TETRA TECH

CULVERT INSPECTION TO ASSET MANAGEMENT:

Climate-Change Informed Capital Works Program

Alaska Highway

Presented by: Tetra Tech Canada Inc.

PROJECT OUTLINE

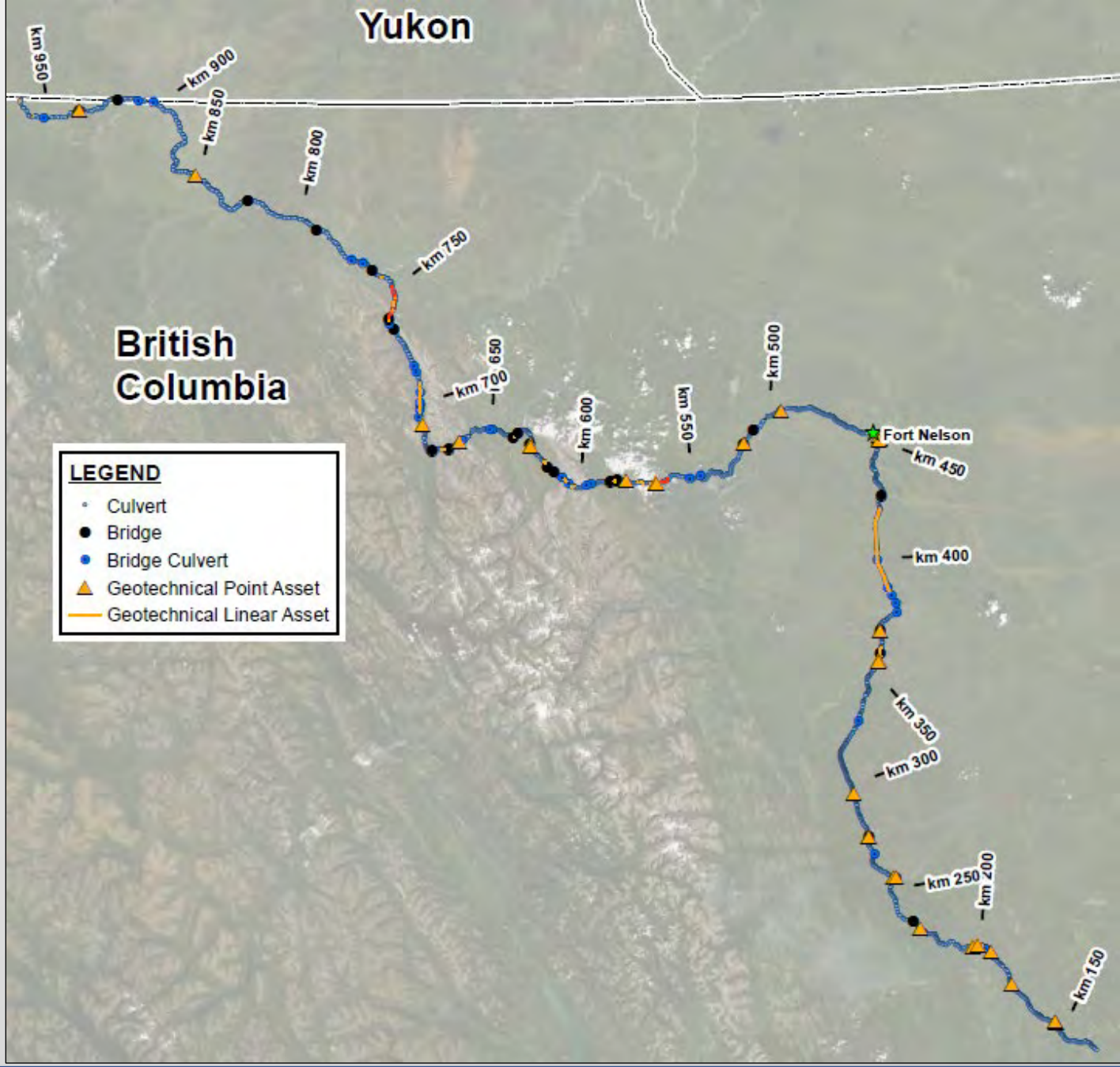
- Objective and Scope
- Inventory and Condition Data
- Predictive Modelling
  - Climate Data and Hydrologic Analysis
  - Vulnerability Assessment
  - Condition Deterioration
- Treatments
- Analysis
- Capital Works Program

ALASKA HIGHWAY

- Alaska Highway stretches **2,450 kilometres**
- **80% (around 1,960 km)** of the Alaska Highway is in Canada.

Project Scope

- **835 km** in British Columbia
- **2162 Culverts**
- **≈$500 Million** culvert replacement value



PROJECT SCOPE

1. Develop a 20-year capital works program prioritizing culvert replacements and adaptation.
    a) Utilize 2021 culvert inventory and condition inspection data
    b) Identify culverts vulnerable to climate and weather-related impacts
2. Integrate with the existing 20-year Strategic Asset Management Program (SAMP)
3. The capital work program will be used to prepare a future standalone tender or packaged with other reconstruction/realignment projects

WHAT'S A STRATEGIC ASSET MANAGEMENT PLAN (SAMP)

- **ISO 55000 provides the following definition of a SAMP:**
  - Addresses **organizational objectives**
  - Framework to convert **organizational objectives** to the **asset management** plan
- **2020 Alaska Highway Strategic Asset Management Plan**
  - **Assets/Strategies:** Safety improvements, Roads (Geometry), Pavements, Bridges, Bridge-Culverts
  - **Performance Indicators:** Monetized cost over benefit in reduced risk ratio (BCR)
  - **Organization's strategy:** Equitable cross-asset resource allocation
- This study incorporates all culverts

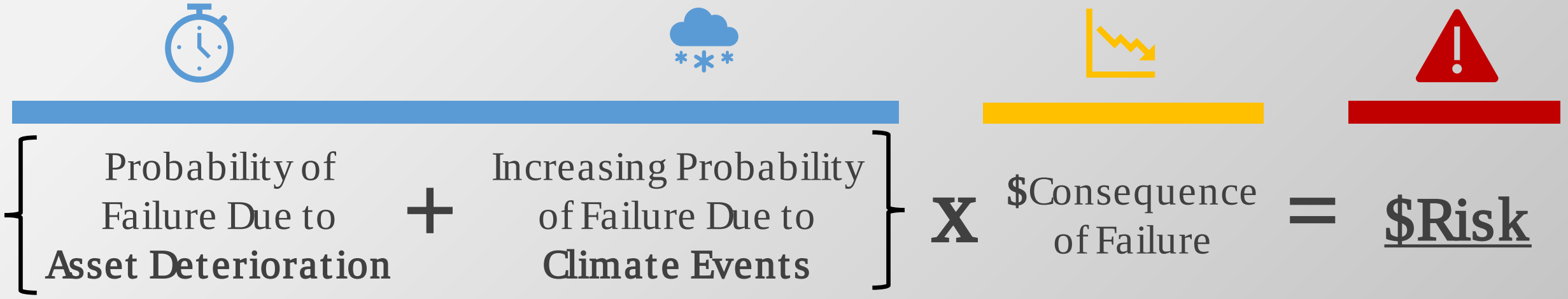
ASSET MANAGEMENT HIERARCHY

- Roadmap for implementation
- Identifies the AM objectives
- Defining performance objectives
- Establishes the AM framework

- Life Cycle Cost Analysis
- Long term plan for assets
- Timelines, resources, and funding requirements to meet performance objectives

LEVEL OF SERVICE INDICATOR
Monetized $Risk

Asset management strategies are developed based on the risks identified. The strategies include maintaining, repairing, and upgrading the assets to reduce the risks associated with asset failure and resulting consequences.



$BENEFIT OF INFRASTRUCTURE IMPROVEMENT

$$BENEFITS = \sum(\$Risk\ without\ \textbf{Capital Improvement}) - \sum(\$Risk\ after\ \textbf{Capital Improvement})$$

Benefits in terms of Reduction in Risk of Consequences included:

- Physical damage
- Response and recovery
- Transportation services loss
- Environmental benefits

CONCEPT
$Benefit Must Justify Cost of $Risk Reduction

Reducing Risk has a Cost

Reduced $Risk → $Benefit

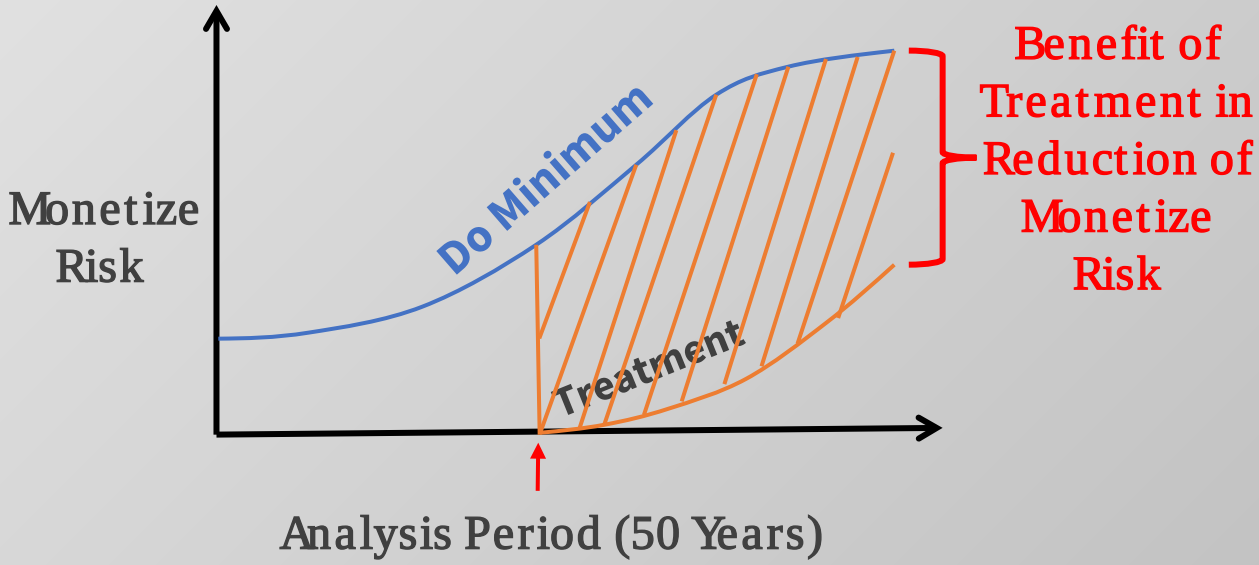
Added resilience can be justified if

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

or

$$\$Benefit - Cost \geq 0$$

Benefit Cost Analysis (BCA)



