Transport Canada | Transports Canada

Transportation Asset Risk Assessment initiative: Climate Risk Assessment Tools and Frameworks for the Transportation Sector

Transport Canada Adaptation Webinar Series
Monday, March 22nd, 2021

Sophie Donoghue
Research Officer, Transportation Asset Risk Assessment (TARA) initiative,
Transport Canada

Gary St. Michel, P.Eng
Technical lead for Tetra Tech's Vancouver Asset Management group
Presenting on behalf of Public Services and Procurement Canada

Vincent Leys, MSc, P.Eng, PMP
Senior Coastal Engineer for CBCL Consulting
Presenting on behalf of TC Atlantic Region

Megan Roche, BSc
Climate Change and Environmental Analyst, Calgary Airport Authority
Presenting on behalf of Calgary Airport Authority

Introduction to the TARA initiative

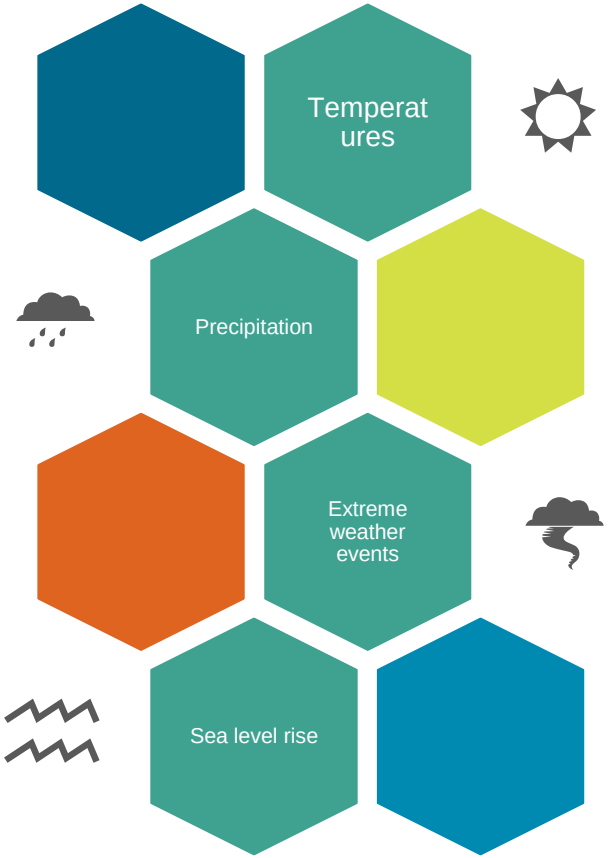
Michael Daudlin, Policy/Economic Officer

March 2021

The Changing Climate

Impacts associated with climate change and extreme weather are **disrupting** the movement of both freight and people, and **increasing costs** within the transportation sector. These impacts are projected to **intensify** in the future.

TC's **Climate Change Adaptation and Planning** team supports efforts to help the transportation sector **adapt and build resiliency** to this changing climate.



Transportation Assets Risk Assessment initiative (TARA)

OBJECTIVE

- Aims to better understand climate risks to federally-owned transportation infrastructure and potential adaptation solutions that could be employed.

FUNDING

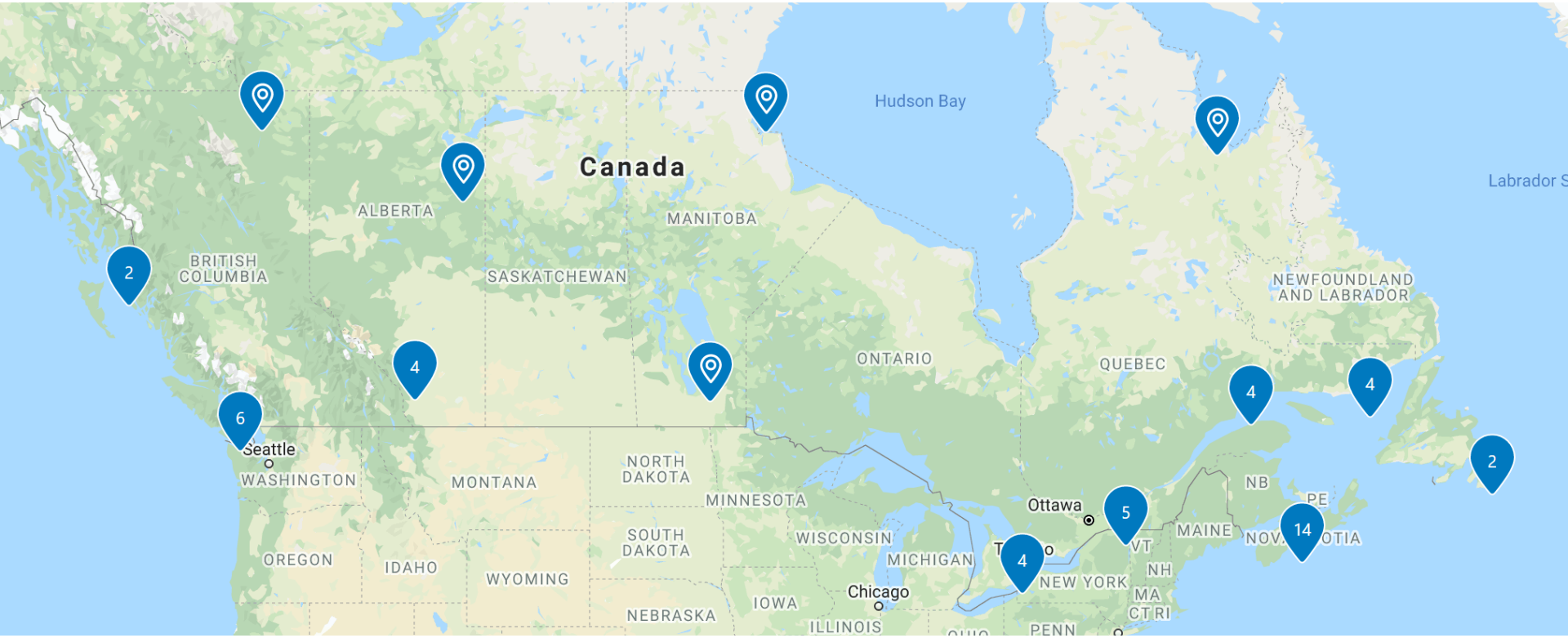
- Established 2017
- $16.35M over five years (2017-2022)

