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Framework for the Development and Deployment of a Culvert Asset Management Plan in Alaska

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This report describes the results of a Culvert Asset Management Plan study. The objectives of the study are to increase the understanding and confidence necessary to design and execute a culvert asset management plan in Alaska. The essential features of a CAMP are the use of inventory, inspection and rating data, and life cycle planning models based on engineering and economic analysis. These features will lead to the development of optimal strategies and investments for maximum value and minimal risk. The strategies, investments, and results are subsequently measured to determine their effectiveness and success, to ensure that Department objectives are achieved. Culvert inventories should be developed and managed by the three individual regions. The inventory attributes to be selected for measurement should be chosen to answer the core question: what is the current state of the physical asset? Culvert inspection teams have two tasks: 1) assess service performance, and 2) make accurate ratings that are repeatable by other inspectors. A database software product should be selected for use in all three regions. The use of a single database software package will allow regional control over inventory management, and enable the seamless creation of a living active statewide culvert inventory database.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4		mm
ft	feet	0.3048		m
yd	yards	0.914		m
mi	Miles (statute)	1.61		km
		AREA		
in^2	square inches	645.2	millimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.4046	hectares	ha
		MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g
lb	Pounds (avdp)	0.454	kilograms	kg
T	Short tons (2000 lb)	0.907	megagrams	mg
		VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL
gal	Gallons (liq)	3.785	liters	liters
ft^3	cubic feet	0.0283	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3

		TEMPERATURE (exact)		
ºF	Fahrenheit temperature	5/9 (ºF-32)	Celsius temperature	ºC
		ILLUMINATION		
fc	Foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

These factors conform to the requirement of FHWA Order 5190.1A *SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	Miles (statute)	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.471	acres	ac
		MASS (weight)		
g	grams	0.0353	Ounces (avdp)	oz
kg	kilograms	2.205	Pounds (avdp)	lb
mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces (US)	fl oz
liters	liters	0.264	Gallons (liq)	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3

		TEMPERATURE (exact)		
ºC	Celsius temperature	9/5 ºC+32	Fahrenheit temperature	ºF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

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Cover photo by K. Karle.

EXECUTIVE SUMMARY

In 2019, the DOT&PF adopted its first Transportation Asset Management Plans (TAMP) for the preservation of bridges and pavements with all federally required elements. Federal rules do not require the inclusion of culvert assets in the TAMP. However, integrating the Transportation Asset Management principles into the administration of other types of transportation facilities in Alaska could provide similar benefits: effective, systemic, and accountable management of those assets. To achieve this goal, the Department initiated a Culvert Asset Management Plan (CAMP) study; accordingly, the objectives of the study are to increase the understanding and confidence necessary to design and execute a CAMP in Alaska.

The essential features of a CAMP are the use of inventory, inspection and rating data, and life-cycle planning models based on engineering and economic analysis. These features will lead to the development of optimal strategies and investments for maximum value and minimal risk. The strategies, investments, and results are subsequently measured to determine their effectiveness and success to ensure that the Department's objectives are achieved.

The development and deployment of an effective asset management plan requires an up-to-date understanding of the number, location, and status of the asset. There is currently no single comprehensive up-to-date statewide inventory of DOT&PF culverts.

Recommendations

Within the DOT&PF, current policy designates regional oversight for design, construction, and maintenance of culverts. This report recommends that culvert inventories should be developed and managed by the three individual regions. A single database software product should be selected for use in all three regions. The implementation and use of a single database software package will allow regional control over inventory activities and data management and will also enable the seamless creation of a living active statewide culvert inventory database.

A database software package for the culvert inventory should be easily accessible to all users in all DOT&PF offices. Additionally, the software should use, or operate with, existing DOT&PF IT infrastructure. We recommend using ESRI ArcGIS applications in the initial stages of a CAMP, including data inventory, field collection of data, mapping, preliminary analysis, presentation of results, and data storage. The applications currently utilized in the Central and Southcoast Regions provide a template for how ESRI applications would be used for a regional/statewide culvert inventory program.

Field data collection can begin once the culvert inventory database tables have been created, tested, and implemented by migrating information from existing databases. Such inspection data, both existing and new, will create the backbone of the CAMP and enable the Department to make decisions that can directly impact the following: 1) safety and 2) maintenance, repair, and

rehabilitation budgets. The culvert inspection teams collecting the data have two tasks: 1) assess service performance and 2) make accurate ratings that are repeatable by other inspectors.

We recommend that the Department adopt the Inspection Procedure described in detail in the Culvert and Storm Drain System Inspection Guide (AASHTO, 2020). The attributes to be selected for measurement as part of a culvert inventory are chosen to address several core questions, the first of which is the following: what is the current state of the physical asset?

Inspection frequency should be often enough to capture the point at which degradation progresses to a level that maintenance could prevent failure and when a culvert is rated poor or severe. AASHTO indicates that a more frequent inspection cycle may be needed where corrosion is of particular concern. The inspection frequency needs to provide a consistent minimum level of safety. The proper inspection cycle may be adjusted as the program matures.

We recommend that the Department adopt the AASHTO Condition Rating System to rate and describe the individual components of a culvert installation. The AASHTO system assigns a rating from 1 (Good) to 4 (Severe), using specific criteria obtained by the visual inspection and basic measurements prescribed by the Tier 2 inspection method.

Once culvert attributes are measured and condition ratings assigned, additional analyses can be conducted statewide or for individual pipes, highway segments, and regions. Utilizing ArcGIS, a culvert inventory database can be draped onto the DOT&PF Roadway Data Map and queried to provide visual analyses of attribute data and statistical information. Culvert deterioration models will allow planners and engineers to repair, rehabilitate, or replace failing culverts in a timely manner. Life-cycle cost analysis (LCCA) can be used to preview budget outcomes and improve management strategies.

Implementation of a CAMP will be a substantial task; in this regard, many different programmatic components must be researched, described in policies and procedures, and managed. We recommend that a pilot study be conducted prior to a full-scale implementation of a CAMP. A pilot study will be used as an assessment of the practicality of a CAMP. Such studies can analyze the technical, operational, and time feasibility factors. A small-scale feasibility study will allow the development of project protocols, assess the methods and required frequency of culvert inspection, develop the framework for data inventory and management, and determine if advanced analyses such as deterioration modeling and LCCA provide economic advantages to the Department.

Funding will be needed for both the pilot study and program implementation. Culvert inventory and inspection costs alone will be significant. For example, a Department proposal for a 2011 budget request was developed to conduct a stand-alone reconnaissance effort to ascertain the condition and function of large diameter (greater than 48 inches), corrugated metal pipes (CMP's) throughout the three Alaska regions. The total estimated cost, spread out over a five-year project timeline, was $7,750,000.

CHAPTER 1 - INTRODUCTION

Problem Statement and Research Objective

Efforts are being conducted nationally to prepare risk-based Transportation Asset Management Plans (TAMP) for the National Highway System to improve or preserve the condition of the assets and the performance of the system (FHWA, 2007). Under the Transportation Asset Management System (TAMS) initiative, the Alaska Department of Transportation & Public Facilities (DOT&PF) is working toward a results-based program for managing, evaluating, repairing, and replacing various transportation-related assets. Results-based management is a strategy by which processes, outputs, and services contribute to the achievement of clearly stated expected accomplishments and objectives. Ultimately, the core focus is achieving results. The DOT&PF has adapted TAMS asset management practices for the preservation of bridges and pavements (DOT&PF, 2019).

The Department recognizes that integrating the TAMP principles into the administration of other types of transportation facilities in Alaska would provide similar benefits: effective, systemic, and accountable management of those assets. By linking planning, programming, and budgeting of more asset classes on data informed analysis and statewide needs, the State of Alaska will have a more effective, credible, and defensible transportation program (DOT&PF, 2019).

To achieve this goal, the Department initiated a Culvert Asset Management (CAM) study; accordingly, the objectives of the study are as follows: 1) gather useful knowledge and other relevant information from other agencies and state departments of transportation (DOTs) that have, successfully and otherwise, implemented statewide culvert inventories and related asset management plans and 2) increase the understanding and confidence necessary to design and execute a Culvert Asset Management Plan (CAMP) in Alaska.

Task 1 of this study was the completion of a literature review. See Appendix 1.

Task 2 – Functional Framework

The focus for Task 2 was to create a framework for the development and deployment of a CAMP within the DOT&PF. The ultimate goal is to simplify complex decisions for culvert replacement through the use of a series of comparative evaluations for condition (culvert and embankment) and cost.

A proposed framework for the development and deployment of a CAMP is found in Figure 1. Key features of the process are described in the following paragraphs.

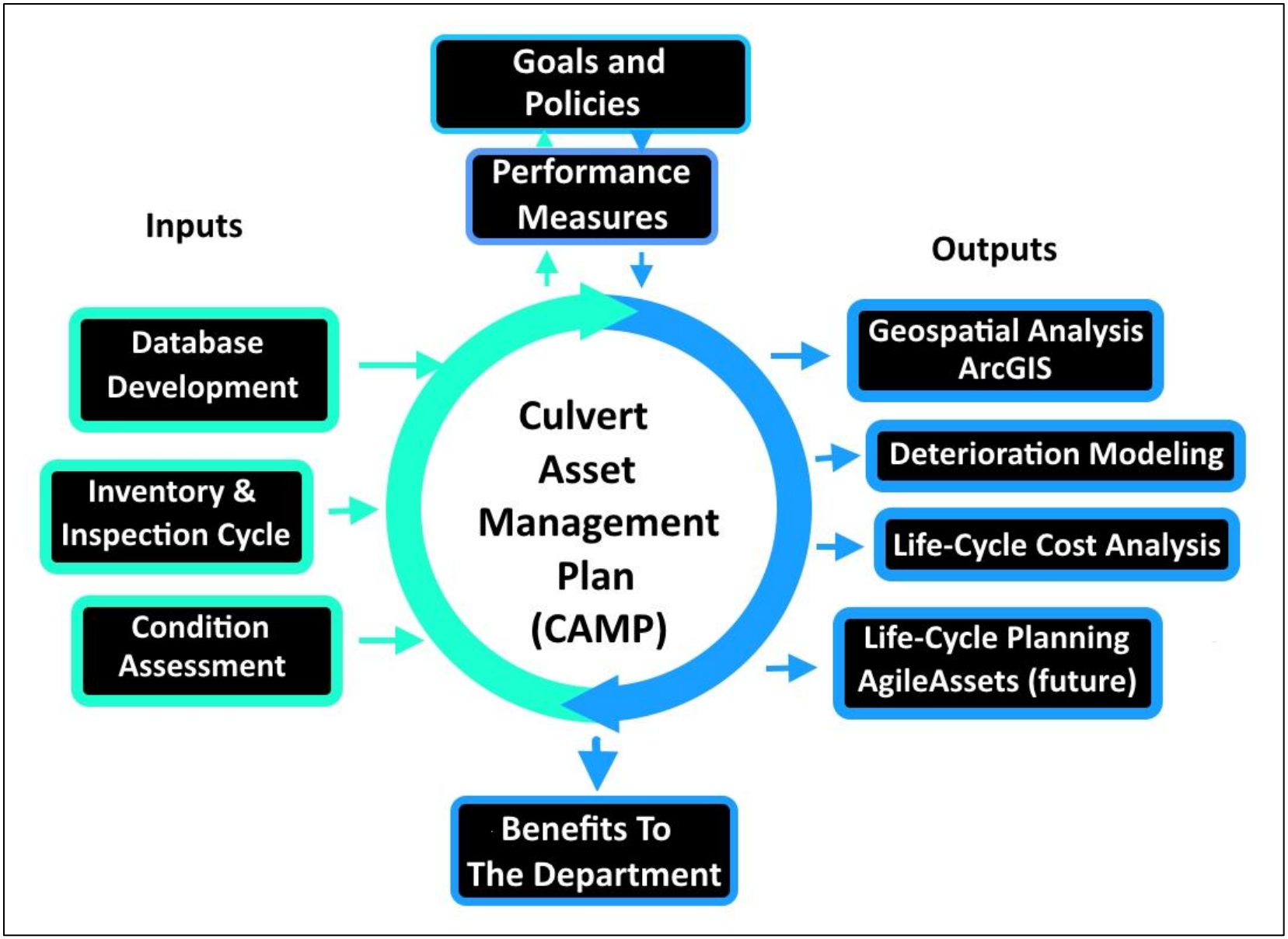


Figure 1. Framework for the development and deployment of a Culvert Asset Management Plan.

CHAPTER 2 – GOALS AND POLICIES

Transportation Asset Management in Alaska

In 2013, the Alaska Legislature passed the Alaska Statute AS 37.07.014, which describes and promotes the concept of 'results-based government' for state agencies. The Alaska Department of Transportation & Public Facilities (DOT&PF) is working toward a results-based program for managing, evaluating, repairing, and replacing various transportation-related assets. The DOT&PF has adapted TAMS asset management practices for the preservation of bridges and pavements (DOT&PF, 2019). The Department has replaced their legacy systems with the proprietary software AgileAssets in an effort to minimize the life-cycle costs associated with managing and maintaining their transportation assets and increase staff efficiency through data integration across the agency. The DOT&PF is currently using the AgileAssets Pavement Management System to perform life-cycle planning analysis to preview budget outcomes and improve management strategies.

At this time, the TAMP for Alaska includes National Highway System bridges and pavement only. Integrating the TAMS principles into the administration of other types of transportation facilities in Alaska would provide similar benefits: effective, systemic, and accountable management of those assets. By linking planning, programming, and budgeting of more asset classes on data informed analysis and statewide needs, the State of Alaska will have a more effective, credible and defensible transportation program (DOT&PF, 2019).

The DOT&PF is responsible for designing, installing, and maintaining culverts across Alaska. When properly designed and maintained, functioning culverts are a key component to an efficient and safe transportation system, enabling the DOT&PF to meet their objectives as prescribed by AS 37.07.014.

The objective of AS 37.07 is to direct the DOT&PF and other state agencies to meet their mission statements by setting priorities, allocating sufficient resources to accomplish those priorities, assign accountability, and develop methods to measure, report, and evaluate results. To meet these objectives, new policies are needed to ensure Department personnel have the tools to succeed.

Culvert Asset Management Plan

The essential features of a CAMP are the use of inventory, inspection and rating data, and life-cycle planning models based on engineering and economic analysis. These features will lead to the development of optimal strategies and investments for maximum value and minimal risk. The strategies, investments, and results are subsequently measured to determine their effectiveness and success to ensure that the Department's objectives are achieved.

Culvert inventories are often conducted only during the initial phase of a pavement preservation or rehabilitation project, with the goal of determining immediate culvert replacement needs and budget requirements. For pavement preservation projects, even though numerous culverts may need replacing or are in poor condition, only culverts in the worst condition or near failure are typically chosen for replacement. For larger rehabilitation projects, budgets for projects with older assets will have substantially higher funding levels for culvert replacement. However, pre-project scoping may still fail to identify all culverts within the project limits that exhibit poor conditions.

Complete and up-to-date culvert inventories will be critical for properly scoping drainage needs and replacement priorities for pavement preservation or rehabilitation projects, both large and small. Any inspections conducted to prepare a scoping budget for project planning should be added to, or used to update, the regional culvert inventories.

In addition to drainage activities tied to pavement projects and maintenance activities, regional hydraulic engineers are often alerted by Maintenance and Operations (M&O) or others to critical culvert conditions that suggest function and highway safety are at immediate risk. Such conditions generally require immediate attention and significant action; minor repair actions such as debris clearance or appurtenance replacement are not always sufficient repairs. M&O crews or contractors frequently perform such emergency repairs; however, the Department does not have dedicated resources for this type of work. As a result, replacement delays and temporary repairs occur frequently in such situations. It will be important to address this issue as CAMP implementation proceeds.

Fundamental to ranking culverts as to their need for repair or replacement is the requirement to have accurate, accessible data for this asset. How culverts are inspected, evaluated, and reported is critically important.

CHAPTER 3 – DATABASE DEVELOPMENT

Inventory Platform Recommendation

The development and deployment of an effective asset management plan requires an up-to-date understanding of the number, location, and status of the asset. Transportation researchers have noted that agencies that monitor culverts and regularly assess culvert condition will benefit from the lower culvert repair costs that come from eliminating or significantly reducing failures. Safety is also an important reason for culvert inventory and inspection as part of a CAMP (Perrin and Dwivedi, 2006).

There is currently no single comprehensive up-to-date statewide inventory of DOT&PF culverts. Descriptions of individual culvert inventories developed and used by the DOT&PF, including the M&O Maintenance Management System (MMS) inventory and individual regional inventories, are found in the literature review (Karle, 2021).

Culvert inventories should be developed and managed by the individual regions. A single database software product should be selected for use in all three regions. Database software is used to create, edit, and maintain database files and records, enabling easier file and record creation, data entry, data editing, updating, and reporting. The software also handles data storage, backup and reporting, multi-access control, and security.

The implementation and use of a single database software package will allow centralized data governance and stewardship, while regional management of local inventory activities and attribute selection will enable the seamless creation of a living active all-inclusive statewide culvert inventory database.

Two primary considerations for the selection of a database software package are as follows: 1) the database(s) should be easily accessible to all users in all DOT&PF offices, and 2) the software should use, or operate with, existing DOT&PF IT infrastructure.

ArcGIS

We recommend using ESRI ArcGIS applications in the initial stages of a CAMP, including data inventory, field collection of data, mapping, preliminary analysis, presentation of results, and data storage. Widely used across the Department for other programs, ArcGIS should be incorporated in a CAMP as the center of spatial data storage and GIS data management workflow. The ArcGIS applications and methods currently utilized in the Central and Southcoast Regions for their respective culvert inventory efforts provide an existing and excellent template for how ESRI applications could be used to develop and maintain a statewide culvert database.

At a future stage, the Department may wish to employ AgileAssets to conduct advanced analysis such as life-cycle cost planning. With all of the data required for such analyses stored in a centralized repository, statewide policies for items such as material type selections, preferred corrosion management provisions, or fish passage standards could be readily supported. It may also be advantageous to ultimately store the culvert inventory data in an AgileAssets dataset and then export to ArcGIS for mapping and other geospatial purposes.

Culvert Inventory Database

Though a separate GIS can be created solely for culvert data storage and management, substantial advantages will be achieved by incorporating data tables and management within the existing DOT&PF statewide GIS managed by the Transportation Geographic Information Section (TGIS). For example, the culvert spatial data can overlay the existing DOT&PF statewide road network GIS map, which includes the National Highway System (NHS) and Alaska Highway System (AHS) routes. The benefits include superior mapping, spatial joins and queries, association of culvert to route ID, road name and milepost, and automated mapping and directions to culvert sites on portable data collectors.

Database Tables

Within the GIS, database tables would be created for culvert inventory and measured attribute storage. A master list of all attributes will form the basis of data columns for the tables. The three regional data tables can be individualized per the region's specific needs and interests by restricting data entry according to the attributes desired for the region they represent. In this manner, the regional tables are essentially unique but can be queried together for a seamless analysis or a report of all statewide culvert data.

Note that for attributes that are shared across all three tables, it is critical that the measurement or assessment of those attributes utilize the exact same evaluation methods and standards of assessment. Such evaluations, performed in different regions by various personnel, will require training and consistent guidance on what to inspect and how to assess inspection findings (AASHTO, 2020).

Data Collection

The CAMP would utilize an ESRI mobile application such as Survey123 or Collector for the field collection of culvert data. Survey123 is designed for collecting new data and not editing or updating existing data; on the other hand, Collector for ArcGIS is designed for the collection/editing of map data from the field and allows for the updating and changing of polygons, lines, and points.

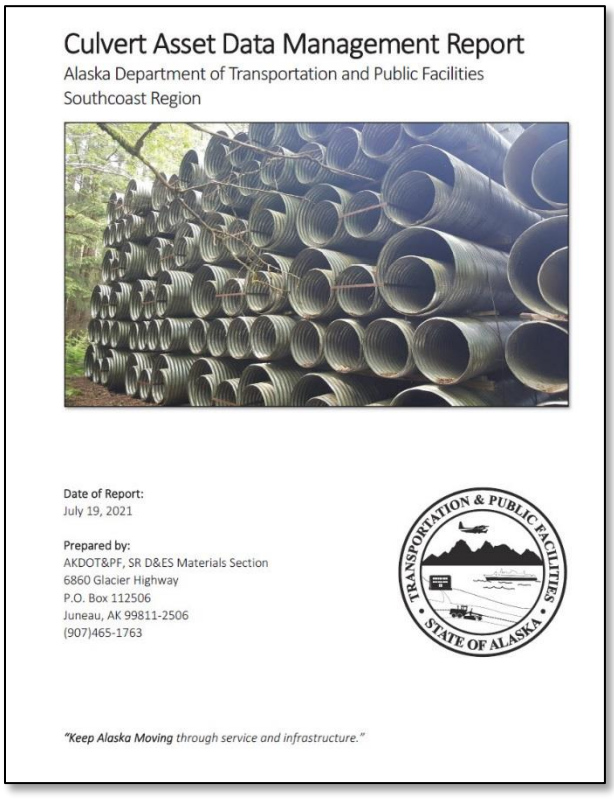
Such applications may be loaded onto dedicated tablets or even smart phones. When loaded inside of the ESRI Field Maps application, the data collection device can use data-driven maps to help mobile workers perform data collection and editing, find the culvert assets, and report their real-time locations. The collected data will be automatically inserted into the regional culvert database table; on this note, if the data collection effort occurs outside the range of connectivity, the device will hold the data and transfer once it is in range of cell service.

CHAPTER 4 – ASSET INVENTORY

Migrate Existing Databases

Once database tables have been created for each of the three regions, the process of populating those tables begins, thereby initiating the basic component of the culvert inventory. Database entry can begin well before any field measurements are taken, using one or more of the following data sources.

Regional Culvert Inventories


Culvert Asset Data Management Report

Alaska Department of Transportation and Public Facilities

Southcoast Region

Date of Report:
July 19, 2021

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TRANSPORTATION & PUBLIC FACILITIES
STATE OF ALASKA

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Figure 2. Southcoast Region culvert asset data management report.

The Southcoast Region (SR) maintains an active culvert inventory (Figure 2). Similar to the Northern Region (NR) and Central Region (CR), culverts within the SR have been historically inventoried on a per-project basis. Though extensive gaps of culvert location and condition still exist, an online database has provided an easy and quick method to update and add culvert data. The SR consolidated inventory is hosted and updated through ArcGIS Online. Updates to the online version are managed through ArcGIS Collector (mobile data collection app), Survey123 (ArcGIS survey data app), and Web maps (ArcGIS geographic interactive display app). An example of the SR ArcGIS Online Dashboard for Culverts is shown in Figure 3. If a DOT&PF CAMP is adopted, the existing SR database would be moved into the new CAMP ArcGIS database, along with an inventory record.

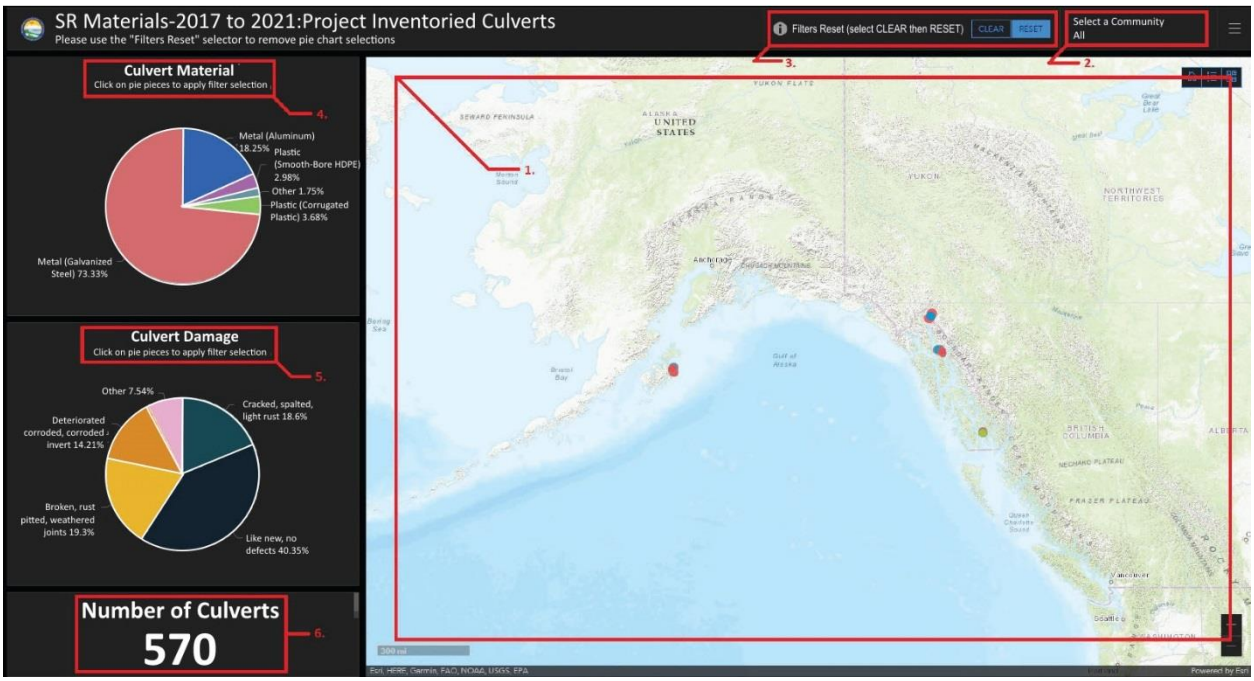

Figure 3. Southcoast Region ArcGIS online dashboard.