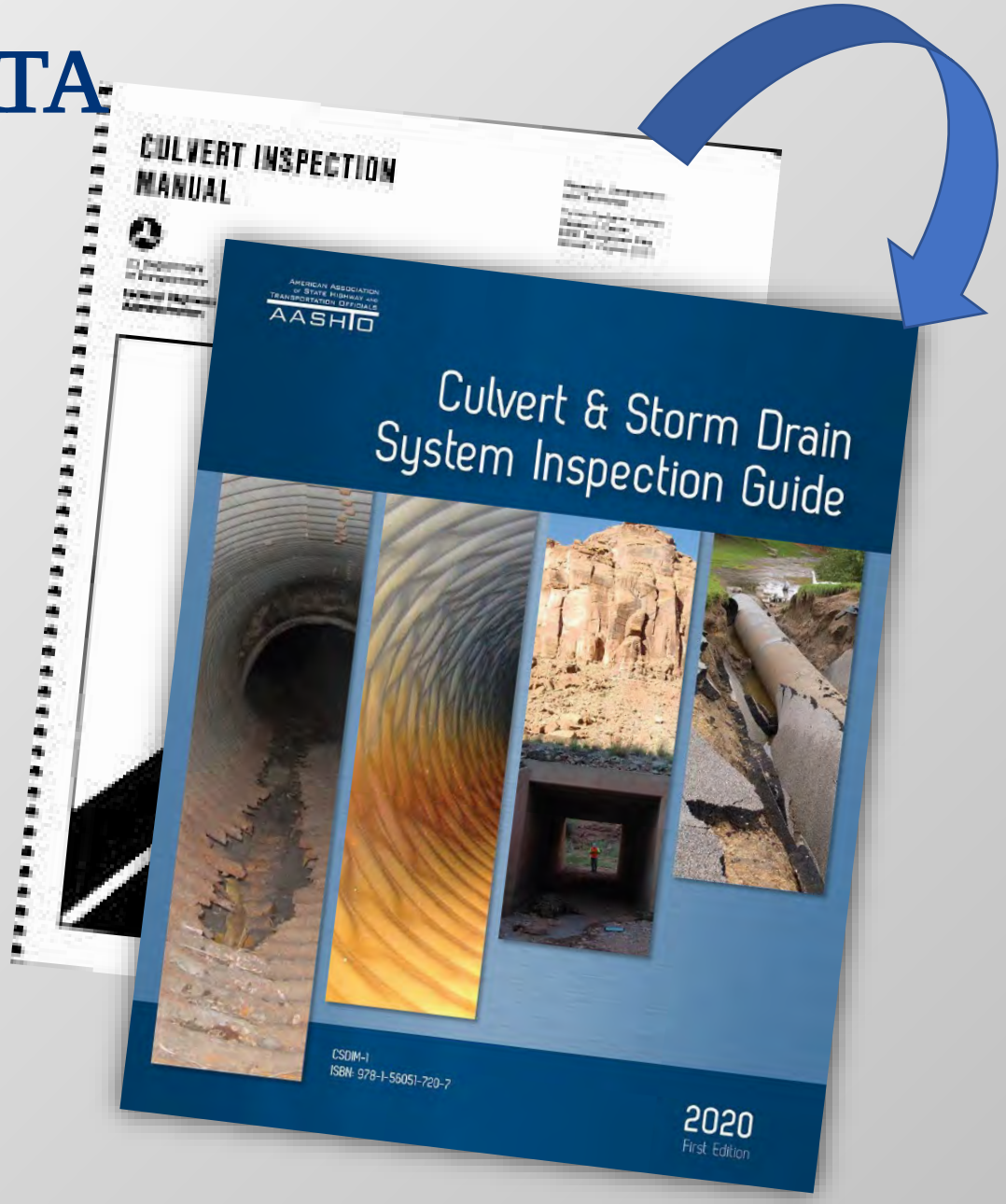
ASSET MANAGEMENT STEPS

1. Inventory
2. Condition
3. Current Status
4. Predictive Modelling
5. Treatments
6. Program Development

INVENTORY AND CONDITION DATA

Data Collection Criteria

- Alaska Highway culvert data collection criteria were developed based on:
  - AASHTO Culvert and Storm Drain System Inspection Guide (2020)
  - Review of the previous culvert inspections and agency requirements



INVENTORY AND CONDITION DATA

Culvert Inspection Data Types

- Culvert Inspection consists of the collection of two types of data:

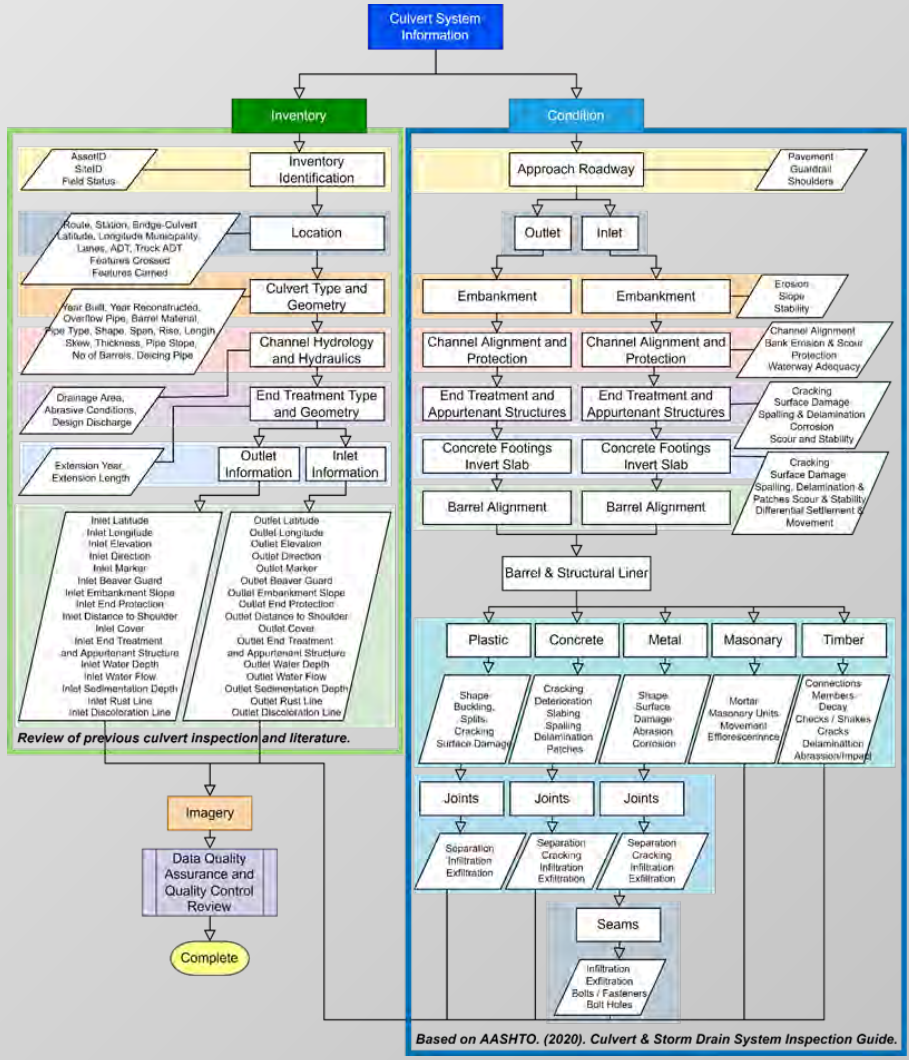
1. **Inventory:**

   The inspection involves verifying and updating the existing culvert database locations, culvert type, geometry, and inlet and outlet-specific information.

   Addition of new culverts, and gaps and removing non-existent culverts from the existing inventory.

2. **Condition:**

   The inspection consists of a visual assessment and condition rating of individual culvert components.