ELIGIBLE PROJECTS

- Full climate risk assessment
- Subcomponents of a climate risk assessment
- Research projects

TARA projects to date

50 assets
9 provinces
Surface, Air, Marine



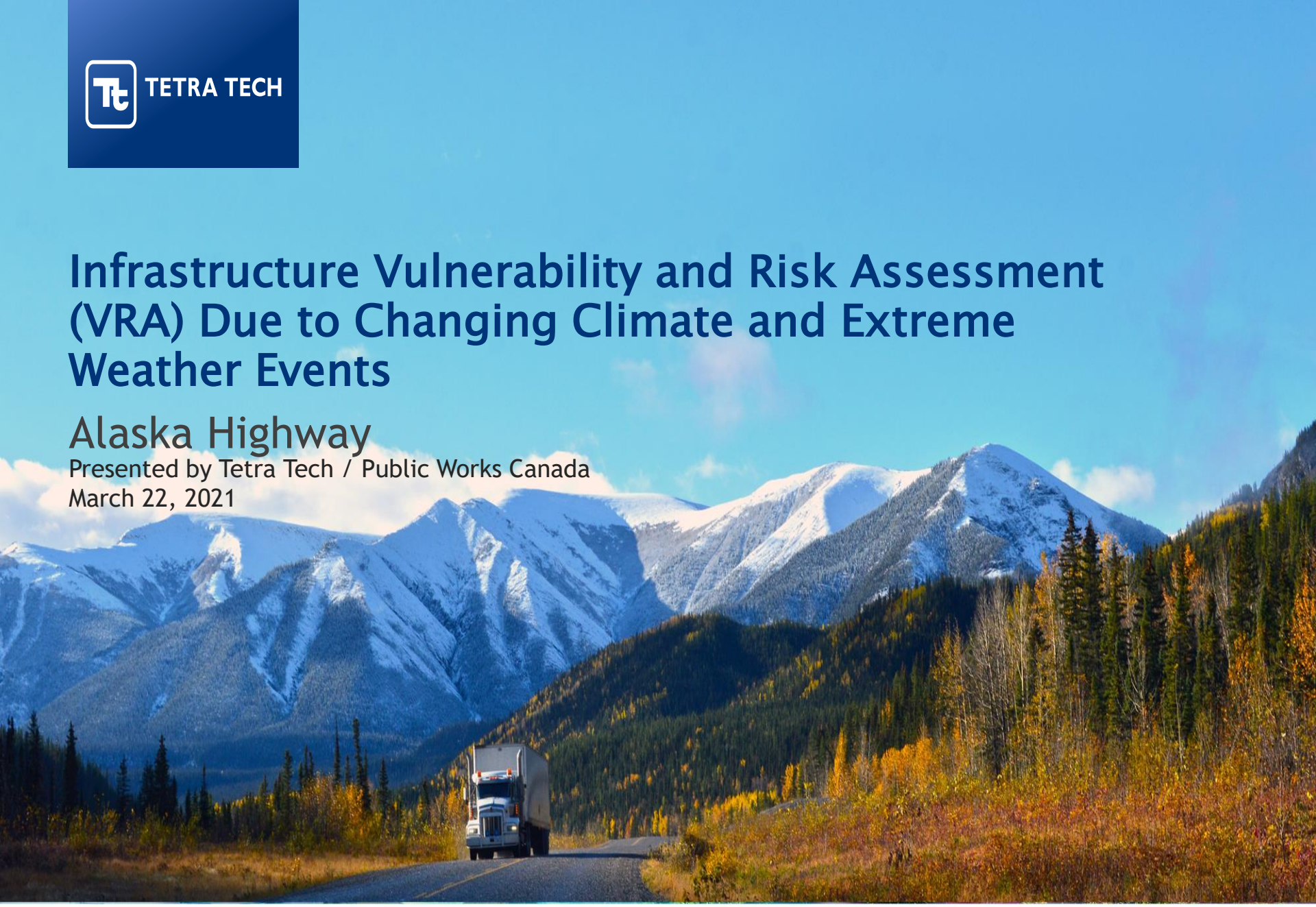
Webinar goals

- **Build capacity** on the use of climate risk assessment tools and frameworks
- **Share knowledge** from TARA projects with broader transportation sector to spur adaptation action
- **Grow peer-to-peer networks** to facilitate the exchange of experiences, lessons-learned, and best practices

Infrastructure Vulnerability and Risk Assessment (VRA) Due to Changing Climate and Extreme Weather Events

Alaska Highway

Presented by Tetra Tech / Public Works Canada
March 22, 2021



Presentation Outline

- Analysis Concept
- US Army Corp of Engineers – Risk Based Assessment
- FHWA Framework - Vulnerability Assessment and Adaptation Framework (FHWA 2017)
- Stepping through the Framework
- Applicability to Other Transportation Infrastructure Assets