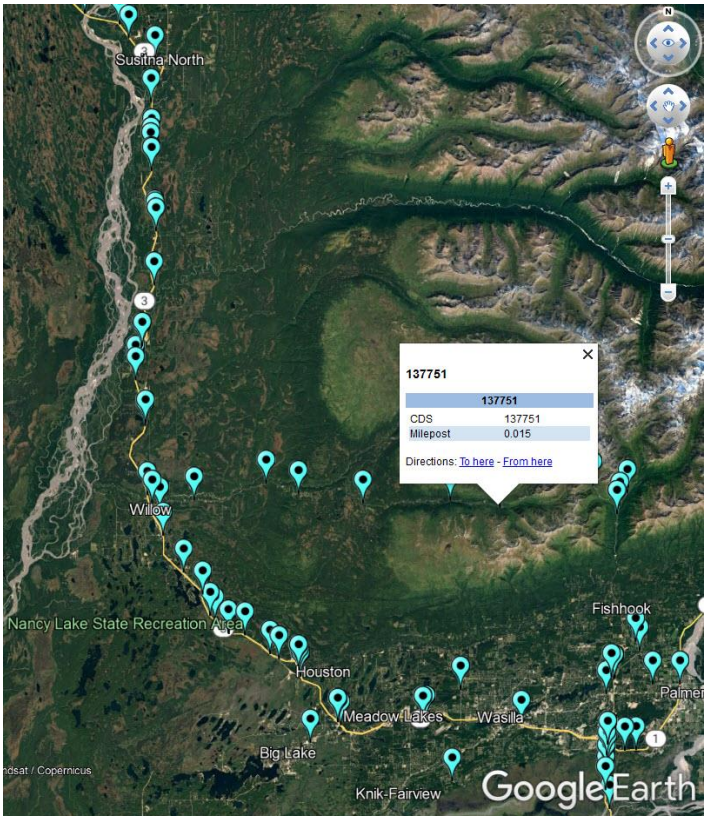

Figure 4. In addition to their ArcGIS culvert database, the Central Region maintains inventoried culvert locations in a KMZ file.

The Central Region (CR) maintains a culvert and storm drain inventory with a rise of 48 inches and greater. Estimates are that the inventory accounts for over 90% of the existing culverts (48 inches and greater) within the region. The inventory is based solely on as-built drawings and was last updated in 2018. Recorded attributes include the following: diameter, skew, span, pipe length, end treatment, material, stream name, structure name, bridge number, and remarks (Jake Ciufo, personal communication, August 19, 2021). CR engineers have been using Survey123 for ArcGIS to collect culvert inspection data. This data is stored as an ArcGIS feature layer in the ArcGIS online cloud. Before actual fieldwork and additional attribute measurements, effort would focus on moving the CR databases into the new CAMP ArcGIS database. Much of the information currently in the CR

databases will be used to create an 'inventory record.' See Figure 4.

The Northern Region (NR) does not have a comprehensive culvert inventory database in place. However, culvert inspections have been performed as part of the preliminary data collection for complete highway reconstruction projects as well as rehabilitation projects; most projects begin with a review of as-built drawings for culverts 48 inches and greater and the associated Culvert Summary sheet. Individual project files for previous and ongoing highway rehabilitation or reconstruction projects would be reviewed and mined for culvert inventory data. These data would be used to populate a new CAMP ArcGIS database for the NR, along with an inventory record. An example of an NR culvert inventory and inspection project is found in Figure 5.

MMS 2007 Culvert Database

Approximately 13,000 culverts were located and recorded during a 2007 project conducted in conjunction with the three regions. The M&O MMS was designated as the original repository for the collected culvert data. Some areas of the state were missed, especially off the road system. Note that culvert size was not a factor in collection for this project; hence, it most likely contains all sizes, including those which now have an assigned bridge number as part of the National Bridge Inventory (NBI).

The 2007 data are maintained by the Department's Geospatial Engineering Services group within the Information Systems and Services Division. Formats include Excel and GIS files (Sean Jordan, personal communication). Acquired field data included site photographs and centerline locations. No culvert condition information was collected or recorded. Even without measured attributes, these data are valuable for creating individual culvert inventory records. The dataset should be sorted by region and then used to create inventory records within their respective regional datasets.

Minor Structures Inventory

Culverts with a width/diameter of between 10 and 20 feet and owned by the DOT&PF are designated with a 7000 series bridge number, are classified as 'minor structures,' and are maintained in a separate database. This dataset has a little more information such as length, bridge number, and location. The assigned bridge number allows the culvert to be referenced back to the bridge system for additional information. The dataset is available on the DOT&PF Atlas website (Sean Jordan, personal communication). These culverts are generally inspected every 5 years. The dataset should be sorted by region and then included within their respective regional culvert datasets.

Richardson Hwy MP 266-341 SPL
Existing Crossing Culvert Inventory and Inspection Summary

Pipe No.	Approx. Mile Post	Size (in)	Number of Barrels	Approx. Length (ft)	Skew (deg)	Pipe Type	Inlet Side	Anadro-mous	End Section		Year Inspected	Project Impacts	Condition Rating	25 Yr Remaining Life?	Recommendation	Observations
									Inlet	Outlet						
51	301.4	36	1	110	0	CMP-R	RT	NO	PROJ	FES	2017	NB (LT) passing lane full width widening	D	No	Replace	Very mild flow. Significant frost heave in middle of pipe, with standing water in barrel upstream. Outlet has been extended 12' with new helical CMP. Flared end section is perched 18" above grade.
52	301.3	24	1	115	0	CMP-R	RT	NO	PROJ	FES	2017	NB (LT) passing lane full width widening	D	No	Replace	Very mild flow. Significant frost heave in middle of pipe, with standing water in barrel upstream. Outlet has been extended 12' with new helical CMP. Flared end section is perched 8" above grade. Inlet is 25% blocked with dirt and vegetation.
53	301.2	24	1	110	0	CMP	RT	NO	PROJ	PROJ	2017	NB (LT) passing lane full width widening	A	Yes	Extend and stabilize outlet	Very mild flow. Outlet is perched 6" above grade. Moderate rusting along barrel bottom.
54	301.1	24	1	125	0	CMP-R	RT	NO	PROJ	PROJ	2017	NB (LT) passing lane full width widening	D	No	Replace	Ephemeral flow. Outlet is 25% blocked with debris with standing water inside pipe. Inlet is crushed and jacked up, with possible flow piping under culvert. Heavy rusting along barrel bottom.
55	301.0	36	1	100	0	CMP-R	RT	NO	PROJ	PROJ	2017	NB (LT) passing lane full width widening	C	No	Replace	Ephemeral flow. Inlet is overgrown with vegetation. Outlet end is 75% blocked by moss and debris, with standing water inside pipe. Barrel is heavily rusted.
56	300.8	24	1	80	0	CMP-R	RT	NO	PROJ	FES	2017	NB (LT) passing lane full width widening	C	No	Replace	Ephemeral flow. Inlet is 25% blocked by overgrown vegetation. Outlet end section is overgrown with 6" of standing water inside pipe. Outlet end has been extended with new helical CMP.
57	300.7	24	1	80	0	CMP-R	RT	NO	PROJ	PROJ	2017	NB (LT) passing lane full width widening	D	No	Replace	Very mild flow. Inlet is overgrown with 12" of standing water in pipe. Outlet is crushed and buried with 16" of standing water in pipe. Barrel is heavily rusted.
58	300.4	84	1	220	45	SPP	LT	NO	P-HW	P-HW	2017	NB (LT) passing lane full width widening	C	Yes	Extend, regrade and armor outlet channel.	Conveys Canyon Creek, small stream with OHW width = 5'. Inlet headwall atttached but one anchor bolt missing. Moderate rusting along barrel bottom but no visible rust holes in main pipe. Some settlement of outlet section of pipe. Backwater at outlet. Stream has jumped bank of outlet pool, creating a new channel.
58B	300.4	36	1	210	45	CMP-R	LT	NO	PROJ	PROJ	2017	NB (LT) passing lane full width widening	B	Yes	None	Canyon Creek overflow relief culvert. Visible embankment erosion under inlet. Very little rust inside barrel.
59	299.9	84	1	150	45	SPP	RT	NO	P-HW	P-HW	2017	NB (LT) passing lane full width widening	B	Yes	Extend, regrade and armor inlet channel	Conveys Canyon Creek. OHW width = 5'. Channel widens slightly downstream of outlet with some minor scour. Outlet headwall partially exposed but in good condition; light damage to one anchor bolt. Sediment wedge present at inlet, which pushes flow out of alignment with pipe, causing eddy adjacent to pipe. South end of headwall is exposed with moderate scour at footer. Erosion has propogated 10' into embankment.
60	299.7	36	1	100	0	CMP-R	RT	NO	PROJ	PROJ	2017	NB (LT) passing lane full width widening	C	No	Replace with larger pipe	Conveys small stream that outfalls to Canyon Creek. Inlet is completely blocked by woody debris, likely due to fact that channel enters culvert at a 90° angle. Outlet is perched 4'.
61	299.6	36	1	125	0	CMP-R	RT	NO	PROJ	PROJ	2017	NB (LT) passing lane full width widening	D	No	Replace	Very mild flow. Pipe has a severe frost heave near its midpoint. Outlet outfalls to Canyon Creek. Outlet is perched 18" with some erosion underneath. Inlet end of pipe has been extended with new helical CMP
62	299.5	84	1	180	10	CMP-R	LT	NO	P-HW	P-HW	2017	No anticipated impacts. Pipe is stationed 250' beyond NB (LT) passing lane taper	C	No	Stabilize outlet	Conveys Canyon Creek. OHW width = 5.5'. Outlet has been severely undermined by scour. Outlet is perched 6' above water surface, and the headwall is completely exposed and partially supported by foundation soils. One side of the headwall is tipping and twisting the pipe with it. A very large scour pool has formed downstream, approximately 30'W x 40'L. Barrel has significant rusting but no visible rust holes.
63	294.1	24	1	120	0	CMP	LT	NO	FES	FES	2017	SB (RT) passing lane taper widening	A	Yes	Clear ends and extend	Ephemeral flow. Both ends are partially overgrown. Pipe has very little rusting.
64	293.7	36	1	110	0	CMP	LT	NO	FES	FES	2017	SB (RT) passing lane full width widening	C	Yes	Extend; consider replacement	Ephemeral flow. Outlet is 50% blocked with embankment material. Pipe sags sharply in the middle with ponded standing water.
100	293.5	24	1	125	10	CMP	LT	NO	PROJ	PROJ	2017	SB (RT) passing lane full width widening	B	Yes	Clear ends and extend	Ephemeral flow. Both ends partially overgrown. 4" of standing water inside pipe. Very little barrel rusting.
101	292.2	24	1	100	0	CMP	LT	NO	PROJ	PROJ	2017	NB (LT) passing lane full width widening	D	No	Replace	Ephemeral flow. Inlet is crushed and buried. Approximately 15' upstream of outlet a debris blockage obstructs 90% of the pipe, with structural damage to barrel.
65	291.6	24	1	105	0	CMP-R	RT	NO	FES	FES	2017	NB (LT) passing lane full width widening	D	No	Replace	Very mild flow. Inlet end section is damaged and separated from pipe. Barrel is heavily rusted and has standing water throughout pipe length.

Figure 5. Northern Region culvert inventory and inspection conducted by HDL Engineers for Richardson Hwy MP 246-341 SPL.

ADFG Fish Passage Inventory Database

Other agencies throughout the State of Alaska maintain their own culvert inventories. For the purposes of the proposed CAMP, the most useful and up-to-date inventory is maintained by the Alaska Department of Fish and Game (ADFG). The Fish Passage Inventory Database (FPID) contains data on over 3,129 stream crossings assessed for fish passage by the ADFG since 2001, which represents over 95 percent of all state-owned roads and thoroughfares (ADFG, 2021; Gillian O'Doherty, personal communication, September 13, 2021). Culverts outside the road system are also mapped if they appeared to have fish habitats upstream of them. The information is available online and may be accessed using the online ArcGIS Fish Resource Monitor interactive mapping application.

Use of the ADFG FPID has become one of the tools that DOT&PF regional hydraulic engineers utilize when starting to assess projects. In fact, contributions to the database have been made by DOT&PF when fish presence has been discovered during the early project assessment stages (Jeff Stutzke, personal communication, October 2022).

Typical culvert measurements in the FPID include location (latitude/longitude), pipe type, length, inlet type, corrugation depth and width, gradient, and others. Habitat attributes and culvert photographs are typically included. Condition ratings are assigned to each surveyed culvert; ratings describe the suitability of a culvert for the passage of juvenile and weak-swimming fish.

The ADFG FPID dataset would be sorted by region and then used to create inventory records and initial culvert attribute records within their respective regional datasets. Note that the list of culvert attributes collected for the FPID is not identical to those recommended for the CAMP, which are described below in the section labeled **Culvert Metrics to Evaluate**. The FPID condition ratings are based on entirely different criteria than those recommended below for the CAMP. These two programs have different missions, objectives, and measures of performance. However, the FPID could be utilized to locate culverts, initiate database creation, anchor dates for condition changes and rates of change, and provide information for creating an inventory record for each culvert entry.

Initiate Field Data Collection

Field data collection can begin once the culvert inventory database tables have been created, tested, and implemented by migrating information from existing databases. Such inspection data, both existing and new, will create the backbone of the CAMP and enable the Department to make decisions that can directly impact maintenance, repair, and rehabilitation budgets. As such, the culvert inspection teams collecting the data have two tasks: 1) assess service performance and 2) make accurate ratings that are repeatable by other inspectors.

We recommend that the Department adopt the inspection procedure described in Section 3 of the 2020 Culvert and Storm Drain System Inspection Guide (AASHTO, 2020). This guide:

- Outlines the elements of an inspection program
- Provides general procedures for conducting and reporting inspections
- Describes the roles, duties, responsibilities, and qualifications of the inspectors
- Describes the safety measures for performing culvert inspections
- Provides guidance for an inspection quality management system

Note that routine inspections are the focus of the AASHTO guide; such inspections consist of the visual and nondestructive measurements necessary to assess the condition and assign condition ratings. The AASHTO guide does not include special inspections that are conducted outside of the routine inspection. Specialists in hydraulics, soils, materials, structural analysis, or load ratings may be required for inspections other than routine inspections (AASHTO, 2020).

Culvert Metrics to Evaluate

The culvert attributes to be measured during inventory are chosen to fulfill the project goal, which is to develop and maintain a culvert asset management program for the DOT&PF. Transportation asset management is a business model, a decision support system, and a management approach to address several core questions, the first of which is: **what is the current state of the physical asset?** This question clarifies the type and number of attributes that may be collected during culvert inventory.

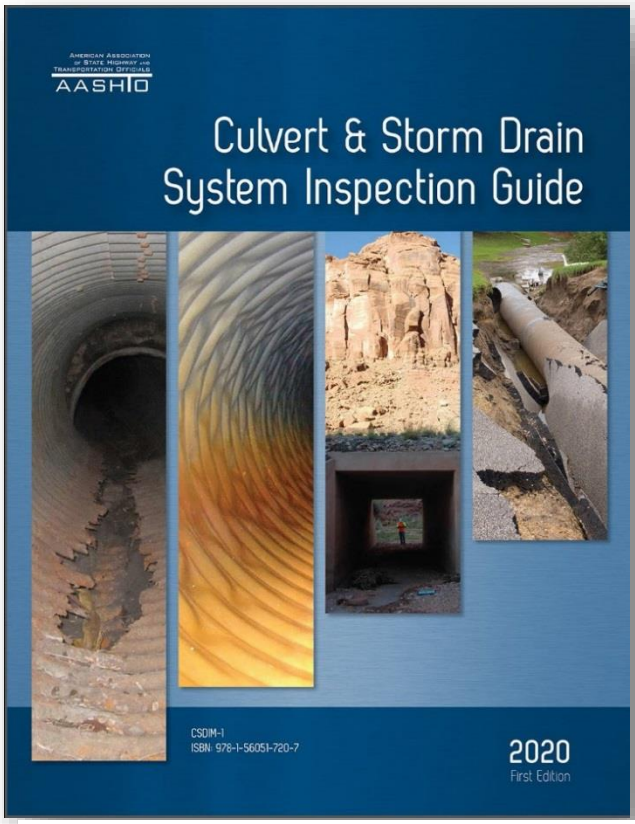

Figure 6. AASHTO guide for culvert inspection and assessment rating.

Routine inspections should be conducted at a defined frequency or cycle. These inspections utilize visual and non-destructive measurements to assess culvert condition and assign condition ratings. Routine inspections are used to do the following: 1) document the condition of the system components at the time of inspection, 2. evaluate the overall system functional performance, and 3) track how the system components are aging

The primary objective of a culvert inventory effort is to answer the question: what is the current state of the physical asset? In addition to attributes that are used to describe and rate the condition of the current state of the culvert, there has been interest in including design information in the inventory as well. Such information could include items such as design discharge estimation, slope, channel width, and many others.

An earlier effort by the Department to establish a statewide culvert inventory database resulted in a suggested attribute list that exceeded one hundred entries. Though desired or required inventory attributes will vary by region, an overly expansive and wide-ranging attribute list could become cumbersome and lead to inefficient use of time by field personnel and/or database managers.

One solution is to develop and use the AASHTO-recommended inventory record, which is described in detail in the next section of this report. Inventory records are designed to provide a method to record and catalog non-repeating attributes such as design and installation records. By keeping these data in a separate location, field attribute lists are kept smaller and simpler, and it may also improve the efficiency of field data collection.

There are differing opinions as to how many and what types of attributes should be measured during a culvert inventory site visit. The final comprehensive list should be developed by a consensus between DOT&PF engineers, considering the primary objective of the culvert inventory effort.

SR Tier System for Data Collection

In recognition of the time-consuming process involved in culvert attribute fieldwork, the SR developed a tier system for data collection. To accommodate the differing data needs depending on project objectives, a three-tier system was implemented. This tier system allows the user to collect only the amount of data needed for his or her intended objective. The SR tiers are described below:

SR Tier 1-Picture and Point Collection. Culvert geolocation and pictures are collected, providing a baseline for future surveys and enough data to get the geo-located culvert into the inventory.

SR Tier 2-Reconnaissance. Data are provided for recon-level engineering. Attributes include culvert geometry, condition, material, and inlet and outlet types, among others. Note that the data collection table is set up such that subsequent tiers are not able to be filled out until the previous tier's requirements are met.

SR Tier 3-Design. Additional attributes include ADFG Fish Passage Site ID, ADFG AWC ID, embedment depth, and culvert recommendations.

Tier 1 - Visual Inspection

Following evaluation of several methods of culvert attribute collection, we propose that a simplified two-tier inspection/condition assessment approach is implemented in the CAMP in combination with a separate inventory record for each culvert.

For inspection teams with limited time, a Tier 1 template would be utilized. Attributes to be collected would include the following:

- Location data
- Photographs
- Visual inspection of culvert corrosion, cross-section deformation, invert deterioration, and joints and seams
- Culvert performance observations (blockage, poor channel alignment, overtopping, and scour)

Following the collection of culvert data, the inspection team would make a rapid assessment of the condition and performance of the culvert to be recorded with the dataset and forwarded immediately to the regional hydraulic engineer. The Tier 1 rapid condition assessment is discussed in Chapter 5.

The estimate time required for a two-person team to collect the Tier 1 attribute data is 30–60 minutes per culvert, not including travel time.

Tier 2 – Full Inspection

For inspection teams with adequate available field time, a Tier 2 template would be utilized. See Table 1. Attributes to be collected would include the following:

- Tier 1 attributes if not collected in an earlier visit
- Attributes recommended by AASHTO

The list of recommended attributes listed in Table 1 are taken primarily from AASHTO (2020). Regional hydraulic engineers, statewide engineers, M&O personnel, and others may suggest additional attributes that should be collected during a culvert inventory effort. For example, water pH and soil resistivity data may also be collected in regions where corrosion is a significant factor for culvert deterioration. Such regional differences may dictate specific and unique regional attributes to be collected during inspection.

Full culvert inspections of multiple attributes are time consuming. Such an inspection, along with associated data collection of photographs, notes, and other items, may reasonably be expected to take a two-person crew anywhere from four to eight hours per culvert, not including travel time.

Table 1. Proposed components and attributes to be measured during the Tier 2 inspection process.

Component	Attributes
Roadway Condition	pavement distress
	guardrail sags
	shoulders
Embankment	sloughing
	tension cracks
	embankment erosion
Channel	alignment
	bank erosion
	scour
	protection
	waterway adequacy
End Treatments and Appurtenant Structures	erosion and scour
	end section drop-off
	buoyancy
	headwall separation
	corrosion
Barrel Alignment	vertical-sags and heaving
	horizontal-straightness
Corrugated Metal Barrel	corrosion
	abrasion
	shape
Joints and Seams	joint separation, offset, and rotation
	infiltration and exfiltration
	seam alignment
	bolts and fasteners
Water and Soil Acidity	water pH
	soil resistivity

It is important to recognize that there are many hazards associated with culvert inspections (either Tier 1 or 2), including confined space, drowning, traffic, and steep banks. The safety of the inspection team and the public is important when conducting inspections. The AASHTO manual describes the hazards, suggests methods to avoid or address those hazards, and recommends that safety issues be included in the inspection team training (AASHTO, 2020).

Inventory Record

In addition to measurable attributes that will be used to rate the condition of a culvert, AASHTO also recommends that an **inventory record** should be developed and maintained in the database. Inventory records are different than the culverts' measurable attributes. Such records include design and installation records, location, type of structure, span, barrels, road, stream, repair history, and other descriptive items. Hydraulic data should also be included in the record,

including drainage area, design storm frequency and discharge, and normal and high water surface elevation. Note that the documentation of culvert design is required by the policy described in the Alaska Highway Drainage Manual (DOT&PF, 1995).

AASHTO provides sample inspection forms and notes that agency-specific forms should be tailored for the agency's asset management system, include flexibility for each system to maximize efficiency, reduce redundant entries required in the field, and collect all data required for the inspection record (AASHTO, 2020).

The sheer number of culverts to be inventoried in a region will require a substantial labor effort over a multiple-year period, especially during the initial inspection cycle.

Inspection Cycle

Federal regulations mandate that all bridges, including culvert-like structures with spans greater than 20 ft, are to be inspected on a two-year cycle. In contrast, culverts and storm drains with under-20-ft spans have no federally mandated or funded minimum inspection cycle (AASHTO, 2020).

Inspection frequency is critical for planning maintenance and rehabilitation activities.

Inspection frequency should be often enough to capture the point at which degradation progresses to a level that maintenance could prevent failure and when a culvert is rated poor or severe. AASHTO indicates that a more frequent inspection cycle may be needed where corrosion is of particular concern. The inspection frequency needs to provide a consistent minimum level of safety. The proper inspection cycle will be difficult to quantify and may be adjusted as the program matures.

Factors that may affect inspection frequency include culvert size, condition rating, structure age, average daily traffic (ADT), environmental conditions, risk criteria, and special function. A review of agency schedules indicates that the most common criteria is barrel size. AASHTO provides a table of example inspection frequencies for routine inspection and condition assessment/rating but notes that agency-developed frequencies may be less than those shown in their example table. See Tables 2 and 3 for a list of the AASHTO-recommended routine inspection frequencies, modified by suggestions received from DOT&PF reviewers. As culverts deteriorate or experience design discharges, inspections should be more frequent.

In Alaska, culverts included in the minor structures program are generally inspected every five years. This includes culverts between 10–20 feet in diameter.

Table 2. Modified AASHTO routine inspection frequencies for culverts that were in good or better condition during the previous inspection and have not experienced a design discharge after the previous inspection.

Barrel Span (S)	Inspection Frequency
S < 4 ft	Inspect every five years.
4 ft ≤ S < 10 ft	Every 10 years or prior to routine roadway maintenance activities, whichever is less.
S >= 10 ft	Every five years or prior to routine roadway maintenance activities, whichever is less.

Table 3. Modified AASHTO inspection frequencies for culverts that have a poor or severe condition rating or that have experienced a design discharge (or greater) following the previous inspection.

