Streamlining Culvert Inspection:
A Tablet-based Comprehensive Inventory and Condition Inspection System
for Asset Management

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ABSTRACT

This paper presents a tablet-based inventory and condition inspection procedure for culvert assets using the data collection criteria outlined in the Culvert and Storm Drain System Inspection Manual (AASHTO, 2020). The procedure streamlines the inspection process by allowing for the digitization of data collection and real-time reporting, resulting in significant time and cost savings, improved accuracy, and repeatability. The procedure has been tested and implemented on the Alaska Highway in British Columbia, where approximately 2,200 culverts were inspected.

Effective management of culvert assets requires reliable inventory and condition data on their structural and geometric characteristics and component conditions. The AASHTO Inspection Manual, published in 2020, addresses this need by updating the inspection and rating criteria, incorporating over 30 years of changes since its original publication in 1986.

The rating system, based on the AASHTO Inspection Manual, includes the rating of culvert components such as roadway, seams, barrel condition, embankment, channel, end treatments, barrel alignment, joints, and seams. This component-level rating allows for a practical and efficient capital works program, as the entire culvert is rarely in poor condition.

The approach utilizes an ArcGIS-based mobile solution to collect inventory and condition data, perform inspections, take notes, and share information with the office. The paper summarizes the methodology used, including the culvert inspection criteria, mobile solution, training workshops, data repeatability, collected inventory and condition data and development of a Multi-Criteria Decision Analysis Index.

Digitizing data also allows for improved data analysis and asset management decision-making. Overall, this paper demonstrates the culvert data collection requirements and effectiveness of tablet-based technology in inspection and highlights the potential for similar applications for other agencies. The inventory, condition and MCDA data are suitable for developing a 20-year climate change informed culvert capital works replacement and adaptation program.

Keywords: Culvert Inventory and Condition Inspection, Culvert Asset Management, Culvert Inspection, Tablet-based Inspection, AASHTO Culvert and Storm Drain System Inspection Manual

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by the Public Services and Procurement Canada (PSPC) to provide engineering services to carry out a culvert inventory and condition inspection for the development of a culvert capital works program for the Alaska Highway km 133-968, British Columbia. The Alaska Highway stretches 2,450 kilometres through northern BC, the Yukon and the State of Alaska. Responsibility for the 835 km section from km 133, north of the City of Fort St. John, BC, to km 968 at the BC/Yukon border, rests with PSPC's responsibility for maintenance and operations.

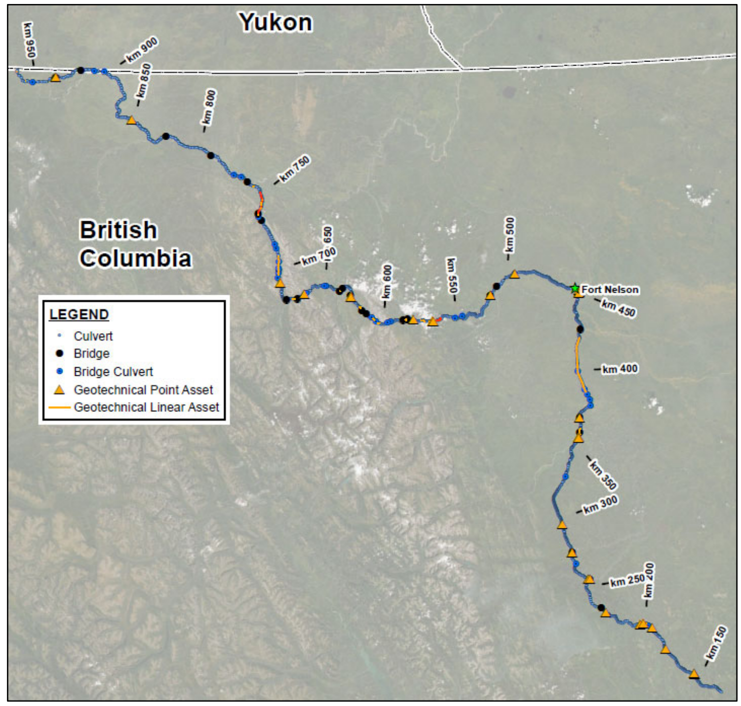


Figure 1: Infrastructure Assets within Project Limits

Culvert inspection has traditionally received less importance from agencies than bridges, leading to many structures with deferred maintenance and varying levels of distress that are not contained in any formal inventory database. Individual culverts cost significantly less to replace and maintain than other major assets; however, the total inventory of culverts is significant. The culvert assets are vulnerable to failure due to several factors such as age, physical damage, larger loads, environmental exposure, etc. A standardized inspection approach is required to identify the culvert problems early in life to repair the issue before total system failure, cost-effectively.

A previous culvert inventory and condition inspection was carried out in 2010 and 2011 on this highway. However, to develop a forward-looking culvert capital works program, a comprehensive culvert inventory and condition inspection were required to assess the culvert's current condition. Figure 1 shows the project limits.

Because the effective management of the culvert assets requires reliable inventory and condition data on culvert structural and geometric characteristics and culvert components conditions, in 2021, an in-depth culvert inventory and condition inspection were carried out.

2.0 LITERATURE REVIEW

In 1986 Federal Highway Administration (FHWA) published a Culvert Inspection Manual (FHWA, 1986) supplement to the "Bridge Inspector's Training Manual," which provided a commentary on culvert structures, inspection procedures, culvert component inspection, and methodology to inspect the culverts. For a long time, it has been the only Guide providing a comprehensive guide to provide a methodology to inspect and rate culverts and their components. It also provided a numerical condition rating criterion for culverts on a scale of 0 to 9; similarly, a maintenance rating scale was also provided.

In 2008, Midwest Regional University Transportation Center researchers developed field protocols and operational business rules for inventory data collection, frequency of inspection, and analysis and reporting mechanisms (Mohammad Najafi, 2008). The condition assessment protocol developed can be used to evaluate the overall condition of the culverts and can be used for decision-making regarding the repair, renewal or replacement of culverts.

In 2016, under NCHRP 14-26, research was conducted to develop an inspection manual, primarily through an update of the 1986 FHWA manual, for accessing the condition of in-service culvert and storm drain systems. In 2020, the Culvert and Storm Drain System Inspection Manual (AASHTO, 2020) was published as the final deliverable of the NCHRP 14-26 project. The manual addresses the need to collect inventory, quantify, and rate the condition of in-service culverts and to update the inspection and rating criteria incorporating over 30 years of change since its original publication in 1986. Culvert inventory and condition inspection were carried out based on the data collection criteria documented in the published Guide and the customized parameters based on reviewing previously gathered information.

Drainage infrastructure (culverts and related drainage elements) represents an integral portion of a transportation agency's assets. These assets are subject to deterioration and degradation over time. The deterioration of culverts can lead to reduced service levels, increased maintenance costs, and ultimately deterioration of the transportation system.

3.0 METHODOLOGY

Alaska Highway culvert data collection criteria were developed based on AASHTO's Culvert and Storm Drain System Inspection Guide (2020) and the 2010-2011 culvert inspection review. Figure 2 shows the AASHTO Culvert and Storm Drain System Inspection Guide (2020).

The inspection team reviewed the 2010 and 2011 inspection inventory and gathered data, locations, and condition ratings before developing the data collection criteria for the current inspection assignment.

Culvert Inspection consists of a collection of two types of data:

- **Inventory:** The inspection involves verifying and updating the existing culvert database locations, culvert type, geometry, inlet and outlet-specific information. The inventory inspection also includes the addition of culverts that were missed in the 2010 -11 inspections as well as any new culverts and culverts that were removed since the previous inspection.
- **Condition:** The inspection consists of visual assessment and condition rating of individual components of the culvert such as the approach roadway, embankment, channel, end treatments, and appurtenant structures, barrel alignment, barrel, joins, and seams.

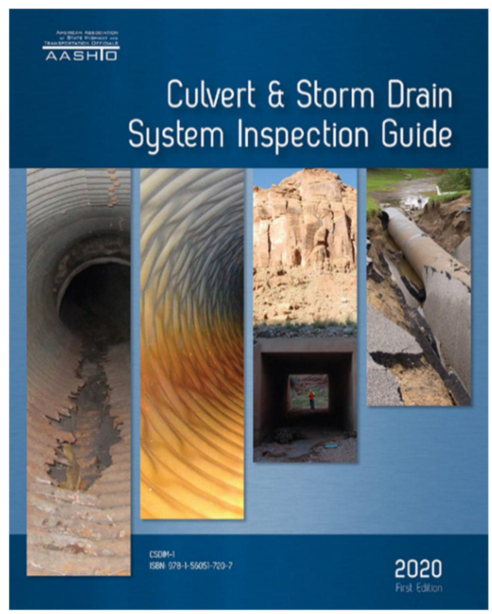


Figure 2: AASHTO Culvert and Storm Drain System Inspection Guide (2020)

3.1 Inventory Inspection

The initial system inspection, or inventory inspection, is the first inspection conducted after a culvert is commissioned, just after the completion of constriction. Similarly, initial inspections are also conducted after any major rehabilitation or expansion work is completed on the Highway. Since the previous inspection on Alaska highway was ten years out of date, it was anticipated that a review of the existing culvert inventory should also be included as part of the inspection to update the database of all the major rehabilitation and realignment work completed since 2010 and 2011. The inventory level data is also needed to make agency asset management decisions in order to develop a proactive capital works program and make reliable estimates of capital needs.