Concept → $Benefit Must Justify Cost of Climate Adaptation

Added Resiliency has a Cost

But it reduces $Risk → $Benefit

Adaptive resilience can be justified **if**

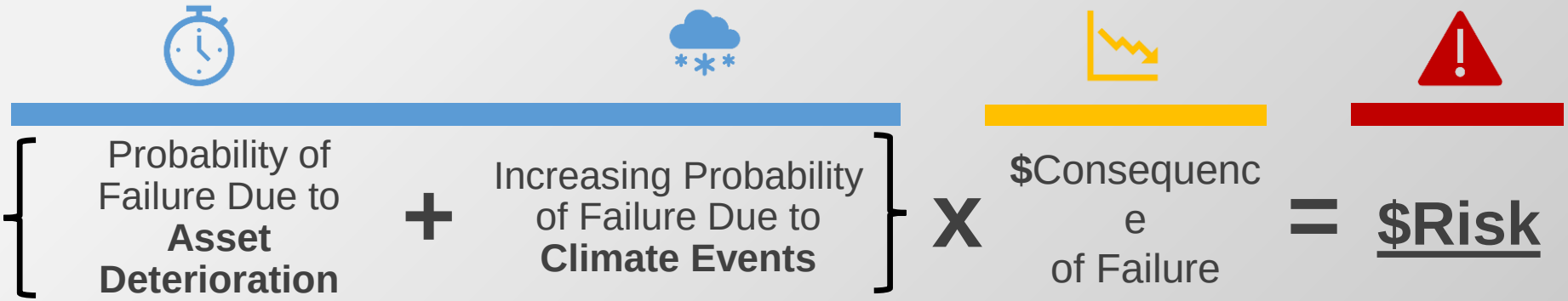
$Benefit **/** Cost $\geq$ 1

or

$Benefit **–** Cost $\geq$ 0

} **Benefit Cost Analysis (BCA)**

VRA Project Monetizing Risk



US Army Corps of Engineering - EC 1110-2-6062

Risk and Reliability Engineering for Major Rehabilitation Studies

(Asset Deterioration)

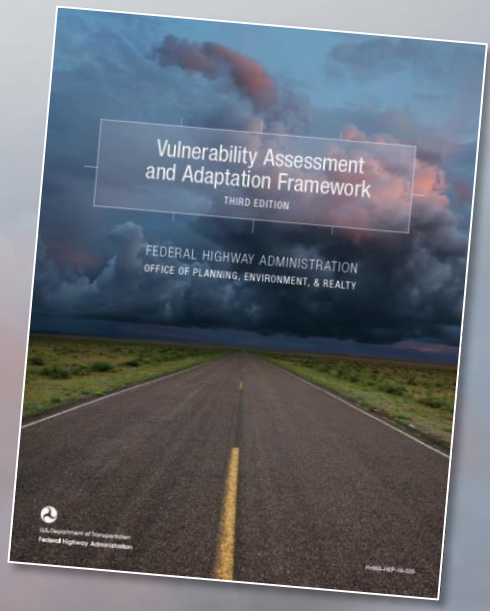
$Risk = PUP x $Consequences

Vulnerability Assessment and Adaptation Framework (FHWA, 2017)

- Step 1: Articulate Objectives and Scope **(Terms of Reference)**
- Step 2: Obtaining Asset Data **(Existing Historic Data)**
- **Step 3: Obtaining Climate Data**
- **Step 4: Assessment of Vulnerability**
- **Step 5: Identify, Analyze and Prioritize Adaptation Options**

Benefit Cost Analysis

- **Step 6: Incorporate Assessment Results in Decision Making**
- Step 7: Monitor and Revisit