Barrel Span (S)	Inspection Frequency For Culverts in Corrosive Locations or Culverts with 'Poor' or 'Severe' Condition Rating
S < 4 ft	Inspect every two years or during roadway maintenance activities.
4 ft ≤ S < 10 ft	Every two years or prior to routine roadway maintenance activities, whichever is less.
S >= 10 ft	Every one year or prior to routine roadway maintenance activities, whichever is less.

Regional or statewide program managers may also wish to shorten the inspection frequency for the following reasons:

- Problems noted during the previous inspection
- Previous repair work
- Road functional classification
- Priority route
- No alternate routes
- Culvert cover
- Average daily traffic
- Stream designated as anadromous by ADFG

AASHTO recommends that all culverts should be inventoried when initially developing a culvert database. However, periodic inspection will require a considerable effort and budget, which may present an obstruction to program success. Therefore, some limitations for culvert re-inspection are justified. For example, many small culverts do not warrant routine inspection. If small-diameter, buried culverts are not repaired but are replaced after failures occur, then the periodic collection of detailed condition data is not prioritized above collection of that same data for the larger-diameter buried culverts (AASHTO, 2020).

CHAPTER 5 – CONDITION ASSESSEMENT

The primary purpose of the culvert inventory process is to determine and assign a condition rating to a culvert using specific criteria obtained by visual inspection and basic measurements. Condition ratings are generally intended as a comparison of the inspected culvert to the as-designed/constructed condition.

As described in Chapter 4, we recommend a two-tier inspection/condition assessment framework. A Tier 2 level of inspection and condition rating is the desired performance level for culvert inventory. If lack of time prevents a Tier 2 inspection/rating, then a Tier 1 inspection/rating will create a placeholder and serve to notify the regional hydraulic engineer and M&O staff if immediate action is needed to repair or replace a culvert.

Tier 1 - Rapid Condition Assessment

As noted in Chapter 4, a Tier 1 template would be utilized for inspection teams with limited fieldwork time. Using Tier 1, an inspector would acquire basic culvert information, including location, photographs, and visual inspection. This will allow a culvert to be identified and placed into the regional culvert database tables, with an accompanying inventory record.

The second component of a Tier 1 inspection is the rapid assessment of a culvert's condition and performance based on the inspector's visual inspection. Following the collection of culvert data, the inspection team would make a rapid assessment of the condition and performance of the culvert to be included in the dataset and forwarded immediately to the regional hydraulic engineer. The Tier 1 assessment procedure is used to develop one of three recommendations:

(1) The condition and performance appear to be acceptable, and no urgent action is needed.
(2) Maintenance (e.g., cleaning/clearing) is needed to remedy an observed performance problem. Tier 2 assessment should be conducted following recommended maintenance.
(3) Action is needed to repair or replace the culvert or appurtenances. An in-depth assessment (Tier 2) should be conducted immediately to provide additional information and guidance.

The culvert attributes that would be inspected include culvert corrosion, cross-section deformation, invert deterioration, and joints and seams. In addition to these attributes, the guide includes a list of observations of the performance of the culvert, which is determined by identifying problems such as blockage, poor channel alignment, overtopping, and scour. Depending on the severity of the problem(s), the investigator may recommend maintenance, repair, or a more detailed (Tier 2) inspection, noting the urgency of the recommended inspection.

Tier 2 - Full Condition Assessment

The Tier 2 level of inspection and condition rating is the desired performance level for culvert inventory. The AASHTO Condition Rating System (2020) provides a comprehensive method to rate and describe the individual components that comprise a culvert installation. The AASHTO system assigns a rating from 1 (Good) to 4 (Severe) using specific criteria obtained by the visual inspection and basic measurements prescribed by the Tier 2 inspection method.

Rather than one overall condition rating, the rating system uses a component-level rating for each of the following: roadway, embankment, channel, end treatments, barrel alignment, barrel condition, joints, and seams. AASHTO notes that there are typically only specific components of a system that warrant maintenance or evaluation. A component-level rating system allows engineers to understand the nature of any identified problem or concern and take specific and appropriate action (AASHTO 2020).

Each system component may have one or more characteristics. The rating of the system component as a whole is the highest numerical rating (worst condition) assigned to any of the characteristics. A new, properly designed culvert would have conditions ratings of '1' for all system components. Along with the numerical rating indicators, the AASHTO rating scale also includes an associated 'action indicated' recommendation. See Table 4.

Table 4. Culvert inspection rating scale, from AASHTO (2020).

Rating	1	2	3	4
	Good	**Fair**	**Poor**	**Severe**
Condition	Like new, with little or no deterioration, structurally sound and functionally adequate.	Some deterioration, but structurally sound and functionally adequate.	Significant deterioration, functional inadequacy, or both, requiring maintenance or repair.	Very poor conditions that indicate possible imminent failure or failure which could threaten public safety.
Action Indicated	No action is recommended. Note in inspection report only	No action is recommended, but more frequent inspection may be warranted.	Inspector evaluates need for corrective action and makes recommendation in inspection report.	Corrective action is required and urgent. Engineering evaluation is required to specify appropriate repair

Detailed guidelines for using the rating system are provided in AASHTO (2020). The guidelines note the following:

- System components and characteristics are rated on structural condition, ability to perform their function, and possible negative impact to the entire culvert system or the roadway above.

- A numerical rating should be assigned before leaving the site, while it is possible to visually identify the basis for the condition rating. Measurements and photographs should also be obtained.
- If a condition has more than one criterion for evaluation, the criterion with the poorest rating (highest number) should be used to select the condition rating for that component.
- Significant changes in condition since the last inspection should be carefully evaluated to assess the rate of deterioration.

The AASHTO manual provides tables to help the inspector evaluate and rate the system components. Additionally, a catalog of distressed conditions is included in the manual's Appendix B, along with photographs of various types of distress for a range of condition ratings. See Figure 7 for an example of photographs and descriptions of culvert corrosion.

When the inspection and condition rating is completed, the rating should be entered into the regional database, and culverts with a 'poor' or 'severe' rating should be reported directly to the regional hydraulic engineer and M&O staff.

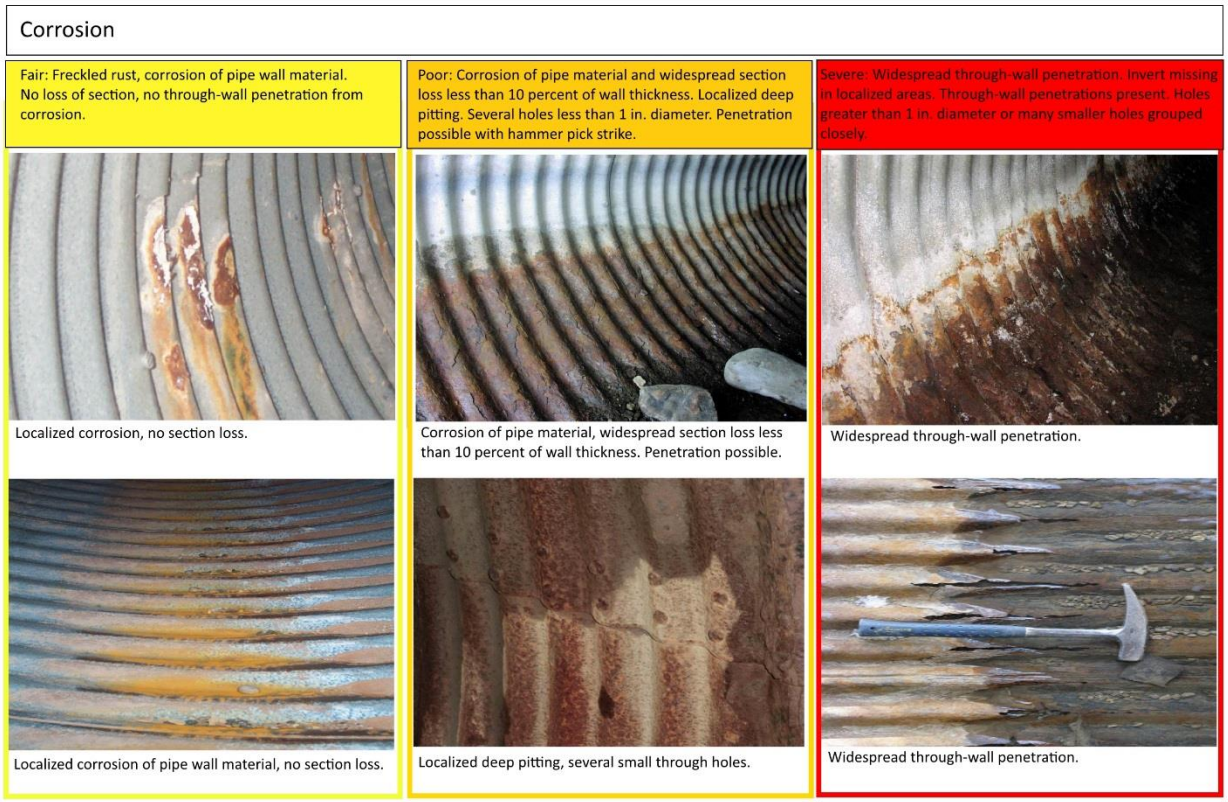

Figure 7. Example of visual aid for culvert condition rating for corrugated metal barrel corrosion. From AASHTO (2020).

CHAPTER 6 – ANALYSIS

The creation and maintenance of a comprehensive, updatable, and regional/statewide culvert inventory database is the primary task in the development and usefulness of a CAMP. With an active database in place and recurring updates on culvert condition, DOT&PF planners will be able to develop a results-based program for managing, evaluating, repairing, and replacing culverts. Examples of such results-based management activities include the following:

- Recommendations for individual culvert repair or replacement projects ranked by the benefit/cost they will provide to the integrity, efficiency, and safety of the highway system

- Development of a comprehensive list of recommended culvert projects for each region, ranked by the "benefit" provided

A definition or explanation of the benefits provided by culvert repair/replacement projects would be developed by the Department for statewide project comparisons. Such a 'benefit index' could include both user and non-user-benefits such as embankment improvements, safety, fish habitat improvements, delay reductions during emergency repairs, and others.

ArcGIS Analysis

In the early stages of the CAMP, analyses of the information contained within the culvert inventory database will be limited to those which can be performed with a geographic mapping and analysis software package. Types of operations that can be performed with a geographic information system such as ESRI ArcGIS include the following:

- Extract, overlay, and visualize data
- Add and calculate attribute fields
- Summarize and aggregate data
- Calculate statistics

These types of operations can be utilized to help make decisions, visualize trends, monitor status in real time, and inform agency personnel. Additionally, the ArcGIS dashboards can enable CAMP personnel to present and analyze location-based datasets visually.

Once culvert attributes are measured and condition ratings assigned, additional analyses can be conducted statewide or for individual pipes, highway segments, and regions. Utilizing ArcGIS, a culvert inventory database can be draped onto the DOT&PF Roadway Data Map and queried to provide visual analyses of attribute data and statistical information. For example, a mockup of the fictional results of a query of a theoretical culvert database from a project on the Richardson Highway is found in Figure 8.

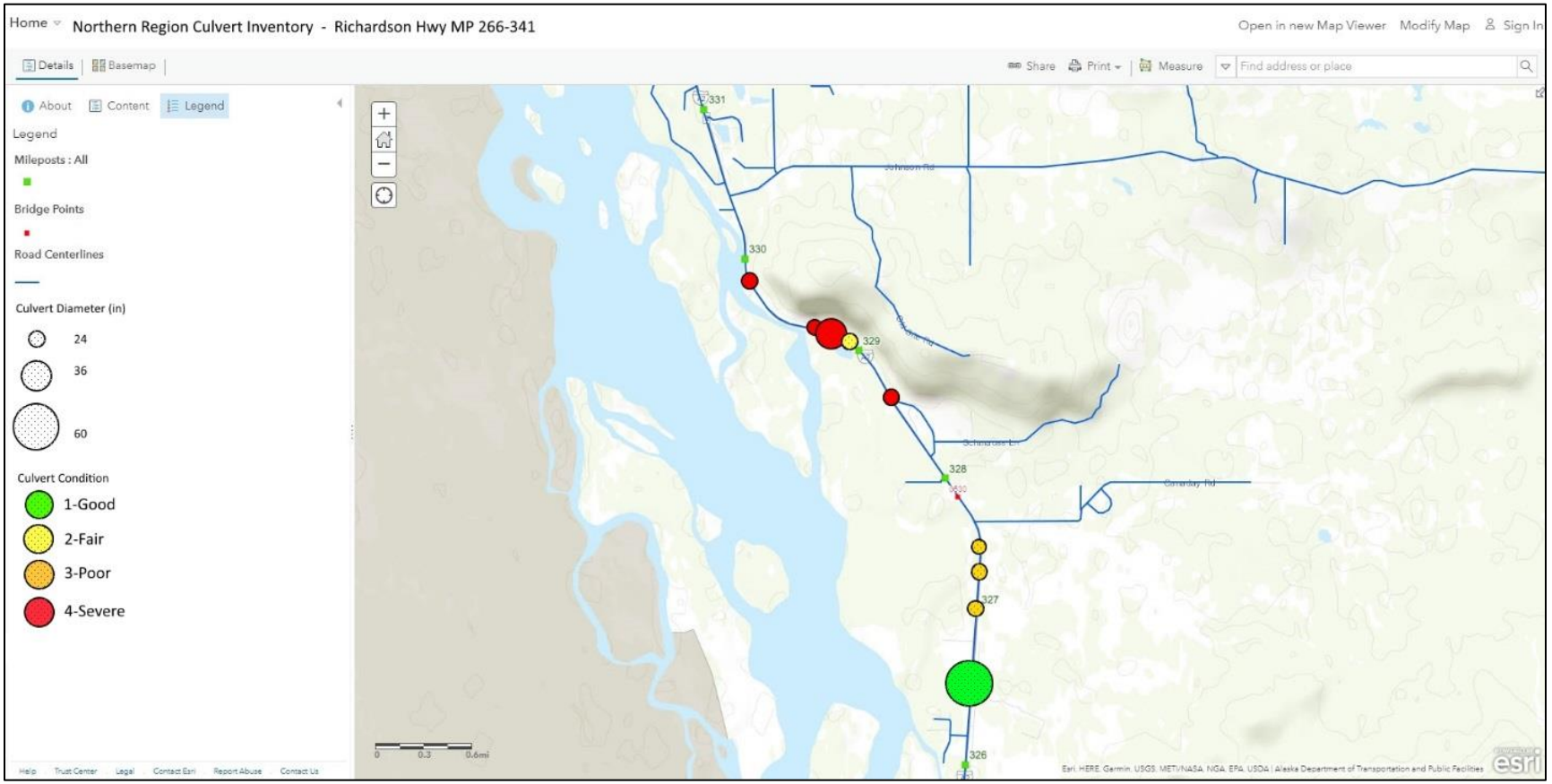

Figure 8. This is an example from a fictional culvert database of a multi-variate ArcGIS map, encoding culvert diameter, condition rating, and location concurrently.

ArcGIS can be utilized to present the results of this type of analysis with bivariate and multivariate maps. Such maps encode two or more data variables concurrently into a single symbolization mechanism, and their purpose is to reveal and communicate relationships among the variables that might not otherwise be apparent via standard single-variable techniques. There are numerous options for presenting and mapping such data analyses in ArcGIS.

Correlation Matrix

Another example of analysis using archived culvert attribute and condition rating data is a correlation matrix, using ArcGIS or a supplemental spreadsheet such as Excel. A correlation matrix is typically in the form of a table: the table displays the correlation coefficients for different variables. The matrix depicts the correlation between all the possible pairs of values in a table. With a large robust dataset, the correlation matrix is a powerful tool to identify and visualize patterns in the given data.

Using the ranked Tier 2 condition assessment for measured attributes, a group of culverts within a study area, such as a highway project, watershed, or region, can be analyzed to determine and map performance trends and identify the critical failure modes, which may be spatially related (such as low water pH), material related (steel versus aluminum), or the result of stochastic factors such as floods or debris clogging.

An example is presented here, using fictional data from a culvert project titled ‘Richardson Highway MP 266-341.’ In this example, 24 culverts between Mileposts 316.7 and 336.3 were evaluated using the Tier 2 attribute measurements and the component rating system. At each culvert, five components were inspected and rated using the numerical system of 1 to 4 representing conditions from good (1) to severe (4). These components included the following: Approach Roadway (AR); Embankment (EM); Channel Alignment (CA); Corrugated Metal Barrel (CMB); and Corrugated Metal Plate Seams (CMPS).

The condition ratings were used to populate five columns in a correlation matrix as seen below in Table 5. Additionally, two other culvert attributes were included as correlation matrix columns: culvert age and water pH. Culvert ages ranged from two to 35 years. Water pH measurements ranged from 5.4 to 7.2.

Using a table of data columns in the form of Table 5, a matrix of correlations between parameters can be created using the ArcGIS Spatial Analysis Tools or spreadsheet software with a Data Analysis ToolPak such as Excel. The Pearson correlation coefficient is a value that ranges from +1 to -1. When the correlation coefficient is 0, it means that there is no linear correlation between the two variables. A value of +1 means that there is a perfectly positive linear correlation between the two variables: as one variable increases, so does the other. A value of -1 means that there is a perfectly negative linear correlation between the two variables: as one variable increases, the other tends to decrease.

Table 5. Data table from a fictional 24-culvert inventory, including component condition ratings.

Culvert MilePost	Culvert Component Condition Rating					pH	Age Yrs
	AR	EM	CA	CMB	CMPS		
336.3	1	1	1	1	1	7.0	5
336.1	1	1	1	1	1	6.8	4
335.6	1	1	3	3	2	6.5	10
329.8	1	1	1	3	2	6.2	15
329.3	2	2	1	4	3	5.5	**25**
329.2	2	3	2	4	4	5.5	**35**
329.1	2	2	2	3	2	5.5	12
328.7	1	2	1	4	3	5.5	25
327.5	2	1	2	3	2	5.4	15
327.3	1	1	2	3	3	5.7	17
327	1	1	3	3	2	6.0	20
326.5	1	4	1	1	1	6.5	2
319.8	2	1	2	3	3	6.5	17
319.4	1	1	2	2	2	6.8	10
319.1	1	1	3	2	2	6.8	10
318.5	2	2	2	2	2	6.8	16
318.1	2	2	1	2	2	6.5	20
317.6	2	1	1	1	1	6.8	5
317.5	2	3	3	3	2	6.5	19
317.3	2	1	1	1	2	6.8	4
317.2	2	1	1	1	2	7	7
316.9	1	1	2	2	2	7	20
316.8	1	1	2	2	1	7.2	25
316.7	1	1	1	1	1	7	4

AR-Approach Roadway **EM-Embankment**
CA-Channel Alignment **CMB-Corrugated Metal Barrel**
CMPS-Corrugated Metal Pipe Seams **pH-water pH**
Age-culvert age
Condition ratings for all culvert components: 1-good, 2-fair, 3-poor, 4-severe

The correlation matrix results for Table 5 are shown in Table 6. Results highlighted in yellow indicate that for individual culvert elements, age has a strong correlation with the condition of corrugated metal barrels and CMP seams. For corrugated metal barrels, a strong (negative) correlation also exists with pH.

Table 6. Correlation matrix results for data in Table 5.

	AR	EM	CA	CMB	CMPS	pH	Age
AR	1						
EM	0.256046	1					
CA	-0.0901	-0.03472	1				
CMB	0.146922	0.225188	0.391555	1			
CMPS	0.328469	0.200446	0.222732	0.802453	1		
pH	-0.24474	-0.31783	-0.09238	-0.80997	-0.67012	1	
Age	0.183146	0.251085	0.29091	0.805369	0.713608	-0.51948	1

Deterioration Modeling

Culvert deterioration models can describe the expected behavior of a culvert and can be an important step in establishing a CAMP. By predictive deterioration modeling, planners and engineers can take necessary actions in a timely manner to repair, rehabilitate, or replace these assets before failure occurs. Shifting the current 'reactionary' approach for culvert maintenance to a more proactive predictive method may lead to better service, fewer failures, and overall reductions in culvert maintenance/replacement costs.

Numerous inspection and evaluation efforts have concluded that corrosion of metallic culverts is caused by pH, resistivity, and abrasion (NCSPA, 2002). Acceptable ranges of pH and resistivity for culverts have been developed by multiple state DOTs across the country. In the CR, corrosion is considered the most common reason for culvert failure (Paul Janke, personal communication). In 2018, the CR initiated a small study to collect water pH and soil resistivity at multiple culvert sites across the region. These data were collected as part of an early effort to determine the feasibility of correlating environmental conditions to culvert corrosion rates. This work only took place for one season due to limited resources.

The service life of corrugated metal (steel) pipe can be satisfactorily predicted based on the environmental conditions, the thickness of the steel, and life of the coating. A number of states have evaluated several similar methods of service life prediction for galvanized corrugated steel pipe for their area, most notably California (Caltrans, 1999). The Caltrans durability method is considered extremely conservative as it predicts culvert life to first perforation. Newer models permit a 25 percent loss of invert (Sargand et al., 2016).

Average service life using more reasonable methods may be predicted by the American Iron and Steel Institute (AISI) chart, shown in Figure 9. Average invert life may be predicted given the soil resistivity, water pH, and steel gage (thickness). Conversely, the gage required for the desired culvert life can be predicted, given the stated site conditions. The CSP Durability Guide (NCSPA, 2000) notes that additional service life can be provided by not only increasing the thickness of the base steel but also using additional non-metallic coating systems such as asphalt, polymer precoat, aramid fiber asphalt coated, and concrete, or a metallic coating (aluminum). A companion table to the AISI chart also provides the estimated add-on service life, in years, for non-metallic coatings, segregated by the level of abrasion the culvert is subject to (NCSPA, 2002).

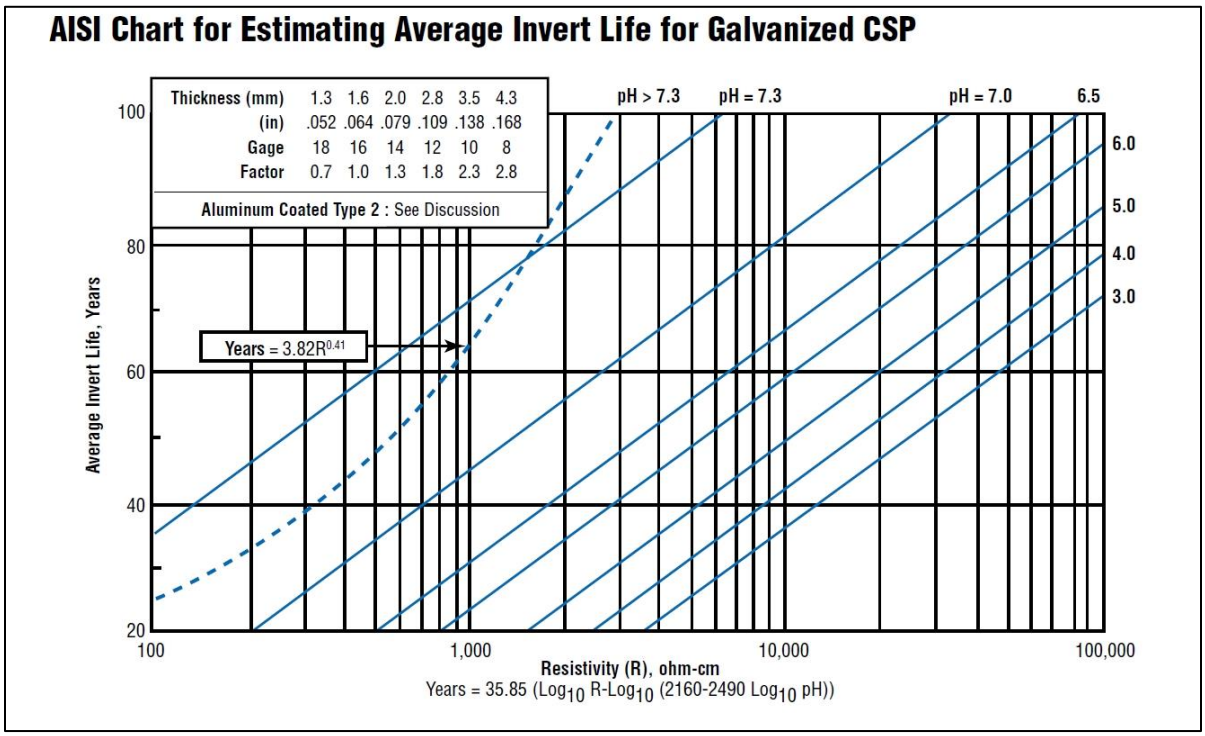

Figure 9. Chart for estimating average zinc-coated galvanized culvert service life. From NCSPA (2000).