The inspection included verifying the location of culverts identified in the existing inventory and updating the inventory data to include new culverts. The culvert inventory included the following major types of data for culverts:

- Inventory Identification
- Location
- Culvert/Drain Type & Geometry
- Channel, Hydrology and Hydraulics
- End Treatment Type & Geometry
- Inlet Information
- Outlet Information

Complete information on the culvert inspection criteria and the inventory level input parameters are provided in AASHTO Culvert and Storm Drain System Inspection Guide (AASHTO, 2020).

3.2 Condition Inspection

Condition inspection of the culverts consisted of ratting common types of culvert deficiencies and recognizing the severity and significance of distress to allow assignment of a rating to culvert components. Thae condition rating system consists of five conditions: Excellent, Good, Fair, Poor, and Severe. Table 1 provides the rating scale and associated action.

Table 1: Rating Scale and Associated Action

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 an 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 recommendation in inspection report.	Corrective action is required and urgent. Engineering evaluation is required to specify appropriate repair.

An "Excellent" rating indicates a new component, with no deterioration, that is recently installed within 1 or 2 years. A "Good" rating means a like-new component, with little deterioration, that is structurally sound and functionally adequate. A rating of "Fair" indicates some deterioration, but is structurally sound and functionally adequate. A rating of "Poor" indicates significant deterioration and/or functional inadequacy, requiring maintenance or repair. A "Severe" rating indicates very poor conditions that indicate possible imminent failure or failure, which could threaten public safety.

The condition rating system based on the inspection guide (AASHTO, 2020) consists of rating culvert components such as roadway, seams, barrel condition, embankment, channel, end treatments, barrel alignment, joints and seams etc. Component level rating effectively develops a practical and efficient capital works program because the entire culvert is rarely in poor condition. The component level rating can be used to identify the develop a component-specific repair program for the culvert inventory. The following components were individually rated depending on the type and size of the culverts.

- Approach Roadway Rating
- Seams (Corrugated Metal Plate) Rating
- Concrete Barrel Rating
- Plastic Barrel Rating
- Masonry Barrel Rating
- Timber Barrel Rating

Inlet and Outlet Condition Components:

- End Treatment and Appurtenant Structures Rating (Culvert Specific)
- Embankment Rating
- Channel Alignment and Protection Rating
- Barrel Alignment Rating
- Corrugated Metal Barrel Rating
- Joints Rating
- Concrete Footing and Invert Slab Rating (Culvert Specific)

Figure 3 shows the Culvert System Inventory and Condition Inspection Information Collection flowchart based on the culvert inspection guide, previous inspection, and literature review.

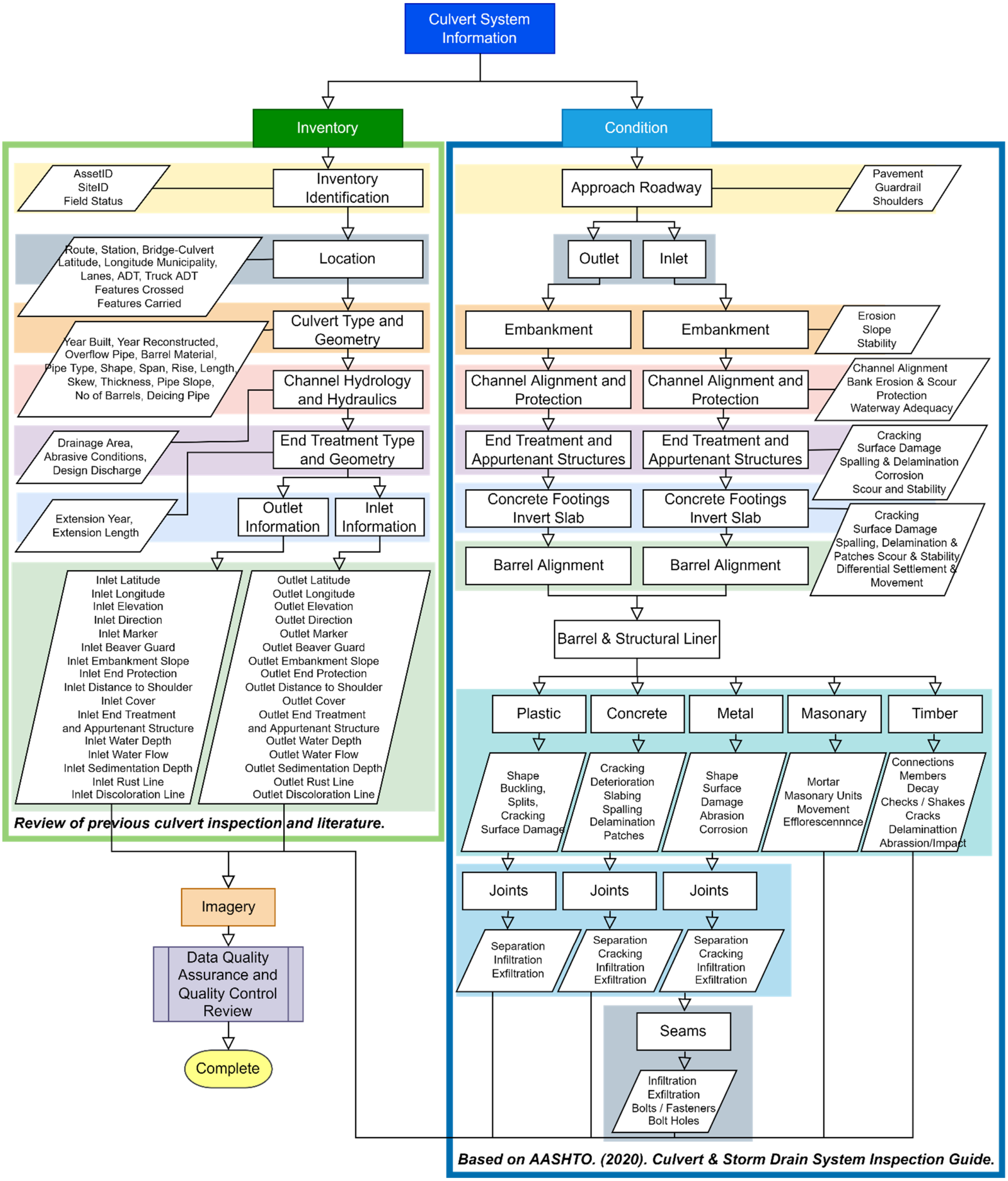


Figure 3: Culvert System Inventory and Condition Inspection Information Collection

4.0 CULVERT MANAGEMENT DATABASE

The culvert management database is a tool or system that can be used by organizations to track and manage the culverts within their jurisdiction. The database tracks culvert information such as location, size, type, and condition. The database also allows owners to track maintenance and repair information such as date of last inspection, type of repair, and cost. The culvert management database can be used to generate reports that can be used to identify trends and areas of need.

4.1 Culvert Age

Culvert construction and maintenance history is important for determining the likely cause of failure and the appropriate repair strategy. It can also provide information on the expected lifespan of a culvert and the expected frequency of maintenance.

A review of available historical information for culvert construction and maintenance strategies was carried out for Alaska Highway. A comprehensive culvert management database containing the entire culvert construction and maintenance history does not exist for the Highway. An estimation of the construction year of existing culverts was made based on the highway realignment or highway construction year. The individual culvert replacement history for some culverts was available for the years between 2013 and 2022, and the history for those years were also incorporated in the estimation of age.

The approach of estimating construction years, results in accurately estimating the age of all culverts which were constructed at the time of highway construction; however, the approach does not consider the culverts which were replaced individually after highway construction due to failure, as a result the age estimate will not reflect the culverts that were replaced after realignment and are not recorded. As a result, the resulting statistics are conservative for the general inventory.

Table 2 shows the average of different pipe types within the Alaska Highway culvert system. The inventory shows that the average age of culverts is 32 years, with Corrugated Steel Pipe being most culverts within the inventory.