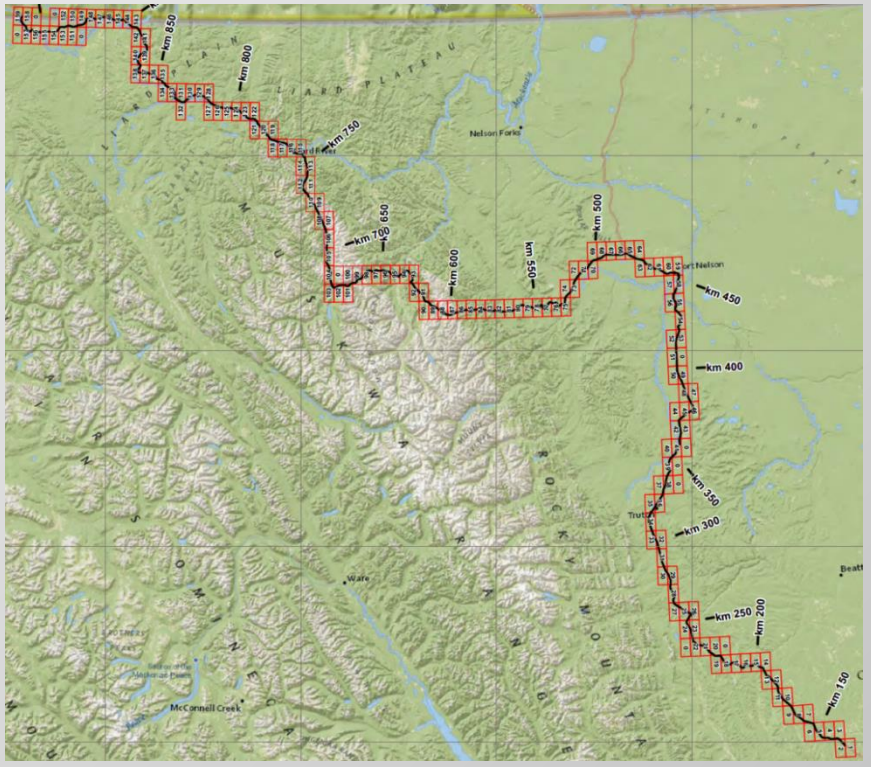


Stepping through the Framework

Step 3: Obtaining Climate Data
Analysis of Projected Climate Change Data

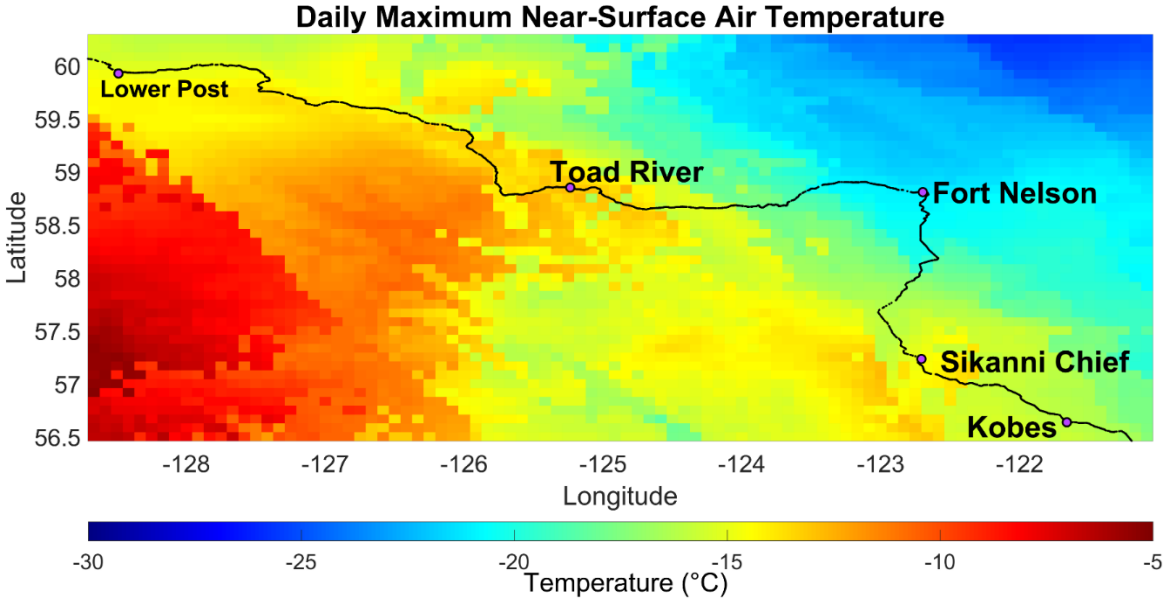
Approach:

- Direct download of modelled climate change projections to 2098
  - Daily max/min air temperature
  - Daily precipitation flux (per unit area)
- 170 grid cells along Alaska Hwy between Km 133 and Km 967
- Statistical analysis done for each grid cell to produce climate parameters relevant to asset management for three future scenarios:
  - Average Climate Change (mean)
  - Middling Climate Change (75th percentile)
  - Extreme Climate Change (90th percentile)



Step 3: Obtaining Climate Data
Model Ensemble for Western North America Region

- 12 climate models most applicable to the region
- Moderate (RCP4.5) and high (RCP8.5) future emissions scenarios
- 24 total data series per grid cell
- 670 million data points



Step 3: Obtaining Climate Data
Climate Change Parameters

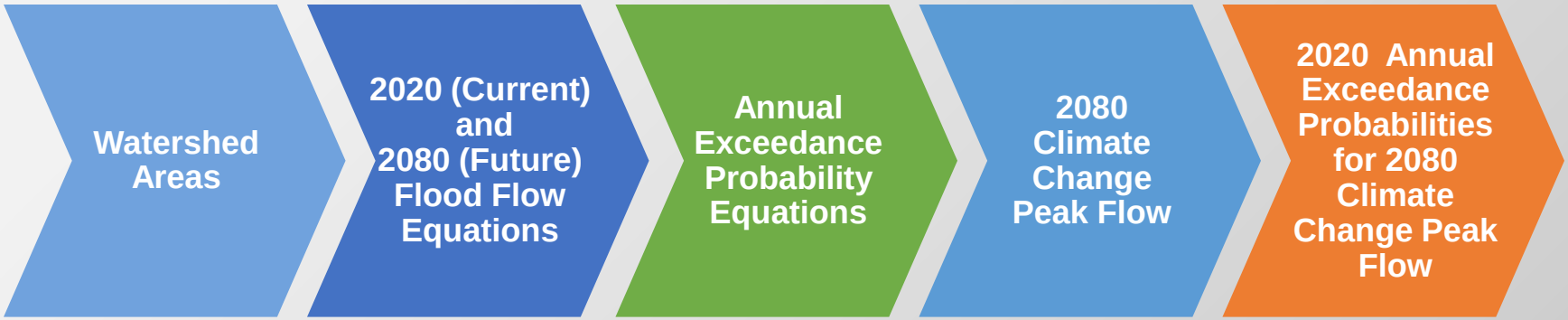
- Various engineering-related climate parameters were determined statistically from the ensemble data, including:
  - Extreme daily precipitation
  - Extreme daily and annual snowfall
  - Annual freeze-thaw cycles
- Assessed change from baseline to horizon years (2050 and 2080) to provide short- and long-term asset performance and risk projections within each section of highway

Grid Cell	Lat	Lon	Hwy Kms		Max 3-Day Precipitation (Annual) [mm]												
					2020 (Baseline)	2050						2080					
			Start	End	Mean	Mean	Change	75th	Change	90th	Change	Mean	Change	75th	Change	90th	Change
1	56.5417	-121.4583	133.28	133.30	47	53	+6	62	+15	79	+32	54	+7	65	+18	82	+35
2	56.5417	-121.5417	133.30	137.79	47	53	+6	62	+15	79	+32	54	+7	65	+18	82	+35
3	56.6250	-121.5417	137.79	140.24	46	52	+6	62	+15	78	+32	54	+8	64	+17	81	+35
4	56.6250	-121.6250	140.24	145.54	47	53	+6	62	+15	79	+32	54	+7	64	+17	82	+35
5	56.6250	-121.7083	145.54	154.80	47	53	+5	62	+15	79	+32	54	+7	65	+18	82	+35
6	56.6250	-121.7917	154.80	156.73	47	52	+5	61	+15	78	+31	54	+7	64	+17	81	+34