Regional managers should determine if their Tier 2 data collection effort should include measurements of soil resistivity and water pH. With adequate pH data, analysts can begin to compare the service life of inventoried Alaska culverts to that predicted by the AISI chart and refine that relationship through a model calibration process. Such analysis becomes part of the foundation for the Department's goal of identifying the functional status and remaining service life of aging culverts and taking necessary actions in a timely manner to repair, rehabilitate, or replace them before failure occurs.

Life-Cycle Cost Analysis

With robust datasets in place, additional analytical tools are available to help the DOT&PF meet their objectives. For example, the life-cycle cost analysis (LCCA) can be used to evaluate alternative drainage system designs using corrugated metal pipe that satisfies the same functional requirements. Using the results of the LCCA, an analyst can identify the alternative with the lowest estimated total cost based on the present value of all costs needed. Within the field of infrastructure planning and management, adopting LCCA to attain a sustainable infrastructure network is considered a mandatory requirement in many transportation agencies (Jawad et al., 2018).

The LCCA evaluation measures the present value of all relevant costs of installing, operating, and maintaining alternative drainage systems, such as engineering, construction, maintenance, and rehabilitation or replacement, over a specified period. LCCA allows an analyst to compare the life-cycle cost between different materials, material thicknesses, and treatment plans for a

selected structure and select the best design/construction/maintenance plan on an individual or project-wide level.

In conjunction with a robust culvert inventory, LCCA will enable Department decision makers to able to do the following: 1) evaluate the impacts of varying budgets on culvert conditions so that they can understand the impact/risk of cutting budgets and 2) evaluate the benefit of potentially increasing drainage budgets based on the surveyed good/fair/poor culvert conditions and Department targets.

Currently, LCCA for culvert evaluation is used for value engineering studies to assist the Department in decision-making at an early design level. In fact, the greatest opportunities for reducing the life-cycle cost are at the beginning of the project, when scoping, option evaluation, and selection occur. These opportunities reduce as the asset moves through its life cycle. Once the asset is built, the focus then shifts to managing and maintaining it in the most cost-effective manner, doing the right work at the right time to get the best value for money in terms of the services that the asset delivers. See Figure 10.

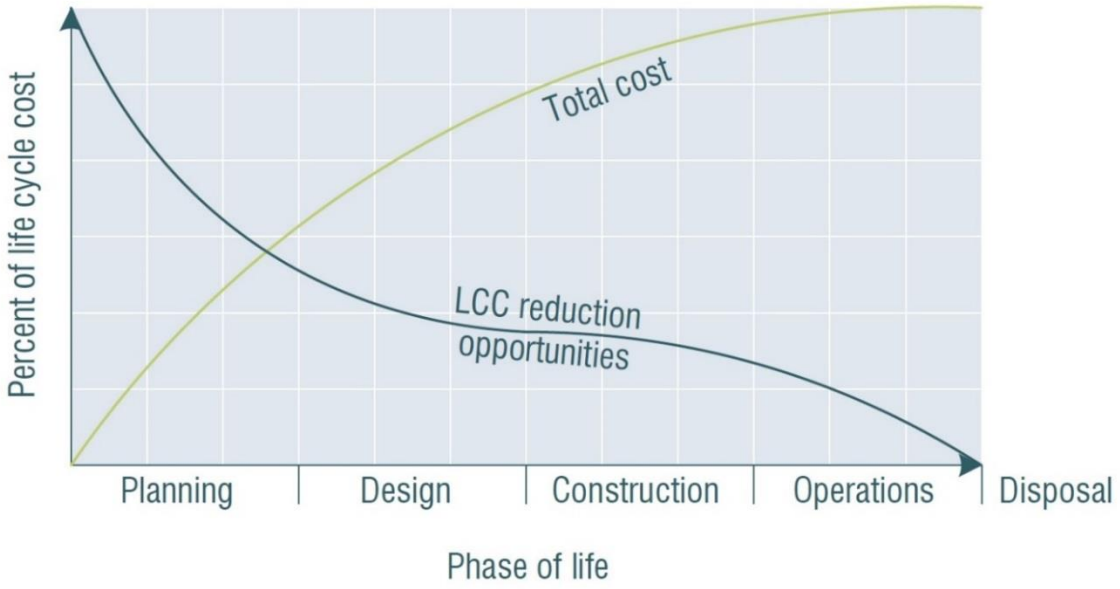

Figure 10. The opportunity to reduce costs decrease as the life cycle ages. From FHWA (2011).

Though complex in data requirements and execution, LCCA can be accomplished by knowledgeable analysts with sufficient inventoried data and a variety of analytical tools. The American Standards of Testing Materials (ASTM) has developed a standard practice, ASTM A930-09, for LCCA of corrugated metal pipes used as culverts and storm sewers (ASTM, 2009).

This example of an LCCA for a fictional culvert replacement project was prepared to demonstrate the application of this procedure. See Table 7.

A 60-inch culvert at MP 326 will be replaced. Hydraulic analysis has determined that a 72-inch culvert should be installed. Two alternatives are considered: Alternative A is a standard 16-gauge CMP. A partial invert rehabilitation in year 25 is expected, and the life of the rehabilitation effort

is 25 years. Alternative B is a 10-gauge CMP. No rehabilitation is expected, and the culvert is expected to have a residual or salvage value at the end of the project design life of $30,000. Though the material lives are different, the functional performance is equal. The design engineer wishes to compare life-cycle costs to determine the economically preferred alternative.

Table 7. Example life-cycle cost analysis for fictional culvert replacement project.

Project Design Life:	50 years	
Nominal Discount Rate:	8%	
General Inflation Rate:	5%	
Common Design Costs:	$150,000	
Alternatives:	Material A – 16-gauge CMP	Material B – 10-gauge CMP
Material Service Life	25 years	50 years
Initial Costs-Materials, Installation, Inspection	$500,000	$650,000
Annual inspection and maintenance	$6,000	$3,000
Partial Invert Rehab in Year 25; Life of Rehab is 25 years	$150,000	None
Terminal Value in Base Year:	None	$30,000
Discount Rate $d_r = \frac{1 + d_n}{1 + I} - 1$	$\frac{1+0.08}{1+0.05} - 1 = 0.029$	$\frac{1+0.08}{1+0.05} - 1 = 0.029$
Present Value of Future Costs-Annual Inspection and Maintenance $PVA_r = \frac{A_r(1 + d_r)^n - 1}{d_r(1 + d_r)^n}$	$\$6000 \frac{(1+0.029)^{50}-1}{0.029(1+0.029)^{50}} = \$157400$	$\$3000 \frac{(1+0.029)^{50}-1}{0.029(1+0.029)^{50}} = \$78700$
Present Value of Rehabilitation/Terminal Value $PVA_S = A_S \left(\frac{1}{1+d_r}\right)^n$	Rehabilitation $\$150000\left(\frac{1}{1+0.029}\right)^{25} = \$73400$	Terminal Value $-\$30000\left(\frac{1}{1+0.029}\right)^{50} = -\$7200$
Present Value of: **Initial Cost** **Annual Inspect/Maintenance** **Rehabilitation**	 $500,000 $157,400 $73,400	 $650,000 $78,700 $ -7200
Total Life-Cycle Cost	$730,800	$721,500

In the above example, Material A is preferred to Material B as the life-cycle costs are substantially lower. ASTM A930-09 notes that the effect of variations in key assumptions on LCCAs can be developed by a sensitivity analysis. By varying the discount rate, material service life, and timing and magnitude of future costs, the decision maker can determine which factors have the greatest effect on the LCCA of each alternative.

Modified LCCA

One criticism of the LCCA method described above is that it does not account for delay costs incurred by highway users when delay occurs due to road closures and detours. While planned culvert replacements can incur large closure and detour costs, the cost of emergency replacement of a culvert is generally significantly greater than the cost of normal replacement (Perrin and Jhaveri, 2004).

Although data demonstrate that material and labor costs are a huge component of the total cost, user delay costs are often not considered in the LCCA because user costs are experienced by traffic users and are not a direct expense to any agency's budget. However, these are, in fact, real costs and need to be considered in the analysis.

A modified method of LCCA was developed by Perrin and Jhaveri (2004). It estimates the total costs for CMPs based on the following: 1) initial installation costs and replacement costs over time and 2) user delay costs. User delay costs are those costs associated with user delay for traffic interruptions at the point of construction. The simplified equation is as follows:

$$T = I/R + D$$

where:
T = total cost;
I/R = installation and replacement costs (from LCCA);
D = cost of delay.

User delay cost is associated with both traffic conditions and costs associated with traffic types. The equation developed for the modified LCCA method is as follows:

$$D = \text{AADT} \times t_k \times d \times (c_v \times v_v \times v_{of} + c_f \times v_f)$$

where:
D = cost of delay;
AADT = annual average daily traffic at culvert location;
t_k = average increase in delay per day caused to traffic during installation;
d = number of days the installation will take;
c_v = average rate of person-delay in dollars per hour;
c_f = average rate of freight-delay in dollars per hour;
v_v = percentage of passenger vehicles traffic;
v_{of} = vehicles occupancy factor;
v_f = percentage of truck traffic at location.

Values for the variables used in the modified LCCA equation may be readily available. For example, the Department operates a Transportation Data Program that collects, validates, analyzes, and reports traffic volume, class, and speed. Three field offices collect and process traffic data to produce AADT, truck class data, and more (DOT&PF, 2022a). AADT reports are

accessed online at several URLs, including the Department Traffic Data Site (DOT&PF, 2022b) and the Department ArcGIS gateway (DOT&PF, 2022c).

Life-Cycle Planning Analysis

A long-term dataset will allow analysts to conduct more complex evaluations beyond geospatial analyses. Specialized infrastructure asset management software is designed to track transportation assets through their full life cycles, with the goal of providing greater predictability, sustainability, and lower lifetime asset costs.

This type of analysis is an application of Transportation Performance Management (TPM), a program administered by FHWA as required by Title 23 U.S.C. 15O€. TPM is a strategic approach that uses system information to make investment and policy decisions to achieve national performance goals. As required by the FAST Act (23 U.S.C. 133), performance targets for pavement condition, bridges, safety, and traffic have been mandated nationally and established by state DOTs. As part of a CAMP, such life-cycle planning analysis could provide significant benefit to the Department.

Currently, the DOT&PF is currently using the AgileAssets Pavement Management System to perform life-cycle planning analysis (LCPA) to preview budget outcomes and improve management strategies. An example of this type of analysis developed by the Department is shown in Figure 11. LCPA allows decision makers to evaluate the impacts of varying budgets on pavement conditions so that they can understand the impact and risk of cutting budgets or the benefit of potentially increasing them based on the federal good/fair/poor conditions and Department targets. The top graph in Figure 11 ($70M Investment Level) illustrates the percent poor pavement condition increasing with a low investment level; a high investment level of $150M over the 20-year life of the analysis illustrates that the percent good pavement condition stays fairly steady, while the backlog of poor pavements is eliminated (Drew Pavey, personal communication, 4/9/2021).

DOT&PF analysts use the system annually to provide a list of recommended pavement preservation projects for each region. These projects are constrained by their budget and ranked by their benefit, which is a calculation of the improvement the pavement preservation project will provide given the pavement conditions.

As AgileAssets is already in use by the Department for conducting LCPA for pavement assets, there is interest in determining whether this system (or something similar) would be appropriate for LCPA as part of a CAMP. It is important to consider the type, extent, and logistics of data required for the two types of assets.

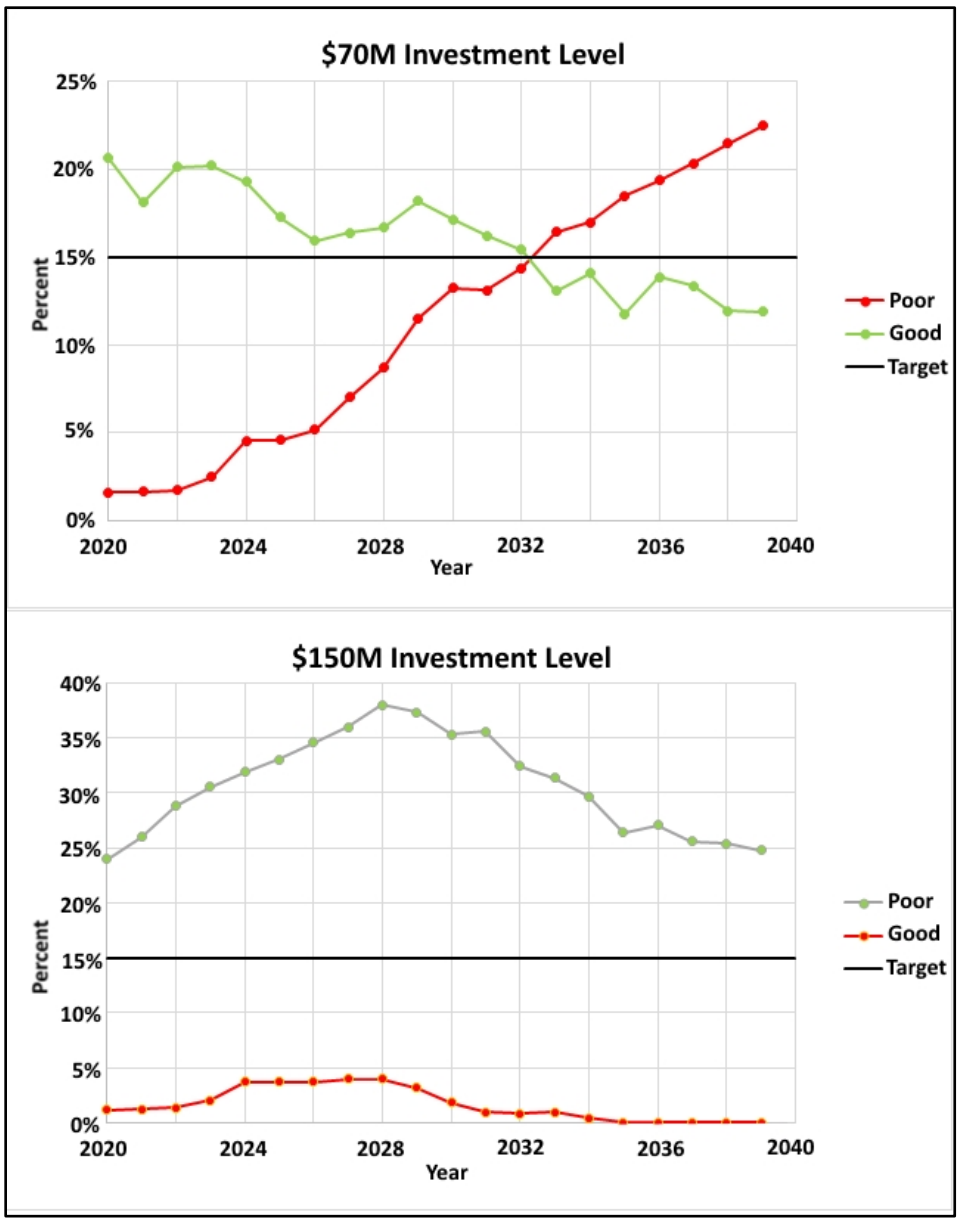

Figure 11. DOT&PF example of LCPA for pavement. The 15% target level is for both poor and good pavement conditions on the NHS (excluding the Interstate).

For the analysis of pavement asset conditions, only three variables are measured: rut depth, International Roughness Index (IRI), and cracking (% and length). Automated data collection takes place on approximately 4,200 centerline miles per year. The data collection is performed under a contract with a third-party consultant (Fugro) using Road Surface Profiling (RSP) equipment consisting of distance measuring instruments, accelerometers, and a Laser Crack Measurement System (LCMS) providing high definition 3D profiles and 2D images of the road surface (Figure 12). The condition data is uploaded into the Department's Agile Assets Pavement Management System along with traffic data, construction information and other roadway data. This information is necessary to forecast condition deterioration and perform cost/benefit analysis to optimize network-level budgets and work scenarios (DOT&PF, 2022d).

Figure 12. Furgo pavement data collection vehicle.

By contrast, data collection of culvert condition is extremely slow and burdensome. Data is collected and measured by a two-person (or more) field crew using a variety of surveying instruments, measuring tapes, manual cameras, and other instruments requiring manual manipulation. Data measurements are recorded by hand onto either field notebooks or handheld tablets.

Another issue that affects culvert data collection is the difficulty in locating culverts. Unlike bridges and pavement, culverts are often hidden from view and not easily accessible for inspection. Even culverts with associated site data are often difficult to find due to thick vegetation, high fills, and out-of-date location coordinates.

Performance measures for culverts, such as 'percentage of culverts in good condition' and 'percentage of culverts in poor condition' have not been incorporated into the initial framework of the TPM. Once an active and long-term culvert inventory database has been established, the State could develop culvert performance measures and establish targets based on the analysis of trends and projections of future efforts.

Developing performance measures and estimating the replacement value of the State's culverts could ultimately lead to improved project decision-making through performance-based planning and programming. However, given the sheer number of culverts in the State that have not been inspected regularly (or at all), it will likely take a number of years before sufficient data are obtained to conduct a functional and beneficial LCPA program using either AgileAssets or another method.

CHAPTER 7 – ESTIMATED BENEFIT TO THE DEPARTMENT

Meeting the 'Results-Based Government' Goal

The FHWA Transportation Asset Management Implementation Guideline provides a list of important benefits for agencies considering the implementation of TAMS (FHWA, 2013):

- Long-term view
- Clear relationships, transparency, and accountability
- Desired levels of service (if requisite funding is available)
- Plans for growth
- Maximization of the benefits of infrastructure
- Better use of existing funds
- Improved agency competitiveness for limited funds
- Aid with building constructive political relationships

Alaska Statute AS 37.07.014 describes and promotes the concept of 'results-based government' for state agencies. The DOT&PF is working toward a results-based program for managing, evaluating, repairing, and replacing various transportation-related assets. The DOT&PF has adapted TAMS asset management practices for the preservation of bridges and pavements. Integrating the Transportation Asset Management principles into the administration of other types of transportation facilities in Alaska would provide similar benefits: effective, systemic, and accountable management of those assets.

By linking planning, programming, and budgeting of more asset classes with data-informed analysis and statewide needs, the State of Alaska will have a more effective, credible, and defensible transportation program. The DOT&PF is responsible for designing, installing, and maintaining culverts across Alaska. When properly designed and maintained, functioning culverts are a key component to an efficient and safe transportation system and enable the DOT&PF to meet their objectives as prescribed by AS 37.07.014.

One of the most important steps in establishing an infrastructure asset management plan is the development of deterioration models that will assist in describing the expected behavior of the infrastructure. By analyzing available databases and calibrating models with actual measurements and observed culvert conditions, planners and engineers should be able to identify critical infrastructure assets and take necessary actions in a timely manner to repair, rehabilitate, or replace these assets before failure occurs.

Systematic inspection of culverts would prevent catastrophic failures and would facilitate lower-cost interventions (i.e., slip lining) in lieu of total reconstruction of culverts and highways. This would also reduce the likelihood of sinkholes in highways that can cause traffic fatalities and injuries.

Although the cost of inspecting and maintaining culverts is an added economic burden to agencies, it saves the costs of emergency repair of culvert failures. By establishing a regular cycle for culvert inspection, agencies could minimize culvert damage. Shifting the current 'reactionary' approach for culvert maintenance to a more proactive predictive method should lead to better service, fewer failures, and overall reductions in culvert maintenance/replacement costs.

Recent studies have demonstrated that initial savings that occur by installing a culvert with a lower life expectancy are quickly exceeded by subsequent replacement installations and user delays. By quantifying both the additional costs of emergency replacement and actual user delay during replacement, an inspection/maintenance program should produce an attractive cost benefit. Ultimately, culvert materials with a longer life can be more cost effective than materials with lower life expectancy, even if initial installation is more expensive.

A management approach based on an asset management plan will feature life-cycle cost and planning analyses. Life-cycle strategies for culverts include regular inspections, cleaning, and corrective actions to extend culvert life. Corrective actions could include resetting of culvert ends, joint repair, invert repair, slip lining, and replacement as needed. By developing decision trees for treatments that focus on annual life-cycle cost savings, the Department will be able to determine the best investment strategies for operations, maintenance, replacement, and improvement and the best long-term funding strategy.

Including culverts in a TAM plan emphasizes their importance as a critical transportation system component, and highlights their role in improving an agency's resilience capability. With inventory, condition data, and a robust asset management plan, a vulnerability analysis can be conducted to assess the likelihood of culvert disruption from natural and human-based causes. A risk assessment specifically for culverts can then be tied directly to resilience planning.

A CAMP may also be an asset when the Department is engaged in the Planning and Environmental Linkages (PEL) process (DOT&PF, 2021). For projects with a significant culvert component, delivery times for planning and environmental review processes will be improved with an up-to-date inventory and completed condition analyses and replacement recommendations.

Finally, a CAMP could also facilitate and streamline the process of seeking and obtaining various grant funding opportunities for stand-alone culvert projects, especially associated with fish passage improvements.

Recommended Policies and Procedures for CAMP Implementation

A proposed CAMP may be instituted either as an appendix to the existing TAMP or as a Stand-Alone Asset Management Plan (similar to the DOT&PF GAM plan). Either way, new policies

are needed to ensure that Department personnel have the tools to succeed. Organizational changes, both regional and statewide, will be required to allow for the funding, development, testing, implementation, and widespread use of a culvert asset management tool. Along with the primary CAMP components noted earlier in this document, other policies and strategy are briefly described below.

Financial Plan

As part of the requirements for implementing a CAMP, the Department must develop a financial plan. The plan should do the following: 1) estimate the funding needed for managing the State's culvert assets, 2) determine the funding availability to address existing culvert conditions, 3) consider the quantity and implications of gaps between needed and available funding levels, and 4) estimate the value of Alaska DOT&PF culvert assets on the NHS. The DOT&PF uses straight-line depreciation as the standard method for the valuation of infrastructure assets (DOT&PF, 2019).

The development of a financial plan will require a significant effort. The DOT&PF completed its first TAMP financial plan in 2019 with considerable assistance from FHWA. The process for developing the financial plan consisted of the following four steps leading to the selection of investment strategies:

1. Identify available funding for asset management. This will likely come from a combination of federal funds and stage general funds.
2. Estimate funding needs. Funding needs are the estimated expenditures required to achieve condition targets and/or the desired state of good repair for culverts on the NHS. Funding needs are forward looking and are estimated based on predictions of asset performance under different investment scenarios.
3. Quantify funding gaps. Funding needs are the estimated expenditures required to achieve condition targets and/or the desired state of good repair for pavement and bridges on the NHS. Funding needs are forward looking and are estimated based on predictions of asset performance under different investment scenarios.
4. Select investment strategies. Once funding gaps have been quantified, the DOT&PF would conduct a review of options to best address its needs across asset classes and programs. Investment strategies would be selected through a process that includes the following:
    - Review of life-cycle cost scenarios
    - Preservation prioritization before more costly replacement projects
    - Funding gap anticipation
    - Assessment of investment strategies and risks

Additional information and a description of the process for the development of the Department's first TAMP financial plan is found in the DOT&PF (2019). Other guidance for developing TAMP financial plans is also available (FHWA, 2017a).

Funding

Funding sources must be identified and captured for the development and implementation of a CAMP. TAMP requirements in 23 CFR 515 links the TAMP to the Statewide Transportation Improvement Program (STIP). Section 515.9(h) states that "a State DOT shall integrate its asset management plan into its transportation planning processes that lead to the STIP, to support its efforts to achieve the goals" of the TAMP.

Transitioning to performance and outcome-based programs through TAMS is the key feature of the Moving Ahead for Progress in the 21st Century Act (MAP-21). MAP-21 establishes national performance goals for the federal highway program. Two of those goals are: 1) safety—to achieve a significant reduction in traffic fatalities and serious injuries on all public roads—and 2) infrastructure condition—to maintain the highway infrastructure asset system in a state of good repair. These goals (and others) should provide the justification to create and implement a CAMP for the State of Alaska with funding in the STIP.

In addition to the STIP, other funding sources will be required to sustain a CAMP. As noted, dedicated staff will be required to manage the program, conduct field inspections, and provide GIS/database management support. Several authorized full-time positions and possibly several part-time positions for seasonal inventory work will likely require State of Alaska Operating Budget funding.

Other funding sources may exist, especially for early-stage projects such as initial inventory efforts. For example, the SR, both by itself and in conjunction with the NR and CR, made proposals, going back as far as 2010, to fund both region-wide and statewide reconnaissance efforts for a specific niche of culverts through State Capital Budget requests. Although the SR had some success in securing funding to pay for culvert rehabilitation projects, the efforts to obtain funding for reconnaissance efforts never gained traction (Robert Trousil, personal communication, July 20, 2021). However, the State Capital Budget may still have potential as a discrete funding source, especially during the start-up inventory phase of the CAMP.