Table 2: Average Age of Alaska Highway Culvert Pipe Type

Pipe Type	No of Culvert[1]	Average of Age
Concrete - Precast	5	6
Corrugated Aluminum Pipe (CAP)	1	37
Corrugated Steel Pipe (CSP)	1,829	33
Plastic - Corrugated High Density Poly Ethylene (HDPE) Pipe	25	31
Solid Wall Steel Casing	99	16
Structural Plate Steel	42	25
Timber - Wood	139	> 50
Total	**2,140**	**32**

[1] The table also includes the existing Bridge-Culvert along the Highway.

The results also shows that concrete culverts are a recent inclusion in the inventory. Similarly, Solid Wall Steel Casing have an average age of 16 years, this means that several culverts after failure are being replaced by Solid Wall Steel because of cheaper cost in higher embankments as compared to CSP.

Figure 4 shows the cumulative percentage of culverts age. It shows that 87% of the culverts were 20 years or older, 53% of the culverts are 30 years or older, and 29% of the culverts are 40 years or older. The data shows similar trends as observed in other studies. In 1999, American Society of Civil Engineers (ASCE) conducted a study on wastewater utilities under Environmental Protection Agency (EPA) Cooperative Agreement. The data suggested that by 2020, half of the assets would be midpoint of their useful service life.

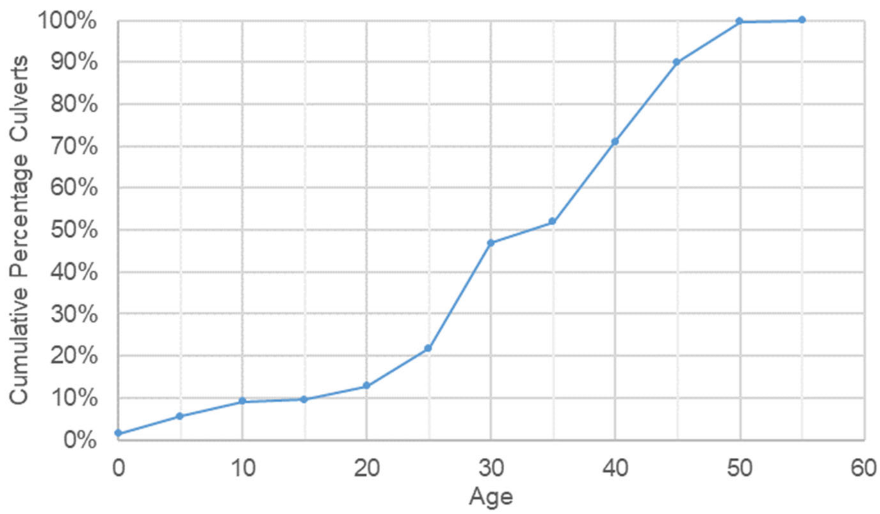


Figure 4: Cumulative Percentage of Culverts Age

5.0 CULVERT INSPECTION PROCEDURE

The successful implementation of the culvert inspection program depends on the inspector's ability to effectively assess the condition of the structure and materials and make an effective evaluation that leads to repeatable and consistent condition results throughout the inventory. A workshop explained the culvert condition rating criteria and its elements to inspectors. The workshop aimed to get all inspectors trained to obtain a consistent and repeatable condition and inventory collection during the inspection. The inspectors were trained to collect accurate and repeatable inventory and condition data following a rating system developed in the inspection guide. The training of inspectors included an educations seminar based on the Guide to prepare the inspectors for the following requirements:

- Familiarity and understanding of culvert structural behavior;
- Familiarity and knowledge of culvert function, including hydraulic performance;
- Culvert failure modes, critical inspection points and the condition rating system described in this Guide;
- Working knowledge of inspection tools, their use applications, and limitations; and
- Appropriate training in safety requirements for site access and culvert entry.

5.1 GIS-Based Inspection

The field inspection was carried out from August to October 2021 by trained inspectors. GIS-based data collection was carried out using an ArcGIS Field Maps application on a tablet. ArcGIS Field Maps™ is an all-in-one app that uses data-driven maps to help mobile workers collect and edit data, find assets and information, and report their real-time locations. ArcGIS Field Maps™ application collected culvert inlet, outlet locations, culvert inventory data, culvert condition data, and culvert imagery. The application-based field data collection improves the quality control and quality assurance of the collected data, such that for the majority of the attributes, the inspector can choose the condition from the predefined set of conditions parameters.

The data collected by the ArcGIS application was used to create a culvert inventory database. The database was then used to create a culvert condition report. The culvert condition report was used to identify culverts in need of repair.

Figure 5 shows the ArcGIS-based Field Maps™ data collection application used for the inspection.

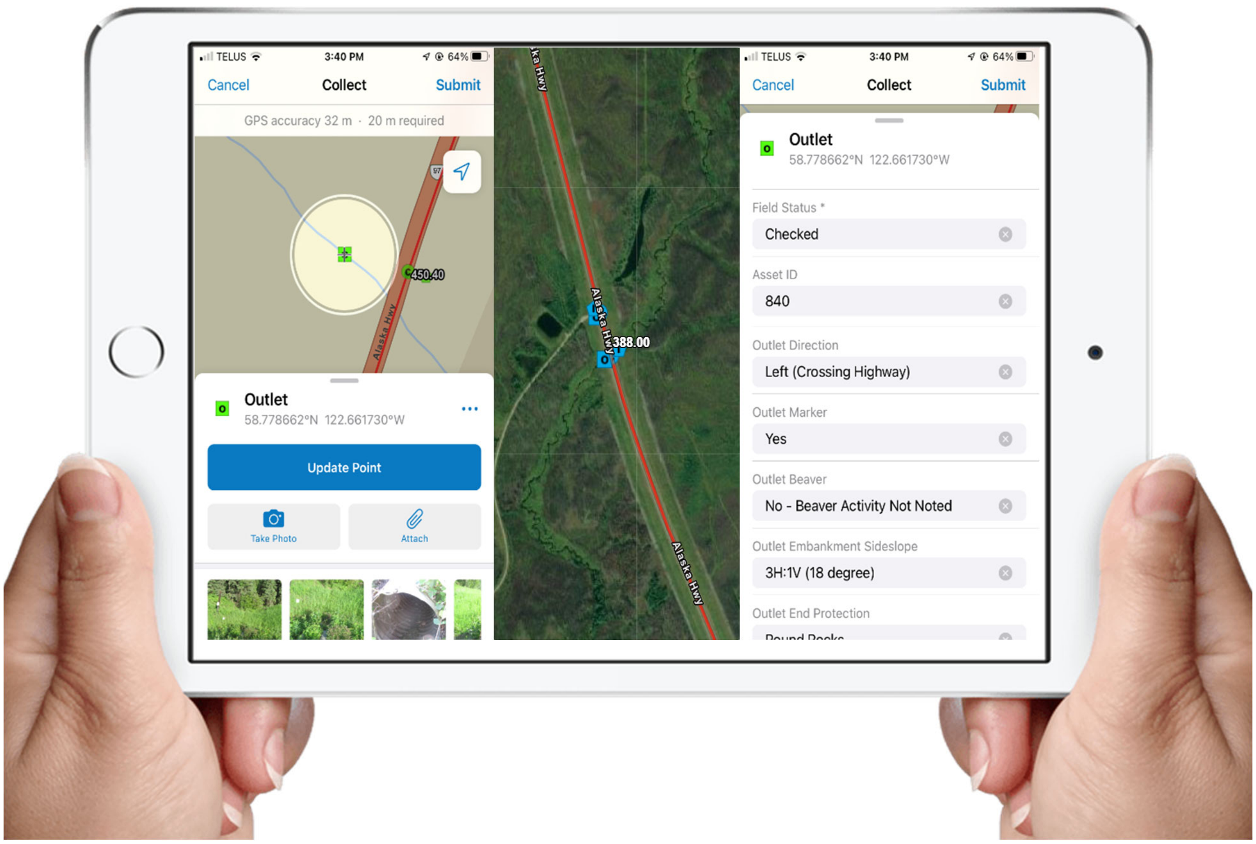


Figure 5: ArcGIS-based Field Maps™ Data Collection

6.0 QUALITY CONTROL AND QUALITY ASSURANCE (QC/QA)

A quality management program was implemented during the field data collection and post-data collection to maintain a minimum level of quality. The quality management program consisted of the following: A quality control person was assigned to oversee the quality of the data collection. The quality management program consisted of quality control procedures, which were reviewed and approved by the project manager. The quality control procedures were implemented during the field data collection and were monitored during the data collection.

Field inspectors used a consistent stepwise approach to collecting data on the culvert components starting from approach roadway, embankment, culvert end, barrels, and so on. Routine quality control checks were carried by the office staff during the data collection to ensure accurate and consistent information is being collected between individual inspectors regarding condition interpretation. Correct and consistent inspection between different inspectors and across the inventory is critical to a successful inspection program. A well-functioning quality system allows the agency to have improved confidence in making asset management decisions using the inspection results. The images gathered during the field survey were thoroughly examined in the subsequent phase of developing a 20-year capital works program. This review process serves as a means to verify and validate the accuracy of the collected data, ensuring a solid foundation for informed decision-making in infrastructure planning and maintenance.

