there will be increased user delays and/or detours in addition to the costs of reinstating the lost infrastructure, all of which can be reduced with added resiliency. These construction, delay and detour activities generate greenhouse gasses through increased vehicle energy consumption related to increased direct fuel consumption and indirectly through increased parts and tire consumption as well as the effort required to reconstruct the failed area. All of these increased CO_2 equivalents were quantified and monetized in terms of current carbon cost/tax rates. Reduction in these costs were then used in the economic analysis as part of the calculating economic value of the risk reduction.

Uncalculated environmental benefits are accrued in the form of protection of downstream habitat, reduction in stream turbidity etc. that are intrinsic to the reduction in probability of a washout event occurring. Building a resilient asset network improves the network's ability to handle more frequent and severe climatic events. As a result, assets will last longer and perform better, limiting the need for future replacement and restoration, and in turn reducing the consumption of natural resource and construction materials.

Applicability to Other Transportation Infrastructure Assets

Meeting Client's Needs

Climate impacts are projected to lead to increases in investment required for infrastructure, particularly drainage, flood defences, and geotechnical slope stability in the northern areas of BC. Using the developed methodology and analysis framework for decision-making under uncertainty can reduce the need for costly remedial measures after failure while targeting the critical infrastructure. The primary objective was to assess and quantify the costs of the risks and the costs of potential risk mitigation options to its critical drainage and geotechnical assets.
In the asset manager's eyes, the result of the study provides economic metrics for the infrastructure assets, which can be used to prioritize the high-level investigation and subsequently targeted spending of capital expenditure to mitigate the probable monetized risk. The methodology provides an unbiased method of analyzing risk and using the resulting quantitative data for decision-making.

Transport Canada (TC) Transportation Assets Risk Assessment (TARA) Program

The Transportation Assets Risk Assessment (TARA) initiative at Transport Canada (TC) provided funding to assess the impacts of the changing climate on federally-owned and/or federally-managed transportation assets such as bridges, ports and airports. The Climate Change Vulnerability Assessment of Alaska Highway was successfully completed under the funding provided under the TARA program. Tetra Tech's Technical Lead, Mr. Gary St. Michel, presented the results of the study in a webinar entitled Transportation Asset Risk Assessment: Climate Risk Assessment Tools and Frameworks for the Transportation Sector organized by Transport Canada. Tetra Tech presented how the Framework was adapted to facilitate decision-making and incorporate climate risks into asset management and business practices. This webinar was well attended by federal, provincial and municipal level transportation asset owners and operators interested in learning more about completing a climate risk assessment and integrating climate change resiliency into their work.

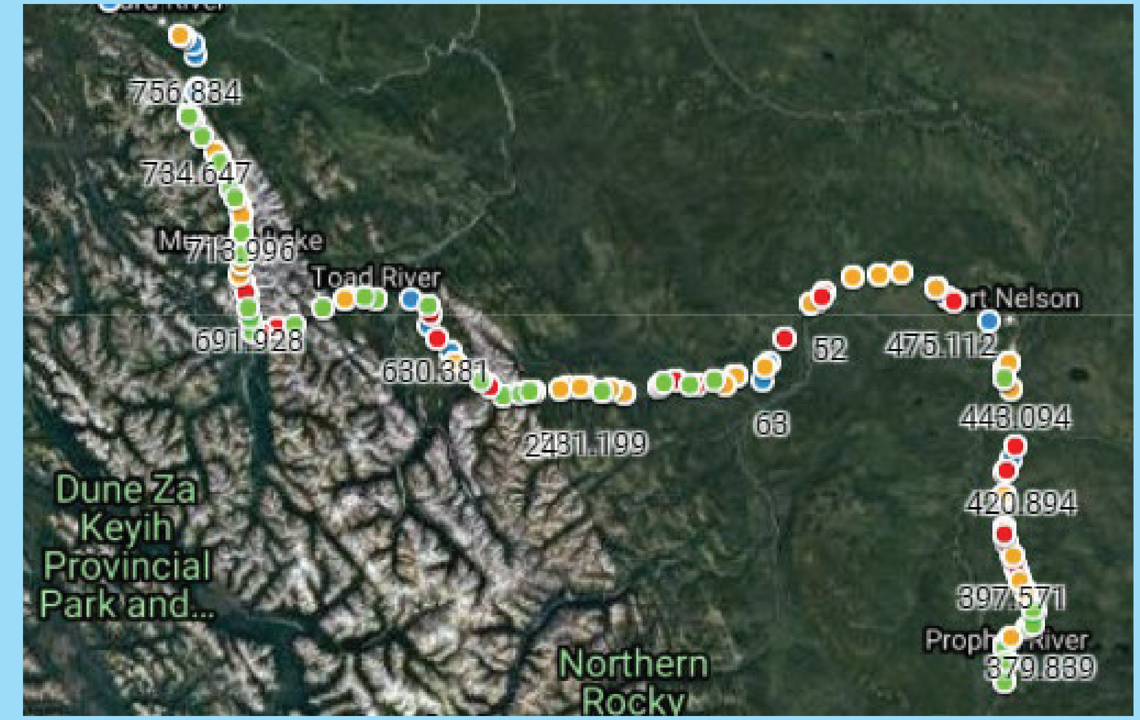
Transportation Association of Canada's (TAC) Asset Management Committee