A key element of identifying and developing funding sources is estimating the cost of the program. The cost estimation for culvert inventory/inspection efforts is of particular interest as the culvert inventory is the primary component of a CAMP. Complete and up-to-date culvert inventories will be critical for properly scoping drainage needs and replacement priorities for pavement preservation or rehabilitation projects both large and small.

Due to Alaska's great distances and the wide range of physiographic and environmental regions, estimating a 'typical' field effort for inventory/inspection cost is difficult. Culvert inventories/inspections conducted in a central hub such as Anchorage, Fairbanks, or Juneau will incur less expenses than a similar effort for a remote section of highway.

The following cost estimation information for three regional-based multi-culvert inspection projects were provided by a consultant. See Table 8.

Table 8. Consultant fees for contracted multi-culvert inventory projects.

Project Location	Project Year	# of Culverts	Size of Culverts & Total Length	Inspection Elements	Cond. Rating	Field Hours	All Other Hours	Total Estimated Cost	$ per Culvert foot
Richardson Highway MP 266-341	2017	86	24" – 84" 8,960 ft	Note #1	A-D	120	126	$30,700	$3.43
Parks Highway MP 99-146	2013	199	24"- 144" 19,504 ft	Note #2	A-E	312	340	$66,600	$3.41
KDK Chiniak Highway MP 15-31	2022	118	24-120" no data	Note #3	A-D	128	380	$70,890	no data

Note #1: Location, size, number of barrels, length, skew, type, inlet side, anadromous, end sections, condition rating A-D, 25-yr remaining life, recommendations for repair or replace.

Note #2: Location, size, number of barrels, length, skew, type, inlet side, anadromous, end sections, condition rating A-E, recommendations for repair or replace.

Note #3: Location, size, number of barrels, length, skew, type, inlet side, anadromous, end sections, condition rating A-E, recommendations for repair or replace.

The SR prepared a cost estimate for a 2010 budget request memo (B. Brunette, Memo: Governor's Capital Budget Request, Phase II Funding for Culvert Slip Lining/Culvert Rehabilitation Reconnaissance, SE Region, August 27, 2010). **The total estimated costs to evaluate CMP structures in Southeast Alaska were $250,000.** The request was to conduct a reconnaissance-level analysis to ascertain the condition and function of large-diameter (greater than 48 inches) corrugated metal pipes. These costs include field evaluation throughout Southeast Alaska, the development of rehabilitation options, the facilitation of consensus with M&O sections to identify priority structures, and construction cost estimates to replace and/or rehabilitate CMPs. The exact number of large-diameter pipes to be included in the reconnaissance project was not stated. The budget proposal was not successful (Robert Trousil, personal communication, July 20, 2021).

The 2010 SR budget request led to the development of a similar proposal in 2011 on behalf of all the regions, and it was titled 'Statewide: Culvert Reconnaissance, Inventory, Monitoring, and Inspection-Reference No. 50816.' With a significant data gap to contend with, several assumptions were made to develop the scope of work and proposed budget. The scope of work was expanded from the 2010 budget request to conduct a reconnaissance-level analysis to ascertain the condition and function of large-diameter, (greater than 48 inches) corrugated metal pipes (CMPs) throughout the three Alaska regions, SR, CR, and NR. Aging and corroded CMPs installed within State and NHI roadways would be evaluated.

The total estimated cost to begin in FY2015 and spread out over a five-year project timeline was $7,750,000. The proposal noted that once candidate culverts were identified, a three-to-five-year construction phase was planned to remedy failing and aging conditions of large-diameter CMPs. These culverts would be rehabilitated with separate construction-related funding in FY2012 through 2015, restoring failing CMP structures to an acceptable level of service.

The 2011 Statewide Culvert Reconnaissance proposal was also not successful (Robert Trousil, personal communication, September 22, 2022).

Performance Measures

Since asset management is performance based, performance measures and associated data collection procedures and analytic tools are critical to its successful application. Mission performance measures, also called outcome measures, should be developed by the Department for inclusion in a CAMP. Performance measurement is a way of monitoring progress toward a result or goal. They quantify how well the agency is accomplishing its mission. Developed from asset data, they can be used for multiple purposes, including reporting of current performance, trend analysis, and predictive analysis. Such performance measures are often published on a public-information website for the review and education of the public and other stakeholders (FHWA, 2013). Table 9 includes a list of desired performance measure characteristics and the purpose or rationale of those characteristics.

Table 9. Desired performance measure characteristics (AASHTO, 2022).

Desired Characteristics	Rationale/Purpose
Measurable with available tools/data	May require no additional cost for data collection
Forecastable	Enables data-driven target setting based on future conditions
Clear to the public and lawmakers	Allows performance story-telling to customers and policymakers
Agency has influence over result	Measures agency activities rather than impact of external factors

Performance targets should be set in relation to achieving the agency's strategic goals, considering policy guidance and public input, funding availability, benefits, costs, risks, and tradeoffs. Short-term and long-term goals may be developed to account for available resources. Once targets are established, procedures should be put into place to track progress toward the achievement of the targets. A process of periodic adjustment to performance targets is also recommended to reflect changes in policy, priorities, or the emergence of new information (NASEM, 2006).

An example of culvert performance measures and targets is provided by the Minnesota Department of Transportation (MnDOT), which includes state highway culverts and deep

stormwater tunnels in their TAMP. The State performance measure for culverts is the percent in poor or severe condition based upon NBI inspection standards and MnDOT requirements. Condition levels are assigned during inspections with poor/severe culverts displaying cracks, holes, joint separation, or loss of surrounding material (FHWH, 2020).

Results of the poor or severe condition performance measure for the years 2012–2021 are found in Figure 13. The performance target for culverts is to have less than 10 percent poor or severe condition, so there has been a performance gap for the 10 years shown (MnDOT, n.d.).

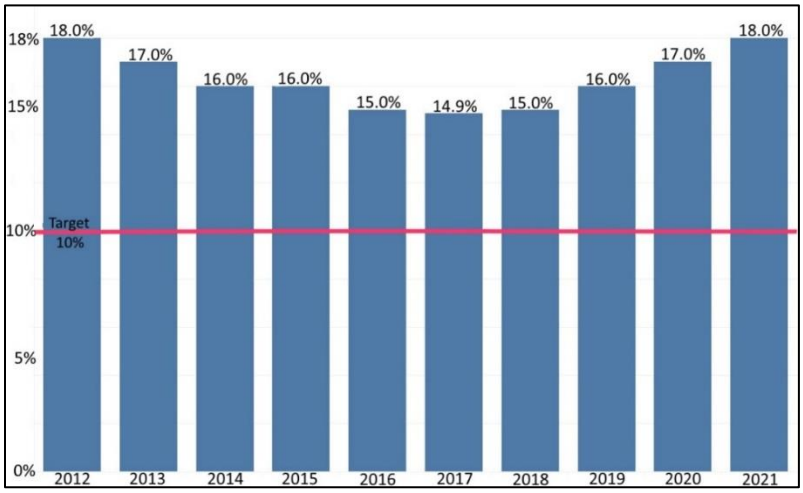

Figure 13. Percentage of culverts in Poor or Severe condition. From MnDOT (n.d.).

The TAMP states that the condition of culverts was assessed as 2.6 percent good, 55.9 percent fair, and 14.6 percent poor, and 6.9 percent were not accessible to be rated. The target for culverts was to have less than 10 percent poor, so there was a performance gap (FHWA, 2020).

MnDOT also developed a performance measure based on the percentage of routine culvert inspections completed on time. Inspections occur regularly: inspection frequency is based on the previous condition rating. If the defect is serious, then inspections happen every one or two years. If the culverts are in good condition, then inspection happens once every six years. See Figure 14.

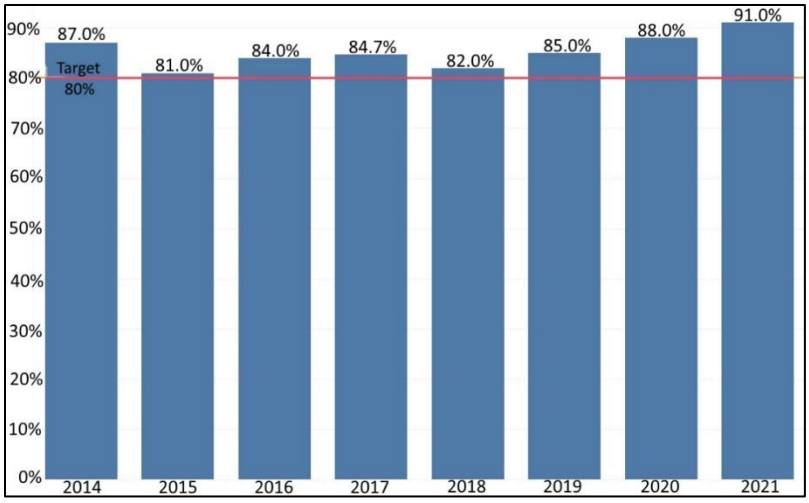

Figure 14. Percentage of routine culvert inspections completed on time. From MnDOT (n.d.)

Risk Management Analysis

Risk management is the processes and framework for identifying, analyzing, evaluating, and addressing risks to the assets and system performance. For the Alaska TAMP, the DOT&PF identified and evaluated the asset management risks for bridges and pavements. Those risks included funding, data and IT systems, seismic activity, program delivery, and resilient infrastructure. Some of these risks will be identical for a CAMP. Risks specific to culvert asset management might include failure or collapse, flooding caused by a lack of capacity, the inability to manage culverts for the lowest life-cycle cost, and difficulty in managing culverts because of inadequate funding. In fact, there are likely specific risks for each of the three regions. For example, accelerated corrosion of CMPs is a risk specific to coastal areas, while clogging of culverts by aufeis formation may be predominant within the NR. A risk management analysis should be conducted for culverts. Guidance for incorporating risk management into TAMPs is available (FHWA, 2017b).

Staffing

Personnel will be needed to conduct the multiple tasks required for a CAMP. Essential staff levels are discussed below.

Program Manager: A culvert management engineer would act as the Department's technical expert on culvert management. This role would include managing the inventory and condition rating of culverts conducted within and by the three regions, coalescing the three inventories into a single statewide inventory database and maintaining that culvert database system, and insuring field inspectors receive adequate and consistent training. The culvert management engineer would use this database to conduct LCCA and help the DOT&PF regional staff and managers create project recommendations to preserve and repair the State's culvert assets.

This position could be located within one of at least three statewide sections within the Department:

1. As the position will likely manage the statewide inventory database, it could be located within the Geospatial Engineering Services group, within the Information Systems and Services Division.

2. The culvert management engineer could work alongside the pavement management engineer within the Department's Asset Management group under Statewide Materials. Pavement preservation and rehabilitation projects often require culvert inventory efforts, which can lead to significant culvert replacement construction.

3. Many large culverts are currently being inspected through the Bridge Section's Minor Structures Program. Shared resources and existing inspection efforts could provide the justification to create a culvert management engineer position alongside the existing bridge management engineer position.

Regional Culvert Manager: A regional culvert manager would act as the primary technical expert on culvert inventory, condition rating, and database management. The manager would report directly to, and work closely with, the regional hydraulics engineer. The manager would be responsible for populating the regional culvert database, using existing culvert inventories (belong to both the Department and other agencies) and new culvert inventories. Other responsibilities include ensuring that field inspectors receive adequate and consistent training for culvert condition inspection and rating methods, along with abiding by the required safety requirements.

This position could be located within one of at least three organizational divisions within the Department:

1. One option would be to use this position as a regional GIS/database manager rather than just focusing on culverts as there are likely many assets and components that could be tracked within the Department's GIS system.

2. This position could be attached to M&O since much of the CAMP objective is to program life-cycle improvements using maintenance actions. This person could also be a contract manager if the inspection effort is to be completed by consultants.

3. As the goal of this CAMP is to optimize program funds, this position could be placed within the Planning Department.

Culvert Inspectors: Inspectors perform the routine inspections, including assignment of component condition ratings. Inspectors would likely work in teams of two. Due to a short

inspection season, multiple teams will be needed to inspect enough culverts annually to maintain the recommended inspection interval.

Personnel Options: Rather than hire new employees, the Department may also consider implementing culvert data collection under a contract with a third-party consultant, similar to the Department's use of a contractor for the pavement inventory program.

A second option would be to contract with another agency to perform the data collection and condition assessment. For example, the Alaska Department of Fish and Game (ADFG) has conducted culvert inventories and maintained the ADFG Fish Passage Inventory Database (FPID) for years.

The FPID contains data on over 3,129 stream crossings assessed for fish passage by the ADFG since 2001, which represents over 95 percent of all state owned roads and thoroughfares (ADFG, 2021; Gillian O'Doherty, personal communication, September 13, 2021). In the past, the FPID has received some funding support from the FHWA through the DOT&PF.

The FPID is updated on an ad-hoc basis by ADFG staff as no base funding exists other than salary. Data collection and condition assessment attributes are obviously different for the DOT&PF and ADFG. However, an agreement for ADFG to conduct culvert surveys funded by the DOT&PF could be used to modify the data collection methods to ensure that attributes desired by both agencies were measured. Training would be required to ensure non-agency inspectors understand and utilize the DOT&PF inspection methods. Such an arrangement could provide benefits to both agencies.

A third option would be to utilize Department personnel from other divisions to assist with culvert inspection. For example, the Bridge Section is assisted by personnel in Design and the Bridge Hydraulics group during bridge inspection efforts. Similarly, other Department engineers such as highway designers could participate in culvert inspections and update the data base.

Immediate Funding Needs

A robust, long-term culvert database will allow Department analysts to ascertain expected deterioration rates and replace culverts that have reached their expected life prior to failure. However, until those analyses can be completed, unexpected culvert failures from corrosion and abrasion may continue to occur. Additionally, it is important to note that many culvert failures in Alaska are not the result of deterioration of the culvert material but are due to conditions and failures in the surrounding environment. These conditions can lead to culvert failure resulting from erosion of the bedding material, scour and erosion of the inlet and/or outlet aprons, embankment overtopping and erosion, and pipe buoyancy. Failure may occur quickly or may be the result of cumulative events.

Without a CAMP, severely deteriorated culverts that are approaching structural failure will have to be replaced at emergency rates instead of normal rates. Such scenarios significantly increase the costs involved (both construction replacement and user delays) and the threats to public safety if catastrophic failure occurs.

One example of an emergency culvert repair is the DOT&PF project 'Copper River Hwy MP 21.5 Culvert Replacement.' A 48-inch culvert located at MP 21.5 of the Copper River Highway catastrophically failed in 2018. Due to severe corrosion, the culvert collapsed and created a large hole in the middle of the highway driving surface (Shellhorn, 2018). As a result of the culvert failure, additional costs were incurred by the Department in two ways: 1) installation and subsequent removal of a temporary culvert and 2) higher per-unit cost for a small single culvert.

Design, funding, and permitting of permanent culvert installations all require significant lead-in time, even for 'fast-track' projects. Where culvert failures can create a hazard, the Department commonly installs temporary culverts designed to function for a short period until a permanent culvert can be installed (Jeff Stutzke, personal communication). For the MP 21.5 project, installation of the temporary 60-inch culvert was permitted by the ADFG with the condition that it be replaced with a larger Tier 1 Stream Simulation Fish Passage culvert no later than Dec. 31, 2021. We were unable to obtain the cost of the temporary culvert repair; such costs would typically include materials, labor, excavation and removal of structures, traffic management, and other items. Road user delay costs may have been incurred as well.

The permanent culvert installation is a 200-ft long 120-inch diameter aluminum pipe, requiring 200 ft of roadway rebuilding, removal of structures, aggregate, special dewatering, Class 1 riprap, and other expenses. The engineer's estimate was $519,375 (DOT&PF, 2022e).

The per-unit culvert replacement costs are likely higher for a single-culvert project compared with a typical larger multi-culvert R&R project. For example, where small quantities are involved, estimators commonly increase allowances due to the inefficiencies generally encountered in small projects. Of particular concern are projects with small quantities of aggregate or asphalt materials. Mobilization of equipment may exceed the direct costs of the material itself. Small construction projects may have a relatively high mobilization cost for transport of dozers, excavators, and other specialized equipment (USFS, 2020).

Without data on the full expenses from recent emergency repair projects and a detailed analysis, it is difficult to predict how much greater unit costs are for a single-culvert replacement project compared to a multi-culvert project.

Rather than rely on deterioration modeling, stochastic failures highlight the need for regular inspections and budgeting solutions that provide for quick repair or replacement. The Department should assess the future risks, liability, and costs of emergency culvert failures and consider implementing a funding mechanism for immediate (emergency) culvert repairs until such time as a CAMP leads to an overall improvement in culvert inspection and condition.

Maintenance and Repair Reporting

Several programmatic aspects of a CAMP require the timely acquisition and analysis of accurate maintenance and emergency repair/replacement information, including costs, activity types, and project location. However, a review of Department-supplied M&O drainage reports ascertained that M&O records may not contain enough data to be able to accurately assess the specific cost of maintenance-related culvert and drainage issues in some regions. Additionally, some have noted that culvert/drainage costs, when noted, are frequently understated due to ambiguities in the reporting method.

Currently, M&O does have maintenance activity codes specifically focused on drainage activities, which includes culverts, ditches, and other assets. A review of files that contain drainage activities for the CR for the years 2018–2020 reveals that specific work activities and clear descriptions of which asset type required the maintenance activity were not explicitly identified. For example, in the file 'drainage_activities_cy2018.xlsx,' the column labeled Acty_Descr (Activity Description) contained just three different entry codes for 1446 items, including the following: DRAINAGE STRUCTURE MAINT; DRAIN STRUC THAW & CLEAR; SHOULDER, SLOPE & DITCH. Similarly, although organizational units and road names are identified with each entry, the locations described for each entry are not specific enough to identify the individual asset requiring the maintenance activity.

To meet the goals and objectives of a CAMP, it is vitally important to be able to identify the funds required to maintain the assets, assign accountability for maintenance activities, and measure and evaluate the results of those expenditures. Improvements to the Maintenance Management System are required to improve the information detail of tracking and reporting of culvert repairs, locations, and funding levels.

CHAPTER 8 – CONCLUSIONS AND SUGGESTED PLAN OF ACTION

Conclusions

Federal rules do not require the inclusion of culvert assets in individual state TAMPs. However, integrating the Transportation Asset Management principles into the administration of a CAMP in Alaska could provide similar benefits: effective, systemic, and accountable management of those assets.

The essential features of a CAMP for Alaska are the use of inventory, inspection and rating data, and life-cycle planning models based on engineering and economic analysis. These features will lead to the development of optimal strategies and investments for maximum value and minimal risk.

The development and deployment of an effective asset management plan requires an up-to-date understanding of the number, location, and status of the asset. There is currently no single comprehensive up-to-date statewide inventory of DOT&PF culverts. As part of a statewide CAMP, culvert inventories should be developed and managed by the three individual regions.

The implementation and use of a single database software package will allow regional control over inventory activities and data management and will also enable the seamless creation of an active up-to-date statewide culvert inventory database. ESRI ArcGIS applications are recommended for the development and implementation stages of a CAMP. ESRI ArcGIS applications are currently utilized in the CR and SR, operate with existing DOT&PF IT infrastructure, and are readily available to most statewide DOT&PF offices. With the ESRI applications for data inventory, field collection of data, mapping, preliminary analysis, presentation of results, and data storage already in use, the CR and SR will be able to jumpstart a regional/statewide CAMP.

Inspection frequency should be often enough to capture the point at which degradation progresses to a level that maintenance could prevent failure. Moreover, the inspection frequency needs to provide a consistent minimum level of safety. The proper inspection cycle will be difficult to quantify and may be adjusted as the program matures. A more frequent inspection cycle may be needed where corrosion is of particular concern.

We recommend that the Department adopt both the Culvert Inspection Procedure and the Culvert Condition Rating System from the 2020 Culvert and Storm Drain System Inspection Guide (AASHTO, 2020) to inspect, rate, and describe the individual components of a culvert installation.

Once culvert attributes are measured and condition ratings assigned, additional analyses can be conducted statewide or for individual pipes, highway segments, and regions. Utilizing ArcGIS, a culvert inventory database can be draped onto the DOT&PF Roadway Data Map and queried to provide visual analyses of attribute data and statistical information.

Furthermore, it is essential to employ culvert deterioration models that will allow planners and engineers to repair, rehabilitate, or replace failing culverts in a timely manner. LCCA can be used to evaluate alternative drainage system designs using corrugated metal pipes that satisfy the same functional requirements. Using the results of the LCCA, an analyst can identify the alternative with the lowest estimated total cost based on the present value of all costs needed.

Specialized infrastructure asset management software is designed to track transportation assets through their full life cycles, with the goal of providing greater predictability, sustainability, and lower lifetime asset costs. Although the DOT&PF is currently using the AgileAssets Pavement Management System to perform LCPA for pavement asset management, we do not recommend its use for culvert management at this time. Both the CR and SR have established culvert data collection and inventory database ArcGIS layers, stored in the Department's ArcGIS online cloud. The CR and SR experience using the ArcGIS platform, combined with the wide adoption and use of ESRI applications throughout the Department by numerous employees and programs, will ensure a statewide database platform that is from the start: 1) easy to use, 2) familiar to multiple employees, 3) readily available across divisions, and 4) promoted by frequent training programs through multiple sources.

In the future, once a robust, long-term dataset has been established and performance targets for culverts in Alaska have been developed, the Department should consider the use of AgileAssets for culvert data management and analysis. A knowledgeable AgileAssets analyst will be capable of leveraging the Department's ESRI platform and employing the ArcGIS culvert database to manage the culvert assets and conduct more complex life-cycle planning evaluations.

Suggested Plan of Action

Whether instituted as an appendix to the existing TAMP or as a stand-alone asset management plan (similar to the DOT&PF GAM plan), policies and procedures are needed to enable the creation and establishment of a CAMP. Implementation of a CAMP will be a large task; many different programmatic components need to be researched, described in policies and procedures, managed, and funded.

We recommend that a pilot study be conducted prior to a full-scale implementation of a CAMP. A pilot study will be used as an assessment of the practicality of a CAMP. Such studies can analyze the technical and operational factors. A small-scale feasibility study will allow the development of project protocols, assess the methods and required frequency of culvert inspection, develop the framework for data inventory and management, and determine if

advanced analyses such as deterioration modeling and LCCA provide economic advantages to the Department.

The suggested plan of action detailed below should eventually provide the information needed to develop a CAMP Business Plan. A compilation of the analyses conducted in the initial studies should contain the operational and financial framework of the proposed CAMP and detail how its objectives will be achieved. It should serve as a road map for the Department and can be used when seeking startup or fully-operational funding.

The plan of action is broken up into arbitrarily selected time frames, which will likely be adjusted by the work schedules and existing duties of the Department personnel charged with conducting the suggested tasks. See Figure 15.

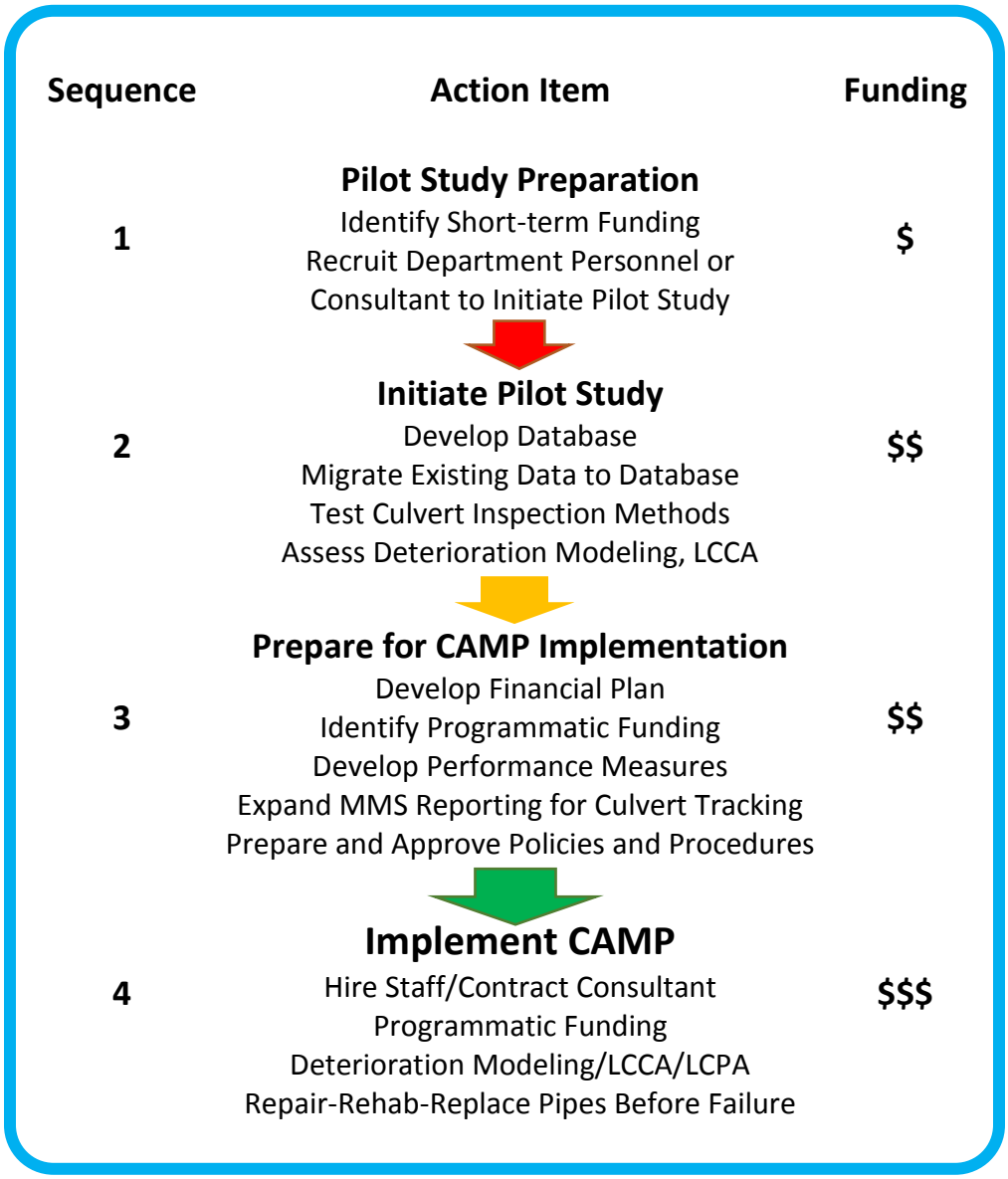

Figure 15. Suggested plan of action for CAMP implementation.