7.0 CULVERT INSPECTION DATA

Table 3 provides the culvert inventory data types collected during the field inspection.

Table 3: Culvert Inventory Data Attributes

Component	Attribute	Description
Inventory Identification	Asset ID	It is the unique identification number of the Asset. Asset ID is the same as Site ID for sites with one Asset. A site can have more than one culvert.
	Field Status	The status of the culvert for tracking inventory in the field in relation to previous reviews
Location	Route	It is the road's name.
	Station	It is the chainage of the Asset assigned based on the linear referencing of the asset along the route in ArcGIS.
	Bridge Culvert	Name of the Bridge-Culvert on Alaska Highway.
	Center Latitude	Center Latitude is the y-coordinate associated with the Geographical Coordinate System for the Asset at Center Line of the Highway in degree North.
	Center Longitude	Center Longitude is the x-coordinate associated with the Geographical Coordinate System for the Asset at Center Line of the Highway in degree West.
	Center Elevation	Center Elevation is the elevation associated with the Geographical Coordinate System for the Asset at Center Line of the Highway.
	Number of Lanes	It is the total number of lanes along the culvert cross the highway.
	ADT	It is the Annual Daily Traffic at the culvert site.
	Truck ADT	It is the Annual Daily Traffic of Trucks at the culvert site.
	Features Crossed	Features crossed by the culvert
	Features Carried	Features carried in the culvert.
Culvert/Drain Type & Geometry	Year Built	Year of construction.
	Year Reconstructed	Year of reconstruction
	Overflow Pipe	Overflow is a supplementary pipe installed to prevent overtopping when the primary culvert capacity is exceeded.
	Barrel Material	Type of barrel material culvert is made up.
	Pipe Type	Type of pipe.
	Shape	Shape of the culvert among the standard shapes available.
	Span (mm)	Span is the horizontal diameter or width of the culvert.
	Rise (mm)	Rise is the vertical diameter or height of the culvert.
	Length (m)	It is the length of the culvert barrel from inlet to outlet end.
	Length Checked	Is the existing length in the Inventory Table checked.
	Skew (deg)	The acute angle formed by the intersection of the line normal to the centerline of the road with the centerline of a culvert.
	Thickness (mm)	Culvert wall thickness.
	Pipe Slope (%)	The slope of the pipe along the buried pipe length used for evaluation of sagging and heaving and general alignment along the barrel length.
	No. of Barrels/Cells	No of adjacent barrels or multicell concrete box section.
	Deicing Pipe	Pipe used for thawing frozen culverts during freshet season.
	Culvert Type and Geometry Remarks	Remarks regarding culvert type and geometry not covered in the other attributes.
Channel, Hydrology and Hydraulics	Drainage Area (Sq Km)	Drainage area for the culvert crossing.
	Abrasive Conditions	Remarks on environmental conditions such as acidic soil or water
	Channel, Hydrology and Hydraulics Remarks	Remarks regarding channel, hydrology and Hydraulics not covered in the other attributes.
	Design Discharge (m3/s)	The flow rate used in the design of the culvert
End Treatment	Inlet Extension Year	Year of any inlet extension
	Inlet Extension Length (m)	Amount the inlet was extended
	Outlet Extension Year	Year of any outlet extension

Type & Geometry	Outlet Extension Length (m)	Amount the inlet was extended
	End Treatment Type & Geometry Remarks	Remarks regarding end treatment and geometry not covered in the other attributes
Inlet	Inlet Latitude	Inlet Latitude is the y-coordinate associated with the Geographical Coordinate System for the Asset at Inlet End of the Culvert in degree North.
	Inlet Longitude	Inlet Longitude is the x-coordinate associated with the Geographical Coordinate System for the Asset at Inlet End of the Culvert in degree West.
	Inlet Elevation	Inlet Elevation is the elevation associated with the Geographical Coordinate System for the Asset at Inlet End of the Culvert.
	Inlet Direction	Inlet Direction indicates location of Inlet Left/Right of centerline in increasing highway chainage.
	Inlet Marker	Whether the inlet has a marker or not
	Inlet Beaver Guard	Whether the inlet has a beaver guard or not, and if any beaver activity is noted
	Inlet Embankment Sideslope	It is the sideslope of the embankment at the Inlet End.
	Inlet End Protection	Description of any materials used to protect the inlet
	Inlet Distance to Shoulder (m)	The horizontal distance from the inlet to the road shoulder
	Inlet Cover (mm)	The depth of backfill over the top of the pipe at the Inlet end.
	Inlet End Treatment and Appurtenant Structure	The type of any end treatment or appurtenant structure at the inlet
	Inlet Water Depth (%)	The depth of water at the inlet as a percent of the culvert rise
	Inlet Water	Description of water presence at the inlet
	Inlet Sedimentation Depth (%)	The depth of sediment at the inlet as a percent of the culvert rise
	Inlet Rust Line (%)	The depth of rust at the inlet as a percent of the culvert rise
	Inlet Discoloration Line (%)	The depth of discoloration at the inlet as a percent of the culvert rise
	Inlet Remarks	Remarks regarding the inlet not covered in the other attributes
Outlet	Outlet Latitude	Outlet Latitude is the y-coordinate associated with the Geographical Coordinate System for the Asset at Outlet End of the Culvert in degree North.
	Outlet Longitude	Outlet Longitude is the x-coordinate associated with the Geographical Coordinate System for the Asset at Inlet End of the Culvert in degree West.
	Outlet Elevation	Outlet Elevation is the elevation associated with the Geographical Coordinate System for the Asset at Inlet End of the Culvert.
	Outlet Direction	Outlet Direction indicates location of Outlet Left/Right of centerline in increasing highway chainage.
	Outlet Marker	Whether the outlet has a marker or not
	Outlet Beaver Guard	Whether the outlet has a beaver guard or not, and if any beaver activity is noted
	Outlet Embankment Sideslope	It is the Sideslope of the embankment at the Outlet End.
	Outlet End Protection	Description of any materials used to protect the outlet
	Outlet Distance to Shoulder (m)	The horizontal distance from the outlet to the road shoulder
	Outlet Cover (mm)	The depth of backfill over the top of the pipe at the Outlet End.
	Outlet End Treatment and Appurtenant Structure	The type of any end treatment or appurtenant structure at the outlet
	Outlet Water Depth (%)	The depth of water at the outlet as a percent of the culvert rise
	Outlet Water	Description of water presence at the inlet
	Outlet Sedimentation Depth (%)	The depth of sediment at the outlet as a percent of the culvert rise
	Outlet Rust Line (%)	The depth of rust at the outlet as a percent of the culvert rise
	Outlet Discoloration Line (%)	The depth of discoloration at the outlet as a percent of the culvert rise
	Outlet Remarks	Remarks regarding the outlet not covered in the other attributes

Table 4 provides the culvert condition data types collected during the field inspection.

Table 4: Culvert Condition Data Attributes

Component	Attribute	Description
Inspection Identification	Date of Inspection	The date the inspection was conducted
	Inspection Frequency	How often the culvert is scheduled for inspection