Step 4: Assessment of Vulnerability
Drainage Assets

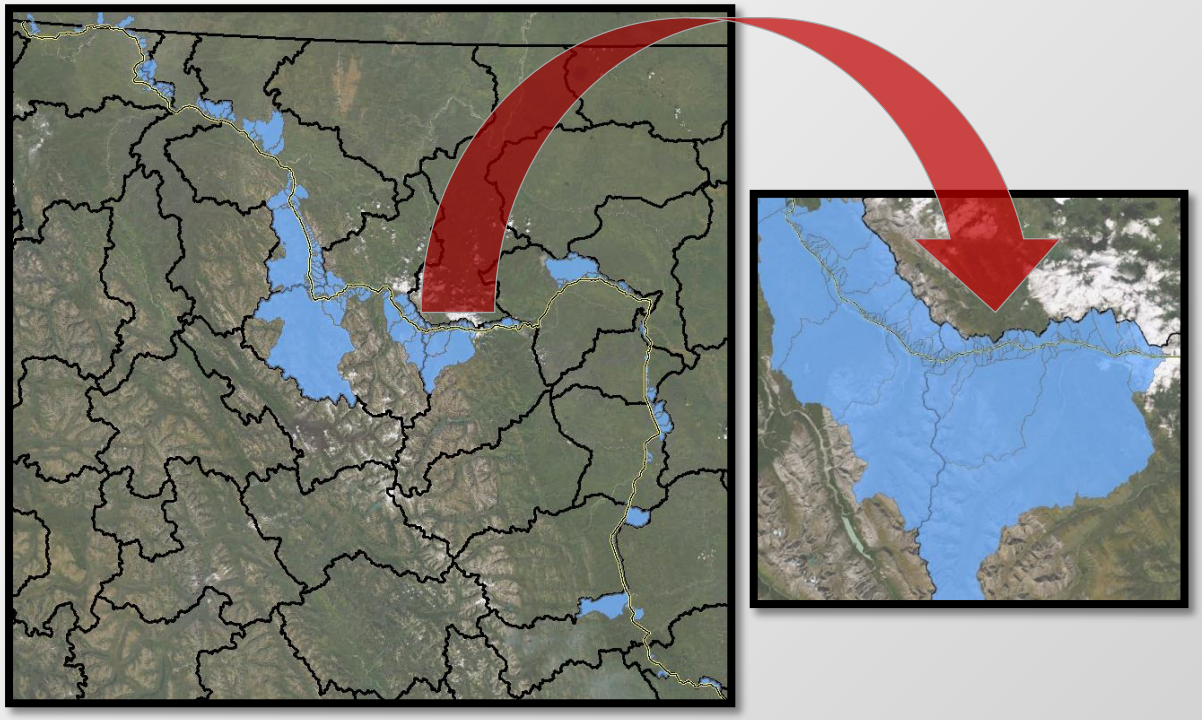
Step 4: Assessment of Vulnerability

Watershed Areas to Annual Exceedance Probabilities and Climate Change Rate



- Watersheds delineated in ArcGIS
- Flood Flows Estimated from Watershed Area for 2-Year to 1000-Year Return Period
- Equation to predict Annual Exceedance Probability from 2020 and 2080 Failure Flows
- 2080 Climate Change Peak Flow Calculated for Adaptation Options for 100-Year to 1000-Year Return Period
- Site specific Annual Exceedance Probabilities is 2020 calculated for all adaption treatments for the 2080 climate change peak flow

Step 4: Assessment of Vulnerability
Hydrological Analysis: Watershed Delineations



Typical Watershed Areas in ArcGIS

Watersheds delineated for ~ 500 Bridges and Culverts utilizing 1:50,000 NTS datasets

Step 4: Assessment of Vulnerability
Hydrological Analysis: Development of Flood Flows

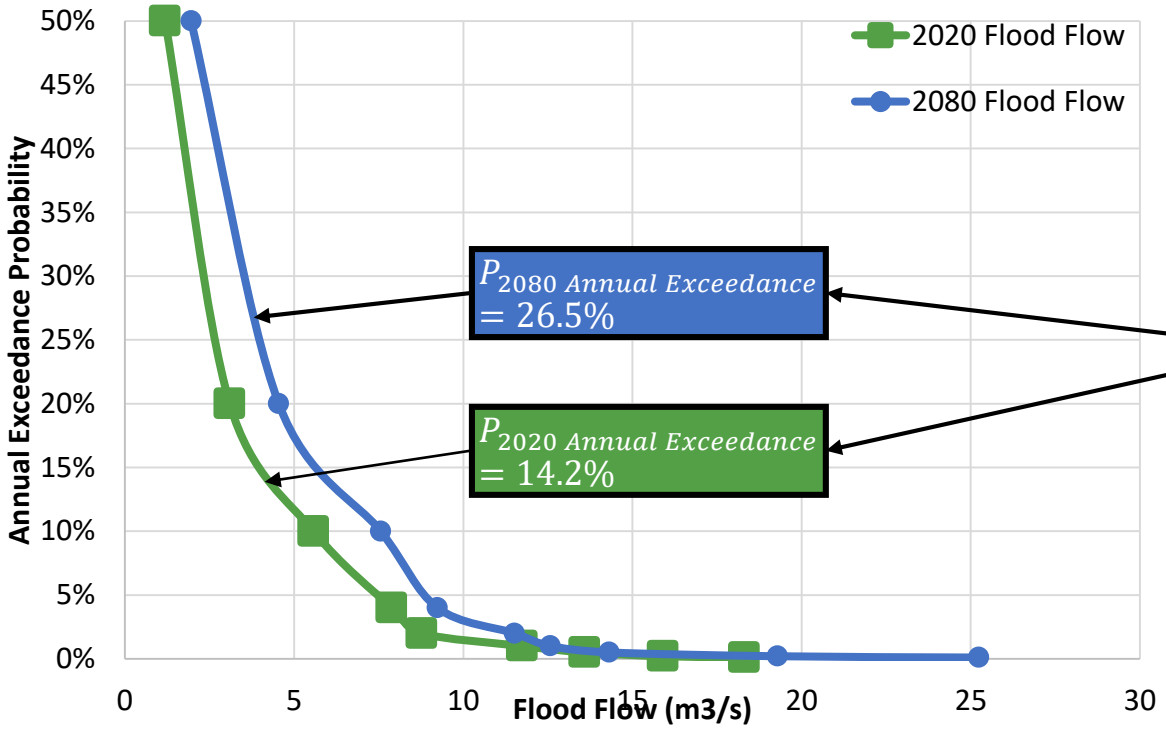
Flood flow magnitudes were estimated for present day and all future years for each crossing