Year 1 - Identify short-term funding sources for development and implementation of a CAMP pilot study. Identify and enlist Department personnel to initiate and manage a small-scale pilot study.

Funding will be needed to support multiple tasks in the initial phases of the study, including database migration, culvert inspections, development of a GIS database and analyses, and other tasks. Funding may be adjusted to allow recruiting a consultant to conduct some of the duties of the pilot study.

Staffing needs for a fully implemented CAMP were outlined in Chapter 7. For the pilot study, personnel in existing positions who are capable of incorporating pilot study tasks into their current workload must be identified. The personnel will be needed to conduct the duties described for Years 2 to 5. If the personnel are not available to conduct all tasks for the pilot study, a contract with a consultant may be considered.

Years 2 to 4 – Initiate Pilot Study

The purpose of the pilot study is to conduct, on a small scale, the primary tasks of a CAMP to determine the effort, time, personnel, costs, and policies and procedures that will be required to plan and execute a full-scale CAMP.

More financial information regarding historical culvert repair/replacement/inventory is needed. Emergency replacement of failed culverts is recognized as much more costly than programmatic replacement; however, obtaining such costs and comparisons from Department sources has proven difficult to achieve. Additionally, the costs involved in previous inventory efforts by both Department personnel and consultants has been difficult to identify. Such information will be critical when developing the benefit-cost analysis for CAMP implementation.

A culvert inventory database for pilot study culvert inventory database should be developed. The CR and SR already have existing databases; as such, the framework for a statewide database could utilize and/or modify existing formats. The culvert attributes to be measured during inventory should be selected with the core program goal in mind: what is the current state of the physical asset?

Migration of some portion of the existing databases into the pilot study database would give managers an estimation of the time and expense to do so for all current culvert data.

To test inspection techniques, Tier 1 and 2 methods must be assessed, the time and costs involved must be determined, and the field data collection should occur. Pilot study inspections would ideally occur in each region. Inspections could utilize scheduled pavement preservation or rehabilitation projects or could focus on known problem areas. Field data collection ESRI mobile applications such as Survey123 or Collector should be tested and rated.

Following each season of data migration and field collection, ESRI ArcGIS applications should be employed to assess their applicability for the program goals, including mapping, preliminary analysis, presentation of results, and data storage.

Tier 1 (rapid condition assessment) and Tier 2 (full condition assessment) methods should be tested and assessed.

Following two or more seasons of data collection, advanced analysis of data, including deterioration modeling and LCCA should take place to determine the adequacy of available data, time, training and staff required to conduct advanced analyses.

Improvements to the Maintenance Management System are required to improve the information detail of tracking and reporting of culvert repairs, locations, and funding levels. Collaboration with M&O should be initiated to improve MMS utility by increasing the accuracy and detail of maintenance-related culvert and drainage activities and estimates of labor and material expenses for those activities.

Years 4 to 5 – Preparation for Full CAMP Implementation

Results from the pilot study will inform the preparation and implementation of a full-scale CAMP. Described earlier in this report, the following items to be completed before implementation will require some level of research effort:

- Development of a financial plan. The plan should 1) estimate the funding needed for managing the State's culvert assets, 2) determine the funding availability to address existing culvert conditions, 3) consider the quantity and implications of gaps between needed and available funding levels, and 4) estimate the value of Alaska DOT&PF culvert assets on the NHS.
- Identify funding sources for the development and implementation of a CAMP.
- Develop mission performance measures based on the Department's strategic goals and objectives.
- Identify risks specific to culvert asset management.
- Improve the Maintenance Management System activity codes to provide more detail of culvert maintenance and emergency repair/replacement information, without creating significant workload increase for reporting personnel.

Year 6 – CAMP Implementation

Staffing requirements should be filled by assigning duties to existing personnel, recruiting new hires, or securing consulting contracts. With programmatic and repeat funding in place, the CAMP implementation should occur.

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APPENDIX A-LITERATURE REVIEW

Culvert Asset Management

The advantages and requirements of asset management for transportation systems has been described and defined in numerous reports and papers. Perrin and Dwivedi (2006) concluded that asset management systems should include the following items:

- Strategic goals,
- Inventory and valuation of assets (physical and human resources),
- Quantitative condition and performance measures,
- Measures of how well strategic goals are being met,
- Usage information,
- Performance-prediction capabilities,
- Relational databases to integrate individual management systems,
- Consideration of qualitative issues,
- Links to the budget process,
- Engineering and economic analysis tools,
- Effectively presented useful outputs, and
- Continuous feedback procedures.

The items above can be summarized as components of a business model/decision support system. According to the AASHTO TAM Guide (AASHTO, n.d.), an asset management system can be used to answer five primary questions:

1. What is the current state of physical assets?
2. What are the required levels of service and performance delivery?
3. Which assets are critical to sustained performance?
4. What are the best investment strategies for operations, maintenance, replacement, and improvement?
5. What is the best long-term funding strategy?

Asset management is a systematic process of maintaining and operating physical assets cost-effectively. The DOT&PF has adapted TAMS asset management practices for preservation of bridges and pavements within Alaska. Bridges and pavements are very visible, and they are typically easily accessible for inspection. However, culverts are often hidden from view, and as a result may not receive as much attention as bridges. Implementing an asset management plan for culvert and other drainage components can create significant advantages for DOT&PF, including extending culvert lifespans and improving utilization of agency resources (AASHTO, 2020).

Resilience

The definition of resilience is the capacity to recover quickly from difficulties, challenges, and setbacks. Put another way, it is the process of adapting well in the face of adversity. The concept of 'resilience' in transportation systems is gaining ground, as agencies recognize the need to integrate and improve resilience in order to recover from any form of disruption. High water is a predominant climatic hazard for both culverts and bridges; flooding conditions can damage foundations, structural members, embankments, and roadways (NASEM, 2019). In Alaska, extreme weather events that result in high water conditions often act to highlight the risk of failure for DOT&PF assets.

Transportation-related disruptions can have economic, social, and public health implications. By recognizing and enhancing resilience capabilities, transportation agencies are better equipped to meet their own policies, missions, and goals, and serve the public better (NASEM, 2021a). The National Cooperative Highway Research Program (NCHRP) has published a guide to help transportation officials assess the current status of an agency's transportation system resilience, and provides tools to improve that resilience. Among the topics described in the guide for improving resilience are the following: data collection and analysis, hazard and threat assessment, and communication. These topics are key components for a TAM plan. As such, a set of recommended actions for improving resilience capabilities includes the development and use of an asset management plan (NASEM, 2021b).

A TAM plan will include performance and condition metrics and targets based on the primary policy goals of the agency. Including culverts in a TAM plan emphasizes their importance as a critical transportation system component, and highlights their role in improving an agency's resilience capability. With inventory, condition, and other data analyses that come from a robust asset management plan, a vulnerability analysis can be conducted to assess the likelihood of culvert disruption from natural and human-based causes. A risk assessment specifically for culverts can then be tied directly to resilience planning (NASEM, 2021b).

Inventory and Inspection

The development and deployment of an effective asset management plan requires an up-to-date understanding of the number, location, and status of the asset. There is currently no single comprehensive up-to-date statewide inventory of DOT&PF culverts (Mike Knapp, personal communication). By recognizing and detecting developing hazards, frequent inspections serve to reduce the risk of service disruptions.

Culverts are one of the many highway system components that DOT&PF hydraulic engineers and M&O staff inspect. Though most culverts are not inspected annually, those known to exhibit, or have potential for, problems that may reduce or disrupt transportation service are inspected more frequently. For example, due to time and funding constraints, only a small

portion of culverts in the CR are inspected annually. These are some of the culverts in the region that are in very poor or worse condition. When culvert repair or replacement is recommended, several years are typically required to obtain funding, prepare the design, advertise for construction bids, and begin construction. Therefore, inspection frequency and recommendations must accommodate this development time (Paul Janke, personal communication).

When inspected, trained inspectors record a variety of characteristics describing the current condition, and likely to affect future disruption of service. In addition to the physical condition of the pipe, inspections often include the following:

- diminished hydraulic capacity, due to blockage or internal cave-in,
- insufficient hydraulic capacity with flooding at the inlet,
- settlement of the roadbed above the culvert alignment,
- separation of headwall from inlet or outlet,
- embankment condition
- scour and deposition at the inlet or outlet
- erosion of backfill material at aprons.

There have been some previous attempts to develop culvert inventories in Alaska, both by the DOT&PF and other agencies as well. A relatively recent inventory was developed by the DOT&PF M&O Group; culverts were field-located, physically marked on the highway for ease of discovery, and the condition was described. Though of some immediate value to regional hydraulic engineers and M&O crews, this effort was not designed as part of an over-arching asset management system. At this time, it is reportedly used infrequently (Jeff Stutzke, personal communication).

When required for a DOT&PF project, culvert inventories are performed either by Department personnel or by Contractors. For projects under the auspices of a Contractor (consulting engineering firm), the protocol for culvert condition data collection is not consistent, and is often left to the discretion and selection of the Contractor conducting the inventory.

Though there are multiple guidelines in existence for culvert assessment projects, many are intended for project-level rather than programmatic or inventory-level use. Other issues involving standard culvert inspection guidelines include the following:

Embankment conditions – Detailed embankment conditions are often not reported in project culvert inventories. The condition of the roadway above the culvert may indicate structural or hydraulic problems in the culvert. The qualifications to correctly identify hydraulic issues at a culvert (i.e. capacity, scour) are significantly different than those required to identify geotechnical stability and structural integrity (AASHTO, 2020).

Alaska conditions – Six major hydrographic regions have been identified in Alaska, and present a wide range of conditions that must be accounted for when inventorying culverts

throughout the state (USGS, 2003). In particular, severe winter conditions will create unique forces and modes of failure for culverts, and have often disappeared from view when visited by inventory crews in summertime. Aufeis, permafrost, sediment mass movements, extreme precipitation events, buoyancy forces, and other complex processes may be noted during a culvert inventory; however, the ability to accurately forecast long-term deterioration rates for these processes may be limited.

With culvert inventories primarily undertaken for discrete project purposes, DOT&PF engineers and planners are unable to make asset assessment level decisions about the effectiveness of a proposed project. Comprehensive, updated culvert inventories combined with life cycle and deterioration models could enable maintenance staff to replace or repair underperforming culverts long before a catastrophic failure leads to a road closure, and could also lead to more robust preventative maintenance plans, promoting significant cost savings. Transportation researchers have noted that agencies that monitor culverts and regularly assess culvert condition will benefit from the lower culvert repair costs that come from eliminating or significantly reducing failures. Safety is also an important reason that culverts should be inspected (Perrin and Dwivedi, 2006).

Although the cost of inspecting and maintaining culverts is an added economic burden to agencies, it is a cost savings over the emergency repair of culvert failures. By establishing a regular cycle for culvert inspection, agencies could minimize culvert damage (Salem et al., 2012). Though the effects and impacts of a culvert failure have a wide range, they can be catastrophic, both in damage and human life. At either end of the impacts spectrum, culvert failures are seldom small and easy to fix.

AASHTO Inspection Guide

Asset management systems should include such items as ‘Inventory of assets’ and ‘Quantitative condition and performance measures’ (Perrin and Dwivedi, 2006). Perhaps the most relevant document available to help Department engineers and planners develop a Culvert Inventory and Condition database is the AASHTO publication *Culvert & Storm Drain System Inspection Guide, First Edition* (AASHTO, 2020). This guide is an update to the publication *Culvert Inspection Manual* (FHWA, 1986), which was a supplement to the Bridge Inspector’s Training Manual, first published in 1970 and updated in 1990.

The objective of this guideline is to provide inspectors with recommendations and standards for routine condition assessment of culverts and storm drains. Of critical importance to DOTs with large culvert inventories managed by separate regions, the guideline presents a reliable and reproducible method to rate the condition of all system components. The advantage of the guideline rating system is that assets are evaluated in a systematic manner, allowing qualified inspectors to assess common distress types, evaluate their severity, rank the severity in relation to the entire inventory, and assign a numerical condition rating that is associated with recommendations of further action if necessary. Though the guideline provides methods to

systematically evaluate and rank culverts, it also is designed to allow agencies to decide which inspection, assessment, and management criteria is best suited to their particular agency needs.

The guide is organized into five sections, beginning with **Section 1-Introduction**. The following section descriptions are:

Section 2-Design and Performance Characteristics: this section describes basic design characteristics, including hydraulics, structural behavior, and design loads. It also presents performance issues related to the durability of culverts and storm drains. The guide notes that durability problems are the most frequent cause for replacement, as culverts are more likely to wear away than fail due to structural problems. Two durability issues, corrosion and abrasion, are discussed.

Section 3-Inspection Procedure: A department culvert inspection program provides the database from which statistics on service function and safety are derived; the database is also the basis for developing a culvert asset management program. Inspection procedures are detailed such that culvert ratings should be repeatable by different inspectors. Inspection frequency, types of inspections, inspection sequence, qualifications of the Inspector, and other parameters are detailed.

Inspection frequency is discussed in detail, and is critical for planning maintenance and rehabilitation activities. A review of agency schedules indicates that the most common criteria is barrel size. AASHTO provides a table of example inspection frequencies for routine inspection and condition assessment/rating, but notes that agency-developed frequencies may be less than those shown in their example table.

Other factors that may affect inspection frequency include culvert size, condition rating, structure age, average daily traffic (ADT), environmental conditions, and special function. AASHTO indicates a more frequent inspection cycle may be needed where corrosion is of particular concern. AASHTO does not provide specific frequency guidance based on condition, but states that it should be often enough to capture the point at which degradation progresses to a level that maintenance could prevent failure and when a culvert is rated poor or severe the inspection frequency needs to provide a consistent minimum level of safety.

Section 4-Condition Rating System: This section describes the process of determining and assigning a condition rating, from 1 (Good) to 4 (Severe) using specific criteria obtained by visual inspection and basic measurements. Rather than one overall condition rating, the rating system uses a component-level rating for each of the following: roadway, embankment, channel, end treatments, barrel alignment, barrel condition, joints, and seams. Each system component may have one or more characteristics. The rating of the system component as a whole is the highest numerical rating (worst) condition) assigned to any of the characteristics. A new, properly designed culvert would have conditions ratings of ‘1’ for

all system components. The rating scale developed by AASHTO assigns a numerical rating indicator, along with an associated 'Action Indicated' recommendation.

Section 5-Asset Management: This section first explains the concept of TAM as a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets by utilizing business and engineering practices, with the ultimate goal of safely prolonging the service life of highway assets. AASHTO notes that culverts are not typically included in a TAM plan, and therefore are slow to respond to culvert problems, describing the situation as a "reactionary process that precludes opportunities for efficiency through proactive management."

AASHTO promotes the objective of a culvert asset management program as a method that utilizes asset inventory to address maintenance and preservation to prolong the service life of culverts and ultimately highway assets. It will provide a cost-effective method of maintaining, rehabilitation, upgrading and operating culverts throughout their life-cycle, while maintaining public safety. Examples of the current state of culvert and storm drain systems management programs are provided.

This section also explains that, in addition to a management method for physical assets, TAM is also a business model. As such, investment strategies that consider operations, maintenance, replacement, and improvement, as well as a long-term funding strategy, need to be developed for the implementation of a successful CAM plan (AASHTO, 2020).

Office of Federal Lands Highway

The Office of Federal Lands Highway (FLH) is part of FHWA, and works in cooperation with federal land management agencies such as the National Park Service and others to plan, design, construct and rehabilitate highways and bridges on federally owned lands. FLH developed project-level guidelines for assessing the condition and performance of culverts, and selecting corrective actions for repairing or replacing deficient culverts. Although the guidelines are intended for project-level rather than programmatic or inventory level, their development was based on existing practices for culvert inventory and management. Though inventory-level use was not a goal for the development of this manual, the manual and its component tools may be used for programmatic applications and should function well as a basis for culvert asset management development efforts (Hunt et al., 2010).

The FLH guidelines apply to culverts with a span of less than 20 feet. The manual identifies the minimum set of parameters necessary to evaluate both existing condition and performance for a broad range of culvert structure types. The procedure also describes the defining criteria for each parameter, provides a rating system, and suggests methods and tools for measuring and recording the parameters. For this method, Level 1 is a rapid field assessment tool for a culvert's condition (physical deterioration) and performance (water conveyance). For each major culvert material

type and common appurtenances, typical modes of deterioration and associated rating codes are provided for the Level 1 assessment.

If additional investigation is needed, the method includes a description of Level 2 assessments, which involve technical discipline specialists in hydraulic, geotechnical, structural or materials engineering (Hunt et al., 2010).

Deterioration Modeling

One of the most important steps in establishing an infrastructure asset management plan is development of deterioration models that will assist in describing the expected behavior of the subject infrastructure. By analyzing available databases, planners and engineers should be able to identify critical infrastructure assets and take necessary actions in a timely manner to repair, rehabilitate, or replace these assets before failure occurs (Salem et al., 2012). Shifting the current 'reactionary' approach for culvert maintenance to a more proactive predictive method may lead to better service, fewer failures, and overall reductions in culvert maintenance/replacement costs. Though corrugated metal culverts (CMPs) are by far the most commonly used culvert material type in Alaska, they do present several disadvantages over concrete pipes:

- Presence of sand, rocks, or both, in a high-velocity stream may cause loss of pipe material as a result of abrasion.
- Sensitivity to soil or water pH or soil and water resistivity makes them susceptible to corrosion.
- Backfill operations must be handled with care because of the importance of soil support for load-bearing purposes.

The soil conditions that affect the extent and rate of corrosion in culverts includes: electrical conductivity (resistivity), moisture content, pH, aeration, presence of microbes, soil chemistry, and others (Hepfner, 2001). As culverts are designed to carry water, they are commonly subjected to large variations in soil moisture, oxygen content, and soil chemistry, which all help to create a corrosive environment.

The Ohio Department of Transportation (ODOT) developed service life prediction methods for culvert design and maintenance purposes based on invert durability (Meacham et al., 1982). The definitions of service life used (significant perforation of the invert for corrugated steel pipe (CSP) and exposure of reinforcing steel for reinforced concrete pipe (RCP)) are not the same as definitions used in other studies performed before and after the ODOT work. A recent ODOT study was conducted to update the 1982 report, and new data from galvanized steel, concrete, and thermoplastic culverts were analyzed along with previous data (Sargand et al., 2016). A multivariate regression analysis was conducted on each type of culvert for acidic ($pH < 7.0$) and alkaline ($pH > 7.0$) environments. The best fits were provided by linear regression models, and the low-pH data sets had models with higher correlation coefficients.

A modified Los Angeles abrasion test was used to compare abrasion resistance polymer, bituminous, aluminized, and standard galvanized coatings on steel plates. The polymer coating showed the least mass loss from abrasion, followed by bituminous, aluminized, and galvanized. The report notes that the results may not reflect actual field conditions which include freeze-thaw cycles and aging (Sargand et al., 2016).

A number of states have evaluated several similar methods for suitability to predict the service life of galvanized corrugated steel pipe for their area. For example, the Original California Chart' was developed for Caltrans to estimate invert life of galvanized corrugated steel pipe (Caltrans, 1999). This model defined the end of service life as time to first perforation, while newer models permit a 25 percent loss of invert (Sargand et al., 2016).

An excellent literature review of culvert rating systems was conducted for ODOT, and is found in Sargand et al. (2016)

In the DOT&PF Central Region (CR), corrosion is considered the most common reason for culvert failure. In response, the CR initiated a small study in 2018 to collect water pH and soil resistivity at multiple culvert sites across the CR. These data were collected as part of an early effort to determine the feasibility of correlating environmental conditions to culvert corrosion rates. This work only took place for one season due to limited resources (Paul Janke, personal communication).

Corrosion is also considered the primary reason for culvert failure in the DOT&PF's NR and SR as well (Jeff Stutzke, personal communication).

Stochastic Failures

It is important to note that many culvert failures in Alaska are not the result of deterioration of the culvert material, but are due to conditions and failures in the surrounding environment (Mike Knapp, personal communication). Such environmental conditions include aufeis formation, permafrost, sediment mass movements, and extreme precipitation events that create flood flows. These conditions can lead to culvert failure resulting from erosion of the bedding material, scour and erosion of the inlet and/or outlet aprons, embankment overtopping and erosion, and pipe buoyancy. Failure may occur quickly or may be the result of cumulative events.

Stochastic refers to a variable process where the outcome involves some randomness and has some uncertainty. The ability to accurately forecast service problems and/or failure based on stochastic environmental condition is limited or impossible.

Though environmental conditions and events that contribute to or solely cause culvert failure may be stochastic in nature, some locations may experience more events than others. M&O personnel and regional hydraulic engineers are generally aware of such culvert locations, and inspect them more frequently (Paul Janke, personal communication). Rather than rely on

deterioration modeling, stochastic failures highlight the need for regular inspections and budgeting solutions that provide for quick repair or replacement.

ADOT&PF Current Culvert Policies

At the time of this writing, there is no statewide comprehensive, up-to-date culvert inventory for ADOT&PF. The road network, attribute data, and transportation feature data, including many of the department's transportation assets, are stored in a legacy mainframe transportation database, the HAS (TRC, 2006). In 2005, a Maintenance Management System (MMS) was deployed by the Maintenance & Operations Division (M&O). M&O personnel use various MMS modules for daily work activities and for managing the department's assets. Though the exact timeline is unclear, a culvert inventory was launched in conjunction with the three regions, and the MMS was designated as the repository for the collected data. At the time, maintenance station personnel found and marked culvert locations in such a way that the marks could be picked up through the cameras of the data collection contractor's van. For paved roads, small green triangle were painted on the side of road where there was a culvert. For dirt roads, paper plates were attached to a wooden stake on the side of the road. The sites were photographed and centerline locations were recorded. No culvert condition information was collected or recorded (Sean Jordan, personal communication).

Approximately 13,000 culverts were located and recorded during the 2007 project. Some areas of the state were missed, especially off the road system. Note that culvert size was not a factor in collection for this project, so there are most likely all sizes including those which now have an assigned bridge number as part of the National Bridge Inventory (NBI).

The 2007 data are maintained by the Department's Geospatial Engineering Services. Formats include an Excel file, and GIS files (Sean Jordan, personal communication).

Some Department planners considered the MMS to be the best comprehensive system for housing all of the various culvert data inventories maintained in the three regions or statewide (Cambridge Systematics, Inc., 2015). However, because the MMS was maintained by the M&O Division, organizational issues prevented the culvert database from becoming a long-term 'living' (frequently updated) system. M&O could not update the culvert database with new culvert-related construction projects, either by using as-built drawings or other methods.

At some point between 2014 and 2017, approximately 200 culverts were added to the culvert database, and approximately 500 of the existing entries have added data, including pipe shape, material, condition, and others. The expanded inventory is maintained in an Excel spreadsheet. The statewide culvert inventory is no longer actively maintained within the MMS, which is now primarily used for administrative purposes.

As part of the Department's efforts to adapt TAMS asset management practices, DOT&PF replaced their legacy systems with the proprietary software AgileAssets in an effort to minimize the life-cycle costs associated with managing and maintaining their transportation assets, and to increase staff efficiency through data integration across the Department. For example, DOT&PF is using the AgileAssets Pavement Management System to perform Life Cycle Planning Analysis to preview budget outcomes and improve management strategies (DOT&PF, 2022d).