INVENTORY AND CONDITION DATA

Inventory

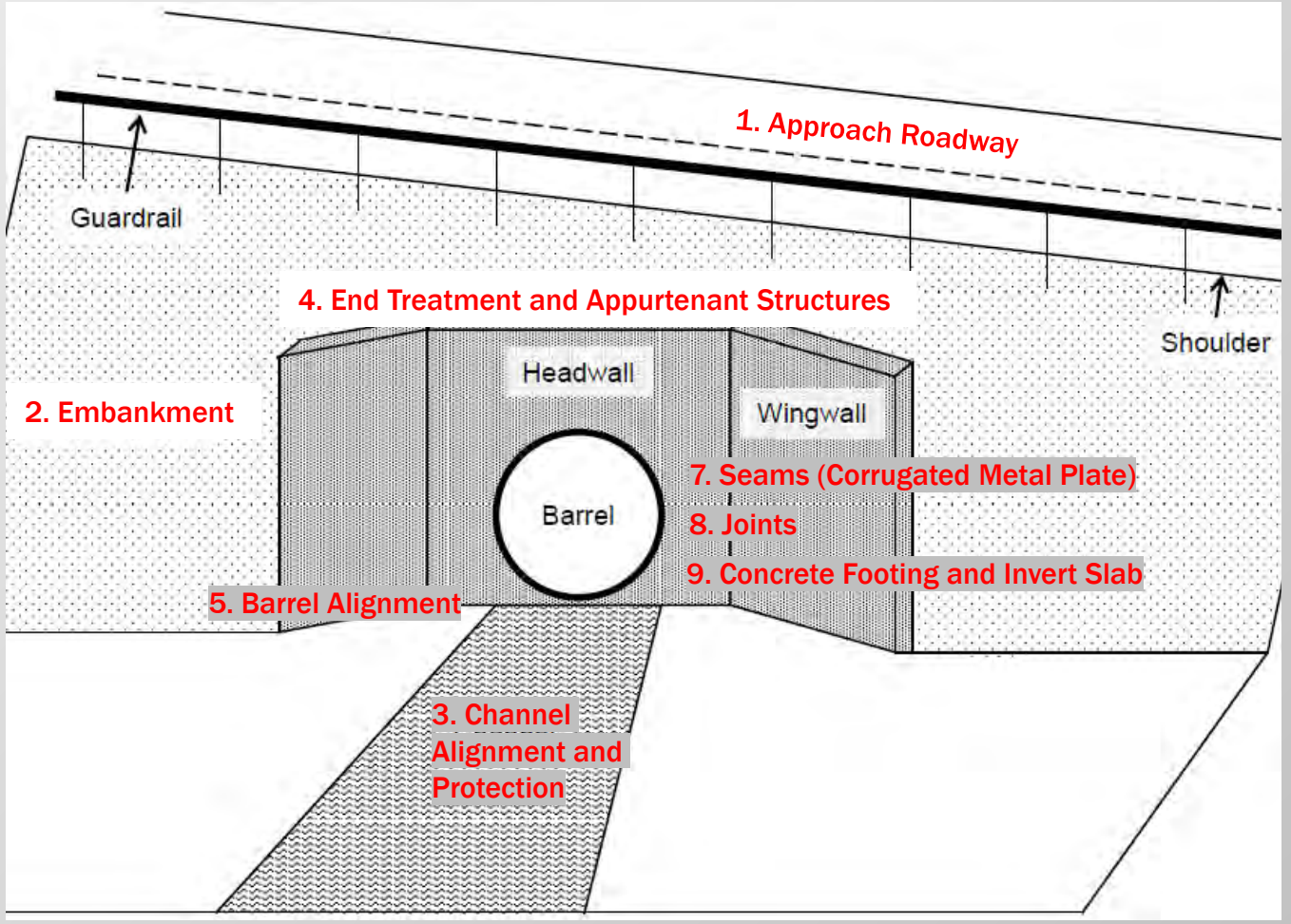
- Inventory
  - **Location**
    - Station, Center, Inlet and Outlet location (Longitude and Latitude), Lanes, Traffic
  - **Culvert Type and Geometry**
    - Overflow pipe, Barrel Material, Pipe Type, Shape, Span, Rise, Length, Skew (deg), Thickness, Pipe slope, Number of Barrels, Deicing Pipe
  - **Inlet and Outlet Information**
    - Latitude, Longitude, Elevation, Direction, Marker, Beaver Guard, Embankment Sideslope, End Protection, Distance to Shoulder (m), Inlet Cover (mm), End Treatment and Appurtenant Structure, Water Depth (%), Water, Sedimentation Depth (%), Rust Line (%), Discoloration Line (%), Remarks

INVENTORY AND CONDITION DATA

Condition Data

- Culvert Condition Components

No.	Culvert Component	Culvert Rated
1	Approach Roadway	All
2	Embankment	All
3	Channel Alignment and Protection	All
4	End Treatment and Appurtenant Structures	If Applicable
5	Barrel Alignment (Angle with Road Alignment)	All
6	Barrel Type (Corrugated Metal Barrel, Plastic Barrel, Timber Barrel, Concrete Barrel)	All
7	Seams (Corrugated Metal Plate)	If Applicable
8	Joints	If Applicable
9	Concrete Footing and Invert Slab	If Applicable



INVENTORY AND CONDITION DATA

Condition Rating System

Rating	Excellent	Good	Fair	Poor	Severe
Condition	New	Like new, with little or no deterioration, structural sound and functionally adequate	Some deterioration, but structurally sound and functionally adequate.	Significant deterioration and/or functional inadequacy, requiring maintenance or repair.	Very poor conditions that indicate possible imminent failure or failure which could threaten public safety
Action Needed	No action is recommended. Note in inspection report only.	No action is recommended. Note in inspection report only.	No immediate action is recommended, but more frequent inspection may be warranted. Maintenance personnel should be informed	Team Leader (Inspector) evaluates for corrective action and makes a recommendation in the inspection report.	Corrective action is required and urgent. Engineering evaluation is required to specify appropriate repair.

INVENTORY AND CONDITION DATA

Condition Rating System

1. Approach Roadway
2. Embankment
3. Channel Alignment and Protection
4. End Treatments and Appurtenant Structures
5. Concrete Footings and Invert Slabs
6. Barrel Alignment
7. Barrel & Structural Liner
   a) Plastic
   b) Concrete
   c) Metal
   d) Masonry
   e) Timber
8. Joints
9. Seams

Table 14: Seams (Corrugated Metal Plate) Rating

RATING	1 Excellent	2 Good	3 Fair	4 Poor	5 Severe
INFILTRATION / EXFILTRATION	New	No dents or other localized damage.	Small dents or impact damage to pipe wall or end section with no wall breaches.	Large dents or impact damage to pipe wall or end section with localized wall breaches, no more than one corrugation over circumferential length of 6 in.	Dents or damage that warrant engineering evaluation. Through-wall holes greater than one corrugation over a length more than 6 in., allowing unimpeded soil infiltration.
SEAM ALIGNMENT	New	No visible misalignment.	Slight cocked seams without cusp effect, but does not affect cross section shape.	Cocked seams such that it affects cross section shape. Cusped effect with local wall bending.	Cocked seams severely affecting cross-section section shape. Cusp effect with seam cracking. Seam capacity loss imminent.
SEAM BOLTS/ FASTENERS	New	No loose or missing bolts/fasteners.	Less than 5% loose or missing bolts in any seam.	5% to 15% of loose or missing bolts in any seam.	Greater than 15% loose or missing bolts in any seam
SEAM BOLT HOLES	New	No yielding or deformation of bolt holes. No wall prying due to bolt tipping.	Minor yielding of steel and/or cracking/splitting less than 1 in. long local to bolt holes. Minor corrosion developing around bolt holes or on bolts.	Yielding of steel and/or cracking/splitting 1 in. to 3 in. long local to bolt holes. Corrosion with section loss around bolt holes or on bolts.	Significant yield of steel at bolt holes. Cracking/splitting 3 in. or more local to bolt holes. Corrosion with section loss around bolt hole or on bolts.
DISTORTION	New	warping, crushing, or sagging of individual members	not requiring mitigation or has been previously mitigated	of cross sectional shape. Crushing of member (s).	Widespread warping, crushing or sagging.

INVENTORY AND CONDITION DATA

Culvert Inspection Procedure

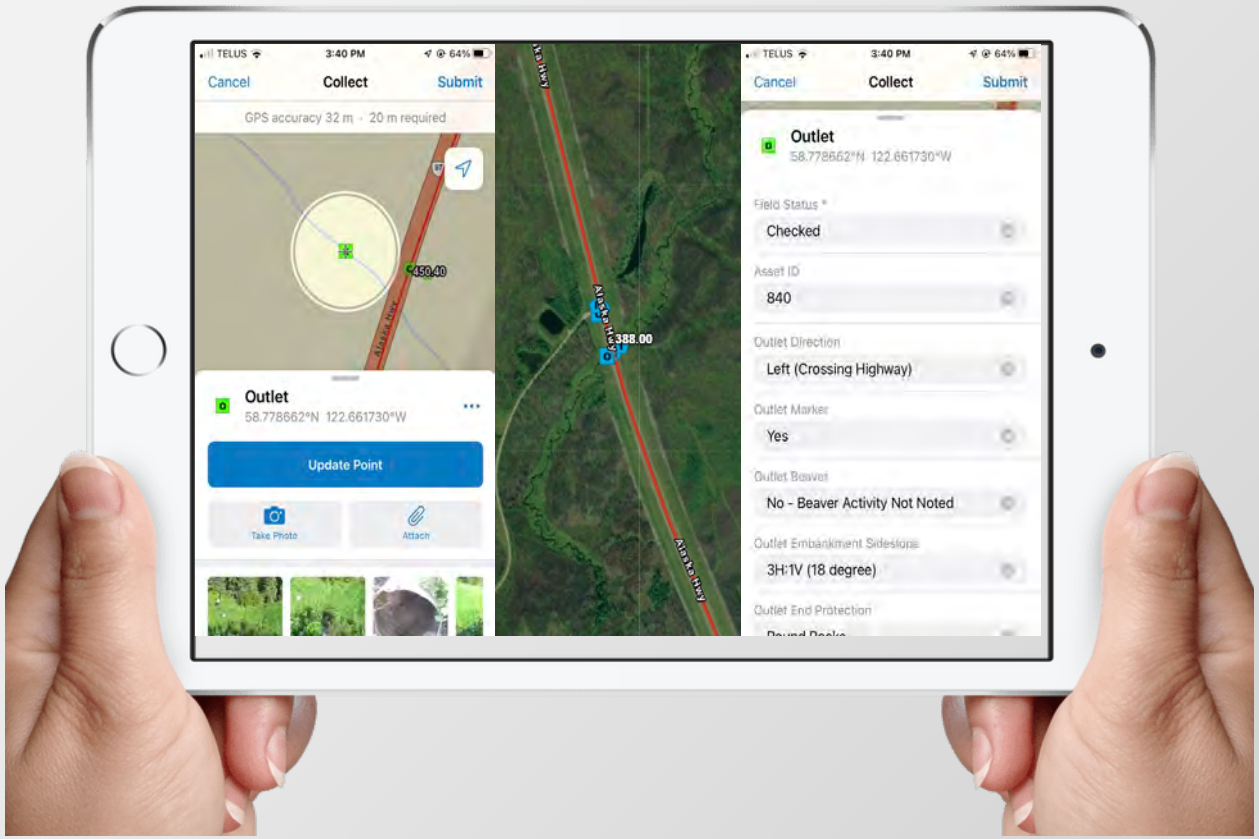
- Training workshops
- Repeatable and consistent condition results