Return Period:	2020 Present Day Flood Flows (m^3/s)									2080 Present Day Flood Flows (m^3/s)								
Annual Exceedance Probability:	Q2	Q5	Q10	Q25	Q50	Q100	Q200	Q500	Q1000	Q2	Q5	Q10	Q25	Q50	Q100	Q200	Q500	Q1000
	0.5	0.2	0.1	0.04	0.02	0.01	0.005	0.002	0.001	0.5	0.2	0.1	0.04	0.02	0.01	0.005	0.002	0.001
KM 237.2	0.83	1.31	1.79	2.01	2.64	3.27	3.89	4.89	5.61	0.98	1.59	1.97	2.66	3.49	4.19	5.03	5.95	6.28
KM 238.6	1.50	2.37	3.23	3.64	4.76	5.90	7.02	8.81	10.09	1.77	2.88	3.56	4.81	6.29	7.55	9.06	10.71	11.30
KM 241.8	0.16	0.26	0.36	0.40	0.53	0.66	0.78	0.99	1.13	0.20	0.32	0.39	0.53	0.70	0.84	1.01	1.20	1.27
KM 242.6	0.66	1.04	1.41	1.60	2.09	2.59	3.09	3.88	4.45	0.78	1.26	1.56	2.11	2.77	3.32	3.99	4.72	4.99
KM 249.7	0.15	0.24	0.32	0.36	0.48	0.59	0.71	0.89	1.03	0.18	0.29	0.36	0.48	0.63	0.76	0.92	1.09	1.15
KM 253.1	0.90	1.43	1.95	2.20	2.88	3.57	4.25	5.34	6.11	1.07	1.74	2.15	2.90	3.80	4.56	5.48	6.49	6.84
KM 267.7	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.12	0.13	0.02	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.15
KM 267.9	0.07	0.11	0.15	0.17	0.23	0.28	0.34	0.43	0.49	0.08	0.14	0.17	0.23	0.30	0.37	0.44	0.52	0.55

Step 4: Assessment of Vulnerability

Watershed Areas to Annual Exceedance Probabilities and Climate Change Rate

The Annual Exceedance Probabilities were calculated by developing these curves at all sites separately



Annual Exceedance Probability will increase from 14% to 27% for the example culvert

Step 4: Assessment of Vulnerability
Geotechnical Assets

Step 4: Assessment of Vulnerability
Geotechnical Assets

- Total of 74 geotechnical assets have been identified based on historic information, georeferenced imagery, published data and other studies along the Alaska Highway.
- Four types of geotechnical assets:
  - Fill Slope
  - Cut Slope
  - Rock Slope
  - Debris Flow

Step 4: Assessment of Vulnerability
Geotechnical Assets

Each geotechnical asset was assessed for two conditions:

- Present condition
- Future condition due to climate change

The **present condition** of each asset was assigned with a probability of unsatisfactory performance based on:

- Risk assessment from available data
- The Delphi method

Step 4: Assessment of Vulnerability
Geotechnical Assets

Climate stressors were used to assess the **future condition** of the geotechnical assets, which include:

- Precipitation
  (Intense – Maximum 3-day period and Heavy >10 mm/day)
- Freeze-Thaw Cycles
- Flooding
- Snowfall

The mean (in terms of percent change) of the predicated climate stressor was considered to increase the annual probability of failure of the geotechnical asset due to climate change

Step 5: Identify, Analyze and Prioritize Adaptation Options

Drainage Asset Adaptation Treatments

Strategies	Adaptation Treatments
CLIMATE CHANGE ADAPTATION STRATEGIES	▪ **Open-Cut Replacement** – Culvert Upgrade with 100 Year flood flow – Culvert Upgrade with 200 Year flood flow – Culvert Upgrade with 500 Year flood flow – Culvert Upgrade with 1000 Year flood flow ▪ **Trenchless Treatments** – Culvert Upgrade with 100 Year flood flow – Culvert Upgrade with 200 Year flood flow – Culvert Upgrade with 500 Year flood flow – Culvert Upgrade with 1000 Year flood flow
	▪ **Bridge-Culvert Treatments** – Culvert Upgrade with 100 Year flood flow – Culvert Upgrade with 200 Year flood flow – Culvert Upgrade with 500 Year flood flow – Culvert Upgrade with 1000 Year flood flow
END OF SERVICE LIFE DUE TO EFFECTIVE AGE	▪ **Culvert Replacement** – Minimum Construction Cost of Open-Cut and Trenchless Method
	▪ **Culvert Replacement Bridge-Culvert**