Discussions within the Department and with AgileAssets in 2017 focused on including a culvert template for that database. An original attribute list provided to the databased developers at AgileAssets consisted primarily of the MMS attribute list. A substantial effort was made to develop a supplementary list of culvert attributes to include in AgileAssets; however, schedule and budget constraints eventually led to a decision to include just one attribute, culvert condition (Mike Knapp, personal communication).

Culverts with a span of twenty feet or greater meet the definition of a bridge, are designated with a 4000 series bridge number, and are inventoried in the National Bridge Inventory (NBI) database. Inspections are conducted every two years. Culverts with diameters between ten and twenty feet and owned by DOT&PF are designated with a 7000 series bridge number, are classified as 'Minor Structures,' and are maintained in a separate database. This dataset has a little more information such as length, bridge number and location. Using the bridge number it can be referenced back to the bridge system for additional information. The dataset is available on the DOT&PF Atlas website (Sean Jordan, personal communication). These culverts are generally inspected every 5 years.

At this time, there is no comprehensive culvert inventory program in place in the NR. Culvert inspections are generally performed as part of the preliminary data collection for complete highway reconstruction projects as well as rehabilitation projects. Most projects begin with a review of As-built drawings for culverts 48 inches and larger, and the associated Culvert Summary sheet. For reconstruction projects, personnel (either DOT&PF or their contractors) go out and inspect every single culvert, including 24" cross-drainage pipes. For rehabilitation projects, personnel may just inspect the 48" and larger culverts, or rely on M&O to advise about culvert installations with known problems (Jeff Stutzke, personal communication).

Contractors that conduct inspections in lieu of Department personnel are not required to use the ADOT&PF forms, though their culvert data collection efforts often match or exceed those set by the NR (Jeff Stutzke, personal communication).

Culvert data collected during these inspections are stored only in the individual project files. At this time, there is no mechanism for combining individual culvert datasets into a single region-wide culvert inventory (Jeff Stutzke, personal communication).

The CR maintains a culvert and storm drain inventory with a rise of 48" and greater. Estimates are that the inventory accounts for over 90% of the existing culverts (48" and greater) within the

region. The inventory is based solely on as-built drawings and was last updated in 2018. Recorded attributes include: diameter, skew, span, pipe length, end treatment, material, stream name, structure name, bridge number, and remarks (Jake Ciufo, personal communication). Culverts are inspected for rehabilitation and pavement preservation projects. Observations and recommendations for repair and replacement are documented in a memorandum sent to the design project manager.

In the last few years, CR engineers have been using Survey123 for ArcGIS to collect culvert inspection data. This data is stored as an ArcGIS feature layer in the ArcGIS online cloud. Within Survey123, reports can be generated, along with Excel spreadsheets, Google Earth kmz files, and other file formats (J. Ciufo, personal communication). In 2018, additional data were collected at a number of culvert sites, including soil and water pH and soil resistivity. These data were collected as part of an early effort to determine the feasibility of correlating environmental conditions to culvert corrosion rates. This work only took place for one season due to limited resources.

Some culverts have known problems considered serious enough to warrant inspections on a frequent basis. Though condition ratings are not noted in the CR inventory, hydraulic staff keep track of such culverts through their own inspections and in conjunction with M&O personnel. Efforts to fund culvert repair or replacement for at-risk culverts outside of larger rehab/reconstruction projects are attempted, though often not successful (Paul Janke, personal communication).

Efforts in the SR to create a culvert inspection and inventory database began in 2010. The SR submitted a Capital Budget Request for a proposal titled 'Phase II Funding for Culvert Slip Lining/Culvert Rehabilitation Reconnaissance' to inventory culverts in the Region. The request was focused or large diameter pipes, but it was the SRs attempt to begin developing a systematic way of inventorying all culverts (Robert Trousil, personal communication).

The SR maintains an active culvert inventory. Similar to the NR and CR, culverts within the SR have historically been inventoried on a per-project basis. As a result, a culvert database was constructed from several individual databases in an effort to create an inventory that would provide planners and designers with up-to-date information. Though extensive gaps of culvert location and condition still exist, an online database is providing an easy and quick method to update and add culvert data (Robert Trousil, personal communication).

The four individual databases were: Kodiak, Juneau, and Ketchikan (2017, 2018); Skagway (2019); June and Ketchikan (2020); and M&O Chipseal (2021). A total of 728 culvert entries were included in the consolidated inventory. Formats and attribute fields varied somewhat, but consolidation was achieved with little manipulation (DOT&PF, 2021b).

As part of an initial research study to test inventory methods for geotechnical asset classes, a culvert inventory was conducted along the Tongass Highway (Beckstrand et al., 2017). Culvert

inlets were located, and diameters and functionality added to an ArcGIS layer. Culvert IDs were assigned from the CDS Route Number and CDS Milepoint, measured to the nearest hundredth of a mile. For this inventory, relatively simple narratives were developed for a single rating category that evaluated culvert function as judged by the field engineer. The three ratings were:

- Yes. No-to-slight damage to the culvert inlet; no-to-little debris in culvert mouth; no impounded water around the culvert inlet; no obvious damage to the roadway over the culvert. Culvert condition Good.
- Marginal. Moderate to significant damage to the culvert inlet; slight to moderate debris in the culvert inlet mouth; no evidence of impounded water around the culvert inlet. Damage to the roadway over the culvert is not accompanied by noticeable vertical movement when driving over the culvert at the speed limit functionality. Culvert condition Fair.
- No. Significant debris in the culvert inlet or the inlet entirely buried; impounded water at inlet or evidence of water regularly impounded behind inlet during storm events; damage to the roadway with noticeable vertical movement when driving over the culvert trace at the speed limit. Culvert condition Poor.

The SR consolidated inventory is hosted and updated through ArcGIS Online. Updates to the online version are managed through ArcGIS Collector (mobile data collection app), Survey123 (ArcGIS survey data app), and Web maps (ArcGIS geographic interactive display app). An offline version of the database is obsolete and is no longer updated. Users must have an official ADOT&PF ArcGIS account to access the database.

The total size of the database as of July 2021 is 2.6 GB. The bulk of storage is dedicated to the various photo attachments for each entry. The table and geolocation data from recorded entries make up a very small percentage of the total size.

To collect new data for the inventory, a user goes into the field and accumulates points on a tablet using ESRI software, then uploads the data online. To accommodate differing data needs depending on project objectives, a three-tier system was implemented. This tier system allows the user to collect only the amount of data needed for his or her intended objective. The tiers are:

Tier 1: Picture and Point Collection. Culvert geolocation and pictures are collected; provides a baseline for future surveys.

Tier 2: Reconnaissance. Provides data for recon level engineering. Attributes include culvert geometry, condition, material, inlet and outlet types, and others.

Tier 3: Design. Additional attributes include ADFG Fish Passage Site ID, ADFG AWC ID, embedment depth, and culvert recommendations.

In addition to the inventory, other work has been conducted in the SR to advance the concept of a Culvert Asset Management program. For example, funding justification documents have been

prepared specifically to conduct reconnaissance level condition inspections of large diameter corrugated metal pipes. Cost estimates for large culvert inventory and rehabilitation in SR Zones A & B have also been prepared and updated. Finally, a draft SR H&H manual is under development and is intended to act as a supplement to the statewide Alaska Highway Drainage Manual among others. This manual includes policy, process, and procedures for culvert management specifically within the SR, and should provide an explanation of the H&H process for SR design staff (DOT&PF, 2019b; Robert Trousil, personal communication).

ADOT&PF M&O Culvert Performance Targets

Performance targets for maintaining functional culverts in Alaska were developed in a report prepared for ADOT&PF M&O (McDonald and Sperry, 2014). Though not designed for rating culvert condition during inventory or for asset management purposes, the 5 targets do illustrate common problems that impede culvert function and lead to failure. These targets range from A (Excellent Drainage) to E (Failing Drainage). The M&O culvert performance table with the 5 performance targets, their descriptions, and an illustration, is found on the next page.

It is unknown if DOT&PF M&O currently utilizes this method of culvert maintenance of matching culvert conditions to performance targets.

Other agencies throughout the State of Alaska maintain their own culvert inventories. Culvert inventories for municipal, land management, or resource conservation agencies are generally conducted for one of two reasons: (1) to provide data for fish passage/aquatic inventory passage programs, and (2) to map stormwater conveyances as required by a National Pollutant Discharge Elimination System (NPDES) permit.

Perhaps the most up-to-date and widely used inventory is maintained by the ADFG. The objectives of the ADFG Fish Passage Inventory Database (FPID) are to: determine if crossing structures impede the movements of juvenile salmonids, other anadromous fish, or resident fish; prioritize barriers with respect to replacement or removal; and make all inventoried culvert data publicly available.

The FPID contains data on over 3,129 stream crossings assessed for fish passage by ADFG since 2001, which represents over 95 percent of all state owned roads and thoroughfares (ADFG, 2022; Gillian O'Doherty, personal communication). Culverts outside the road system are also mapped if they appeared to have fish habitat upstream of them. The information is available online and may be accessed using the Fish Resource Monitor interactive mapping application. In the past, the FPID has received some funding support from the Federal Highway Administration through ADOT&PF, and is used by local, municipal, state, and federal transportation managers, local watershed groups, non-governmental organizations, and the general public.

DOT&PF M&O culvert performance targets. From McDonald and Sperry (2014).

Performance Target	Performance Target Description	Illustration
A (Excellent Drainage)	Culvert, Inlets and ditches are structurally sound and unobstructed. They are kept free of silt, debris and vegetation and 90 percent of the cross section is unobstructed. Ditches have little to no scour or erosion and no standing water evident. Structures are unobstructed and functioning as intended.	
B (Good Drainage)	Culverts, inlets and ditches are structurally sound and unobstructed. They are kept free of silt, debris and vegetation and 75 percent of the cross section is unobstructed. Ditches show minor signs of scour or erosion and small amounts of standing water evident. Structures are functioning.	
C (Fair Drainage)	Culverts, inlets and ditches are showing minor to moderate restrictions. 50 percent to 75 percent of the cross sections are unobstructed. Ditches show signs of small amounts of erosion and a moderate amount of standing water due to uneven cross section. Structures are functioning but limited during normal storm events.	
D (Poor Drainage)	Culverts, inlets and ditches are showing large amounts of restrictions. Less than 50 percent of the cross sections are unobstructed. Large sections of ditches show signs of deep erosion and large amounts of standing water due to uneven cross section. Structures are not functioning as intended.	
E (Failing Drainage)	Culverts, inlets and ditches are more than 50 percent restricted. Large sections of ditches show signs of deep erosion and large amounts of silt filled ditches. Large amounts of standing water due to very uneven cross section. Small to large sections of road flooding during storm events. Structures are not functioning as intended.	

Data collected at each inspected culvert site includes: location (coordinates), dimensions, shape, material type, inlet/outlet type, headwall/wingwall/apron, substrate, and photographs. Culverts receive a ranking of 1 through 5 based on the condition, ranging from Defective (in dire need of repair or replacement; threatens to disrupt or hinder traffic) to Excellent (allows flow at full capacity without disrupting fish passage). Stream measurements are also made. Procedures and techniques for data collection are described in Eisenman and O'Doherty (2014).

A two-person team can do an average of 3 culverts per day working a 9-10 hour day (depending on location and driving time). An abbreviated data collection method (named Inventory, as

opposed to Assessment) may also be used when time is limited; that method takes about 15-20 minutes per site and consists of taking some photos and a few basic measurements.
The FPID is updated on an ad-hoc basis by ADFG staff, as no base funding exists other than salary. Third parties may also submit data occasionally. Inspectors attend an ADFG 5-day training course prior to data collection activities. ADOT&PF reportedly provided some funding in the past for data collection, though not currently.

The U.S. Forest Service (USFS) conducts structure inventories, including culverts and bridges, primarily for the purposes of replacing structures that act as barriers to aquatic species with functional structures that allow aquatic organism passage. Inventories are generally conducted and maintained by individual national forest units, using a USFS nationwide inventory procedure that is generally modified with regionally defined measurable criteria (screens). For example, the USFS is nearing completion of forest-wide structure inventories for both the Chugach and Tongass National Forest units. The amount and type of data collected at each site during inventory is dependent on whether or not the existing structure simulates natural channel stream conditions. Sites that don't meet such conditions are surveyed more rigorously, often with enough quantitative measurement to permit numerical hydraulic modeling of the site (Clarkin et al., 2003; USFS, 2022; Flanders and Cariello, 2000).

Culvert inventories for fish habitat assessment and passage programs have also occurred in the Haines Borough (TWC, 2021), and within the City and Borough of Juneau (Seifert and Sumner, 2015). Some fish passage culvert inventory work has also been conducted by the Matanuska-Susitna Borough and the Kenai Peninsula Borough.

A Municipal Separate Storm Sewer System (MS4) is a publicly-owned conveyance system that collects or conveys stormwater runoff and discharges to waters of the U.S. Within Alaska, MS4 permits have been issued to the urbanized areas in Anchorage and Fairbanks as well as several military installations. A key requirement of an MS4 permittee is to inventory and map the locations of the components of the MS4 including catch basins, manholes, storm drain pipe, ditches, culverts, and outfalls, as well as the locations of water bodies that will receive the storm water discharges from the outfalls. For example, the City of Fairbanks maintains a layer of culvert linear features and points within their Stormwater GIS, developed jointly with the ADOT&PF, the University of Alaska, the Fairbanks North Star Borough (FNSB), and the City of North Pole. The attributes are of varying quality and most were last updated over a decade ago, but there is attribute data on the owner of the asset, and the data point layer has culvert material types, sizing, elevation, and in some cases the direction of flow (Andrew Ackerman, personal communication). The GIS is online.

In 2013, a consultant to ADOT&PF worked with the City of Fairbanks to develop an initial database of stormwater assets, including culverts, within a subset of the City boundaries. The goal of the project was to complete drainage mapping for the City of Fairbanks' MS4 system within the Fairbanks Urban Area in order begin developing a database that is easy to use and maintain, that will allow for asset management, flow path tracking, planning-level capacity

analysis, and to help identify any stormwater system deficiencies. The inventoried area covers an area just north of Airport Way and west of downtown, and some areas to the south and west of Airport Way (A. Ackerman, personal communication, November 2, 2021). Annual culvert maintenance is conducted by the Public Works staff, and failed structures are replaced on an as-needed basis. System upgrades occur during reconstruction project planning (Jerimiah Cotter, personal communication).

Online GIS inventories and maps of stormwater facilities, including culverts, have also been compiled by the City of Anchorage and the City and Borough of Juneau (City and Borough of Juneau, 2022).

DOT&PF Geotechnical Asset Management Plan

As in many other states, DOT&PF has adapted TAMS asset management practices primarily for preservation of bridges and pavements. MAP-21, Moving Ahead for Progress in the 21st Century, encourages state DOTs to extend their asset management efforts beyond pavement and bridges to include ancillary structures through the use of risk-based asset management plans (FHWA, 2012). In recognition of MAP-21 and the knowledge that the management of other asset classes may benefit from the same application of TAM methods and policies, DOT&PF developed and implemented a program to manage a number of geotechnical assets that contribute to a functioning transportation system.

DOT&PF estimates that the reconstruction value of geotechnical assets has a value more than three times as large as the AK bridge inventory (Thompson, 2017). Such assets include rock slopes, unstable soil slopes and embankments, retaining walls, and material sites. Intended as a subset of TAM, the Geotechnical Asset Management (GAM) program focuses on providing the information needed to maintain geotechnical assets and extend their service life; expanding DOT&PF's asset management to geotechnical features will lead to enhanced overall system performance while optimizing the operating cost of the transportation network.

Key features of the GAM Plan are the use of inventory and condition data, and quantitative forecasting models based on engineering and economic analysis, to optimize the development and selection of preservation and risk mitigation investments. The objective of the program was to prioritize project needs, optimize investments and funding, and measure effectiveness to ensure that Department objectives are achieved and to further improve the forecasting and delivery capability. In this way, the Department engages in a process of continuous improvement.

The purpose of a GAM Plan is very similar to a TAM Plan. The specific objectives for the DOT&PF TAM Plan are:

- Develop and apply a consistent, objective basis for selecting actions.
- Estimate costs and 10-year needs using available data.

- Invest at the right times to keep assets in service for as long as possible.
- Prioritize for long-term success (as explained to stakeholders).
- Determine 10-year network performance targets that are feasible with expected funding.
- Allocate limited funding toward the greatest reduction in risk and life cycle cost.
- Improve the reliability of cost and performance forecasts.
- Provide a migration path so future research can improve the measures without re-defining them.
- Be compatible with pavement and bridge asset management, to facilitate long-term implementation.

Research to investigate and determine the information and analysis necessary to create a TAM-compatible GAM program included the following components (Thompson, 2017):

- Initial review of existing programs;
- Inventory and assessment of department assets;
- Construction of an database containing asset information using existing infrastructure;
- Preliminary monetization of risk and estimation of event likelihood based on asset
- condition;
- Development of preliminary performance measures;
- Development of unit asset improvement costs based on asset condition;
- Initial deterioration, life-cycle cost, and trade-off analysis models;
- Example utilization of these models in developing performance targets.

The work to develop the GAM program was conducted under multiple tasks, including Phases 1, II, and III, and the Tongass Corridor Study. A description of the three phases is available elsewhere (Thompson, 2017). An important aspect of the program development, the Tongass Corridor Study included early work on developing culvert inventory methods.

The study focused on the North and South Tongass Highway corridor, which includes a wide range of geotechnical assets in various states of condition (Beckstead and Mines, 2017). Evaluating geotechnical assets over such a wide condition range led to the formulation of more robust performance measures; this initial work enabled researchers to test and refine inventory and assessment methods prior to applying them on a statewide basis.

Field work for this study included conducting inventories for unstable slopes, retaining walls, and culverts. Culvert inlets along North and South Tongass were located, rated, and added to an ArcGIS layer. The approximate culvert location was entered as a point in the layer, and the culvert inlet diameter, functionality rating, and any relevant comments were added to the attribute table. Culvert IDs were assigned from the CDS Route Number and CDS Milepoint, measured to the nearest hundredth of a mile.

Other data collected for the initial research effort to develop geotechnical asset condition measurements included a retaining wall inventory, unstable slope inventory (new sites added to

previous inventory), right-of-way data, and other incident data acquisition from the DOT&PF MMS database for the Ketchikan Borough. The results of this project indicated that transportation managers can jump-start a GAM program with existing inventory data. Existing data can be analyzed and used to develop decision support tools similar to those used in bridge and pavement asset management programs (Beckstrand and Mines, 2017).

An important aspect of any Asset Management Program is the ability to make the information widely available to both Department personnel and the public. To achieve this goal, an Interactive GAM Program Overview was developed and is available using DOT&PF's online GIS system. The overview provides a description of the GAM program, methods of condition assessment, asset locations and extents, and the risks posed. Tools to track the occurrence of adverse geotechnical events include a 12,000+ entry of events and maintenance activities, developed from M&O's MMS from December 2003 to October 2021. Presented in Dashboard format, the depository presents a one-stop, easy to use depository of visual presentations, reports, maps, and risk assessment for slopes and snow avalanches (DOT&PF, 2022f).

In addition to inventory and condition and assessment purposes, a TAM is designed to include engineering and economic analysis tools, used to support fiscal modeling and business decisions. Early results from the GAM indicated that each dollar invested in asset preservation pays for itself and saves an additional $1.06 in long term costs. The benefit of extending the service life of geotechnical assets outweighs the cost of developing new assets (DOT&PF, 2022g).

Similar to bridges, pavement, and geotechnical assets, culverts provide critical function to the highway system; deterioration of that function will negatively affect road user mobility, safety, and fiscal planning. With adaptation, the successful research, development, and implementation of the GAM Plan can serve as an example blueprint for culvert and other asset management plans being considered by DOT&PF.

ADOT&PF AASHTO Survey

Early in this study, we conducted a review of existing state transportation agency culvert inventory and assessment practices, based on responses to a DOT&PF survey to AASHTO committee members in March 2021. AASHTO is a nonprofit association representing highway and transportation departments in the 50 states, the District of Columbia, and Puerto Rico. Much of AASHTO's work is done by forums, councils, committees and task forces comprised of member department personnel who serve voluntarily.

DOT&PF asked AASHTO committee members around the country to provide information regarding inventory methods and programs for culvert and drainage systems. Results from the AASHTO Survey are shown below, followed by a summary of previous research on the topics of culvert inventory and management.

The survey included specific questions to highlight any technical issues dealing with cold regions, marine environments, geographically isolated areas, or any other specific issues that are likely to be similar within the State of Alaska.

The survey included the following questions for DOTs:

1. Does your state maintain a culvert asset database and/or plan (stand alone or incorporated as part of TAM)?
2. If so, are you willing to share your plan and/or metrics with Alaska DOT&PF?
3. If no official database or system, how does your DOT address culvert repair and replacement priorities?
4. Any lessons learned with setting up a culvert asset database and/or plan?
5. What were the reasons for setting up the culvert asset database and/or plan? (i.e. expensive emergency replacements?, planning that aligns with TAM?, lack of routine maintenance? Non-NHS culverts being ignored?)

Fourteen DOTs responded to the survey during March and April 2021. The responses varied in depth and detail. While some DOTs responded with very short direct answers, others included more informative information and ancillary files and reports that described their particular program. A short summary of the responses is found below. Survey items that were not fully or clearly answered are left blank in the table.

The full response from the fourteen responding DOTs is found in APPENDIX B.

Summary: Most of the states who responded did indeed maintain a culvert asset database, plan, or inventory. State DOTs that undertake culvert inventories and/or culvert asset management plans are increasing over time. According to a survey that was conducted for NCHRP approximately 20 years ago, 27 of 37 DOTs did not have guidelines for pipe assessment, 34 of 36 DOTs did not have guidelines for repair methods, 35 of 36 DOTs did not have guidelines for rehabilitation methods, and only 19% of the overall respondents were reported as using the pipe assessment data in their management systems (Wyant, 2002).

Although each state has different approaches and requirements, there were some reoccurring similarities throughout. Many states culvert databases are not standalone databases but are combined to work within the bridge management system. At least one state (New York) took their bridge inspection/inventory database and copied it with modifications for a standalone culvert system. Various states with culvert databases also were in a similar phase with a rudimentary database or inventory system that is intended to be updated or revamped. A range of various data inventory/management software packages were used across the states responding, including: ESRI applications, TAMS Hydinfra, MS Excel, AgileAssets, and ATOM.

The survey question regarding DOTs' procedures to address current culvert repair and replacement were answered with a wide range of detail, from none to some extent. Regular

planning and programming was described, and terms used included *maintenance planning projects, capital projects*, and *pavement/resurfacing cycle*.

The reasons given for setting up a database and/or management plan included the following:

- to help with funding needs
- project scoping
- MS4 data needs
- improve maintenance planning process
- culvert failures(s) led to implementation
- culvert assets nearing the end of their lifecycle.

The survey request for a description of lessons learned had a variety of responses as well, though several themes showed up. Themes mentioned by multiple DOTs included:

- involvement from stakeholders
- dedicated staff and training for culvert inventory/inspection programs
- involve IT specialists, and make data available.

Other responses for lessons learned included the following:

- poor accuracy in initial inventory systems
- leverage other data collection
- potential for dangerous conditions
- plan ahead for how to use and showcase data
- remove or code replaced structures as obsolete to avoid confusion

There was no discussion from responding DOTs that included topics with particular relevance to Alaska and its geography and climate. Though responding states such as Washington, Minnesota, Utah, New York and others share such common traits as cold regions, marine environments, and geographically isolated areas, these traits did not warrant a mention or analysis in the survey responses.

Summary of responses from participating AASHTO member DOTs to a DOT&PF culvert inventory/assessment survey.