Approach Roadway	Approach Roadway Rating	Approach roadway is the length of roadway, shoulder, and guardrail above the buried culvert or storm drain system that is influenced directly by the performance of the buried system. **Purpose:** Identify roadway distress indicators for problems with the culvert or storm drain below and often to locate the buried structure.
	Roadway Pavement	A rating of cracks, sags, humps and ruts in the roadway pavement
	Roadway Guardrail	A rating of the post alignment, settlement and rotation due to ground movement.
	Roadway Shoulders	A rating of cracks, sags, voids and soil in the shoulder area.
	Approach Roadway Comment	Remarks regarding the approach roadway not covered in other attributes.
Embankment	Embankment Rating	Inspection focuses on immediate slope area that provides burial for the culvert, 20 ft either side of culvert **Purpose:** Identify conditions that may be distress indicators for the structure. Must be paired with findings from other components
	Slope Stability and Embankment Erosion	A rating of rill and sheet erosion, sloughing, backfill displacement and soil cracks in the embankment
	Slope Stability and Embankment Erosion Comment	Remarks regarding the embankment not covered in other attributes
Channel Alignment and Protection	Channel Alignment and Protection Rating	The stream channel consists of the stream or river, its bed and the adjacent banks. **Purpose:** Identify channel-related problems that may affect the performance or structural stability of the culvert
	Channel Alignment	A rating of the channel angle and offset relative to the culvert centerline, ponding, and barrel undercutting
	Bank Erosion and Scour	A rating of bank erosion, scour, head cutting and undercutting
	Protection	A rating of protection displacement, undermining and material degradation of protection material
	Waterway Adequacy	A rating of sedimentation, debris, blockage and ponding in the culvert
	High Water Marks	Depth of marks indicating highs water levels
	Channel Alignment and Protection Comment	Remarks regarding channel alignment and protection not covered in other attributes.
End Treatment and Appurtenant Structures	End Treatment and Appurtenant Structures Rating	End treatments and appurtenant structures are the inlet/outlet structures and associated components that are used to reduce erosion, retain fill material, inhibit seepage, improve hydraulic efficiency, provide structural stability to the culvert ends and improve the appearance of the culvert. Purpose: Asses their structural stability, hydraulic performance and traffic safety characteristics.
	Cracking (Concrete)	A rating of cracks, infiltration, efflorescence, rust and corrosion in the concrete
	Surface Damage Spalling or Delamination (Concrete)	A rating of scaling, abrasion, impact damage, weep holes, rust and delamination of the concrete
	Deformation and Damage (Metal)	A rating of dents, impact damage and abrasion.
	Corrosion (Metal)	A rating of rust, corrosion, pitting and holes
	Scour and Stability	Scour refers to the process of erosion or removal of sediment, such as soil, sand, or rocks, from the areas around a culvert or within the channel due to the force of flowing water.
	Settlement/Rotation	Settlement refers to the vertical downward movement or displacement of a culvert or its associated structures, such as end treatments and appurtenant structures, as a result of changes in the supporting soil or foundation.
	End Treatment and Appurtenant Structures Comment	Remarks regarding end treatment and appurtenant structures not covered in other attributes
Barrel Alignment	Barrel Alignment Rating	Barrel alignment is a measure of horizontal and vertical deviation from the design profile. Purpose: To identify distress indicators that result in misalignment of pipe segments
	Barrel Alignment	A rating of sagging, heaving, ponding and sediment accumulation
	Barrel Alignment Comment	Remarks regarding barrel alignment not covered in other attributes
Corrugated Metal Barrel	Corrugated Metal Barrel Rating	The Corrugated Metal Barrel Rating is an assessment of the condition and performance of a corrugated metal culvert barrel. A culvert barrel is the primary conduit through which water flows, and in this case, it is made of corrugated metal.
	Surface Damage	A rating of dents, impact damage and wall breaches
	Corrosion (Metal)	A rating of rust, corrosion, pitting and holes
	Abrasion	Abrasion refers to the gradual wear and tear of the corrugated metal barrel's interior surface, caused by the continuous flow of water, sediment, debris, or other materials within the culvert.
	Shape (Closed Shape)	A rating of bulges, flattening, deformation, distortions and kinks

	Shape (Open Bottom)	The Shape (Open Bottom) attribute refers to the assessment of the structural condition and geometric profile of a corrugated metal culvert with an open bottom, also known as a bottomless culvert.
	Corrugated Metal Barrel Comment	Remarks regarding the corrugated metal barrel not covered in other attributes
Seams (Corrugated Metal Plate)	Seams (Corrugated Metal Plate) Rating	The Seams (Corrugated Metal Plate) Rating is an assessment of the condition and performance of the seams in a corrugated metal plate culvert. Seams are the connections between individual metal plates, which are assembled to create the culvert barrel. Properly functioning seams are crucial for maintaining the structural integrity, water tightness, and overall performance of the culvert.
	Infiltration / Exfiltration	A rating of water leakage through the seams, which can indicate issues with seam tightness, gasket performance, or corrosion-related damage.
	Seam Alignment	A rating of the alignment and fit of the metal plates at the seams, ensuring that the connections are secure and properly engaged.
	Seam Bolts/Fasteners	A rating of the condition and functionality of the bolts or fasteners used to secure the metal plates at the seams. This includes assessing for missing, loose, or corroded fasteners that may compromise the seam's integrity.
	Seam Bolt Holes	A rating of the condition of the bolt holes in the metal plates, looking for signs of yielding, cracking, splitting, or corrosion that may weaken the connection or result in leakage.
	Seams (Corrugated Metal Plate) Comment	Remarks regarding the seams not covered in other attributes
Joints	Joints Rating	The Joints Rating is an assessment of the condition and performance of the joints in a culvert system. Joints are the connections between separate sections or elements of the culvert, such as pipe segments, concrete slabs, or masonry units.
	Joints Separation, Offset, and Rotation	A rating of joint separation, offset, or rotation, which may indicate issues with the connection, misalignment, or deformation.
	Joint Cracking (Concrete)	A rating of cracks in concrete joints, which may be caused by various factors, such as thermal expansion, shrinkage, or external loads.
	Infiltration / Exfiltration	A rating of water leakage into or out of the culvert through the joints, which may indicate damage to the connections, improper sealing, or other issues that compromise the watertightness of the culvert system.
	Joints Comment	The Joints Comment section provides space for remarks regarding the joints that are not covered by the specific attributes mentioned above.
Concrete Barrel	Concrete Barrel Rating	The Concrete Barrel Rating is an assessment of the condition and performance of a concrete culvert barrel. A culvert barrel is the primary conduit through which water flows, and in this case, it is made of concrete.
	Cracking	A rating of cracks, infiltration, efflorescence, and rust in the concrete, which may indicate potential structural issues or reduced service life.
	Spalling / Slabbing / Delamination / Patches	A rating of spalls, slabbing, delamination, and rust, which are signs of surface damage or deterioration in the concrete.
	Deterioration	A rating of scaling, abrasion, impact damage, weep holes, aggregate pop-out, and corrosion. These factors indicate wear and tear or material degradation, which may compromise the culvert's structural integrity or hydraulic performance.
	Concrete Barrel Comment	The Concrete Barrel Comment section provides space for remarks regarding the concrete barrel that are not covered by the specific attributes mentioned above
Concrete Footing and Invert Slab	Concrete Footing and Invert Slab Rating	The Concrete Footing and Invert Slab Rating is an assessment of the condition and performance of the concrete footing and invert slab in a culvert system. Concrete footings provide foundational support for the culvert structure, while the invert slab forms the bottom surface of the culvert, aiding in water flow and preventing erosion of the underlying soil.
	Differential Settlement and Movement	A rating of uneven settling or movement of the concrete footing and invert slab, which may indicate issues with the underlying soil or foundation, leading to misalignment or deformation of the culvert structure.
	Scour and Stability	A rating of the stability of the concrete footing and invert slab in relation to water flow and erosion.
	Cracking	A rating of cracks in the concrete footing and invert slab, which may be caused by various factors such as thermal expansion, shrinkage, or external loads.
	Surface Damage	A rating of surface damage, such as spalling, scaling, or abrasion, which may affect the structural integrity and durability of the concrete footing and invert slab.
	Spalling / Delamination / Patches	A rating of spalling, delamination, or patched areas in the concrete footing and invert slab, which may indicate previous repairs or ongoing deterioration of the concrete material.
	Concrete Footing and Invert Slab Comment	The Concrete Footing and Invert Slab Comment section provides space for remarks regarding the concrete footing and invert slab that are not covered by the specific attributes mentioned above.
Plastic Barrel	Plastic Barrel Rating	A flexible barrel commonly made of materials including HDPE, PVC, PP and FRP Purpose:
	Shape	Identify distress in the barrel, other than misalignment, that may affect structural stability or functional performance

	Surface Damage	A rating of impacts, creases, crack, tears, abrasion, splitting and photodegradation
	Local Buckling, Splits and Cracking	A rating of rippling, cracking, splits, infiltration, kinks and buckling.
	Plastic Barrel Comment	Remarks regarding the plastic barrel not covered in other attributes
Masonry Barrel	Masonry Barrel Rating	A barrel constructed of individual masonry units made of stone, brick or concrete blocks Purpose: Identify distress or potential distress
	Masonry Units and Movement	A rating of cracking, weathering, spalling, scaling, movement, dislocation, splitting, crushing and distortion
	Mortar	A rating of cracks, missing mortar, deterioration, infiltration, exfiltration and vegetation
	Efflorescence or Staining	A rating of efflorescence and staining
	Masonry Barrel Comment	Remarks regarding the masonry barrel not covered in other attributes
Timber Barrel	Timber Barrel Rating	The Timber Barrel Rating is an assessment of the condition and performance of a timber culvert barrel. A timber barrel is the primary conduit through which water flows, and in this case, it is made of timber products. Timber culverts can provide a more natural and aesthetically pleasing appearance but may be more susceptible to decay, structural overload, or material deterioration over time compared to concrete or metal culverts.
	Connections or Missing Members	A rating of the connection integrity, missing bolts, rivets or fasteners, broken welds, rusting, and distortion.
	Decay	A rating of the decay or rot present in the timber barrel, which may compromise its structural integrity and shorten its service life.
	Checks / Shakes	A rating of checks or shakes (cracks or separations) in the wood, which may be caused by drying, stress, or other factors. These can affect the timber barrel's structural stability and performance.
	Structural Cracks	A rating of structural cracks in the timber barrel, which may indicate potential structural issues or reduced service life.
	Delamination	A rating of delamination or separation of wood layers, which can compromise the structural integrity of the timber barrel.
	Abrasion/Impact Damage	A rating of abrasion or impact damage to the timber barrel, which may be caused by water flow, debris, or other external factors.
	Distortion	A rating of distortion or deformation in the timber barrel, which may affect its structural stability and hydraulic performance.
	Timber Barrel Comment	The Timber Barrel Comment section provides space for remarks regarding the timber barrel that are not covered by the specific attributes mentioned above.