Step 5: Identify, Analyze and Prioritize Adaptation Options

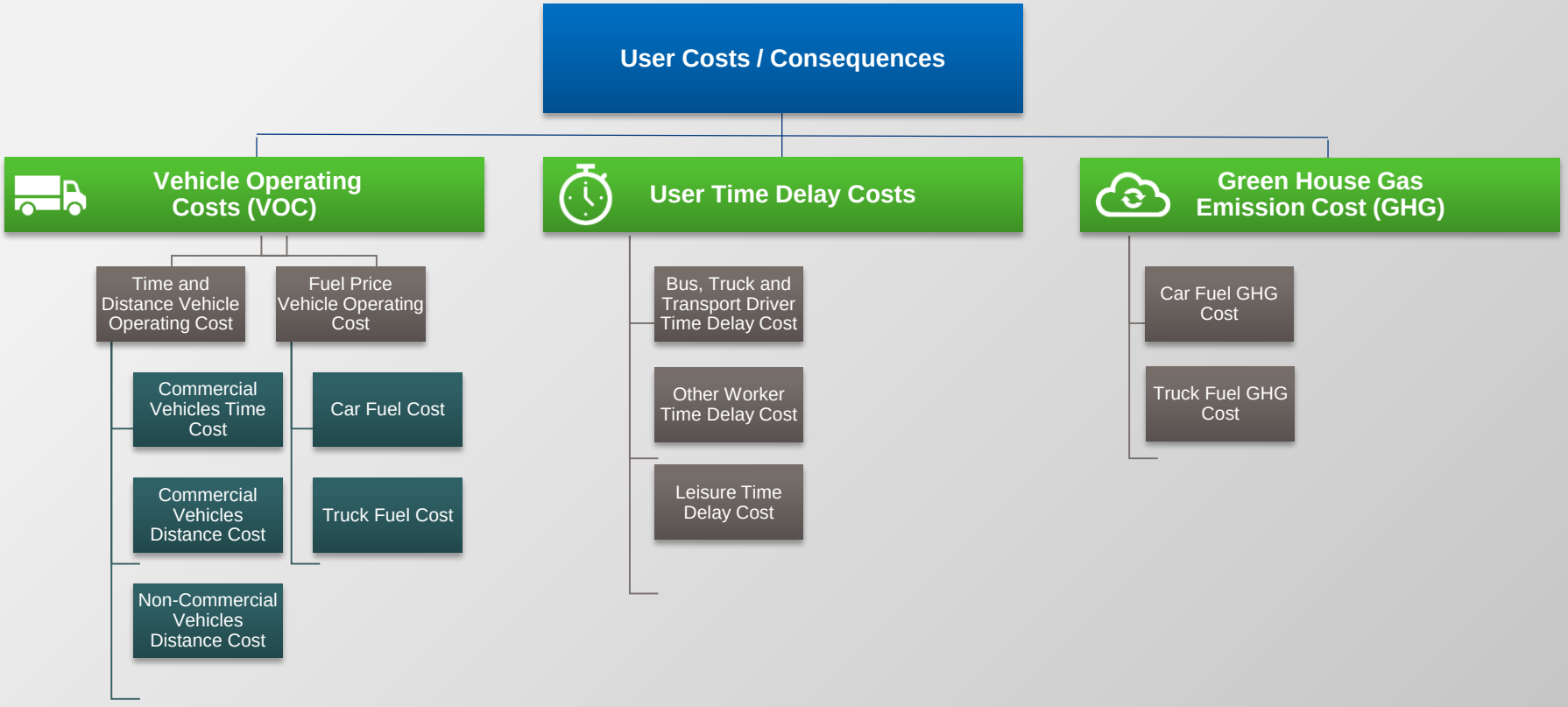
Geotechnical Asset Adaptation Treatments

Mitigation strategies were developed for each geotechnical asset ranged from "Do Nothing" to 2-3 potential treatments

Asset Type	Treatment
Cut Slope / Fill Slope	Regrading – flatten the slope
Cut Slope / Fill Slope	Toe buttress
Cut Slope / Fill Slope	Hydroseeding / Vegetation
Cut Slope / Fill Slope and Bank Erosion	Retaining Structures
Cut Slope / Fill Slope	Soil Nails
Fill Slope	Lightweight Fill (EPS)
Rock Slope	Rock Mesh
Rock Slope	Barriers – Rock Fall
Rock Slope	Rock Bolt
Bank Erosion	Riprap Protection
Bank Erosion and Flooding	Elevate Roadway with Riprap Protection
Debris Flow	Basins – Debris Flow
Debris Flow	Highway Realignment

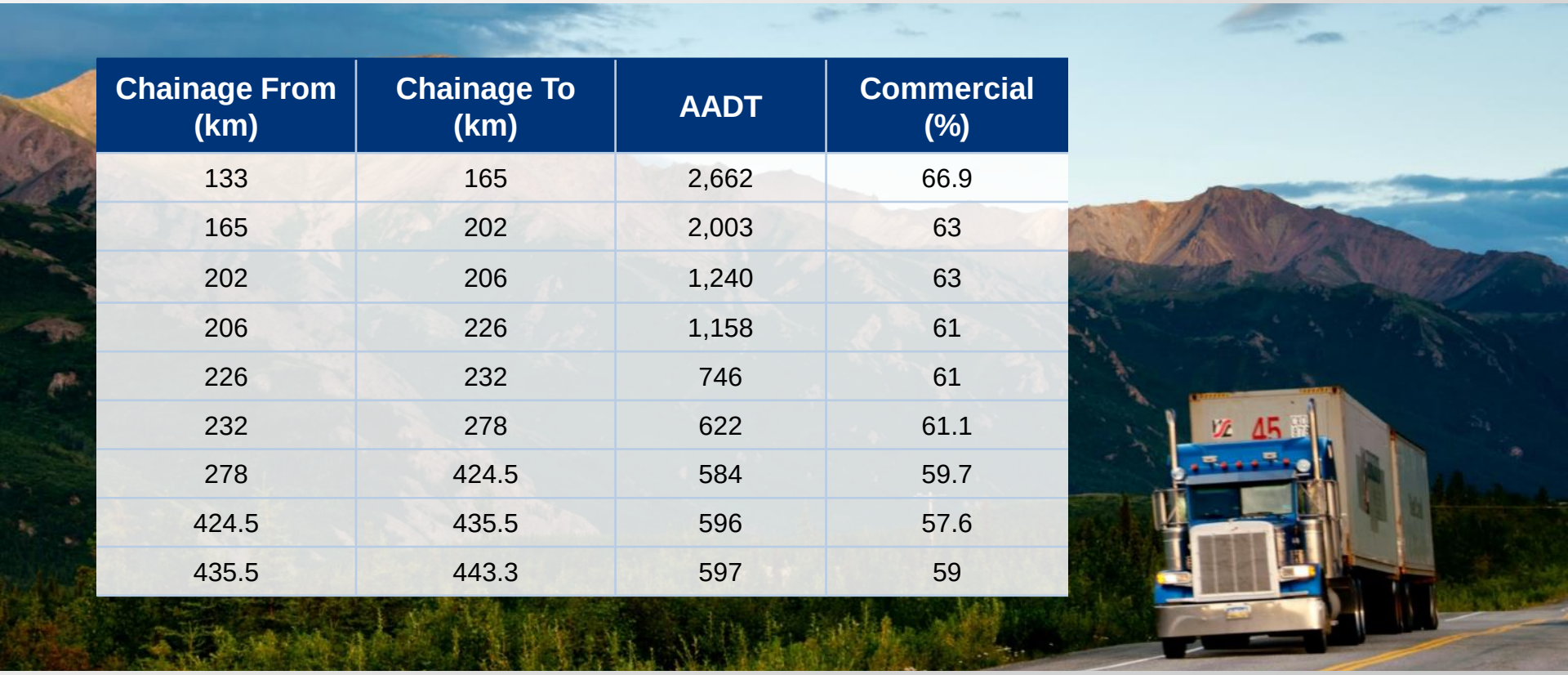
Step 5: Identify, Analyze and Prioritize Adaptation Options