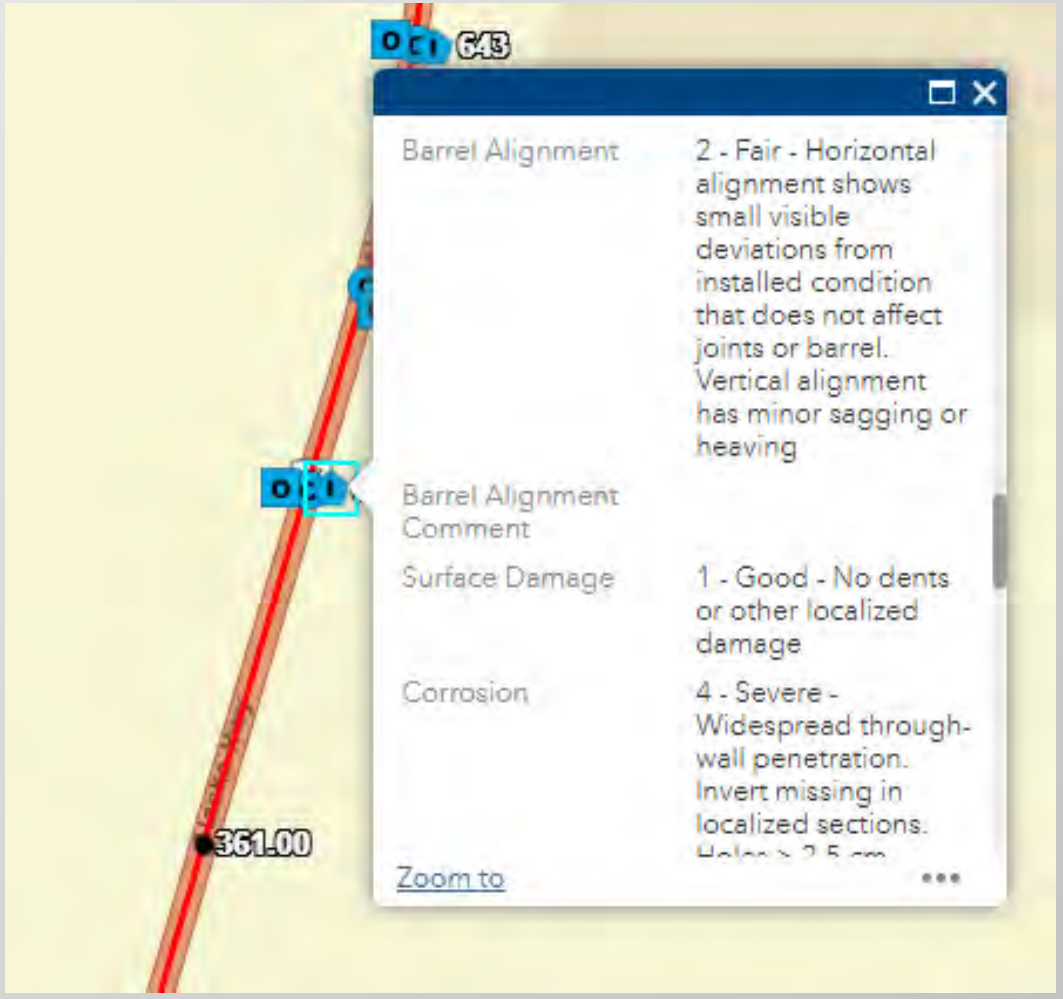
Prepare inspectors for:

- Understanding of culvert **structural behaviour**;
- Culvert function, including **hydraulic performance**;
- Culvert failure modes, critical inspection points and **condition rating system**;
- Knowledge of **inspection tools**, their use applications, and limitations; and
- Appropriate training in **safety requirements** for site access and culvert entry.

INVENTORY AND CONDITION DATA

ArcGIS Field Maps™





INVENTORY AND CONDITION DATA

Condition Results

- Culvert Component Ratings
- Overall Condi

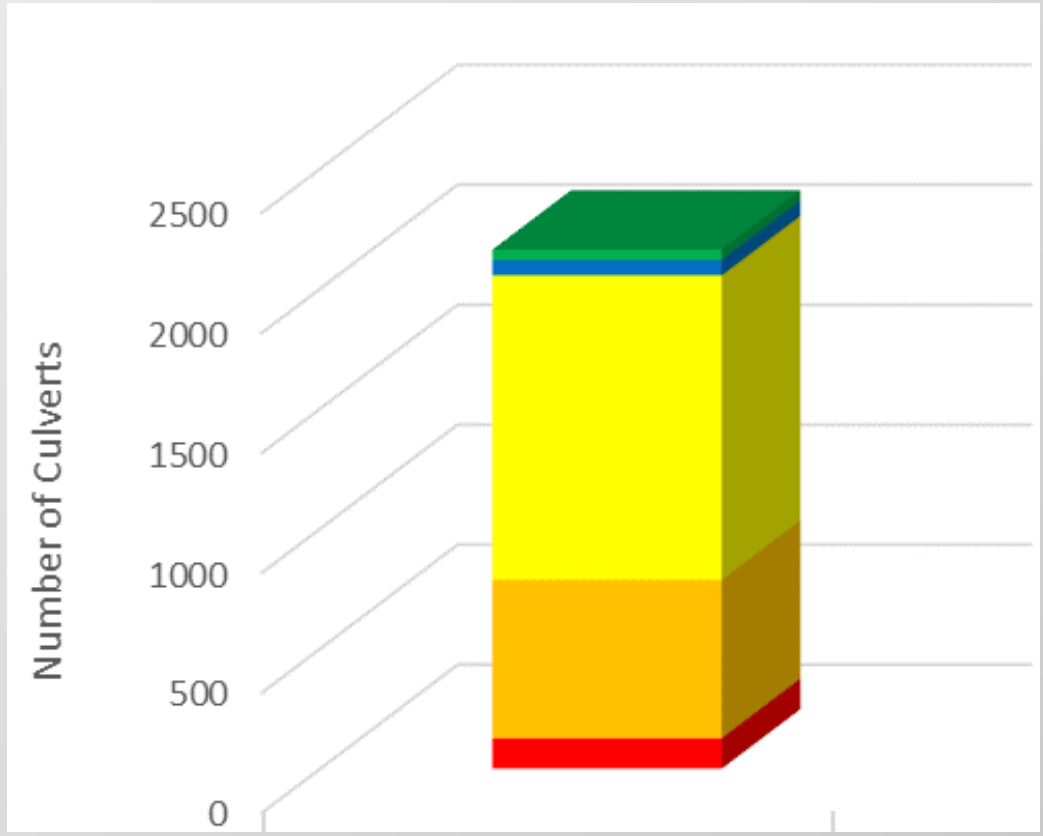
Individual Culverts

CULVERT COMPONENT CONDIT

Rise (mm)	Length (m)	Approach Roadway Rating	Seams (Corrugated Metal Plate) Rating	Outlet End Treatment and Appurtenant Structures Rating (Culvert Specific)	Outlet Embankment Rating	Outlet Channel Alignment and Protection Rating	Outlet Barrel Alignment Rating	Outlet Corrugated Metal Barrel Rating	Outlet Joints Rating	Inlet Trea	App St	Inlet Embankment Rating	Inlet Channel Alignment and Protection Rating	Inlet E Alignm Rating	Inlet Joints Rating	Inlet Concrete Footing and Invert Slab Rating (Culvert Specific)
900	48	Good	N/A	N/A	Good	Severe	Fair	Severe	Good			Poor	Severe	Fair	Good	N/A
900	31	Good	N/A	N/A	Good	Fair	Poor	Poor	Poor			Good	Fair	Poor	Fair	N/A
900	28	Good	N/A	N/A	Good	Severe	N/R	Poor	N/A			Good	Severe	Fair	Good	N/A
900	20	Poor	N/A	N/A	Good	Poor	Poor	Severe	Severe			Good	Severe	Severe	Severe	N/A
600	34	Fair	N/A	N/A	Fair	Severe	Fair	Poor	Good			Good	Severe	Fair	Good	N/A
600	25	Fair	N/A	Fair	Poor	Fair	Good	Poor	Severe			Fair	Severe	Fair	Good	N/A
600	30	Fair	N/A	Fair	Severe	Fair	Fair	Severe	Poor			Good	Good	Good	N/A	N/A
600	30	Good	N/A	Severe	Good	Good	Poor	Severe	Severe			Good	Poor	N/A	Good	N/A
900	34	Fair	N/A	N/A	Poor	Poor	Good	Fair	Poor			Good	Poor	Good	Good	N/A
800	30	Good	N/A	N/A	Good	Severe	Fair	Severe	Good			Good	Poor	Fair	Good	N/A
900	45	Good	N/A	N/A	Severe	Severe	Poor	Severe	Good			Severe	Severe	Go	Good	N/A
900	35	Good	N/A	N/A	Poor	Severe	Good	Fair	Good		N	Good	Poor	F	Good	N/A
900	28	Good	N/A	N/A	Severe	Severe	Poor	Poor	Severe		N/	d	Severe		Good	N/A
900	24	Fair	N/A	N/A	Poor	Poor	Fair	Severe	Good		N/A		Severe		Good	N/A