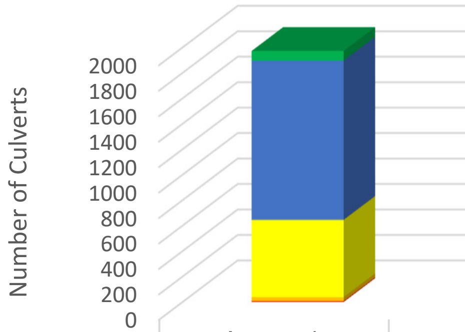
7.1 Component Condition

The condition of component depends on the worst condition of all attributes/criteria representative of component condition. The current condition of culvert was estimated on a scale of 1 to 5 as shown in Table 5.

Table 5: General Condition Rating scale for attributes

Rating	State
Excellent	1
Good	2
Fair	3
Poor	4
Severe	5
N/R: Culvert factors not-rated (N/R) in the field are assigned a Fair condition.	

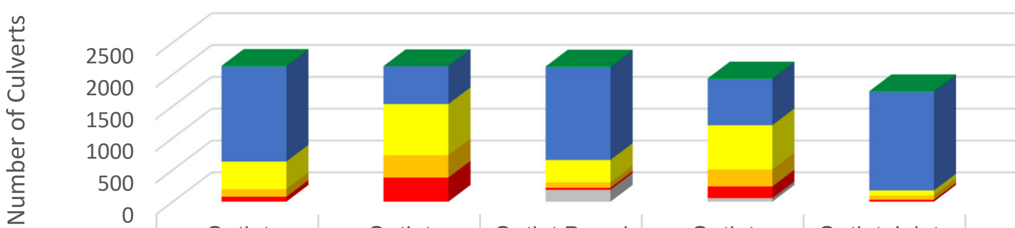
Approach Roadway Condition was generally in good condition with 40 approach roadway components where at least one attribute among pavement, guardrail and shoulder was in poor or severe condition. Figure 6 shows the approach roadway condition.



	Approach Roadway Rating
Excellent	76
Good	1251
Fair	607
Poor	32
Severe	6
N/R	0

Figure 6: Approach Roadway Condition

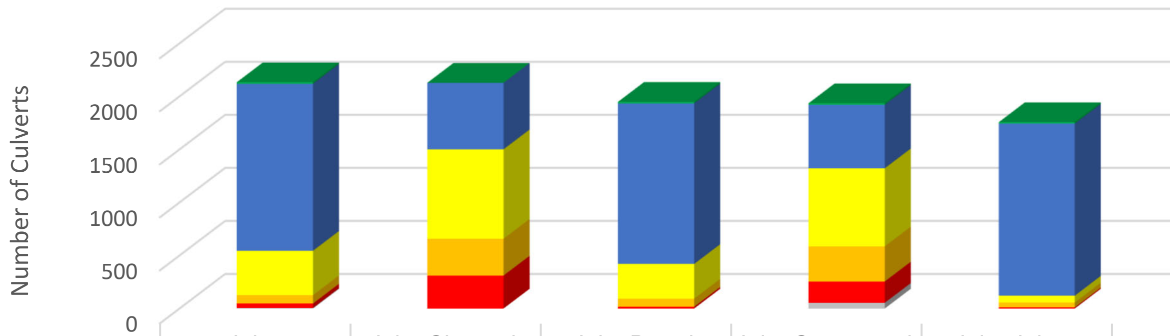
Select components were rated separately for outlets and inlets sides of the culvert. Figure 7 shows the outlet component condition. Overall, in terms of Poor and Severe condition, the outlet side channel alignment and protection, and metal barrel material is leading. It is also important to point out that three quarter of the inventory outlet channel alignment and protection was found to be in Fair condition or worst.



	Outlet Embankment Rating	Outlet Channel Alignment and Protection Rating	Outlet Barrel Alignment Rating	Outlet Corrugated Metal Barrel Rating	Outlet Joints Rating
Excellent	13	0	15	13	14
Good	1490	597	1453	722	1545
Fair	433	803	352	697	80
Poor	119	351	84	265	65
Severe	78	379	32	183	31
N/R	0	0	187	56	0

Figure 7: Outlet Components Condition (Embankment, Channel Alignment and Protection, Barrel Alignment, Corrugated Metal Barrel, Outlet Joints)

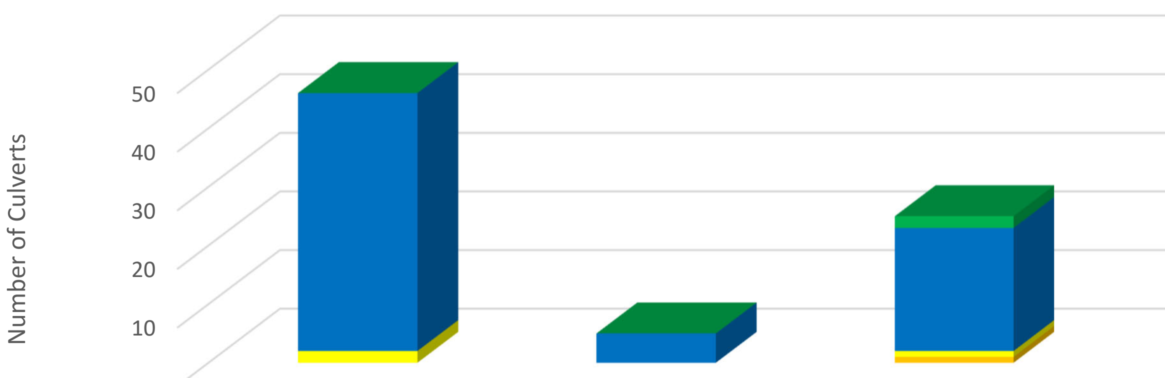
Figure 8 shows the inlet components condition (Embankment, Channel Alignment and Protection, Barrel Alignment, Corrugated Metal Barrel, Outlet Joints). The figure shows that the quarter of Channel Alignment and Protection, and Corrugated Metal Barrel components are in poor and very poor condition.



	Inlet Embankment Rating	Inlet Channel Alignment and Protection Rating	Inlet Barrel Alignment Rating	Inlet Corrugated Metal Barrel Rating	Inlet Joints Rating
Excellent	14	0	14	14	14
Good	1575	627	1514	599	1622
Fair	418	843	327	736	64
Poor	79	347	76	331	46
Severe	42	311	17	201	11
N/R	5	0	0	54	0

Figure 8: Inlet Components Condition (Embankment, Channel Alignment and Protection, Barrel Alignment, Corrugated Metal Barrel, Outlet Joints)

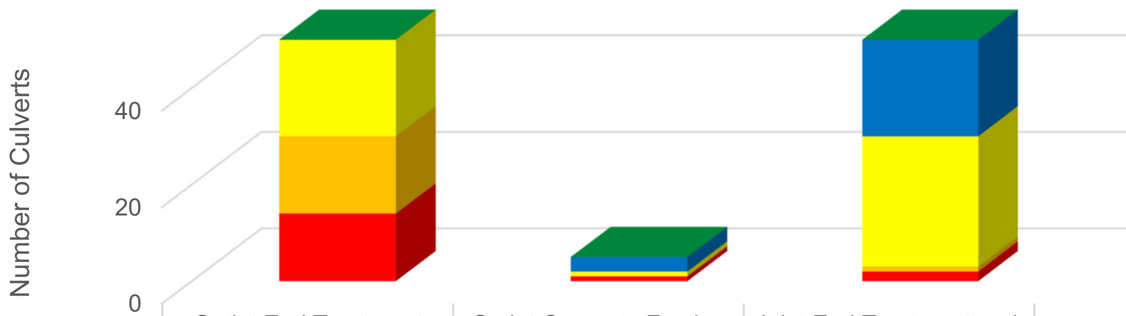
Figure 9 shows the other component rating such as seams, concrete barrel, plastic barrel, and timber barrel.