Calculating User Costs / Consequences



Step 5: Analyze and Prioritize Adaptation Options
High Percentage of Commercial Traffic

Chainage From (km)	Chainage To (km)	AADT	Commercial (%)
133	165	2,662	66.9
165	202	2,003	63
202	206	1,240	63
206	226	1,158	61
226	232	746	61
232	278	622	61.1
278	424.5	584	59.7
424.5	435.5	596	57.6
435.5	443.3	597	59



Step 5: Analyze and Prioritize Adaptation Options
$Consequence of Asset Failure

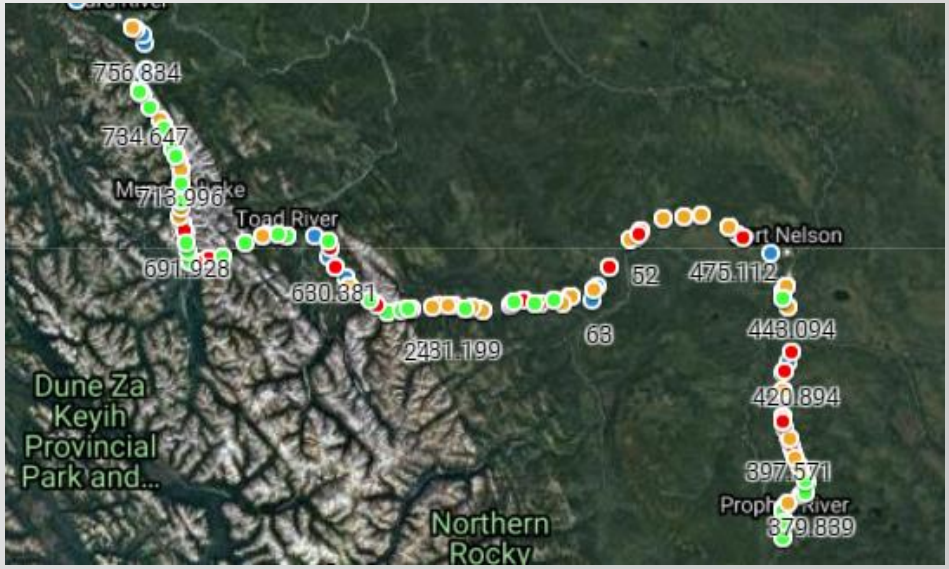
Asset Failure = ⬆ $$

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

Step 5: Analyze and Prioritize Adaptation Options

Prioritizing Asset Replacement Assessment of Infrastructure Vulnerability

	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



Priority Ranking based on $Benefit/$Cost

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

Step 6: Incorporate Assessment Results in Decision Making
Assets Scheduled for Project Level Assessment Funding

Funding can be allocated based on highest $Benefit/$Cost

Step 6: Incorporate Assessment Results in Decision Making
Full Transportation Corridor Asset Condition Assessment

Bridges

Culverts

Geotechnical Assets

Road Safety (accidents)

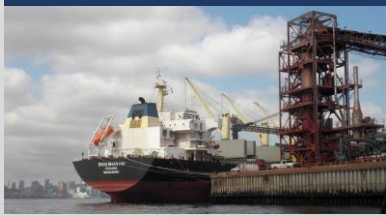
Pavements

Funding allocation can be equitably compared across all transportation assets to provide a basis for decision making

Applicability to Other Transportation Infrastructure Assets

- ✓ Provides a means for monetizing $Risk/$Benefit
- ✓ Justifies Capital Expenditure decision making
- ✓ Applicable to Climate Events, Geo-hazards, Avalanches and Seismic events
- ✓ Can be applied to virtually any transportation asset network

Ports



Airports

Rail Systems

The Project Team

Paul Frame, P.Eng.
Chief Engineer, Alaska Highway
Government of Canada

Gary St. Michel, P.Eng.
Principal Specialist – Pavement Management

Albert Leung, M.A.Sc., P.Eng., PE
Hydrotechnical Engineer

David Moschini, P.Eng.
Senior Civil/Water Resources Engineer

Travis Miguez, B.Sc., P.Met.
Meteorology & Air Dispersion Specialist

Afzal Waseem, M.A.Sc., P.Eng.
Pavements and Asset Management Engineer

Gordon Fung, P.Eng.
Senior Geotechnical Engineer

Chironjeev Kanjilal, B.Sc., B.Mus.
Scientist

Mark Aylward-Nally, P.Eng.
Hydrotechnical Engineer

Matt Keleher, B.Eng., E.I.T.
Transportation Engineer

TETRA TECH

Questions?