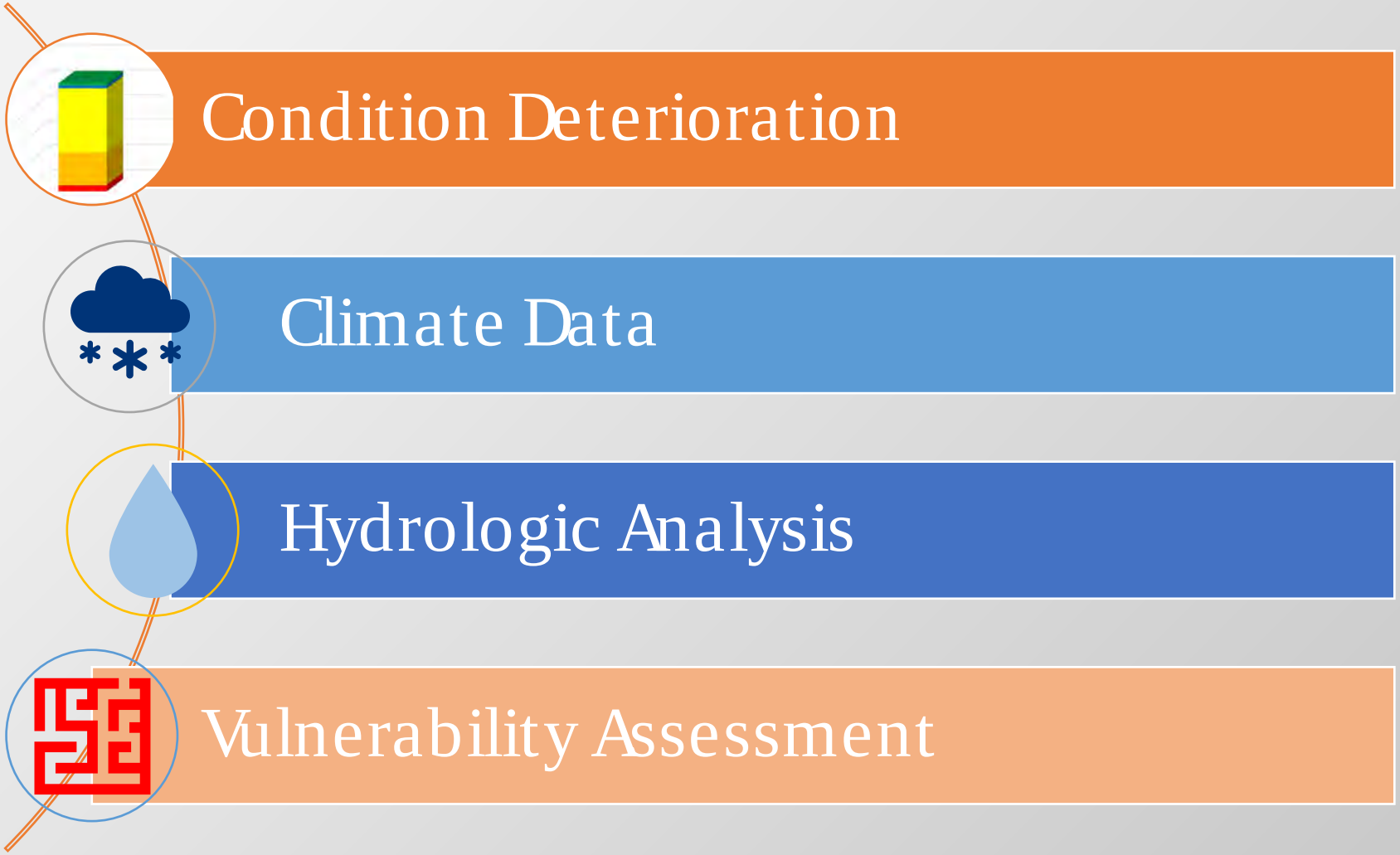
CURRENT STATUS

- The condition score is a weighted condition of all components in general.
- Culvert inspection identified backlog in terms of culvert replacement.



Excellent	43
Good	64
Fair	1269
Poor	660
Severe	126

PREDICTIVE MODELLING

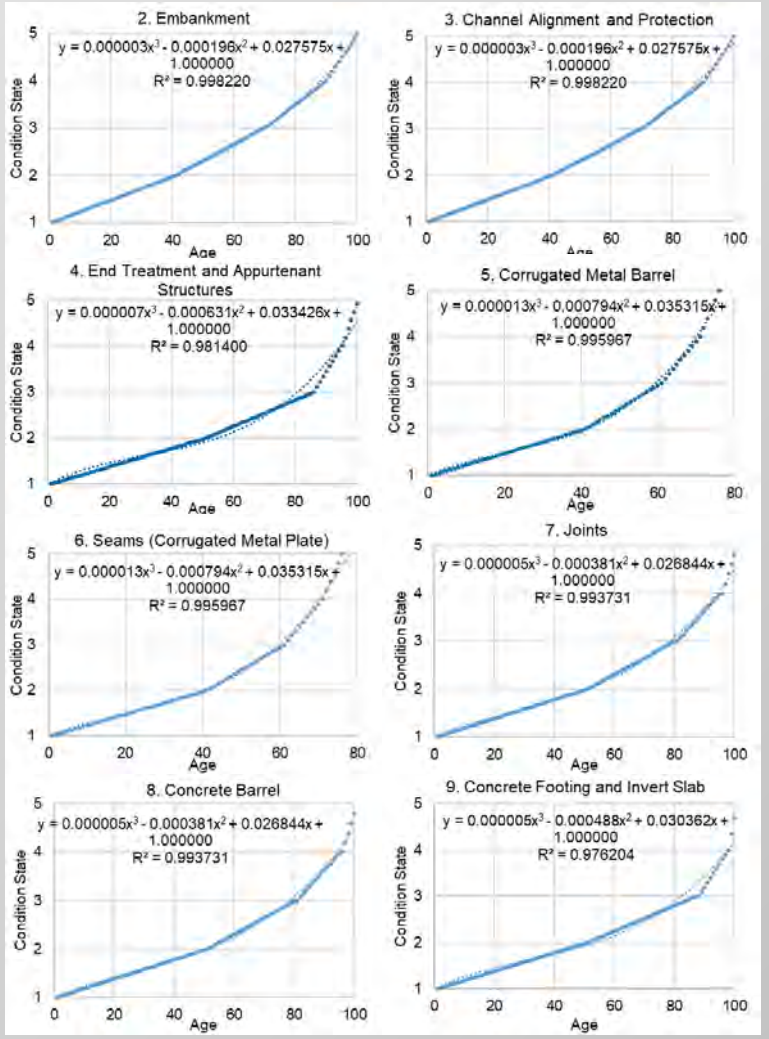


CONDITION DETERIORATION

- Multi-Criteria Decision Analysis (MCDA)
  - Culvert State

- Component States Deterioration
  - Embankment
  - Channel Alignment and Protection
  - End Treatment and Appurtenant Structures
  - Barrel Alignment (Angle with Road Alignment)
  - Barrel Type (Corrugated Metal Barrel, Plastic Barrel, Timber Barrel, Concrete Barrel)
  - Seams (Corrugated Metal Plate)
  - Joints
  - Concrete Footing and Invert Slab

$$Culvert\ Modelling\ State = Max\ (Culvert\ State, Barrel\ State)$$



CLIMATE DATA AND HYDROLOGIC ANALYSIS

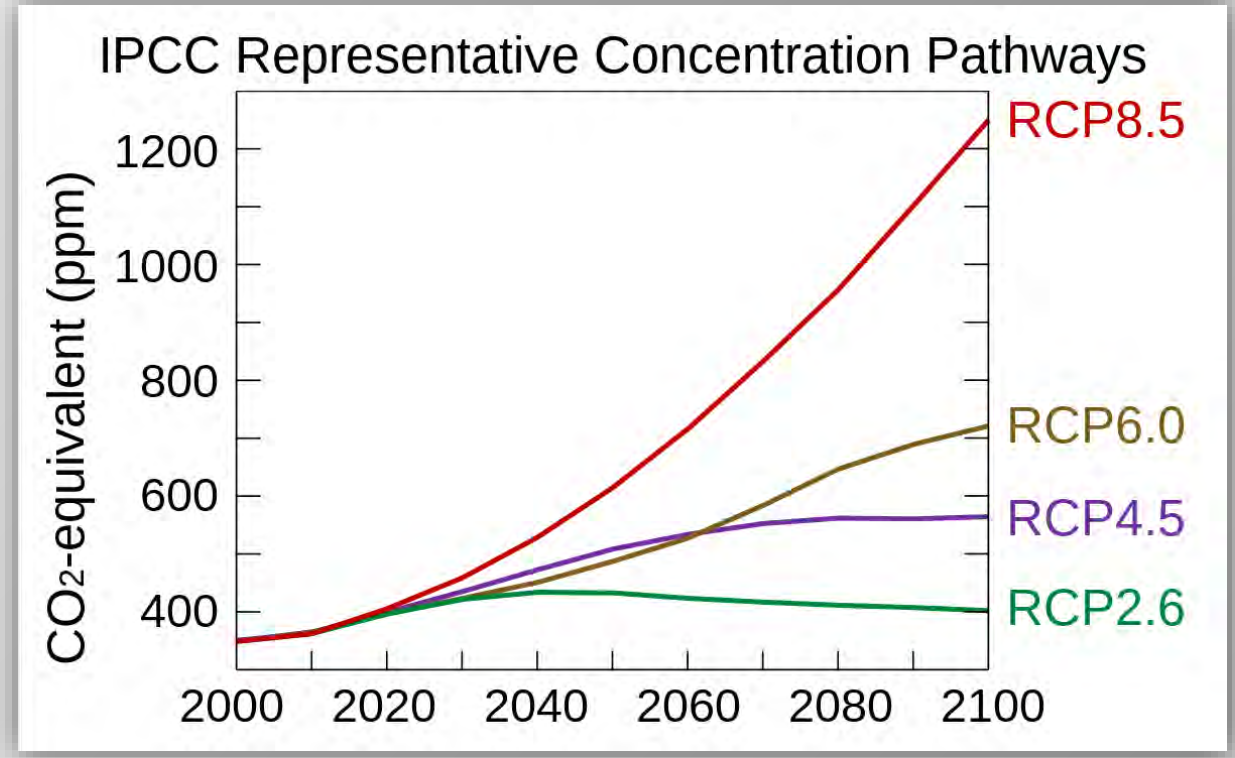
Hydrological Zones

- Five Hydrological Zones delineated
- Flow equations for each zone developed using data from nearby stations

CLIMATE DATA AND HYDROLOGIC ANALYSIS

Model Ensemble for Western North America Region

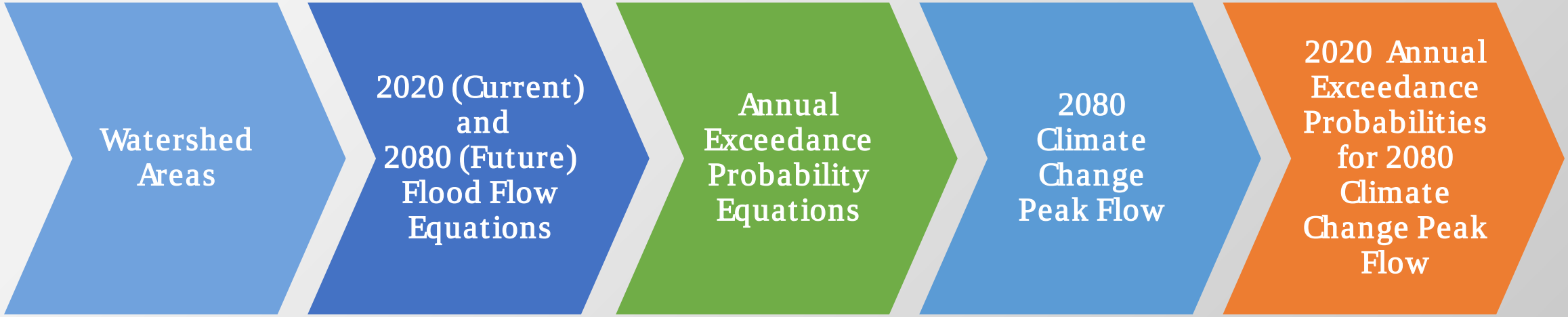
- Climate models most applicable to the Western North America Giorgi Region from the Coupled Model Intercomparison Project Phase 5 (CMIP5)
- Moderate (RCP4.5) and High (RCP8.5) future emissions scenarios