State	Culvert Asset Database			How do you address culvert repair/replacement?	Lessons Learned, Reasons for setting up database and/or plan, Notes
	Stand-alone?	Part of TAM?	Large culverts in NBI/TAMP?		
DE	Y	N*	Y	unknown	database for NPDES inventory
IL	N	Y		repair/replacement priorities with regular planning and programming	began inventorying smaller culverts in mid-2000s after issues encountered.
IN	Y <4’	Y	Y 4’ to 20’	$15M program to replace pipes.	small pipes inventoried in MMS until 2017, then transitioned to GIS. Early system had low accuracy. New program to determine condition & count will improve accuracy and help funding needs.
MN		Y	Y 10’ +	Culverts under pavement are inspected regularly based on a schedule determined by their condition; includes a performance measure. TAMS Hydinfra is used to identify highway culverts that need replacement or repair for both maintenance projects and capital projects.	Needed database for project scoping and MS4 data needs. Inventory led to higher visibility of system condition; supported increased maintenance and higher prioritization of repair. Lessons-involvement from stakeholders;keep data collection feasible, leverage other data collection, make data access possible, advertise and train users and inspectors.
NY	unclear	unclear	Y 5’ to +	For small culverts, typically rely on spreadsheet analysis of system extract data for management purposes of these (relatively small/simple) structures. Inventory & inspection data, including NYSDOT specific metrics, are used in sorting and prioritizing structures in this effort.	system is nearly a copy of bridge asset inspection/inventory database. non-NBIS sized structures use fully customized Agile system, with modules incorporating inspection, inventory, diving inspection, vulnerabilities, load ratings, and a BMS/BrM type analysis module. Inspection requirements are similar to NBIS structures; different inspection frequencies & inspector requirements. Lessons- since the program for NBIS structures already exists, these are similar enough to use the same basic framework.
NC	Y			Database in progress; plan to move data from ESRI to asset management system soon. Right now, only accounting codes to track work. Inventory will soon be used for maintenance planning decisions.	set up the database to improve data tracking and maintenance planning process. Beyond pavements/bridges, culvert system was probably next biggest risk area in regards to roadway assets, so investment to get a full inventory was worthwhile.
OH	Y				Culvert database started due to interstate culvert failure. Data collected via the ESRI Collector application on Apple iPads by inspectors; housed in centralized databases and is served via a variety of software,includes Web Viewers, GIS, MS Access, Excel, BI Queries, etc. data served to the public via the TIMS application. Lessons - Get buy-in from Executive Management folks followed by having a dedicated staff for inspection.

SD	Y			Non-NBI culverts have traditionally been addressed with the pavement cycle.	Careful planning of the inventory system is essential to support all the stakeholders properly. Due to average age of culverts increasing, more repairs/ rehab //replacement are needed; has potential to impact pavement project schedules. Also leads to dangerous conditions going undetected. Planning needed to be more long term and consistent.
TN	Y			Field staff creates manual reports to showcase culvert conditions. Regions contacts our Contract's section or our Asset Management section if they have a large culvert in need of replacement.	Culvert assets are a large investment that are nearing their end of lifecycle. Know where all cross culverts are located and not just the 4' to 20'. Locating all culverts will help to streamline replacement/repair cycle based on pending resurfacing projects. Lessons-plan ahead for how to use & showcase data. Use IT data architects.
UT	Y	Y		Currently culverts are part of our TAM but are not included in the current TAMP. Culverts a Tier 2 or Condition Based asset. Want to make financial decisions based on condition targets. next TAMP will include a State Level Asset Management Plan that will cover culverts and future plans.	3 separate inventories in past 10 years, with different location and condition data. Currently using an Asset subcommittee to evaluate culverts to ensure correct inventory, condition, life cycles, age, and condition targets. Developing a new Asset/Maintenance Management System by ATOM.
WA	Y	-	-	Culvert network is managed on a reactive run-to-failure model. Initial plan to inspect each culvert every 5 yrs; currently behind schedule. No lifecycle models or data to supports strategic maintenance and preservation investments that extend the useful life of the asset and reduces the likelihood of asset failure.	Needed better data to reduce the likelihood of failures and shift away from a run-to-failure type model. Culvert database was created to help better understand assets. In 2018, a more concerted effort to compare and align existing management practices to the TAM framework required by FHWA for the TAMP occurred. Training required for inspectors. Databases should communicate with each other.
WI	Y	-	-	Planning, scoping, replacement, maintenance, and funding.	Lessons learned with setting up a culvert asset database and/or plan: Technology, getting licenses, firewalls, disconnected editing, which app to use, training inspectors, quality of inspections, etc…
WY	Y		Y >35 ft^2 (minor)	WYDOT Bridge Program relies on District recommendations and site inspections during project development, especially when the inventory is incomplete or incorrect.	No condition data collected, just construction info, location, design. Having accurate as-constructed plans available is necessary for an accurate inventory; Remove or code replaced structures as obsolete in the inventory to avoid multiple structures in the same location or close proximity to avoid confusion, Field verify structure size, types and locations.
VA	Y <36 ft^2	N	Y >36 ft^2	Culvert repair/replacement/rehab decisions provided in VA 'Manual of the structure & bridge division' and 'road and bridge specifications'	Culverts with openings smaller than 36 ft^2 are maintained through VDOT's Maintenance Division but have a different inventory and maintenance process than NBI culverts.

In addition to survey results, other states have published reports describing their efforts to develop culvert inventory/management programs. We found project descriptions for studies conducted by or for the Michigan, New Jersey, and Oregon DOTs.

Michigan - Though the Michigan DOT (MDOT) did not respond to the AASHTO survey, they have reported on efforts for a pilot project conducted by the Transportation Asset Management Council (TAMC) at Michigan Technological University (MTU) to collect data, develop a unified culvert inventory, and evaluate culvert condition using that inventory (Gilbertson et al., 2020). Tasks conducted for this pilot project are listed below, along with preliminary results:

1. Task 1-webinars for data collection and culvert condition evaluation were developed for inspector training.
2. Task 2-Data from three sources (MDOT, MDNR, MTU TAMC) was reviewed and analyzed to determine if it could be easily combined to create a statewide culvert inventory. Duplicate assets proved to be a concern, and a process was developed to identify duplicate culverts. Non-transportation agencies within the state were contacted and indicated interest in collecting and using culvert data.
3. Task 3-For assessing culvert conditions, MDOT uses a Transportation Asset Management System (TAMS) for culverts less than 10 ft, and the NBIS for culverts 10 to 20 ft. However, local agencies use the 1986 FHWA culvert inspection system (FHWA, 1986). An analysis was conducted to determine if the two systems, along with the new AASHTO method (AASHTO, 2020) would produce similar ratings for culvert evaluations. The AASHTO method considers more elements than either of the two other methods, requiring more data collection. However, with fewer 'condition state' options (four versus ten), ratings may be quicker with the AASHTO method.

The report highlighted the need for a policy document to help guide the decision for adoption (or not) of standardized culvert inspection procedures, and a transition plan if standardization is desired. Other recommendations include:

- Training of inspectors and field verification of collected data-training is required to assure that each inspector will assign the same rating to a culvert within an established tolerance.
- QA/QC & Field Verification-A QA/QC program should be defined if data is made available for public interpretation, as it is a good way to ensure consistent ratings within a rating system.
- Inspection frequency-required to ensure data is up-to-date. Three variables affect inspection frequency: culvert size, material, and condition.

New Jersey - Though the New Jersey DOT (NJDOT) did not respond to the AASHTO survey, the New Jersey Institute of Technology has reported on efforts for a pilot project to develop a culvert information management system (CIMS). The system is based on the determination of culvert 'condition states' to describe the extent of culvert deterioration and survival probability. The pilot CIMS can analyze prescribed culvert information and make decisions to inspect,

rehabilitate, or replace culverts or to do nothing at project and network levels. At the project level, this is achieved by comparing inspection, rehabilitation, or replacement costs with risks and costs associated with failure. At the network level, the associated costs are optimized to meet annual maintenance budget allocations by prioritizing culverts needing inspection and rehabilitation or replacement (Meegoda et al., 2009).

The pilot project was developed to perform the following tasks: 1) maintain an up-to-date inventory of eligible infrastructure assets; 2) perform maintenance of eligible infrastructure assets for a given budget using a replicable basis of measurement and measurement scale; and 3) summarize results, noting any factors that may influence trends in the information reported. Software developed for the project includes a database, routines to assess and optimize culvert management, and a user interface.

As of April 2011, the CIMS application contained an up-to-date inventory of over 8,500 culvert infrastructure assets throughout New Jersey. The survey also conducted an analysis of VHS tapes from old inspections to provide a cost and time estimate to update and upload the data into CIMS. The pilot demonstration project final report included recommendations and proposals for future versions of the CIMS application to make it all-inclusive and convert the current CIMS system into a pilot scale online web-application/database with a data submission system, maintained by NJDOT, for the NJDOT vendors (Meegoda et al., 2011).

Oregon – Though the Oregon DOT (ODOT) did not respond to the AASHTO survey, the ODOT Research Unit conducted research and published reports describing ODOT's efforts to create and maintain a drainage facility (culvert) management system. The study indicated 213 data fields were identified and defined for culvert inventory purposes. A pilot data collection effort indicated that the time to gather and enter the information for one culvert was approximately 3 person-hours (ODOT, 2007).

ODOT maintains a comprehensive culvert inventory (ODOT, n.d.). Culvert data is uploaded into ODOT's Drainage Facilitates Management System and is used to:

- Prioritize culvert projects
- Assist agency with funding and planning decisions
- Maintenance actions
- Preliminary project scoping
- Assist in culvert rehabilitation/renewal options.

APPENDIX B-REPONSES TO ADOT&PF AASHTO SURVEY REQUEST

Delaware: We are currently evaluating how we can pull together our other asset classes into a more deliberate process. We have several asset databases department wide, however, since we do not have a separate section dedicated to asset management or even one whole position, it has been challenging. We are relying on consultant services to assist in this initiative and are looking to develop those "crosswalks" to the other assets so we can provide a "normalizing" playing field for better decision making. The responses from both DelDOT Bridge Section and M&O are below:

Bridge Section: Bridge Management doesn't have an inventory for culvert structures that do not meet our requirements of being a bridge. All bridges/culverts making this requirement (regardless on the NHS or not) are included in our TAMP. DelDOT doesn't have a specific plan to manage culvert bridge structures. Instead, they are included with DelDOT's entire bridge inventory for prioritizing work needs and when forecasting out future budget & associated performance measures.

M&O: Pipe culverts/cross-pipes NOT making the requirement of a bridge, are generally included in our National Pollutant Discharge Elimination Program (NPDES) inventory. The inventory was created over 15 years ago, and some areas have been re-inventoried with condition noted, but other areas have not. A large portion of state maintained drainage features/structures are included: pipes, cross-pipes, catch basins, BMPS, grass swales. Two of the Districts informally use Google Earth for their inventory; culverts/cross-pipes are color coded per their condition as well as have access to the NPDES database. This asset class is NOT included in our TAMP.

Illinois: Yes, culverts are inventoried with bridges, so not a standalone database or plan. We address culvert repair and replacement priorities with regular planning and programming. Culverts larger than 20 ft. were inventoried with bridges from the outset. IDOT maintained culverts/bridges less than or equal to 20 ft. and were inventoried in the mid-2000's after issues were encountered while an RC Slab bridge was saw cut during stage construction.

Indiana: Yes, Indiana defines "small structures" (<=20' span, i.e. not a bridge) into categories:

- Large Culverts = 4' span to 20'. These are managed in the same system as our bridge inventory, they are inspected by our bridge inspection staff.

- Small Culverts = <4' span. These are inventoried in a GIS layer, with Esri field tools (Collector). We have dedicated small culvert inspectors in each district.

We do have a system for culvert repair and replacement. We have a $15 million program to replace just culverts and we are working with our maintenance team and road teams to work on a process for even more/additional funding. When setting up a culvert asset database or plan first

of all make sure you work with all the regions and team affected. We started with just maintenance and realized that our environmental team needed information and photos that we could have collected initially. Also make sure you are using a system that has the information and accuracy that you want for your system. We made several mistakes at the start and had to clean up data and add data to our system.

Indiana has been managing large culverts in our bridge system since the early 2000's. We managed small culverts in our maintenance management system from that time until about 2017, when we transitioned to GIS. But the maintenance program didn't have very good accuracy so to improve the accuracy and to help on funding needs we decided to pull the data out and set up a program to determine the condition and count of small culverts in the state. We are developing a 20 year asset plan for all of our roads and bridges to be able to manage our system better plus plan better. We are also working with maintenance to develop a better life cycle program for our assets.

Minnesota: Yes, MnDOT has a hydraulic infrastructure (HydInfra) database that includes culverts under 10' span that is part of MnDOT's TAMS. Culverts with a 10' span or larger are included in MnDOT's bridge managements system. Storm drain pipes and structures and ponds/basins are included in the HydInfra database in addition to culverts. The data inventory is nearly complete for culverts under highway traffic, but varies in completion for other drainage assets.

Culverts under highway traffic are inspected regularly based on a scheduled determined by their condition and we have a performance measure on inspection. There is also a performance measure based on overall condition of the Culverts under the highway pavement. TAMS Hydinfra is used to identify highway culverts that need replacement or repair for both maintenance projects and capital projects.

Lessons learned with setting up a culvert asset database and/or plan:

- Get involvement from range of stakeholders in setting up system and data needs
- Keep data collection as straightforward as possible, need to make sure data collection is feasible, consider multiple ways of collecting data, leveraging other data collection being done.
- Make data access possible by multiple means, advertise and train – the more people using the data, the better it will become.
- Have central key experts who are in regular communication with both data collectors and users, and provide review and feedback to data collectors.
- Provide training for all inspectors. Regular inspector check in meetings help identify problems and solutions especially when rolling out new collection methods or equipment.

What were the reasons for setting up the culvert asset database and/or plan?

- Much of initial effort was from hydraulics and water resources personnel needing database system to store project scoping information and to store data to meet the mapping and inspection documentation requirements for the stormwater MS4 permit.

- About 12 years ago, began more coordinated effort with Maintenance to regularly inspect and track inspections and condition for culverts under highway traffic. This effort led to higher visibility of the system condition and supported increased maintenance and higher prioritization to include culvert repairs in capital projects.

New York: Yes, the system is nearly a copy of bridge asset inspection/inventory database. Inspection requirements are similar to NBIS structures with exception of not collecting NBI component conditions, along with differing inspection frequencies & inspector requirements. AASHTO Element Inspection Methodology is utilized for all state-owned culverts with a span greater to or equal to 5 feet. Locally owned culverts are not inspected or a part of this program and are handled by the local owners.

OoS's management system for bridges & non-NBIS sized structures is a fully customized Agile system, with modules incorporating inspection, inventory, diving inspection, vulnerabilities, load ratings, and a BMS/BrM type analysis module. NYSDOT can model short span/non-NBIS structures in BrM type modeling system, however we typically rely on spreadsheet analysis of system extract data for management purposes of these (relatively small/simple) structures. Inventory & inspection data, including NYSDOT specific metrics, are used in sorting and prioritizing structures in this effort.

NYSDOT has official databases & systems. Priorities for NBIS & non-NBIS structures are typically managed by local bridge managers regardless of size, using a combination of modeling & local knowledge with OoS oversight/BMS review of effort/results.

Lessons learned with setting up a culvert asset database and/or plan:

- It's not necessary to re-invent the wheel, and since the program for NBIS structures already exists, these are similar enough to use the same basic framework.

What were the reasons for setting up the culvert asset database and/or plan?

- NYSDOT has a long history of inspecting non-NBIS structures. Reason for similarity to NBIS program is that these structures are more generally similar to certain NBIS structures in complexity, construction type, effect of failure, inspection means/ability, means of rehabilitation, and in effort/need for demand response than they are to smaller drainage pipes.

North Carolina: Yes, however we are still setting up the official database. Our current data resides in an ESRI environment but we have plans to move the data to our asset management system in the near future. We plan to use the inventory in the future to aid in maintenance planning decisions. Now we only use accounting codes to track work.

Lessons learned with setting up a culvert asset database and/or plan:

- Consult with all stakeholders before setting up the database
- Photos are important
- Document Live Stream Beds
- Track if the interior of the pipe has been inspected. Some pipes are inaccessible

- Non-NBIS Pipes and Small Maintenance Pipes have differing assessment criteria and data attributes. They also have a different inventory numbering system.

What were the reasons for setting up the culvert asset database and/or plan?

- We set up the database to improve data tracking and improve our maintenance planning process. In addition to pavements and bridges, our culvert system was probably our next biggest risk area in regards to roadway assets, so we felt like the investment to get a full inventory was worthwhile.

Ohio: Yes, we have a culvert asset database. Data is collected via the ESRI Collector application on Apple iPads by inspectors. Data is housed in centralized databases and is served via a variety of software packages. Examples include Web Viewers, GIS, MS Access, Excel sheets with pivot table connections, BI Queries, etc. Our data is served to the public via the TIMS application.

Lessons learned with setting up a culvert asset database and/or plan:

- Get buy-in from your Executive Management folks followed by having a dedicated staff for inspection.

What were the reasons for setting up the culvert asset database and/or plan?

- It all started for us by a failure of a culvert in Cleveland Ohio on an interstate in the early 2000's.

South Dakota: Yes, SDDOT maintains a culvert inventory for non-NBI culverts on the state system – primarily mainline culverts at this time. We do not have a formal plan at this time nor an official database or system.

Lessons learned with setting up a culvert asset database and/or plan:

- Culvert improvement workflows depend on a wide spectrum of department resources. Buy in takes time. Careful planning of the inventory system is essential to support all the stakeholders properly.

What were the reasons for setting up the culvert asset database and/or plan?

- Non-NBI culverts have traditionally been addressed with the pavement cycle. Due to the average age of culverts increasing, more repairs/rehabilitations/replacements are being needed. This has potential to impact pavement project schedules. This also can lead to some dangerous conditions going undetected. Planning needed to be more long term and consistent.

Tennessee: Yes, currently we have a 4' to 20' inventory in our Trims Database (we use this to reference locations of assets in MMS – Moving to ESRI Roads and Highways), but it is archaic and not built to showcase the data in dashboards. It is also not automated as our field staff creates manual reports to showcase culvert conditions and then puts this into Trims. Wanted to a new system that you can conduct the inspections with software and upload the data entries directly into a database to remove double/triple data redundant entries.

Most of the Regions contacts our Contract's section or our Asset Management section if they have a large culvert in need of replacement. This issue is that there isn't a good way to showcase all the structures with a dashboard or paginated report by condition, location, priority (resurfacing route, upcoming construction project, etc.). So instead of looking at the entire network, you are looking at the most recent records, which can give a false sense of understanding of network or specific location asset condition. We are changing this.

Lessons learned with setting up a culvert asset database and/or plan:

- Plan ahead and plan what you want to use the data for and how you are wanting to showcase the data. This is have a huge impact to the data structure, which will have a huge impact to the database, which will have an impact on how you are relating the data collection fields. Your IT data architects are your best friend. Loop them in at the start.

What were the reasons for setting up the culvert asset database and/or plan?

- Like many DOTs, culvert assets are a large investment that are nearing their end of lifecycle from the initial roadway expansion of the 50's (+/-). Our chief engineer recognized this and tasked our division out with creating a process for our department to know where all cross culverts are located and not just the 4' to 20'. This would also help to streamline their replacement/repair cycle pending if there is a resurfacing project about to be enacted.

Utah: Yes, UDOT has had 3 separate culvert inventories completed during the last 10 years. These inventories were delivered in spreadsheets that are converted to GIS data, however, each were delivered with different location data and different condition data. We are currently using an Asset subcommittee to evaluate culverts to ensure we have the correct inventory, condition, life cycles, age, and condition targets. We are combining the 3 inventories to establish a baseline and using Risk to help us understand which culverts or roadways will be reevaluated first. We are developing a new Asset/Maintenance Management System by ATOM. This new database will store this data to be updated by inspections. These inspections will correct the location, size, type, number and condition. Currently culverts are part of our TAM but are not included in the current TAMP. We consider Culverts a Tier 2 or Condition Based asset. We want to be able to make financial decisions based on the condition targets. Our next TAMP will include a State Level Asset Management Plan that will cover culverts and our plans for it in the future.

Currently our Regions and districts are using past inventories to help make decisions on culvert replacement or rehabilitations. The new system will allow easier updates to the condition and location of our culverts.

Lessons learned with setting up a culvert asset database and/or plan:

- The use of Asset Risk to help prioritize culverts or routes that need to be addressed first may give you a good place to start ensuring inventory and conditions are correct. Dealing with over 40k culverts, the cost to go out and do a complete inventory in one chunk is very substantial.

What were the reasons for setting up the culvert asset database and/or plan?

- We need to be able to make decisions based on condition targets. The database will help us prioritize which culverts should be inspected and which should be replaced or rehabbed. This information will give our Regions and Districts the needed information to make a plan of how to address culverts in poor condition and how to keep culverts in SOGR.

Washington: Yes, WSDOT maintains a standalone culvert database in two different systems. The first system is the Highway Asset Tracking System (HATS) that is used by our Maintenance division to track maintenance work orders on specific culverts. It also holds data associated with a level 1 and level 2 inspection process that captures asset specific information such as condition and culvert material type. The second system is the Stormwater Features Identification Database (SFID) that is populated through separate inventorying efforts, generally through the review of as-builts and asset field verification activities. It should be noted that WSDOT does not have a statewide inventory through these two databases and only reflects the "known" culverts. It is known there are additional culverts on the network that are not captured as part of the inventory.

WSDOT is very early on in its efforts of developing a more strategic approach to managing the network of culvert assets. Currently WSDOT's culvert network is primarily managed on a reactive run-to-failure model. The initial plan was to inspect each known culvert once every five years, but due to resource constraints, this is currently behind schedule. WSDOT does not currently have lifecycle models or data that supports strategic maintenance and preservation investments that extend the useful life of the asset and reduces the likelihood of asset failure. WSDOT does perform maintenance on culverts, but those activities are primarily associated with clearing blockages and ditches to allow for the more effective flow of water through the culvert. While this helps maintain the function and preserve the asset, it is not an action on the actual asset itself.

Some additional work has been done in developing an asset management executive summary as well as research into available data and alignment of existing data with performance measures, but those efforts should still be considered in a planning phase and have not been implemented or integrated into how decisions are made in managing the network of culvert assets.

Lessons learned with setting up a culvert asset database and/or plan:

- Initial and on-going training is necessary on an annual basis for staff conducting inspections. It is important to set up the database with the ability for the inspectors to add comments for site specific issues that are related to function of an asset. It would be good to make sure other data collection or databases that are similar can communicate with each other to eliminate data duplication. Figure out a way to conduct multiple inspections on the same asset without generating multiple entries.

What were the reasons for setting up the culvert asset database and/or plan?

- The western side of Washington State has significant challenges with directing water around our highway network. It is understood that culvert failures are costly to replace and

that we needed better data to begin analyzing how to more effectively invest to reduce the likelihood of failures and shift away from a run-to-failure type model. Initially the culvert database was created to help better understand the network of culvert assets in the field. In 2018, a more concerted effort to compare and align existing management practices to the TAM framework required by FHWA for the TAMP occurred. This resulted in an asset management summary document that captured current state practices as well as an in-depth look into those practices and available data.

Wisconsin: Yes, Wisconsin DOT does maintain a culvert asset database and/or plan.
Lessons learned with setting up a culvert asset database and/or plan:

- Technology, getting licenses, firewalls, disconnected editing, which app to use, training inspectors, quality of inspections, etc…
- What were the reasons for setting up the culvert asset database and/or plan?
- Planning, scoping, replacement, maintenance, and funding.

Wyoming: Yes, the WYDOT Bridge Program inventories State owned structures with openings greater than 35 square feet but not considered bridges per the NBIS (i.e. bridge lengths less than 20 feet). We call these structures “minor”. There are several minor structures in our inventory, but the inventory is not complete, especially on secondary roads. These structures are not part of our Bridge Management System.
We do not collect or maintain condition data of minor structures. We collect the following inventory data for each structure (when available):Construction info, location info, service info, and design info:

The WYDOT Bridge Program relies on District recommendations and site inspections during project development, especially when the inventory is incomplete or incorrect.

Lessons learned with setting up a culvert asset database and/or plan:

- Having accurate as-constructed plans available is necessary for an accurate inventory.
- Remove or code replaced structures as obsolete in the inventory to avoid multiple structures in the same location or close proximity to avoid confusion.
- Field verify structure size, types and locations.

Virginia: Yes, VDOT's Structure and Bridge Division maintains an inventory in its bridge management system of all culverts that meet the definition for National Bridge Inventory (NBI) bridges as part of its bridge database. Culverts with openings greater than 36 square feet but don't meet the NBI geometric criteria are also included in the inventory of the bridge division and are tracked as "non-NBI culverts", along with our non-NBI bridges. Culverts with openings smaller than 36 square feet are maintained through VDOT's Maintenance Division but have a different inventory and maintenance process. All bridges and culverts managed by VDOT's Structure and Bridge Division are managed with dashboards and performance measures, maintained with bridge division funds, and tracked with VDOT's annual State of the Structures and Bridges

Report. Virginia's federally mandated TAMP covers only the assets required by federal regulation: specifically, NBI structures (bridges and culverts) on the National Highway System. Decisions regarding best practices for culvert repair or replacement, along with the methodology for rehabilitation, are provided in Chapter 32 of the Manual of the Structure and Bridge Division and VDOT's Road and Bridge Specifications. Culverts large enough to qualify as NBI structures may, if in poor (structurally deficient) condition, be replaced with construction rather than maintenance funds. Poor NBI structures eligible for replacement are prioritized through Virginia's State of Good Repair program, which utilizes a multi-variable prioritization formula to select projects.