	Seams (Corrugated Metal Plate) Rating	Concrete Barrel Rating	Plastic Barrel Rating
Excellent	0	0	2
Good	44	5	21
Fair	2	0	1
Poor	0	0	1
Severe	0	0	0
N/R	0	0	0

Figure 9: Other Components Condition (Seams, Concrete Barrel, Timber Barrel)

Some components were only applicable when End Treatment and Appurtenant Structures and/or Concrete Footing and Invert Slab were present on the culverts. Figure 10 shows the culvert specific components condition.



	Outlet End Treatment and Appurtenant Structures Rating (Culvert Specific)	Outlet Concrete Footing and Invert Slab Rating (Culvert Specific)	Inlet End Treatment and Appurtenant Structures Rating (Culvert Specific)
Excellent	0	0	0
Good	39	3	24
Fair	65	1	27
Poor	16	0	1
Severe	14	1	2
N/R	0	0	0

Figure 10: Culvert Specific Components Condition

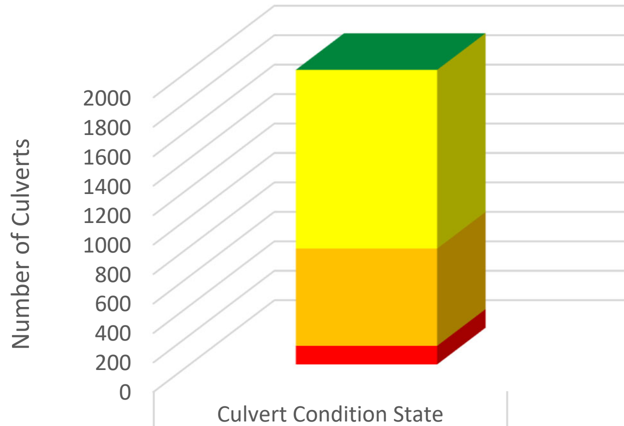
7.2 Overall Condition

The overall condition of the culvert was calculated using a regression equation based on the individual condition of the components which is based on the worst condition of all attributes representative of the component. Figure 12 shows the culvert components condition rating collected for the inventory.

Table D1 - Culvert Component Condition Rating

								Component Ratings											
								Outlet Component Ratings						Inlet Component Ratings					Overall
GIS Station	Asset ID	Center Latitutde	Center Longitude	Features Crossed	Barrel Material	Span (mm)	Rise (mm)	Approach Roadway Rating	Outlet Embankment Rating	Outlet Channel Alignment and Protection Rating	Outlet Barrel Alignment Rating	Outlet Corrugated Metal Barrel Rating	Outlet Joints Rating	Inlet Embankment Rating	Inlet Channel Alignment and Protection Rating	Inlet Barrel Alignment Rating	Inlet Corrugated Metal Barrel Rating	Inlet Joints Rating	Components Rated
133.454	1	56.59545	-121.46040	Highway	Corrugated Steel		450	Fair	Severe	Severe	N/R	N/R	N/A	Poor	Severe	N/A	Severe	N/A	8
133.803	2285	56.59775	-121.46415	Highway	Corrugated Steel		600	Good	Good	Good	Good	Good	Good	Good	Good	Good	Poor	Good	11
134.169	2284	56.60070	-121.46679	Highway	Corrugated Steel		600	Good	Good	Fair	Good	Poor	Good	Good	Good	Good	Severe	Good	11
134.373	2	56.60231	-121.46831	Highway	Corrugated Steel		900	Good	Good	Fair	Fair	Fair	Good	Good	Severe	Fair	Fair	Good	11
134.580	3	56.60357	-121.47075	Access Road	Corrugated Steel		450	Fair	Good	Severe	N/R	Severe	N/A	Good	Severe	N/A	N/R	N/A	8
134.655	4	56.60426	-121.47127	Access Road	Corrugated Steel		900	Poor	Good	Severe	Good	Poor	Good	Good	Severe	Good	Severe	Good	11
134.881	5	56.60557	-121.47407	Highway	Corrugated Steel		600	Fair	Good	Fair	Fair	Poor	Good	Good	Fair	Fair	Severe	Good	11
135.540	6	56.60965	-121.48180	Highway	Corrugated Steel		600	Fair	Good	Poor	Good	Severe	Good	Good	Severe	N/A	Severe	N/A	9
135.700	7	56.61066	-121.48363	Highway	Corrugated Steel		600	Fair	Good	Severe	Fair	Severe	Good	Good	Severe	Fair	Severe	Good	11
135.987	8	56.61242	-121.48705	Highway	Corrugated Steel		900	Fair	Fair	Fair	Good	Fair	Good	Good	Fair	Good	Poor	Good	11
136.241	9	56.61416	-121.48976	Access Road	Corrugated Steel		450	Poor	Poor	Severe	N/R	N/R	N/A	Good	Severe	N/A	N/R	N/A	8
136.432	10	56.61579	-121.49083	Access Road	Solid Wall Steel		450	Poor	Good	Good	Good	Fair	Good	Good	Fair	Good	Good	Good	11
136.500	11	56.61627	-121.49157	Highway	Corrugated Steel		600	Fair	Good	Poor	Fair	Fair	Fair	Good	Fair	Fair	Severe	Good	11
136.715	12	56.61796	-121.49323	Highway	Corrugated Steel		600	Fair	Good	Poor	Fair	Fair	Good	Good	Fair	Good	Severe	Good	11
137.223	13	56.62192	-121.49728	Highway	Corrugated Steel		600	Fair	Good	Poor	Fair	Severe	Good	Good	Poor	Fair	Severe	Good	11
137.855	14	56.62557	-121.50513	Access Road	Corrugated Steel		600	Good	Good	Fair	Good	Fair	Good	Good	Poor	Good	Severe	Good	11
138.129	15	56.62677	-121.50905	Highway	Corrugated Steel		600	Fair	Good	Severe	Fair	Poor	Good	Good	Severe	Good	Poor	Good	11
138.457	16	56.62848	-121.51339	Highway	Corrugated Steel		600	Fair	Good	Severe	N/R	Poor	N/A	Good	Severe	Fair	Poor	Good	10

Figure 11: Culvert Components Condition



	Culvert Condition State
Excellent	43
Good	64
Fair	1269
Poor	660
Severe	126

Figure 12: Overall Culvert Condition

8.0 MULTI-CRITERIA DECISION ANALYSIS (MCDA)

Multiple criteria or multicriteria decision analysis (MCDA) – also known as multiple-criteria decision-making (MCDM) – is the collective name of formal approaches that support decision making by taking into account multiple criteria in an explicit and transparent way (Belton V, 2002).

Multi-criteria decision analysis (MCDA) is a powerful tool for evaluating infrastructure projects. It enables decision-makers to identify and compare the relative merits of alternative projects and assess the impact of uncertainty, and incorporate designers' preferences. MCDA has been increasingly used in the last decade for evaluating infrastructure projects.

MCDA is a systematic process used for analyzing discrete decision problems where the circumstances are not clearly defined. MCDA is based on the concept of deriving an overall score for the decision option, or alternative, being analyzed. The decision maker defines the relative importance factors of criteria as they pertain to a specific project. Relative importance factors are numerical representations of the preference of the decision maker, commonly based on background information and experience. MCDA provides a numerical score, or rating, assigned to a given alternative with respect to each criterion.

In decision-making scenarios there may exist disagreement between varying decision makers as to the relative importance given to criteria. It is possible, with MCDA techniques, to quickly examine many scenarios and provide simple tools for comparison.

A simple linear additive model takes the following form:

$$P_j = \sum_{i=1}^{n} w_i s_{ij} \qquad (1)$$

where P_j is the priority score of the jth culvert, s_{ij} is the score or rating of the jth culvert on the ith criterion and w_i is the weight or value of the ith criterion.

8.1 Overall Culvert State

The overall culvert state consists of 5 state condition rating system similar to component level condition state collected during inspection. The condition score of culverts calculated from the MCDA process were converted to an equivalent 5 state condition rating for overall culvert.

Table 6 provides the culvert state and condition descriptions for overall culvert state.

Table 6: Culvert State and Condition Descriptions

State	Description
1	**Excellent**
2	**Good**
3	**Fair**
4	**Poor**
5	**Severe**

It was determined that overall condition of the culvert cannot be better than the condition of the barrel, therefore following equation was used to determine the overall condition for modelling. This means that even if an asset appears to be in good condition if any of its components are in poor condition, the asset will not be able to properly perform its intended function. Therefore, it is important we use barrel state as the conservative path of deterioration to proactively predict the intervention before a failure.

$$Culvert\ Modelling\ State = Max\ (Culvert\ State, Barrel\ State) \quad (2)$$

8.2 Establishing MCDA Criteria

The MCDA development process for a culvert system should weigh condition, inventory and hydraulic factors to ensure the agency goals and policies are incorporated in decision-making. The decision analysis process should consider all relevant factors in order to make the best decision possible. The current decision criteria were developed to asses' the culvert's overall condition based on the information collected during the survey, such as condition, inventory, and hydraulic data.