VULNERABILITY ASSESSMENT

VULNERABILITY ASSESSMENT

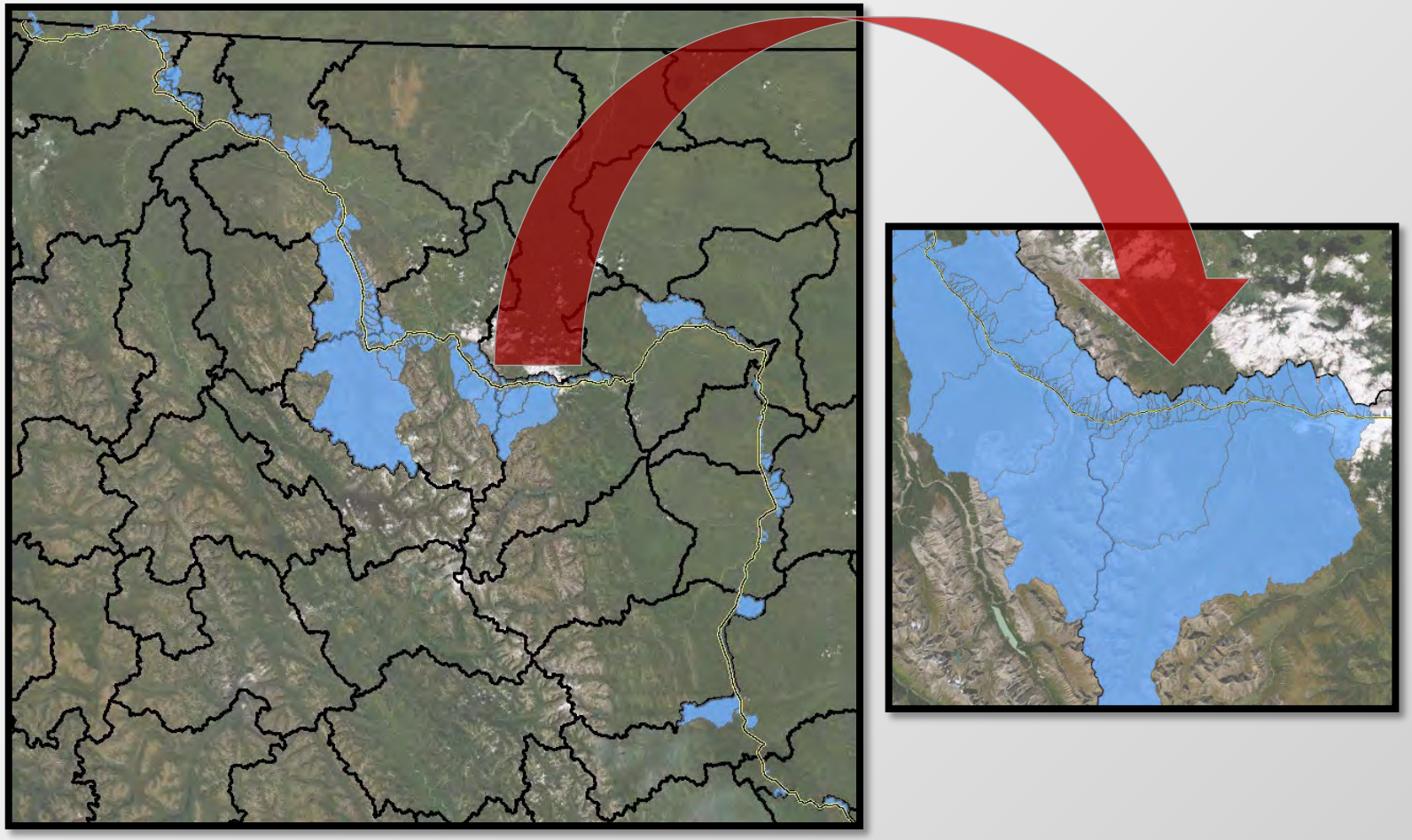
Watershed Areas to Annual Exceedance Probabilities and Climate Change Rate



- 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 in 2020 calculated for all adaption treatments for the 2080 climate change peak flow

VULNERABILITY ASSESSMENT

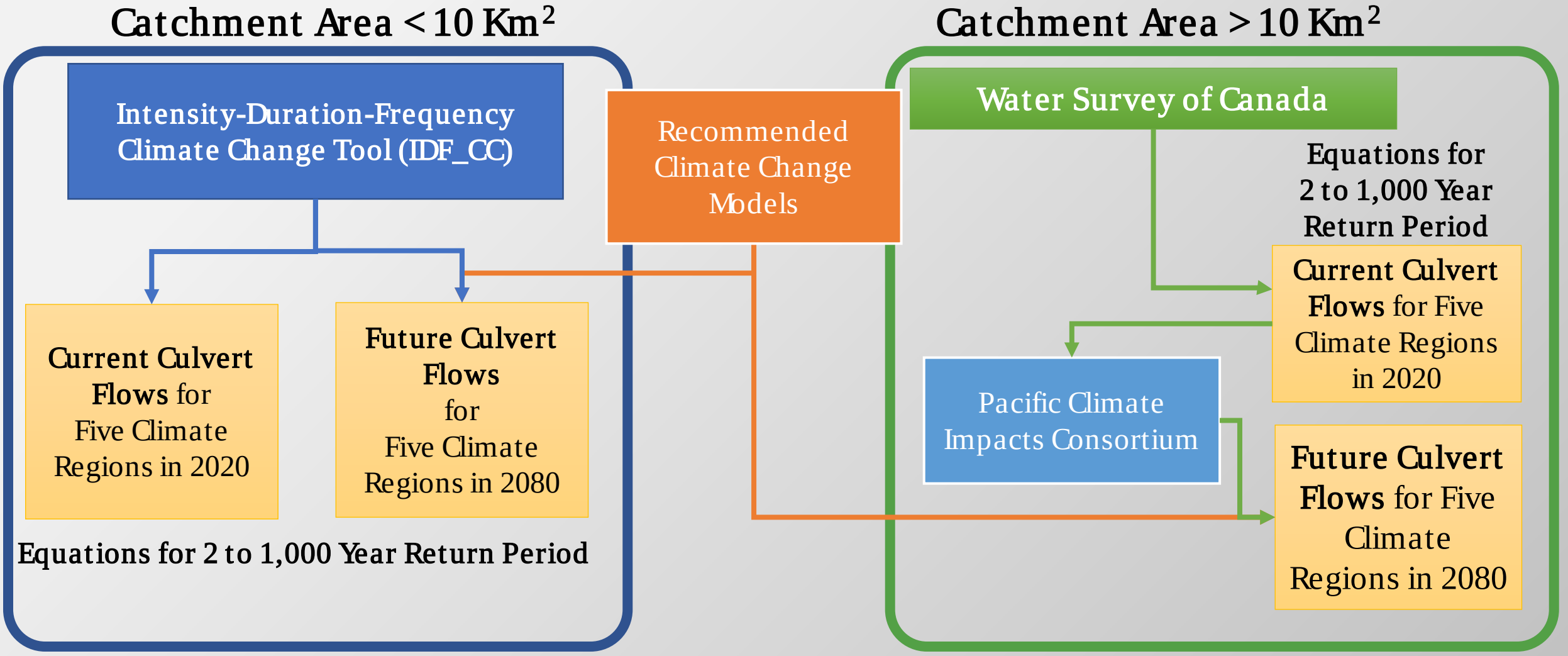
Hydrological Analysis: Watershed Delineations



Typical Watershed Areas in ArcGIS

Watersheds delineated using 1:50,000 NTS datasets

VULNERABILITY ASSESSMENT
Area-Flow Equations



VULNERABILITY ASSESSMENT

Hydrological Analysis: Development of Flood Flows

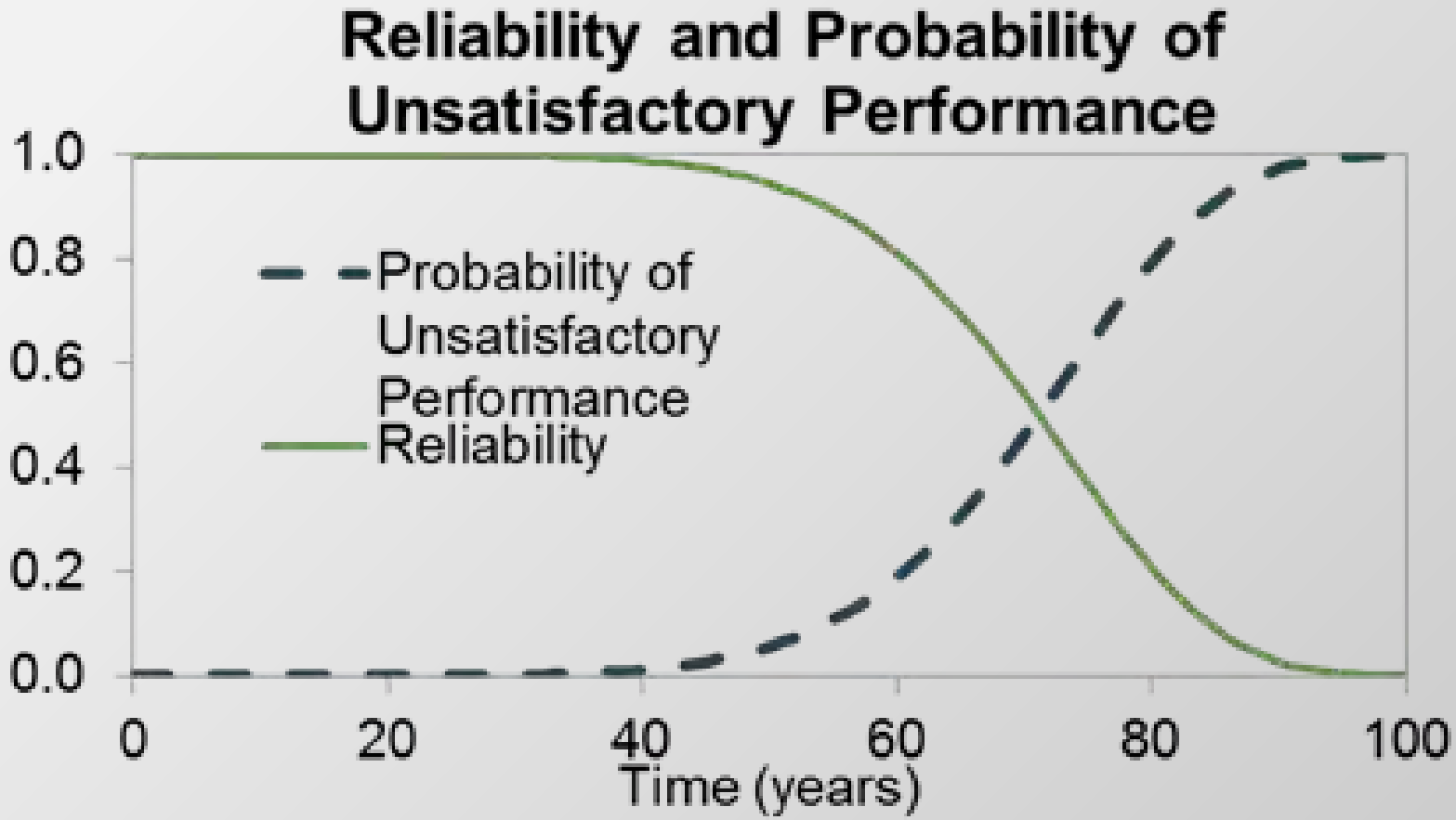
Flood flow magnitudes were estimated for present-day and for future year for each crossing