Transportation Association of Canada's (TAC) Asset Management Committee represents Canada's largest pool of practicing asset managers and engineering consultants. TAC Asset Management Committee invited Tetra Tech to present the adopted Framework and results from the study in a webinar. The webinar was attended by asset managers from agencies and engineering consultants who were part of the asset management committee of TAC. Tetra Tech will also present the study and its result in the upcoming 2021 TAC Annual Conference & Exhibition.

Analyzing/Prioritizing Adaptation Options and Incorporating Assessment Results in Decision Making

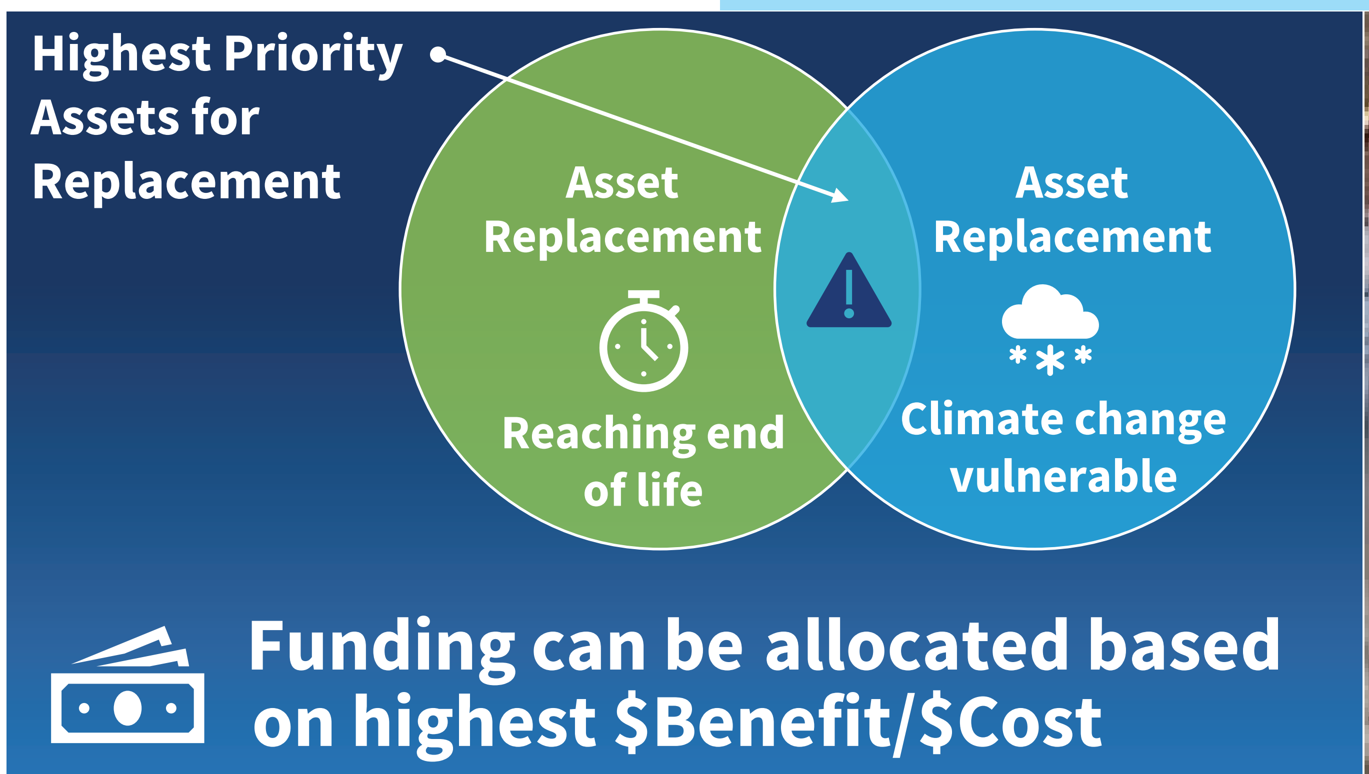
	Asset ID	Present Value $ Benefit	Present Value Net $Benefit	$Benefit/$Cost
	Culvert	$1,700,000	$1,511,000	9.0
	Culvert	$1,680,000	$1,431,000	6.8
	Geotechnical	$375,000	$313,000	6.0
	Bridge	$2,400,000	$1,993,000	5.9
	Geotechnical	$555,000	$459,000	5.8
	Geotechnical	$777,000	$638,000	5.6
	Culvert	$240,000	$197,000	5.6
	Geotechnical	$235,000	$190,000	5.2
	Culvert	$1,045,000	$827,000	4.8
	Bridge	$223,000	$170,000	4.2
	Culvert	$15,000	$11,000	3.6
	Culvert	$1,550,000	$1,094,000	3.4