There are many formal methods for eliciting preferences and aggregating weights. A list of inputs and criteria was developed to serve as the basis of the MCDA process. The criteria consist of the condition of components, inventory parameters and hydrotechnical analysis results, which allowed decision makers to prioritize the repair of culverts based on specific component's condition and inventory-related parameters.

The MCDA score consists of the MCDA Condition score, MCDA Inventory score and MCDA Hydraulic score. The criteria are the factors which will affect the decision as to which assets should be prioritized for funding. The condition numerical scores (from 0.1 to 1) are assigned to each unique value for all factors of the asset. The decision matrix is populated by assigning weights to all attributes. The weights are assigned by expert judgment based on the importance of each attribute in relation to the decision.

The MCDA score of culverts was calculated as the sum of the Score for Condition, Inventory, and Hydraulic-related parameters.

$$MCDA\ Culvert\ Score = MCDA\ Condition\ Score + MCDA\ Inventory\ Score + MCDA\ Hydraulic\ Score \tag{3}$$

The MCDA score can provide an objective metric to prioritize rehabilitation of culverts before a comprehensive economic analysis. The culvert MCDA score is dependent on Condition, Inventory and Hydraulic criteria and score calculated above. Figure 13 shows the MCDA Condition, Inventory, and Hydraulic score and ranking of the culverts.

		COMPONENTS NUMERICAL SCORE											CONDITION, INVENTORY, CULVERT MCDA				CONDITION, INVENTORY, CULVERT MCDA SCORE RANK			
Barrel Material	Rise (mm)	MCDA Approach Roadway Rating	MCDA Outlet Embankment Rating	MCDA Outlet Channel Alignment and Protection Rating	MCDA Outlet Barrel Alignment Rating	MCDA Outlet Corrugated Metal Barrel Rating	MCDA Outlet Joints Rating	MCDA Inlet Embankment Rating	MCDA Inlet Channel Alignment and Protection Rating	MCDA Inlet Barrel Alignment Rating	MCDA Inlet Corrugated Metal Barrel Rating	MCDA Inlet Joints Rating	MCDA Condition Score	MCDA Inventory Score	MCDA Hydraulic Score	MCDA Culvert Score	MCDA Condition Score Rank	MCDA Inventory Score Rank	MCDA Hydraulic Score Rank	MCDA Culvert Score Rank
Corrugated Steel	450	1	15	7	3	10	0	14	7	0	20	0	76	15	1	92	26	1715	1753	49
Corrugated Steel	600	1	5	3	2	6	3	5	3	2	9	3	39	15	1	55	1513	1636	1632	1764
Corrugated Steel	600	1	5	4	2	10	3	5	3	2	11	3	47	16	2	64	825	1222	1283	1002
Corrugated Steel	900	1	5	4	3	9	3	5	7	3	7	3	47	17	5	70	795	614	428	636
Corrugated Steel	450	1	5	7	3	20	0	5	7	0	10	0	57	14	0	71	302	1885	1789	567
Corrugated Steel	900	2	5	7	2	9	3	5	7	2	9	3	52	14	0	65	528	1870	1789	906
Corrugated Steel	600	1	5	4	3	10	3	5	4	3	9	3	48	14	1	63	733	1819	1632	1067
Corrugated Steel	600	1	5	5	2	14	3	5	7	0	20	0	61	15	1	77	197	1586	1632	328
Corrugated Steel	600	1	5	7	3	11	3	5	4	3	10	3	54	14	1	69	407	1801	1632	693
Corrugated Steel	900	1	8	4	2	7	3	5	4	2	11	3	49	17	5	72	684	452	428	519
Corrugated Steel	450	2	14	7	3	10	0	5	7	0	10	0	57	13	0	69	311	2081	1789	659
Solid Wall Steel	450	2	5	3	2	8	3	5	4	2	6	3	41	12	0	53	1385	2121	1789	1901
Corrugated Steel	600	1	5	5	3	8	4	5	4	3	10	3	49	16	2	66	707	1345	1329	889
Corrugated Steel	600	1	5	5	3	8	3	5	3	2	12	3	48	16	2	67	753	899	1162	839
Corrugated Steel	600	1	5	7	3	10	3	5	5	3	13	3	55	16	2	73	352	1111	1136	430
Corrugated Steel	600	1	5	4	2	7	3	5	5	2	9	3	44	15	0	59	1085	1486	1789	1403
Corrugated Steel	600	1	5	5	3	14	3	5	5	2	13	3	57	16	3	76	312	1023	1009	344
Corrugated Steel	600	1	5	7	3	11	0	5	7	3	11	3	54	15	1	70	404	1429	1753	619
Corrugated Steel	600	1	5	7	3	9	0	8	7	0	9	0	47	13	0	61	793	1960	1789	1287

Figure 13: MCDA Condition, Inventory, and Hydraulic Score and Ranking

8.2.1 Condition Score

The culvert condition score is a measure of the condition of a culvert and is used to prioritize culverts for repair or replacement. It combines all information collected during the culvert inspection into one number that can be compared across culverts.

8.2.2 Inventory Score

The culvert inventory score is a measure of prioritization of the culverts based on its characteristics such as features crossed, pipe type, shape, length, rise etc. The higher the Score, the higher the importance of repair or replacement.

The inventory related factors were collected during the field inspection. The inventory related factors collected during the field inspections were grouped by the inventory category for each culvert. The MCDA inventory category was assigned a score of 30 depending on the importance of the group on the overall condition score.

8.2.3 Hydraulic Score

Hydraulic Score measures the adequacy of existing culvert capacity over demand at each culvert crossing. It can be used to prioritize culvert with lower than required capacity across the culverts. The higher the gap in capacity and demand higher will be the prioritization of the culverts. The hydraulic Score also takes in account the future demand of the crossing considering climate change in 60 years.

The hydraulic related factors such as Local Failure Flow (m3/s), Current Failure Flow Annual Exceedance Probability, and Future Failure Flow Annual Exceedance Probability were some of the factors selected for determining the hydraulic Score. The information on how the factors were calculated in more detail is in the hydrotechnical analysis section of the report. The MCDA hydraulic category was assigned a score of 25 depending on the importance of the group on the overall condition score.

9.0 CONCLUSION AND CONSIDERATIONS

In conclusion, this paper has demonstrated the effectiveness of a tablet-based inventory and condition inspection procedure for culvert assets using the data collection criteria outlined in the AASHTO Culvert and Storm Drain System Inspection Manual (2020). By implementing this procedure on the Alaska Highway in British Columbia, it has been shown that the digitization of data collection and real-time reporting offers significant time and cost savings, improved accuracy, and repeatability for culvert inspections.

The adoption of an ArcGIS-based mobile solution facilitated efficient data collection, analysis, and sharing of information, leading to better asset management decision-making. Moreover, the component-level rating system enabled a more practical and cost-effective capital works program, as it allowed for targeted maintenance and repairs instead of replacing the entire culvert.

The successful application of this tablet-based inspection procedure on the Alaska Highway has significant implications for other agencies and asset management programs. The inventory and condition collected can be used to develop long-term culvert capital works replacement and adaptation programs. In the future, this approach can be further refined and expanded to enhance the overall management of culvert assets and other infrastructure components.

- Develop a system for tracking and monitoring the progress of capital works projects. This should include tracking the progress of the projects against their timelines and budgets, as well as identifying areas for improvement or efficiencies.
  - Maintaining an active culvert asset management inventory assists in tracking culvert inventory completed activities such as system maintenance, rehabilitation and replacement activity.
  - The data can be used to refine the predictive analytics approaches which help identify potential issues with culvert assets before they become major problems.
- Inspection frequency for culverts is at the discretion of the agency not dictated by the guidance(AASHTO, 2020). Culvert condition inspection should be carried out on a routine basis to update the existing culvert condition history. The AASHTO guidelines provides an illustrated example of routine inspection of culverts based on the largest barrel size, S, typically taken as the diameter of round pipes or the span for other shapes, however agency developed inspection frequencies may be less frequent than those recommended in Table 7.

Table 7: Barrel Size and Inspection Frequency (AASHTO, 2020)

Barrel Size (S)	Inspection Frequency
S < 1.2 m	Inspect during roadway maintenance activities
1.2 m < S < 3.0 m	Every 10 years or prior to routine roadway maintenance activities, whichever is less.
S > 3.0 m	Every 5 years or prior to routine roadway maintenance activities, whichever is less.

- Agencies typical update their capital works program every 4-5 years for roads. The frequency to update culvert capital works program is at the discretion of the agency.

10.0 ACKNOWLEEDGEMNT

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