Return Period:	2020 Present Day Flood Flows (m^3/s)									2080 Future 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

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

Risk and Reliability Engineering for Major Rehabilitation Studies

(Asset Deterioration)



$Risk = PUP x $Consequences

CONSEQUENCES

The consequences for all assets were accounted for in the analysis in terms of owner and user consequences.

For culverts, the failure mechanism will either be a culvert's washout due to an extreme event or structural failure. The failed culvert is replaced with a new culvert as a direct consequence of asset failure.

Owner Consequence

The owner's consequence is the monetary loss of agency due to the asset's failure or structural or capacity failure. Owner consequence equals the capital construction cost of replacing an asset on an emergency basis.

User Consequence

The user consequence is the monetary loss to road users due to the traffic flow disruption because of the asset's failure or unsatisfactory performance. For drainage assets, user consequence equals the user costs calculated earlier.

CONSEQUENCES

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

CONSEQUENCES

$Consequence of Asset Failure

Asset Failure = $$

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

The **duration of closure** as a result of failure depends on the length of the culvert and height of the culvert.

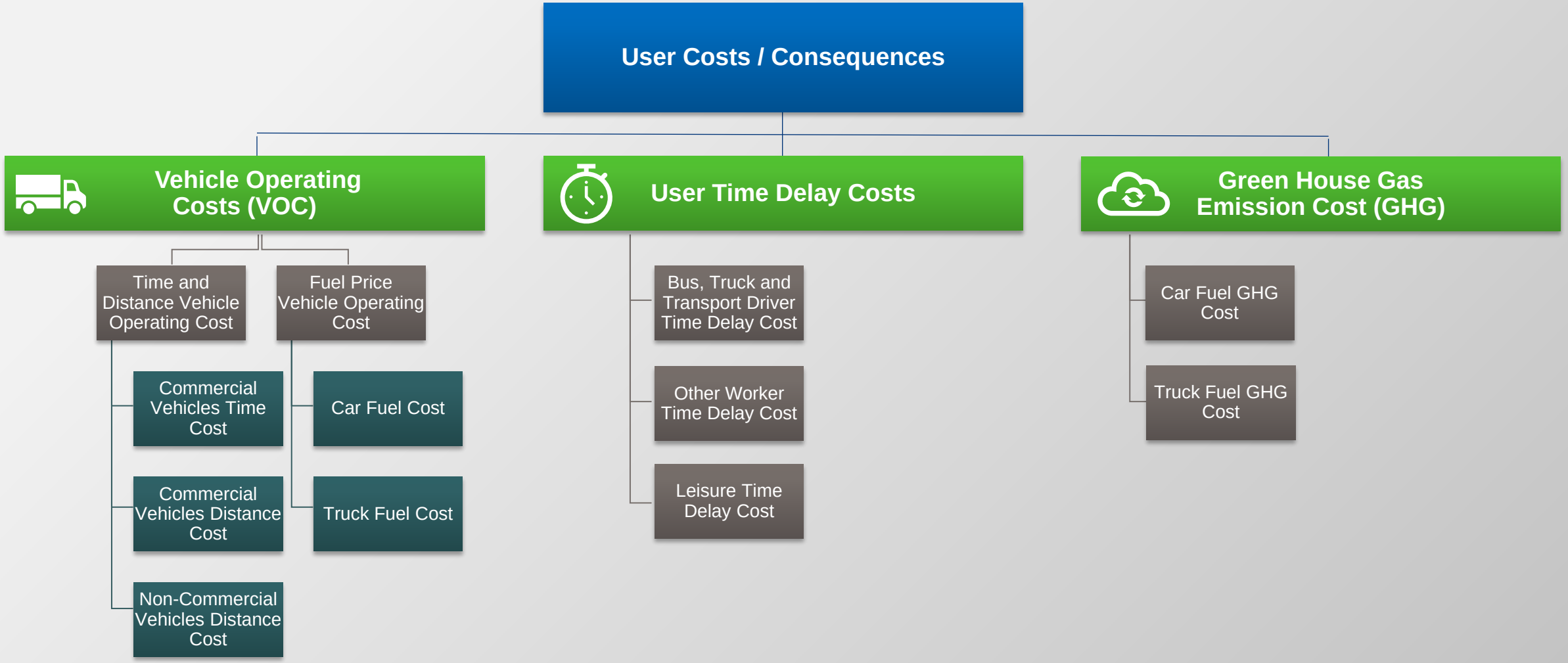
Around 33% of the length of the road has shorter local detours available within the project.

1,900 km Detour

1,800 km Detour

CONSEQUENCES

Calculating User Costs / Consequences



TREATMENTS

Culvert Treatments and Capital Works Options

Strategies	Treatments and Capital Works Options
PREVENTIVE MAINTENANCE, ROUTINE MAINTENANCE AND REHABILITATION	▪ **Beaver Cone** ▪ **Clean Debris Collector** ▪ **Clean Sediment** ▪ **Cut Holes in Inlet** ▪ **Clean Debris Grate** ▪ **Fill Scour Holes** ▪ **Headwall** ▪ **Internal Joint Band** ▪ **Rip-Rap** ▪ **Trim Excess Corrugated Metal** ▪ **Vegetation**
END OF SERVICE LIFE DUE TO EFFECTIVE AGE	▪ **Culvert Replacement** – Minimum Construction Cost of Open-Cut and Trenchless Methods

TREATMENTS
Climate Change Adaptation

Strategies	Adaptation Treatments
CLIMATE CHANGE ADAPTATION STRATEGIES	▪ **Box Concrete Pipe** – 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** – 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 ▪ **Corrugated Metal Pipe** – 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 ▪ **Smooth Wall Pipe** – 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

TREATMENTS
Costs

- Historic Alaska Highway construction costs database (past ten years)
  - Previous tenders/construction contracts
  - Unit rates related to drainage improvements
  - An annual discount factor of 4% was applied to the previous year's projects
- Acontingency factor was applied to the estimated cost of each work item to account for unknowns due to the high-level nature of the study.

ANALYSIS
Economic Analysis

- Economic analysis was conducted to identify and select the most efficient strategy alternative.
- Monetizes the costs and benefits
- Life-cycle cost analysis (in this case, 50 years)
- Economic metrics include:
  - Net Present Value (NPV) of Benefits
  - Benefit-Cost Ratio (BCR)

LIFE CYCLE COST ANALYSIS

- Remember the benefits have to justify the costs:

Added resilience can be justified **if**

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

or

$$\$Benefit - Cost \geq 0$$

Benefit Cost Analysis (BCA)

$$BENEFITS = \sum(\$Risk\ without\ \textbf{Capital Improvement}) - \sum(\$Risk\ after\ \textbf{Capital Improvement})$$