	Geotechnical	$54,000	$38,000	3.4
	Bridge	$1,732,000	$1,191,000	3.2
	Geotechnical	$2,472,000	$1,675,000	3.1
	Geotechnical	$722,000	$489,000	3.1
	Culvert	$114,000	$76,000	3.0
	Geotechnical	$60,000	$40,000	3.0
	Culvert	$2,015,000	$1,295,000	2.8
	Bridge	$267,000	$172,000	2.8
	Culvert	$450,000	$288,000	2.8
	Culvert	$3,152,000	$1,940,000	2.6
	Geotechnical	$746,000	$459,000	2.6
	Bridge	$4,226,000	$2,536,000	2.5
	Geotechnical	$578,000	$337,000	2.4
	Geotechnical	$1,570,000	$887,000	2.3
	Culvert	$1,247,000	$705,000	2.3
	Geotechnical	$629,000	$315,000	2.0
	Culvert	$2,098,000	$1,049,000	2.0
	Pavements	$242,000	$121,000	2.0

Prioritizing Asset Replacement
Assessment of Infrastructure
Vulnerability



Priority Ranking based on $Benefit/$Cost

- ✓ Monetization of Corridor Assets
- ✓ Asset Replacement Optimization
- ✓ More Informed Decision Making



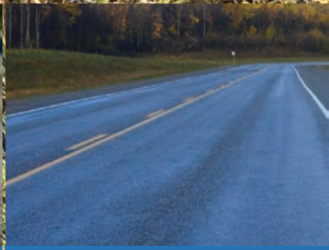
Assets Scheduled for Project Level Assessment Funding

Bridges

Culverts

Geotechnical Assets

Road Safety (accidents)



Pavements

Incorporate Assessment Results in Decision Making

Full Transportation Corridor Asset Condition Assessment

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