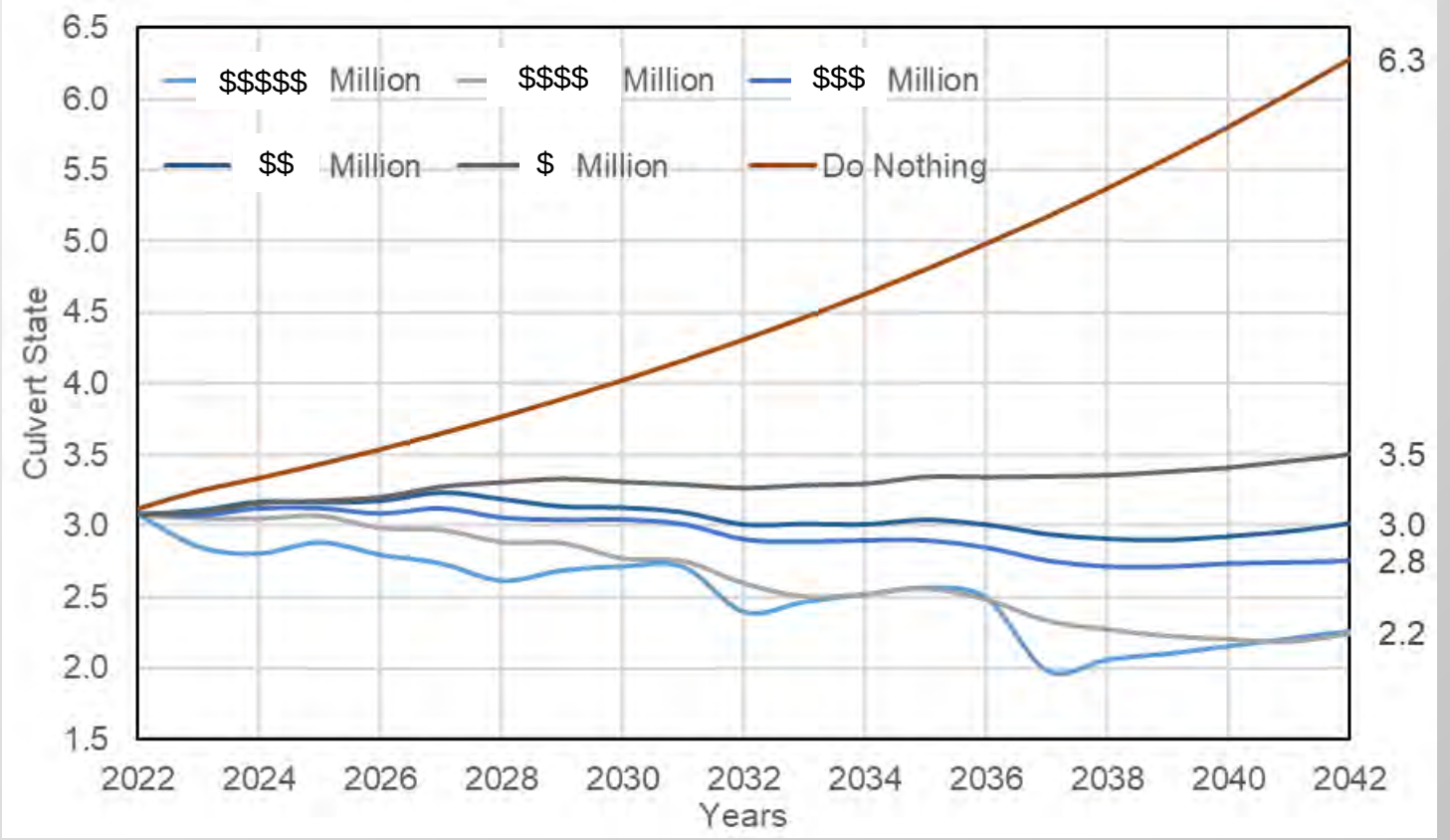
LIFE CYCLE COST ANALYSIS

Benefit in Reduced Risk

- Objective of reducing the damage from future natural hazard events.
- Upgrading existing drainage assets with larger size culverts
- Reduction in Risk of Consequences included:
  - **Physical damage**
  - **Response and recovery**
  - **Transportation services loss**
  - **Environmental benefits**

CAPITAL WORKS PROGRAM
Alternative Budget Scenarios

- Annual average budget scenarios of $$$$$, $$$$, $$$, $$, and $, were analyzed.
- The performance estimates of Culvert State were completed, and LCCAwas carried out to determine an optimal program for analyzed budget levels using the defined benefits.



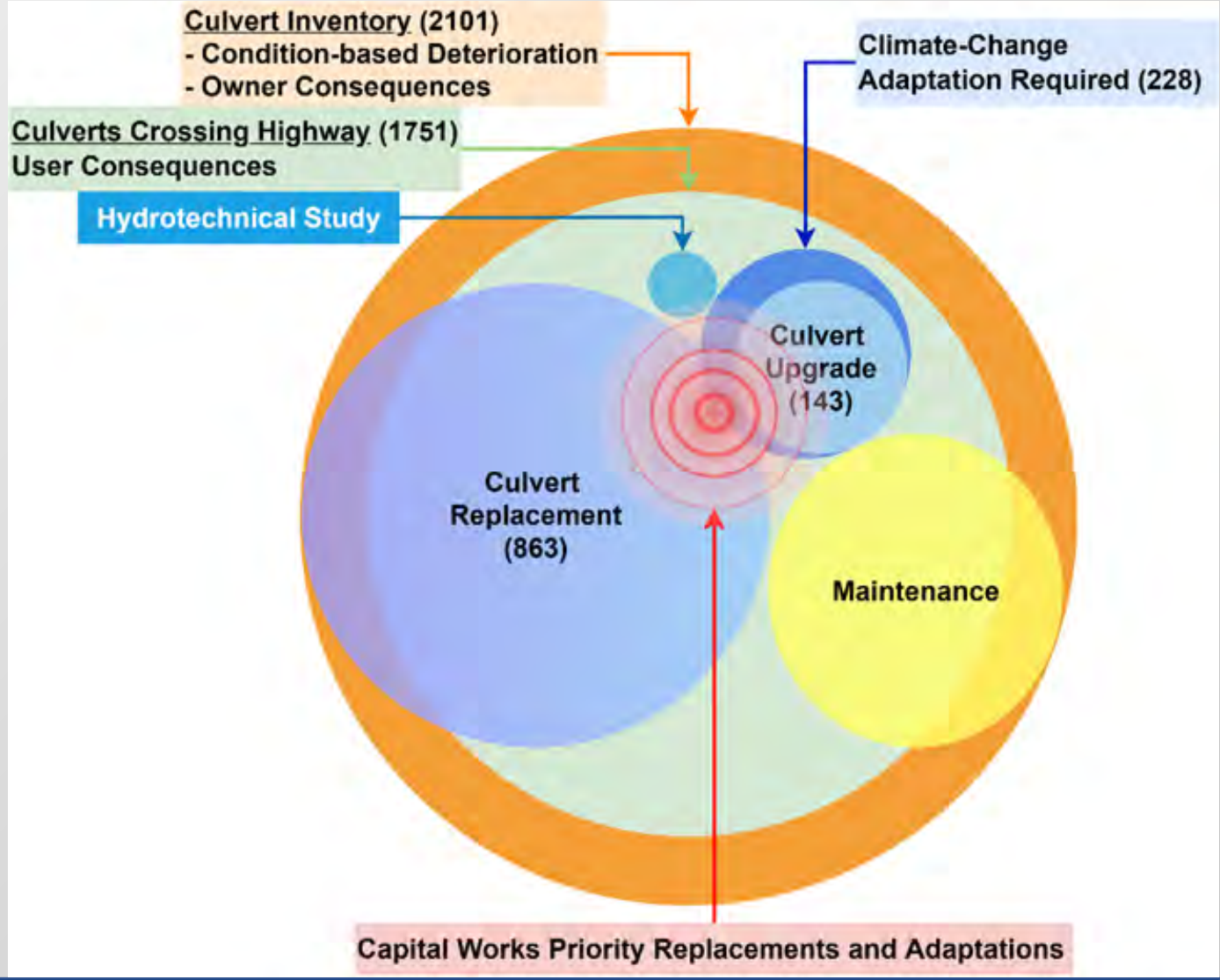
CONCLUSION AND RECOMMENDATIONS
Capital Works Budget Analysis (Suggested Budget)

Network Summary

- Culvert Inventory (2101)
- Culvert Crossing Highway (1751)
- Climate Change Adaptation (228)

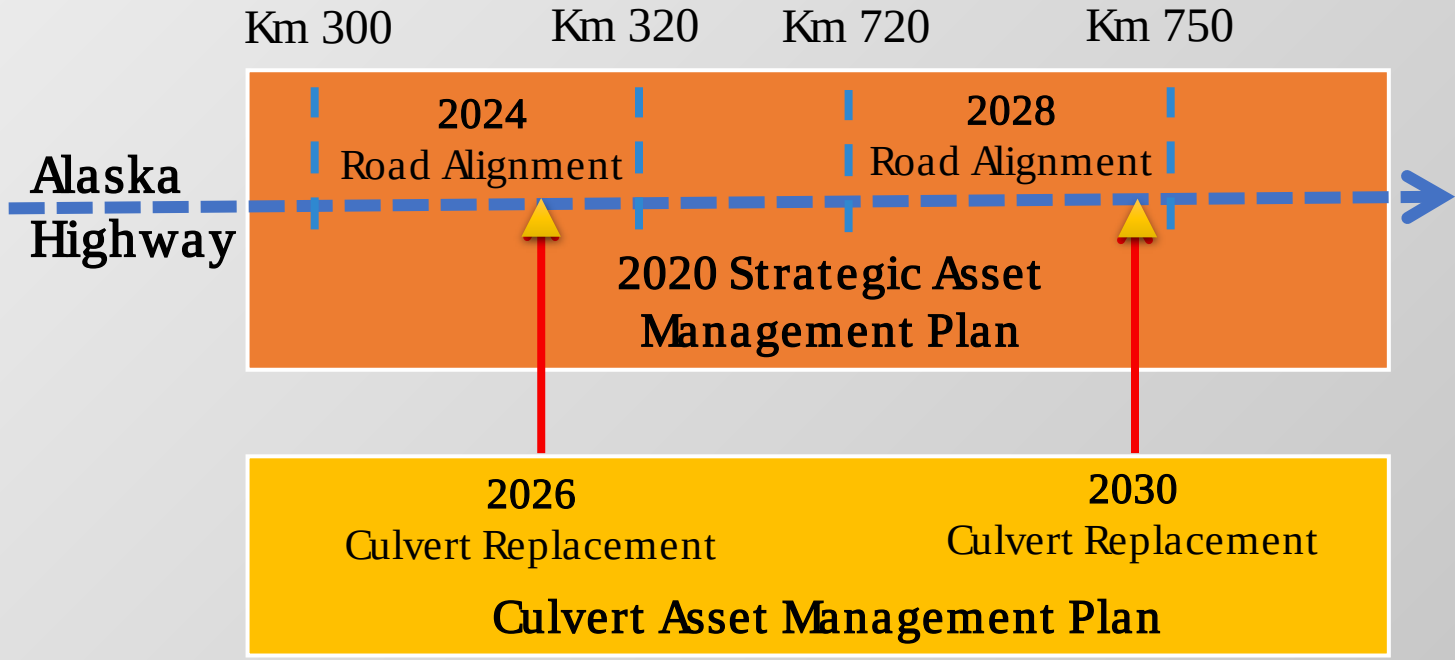
Treatments

- Culvert Replacement (863)
- Culvert Upgrade (143)
- Project Hydrotechnical study
- Maintenance
- Do Nothing



Integrate with Strategic Asset Management Plan

- 2020 Strategic Asset Management Program
- Integrating with 2022 Culvert Capital Works Program
- Synchronizing culvert replacement year with the major rehabilitation work planned under SAMP.



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Questions?